


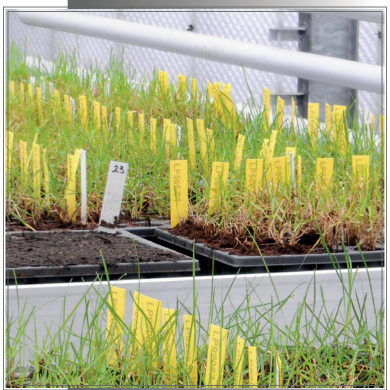


NUTRIHORT

Nutrient management, innovative techniques and nutrient legislation in intensive horticulture for an improved water quality

September 16-18, 2013, Ghent

Proceedings

editors

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NUTRIHORT: Nutrient management, innovative techniques and
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PREFACE

Background

Growers urgently need to find and implement more sustainable strategies for the intensive production of vegetables, potatoes, flowers and ornamental trees. Plant production in the open field or in greenhouses is challenged by the need to balance high productivity and sometimes late harvests with fewer nutrient losses to the environment. The reasons for this are clear: the nutrient enrichment of soil and water disrupts the natural processes in agro-ecosystems and leads to decreased biodiversity. High concentrations of nitrate or phosphate can cause eutrophication of the surface and coastal water. Leaching of nitrate or phosphate to the groundwater can pose a problem for drinking-water production.

Aims of NUTRIHORT

NUTRIHORT presented the current knowledge of sustainable and innovative techniques in vegetable and ornamental plant production. The conference focused on innovative fertilization, crop residues management, crop rotation, organic matter management and soil quality practices in horticulture. Throughout this conference, the focus was on the conflict between crop quality demands and legislative requirements to protect water quality.

In addition to oral and poster presentations on these topics, working groups during dedicated sessions discussed 1) technical and economic benchmarking of sustainable and innovative cultivation and fertilization techniques in horticulture and 2) the implementation of environmental EU directives in different horticultural regions and opportunities for innovative nutrient legislation to control pollution and improve water quality.

Conference themes

The conference covers the following themes:

- Nutrient legislation in horticulture
- Nitrogen dynamics in relation to soil quality
- Nitrogen mineralization from soil organic matter in horticultural fields
- Good agricultural practices for vegetable crop residues
- Conflict between improving soil organic matter and legislative requirements, e.g. the Nitrates Directive
- Phosphorus, horticulture and the environment
- Conflicts between crop quality and legislative requirements
- Nutrient use efficiency and fertilization advice
- Catch crops and crop rotation alternatives in intensive horticultural production
- Innovative cultivation and fertilization techniques in horticulture
- Recirculation of nutrients in greenhouse horticulture

COMMITTEES

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- Georges Hofman (Ghent University, Belgium)
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- Michael Hamell (DG Environment - European Commission)
- Matthias Fink (IGZ Grossbeeren, Germany)
- Rodney Thompson (University of Almeria, Spain)
- Francesco Tei (University of Perugia, Italy)
- Clive Rahn (PlantNutrition Consulting, UK)
- Wim Voogt (Wageningen UR, the Netherlands)
- Sylvain Pellerin (INRA, France)

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- Mia Demeulemeester (Inagro, Belgium)

PROGRAMME

	Sunday September 15, 2013	Monday September 16, 2013	Tuesday September 17, 2013	Wednesday September 18, 2013
8h00-8h30				
8h30-9h00		Registration	Technical session 4	
9h00-9h30		Plenary session	Technical session 4	Introduction workshops
9h30-10h00		Plenary session	Technical session 4	Introduction workshops
10h00-10h30		Plenary session	Coffee break	Introduction workshops
10h30-11h00		Coffee break	Technical session 5	Coffee break
11h00-11h30		Technical session 1	Technical session 5	Workshops
11h30-12h00		Technical session 1	Technical session 5	Workshops
12h00-12h30		Technical session 1	Lunch	Workshops
12h30-13h00		Technical session 1	Lunch	Lunch
13h00-13h30		Lunch	Technical tour	Lunch
13h30-14h00		Lunch	Technical tour	Technical session 6
14h00-14h30		Technical session 2	Technical tour	Technical session 6
14h30-15h00		Technical session 2	Technical tour	Closing session
15h00-15h30	Registration	Technical session 2	Technical tour	Closing session
15h30-16h00	Registration	Coffee break	Technical tour	Network opportunity
16h00-16h30	Registration	Technical session 3	Technical tour	Network opportunity
16h30-17h00	Registration	Technical session 3	Technical tour	
17h00-17h30	Opening reception	Technical session 3	Technical tour	
17h30-18h00	Opening reception	Coffee break	Technical tour	
18h00-18h30	Opening reception	Visit of Ghent	Technical tour	
18h30-19h00	Opening reception	Visit of Ghent		
19h00-19h30		Visit of Ghent		
19h30-20h00			Conference dinner	
20h00- …			Conference dinner	

Monday - September 16, 2013						
	Start	**End**	**Session chair / Keynote speaker/ presenter**			**Title**
	9h00	**10h25**	Georges Hofman			**Opening session**
Oehoe	8h55	9h00	Guido Van Huylenbroeck	Belgium (Flanders)		Welcome by the dean of the Faculty of Bioscience Engineering of UGent
	9h00	9h10	Sibylle Verplaetse	Belgium (Flanders)		Welcome on behalf of the Flemish Minister for Environment, Nature & Culture Ms Joke Schauvliege
	9h10	9h25	Francesco Presicce	European Union	(1)	Implementation of the Nitrates Directive in the EU: Results overview 2007-2011
	9h25	9h55	Silvana Nicola	Italy	(2)	The application of the Nitrates Directive to vegetable crops: tools and strategies from NEV2013 for an integrated fertilisation management
	9h55	10h25	Clive Rahn	United Kingdom	(3)	The challenges of knowledge transfer in the implementation of the Nitrates Directive
Technical session 1	**10h55**	**12u55**	Mathias Fink			**Innovative cultivation and fertilization techniques in horticulture**
Oehoe	10h55	11h25	Rodney Thompson	Spain	(4)	Improved nitrogen management practices for vegetable production
	11h25	11h40	Cody Thompson	Canada	(5)	Optical sensors for the ion-selective management of hydroponic nutrient solution quality
	11h40	11h55	Morgan Abras	Belgium (Wallonia)	(6)	Management of nitrogen fertilization of fresh vegetable crops at field scale in Wallonia (Belgium)
	11h55	12h10	Annette Pronk	The Netherlands	(7)	Row application of fertilizers, manure and manure fractions to increase nutrient use efficiency
	12h10	12h25	Annegret Uebelhoer	Germany	(8)	Soil erosion in vegetable production – Solution approaches
	12h25	12h40	Stefaan De Neve	Belgium (Flanders)	(9)	Minerals and wastewater treatment products effectively increase P sorption capacity in acidic sandy soils
	12h40	12h55				Introduction of poster abstracts 40 - 49

Monday - September 16, 2013						
	Start	**End**	**Session chair / Keynote speaker/ presenter**			**Title**
Technical session 2	**14h00**	**15h45**	Silvana Nicola			**Recirculation of nutrients and irrigation in horticulture**
Oehoe	14h00	14h30	Wim Voogt	The Netherlands	(10)	Sustainable nutrient management in soilless culture in Dutch greenhouse horticulture
	14h30	14h45	Els Berckmoes	Belgium (Flanders)	(11)	Quantification of nutrient rich wastewater flows in soilless greenhouse cultivations
	14h45	15h00	Timothy Hartz	USA	(12)	Improving irrigation and nitrogen management in California leafy greens production
	15h00	15h15	Nico Lambert	Belgium (Flanders)	(13)	Anoxic Moving-Bed BioReactor (MBBR) and phosphate filter as a robust end-of-pipe purification strategy for horticulture
	15h15	15h30	Miguel Quemada	Spain	(14)	Strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield: a comparative meta-analysis
	15h30	15h45				Introduction of poster abstracts 50-59
Technical session 3	**16h15**	**17h45**	Sylvain Pellerin			**Catch crops and crop rotation alternatives in intensive horticultural production**
Oehoe	16h15	16h45	Francesco Tei	Italy	(15)	Optimization of N fertilisation through fertigation and green manuring: case studies in processing tomato
	16h45	17h00	Hanne Kristensen	Denmark	(16)	Nitrogen management by use of in-season living mulch in organic cauliflower production
	17h00	17h15	Greet Ruysschaert	Belgium (Flanders)	(17)	Spatial and temporal variability of rooting characteristics and catch crop effectiveness
	17h15	17h30	Chen Qing	China	(18)	Strategies to reduce nitrogen leaching by summer catch crop in vegetable greenhouse of North China
	17h30	17h45				Introduction of posters abstracts 60-69

Tuesday - September 17, 2013

	Start	End	Session chair / Keynote speaker/ presenter			Title
Technical session 4	**8h30**	**10h30**	Clive Rahn			**Phosphorus, horticulture and the environment**
Oehoe	8h30	9h00	Sylvain Pellerin	France	(19)	Why do we have to increase P use efficiency and recycling in cropping systems?
	9h00	9h15	Jorn Nygaard Sorensen	Denmark	(20)	Phosphorous placement for bulb onions – rates and distances
	9h15	9h30	Fien Amery	Belgium (Flanders)	(21)	The phosphorus cycle in North-West European agricultural soils
	9h30	9h45	Thijs Vanden Nest	Belgium (Flanders)	(22)	The effect of different fertilizer types on soil P conditions, crop yield and P leaching potential
	9h45	10h00	Arjan Reijneveld	The Netherlands	(23)	A more trustworthy P recommendation by implementing the intensity, buffering capacity, quantity concept into agricultural practice
Technical session 5	**10h30**	**12h15**	Francesco Tei - Rodney Thompson			
Oehoe	10h30	11h00	Mathias Fink	Germany	(24)	Future fertilizer legislation will require adapted nutrient management strategies in German vegetable production
Technical session 5A			Francesco Tei			**Management of vegetable crop residues and compost**
E 112	11h00	11h15	Laura Agneessens	Belgium (Flanders)	(25)	Management of vegetable crop residues for reducing nitrate leaching losses in intensive vegetable rotations
	11h15	11h30	Martin Armbruster	Germany	(26)	Integrated nitrogen management – a strategy to improve nitrogen efficiency in intensive field vegetable production
	11h30	11h45	Tomas Van de Sande	Belgium (Flanders)	(27)	KNS – Based advisory system proves to be a useful tool in reducing residual nitrate content of horticultural soils in the fall
	11h45	12h00	Koen Willekens	Belgium (Flanders)	(28)	Strong effect of compost and reduced tillage on C dynamics but not on N dynamics in a vegetable cropping system
	12h00	12h15				Introduction of poster abstracts 70-78
Technical session 5B			Rodney Thompson			**Nutrient use efficiency and fertilization advice**
Oehoe	11h00	11h15	Henk Van Reuler	The Netherlands	(29)	Fertilization of flower bulbs and hardy nursery stock in open field production in the Netherlands
	11h15	11h30	Daniele Massa	Italy	(30)	An integrated model for the management of nitrogen fertilization in leafy vegetables
	11h30	11h45	Mia Tits	Belgium (Flanders)	(31)	Nitrate nitrogen residues, soil nitrogen balance and nitrogen fertilizer recommendation in vegetable fields in Flanders
	11h45	12h00	Janjo de Haan	The Netherlands	(32)	Soilless cultivation of outdoor horticultural crops in The Netherlands to reduce nitrogen emissions
	12h00	12h15				Introduction of poster abstracts 79-88

Wednesday - September 18, 2013

	Start	End	Session chair / Keynote speaker/ presenter			Title
Workshops	**9h00**	**10h30**	Michael Hamell			
Oehoe	9h00	9h30	Inge Van Oost	European Union	(33)	Opportunities provided by the European Innovation Partnership "Agricultural Productivity and Sustainability" and its Operational Groups
	9h30	10h00	Bart Vandecasteele	Belgium (Flanders)	(34)	Benchmark study on innovative techniques and strategies for reduction of nutrient losses in horticulture
	10h00	10h30	Georges Hofman	Belgium (Flanders)	(35)	Benchmark study on nutrient legislation for horticultural crops in some European countries
	11h00	**11h45**				Workshop 1
Oehoe						Nutrient legislation
E112						Innovative techniques for open air vegetable cultures
E115						Innovative techniques for soil bound greenhouse horticulture
E209						Innovative techniques for soilless greenhouse horticulture
E210						Innovative techniques for soil bound floral and ornamental horticulture
Agora						Flemish Action Plan Horticulture (Dutch session)
	11h45	**12h30**				Workshop 2
Oehoe						Nutrient legislation
E112						Innovative techniques for open air vegetable cultures
E115						Innovative techniques for soil bound greenhouse horticulture
E209						Innovative techniques for soilless greenhouse horticulture
E210						Innovative techniques for soil bound floral and ornamental horticulture
Agora						Flemish Action Plan Horticulture (Dutch session)
Technical session 6A	**13h30**	**15h00**	Wim Voogt			**Nutrient legislation in horticulture**
Oehoe	13h30	14h00	Michael Hamell	European Union	(36)	Facing the nutrient challenge in the vegetable sector
	14h00	14h15	Kevin Grauwels	Belgium (Flanders)	(37)	Nitrates Directive in Flanders' horticulture: towards nutrient management through participation
	14h15	14h30	Karin Rather	Germany	(38)	Emission control of soil nitrogen content in water protection areas in Baden-Württemberg, Germany
	14h30	14h45	Filip Rys	Belgium (Flanders)	(39)	Nitrate-leaching from container grown nursery crops on a closed culture system in open air
Oehoe	**14h45**	**15h30**				**Closing session**
Oehoe	14h45	15h15				Summary of workshops
	15h15	15h30	Toon Denys	Belgium (Flanders)		Closing by CEO Flemish Land Agency (VLM)
Oehoe	**15h30**	**16h00**				**Network moment for exploring long-term collaboration and research opportunities**

Monday - September 16, 2013			
	presenter		Title
40	Francesco Montemurro	Italy	In Line Roller Crimper technology in organic vegetables production to mitigate nitrate leaching risk
41	Jacek Dysko	Poland	Use of textile and organic waste mats for soilless cultivation of greenhouse tomato
42	Othman K. Qadir	United Kingdom	Method using gas chromatography mass spectrometry (GC-MS) for analysis of nitrate and nitrite in vegetables
43	Koen Cochez	Belgium (Flanders)	The Flemish approach to reduce nutrient losses from soilless horticulture: legislation to practice
44	Karin Rather	Germany	Improvement of N efficiency in vegetable crops to fulfil the demands of water framework directive
45	Franky Coopman	Belgium (Flanders)	Coordination centre for extension services for sustainable fertilization
46	Micheline Verhaeghe	Belgium (Flanders)	Optimalisation of fertilisation in vegetable crops to reduce nitrate residues and nitrate leaching to surface- and groundwater
47	Rodney B. Thompson	Spain	Sensitivity of optical sensors to crop N status of a tomato crop
48	Rodney B. Thompson	Spain	Sensitivity of optical sensors to crop N status of a melon crop
49	Joachim Vansteenkiste	Belgium (Flanders)	Life cycle assessment of broadcast and fertigation fertilization systems in open field cauliflower production in Flanders, Belgium
50	Filip Rys	Belgium (Flanders)	Reducing P_2O_5-leaching from container grown nursery stock: potential of lower P_2O_5-input and Humifirst
51	Els Mechant	Belgium (Flanders)	NO_3-leaching from Azalea indica on containerfields: effects of current legislatin strategies
52	M. Grazia Tommasini	Italy	Nutrition and water management in the integrated production of Emilia Romagna region (Italy)
53	Henk van Reuler	the Netherlands	Soilless culture of hardy nursery stock in the Netherlands
54	Joachim Vansteenkiste	Belgium (Flanders)	Assessment of root distribution by combining observations of the trench profile method with root length observations
55	Annemie Elsen	Belgium (Flanders)	In search of the optimal N fertigation dose for 'Conference' pear trees.
56	Adriano Sofo	Italy	Soil microbial fertility in olive orchards managed by a set of sustainable agricultural practices
57	Nadezheda Petkova	Bulgaria	Influence of harvest time on fructans content in the tubers of Helianthus tuberosus L.
58	Michael Böhme	Germany	Influence of N and K fertilisation and cultivation methods on the yield and essential oil content in thyme
59	Peter Bleyaert	Belgium (Flanders)	Optimisation of the SUSON strategy as a method for sustainable fertilisation in glasshouse butterhead lettuce

Tuesday - September 17, 2013			
	presenter		Title
60	Francesco Tei	Italy	Fertigation and winter cover crops as complementary tools for the N nutrition of processing tomato
61	Greet Verlinden	Belgium (Flanders)	DEMETER: Sustainable and integrated soil management to reduce environmental effects
62	Tommy D'Hose	Belgium (Flanders)	Soil organic matter management within the legal constraints of the fertilization laws – BOPACT field trial
63	Mia Tits	Belgium (Flanders)	Recent evolution and trends in the soil fertility of Flemish vegetable fields (1998-2012)
64	Laura Agneessens	Belgium (Flanders)	Potential of alternative crop rotations for reducing nitrate leaching losses in intensive vegetable rotations
65	Jeroen De Waele	Belgium (Flanders)	Risk assessment of nitrate leaching in autumn after incorporation of catch crops in spring
66	Steven Sleutel	Belgium (Flanders)	Organic matter fractions and N mineralization in vegetable cropped sandy soils
67	Annelies Beeckman	Belgium (Flanders)	Long term effect of organic fertilization strategies on soil fertility, N dynamics and crop yield
68	Janjo de Haan	the Netherlands	Less organic matter input reduces nitrate leaching and crop yield on a sandy soil in the Netherlands.
69	François Lecompte	France	Plant nutritional status and susceptibility to necrotrophic pathogens : just a question of nitrogen?
70	Jarinda Viane	Belgium (Flanders)	Removing vegetable crop residues for composting and ensilaging: effects on N, P and organic matter
71	Annette Pronk	the Netherlands	Nitrate leaching from vegetable crop residues and the fate of N during composting of leek residues
72	Koen Willekens	Belgium (Flanders)	Crop response of leek on fertilizer N from raw and composted chicken manure in organic horticulture
73	Laura Agneessens	Belgium (Flanders)	In situ management of vegetable crop residues for reducing nitrate leaching losses in intensive vegetable rotations
74	François Orsini	France	Evolution of crop residues nitrogen in lysimeters with N15 in two cultural systems
75	Lijuan Yang	China	Effects of Vermicomposts on Tomato Yield and soil Fertility under Different Amount of Water Irrigated in greenhouse
76	Stanislaw Kaniszewski	Poland	Pelletized dry legume plants as fertilizer for vegetable in organic farming
77	Daniele Massa	Italy	Alternative substrates for overcoming transplanted stress of ornamental plants
78	Józef Babik	Poland	New biodagradeable agrofleece for soil mulching in organic vegetable production
79	Nikolay Panayotov	Bulgaria	Effect of different rates of nitrogen fertilization on vegetative development and productivity of Cape gooseberry (Physlais peruviana L.)
80	Tatyana Bileva	Bulgaria	Effects of some organic fertilizers on growth of infested with Xiphinema index grapevines
81	Rui Machado	Portugal	Effect of nitrogen source on soil nitrate concentration and yield and quality of intermediate-day onions
82	Dimka Haytova	Bulgaria	Influence of foliar fertilization on the nutrient uptake of zucchini squash (Cucurbita pepo L. var. giromontia)
83	Anna Barbara Pisanu	Spain	Survey activities in the area of Sestu (southern Sardinia) aimed at defining the agronomic techniques to reduce the nitrate pollution
84	Annelies Beeckman	Belgium (Flanders)	Organic vegetable crop production needs careful interpretation of nitrogen recommendations
85	Franky Coopman	Belgium (Flanders)	Documenting and environmental adjusting the KNS and other fertilizer systems in horticulture
86	Bert Meurs	the Netherlands	Canopy reflection-based N sidedress system for leeks
87	Veerle De Blauwer	Belgium (Flanders)	Split nitrogen fertilization and in row application in the potato crop
88	Abdek-Khalek Selim	Egypt	Dynamics of integrated organic and mineral nitrogen applications and their impact on crop performance

ORAL PRESENTATIONS

(2) The application of the Nitrates Directive to vegetable crops: tools and strategies from NEV2013 for an integrated fertilisation management

Nicola Silvana[1], *Fontana Emanuela*[2], *Monaco Stefano*[1], *Grignani Carlo*[1]

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Abstract: *The European Commission DG Environment and the University of Turin (Italy) have organized the NEV2013 Workshop on 'Nitrogen, Environment and Vegetables' for providing support to the implementation of the Nitrates Directive (91/676/EEC). NEV2013 has focused on the critical issues of the Nitrates Directive in vegetable crops in European Countries. NEV2013 covered Nitrogen fertilization management, strategies to improve Nitrogen and water use efficiency, relationship of Nitrogen and other nutrients, Nitrogen effects on product quality, vegetable growing systems and their effect on waters pollution, crop residues management, crop rotation, and monitoring of the environmental pollution caused by Nitrogen losses from vegetable cultural systems. The critical issues of the Nitrates directive for vegetable crop systems of different European Countries were tackled. The outcome indicated that the environmental impact due to the Nitrogen fertilization varies not only from country to country but also locally within the same country or region. There is a striking need for increasing the Nitrogen fertilizer use efficiency for all crops in order to reduce its potential negative effects on the environment and, in the case of vegetable crops, its effects on human health when accumulated as nitrate in the plants. In recent years, numerous research programs have assessed the effects of Nitrogen fertilizer rate, fertilization methods, and Nitrogen fertilizer source on Nitrogen uptake and plant growth of many vegetable species. On this base, tools to determine the Nitrogen losses owing to the different cultivation systems for vegetables and to the different climate and soil conditions have been developed. Their spread implementation can lead to environmental-friendly fertilization strategies, applied taking into consideration the needs and suggestions of researchers, farmers, and consumers, and involving policy makers. As any other cropping system, also vegetable systems need valuable indicators: the tool box of indicators that can be used to sustainably manage fertilization is quite large, while modeling allows for quantifying environmental impacts. Combining indicators, empirical predictions and model predictions into expert systems helps to take decisions about management practices. Future strategies need better connection and data transferring among the actors, from policy makers to scientists, extension service technicians and growers.*

Keywords: *environment, fertilization strategies, indicators, models, EU directives*

The fresh vegetable business and the vegetable crops impact in the EU

The EU is still recording a deficit trade for many commodities, including fresh vegetables. In 2011, the import of fresh vegetables counted for 1,800 M€ and the export for 1,400 M€, while potatoes import counted for 200 M€ and the export for 700 M€ (EC, DG Agriculture and Rural Development, 2012). Potatoes counted for 28% of total vegetable (that is, fresh vegetables plus potatoes) exports. Two thirds of the import in terms of value were for tomatoes, beans and sweet peppers, and tomatoes alone now constitute the biggest share of imported fresh vegetables, making up around one fifth of imports. Most of fresh vegetables are imported from four Mediterranean countries: Morocco, Israel, Turkey, and Egypt. Import from this region is gradually increasing due to improved market access to the EU under preferential trade agreements with these countries. The leading supplier, Morocco, covers around 30% of EU fresh vegetable imports. Since 1999, imports from this country doubled and amounted to 534.4 M€ in 2011. Half of Moroccan supplies is taken up by tomatoes. Other imported vegetables include sweet peppers, beans, egg plants and cucumbers. Even though close to two thirds (around 64 %) of all the tomatoes produced in the EU-27 originates from Italy and Spain, the EU is still in deficit and needs import or will need to increase the domestic production.

Vegetables production in the EU 27 countries is ca. 57.5 Mt per year, 42% obtained in two countries alone (24% Italy and 17% Spain) (Fig. 1) (Eurostat, 2011). Out of the 2.35 million hectares used in the EU for vegetables crops, ca. 38% is located in the same two countries (23% Italy and 15% Spain) (FAO, 2010). These cropping areas are already facing environmental stresses and these stresses may increase if EU is willing to increase the domestic vegetable production for sustaining citizen livelihoods. Export of fresh vegetable products, especially to northern European countries, has significantly expanded in recent years in Spain in response to the demand of developed countries for fresh and high-quality products all year round (Romero-Gámez and Suárez-Rey, 2013). Furthermore, other major areas of intensive vegetable production have long been in place (e.g. France, The Netherlands) and will contribute to the environmental stresses as well.

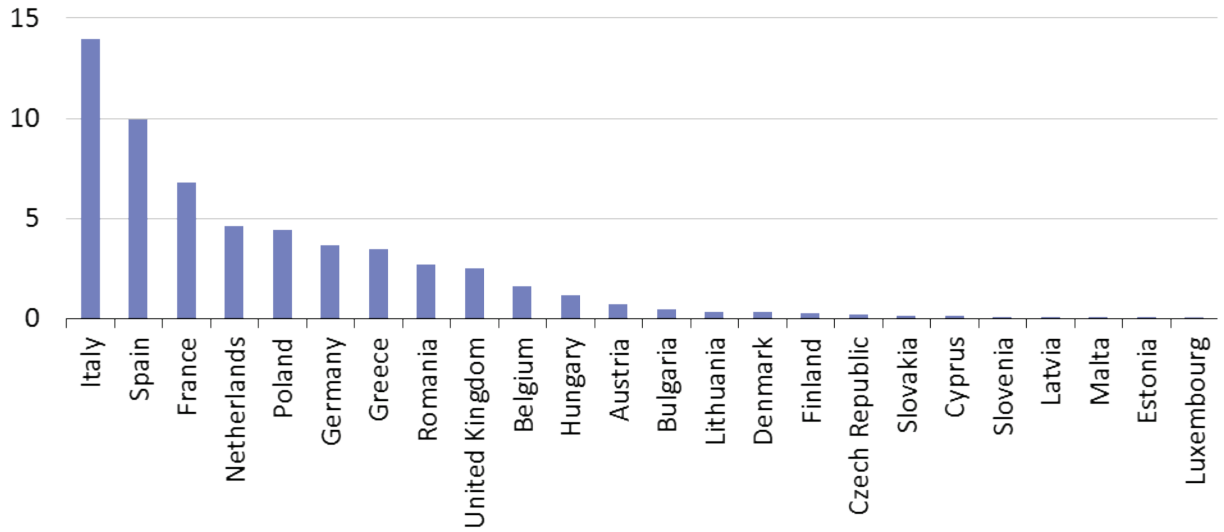

Figure 1 Production of vegetables (million tonnes) in most EU-27 in 2011 (Eurostat) (Data from Ireland, Portugal and Sweden not available).

General considerations on the application in the EU of Nitrates Directive to the vegetable sector

Horticulture is a complex system because of the diverse cultural systems, great variety of species and cultivars, and extended large variability of soil and climatic conditions among the geographic areas cultivated for vegetable productions. Vegetable crop intensification in the EU will continue in the future due to market demand and growers income. However, the importance of efficiency and standardization of practices will increase to reduce production and supply chain costs. Good agricultural practices are in increasing demand from the consumers and from the chain retailers across Europe. Practices include the application of the EU Nitrates Directive as well as any other directive, although the former has often been perceived by stakeholders as related to livestock or arable farms only. In the livestock sector the Nitrates Directive has been successful since it has spread good agricultural practices, aimed at preventing pollution created by excessive fertilization and, at the same time, stimulating efficient manure management. In the application of the Nitrates Directive horticultural systems across Europe can learn lessons from the livestock farming experience.

The environmental impact due to the nitrogen fertilization in the EU varies not only from country to country but also locally within the same country or region. Some intensive vegetable production areas are showing quite high environmental risks deriving from current fertilization and management practices of horticultural crops (Calabrese et al., 2013; Pietrzak and Wojcieszak, 2013; Suárez-Rey and Romero-Gámez, 2013; Thompson et al., 2013a, c). Unfortunately, in some cases there is a lack of awareness by the growers of the environmental issues related to mismanagement of fertilization practices, or even lack of awareness of the relevance of the Directive; this has been highlighted in some surveys conducted (Suárez-Rey and Romero-Gámez, 2013; Thompson et al., 2013c). Consequently, some work has to be done by administrators to train the vegetable growers because there is a need to steer further improvements in nitrogen and phosphorous management practices, without affecting product quality and yields and therefore farmer income. At the moment, the Nitrates Directive is being applied in different ways in the different Member States (e.g. whole territory approach; one or more action programs applying to the designated nitrates vulnerable zones). Regional adaptation is a value, because it fully considers specific climatic conditions as well as characteristics of the agricultural sector in the area.

Vegetable production characteristics

Intensive production systems are by definition using a high level of external resource inputs per area and time. Thereby, vegetable production systems are at the upper limit of production intensity, relying on the high economic value of the produce. Obtaining great yield is thus of paramount importance, taking into account also the high investment costs intensive production systems imply. Nitrogen fertilization represents the ground foundation to reach high yields for many vegetable species, and fertilization costs, despite steadily increasing, do not seem to be a major concern for farmers in vegetable production. In other words, the high cost of fertilizers is not considered by vegetable growers as a sufficient justification to reduce fertilizer use, unless specific product quality aspects are involved (e.g. nitrates accumulation in the edible parts). Farmers concerns are highly concentrated on other aspects such as quantity and quality of the commercial product, market demand and marketing strategies, and above all pest management and maximum residue level allowed.

Most of vegetables are marketed on a fresh weight basis and turgor is one of the first quality attributes that consumers recognize; fertilization and irrigation practices are aimed to maximize the commercial quality. Thus, the physiological nitrogen use efficiency (Novoa and Loomis, 1981) (or utilization efficiency) in many vegetable species is low, being directly related to a low Nitrogen harvest index since immature generative organs are harvested (Kage, 2000). There is also a variation in nitrogen efficiency within populations of same species and accessions, shown on lettuce (Burns et al., 2013; Di Gioia et al., 2013; Ferrante et al., 2013) and endive (Gajc-Wolska et al., 2013), that can be promising for future breeding programs to select low-nitrates varieties. In addition, the uptake efficiency of vegetable species is generally low: not only most of vegetable species are dicotyledonous, but also they have been adapted to modern fertilization practices (e.g. fertigation and mineral fertilization). Root architecture is crucial in determining water and nutrient uptake (Nicola, 1998). Breeding programs might be directed toward higher root density per plant, accompanied by a highly branched system (De Pessemier et al., 2013), but the horticultural sector must be managed now with available varieties, in view of achieving water quality objectives (Nitrates Directive and Water Framework Directive objectives).

Fertilization strategies

In most horticultural systems there are strong interactions between fertilization and irrigation, thus an efficient N fertilization requires an efficient irrigation system. This is especially the case in the Mediterranean regions. Optimal irrigation and salinity management are additional key components of improved N management of vegetable crops (Thompson et al., 2013b). There is probably a need for different fertilization standards for drip irrigation and other irrigation systems. Until now, diversified standards are not often available both in nitrates action programs and in suggested best practices. Plus, there are conflicting interests between single crop quality achievement and farm crop rotation that have to be tackled and solved for reducing fertilizer inputs. Too high fertilizer inputs in turn can lead to an increase in crop residues that are an important source of N and that must be accounted for in the fertilization plan. Therefore, fertilization strategies should take into account the incorporation of nutrients from farmyard manure or from vegetable residues: they are not only amendments but also a source of nutrients while a costly output of vegetable growth. Compost mineralization is often ignored in fertilization plans. The amount of mineralized N should be predicted using specific indicators (such as the fiber fractions content, i.e. NDF). If compost mineralization is disregarded by considering composts only as soil improvers, there is a risk of over fertilization, causing water pollution often long after the growing season. Ultimately, composts have a high nutritional value.

For using organic municipal wastes there is still lack of confidence due to the heterogeneous medium usually obtained, jeopardizing vegetable quality products, and the fear of heavy metal accumulation in soils and in the plants. Recent findings are however pointing out that the bioaccumulation factor depends mostly on species and on soil conditions, more than the concentration in the amendments, due to the fact that only a fraction of the total metals is available for plant uptake (Antonious et al., 2013) leaving for opportunities to a more rational use in the future of waste and residues. Reported results indicate that in several cases municipal solid waste compost can represent a good strategy to incorporate nutrients, and nitrogen in particular, to the crop and improve the soil structure (Barboza et al., 2013a). By fostering the understanding of the crop physiology and the nitrogen use efficiency better crop rotations can be planned and a more rational use of nutrients can take place (Barboza et al., 2013b; Sambo and Lazzaro, 2013). The use of animal slurry is rare in intensive vegetable production in Mediterranean Region, mainly due to food safety issues; in fact, several food outbreaks in the recent decade have taken many vegetable growers away from manure and slurry, most probably as a preventive action and because the quality in terms of safety of the available slurry and manure can be limited. The survival of foodborne pathogens in these products is a potential threat for humans, far more important than any other quality aspect. The reported transfer of *Escherichia coli* from animal slurry fertilizer to lettuce represents food safety hazards (Jensen et al., 2013). Future research must be directed toward providing consistency of results (Matthews, 2013).

A reduction in N fertilization might conflict with profitability of crop production, i.e. production of crop leading to high yield and product quality. However, this is not always the case, as there are instances where dose applications are greater than plant need and thus reductions of N supply might take place, without decrementing yield (Frick et al., 2013). Sometimes legal requirements may be at stake, specifically when preventing the excess of N-NO_3 input: this is the case of the application of the EU Reg. 1258/2011, amending EU Reg. 1881/2006, as regards to maximum level of nitrates in foodstuffs, including baby food, which in turn force the growers to limit N applications. There is a striking need for increasing the Nitrogen fertilizer use efficiency for all crops to reduce its potential negative effects on the environment and, in the case of vegetable crops, its effects on human health when accumulated as nitrate in the plants (Fontana et al., 2013). The EU limits of nitrates in foodstuff are more often required at present by several large scale retail organizations not only for the regulated species but for several vegetables, due to the longer shelf-life of vegetables when less nitrate is accumulated in the edible part and due to the World Health Organization recommendations related to the maximum daily intake of 3.7 mg NO^-_3 per kg of body weight. This can induce an extended reduction of N application to the crop, a market driven behavior more than a regulation driven behavior. Sometimes, national regulations exist (Gajewski, 2013). Unfortunately, local and independent retailers are not stimulating the demand for low nitrate levels in foodstuffs, leaving growers to continue in over dosing N supply to vegetables. Several investigations aimed to reduce the nitrates accumulation in foodstuff can eventually lead to a reduction in N application during plant growth, helping indirectly to optimize N inputs, without detriment yield (Awaad et al., 2013; Di Gioia et al., 2013; Ferrante and Trivellini, 2013; Gajewski, 2013; Kowalczyk et al., 2013; Massa et al., 2013).

Indicators for fertilization management

Intensive vegetable production systems have different potential environmental impact according to cultural systems, soil and climate. Thus, punctual and local specific situations have to be considered when programming fertilization efficiency strategies. When soil is prone to leaching even more attention must be paid.

The complex horticultural systems require adequate and tailored indicators to soundly manage fertilizations. Even though indicators ought to be as simple as possible they have to be reliable and informative. Given the different situations occurring in vegetable fields, often several indicators have to be combined to deliver the optimal decision making. The input-output N budget, despite non sophisticated and simple, remains a cheap and informative indicator; it has been used in many research experiments and surveys to show the potential effects of experimental treatments and regional case studies (Jadoski et al., 2013; Willekens et al., 2013). Further work still needs to be done to refine this indicator while still retaining its simplicity and low cost. The soil residual N check (e.g. the quantity of nitrate-N measured in the upper 90 cm of the soil at the end of the growing season) is often used to assess how good the fertilization with respect to the crop need was (Willekens et al., 2013). The cost of this indicator is high, as many samples are needed to have meaningful information and results.

There is a growing interest on using foliar color and foliar reflectometry as indicators of N availability, and it has been shown to be widely used in many experiments (Armbruster et al., 2013; Fernández Fernández et al., 2013; Weisler et al., 2013. Methods such as "SPAD", "N-Tester" and "Sufficiency Index" have the problem to consider an extremely small leaf area. The "Canopy Reflectance" method has the advantage of integrating the measurement on large canopy area and has been tested in many instances (Peña-Fleitas et al., 2013; Thompson et al., 2013b). The “tool box” of indicators that can be used to sustainably manage fertilization is quite large. The different tools have different effectiveness and efficiency, which may change in relation to local situations. The need is now to have them applied systematically to case studies and pilot farms in the different regions. This applied research activity can increase knowledge on effectiveness and efficiency of the different tools.

The prediction of harvestable production is still a weak point in any ex-ante fertilization plan. A suggested optimal N management approach for intensive vegetable production is based on a combined prescriptive-corrective management (Thompson et al., 2013b). Prescriptive management being an N fertilizer plan that matches N supply to estimated crop N requirements taking into account other N sources, and corrective management being the use of a monitoring approach that assesses crop/soil N status to subsequently adjust and optimize N management.

Models and Decision Support Systems

Models are always necessary to quantify environmental impacts. A number of them are available and adapted to the vegetable production systems. Information about the crop, the soil and weather conditions as well as the cultivation techniques must be known and efficiently combined to predict N leaching losses or other impacts. Models can also analyze economic and environmental effects of nitrogen fertilizer use strategies, using multi-criteria decision model based on economic and ecological indicators (Frick et al., 2013). These indicators include yield per hectare, net returns, land requirement, nitrogen surplus and greenhouse gas emissions per hectare and per unit of product.

There is a strong need to combine indicators, empirical predictions and model predictions into expert systems that help to take decisions about management practices (DSS, Decision Support Systems). A number of DSS have been developed and they are already applied in some regions: KNS system, Veg-Syst (Gallardo et al., 2013; Suárez-Rey et al., 2013; Thompson et al., 2013c), CropSyst (Giménez et al., 2013) Well-N, EU-Rotate_N (Ramos et al., 2013; Suárez-Rey et al., 2013), GesCoN (Elia and Conversa, 2013), and N-Expert (Armbruster et al., 2013; Große Lengerich and Rather, 2013; Wiesler et al., 2013). A comparison of the criteria used by the different systems should be promoted. There is a general consensus that DSS are interesting, but in order to be used in practice they must be user-friendly, reliable and results must be comprehensible to growers or technicians.

Horticulture versus water and air pollution: an integrated assessment

Environmental problems due to intensive horticulture are both related to water (N and P leaching to groundwater and surface water) and air (emissions of greenhouse gases and ammonia). Research should aim at integrated solutions, i.e., minimizing both emissions to water and air. Measures should not result in pollution swapping between pollutants or from one compartment to another compartment. Recent experimental activities are widening. Field experiments with vegetables often include quantification of nitrous oxide emission from vegetables cropping systems (Seiz et al., 2013). It has been shown that a rational fertilization input produces positive impacts on both emissions to water and air (Frick et al., 2013; Wiesler et al., 2013). NH_3 emission is not a major concern in vegetable production in which limited urea or livestock manure is used.

Ideas and suggestions for future research and extension activities

Several aspects can be taken into consideration for future activities. In general, the global analysis of the problems should start from local case-studies to take local conditions into account for better tackling and managing the environmental problems occurring in vegetable culture systems. A collaborative and participative process allows for studying possible solutions. The processes must include farmers, extension services, researchers and policy makers and would greatly benefit if pilot farms were in place, that could give a direct and local set of practical suggestions as well as valuable information to researchers. It has been pointed out that in several cases local extension services and technical assistance are rather scarce, limiting the application on the field of many research findings and outcomes. Future strategies need better connection and data transferring to enhance knowledge transfer and support advisory work. Also the decision makers need to get the information that the scientific community has developed and transfer it to the field and into practice.

Main management practices that can reduce the risk of water pollution in horticultural areas may include: accurate prediction of fertilizer demand (foliar and soil water tests); precision techniques, in view of calibrating timing and doses of fertilizers applications; crop residues management (removal from the field); optimization of crop rotations (deep/shallow roots); use of catch crops in certain situations. Each of them as well as their combinations need to be further studied and researched. But research should not be focused only on one point, it should consider the system entirely, i.e., the different aspects of the system must be considered together. Efforts are needed to harmonize methodologies for yield prediction as well as crop needs. N application standards established in action programs are sometimes different for the same crops, only partly justified by the specific local conditions. Integrated solutions could involve other cropping systems: possible alternative uses of crop residues, produced in great amount by vegetable species, should be investigated as potential integration not only in vegetable growing systems but also in cereals and other crops, or also as advanced recycling, from composting to metabolite extraction. More studies should be aimed to increasing N supply efficiency of the vegetable systems, with a particular aim of increasing knowledge of processes occurring at the root system level. The ‘hidden half’ is still mostly unknown for many vegetable species.

Towards an integrated fertilization management

Many progresses have been obtained in the vegetable sector in the last decades: yield, product quality and safety, agricultural practices, commercial standards, all factors have been enhanced globally and in the EU. Integrated pest management has been a driving force to enhance the environmental acceptability of the sector for the European consumer. Unfortunately, an integrated fertilization management is not yet in place, able to cope the need for high quality produce and environmental protection. There is still a lack of information related to the effect of a reduction of N fertilization supply on the quality of products. Consumer perception of quality is under investigation in several countries, mostly affected by cultural, societal and ethical priorities. The European consumer, and the market, can present advantages with respect to some other consumers and markets more driven by food security connected priorities, given that the former is expecting the environment and human health to be considered equally of great importance. There is the potential to stress the importance of enhancing fruit and vegetable consumption for well being, but with low anti-nutritional factors such as nitrates; these factors should be exploited more to raise environmental risk awareness of mismanaged agriculture.

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(3) The challenges of knowledge transfer in the implementation of the Nitrates Directive

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Abstract: *A previous conference NEV2013 (15-17 April 2013 Turin, Italy) highlighted the risks of N losses from horticultural crops. For EU member states to reduce N losses from horticultural systems and fulfil the requirements of the Nitrates Directive improvements to fertiliser use are needed. The conference concluded that fertiliser management practices could be improved by the use of a range of fertilisation recommendation tools, however the appropriateness of any individual tool, in a given set of circumstances was not always clear.*

For horticultural crops there is a need to ensure that quality as well as yield is maintained leading to a tendency for farmers to over-fertilise. The process leading to more optimised fertiliser applications requires efficient two-way delivery of knowledge between the researcher and farmers on the ground. This process is complicated by the needs and agenda of a range of stakeholders which include the policy makers, the regulators, the market represented in the main by supermarkets, many non governmental organisations and fertiliser companies. Additionally the funding required for effective and sustained communication is not always available.

This paper attempts to understand why farmers fail to follow the best practices that are available and how with better knowledge transfer, such practices can not only help to implement the Nitrate Directive but can benefit the farmer and society in a much wider context.

Introduction

A previous conference NEV2013 (15-17 April 2013 Turin, Italy) highlighted the risks of N losses from horticultural crops. For member states to reduce N losses from horticultural systems and fulfil the requirements of the Nitrates Directive, (EU, 1991) improvements to fertiliser use are needed. For horticultural crops there is a need to ensure that quality as well as yield is maintained leading to a tendency for farmers to over-fertilise. In order to optimise fertiliser use there are a range of fertiliser recommendation tools ranging in complexity from rules of thumb, simple look up tables, and models of different degrees of complexity. The tools and the science behind them has been reported in several ISHS workshops (ISHS, 2013) and more recently in Turin at the NEV2013 conference held in 2013.

However, whilst there were many tools available their implementation has been variable. In the worst cases, badly supported tools, such as fertigation, can give rise to worse diffuse pollution than current practice (*S*uarez-Rey, Pers.commun).

The purpose of this paper is not to review these tools but to provide some guidance on how such knowledge represented by these tools might be more effectively implemented in order to fulfil the requirements of the Nitrate Directive.

The importance of knowledge transfer

The challenges of knowledge transfer as part of the process of influencing farmers behaviour are widely recognised, examples are given below:-

Dwyer et al. (2007) concluded that

> "Advice needs to be practical, accessible and business-savvy, to be taken on board by farmers. It should be seen as independent and confidential. It must recognise and try to work with farmers' key business constraints and motivations, or seek ways to overcome or adapt these by drawing upon other strategies and policy initiatives, wherever relevant. It should also capitalise on any win-win opportunities where environmental and business gains can be made together",

In Africa Ilboudo (2012) concluded that,

> "The greatest impediment to the development of science, technology and innovation in Africa, and its contribution to African development, is the communication gap that exists among the major actors and players,"
>
> The media could play a critical role in bridging this gap, Ilboudo added, since journalists play an important

function as intermediaries between scientists, policy-makers and the public."

Rahn (2010a) reported massive over-fertilisation of tomato crops in China, in spite of research offering reductions of 73% in fertiliser use without any reductions in yield. Wu Kun (2012) also quoted Rahn as saying that,

> "There is a need to transfer knowledge from research to the farmers and this **'last step'** is a big problem."

Anon. (2012) in New Zealand commented that

> "Technology transfer must be based around needs if the client cannot see this need or have the need demonstrated then it will not proceed."

acknowledging that knowledge transfer and behavioural change is a common problem. This paper indicates how these difficulties might be overcome.

Barriers to implementation

Several years ago research in the UK (Rahn et al., 1988) indicated that fertiliser application rate in intensive field brassica rotations could be substantially reduced by careful interpretation of soil mineral N data. It was difficult to change behaviour without on-farm demonstrations in experiments, articles in the press and the use of "window plots" where less fertiliser was applied to small parts of intensively managed fields. These window plots were unfertilised and could not be distinguished from the farmer fertilised areas and eventually led to large reductions of fertiliser use across the farm.

The user of any recommendation system is going to be looking for benefits but the benefits may be perceived differently by different stakeholders. Benefits important to a scientist may be valueless to other stakeholders. The policy-maker will see an opportunity to reduce environmental pollution, the larger farmers may see a massive saving in fertiliser costs and an increase in product marketability but the small family farmer owning one greenhouse may see it as a threat to their income. The fear of loosing any yield will have a direct impact on their well being. The fertiliser company may see the reduction in use as a threat to their income, the supplier of manure may find it more difficult to dispose of his manure. If it cannot be disposed of it could affect the sustainability of the livestock industry.

The 'value chain' (Porter, 1985) (Figure 1) shows the parts of a business where benefits can be located. These will vary with the size of the business, for the small farmer lower fertiliser and manure costs without losses in yield would be most beneficial. If using a recommendation system shows compliance with good agricultural practice, this might benefit marketing of the produce especially for export. For the largest producers recommendation systems could improve operations and inbound logistics by streamlining purchase and use of fertilisers. More targeted applications of fertiliser may not only save on fertiliser costs but increase the quality and storability of produce as well as reducing environmental pollution.

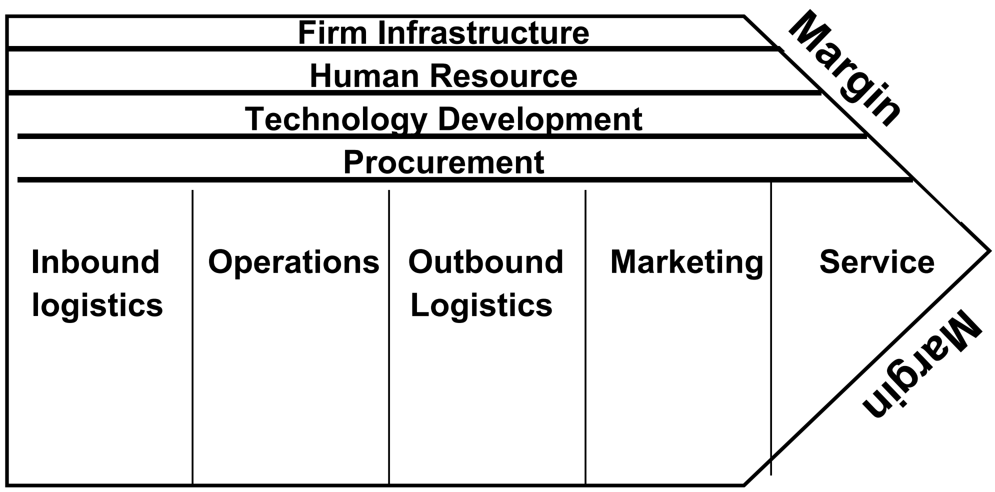

Figure 1 Porters (1985) Value Chain – areas where contributions can be made to improve margin.

If real, material benefits can be demonstrated by the use of the recommendation systems then there is an increased chance of implementation. The best systems will provide benefits to a number of stakeholders at once, for instance if the small farmer can be convinced, he will win, then the reduced amounts of fertiliser will also benefit the implementation of policy.

Barriers to implementation are many and varied and can include:

1) **Frozen behaviour** – why should I change from traditional methods of fertilisation that have been successful for years?
2) **Perceived risk** – if I reduce the fertiliser input I might loose out on income and may not be able to look after my family.
3) **Education** – I do not understand what is being communicated to me, why should I be concerned for the environment.
4) **Cost of implementation** – I cannot afford the soil samplers, or to get the samples analysed.
5) **Time to implement** – I do not have time to take soil samples and read fertiliser recommendation tables as I spend most of my time working in a local factory.
6) **The message** – the message is simply too complex and drastic for me.
7) **Trust in the messenger** – I do not trust the person that is providing the advice what experience does he have in this field.

All these barriers require obvious benefits to be demonstrated before they can be overcome. What steps might be taken to facilitate the adoption of a fertiliser recommendation system?. A framework has been constructed to describe the stages of success in developing and using information systems. The 3-D model (Ballantine et al 1996) describes 3 stages, development, deployment and delivery (see Figure 2) The success of the system depends on passing through three barriers/filters to use; implementation, integration and the environment. Though this framework was originally designed with business information systems in mind, it could be used to assess the likelihood of success for fertiliser recommendation systems in horticulture. It demonstrates that the science is but one part of the chain to improve fertiliser use.

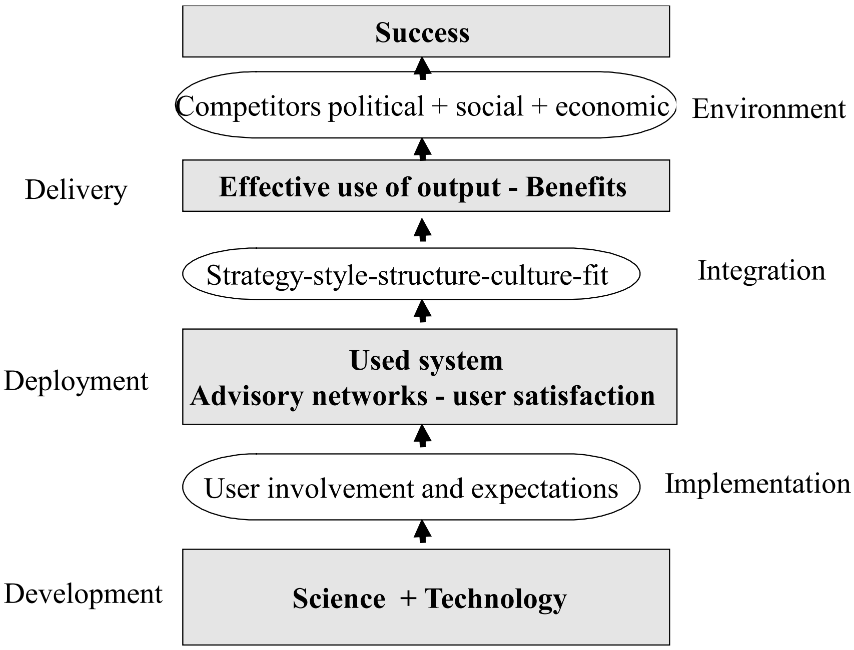

Figure 2 The 3D Information systems model adapted from Ballantine et al 1996

The development stage is where research is carried out that underpins the recommendation system. This depends on the quality of science and its validation. This is the stage that scientists concern themselves with, publication of the research in an academic journal may be seen as the most important output, but in reality is a small part of the process.

Deployment by users depends on the *implementation* filter, which relies on the support of an individual champion or groups promoting the system. Have the potential users been involved in the development of the recommendation systems? Have the expectations of the farmers been taken into account? Are they convinced that the adoption of the new system provides any advantages, benefits over current practices? In the UK when the national recommendation systems were revised the ministry responsible for agriculture (Defra) insisted that the industry was involved in the process of developing the new recommendations to ensure their buy in.

Successful deployment depends on the resources available to support the system – these will include advisory networks and publications. Delivery of booklets and leaflets on their own will be ineffective. Are networks of advisors available? The networks of advisors will need to be sufficiently well trained to inspire confidence in the system and encourage the farmers to adopt the new techniques. In the UK there are schemes to ensure that advisors are trained to an appropriate standard. The FACTS scheme (FACTS, 2010) also requires continuing education and more recently re-training to be sure it is up to date with changes in technology and legislation. If the recommendation systems require soil analysis, are their sufficient laboratories to supply the farmers needs. Are there sufficient numbers of skilled staff to interpret the results and answer queries about the system?

For the larger farmers the recommendation systems must be *integrated* with the business system – it may be that very complex systems do not work well when large areas of crops are being fertilised at once. It may require that the recommendation systems are computerised to fit in with the infrastructure of the company. Do the decisions made fit in with the operating strategies of the company? If they do then the benefits of the recommendation systems can be delivered. The success then depends on the final filter for the system, the *environment.* This dictates the effect of external factors such as political, social or economic factors on the benefits valued by stakeholders, such as government and customers.

At government level, policies to reduce environmental pollution may require legislation to force changes in practice, so it is better that this legislation it is in tune with farming systems, or there may be consequences that unintentionally limit industry sustainability. Legislation in Europe is directed by the Nitrates Directives (EU 1991) driving the needs to reduce N applications – each country has a different approach which was summarised in the (NUMALEC) project (Clercq et al., 2001). This is currently being updated by the NutriHort project (Hofman et al., 2013). In the UK Nitrate Vulnerable Zones have been defined, within these areas there are restriction on the amounts of fertiliser and manures and when they can be applied (Defra, 2010).

If the benefits are common to all stakeholders, such as the demand for growth of quality vegetable crops using optimised amounts of N appropriate to the protection of the environment, then we are more likely to have success with the implementation of the Directive.

The future and the importance of communication

An issue to be faced in the future is that the knowledge base is not being developed to the same degree as in the past. This in part is due to the increasing dominance of biotechnology without applied agronomy. Also Antonio Monteiro (2013) the ISHS President recently stated that

> "When relying solely and blindly on bibliometrics to evaluate their staff, scientific institutions are encouraging research to progressively drift away from the real and important problems science has to solve. This is particularly true in horticulture".

Added to this the expertise in this research field is diminishing with several European countries having few specialists in this field (Rahn, 2010b).

The process of knowledge transfer can be represented by the knowledge translation value chain (Thorpe, 2011). The process of knowledge transfer for land based industries is represented in Figure 3. This shows that there is no particular type of research that is not useful but that it needs to be connected up. Agronomy without a scientific basis can be limited; equally basic science can be irrelevant if it is not connected up with an understanding of the big picture that agronomy provides.

Knowledge transfer requires two way communications to ensure that the results are successfully transferred to the farmers, and that research is relevant and purposeful. Thinking academics in the pools of innovation need to be faced with real questions and problems delivered from the farmers and other stakeholders along the same chain in order to carry out the most relevant research.

In the case of communication it is rare that academics can relate directly with farmers, they are in a different world (Anderson et al., 2001), but so long as they can converse with the next stage along the chain, the development scientists' message can be passed down the chain. Communication at each stage can be hindered if there is no confidence in the message or the messenger. Participative research allows engagement at many levels along this chain, such techniques are not new. Hagmann et al. (1996) share their experiences of participatory research in Zimbabwe.

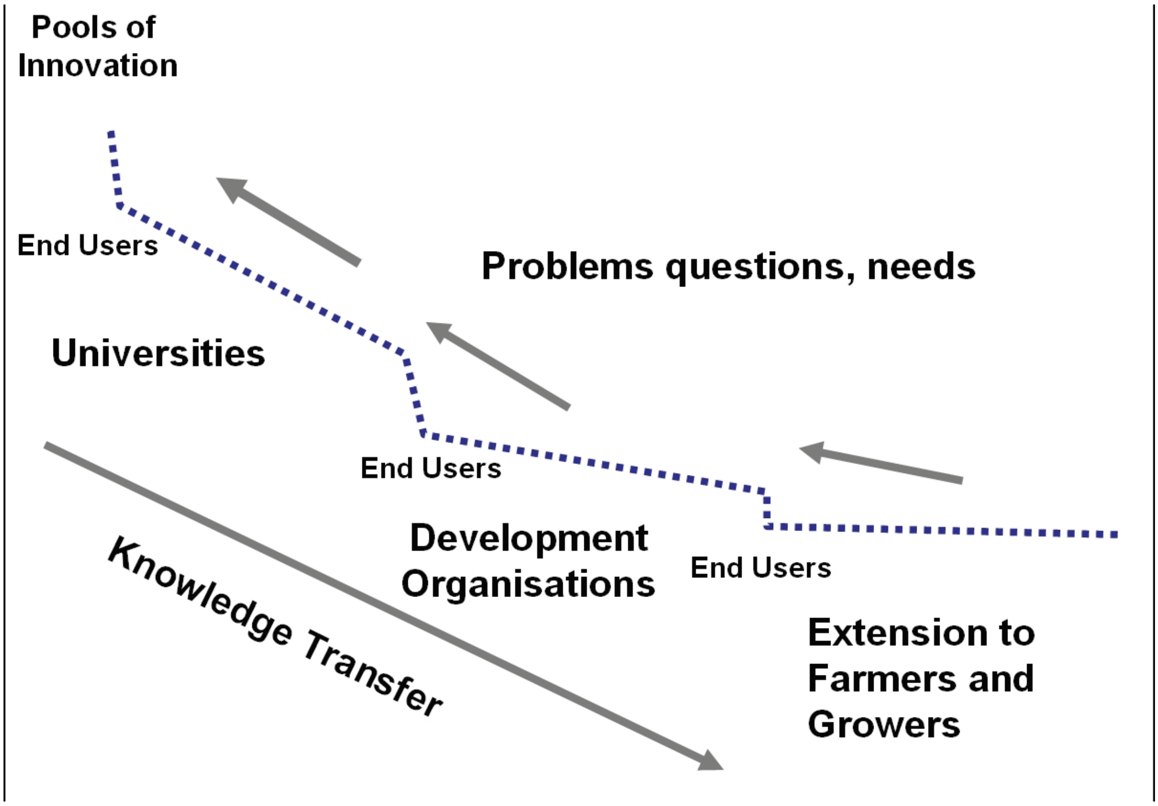

Figure 3 The Knowledge Transfer Chain as applied to Agriculture.

Communication can be at several scales:

1) **National –** generally best suited to alerting stakeholders of big changes in policy of less benefit for changing farmer behaviour.
2) **Large meetings** – Most suitable for engaging larger stakeholders, co-operatives of farmers, consultants, and communication along the knowledge transfer chain.
3) **Small group** – Allows more discussion of the benefits of change especially if linked to local demonstrations, where the benefits can be seen at the field scale, with time trusted relationships can build up.
4) **One to one** – Most effective method of changing behaviour as allows a holistic understanding of the lively-hood of farmers enables trusted relationships to be developed.

Modes of modern communication include

1) **Farming press and other media** – great for advising of policy changes
2) **Leaflets** - mix of documents to inform and as reference items.
3) **Websites** – very effective where information needs frequent revision, benefits depend on the IT skills of the target community.
4) **Smart phone** – can be very effective in delivering up to date information, via texts and more complex information via applications, use will depend on skills of the target audience.

The most successful strategy for overcoming the barriers of implementation previously mentioned would be the use of locally accepted and trusted advisors on a one to one basis as they will have a holistic understanding of their business (livelihoods). However this process is very costly so in reality communication will be by the use of a mix of scales and modes of communication but that mix will have be appropriately decided.

None of this communication can occur without funding. Funding must realise the costs and importance of networking in the process of knowledge transfer. As soon the research project is finished the time and funding left for knowledge transfer is often minimal. Research funding is often based on the development, of a product, involving some element of innovation. Networking and the use of skills to develop practical advice are not seen as sufficiently innovative to attract funding. For efficient knowledge transfer this should change.

As an example of what can be done a new project led by Professor Laurence Smith from the School of Oriental and African Studies (SOAS) in the University of London (Smith, 2013) brings together the minds of social and biological scientists in the UK and China. The project aims to investigate the process of informing the agricultural industry of the science that is available. This will help to identify the steps required to develop and deploy mitigation strategies that will both maintain the livelihoods and productivity of farmers, with a decreased effect on the environment.

Conclusions

With necessary partnerships along the knowledge transfer chain, barriers to implementation of fertilisation recommendation tools can be overcome resulting in more efficient use of fertilisers. These activities leading to reduced leakage of nutrients, to fulfil both the needs of the Nitrate Directive and society as a whole.

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(4) Improved nitrogen management practices for vegetable production

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Abstract: *In intensive vegetable production (IVP), the supply of plant available N often appreciably exceeds crop N requirements resulting in* NO_3^- *contamination of water bodies. Available methods for improving N management in IVP will be reviewed, with an emphasis on recent developments that enable growers to exploit the increasing technical capacity (e.g. fertigation, drip irrigation) of IVP for precise and responsive N management. An overview will be given of available methods with consideration of suitability to different and changing cropping conditions, and practicality. Improved N management systems will be considered as being (a) soil-based N recommendation systems, (b) crop-based monitoring systems, (c) N balance calculations, (c) decision support systems, and (d) scenario analysis tools.*

Soil-based systems consider soil mineral N when determining N fertilizer rates. Crop monitoring can potentially inform of the adequacy of crop N status at given times. However, for each method, there are important considerations. Proximal optical sensors are a promising approach. The N balance considers the various soil N sources. Decision support systems combining N balance calculations with simulations of crop N uptake can provide N fertilizer plans that closely follow crop N needs and consider soil N supply. Scenario analysis tools are relatively complex models used to illustrate consequences of different management practices.

A suggested optimal N management approach is combined prescriptive-corrective management. Prescriptive management being preparation of N fertilizer plans that match N supply to crop N needs while considering soil N supply, and corrective management being monitoring approaches that assesses crop/soil N status to subsequently adjust and optimize N management.

Keywords: *N demand; N supply; soil sampling; crop monitoring; N balance*

Introduction

Intensive vegetable production systems are commonly associated with appreciable loss of nitrogen (N) to the environment. The recovery of applied N in vegetable crop production is generally low, and the unrecovered N is susceptible to N loss processes. Appreciable NO_3^- leaching is a common occurrence in vegetable production where low N recoveries are often combined with excessive irrigation, short growing cycles and shallow rooting plants. Within the European Union, there is increasing pressure on the agricultural sector to appreciably reduce NO_3^- leaching loss which is associated with NO_3^- contamination of subterranean and surface water. Additionally, there is pressure to reduce other N loss processes, which have undesirable environmental consequences, such as nitrous oxide (N_2O) emission, ammonia (NH_3) volatilization and run-off losses. Consequently, there is a strong requirement to appreciably improve crop recovery of N in intensive vegetable production.

For N management of vegetable crops there is a diversity of approaches in use or being researched as practical N recommendation systems. Some approaches are being used in particular regions or countries. Other approaches have been used in numerous research studies, sometimes with conflicting results. Recent developments in sensor and information technologies have provided some promising approaches for on-going monitoring of crop N status. This article will present and review the various approaches used and being developed for N management of vegetable crops. A general management system will be recommended for optimal N management of intensive vegetable production systems.

Improving N Management – General Considerations

In intensive crop production, N application rates commonly exceed the economic optimum rate, and the proportion of unrecovered N increases exponentially with increasing N application. Unrecovered N is either lost to the surrounding environment during the crop or accumulates in soil from where it can be subsequently lost. Given that N application rates in vegetable and crop production are generally excessive (Meisinger et al., 2008), appreciable proportions of applied N can be lost to the environment.

In agricultural practice for a given site in a given year, there are numerous uncertainties that influence what is the economically optimal N fertilizer rate, or what is the minimum rate required for maximum production. The optimal rate for a given site varies between years because of differences in climate, previous crop, timing of the crop etc. Similarly, there will be differences between sites because of soil type, site history and climatic variations. The amounts of N supplied by the soil as (a) mineral N at the start of the crop, and (b) mineralized during the crop from various organic sources (soil organic matter, manure, crop residues) vary; consequently, the optimal amount of supplemental N supplied as mineral fertilizer will vary. During a crop, variable climatic conditions influence the retention of soil mineral N and crop growth. To ensure that these various uncertainties do not cause an N limited reduction in production, growers generally apply excessive N fertilizer.

To improve N management in intensive vegetable production, it is essential to appreciably reduce these various uncertainties. This can be done through the provision of viable information. Growers require practical tools to provide such information. The concept of the “N Toolbox” (Newcastle University, 2013) conveys the concept of having a “kit” of various relevant tools, with an optimal combination being selected for a given cropping situation. The tools in the “N Toolbox for Vegetable Crops” should include tools that provide quantitative information on (a) the expected crop N demand, (b) the expected soil N supply, and (c) whether the N supply matches the N demand, either at critical times or throughout the crop.

The tools chosen for a given crop will depend on the local availability of specific approaches, the availability of support services such as laboratories and relevant technical advice, the crop being grown, the technical level of the grower, and economic considerations. The main categories of available tools in the “N Tool Box for Vegetable Crops” are (a) soil testing approaches, (b) N balance calculations, (c) modelling approaches, and (d) crop/plant testing approaches. Brief descriptions and critical reviews of the major available tools in each category follow. Traditional fixed rates approaches will also be considered as the baseline situation because it is the most commonly-used approach.

Fixed N rate

Fixed rates provide a general “one size fits all” recommendation for a given species in a particular region. In practice, it is an experiential approach that provides sufficient N to ensure maximum production. Recommendations are based on fertilizer trials or the collective experience of growers and/or advisors. Results from several years of fertilizer trials at representative or collective experience are used to derive single recommendations for the total N amount applied and for the partitioning of the N applications. There is generally very little consideration of variations in the soil N supply, differences in planting date, soil type and climatic conditions. Consequently, while ensuring maximum production, this approach is likely to be associated with excessive N supply and the associated N losses to the environment. There is no, or at the most little, consideration of site-specific or season specific characteristics.

Soil testing approaches

With soil testing approaches, the N fertilizer rate is adjusted in response to the amount of soil mineral N in the root zone. These can be considered as generalized site specific approaches, in which the soil mineral N content of a given site in a given year is taken into account using relationships which are generally averages from numerous trials

Nmin method

A widely-used approach, in North-western and Central Europe is the Nmin method (Neeteson, 1994). “Nmin” refers to mineral N, and not to N mineralized from organic material. In this approach, the recommended amount of mineral N fertilizer is influenced by the amount of soil mineral N in the root zone at planting. Numerous field trials are used to derive an inverse linear relationship between the optimum total N rate (the target N value) and soil mineral N for each species within a region (Neeteson, 1994). Each crop has both a species specific rooting depth and inverse linear regression equation describing the reduction in the recommended rate of applied fertilizer N with increasing soil mineral N in the root zone (Neeteson, 1994). The requirement for large numbers of field trials is a practical limitation. To overcome this, a modelling approach has been developed to derive N recommendation values (Feller and Fink, 2002). In its simplest form, using the previously-described inverse linear regression equation, N mineralization from organic material during the crop is not explicitly considered. The modelling approach for deriving target N values described by Feller and Fink (2002) considers apparent N mineralization.

KNS method

Another soil testing approach that is also widely used in North-western and Central Europe is the KNS method. This method is fully described by Ziegler et al. (1996). The KNS method considers root zone mineral N at planting and also during the crop; soil mineral N is determined at least two different times for each crop. The KNS method considers that there is a buffer value for root zone soil mineral N below which production is N limited. The buffer value (in kg N ha^{-1}) is added to the anticipated N uptake for a given period (e.g. several weeks) to calculate the Nmin target value for that period. The Nmin target value in the KNS system is the amount of mineral N that should be available to the crop to ensure optimal production for a given period. Following determination of root zone soil mineral N, the amount of N applied as mineral fertilizer is the difference between the Nmin target value for the period in question and the amount of mineral N measured in the root zone. If measured soil mineral N is greater than the Nmin target value, no N fertilizer is applied.

Soil N Supply Indices

In England and Wales, an index system is used to estimate the “Soil N Supply” (SNS) where soil sampling has not been conducted. The estimation and use of SNS Indices are described in the Fertiliser Manual RB209 (DEFRA, 2010). The SNS Indices consider both estimated soil mineral N and estimated N mineralized from organic material during the crop. SNS indices are determined for each crop species and consider average annual rainfall, soil texture and residues from the proceeding crop. The SNS indices have values of 0 to 6, and each index value corresponds to an amount of soil mineral N in the root zone. For example, for lettuce in a low rainfall zone (500-600 mm), SNS Indices of 0, 3 and 6 correspond to <60, 101-120 and >240 kg N ha^{-1}, respectively. For a given SNS index for a given crop, there is a corresponding N fertilizer rate; for example for lettuce, SNS indices of 0, 3 and 6 require N fertilizer rates of 200, 150 and 30 kg N ha^{-1}, respectively. Where soil sampling at planting has been conducted, there is a procedure to use the measured soil mineral N values.

Pre Side-dress Nitrate test (PSNT)

The Pre Side-dress Nitrate Test (PSNT) measures root zone soil NO_3^- during the crop immediately prior to the main side-dressing N application (Meisinger et al., 2008); only NO_3^- is determined as almost all soil mineral N is in the form of NO_3^-. This is done immediately prior to the main side-dress N application, which proceeds the period of rapid vegetative growth. The PSNT is primarily used to assess whether side-dress N application is required (Meisinger et al., 2008). It was developed for maize and is the recommended N management system for maize in numerous US states and in various regions of Canada. Various research studies have demonstrated its value for use with different vegetable crops such as tomato, lettuce, cabbage and celery (Hartz, 2003; 2006). For maize, soil is sampled to 30 cm when the crop is 15-30 cm tall; when soil NO_3^-–N content is >25 mg ppm no fertilizer N is required (Meisinger et al., 2008). Schmidt et al. (2009) presented N fertilizer recommendations for maize based on PSNT values of <25 ppm NO_3^-–N.

1:2 soil:water extract method

A soil testing approach developed for vegetable crops in The Netherlands and which has used in a number of different countries is 1:2 soil:water extract method. Analysis of the extract following sampling at key times is used to make fertigation recommendations (de Kreij et al., 2007).

Soil solution suction samplers

These samplers also known as ceramic cup suction samplers can be used for N management by maintaining soil solution $[NO_3^-]$ in the main root zone, above a threshold value or within a sufficiency range. In Israel, they are used in commercial vegetable production using a minimum threshold value of 5 mM (Kramer, Israeli Ministry of Foreign Affairs, personal communication). Hartz and Hochmuth (1996) reported their use in vegetable crops with a minimum threshold value of 5 mM; however, Hartz (2003) commented that high spatial variability of soil solution $[NO_3^-]$ was an important consideration. In greenhouse-grown vegetable crops grown with combined drip irrigation and fertigation and which receive N in all irrigations, accumulation of soil solution NO_3^- was associated with excessive N application (Gallardo et al., 2006). In the same system, Granados et al. (2013) maintained soil solution $[NO_3^-]$ within a sufficiency range as part of an improved management system that appreciably reduced NO_3^- leaching and N fertilizer use.

Observations regarding soil testing approaches

Soil testing approaches are more widely-used in commercial farming than other general approaches. A basic requirement for their use is for laboratories capable of rapid analysis of numerous samples. Small portable “quick test” analytical systems (Parks et al., 2012) can be used for on farm determination of NO_3^- concentration in soil solution. On farm analytical procedures have been reported for soil analysis (Hartz and Hochmuth, 1996) but there appears to have been little on-farm adoption. Effective soil sampling requires correct sampling and handling procedures. The speed and costs of transport are issues, as is the cost of the analyses. Determination of root zone soil mineral N should be a component of the N tool box for vegetable crops. However, soil sampling-based approaches can be considered as having limited flexibility within highly variable cropping systems because of fixed assumptions of yield and crop N requirement, no explicit consideration of N mineralization from organic material and their general inability to respond to seasonal variations in N demand and N supply.

N balance

N balance calculations to determine N fertilizer application rate have the advantage of explicitly considering all major N inputs. In its simplest form, N balances are calculated for the duration of a crop, which can be considered as a site specific approach. With the inclusion of simulation modelling, dynamic N balances can be calculated daily or weekly enabling N management that is both site and season specific. The commonly-used N inputs and outputs are listed in Table 1.

Table 1. N inputs and outputs used for developing a N balance

N Inputs	N Outputs
Initial soil mineral N ($N_{min\text{-}ini}$)	Crop N (N_{crop})
N mineralized from soil OM ($N_{minz\text{-}OM}$)	N losses (N_{loss})
N mineralized from org. residues ($N_{minz\text{-}res}$)	Final soil mineral N ($N_{min\text{-}fin}$)
Mineral N fertilizer (N_{fert})	
Total N Inputs (∑Inputs)	Total N Outputs (∑Outputs)

For each given time period, the sum of N inputs equals the sum of N outputs. The apparent recovery or efficiency (E) of each N inputs is N_{crop}/N-Input; it is assumed here (simplistically) that the efficiencies of use of all inputs are the same. Crop fertilizer requirements can be calculated using the equation:

$N_{fert} = (1/E) * [N_{crop} – (N_{min\text{-}ini} + N_{min\text{-}OM} + N_{minz\text{-}res})]$

There are some variations between authors on the details of N balance calculations (see Meisinger et al., 2008). However, a consistent feature is that all major N sources are considered. Seasonal N balance calculations can be done manually. Computer-based decision support systems (DSS) are required for dynamic N balances calculated daily/weekly. These DSS employ varying degrees of simulation. The simplest approach is to simulate only N_{crop}, with the DSS component making simple estimates of other N balance terms e.g. VegSyst-DSS (Gallardo et al., 2013). The more complex approach is to simulate various terms of the N balance e.g. Azofert (Parneaudeau et al., 2009). The latter approach is more accurate but requires appreciably more input data. The simpler approach is more suited for on-farm application because only few and readily available data (e.g. climate data) are used as inputs (Gallardo et al., 2013).

Dynamic DSS provide N demand calculations that reflect actual growing conditions. They are potentially dynamic and responsive tools that provide customized N fertilizer plans for given cropping conditions. Dynamic DSS are a recommended component of the N tool box for vegetable crops.

Simulation models – other approaches

Modelling approaches that are not based on the N balance have been used to develop DSS and scenario analysis tools. The WELL_N DSS (Rahn et al., 1996) has been used for making N recommendations for commercial vegetable production in England. The EU-Rotate_N (Rahn et al., 2010) can be used as DSS and is useful scenario analysis tool that has been used in diverse vegetable cropping systems throughout Western Europe and in China. It is a particularly useful tool for demonstrating to growers and decision makers the effects of management on production, NO_3^- leaching and profitability.

Crop and plant monitoring approaches

Monitoring of crop or plant N status potentially can provide information on the adequacy of the N supply in relation to the N demand.

Tissue analysis approaches such as total N analysis and NO_3^- analysis of dried petiole or mid-rib tissue have been available for a number of years. A general observation is that there appears to have been limited use in commercial vegetable production. This review will be restricted to sap analysis and optical sensors.

Sap NO_3^- analysis

N absorbed by roots is transported to shoot tissue as NO_3^-. [NO_3^-] in petiole sap has been proposed as an indicator of current plant N status. Normally, the last recently fully expanded leaf is sampled; it is recommended that 20-40 petioles be sampled from different representative plants. There are strict protocols for handling and storing petioles, and for the extraction and storage of sap samples. Analysis can be made on farm using quick test systems (Parhs et al., 2012); the Cardy nitrate meter (Horiba, Japan) has given accurate analysis and can measure likely sap [NO_3^-] without dilution (R.B. Thompson, unpublished data). The [NO_3^-] in petiole sap generally declines as vegetable plants age. Sufficiency ranges for a number of important vegetable species, at different phenological stages, have been published (e.g. Hartz and Hochmuth, 1996). Some studies have reported that petiole sap [NO_3^-] is a good indicator of crop N status for various vegetable species in a particular region. An example is processing tomato in central Italy (Farneselli et al., in press). However, sap [NO_3^-] values can be affected by factors such as cultivar, amount and timing of N previous application, and crop water status. Some authors have reported that sap [NO_3^-] was not a sensitive indicator of vegetable crop N status (Hartz, 2006). It appears that sap [NO_3^-] can potentially provide information on the adequacy of crop N status for a given species within a given region, and that consistent N management practices (e.g. timing, pre-plant applications) and similarity of cultivars and general crop management are likely to improve its viability. Little work has been done on interpretation of sap [NO_3^-] to determine N fertilizer rates.

Chlorophyll meters

Chlorophyll meters (CMs) are small, hand-held, clip-on optical sensors that indirectly measure leaf chlorophyll. Leaf chlorophyll content is correlated to leaf N content. There are two commercially available sensors, SPAD-502 (Konica-Minolta, Tokyo, Japan) and the Hydro N-tester (Yara International, Oslo, Norway) which are almost identical; most work has been done with the SPAD-502. The two sensors measure leaf chlorophyll content in their own units (SPAD or HNT units). For each individual measurement, the area measured is 6 mm^2. Consequently, there is a requirement for appreciable measurement replication e.g. 20-40 measurements on different plants per field or experimental treatment, and for strict measurement protocols (which leaf sampled, position on leaf etc.).

There are many research publications on the use of CM to evaluate crop N status of a variety of crops, mostly cereals and field crops e.g. maize, wheat, rice and potato (Fox and Walthall, 2008; Meisinger et al., 2008; Samborski et al., 2009). There have also been studies with various vegetable crops. There are also a number of reports on their use to assist with N management, again mostly with cereals and field crops (Fox and Walthall, 2008; Meisinger et al., 2008; Samborski et al., 2009). CM measurements can be affected by time of day, incident radiation, crop water status and cultivar (Fox and Walthall, 2008; Samborski et al., 2009). To reduce the influence of these effects, and to isolate the effect of crop N status on CM readings, the use of the Sufficiency Index (SI) has been proposed (Gianquinto et al., 2004; Fox and Walthall, 2008; Samborski et al., 2009). SI is the ratio of the measured value of a crop divided by the value from a well-fertilized reference plot in which N is not limiting production. Protocols for the use of CMs to aid crop N management have been develop using both absolute CM values as measured (e.g. Gianquinto et al., 2004) and SI values (e.g. Samborski et al. 2009). In general, it appears that for CMs, as with sap analysis, that there is most potential for their use with specific crop within specific regions, using standardized crop management practices. In recent years, there has been active research on the use of general protocols for using optical sensors, such as CMs for N management (e.g. Holland and Schepers, 2010).

Reflectance sensors

In recent years, there has been substantial research on the use of proximal reflectance sensors to assist with crop N management (e.g. Fox and Walthall, 2008; Meisinger et al., 2008; Samborski et al 2009; Schmidt et al, 2009). This is a form of remote sensing in which these optical sensors are positioned 0.5–6 m from the crop. Much of the recent research has been conducted with cereal crops with a strong interest in their use for precision management of N fertilizer (Fox and Walthall, 2008; Meisinger et al., 2008; Samborski et al., 2009). There are both active reflectance sensors (e.g. Crop Circle sensors, Greenseeker, Yara N Sensor ALS), with their own light source and passive sensors (CropScan) without a light source. Active sensors can be used in any light conditions. The big advantage of proximal reflectance sensors is that because of the large measurement window and continual measurement they measure large representative areas of the crop canopy. Canopy reflectance measurements are based on the interaction of different light wavelengths, in the visible-and NIR (near infra-red) spectrum with the crop canopy (Fox and Walthall, 2008; Samborski et al., 2009). Compared to N sufficient plants, N deficient plants generally reflect more visible and less NIR radiation (Fox and Walthall, 2008). The reflectance of 2-3 individual wavelengths (e.g. 550, 670, 730 and 760 nm) are used to derive mathematical indices. There are numerous indices, the most commonly used is the NDVI (Normalized Difference Vegetation Index), and others are G-NDVI (Green Normalized Difference Vegetation Index), RVI (Ratio of Vegetation Index) and CCCI (Canopy Chlorophyll Concentration Index). Commonly, the selected indices are used within the Sufficiency Index (SI), i.e. values are compared to those of non N limited plants) which was previously described for CM meters, for interpretation.

Reflectance sensors are either tractor mounted or hand-held. Tractor mounted sensors can be used to automatically control N fertilizer rates for precision management, as is currently being done commercially. Reflectance sensors have been used to assess the N status of various crops (Fox and Walthall, 2008; Meisinger et al., 2008; Samborski et al., 2009), most work has been with maize, wheat and cotton. With vegetable crops, there has been some work with various species, particularly tomato (e.g. Gianquinto et al., 2012). There is considerable on-going work on the development of protocols for using reflectance and other optical sensors for determining N fertilizer application rates (e.g. Meisinger et al., 2008; Holland and Schepers, 2010).

Fluorescence measurement of flavonoles or polyphenols

Polyphenolic compounds, in particular flavonoles are produced in plant leaves, the content is usually inversely related to plant N status. The ratio of chlorophyll to flavonoles (or polyphenols) has been reported to be very sensitive to crop N status (Samborski et al., 2009; Tremblay et al., 2012). Optical sensors based on measurement of fluorescence properties have been developed to measure both flavonoles and chlorophyll. The DUALEX4-FLAV is a clip-on sensor and the MULTIPLEX is a proximal sensor; both are produced by Force A, Paris, France. A number of studies have suggested that leaf flavonoles and the ratio of chlorophyll to flavonoles are both sensitive indicators of crop N status (Tremblay et al., 2012). This is a recent and promising line of research.

Recommended Tools and Approach

The recommended approach for optimizing N management of vegetable crops is a combination of prescriptive and corrective management (Giller et al., 2004). Prescriptive management is the preparation of an optimal plan, in this case an N fertilizer plan (Giller et al., 2004). Corrective management is the use of monitoring techniques to make adjustments to ensure crop N sufficiency (Giller et al., 2004). Optimal prescriptive N management must consider all N sources and the crop N demand, this is best done using an N balance approach. We suggest that the ideal prescriptive management tool is a computer-based decision support system that calculates daily N balance with simulation of daily crop N demand; measured soil mineral is a required input, and all other major N inputs should be considered. Ideally, corrective management should be done through crop monitoring. However, the currently more established crop monitoring approaches (sap testing, CM) have various caveats and appear limited to region and species specific applications. Proximal optical sensors appear to be a promising tool; however, more work is required before they can be recommended for practical on-farm use with vegetable crops. It is suggested that scenario analysis tools such as EU-ROTATE_N should be part of the N tool box for vegetable crops.

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(5) Optical sensors for the ion-selective management of hydroponic nutrient solution quality

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Abstract: *Traditional management practices for maintaining hydroponic solution quality waste considerable volumes of water and fertilizers. In general, hydroponic solutions are created to provide an ideal mixture of nutrients to plants, the quality of which depletes as the plants grow. Because plant nutrient uptake is variable and dependent on many environmental factors, growers cannot know the composition of their nutrient solution without outsourcing expensive lab analysis. Typically, measures of electrical conductivity and pH help growers determine hydroponic solution quality (although crudely) and weak solutions are eventually discharged and replaced. If detailed information describing the composition of a hydroponic solution was readily available to a grower, management practices could be developed such that nutrient solutions are adjusted to replenish ions that are depleted. Ion-Selective (IS) Sensor technologies have been developed in the last few decades and are now realizing market availability. We are characterizing novel IS Optodes alongside commercially available IS Electrodes in the hydroponic environment to assess the feasibility for use in an automated nutrient management system (HPLC is used to validate measurements). The most suitable technology will be integrated into the design of an online IS Monitoring System. The IS Monitoring System will be tested in custom plant growth chambers at the University of Guelph as we monitor plant nutrient uptake in response to environmental variables with a focus on light quality and quantity. Ultimately this system could be used for feedback control of an IS Nutrient Dosing Apparatus that can maintain an ideal nutrient solution composition, continuously.*

Keywords: *optodes; electrodes; HPLC; monitoring; control*

Introduction

Traditional methods for managing solution quality in hydroponic systems are very wasteful in terms of water and nutrients. The biggest challenge faced in modifying nutrient solution is to maintain appropriate nutrient concentrations to avoid deficiency, while at the same time ensuring concentrations do not exceed toxicity limits of crops. It can be challenging to identify symptoms of deficiency and/or toxicity and quite often, visible signs of deficiency may be a symptom of some other imbalance. Additionally, plants uptake nutrients at variable rates dependant on many factors including: development stage, environmental conditions, imposed stress, and acclimatization to name a few. Uptake rates also vary between species of plant and individual cultivars. Environmental factors are intrinsically interrelated and generally quite variable on micro - and macro scales. This makes “topping-up” nutrient solutions to maintain concentrations of each nutrient ion very difficult.

Growers make decisions about their nutrient solution quality based on generalized measures. Solution pH is measured as it is critical to maintain an appropriate range allowing for ion mobility in the system. Typically electrical conductivity (EC) is measured to gain an indication of the abundance of nutrient ions. However EC does not differentiate ionic species and thus does not indicate which ions are deficient (Kupers et al. 1992; Morimoto et al. 1992). When growers lose confidence in their solution chemistry they generally dump their reservoirs and mix fresh solutions.

Attempts have been made to characterize nutrient solutions in-situ using Ion-Selective sensors but typically encounter practical limitations (Bailey et al. 1988; Heinen 1992; Gieling 2005). Ion-selective sensor technology has historically been insufficient to resolve ionic composition of nutrient solutions using direct measurements. Analysis requires advanced technology and highly qualified personnel, both of which are expensive. Laboratory analysis using High Pressure Liquid Chromatography (HPLC) is performed to assess nutrient solution quality. However, this method is cost prohibitive for most growers and results are not available in real-time (1-3 week waits are typical) (Voogt 1997).

Monitoring solution chemistry is challenging due to many factors. At a fundamental level, sensors measure the activity of target species in their environment, *not* concentration. The activity of an ion in solution is related to its concentration but it is also influenced by the activity of all other species that exist around it. In short, the more molecules in your mixture the harder it is to measure their abundance.

The present study aims to test novel sensor technologies in hydroponic solutions to assess their suitability for on-line detection/monitoring of important nutrient ions. A review of ion-selective sensor technologies as they relate to hydroponic plant production is presented by Bamsey et al. (2012b). From this review, a group of technologies were selected for the development of an online, ion-selective monitoring system for hydroponic systems. The technologies under consideration are: Ion-Selective (IS) Optodes, IS-Electrodes, and HPLC.

For the development of an online monitoring system, a focus was made on IS-optodes which, owing to the nature of their design and operation, do not require filling solutions or regular calibrations. Optical sensors for nutrient ion measurement were first explored in the mid-1990s for use in biological life support systems (Tobacco, 1994; 1996). Although this research was promising, it did not generate technologies in use today. More recently, IS-optodes for K^+ and Ca^{2+} ions were tailored for use in hydroponic nutrient solutions and characterized (Bamsey et al., 2012a). INO (2012) developed additional IS-optodes for other ions relevant to plant nutrition (K^+, NH_4^+, Na+, Ca^{2+}, NO_3^-) and designed to operate in hydroponic solutions.

Ultimately, once on-line monitoring of essential nutrient ions is achieved, management of hydroponic nutrient solutions can be optimized. Direct benefits include: independence from outsourced nutrient solution analysis; real-time modification of nutrient solution recipes; maintenance of optimal nutrient concentration; complete nutrient water recycling; and improved understanding of plant-environment interactions.

Materials and Methods

Experiment Phases:

1) Characterize the performance of ion-selective sensor technologies in controlled environment, hydroponic plant production chambers.
2) Characterize nutrient uptake in plants in high temporal resolution in response to variations of important environmental variables (light quality and intensity, temperature, vapour pressure deficit, water stress, atmospheric composition).

Experiment Materials and Methods:

1) *Phase One* of the project focuses on technology development. A prototype, in-line system for automated monitoring of nutrient solution composition using Optode sensors was developed. The in-line system uses a coated optical fibre sensor technology developed by INO.

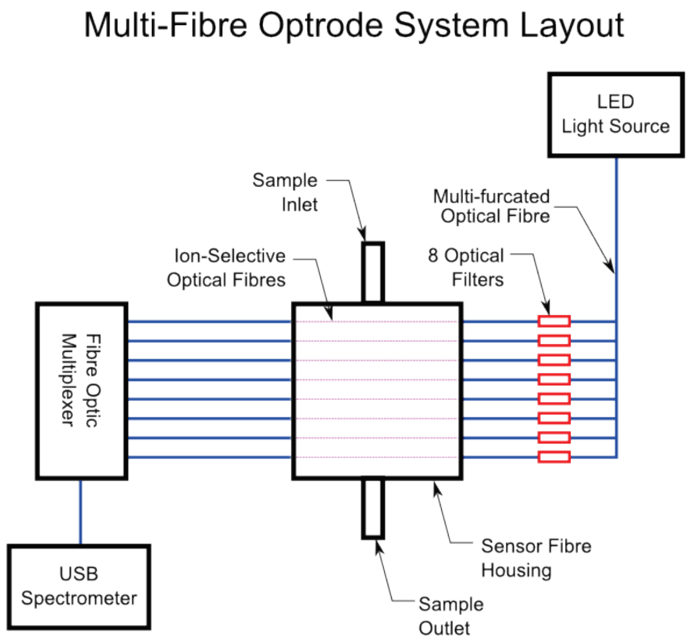

Figure 1- Diagram of the in-line optode fibre system for nutrient analysis. A LED-Light Source provides a stable input of photons that is distributed to each sensor fibre via a Multi-Furcated Optical Fibre. The light signal is modified by the coloured sensor fibres inside the Fibre Housing as a portion of the photons are absorbed. The modified signals are measured using a USB spectrometer (USB4000 by Ocean Optics).

a. Nutrient solutions of known concentration are prepared at various strengths to test the function of the IS-Optrode system. A ½ strength Hoagland's solution is used as a standard to test the function each fibre.

b. The ½ strength Hoagland's solution is modified to test sensor response and repeatability by diluting the solution or adding additional ions of interest. For each IS-optode fibre, exposure to a dilute Hoagland's solution (¼ strength), a ½ strength Hoagland's solution, and a ½ strength Hoagland's solution with extra ion of interest is performed.

Figure 2 illustrates typical sensor response in terms of absorption spectra, as calculated from the actual measured spectra recorded by the spectrometer, according to the following relation:

$$Absorbance = -\log\left(\frac{I}{I_o}\right)$$

where I is the *measured spectrum* and I_o is the *reference spectrum* (a *dark spectrum* is subtracted from both I and I_o)

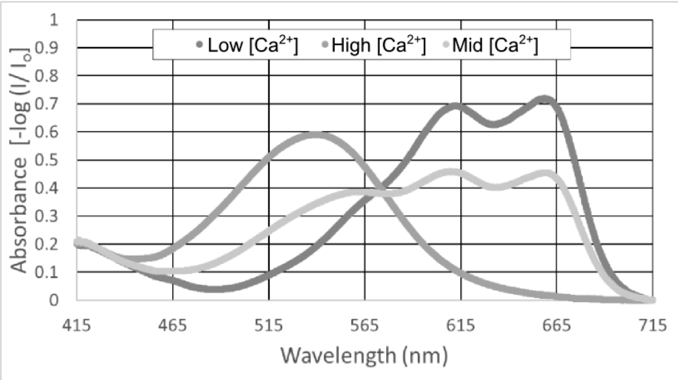

Figure 2 - Sensor response to variation of Ca^{2+} concentration illustrating the absorbed spectra at High, Low and Mid-Range Ca^{2+} concentration. Fibre colour changes from Pink to Blue as concentration changes from High to Low

The sensor fibre for Calcium has peaks in the blue (540 nm) and red (660 nm) regions of the visible spectrum. For cases where Calcium concentration is *high* the sensor fibre turns *pink* and the absorbance curve peaks in the blue end of the spectrum. In the opposite case, a *low* concentration of Calcium turns the fibre *blue* and the absorbance curve peaks in the red end of the visible spectrum. For mid-range cases, absorbance curves reveal two peaks of moderate intensity at both the blue and red peaks.

2) *Phase Two* of the project is focused on testing sensor performance in dynamic plant growth systems.

a. Specific varieties of plants (yet to be determined) are grown in controlled conditions to provide uniform populations with identical acclimation history

b. Plants are moved into controlled environment chambers where they experience new environmental conditions: Advanced 7-Band LED systems adjust the light quality and intensity in several different combinations; temperature, humidity and pressure are controlled using PLCs and hardware systems (Figure 3).

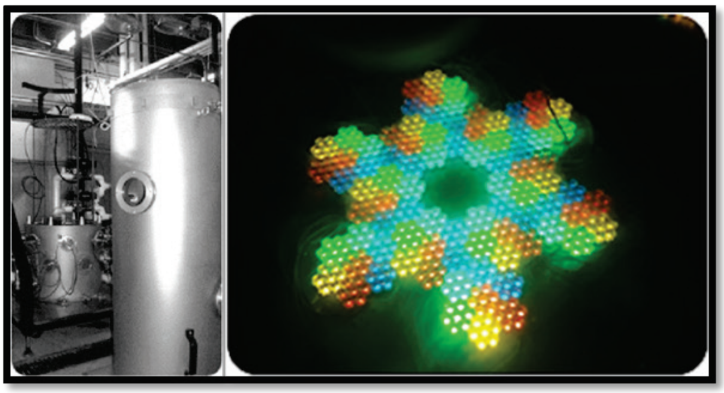

Figure 3 (Left) Photo of sealed, controlled-environment chamber (CESRF, University of Guelph) wherein IS-Optode performance will be characterized. (Right) Photo of prototype LED-array illuminated to show existing 7-band light output.

c. As plants grow in the controlled environment chambers, changes in nutrient solution chemistry are monitored in 3 ways: (1) an in-line automated collection system (developed in phase 1) draws samples from the chamber reservoir for periodic measurement of 4 ion concentrations (K^+, Ca^{2+}, NO_3^-, Na^+); (2) periodic samples are extracted manually and commercially available IS-Electrodes (Orion 9700BNWP) are used for secondary measurement of 4 ion concentrations (K^+, Ca^{2+}, NO_3^-, Na^+); (3) periodic samples taken manually in method 2 will also be analysed using HPLC for benchmark measurements of all ionic species of interest.

Data from each technology stream is compared to assess the overall performance of each technology. Results from these studies will be used to further the development of a real-time monitoring/control system for nutrient solution composition.

Results and Discussion

Phase 1.a – Preliminary Results, Challenges and Solutions

Initial attempts to use IS-Optodes in hydroponic solutions were met with challenges. Reproducible results were confounded by the growth of biofilm on the sensitive portion. Only by flushing all hardware with disinfectant (Chlorine and acid rinse) were repeatable results obtained. This result led to the development of an optode housing that would isolate sensitive fibres from the environment and permit inline conditioning for incoming samples. A 3D printer was used to generate a prototype housing shown in Figure 4 that was subsequently tested and optimized.

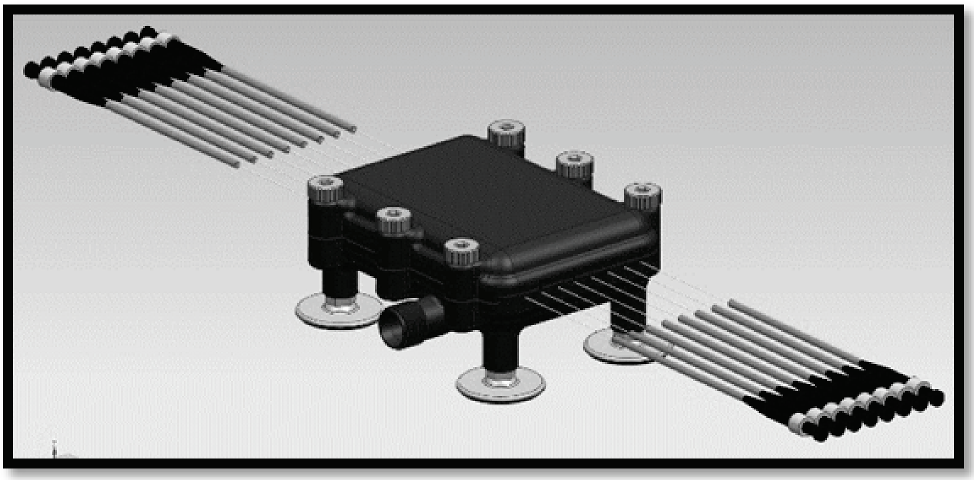

Figure 4 Optode sensor housing prototype holding 8 ion-selective sensor fibres in isolation. The sensitive portion of the fibres are contained within the housing body while the connectorized ends protrude from the housing along each side.

Preliminary testing of the optode housing revealed minor engineering issues (gasket seals, fibre mounting) that are resolved. Some challenges in optode-fibre fabrication must be overcome to facilitate an easy-to-use multi-fibre (multi-ion) system. Repeatable results were affected by inconsistency in the sensitive fibre coating. A mechanical coating process was developed by INO to improve the consistency of manufacture. A final design of the in-line optode housing is currently in development phase.

Phase 1.b – Current Investigations

Part i – Sensor Response: Calcium Fibre Example

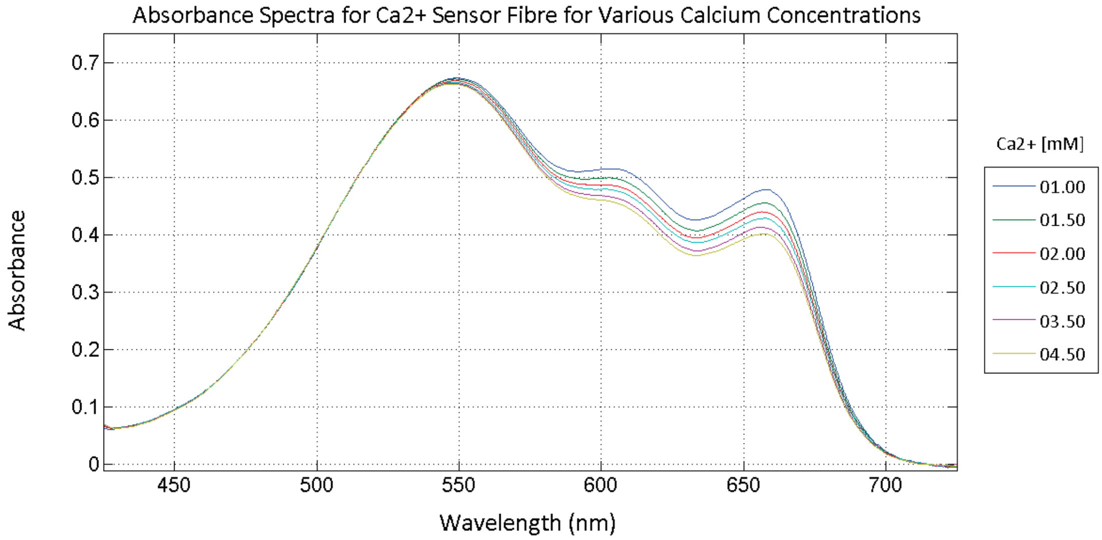

Figure 5 Absorbance spectra for Ca^{2+} fibre immersed in a Calcium solution. Small amounts of $CaCl_2$ are added to the solution to demonstrate the sensor response – the sensor becomes less "blue" as Calcium is added since fewer "red" photons are absorbed by the film.

The absorbance spectra in Figure 5 were collected to test the response of the Calcium optode fibre to changes in Calcium concentration in solution. The spectra of *absorbed* light changes as calcium concentration increases from 1.00 mM to 4.5 mM, indicating that the sensor fibre becomes "less blue" and shifts toward a "more red" colour. This is illustrated by the decreasing peaks in the red end of the visible spectrum meaning fewer red photons are absorbed by the fibre as more are reflected. Figure 6 shows this change graphically in a plot of absorbance ratio, the ratio of peak absorbance values measured at 540 and 660 nm.

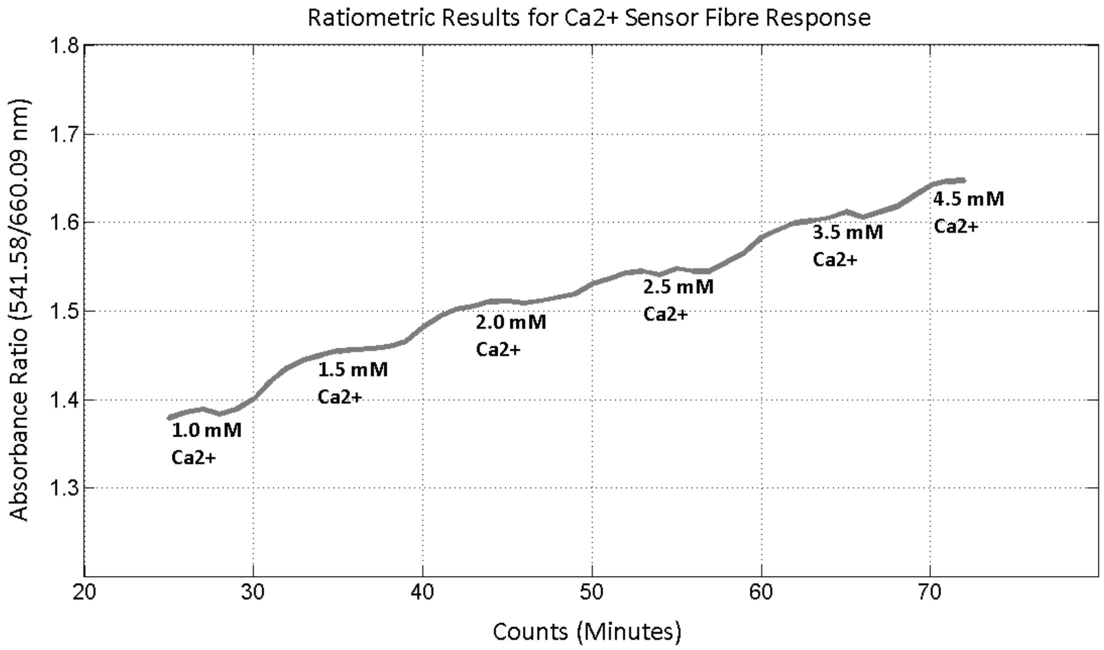

Figure 6 The ratio of the height of absorbance peaks at 540 nm and 660 nm reflects the changes in absorbance spectra shown in Figure 4. Changes of this ratio are indicative of changes in Calcium concentration.

Part ii – Sensor Repeatability: Calcium Fibre Example

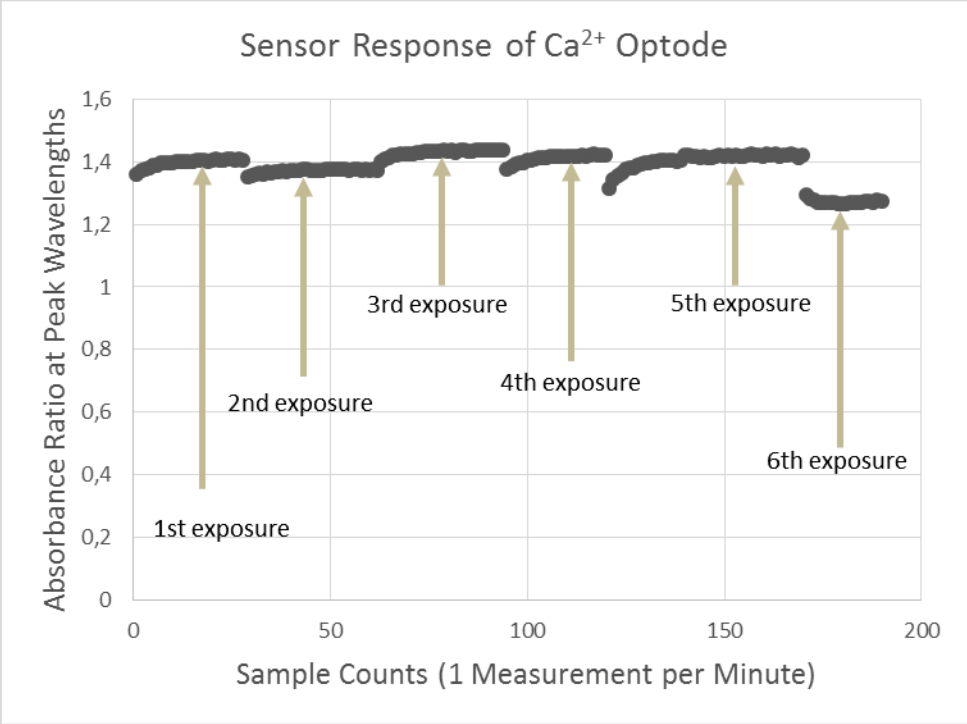

Figure 2 Repeatability data for Ca^{2+} sensor fibre exposed to 1/2 strength Hoagland's solution (1st - 5th exposure) and 1/4 strength Hoagland's solution (6th exposure). Small variations in sensor response observed for 1st-5th exposure are due to small changes in solution pH.

Figure 6 illustrates repeatability of a Calcium sensor fibre immersed in a ½ strength Hoagland's solution. The result is plotted as the ratio between the two absorbance spectrum peaks (refer to Figure 2). The same optical fibre was repeatedly immersed into the same sample for similar periods of time for the 1st through 5th exposure. It is apparent that small variation occurs in the sensor response within this data set; however it was determined that the variation was correlated to small changes in pH that occurred during the measurement process. At exposure #3 the pH was corrected to the original starting point of 6.998. The source of the pH drift is yet undetermined – although, it seems that pH drifts slowly toward acidic as the fibre is immersed in solution. For Exposure #6 the fibre was immersed in a ¼ strength Hoagland's solution.

Overall the Calcium fibre performs as expected. The data in Figure 5 show repeatable measurements can be achieved and problems facing repeatability may be overcome through improved membrane fabrication process. Sensor response is also very stable during immersion in the hydroponic solution, suggesting that the optode is suitable for monitoring of hydroponic solutions over time. Additional single ion tests are required to further characterize optode performance and determine the suitability of the sensors for a multi-ion system.

Phase 2 – To Be Performed

Technical challenges have prevented the integration of the multi-ion sensor system into controlled environment plant growth chambers. Phase two is expected to commence Summer 2013.

Conclusion

The results of this technology development study provides proof of concept that a real-time, multi-ion detection system can be developed for the monitoring of hydroponic nutrient solution chemistry. With further refinement, this technology can be used to improve the control any grower has over the quality of their nutrient solutions. Ion-selective sensor technology continues to improve and ion-selective sensors for other important nutrient ions will become available in the future. Ultimately, it is feasible that a real-time monitoring system for all ions important for plant nutrition can be realized.

Further characterization of individual ion-selective optodes is required before a multi-ion system can be developed. Specifically, sensor lifetime is an apparent issue as the optode sensors currently in use expire with continued use. The present study intends to explore options for increasing sensor lifetime by developing appropriate use, storage and care procedures.

The next phase of the current project will focus on developing feedback control strategies for nutrient dosing. Just as the concentration of each important ion can be measured individually, the concentration can be modified using controlled injections of nutrient stock solutions. The goal of future work is to develop a feedback control system to maintain specific nutrient thresholds within hydroponic solutions that can be adjusted based on the physiological requirements of plants.

Acknowledgements

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(6) Management of nitrogen fertilization of fresh vegetable crops at field scale in Wallonia (Belgium) - Combination of soil or crop nitrogen status evaluation and splitting of nitrogen fertilizer application

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Abstract: *Fresh vegetable crops frequently receive high supplies of organic or mineral nitrogen (N) fertilizer leading to quality loss and water or atmosphere pollution. An optimal management of N fertilization of these crops should largely contribute to their productivity and to reduce environmental risks. Based on previous research to the set-up of provisional N recommendations, several field trials with increasing N fertilizer rate and including split rates have been conducted on loam soil in Wallonia (Belgium) from 2005 to 2010 aiming to improve N efficiency of four crops (carrot, escarole, Welsh onion and curled-leaved endive). For arbitrary application dates of split N rates, results have not shown any difference between split and non-split N rates for carrot and escarole. For Welsh onion and fine curled-leaved endive the results show an advantage to split N, regarding yield as well as nitrate concentration in leaves at harvest. Soil mineral N residues at harvest were also lowered. For these two crops, tools to assess crop N status were tested for their ability to decide on the best time for split N rate application aiming to improve N use efficiency. Tools are based either on leaf chlorophyll content assessed with a chlorophyll meter or on shoots nitrate concentration assessed by colorimetry. For each tool, discrimination in readings appeared between increasing N rates. Moreover, optimal periods for a second N application were determined through good correlations between total plant N content or N-uptake and the values of the "plant-based" tools. For these identified periods, tool values have been plotted against the Nitrogen Nutrition Index (NNI) and threshold values for both tools have been identified, but are still to be validated for further implementation in practice.*

Keywords: *Vegetables, N efficiency, split N rates, crop N status, decision support tools*

Introduction

The characteristics of vegetables tend to force farmers to apply nitrogen (N) fertilizers in excess leading to a high mineral nitrogen residue in the soil after harvest, high nitrate concentration in plants and financial losses for farmers. A better management of N fertilization is essential for these crops.

Careful management can come from different strategies, including the balance sheet method at field scale used by the Azobil software (INRA, Laon, France) as a tool for N fertilization recommendation (Machet et al., 1990) and already used by the Walloon Agricultural Research Centre on vegetable crops (Abras et al., 2010).

In this paper, the strategy studied is based on the splitting of N supplies reinforced by the monitoring of crops N status (CNS). The split application is recommended for certain crops (cereals, potato) to minimize the N fertilizer losses by immobilization, denitrification or leaching as well as to match crop N needs and supplies (Vos and MacKerron, 2000). Split N applications are expected to fit the N requirements of carrot, Welsh onion, escarole and curled-leaved endive crops to allow N availability when the crop needs are important according to their N-uptake kinetics. Splitting of fertilizer N applications, based on the assessment of CNS, is currently considered as a good strategy for this purpose (Weier et al., 2001; Matthaüs and Gysi, 2001). In addition, monitoring of the CNS allows avoiding accumulations of residual mineral N in the soil while matching N needs of the crop.

Materials and methods

<u>Field experiments</u>

Field trials with increasing N-rates were conducted on loam soils in Wallonia from 2005 to 2010. The species tested were carrot (*Daucus carota* L.), escarole (*Cichorium endivia* L. var *latifolia*), Welsh onion (*Allium fistulosum* L.) and curled-leaved endive (*Cichorium endivia* L. var. *crispa*). For each trial, **Fout! Verwijzingsbron niet gevonden.** shows the amount of nitrogen applied per treatment the first and second date and harvest dates for each trial. Split N rates and application dates were determined arbitrarily in a first step to measure their effects on yields. Following these initial results, these rates were modified for the subsequent trials in Welsh onion and curled-leaved endive crop (in 2007 and 2008 for Welsh onion and in 2007 and 2009 for curled-leaved endive).

A randomized block design was used with four replications by level of N rate. The average area of a basic experimental plot was 40 m² for carrots, 25 m² for escarole, and 26 m² to 30 m² for Welsh onions and curled-leaved endive. Sowing densities for carrot and Welsh onion crops were from 1.2 to 1.3 million seeds per hectare and 3 million seeds per hectare respectively. For escarole and curled-leaved endive crops, planting densities were of 65 000 plantlets per hectare. Ammonium nitrate fertilizer (solid granules, 27% N + 4% MgO) was used for these trials. It was supplied around sowing or planting time for the first N application and for split N treatments, the second dates of N application are given in Table 1. Welsh onion trials also received potassic scories fertilizer (solid granules, 11% P_2O_5 + 11% K_2O + 4% de MgO) at the rate of 82.5 kg P_2O_5 and K_2O ha^{-1}. All trials were conducted under irrigated conditions. The mean values of yields at harvest were plotted against N rates applied. N response curves were approximated by second-degree polynomial regressions and the coefficients of determination (r^2) of these regressions were calculated. Optimal N rate is defined as the value that makes the first derivative of the trend line equal to zero. Results are given in Table 1.

Table 1. Field trials characteristics conducted on carrot, escarole, Welsh onion and curled-leaved endive on Belgian loam soils (Wallonia region) from 2005 to 2010. Dates (sowing or planting and 2nd N fertilizer application), N rates (non-split, split and optimal rates).

Species	Year	Site	Sowing/ planting date	Second N application date (2)	Harvest date	Non-split N rates (kg Nha^{-1})	Split N rates (1) (kg Nha^{-1})	Optimal N rate (3) (kg Nha^{-1})
Carott	2005	Héron	May-05	Aug-05	Nov-05	0-20-40-60-80-100	(20+20)-(40+20)	12
		Hingeon	May-05	Aug-05	Oct-05	0-20-40-60-80-100	(20+20)-(40+20)	25
	2006	Pontillas	May-06	Aug-06	Oct-06	0-20-40-60-80-100	(20+20)-(40+20)	40
	2007	Pontillas	Apr-07	Jul-07	Oct-07	0-20-40-60-80-100	(20+20)-(40+20)	0
		Eghezée	Jun-07	Aug-07	Oct-07	0-20-40-60-80-100	(20+20)-(40+20)	40
Escarole	2005	Vottem	Aug-05	Sep-05	Sep-05	0-25-50-75-100	(30+20)-(55+20)	20
	2006	Vottem	Jul-06	Aug-06	Sep-06	0-25-50-75-100	(30+20)-(55+20)	30
Welsh onion	2005	Hognoul 1	May-05	Jun-05	Jul-05	0-30-60-90-120-150	(60+30)-(80+40)	140
		Hognoul 2	May-05	Jun-05	Aug-05	0-30-60-90-120-150	(60+30)-(80+40)	100
	2007	Hognoul	Jun-07	Jul-07	Aug-07	0-30-60-90-120-150	(30+30)-(60+30)	60
	2008	Leernes 2	May-08	Jun-08	Aug-08	0-100	(70+30)-(50+50)	-
	2010	Hognoul	May-10	Jun-10	Aug-10	0-60-100	(60+40)	-
Curled-leaved endive	2005	Cointe 2	Jul-05	Aug-05	Aug-05	0-50-75-100-125-150	(50+25)-(75+25)	85
	2006	Cointe	May-06	Jun-06	Jul-06	0-25-50-75-100-125-150	(50+25)-(75+25)	65
	2007	Gerpinnes	Jul-07	Aug-07	Sep-07	0-50-100-150	(25+25)-(50+25)	100
	2009	Leernes	Jul-09	Aug-09	Aug-09	0-60	(30+30)	-
	2010	Vottem	Jun-10	Jul-10	Aug-10	0-40-60	(30+30)-(40+20)	-

(1) Split N rates: first application at sowing/planting time; second application at mentioned date (2)
(3) Optimal N fertilizer rate of each trial assessed through quadratic adjustment of the yield data

Plant sampling

Weekly, a whole plant sample of 1.8 m² for carrots and of 0.84 m² for Welsh onions was collected for each N treatment and each plot. For escarole and curled-leaved endive, six whole plants were collected weekly in each plot for each N treatment. The plants were washed, weighed fresh and stored at 4 °C no longer than one day. The underground parts were then cut and separated from the aerial parts of the plant. A subsample of each part was dried in an oven at 90° C for 48 h to constant weight to assess the biomass dry matter concentration. The dried samples were finely crushed in a mill and analysed for their total N concentration by near-infrared spectroscopy (Osborne and Fearn, 1986). The total N uptake at each sampling date was determined on a dry matter basis. Similarly, total N uptake is assessed on the final harvest for each crop. Measurements of chlorophyll content in the leaves were conducted on samples collected in endive (curled-leaved endive and escarole) using chlorophyll meter (see below).

Crop N status assessment

Aiming to identify the best period to apply supplementary N to the crop while required, two techniques were considered to assess CNS during the growing season. The first one is a quick and non-invasive tool for the determination of the leaf chlorophyll content through the use of a chlorophyll meter (Hydro-N-tester (HNt), Yara, Norway). The chlorophyll meter is a device that was used in this study to assess the CNS of endive crops. The relationship between the leaf chlorophyll content and leaf N content allows considering the level of chlorophyll as a good indicator of the CNS of the plant (Vos and Bom, 1993). It has been successfully developed within a Decision Support System for N fertilizer management in the potato crop by Olivier et al. (2006) and Goffart et al. (2008).The second technique considered the root and shoot nitrate concentrations. It is an invasive technique as it requests to collect and to process leaf samples but it is useful for all crops. Root and shoot nitrate concentrations were assessed on a dry matter basis through colorimetry and flow injection analysis (Automated Ion Analyser, Quickchem Protocol, Lachat Instrument, Colorado, USA). Leaf chlorophyll content were performed on curled leaved-endive and escarole trials and shoots nitrate concentration on all described trials in Table 1, and on the same dates whole plants were collected for total N concentration assessment. HNt readings were performed on 30 leaves per plot for the endive trials.

In order to assess the CNS on an analytical and reference basis, the dilution curve of N was established for each crop and each trial. These curves represent the relationship between the production of dried biomass of the plant and total N concentration. They are determined considering only the optimal rates of N fertilization for each trial. **Fout! Verwijzingsbron niet gevonden.** presents the optimal N fertilizer rate per trial. The relation of these curves allows to assess the critical N concentration (% Nc) of the plant for a given dry matter production. This N_c corresponds to the minimum N concentration for the crop to ensure the expression of its maximal growth and development. The ratio between the observed N concentration of the crop and N_c provides information on the CNS (Lemaire, 1997). This ratio is called Nitrogen Nutrition Index (NNI). Theoretically, the plant is considered sufficiently supplied for N for one NNI equal to 1 and deficient or in excess for N if it is lower or higher than 1, respectively.

To target the optimal time for a second application of N fertilizer, the amount of N taken up by the crop at different dates is plotted with either the leaf nitrate content or the HNt index. These relations are approximated by linear regression and the time interval which corresponds to the relation with the highest coefficient of determination (r^2) is considered as the best one to assess CNS.

The threshold values of both tools to decide on crop N deficiency at optimal date to assess CNS correspond theoretically to an NNI equal to 1 when plotting tools values against NNI values. Under this threshold value, the NNI is less than 1, which indicate crop N shortage and the crop should receive a second fraction of N fertilizer. The relations were established for the roots, shoots and whole plants (except for the HNT index where only the leaves are taken into account) and each is approximated by a linear regression. The line with the highest coefficient of determination (r^2) will be considered to estimate the threshold values.

Soil sampling

Residual soil mineral N content at harvest was assessed for each trial and within each plot according to the method of Guiot et al. (1992).

Results

Effect of split N rate

Split N fertilizer rates in carrot and escarole crops provide no significant benefit in terms of biomass, nitrate concentration and soil mineral nitrogen after harvest compared to the similar non-split and optimal rates. The second fractions of N fertilizer were applied between 90 and 100 days after sowing for the carrot trials and between 26 and 29 days after transplanting the escarole crops. However, according to results of Abras et al. (2010) on kinetics of N-uptake, the second part of N fertilizer should have already been applied between 60 and 80 days after sowing in carrot crop and from 30 days after transplanting in escarole crop. Results of these trials are shown in Figure 1 a) and b) and Figure 3 a) and 3 b)**Fout! Verwijzingsbron niet gevonden.**.

In Welsh onion, the produced biomass is shown in Figure 2 a**Fout! Verwijzingsbron niet gevonden.**. Overall, the split N rates leads frequently to similar yields than the optimal N rates (except for (60+30) and (80+40) kg Nha^{-1} rates respectively in Hognoul 1 and Hognoul 2 trials). The split N rates gave higher yield than non-split N rates but the differences are not significant. The splitting of N rates allows to reduce plant nitrate concentration and soil mineral N after the harvest compared to non-split N rates (see **Fout! Verwijzingsbron niet gevonden.** 3 d).

The results of trials conducted in curled-leaved endive crop, shown in **Fout! Verwijzingsbron niet gevonden.** 2 b) and Figure 3 c), show higher biomass productions in plots with split N rates than those with non-split N rates, except for the rate (75 + 25) kg Nha^{-1} in the “Cointe 2/2005” trial. In addition, yields are generally higher than those obtained with the optimal N rates but not significantly different.

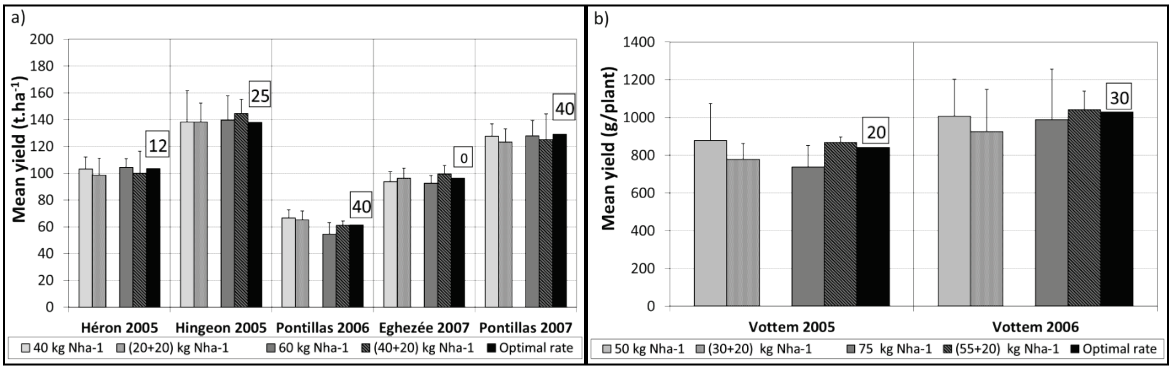

Figure 3. Effect on yield of split N rates compared to non-split N rates and optimal N rates for a) carrot and b) escarole crops

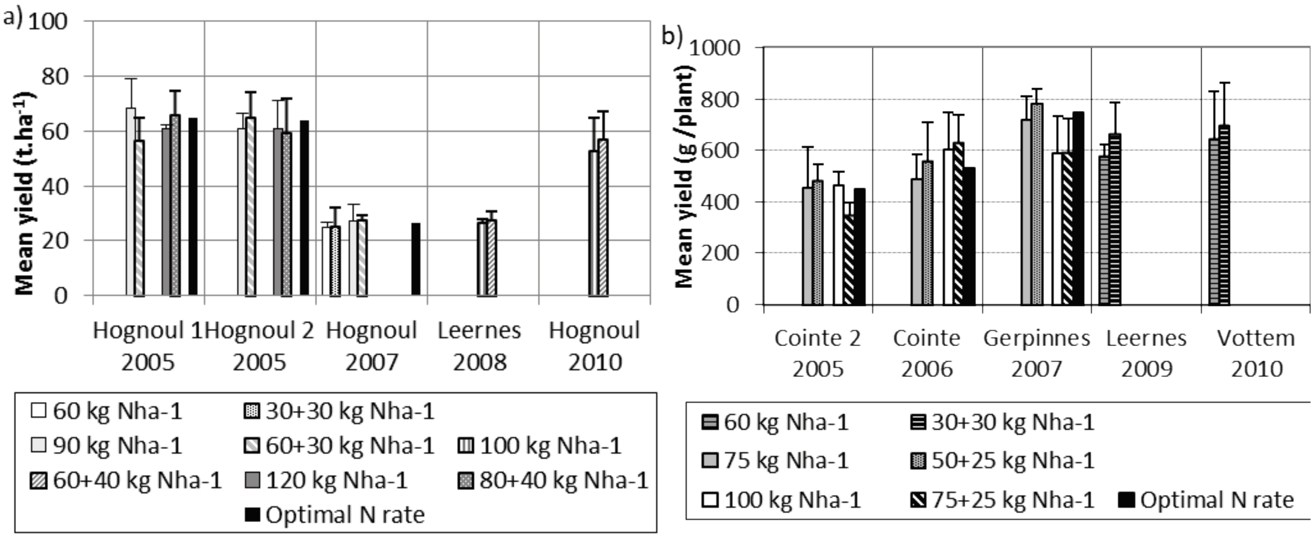

Figure 2. Effect on yield of split N rates compared to non-split N rates and optimal N rates for a) Welsh onion and b) curled-leaved endive crops

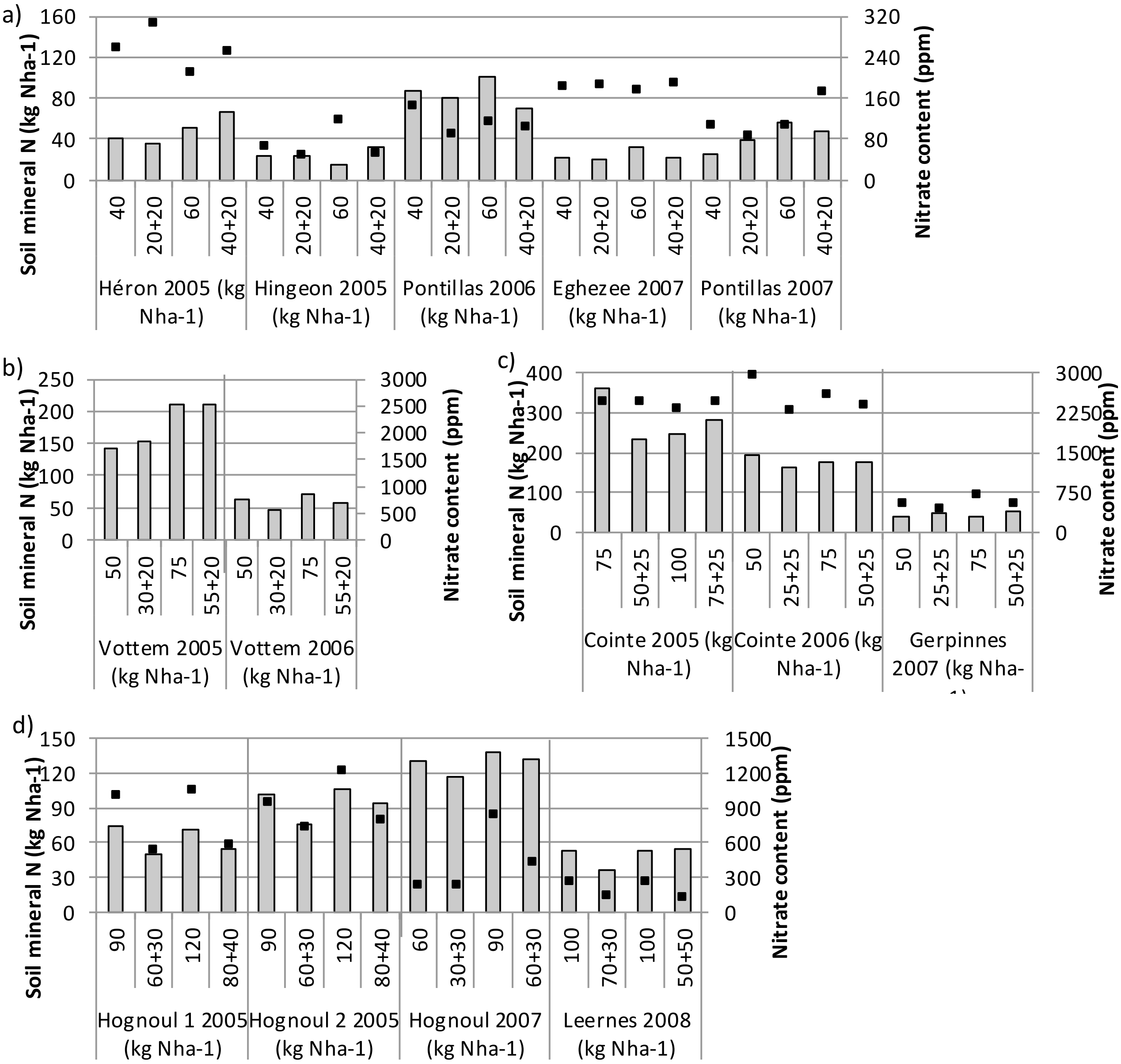

Figure 3. Effect on split N rates compared to non-split N rates on soil mineral N and on shoots nitrate concentration for a) carrot, b) escarole, c) curled-leaved endive and d) Welsh onion crops

Potentialities for crop N status assessment

According to the upper results, studies with measurements tools for CNS were further considered only in Welsh onion and curled-leaved endive crops. Both crops were indeed the only ones to respond to N splitting in terms of yield.

The Welsh onion trials considered in the determination of threshold values were those with an increasing response curve to N (Hognoul 1 2005, Hognoul 2 2005 and Leernes 2008). Two evaluation periods of the CNS where the relationships between plant nitrate concentration and total N concentration have high determination coefficients (r^2=0.64 and 0.72) have been defined (see **Fout! Verwijzingsbron niet gevonden.** 4). These periods range from 40-52 days to 54-74 days after sowing and correspond to the period of intense N uptake identified by Abras et al. (2010), starting from 35 to 40 days and ending between 70 and 80 days after sowing. It is important to note that any additional contributions made during the second period should be done quickly to prevent accumulation of residual mineral N in the soil.

The relationship between shoots nitrate concentration and NNI during these two periods shows high coefficients of determination (r^2= 0.68 and 0.86). The threshold values determined by these relations are 2169 ppm for the period from 40 to 52 days and 1107 ppm for that from 54 to 74 days after sowing (Figure 4).

Measurements of plant nitrate concentration taken into account for establishing threshold values in curled-leaved endive derived from Cointe 1 2005, Leernes 2007 and Gerpinnes 2007 trials. Leernes 2002 and 2003 Burenville trials had very high shoot nitrate concentration and biomass in comparison with the values of the subsequent trials. It would be interesting to deal with these results independently and set different thresholds depending on the biomass produced. The four periods identified for the evaluation of CNS of curled-leaved endive by their nitrate concentration (13-19 days, 24-31 days, 33-40 days and 42-60 days after transplanting) have high coefficients of determination (r^2 from 0.72 to 0.86) (Figure 5). Although the four periods can be available to assess shoot nitrate concentration, making additional N supply during the first period (13-19 days) and the last period (42-60 days) may present some inconvenience. The first period precedes the period of intense N-uptake in curled-leaved endive, defined by Abras et al. (2010) between 20-50 days after planting. During the last period, the time between the second contribution and harvest is quite limited, making this less useful to the crop and increasing the risk of higher amount of residual mineral N in the soil. The threshold values of shoots nitrate concentration for the four periods are respectively 1688, 2142, 2274 and 1903 ppm for periods of 13-19 days, 24-31 days, 33-40 days and 42-60 days after transplanting (Figure 5).

Measurements of leaf chlorophyll content of curled-leaved endive have been tested since 2005, and a preliminary study has been carried out during the years 2002 and 2003. Moreover some trials were not taken into account due to the lack of response to N fertilizer. Measures of five trials (Leernes 2002, Burenville 2003, Cointe 1 2005, Leernes 2007 and Gerpinnes 2007) were then used in order to determine threshold values suitable for measurements with the chlorophyll meter. Determining optimal times for the evaluation of CNS showed periods of 24-33 days, and 35-42 days after transplanting (Figure 6), both characterized by relations "% N - HNT" and "NNI - HNT" with relatively high coefficients of determination (r^2= 0.66 to 0.71). Both time intervals have the advantage to be sufficiently early in order that a second N fertilizer application could be fully effective. Finally, these time intervals are clearly in the period of intense N uptake of curled-leaved endive crop (20 to 50 days after transplanting) as identified by Abras and al. (2010). The HNt threshold values corresponding to a NNI equal to 1 are 453 for the period from 24 to 33 days and 478 for the period from 35 to 42 days after planting (Figure 6). Relations between N and NNI with HNt indices, corresponding to the period of the start and of the end of the growing period (13 to 19 days and 45 to 60 days, respectively) have lower coefficients of determination (r^2 around 0.5). These periods also present practical disadvantages. During the first period, the leaves are relatively underdeveloped, which complicates the HNt readings on the plants at this stage of development. Making an additional contribution in the latest period can be hazardous as the harvest is generally planned around eight weeks of growth.

Discussion and conclusion

Splitting total N-rate does not show interest for carrot and escarole crops in terms of yield production. Based on the results for the Welsh onion and curled-leaved endive crops, arbitrary splitting of N fertilizer applications show a little but not necessary significant benefit compared to non-split N rates. In these crops, yields are higher and soil mineral N content after harvest and plant nitrate concentration are lower for split N rates. However, second N applications are not always necessary and it is suitable to manage these split applications with CNS monitoring tools to decide on the need for supplementary N.

For both tools tested in this study, monitoring periods of the CNS have been identified and threshold values for plant N-deficiency were proposed. For the curled-leaved endive crop, tools based on leaf chlorophyll and shoots nitrate concentrations give results leading to the identification of threshold values whereas in Welsh onion crops, only shoots nitrate concentrations gives relevant results. The threshold values identified during this study should be validated further, which will be the subject of a further paper.

We suggest that the improvement of the N efficiency of mineral fertilizers applied to vegetable crops could be found in the combination of several technics: first a recommended N rate based on the balance sheet method at specific field scale, split into a first rate applied at planting or sowing time and a second rate applied on the basis of a N deficiency detected using tools such as chlorophyll meter or quick meter such as nitrate test strips and reflectometer to assess leaf nitrate concentration.

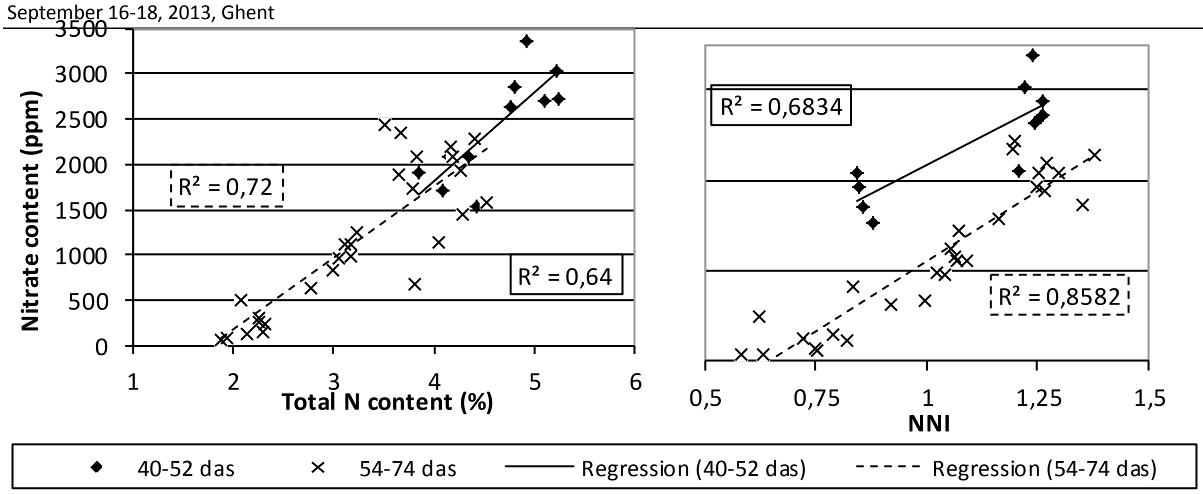

Figure 4. Identification of relevant evaluation periods of the CNS through shoots nitrate concentration of Welsh onion crop (figure on the left) and determination of threshold values for these two periods (figure on the right). Das = Days after sowing

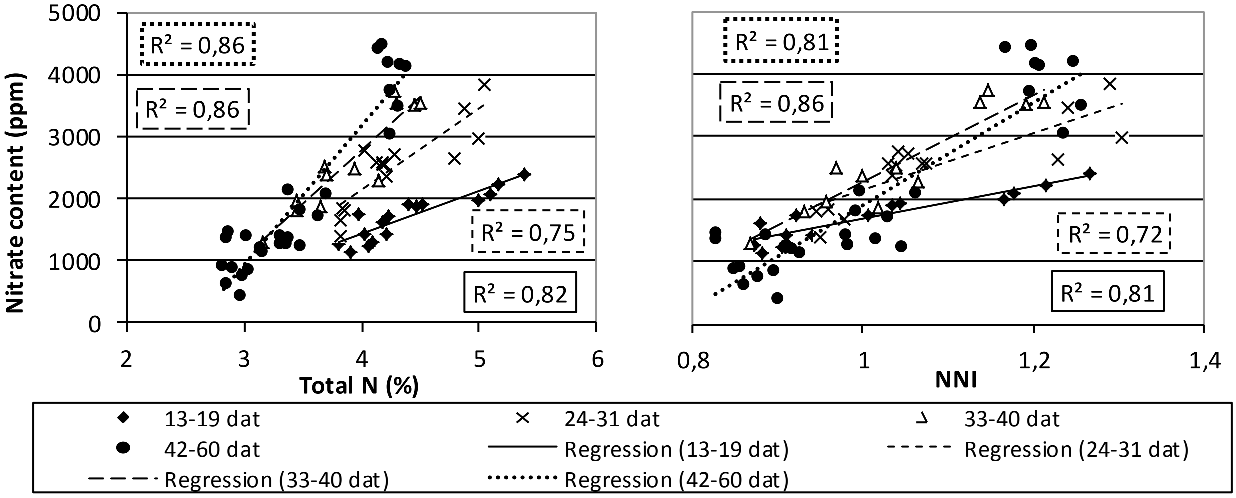

Figure 5. Identification of relevant evaluation periods for the CNS through shoots nitrate concentration for curled-leaved endive crop (figure on the left) and determination of threshold values for these periods (figure on the right). Dat = Days after transplanting

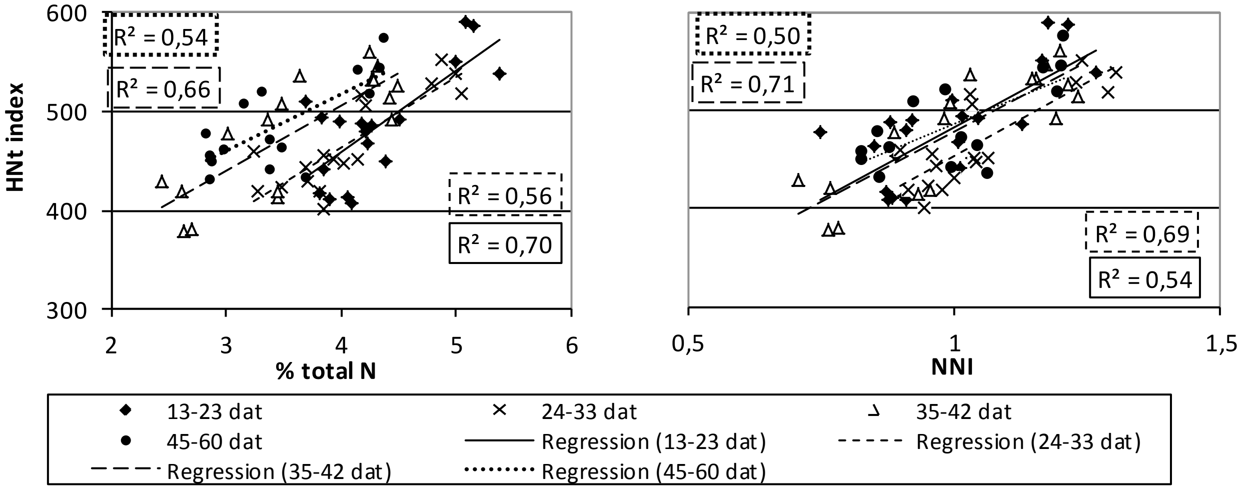

Figure 6. Identification of relevant evaluation periods for the CNS through leaf chlorophyll content (HNt index) for curled-leaved endive crop (figure on the left) and determination of threshold values for these periods (figure on the right). Dat = Days after transplanting

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(7) Row application of fertilizers, manure and manure fractions to increase nutrient use efficiency

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Abstract: *Fertilizers and slurries are valuable products to provide nutrients to crops. However, nutrient use efficiencies are low due to large application rates. Legislation limits application rates in order to minimize losses to the environment.*

Slurries can be separated into a solid and liquid fraction. This creates opportunities for innovative techniques such as row applications of the nitrogen (N) rich liquid fraction. In our research row applications, both as basic fertilization before planting and as side dressing after planting, of mineral fertilizers, slurries and treated products were compared with broadcast applications and a blank on different soil types and locations in potatoes from 2010 to 2012. A precision GPS system was used both with fertilization and with planting to increase the time window for manure and fertilizer applications. This enables planting to be done after and separately from the basic manure application and the additional fertilizer can be applied as row application some time after planting.

Row applications of mineral phosphate fertilizers containing small amounts of N improved potato yields and caused a large shift in the size distribution towards larger tubers on soils characterized by Dutch fertilizer recommendations as sufficient on phosphorus (P) fertility. Row applications thereby improve the P-use efficiency. Positive results on row application were mainly found on young, calcareous clay soils where P availability could be limiting at early stages of crop growth, especially with cold spring temperatures or dry conditions. A shift in the size distribution towards larger tubers was also found for a pre-planted row application of slurry at a high application rate but not for row applications of side dressings of N-fertilizers. At low N application rates, row applications of side dressings of liquid N-fertilizers had a higher N-use efficiency compared to broadcast application of CAN at the same amount of N.

Keywords: *potato, mineral concentrates, phosphorus, nitrogen*

Introduction

To reduce nutrient emissions and deliver 'good water quality for all purposes', limits on nutrient input have been described in the Dutch national action plan in accordance to the European Nitrates Directive. For phosphorus maximum annual input is described for different soil P classes, and for N there are crop specific N standards. This is a maximum N application rate per crop, which varies for arable crops from only 25 kg N ha^{-1} for transplanted alley trees to 260 kg N ha^{-1} for potatoes on sandy soils.

The restriction on the input of N and P urges growers to improve nutrient use efficiencies. Several methods have been explored to improve nutrient use efficiency such as row applications of N-fertilizers (Westermann and Sojka, 1996) and P-placement to reduce P applications (Smit et al., 2010). Row applications of mineral fertilizers have been investigated for some time. For manure, studies in maize suggest that efficiencies also can be improved by row application (Schröder et al., 1997). However, if that is also the case for potatoes is not clear. Potatoes are cropped on ridges and placement of nutrients close to the root system may therefore have a different effect on nutrient use efficiencies compared to maize. This paper describes the results of several field trials on the effects of nutrient placement on potato yields.

Materials and Methods

From 2010 to 2012 four trials were carried out on row applications of mineral fertilizers, slurries and treated products in potatoes on clay and sandy soils of which some characteristics are presented in table 1. Effects of row applications on yield and tuber size distribution > 70 mm were compared with a blank and with broadcast applications at the same total nutrient inputs as the row applications.

In 2010 and 2011 trials were performed with mineral phosphate fertilizers on a calcareous clay soil (table 2, 4 replicates in blocks). In 2010, potatoes were planted on 16 April and harvested on 11 October. Triple superphosphate (TPS) and GrowSolution (GS), broadcast and row, were applied on 6 May just before ridging. In 2011, potatoes were planted on 13 April and harvested on 5 October. TPS and ammonium polyphosphate (APP) were applied just before ridging on 14 April as broadcast and row applications, respectively. The appropriate APP dose was injected into the rows with 460 L ha^{-1}. An addition blank was included in which rows were injected with 460 L water ha^{-1} only. Nitrogen applications of 162 kg ha^{-1} calcium ammonium nitrate (CAN) were performed in both trials on the same day as the phosphate fertilizers before ridging. The dose was reduced for any N applied with the mineral phosphate fertilizers. All treatments received 54 kg N ha^{-1} on 21 June in 2010 and 6 June on 2011. The Dutch fertilizer recommendations describe the P fertility of the fields as sufficient and recommend an application of phosphate of 120 and 105 kg P_2O_5 ha^{-1} for respectively 2010 and 2011.

Table 1 Some soil characteristics of the experimental fields at the beginning of the experiments

Year	Organic matter content %	pH-KCl	P-Al (mg P_2O_5/100 g)	Pw (mg P_2O_5/l)	Clay %
2010	1.8	7.3	26	26	17
2011	1.7	7.4	-	34	19
2012	4.9	5.4	54	48	<1

Table 2 Effects of broadcast (B) or row (R) applications of phosphorus with triple superphosphate (TSP; 45% P w/w), GrowSolution (GS; 27% N w/w, 7% P w/w) and ammonium polyphosphate (APP; 11% N w/w, 37% P w/w) on total tuber yield and tuber yield in the size distribution >70 mm in 2010 and 2011 on calcareous clay

			Application rate		Tuber yield (ton fresh ha^{-1})	
Year	Method	Products	(kg P_2O_5 ha^{-1})	(kg N ha^{-1})[1]	Total	Size distribution >70 mm
2010	-	-	0	0 + 162 + 54	53.9	0.1
	B	TSP	40	0 +162 + 54	57.4	0.2
	R	TSP	40	0 +162 + 54	57.0	0.3
	B	GS	40	124 + 38 + 54	53.1	0.4
	R	GS	40	124 + 38 + 54	54.1	0.1
					n.s.[2]	n.s.
2011	-	-	0	0 + 162 + 54	60.7	10.4
	B	TSP	30	0 + 162 + 54	60.3	10.9
	B	TSP	60	0 + 162 + 54	60.4	11.7
	B	TSP	120	0 + 162 + 54	60.8	11.5
	B	TSP	240	0 + 162 + 54	66.3	15.1
	-	-	0	0 + 162 + 54	59.1	10.4
	R	APP	15	5 + 157 + 54	60.5	11.6
	R	APP	30	9 + 153 + 54	65.9	13.8
	R	APP	60	19 + 143 + 54	64.5	15.1
	R	APP	120	37 + 125 + 54	68.6	16.8
Effect of dose[3]					***	***
Effect of row application					*	*
Effect dose X row interaction					*	*

[1] (N dose originating from the mineral phosphate fertilizer) + (base dressing) + (side dressing)

[2] n.s. = P > 0 .10

[3] *, **, *** Significant at P<0.05, P<0.01 and P<0.001, respectively

In 2012 one trial was performed on row applications of slurry as a pre-planting application (table 3, 4 replicates in blocks) of which 80% of the applied N became available to the crop. No additional N was applied. For the row application a precision GPS system was used to identify the position of the manure rows so the potatoes could be placed at a defined distance from the applied manure. The average distance between planted potato row and manure row was 5.9 cm which was approximately 2 cm off the intended difference of 8 cm. The mismatch was within the acceptable range of variation. In 2012, a second trial was performed with row applications of several mineral N fertilizers, including a concentrate from the liquid fraction of manure and ammonia water and an aqueous ammonia solution from an air scrubber (table 4, 4 replicates in blocks). The liquid fertilizers were injected within the potato ridge shortly after planting at two N doses. The injection machine was also used in the broadcast treatment with CAN to disturb all potato ridges in the same way in order to compare the effects of nutrient placement only. The N-use efficiency or the Apparent Nitrogen Recovery, was calculated as the N uptake subtracted with the N uptake of the unfertilized treatment and subsequently divided by the total amount of applied N (pre planting plus side dressing). In all trials, potatoes were cropped according to standard practices with respect to time of planting, soil management, crop protection and harvesting.

Table 3 Effects of broadcast (B) or row (R) applications of slurry on total tuber yield, tuber yield in the size distribution > 70 mm, N-uptake and N-use efficiency in 2012 on fine sand

Method	Application rate (kg ha^{-1}) P_2O_5	N[1]	Tuber yield (ton fresh ha^{-1}) Total	Size distribution > 70 mm	N-uptake (kg ha^{-1})	N-use efficiency (%)
-	-	-	51.2 a	0.0 a	99 a	-
B	22	68	61.5 b	0.2 a	134 b	52
B	44	136	65.3 c	0.0 a	166 c	50
R	22	68	60.5 b	0.1 a	129 b	44
R	44	136	64.7 c	0.6 b	165 c	49
LSD (5%)			2.834	0.383	13.83	n.s.[2]

[1] Total N of which 80% becomes available to the crop
[2] n.s. = P > 0 .10

Table 4 Effects of broadcast (B) or row (R) applications of side dressed calcium ammonium nitrate (CAN), ammonium nitrate (AN), Urea (U), mineral concentrate (MC) or drain water of an air scrubber (DW) on total tuber yield, tuber yield in the size distribution > 70 mm, N-uptake and N-use efficiency in 2012 on fine sand

Method	Product	Application rate[1] (kg N ha^{-1})	Tuber yield (ton fresh ha^{-1}) Total	Size distribution > 70 mm	N-Uptake (kg ha^{-1})	N-use efficiency (%)
-	-	0	55 a	0.0	119 a	-
B	CAN	50	58 bc	0.0	130 ab	9 a
B	CAN	100	64 f	0.1	168 e	29 cd
R	AN	50	60 bcde	0.1	144 c	21 bc
R	AN	100	61 cde	0.1	168 e	29 cd
R	U	50	57 ab	0.2	136 bc	15 ab
R	U	100	60 cde	0.1	167 e	30 cd
R	MC	50	59 bcd	0.1	137 bc	16 ab
R	MC	100	62 def	0.1	156 d	22 bc
R	DW	50	59 bcd	0.1	145 cd	22 bc
R	DW	100	63 ef	0.5	181 f	37 d
LSD (5%)			3.09	n.s.[2]	11,87	9.47

[1] a pre-planting broadcast application of 68 kg N ha^{-1} and 22 kg P_2O_5 ha^{-1} were applied with slurry

[2] n.s. = P > 0 .10

A standard analysis of variance (GENSTAT, version 15.2) was done on total fresh tuber yield and tuber yield per size distribution class. In 2011 an unbalanced design was used to compare effects of row applications. In 2012, an additional contrast analysis of variance was done on the effects of row application per application level on the N-use efficiency.

Results and Discussion

In 2010, total fresh tuber yield and tuber yield in all size distributions of tubers were not affected by any application of phosphate, broadcast or row applications (table 2). In 2011 however, total fresh tuber yield and tuber yield in the size distribution > 70 mm were increased by row applications as well as by dose (table 2). The effect is not caused by the water injection in the rows as the two blanks yielded equal. The N applied with APP in the row may have accelerated the effects on yield although the amounts were small (5 to 37 kg N ha^{-1}) compared to the total N applied (162 kg N ha^{-1}). Also, the broadcast N was applied before ridging. Differences with respect to N application are therefore small: a total N dose of 162 kg ha^{-1} is 1. mixed entirely through the ridge or 2. partly applied as row application (up to 37 kg ha^{-1}) and the remaining amount mixed through the ridge. These small differences in placement of applied N may have had some effect on crop growth, but as N is very mobile in the soil and N availability in the ridge was high, we expect that the differences in yield and tuber size distribution between the treatments can largely be ascribed to differences in the dose of row-applied phosphate. This is in agreement with effects of row applications of comparable mineral phosphate fertilizers such as monoammonium and diammonium phosphate (Rosen and Bierman, 2008). The interaction between dose and rows shows that yields increased stronger with row applications than with broadcast applications (Figure 1). This increase was most likely related to the extremely dry spring in 2011 (Baerug and Steenberg, 1971). In such conditions the transport of the relatively immobile phosphate ion towards the potato roots will be impaired and placement of phosphate fertilizers close to the root system will be successful then.

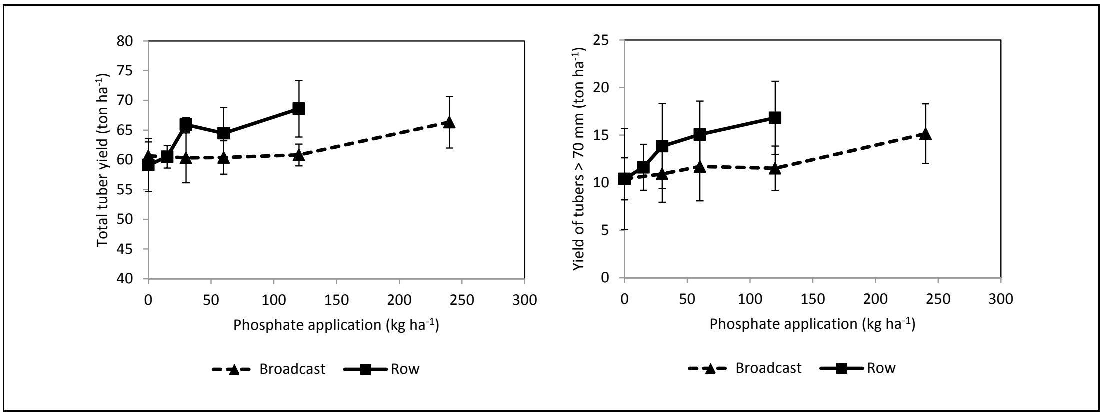

Figure 1 The effect of row applications of phosphate on total tuber yield and tuber yield in the size distribution of tubers > 70 mm (ton fresh ha^{-1})

The pre-planting row application of slurry did not increase yields compared to the broadcast application of the same amount of slurry (table 3). Also, N-uptake was not improved and subsequently no effect on the N-use efficiency was found.

Row application or side dressing of liquid N-fertilizers did not increase yield compared to broadcast application of CAN (table 4). N dose, however, did increase yield, both with broadcast and row application. At the application rate of 50 kg N ha^{-1}, row applications of liquid fertilizers had a higher N-use efficiency (on average 18.5%) compared to broadcast application of CAN (9.4%). At the application rate of 100 kg N ha^{-1} no effects of fertilizer type and placement were found. This may mean that, although not expressed in yield, row applications improve the N-use efficiency at lower application rates compared to broadcast applications of the same amount of N.

Conclusion

Row applications of mineral phosphate fertilizers containing small amounts of N, improved potato yields and caused a large shift in the size distribution towards larger tubers on soils characterized by Dutch fertilizer recommendations as sufficient on P-fertility. Row applications thereby improved the P-use efficiency. Positive results of row application were mainly found on young, calcareous clay soils where P availability could be limiting at early stages of crop growth, especially with cold spring temperatures or dry conditions. A shift in the size distribution towards larger tubers was also found for a pre-planted row application of slurry at a high application rate but not for row applications of side dressings of N-fertilizers. At low N application rates, row applications of side dressings of liquid N-fertilizers had a higher N-use efficiency compared to broadcast application of CAN at the same amount of N.

Disclaimer

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(8) Soil erosion in vegetable production – Solution approaches

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Abstract: *Soil erosion by water is a widespread problem throughout the world. In recent years, there have been more frequent, heavy rainfall events in temperate zones, affecting many regions in Europe. Areas with intensive vegetable or crop production are especially at risk. In Southwest Germany, a highly intensive vegetable production region, on- and off-site damages by soil erosion will be witnessed more frequently due to extreme weather events resulting from climate change and use of heavy machinery and soil compaction. To manage this problem in vegetable cultivation, two different strategies to reduce soil erosion were tested: Soil cover by fabrics and strip-tillage. Covering the white cabbage plants (Brassica oleracea convar. capitata var. alba) with non-woven fabrics, such as fleece or nets, could function as an erosion control measure. Soil losses of fleece covered area were reduced about 90 % and in net covered plots soil losses were reduced about 72 % compared to the uncovered control treatment. Strip-tillage is a conservation tillage technique, which is well established in corn and sugar beet production. For vegetable production, only a limited number of studies exist. In this technique, crop residues from the previous culture remain on the soil surface. In autumn, the strips were prepared with a GPS-RTK based strip-tillage machine. The straw residues between the strips remained undisturbed on the soil surface. Spring white cabbage was transplanted with a modified planting machine. Rainfall simulation to determine soil losses showed significant lower soil losses in strip-tillage plots (20 g m^{-2}) compared to plots managed by mouldboard plough (110 g m^{-2}). Different nitrogen fertilization techniques, band-placed and broadcast application, were tested. Soil mineral nitrogen contents and total nitrogen content in plants indicate that the nitrogen availability in strip-till system is sufficient, which shows that the different application techniques have no significant effect on cabbage yield. Generally, strip-tillage has a high potential to protect against erosion and is suitable for cabbage cultivation. Cabbage yields in strip-tillage systems are comparable to yield levels in mouldboard ploughing systems.*

Keywords: *Strip-tillage; White cabbage; N-fertilization; Erosion control measures; Agrotextiles*

Introduction

Soil erosion is a devastating problem in many areas of the world. The tolerable rate of soil losses by wind or water erosion in Europe is estimated to be < 1.0 t ha^{-1} yr^{-1} (Jones et al., 2004). Cumulative mean soil erosion rates in tilled agriculture in Europe are between 4.5 and 38.8 t ha^{-1} yr^{-1}. Maximum rates of several 100 t ha^{-1} yr^{-1} are observed in individual storms that may happen every two to three years (Verheijen et al., 2012). In Europe, 115 Mio ha of land are at high risk of water erosion and 42 Mio ha of wind erosion (European Environment Agency, 1998). One of the main reasons for increasing erosion rates are intensive farming systems including frequent use of mouldboard plough and other inversion tillage techniques. Several studies illustrate that soil losses and soil erosion are significantly reduced by conservation tillage systems, such as mulch-tillage, strip-tillage or no-tillage (Meyer et al., 1999, Raczkowski et al., 2009, Prasuhn, 2012). For corn, sugar beet and other row crops with wide row distances, the problem of soil erosion is widespread and reduced tillage options are available since many years. Especially strip-tillage is gaining attention in recent years. This technique combines the advantage of conventional mouldboard ploughing (high yields), and no-tillage (protection against soil erosion). In the US, and for some extent in Europe, for corn, sugar beet and rapeseed production, strip-tillage is prevalent and several manufacturers distribute machinery for this technique. For vegetable production systems, conservation tillage techniques are not common at the moment due to the missing technical solutions. Results for corn and sugar beet show optimum protection against soil erosion, and positive effects on other soil properties, such as bulk density and soil moisture. This indicates that strip-tillage is a sustainable, soil-protecting management method with the potential of high yields, which are comparable to conventional mouldboard ploughing systems (Licht and Al-Kaisi, 2005, Evans et al., 2010a). In the German Federal State of Baden-Wurttemberg, there was a legislative amendment in 2010. On the basis of the erosion control regulation (Erosionsschutzverordnung – ErosionsSchV, 2010), by which each field was classified into erosion risk classes, including 3 classes for water erosion and 2 for wind erosion. The classification depends on slope and soil type. The Universal Soil Loss Equation (USLE) is used to make the calculations (Wischmeier and Smith, 1978). According to this regulation, mouldboard ploughing is not permitted in winter until February 15th or in row cultures, with row distances greater than 45 cm, such as white cabbage. Referring to this legislation, new options to conventional mouldboard ploughing system are necessary for vegetable growers. In the project “Development of Erosion Control Measures in Vegetable Cultivation”, which is financed by the Ministry of Rural Affairs and Consumer Protection Baden-Wurttemberg (MLR), the strip-tillage system was modified and tested in white cabbage cultivation on the research station of the University of Hohenheim and in on-farm experiments. The main objective of this project is to develop a package of erosion control measures to help famers and vegetable growers prevent soil erosion and protect soils for the long term.

Therefore, rainfall simulation for detection of soil erosion potential, nitrogen availability in different application systems, and different investigations of water regime and other soil properties were conducted. Furthermore, as another erosion control measure, agrotextiles (fleece and nets) were analysed for erosion protection potential and white cabbage growth under the non-woven fabrics with specific microclimate. Normally, non-woven fleece is used to promote earlier growth of lettuce and other vegetables. Both soil and air temperature are increasing by row covers and furthermore, plants are protected against insect pests (Rekika et al., 2009, Olle, 2010). Soil cover textiles could serve as an erosion control measure because of decreasing impact of raindrops. However, the hypothesis of the recent study was that the application of agrotextiles changes the microclimate of the crop, in particular during the periods of high temperature. We hypothesized that the temperature and humidity under the cover is detrimental to cabbage growth in June and July, the warmest months of the year in Central Europe, but also the months with the highest erosion risk, because of frequent thunderstorms and heavy rainfall events.

Materials and Methods

The field experiments were established at University of Hohenheim´s research station, Ihinger Hof, in southwest Germany (48°40'N, 9°00'E, 478 m a.s.l.). The average annual precipitation is 691 mm and the average annual temperature is 8.3 °C. Soil type is predominantly a stagnogleyic Cambisol with silty, erosion prone properties.

The experimental design of the agrotextile experiment was a randomized complete block design, with three treatments and three replicates. White cabbage cv. Kalorama was transplanted in 2012 in all treatments. The row distance was 50 cm in row and 50 cm between rows. The treatments were (1) plants covered with net (1.35 mm x 1.35 mm), (2) plants covered with fleece (17 g m^{-2}) and (3) non-covered control treatment. Soil temperature and soil moisture content were measured in two weeks intervals until cabbage plants covered the soil completely. Furthermore, plant samples, for dry matter determination, were also taken in two weeks intervals. 99 days after transplanting, cabbage plants with symptoms of Alternaria leaf spot *(Alternaria brassicae)* and *Sclerotinia* rot *(Sclerotinia sclerotiorum)* were examined visually and numbered at the field. At harvest time yield was determined. For rainfall simulation, plots with an area size of 3 m^2 and a slope of 12 % and 18 % were covered with fleece and net and one uncovered control plot. The plots were irrigated with a sprinkling system with an intensity of 25 mm h^{-1}. The experiment was replicated three times in July 2012.

For the strip-tillage experiment a randomized complete block design was established with four treatments and four replications. The field size per plot was 6 m wide and 20 m long. There was a conventional inversion tillage treatment with mouldboard plough (25 cm deep), which was serving as a control treatment (MP) and three strip-tillage treatments. First one was the common strip-tillage treatment with soil preparation in autumn and transplanting of white cabbage in spring (ST). In the second and the third strip-tillage treatment, the first soil preparation with strip-tiller took place in autumn and once more soil loosening was done in spring just before the transplanting. In one intensive (double tillage) strip-till treatment nitrogen fertilization (ST_pN) was band-placed, while the other comprised broadcast nitrogen fertilization (ST_bN). The strips were prepared with a strip-tiller (Horsch "Focus") (Table 1). For an exact transplanting, the tracks were registered with the aid of an RTK-GPS steering system. In 2011 and 2012, rainfall simulation was done with a portable field rainfall simulator with an irrigation area of 1 m^2. The rainfall simulation was conducted 20 minutes with an intensity of 2 l per minute. Soil losses and surface runoff were measured in mouldboard plough and strip-tillage plots. Soil and plant samples were taken in two week intervals for determination of soil mineral nitrogen, total nitrogen content in plants and dry matter content of white cabbage plants. For calculation of N-uptake rate, percentage total nitrogen content was multiplied with dry matter of plants and upscale the results in kg N ha^{-1}. For soil mineral nitrogen, samples were taken in planting row (IR) and between planting row (BR) in each strip-tillage treatment. 14, 28 and 43 days after planting (dap), soil samples were taken at 30 cm depth and 56 dap from 0 to 30 cm and 30 to 60 cm depth according to the fertilizer recommendation of vegetable crops (IGZ-Leibniz Institute of Vegetable and Ornamental crops, 2011). At harvest time in autumn yield was determined.

For the agrotextile experiment one-way ANOVA was used (SigmaPlot 10.0; Systat Software, 2006). If the overall effect was significant in ANOVA, an all pairwise comparison of the mean response of the different treatments according to Tukey Test (α=0.05) was conducted to detect differences in treatment means. Statistical analyses in the strip-tillage experiment were performed using PROC MIXED with SAS Software (SAS, 2004). All data sets were analyzed according to a randomized complete block design with four treatments and three sampling positions in four replicates on each plot. Different sampling dates of soil mineral nitrogen and total nitrogen content in plants were analyzed separate from each other. For letter description a multiple t-test was used only after finding significant differences via an F-test. Before the variance analyses were done, normal distribution and variance homogeneity were tested.

Table 1: Treatments and tillage operations

Treatment	Abbreviation	Stubble tillage[1]	Tillage operation in autumn 2011	Tillage operation in spring 2012
Mouldboard plough	MP	Yes	Mouldboard ploughing[2]	Rotary harrow
Common strip-tillage	ST	No	Strip-tillage[3]	-
Intensive strip-tillage with band-placed N-fertilization	ST_pN	Yes	Strip-tillage[3]	Strip-tillage[4]
Intensive strip-tillage with broadcast N-fertilization	ST_bN	Yes	Strip-tillage[3]	Strip-tillage[4]

[1] 5-10 cm deep; [2] 25 cm deep; [3] 20 cm deep; [4] 5-10 cm deep

Results and Discussion

The experiment with fleece and net as an erosion control measure showed that the yield was significantly affected by textile cover. Highest yields were measured in covered plots. Average yield in net covered plots was 81 t ha^{-1} and in fleece covered plots 80 t ha^{-1}. Significantly lower yields were detected in uncovered plots (65 t ha^{-1}) (Figure 1a). Average soil moisture and soil temperature were higher under fleece cover than under net covered and control plots. At the first two sampling dates, fleece covered plots had significantly higher soil temperature and soil moisture content than uncovered control plots. At the third and fourth sampling date, there were no significant differences between the treatments (Figure 1b). Non-woven fleece or nets could be used to reduce insect pests (Salas et al., 2008, Rekika et al, 2009). Due to the special microclimate under non-woven fabrics, the risk of fungal diseases increased. High temperatures and wet conditions under the textile cover produced optimum conditions for fungal diseases. For cabbage, especially, Alternaria leaf spot *(Alternaria brassicae)* and *Sclerotinia* rot *(Sclerotinia sclerotiorum)* are a problem (Koike et al., 2007). In the recent study, the observation of symptoms showed a significantly higher infestation of *Alternaria* spots on leaves during the growth period in fleece and net covered plots. *Sclerotinia* rot occurred in fleece-covered plots during the second half of cultivation time. The fungal disease was detected on 3.7 % of plants. Under net cover only 0.5 % of cabbage plants were affected by *Sclerotinia.* In rainfall simulation experiments with fleece and net cover, runoff and soil loss was lower at fleece and net covered treatments compared to the controlled non-covered treatment. For a 12 % slope, the soil losses at fleece-covered area were reduced about 78 % compared to the non-covered control treatment. For a slope of 18 %, soil losses of fleece covered area were reduced about 90 % and in net covered plots soil losses were reduced about 72 % compared to control treatment. Agrotextiles can be used as an erosion control measure, but it is necessary to consider the effects on microclimate and cost efficiency.

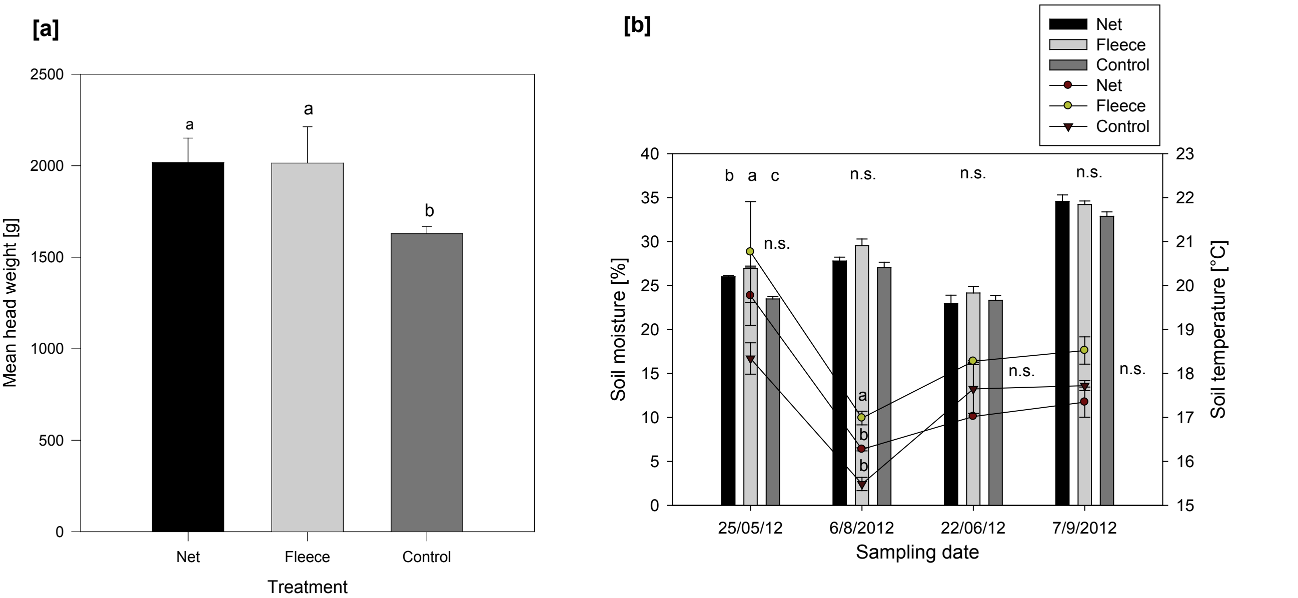

Figure 1: **[a]** Mean head weight [g] in different agrotextile and non-covered control treatment. **[b]** Soil moisture and soil temperature under fleece and net covered plots across 5 sampling dates. Bars represented soil moisture [%] and lines with dots represent soil temperature [°C]. No significant differences for values with same letters, $P < 0.05$. Comparison only for each sampling date, n.s.: not significant

Experiments with a small rainfall simulator in 2011 and 2012 demonstrated that the potential to reduce soil erosion is very high in strip-tillage treatments. In 2011, soil losses in strip-tillage plots were five times less than in plots tilled with mouldboard plough. In 2012, soil losses in ST were reduced by 90 % compared to MP and 52 % by ST_bN. Significant lower soil losses in strip-tillage treatments have shown a high potential to protect from erosion. The difference between common strip-tillage treatment (ST) and the intensive, double-tillage strip-tillage treatment (ST_bN) show, that the protection against soil erosion decreased with any further soil preparation. In several studies, conservation tillage techniques show significantly lower soil losses compared to conventional mouldboard plough (Bosch et al., 2005, Evans et al., 2010b, DeLaune and Sij, 2012).

The soil mineral nitrogen content had the highest value at the beginning of the experiment (14 days after transplanting=dap) in intensive strip-till treatment with placed nitrogen fertilization within planting rows (ST_pN_IR) (183 kg N ha^{-1}). The soil mineral nitrogen content in ploughed plots was significantly lower (84 kg N ha^{-1}), indicating that the broadcast N-fertilization in ploughed plots has a high risk of nitrate leaching because the original N-amount at the planting day was the same in each treatment. Another explanation of lower soil nitrogen contents is the lower infiltration rate in ploughed plots. It may be possible, that the runoff was triggered by heavy rainfall events, or excess irrigation (Gheysari et al., 2009, Cameron et al., 2013). ST (133.8 kg N ha^{-1}) and ST_bN_IR (124.2 kg N ha^{-1}) have shown no significant differences to MP and ST_pN_IR. Soil mineral nitrogen in ST_pN_IR was also significantly higher than in MP 28 dap. 43 dap, soil mineral nitrogen in ST_pN_IR was significantly higher in MP and ST_IR. At 56 dap and at harvest, there were no significant differences between the treatments. Soil mineral nitrogen content in soil samples between the planting rows (BR) show significant difference between ST_bN_BR (172.8 kg N ha^{-1}) and ST_pN_BR (75.5 kg N ha^{-1}), exclusively 14 dap. At all other sampling dates no significant differences between the treatments could be detected (Figure 2). These results are confirmed by other studies, which also document small and non-significant differences in soil mineral nitrogen (Oorts et al., 2007, Gruber et al., 2011). Dry matter of cabbage plants in ST plots was significantly higher 28 dap than ST_pN and 56 dap than in mouldboard plough plots (MP) and the intensive strip-till treatments (ST_pN and ST_bN). At other sampling dates (14 and 43 dap) dry matter was not significantly affected by different soil tillage techniques or different N-application systems (Figure 3a). For total nitrogen content in shoots 14 and 28 dap, ST_pN treatment had significantly higher nitrogen content compared to MP. At 14 dap, there were also significant differences to the intensive strip-till treatments (ST_pN and ST_bN) (data not shown). N-uptake rate was significantly different between the treatments at 28 and at 56 dap. At 28 dap, significantly higher N-uptake was detected in ST (22.11 kg N ha^{-1}) than in ST_pN (12.17 kg N ha^{-1}). No significant differences were detected between MP (17.06 kg N ha^{-1}) and ST_bN (16.20 kg N ha^{-1}). At 56 dap, significantly higher N-uptake was measured in ST compared to MP, ST_pN, ST_bN. Strip-till treatment (ST) showed highest N-uptake rate at harvest time (290.4 kg N ha^{-1}), but there was no significant difference compared to other treatments. Mouldboard ploughing plots (MP) have a N-uptake of 265.8 kg N ha^{-1} and in the intensive strip-tillage treatments, N-uptake of 269.3 kg N ha^{-1} in band-placed treatment and 279.1 kg N ha^{-1} broadcast treatment were detected (Figure 3b). In 2012, significantly higher yield was detected in ST (74.3 kg ha^{-1}) compared to MP (64.8 kg ha^{-1}). ST_pN (67.2 kg ha^{-1}) and ST_bN (69.2 kg ha^{-1}) showed no significant difference to MP and ST (Table 2). Results indicate that strip-tillage is suitable for cabbage cultivation. Compared to mouldboard plough treatment, the conservation technique, strip-tillage had significantly higher yields and the risk of nitrate leaching was decreased.

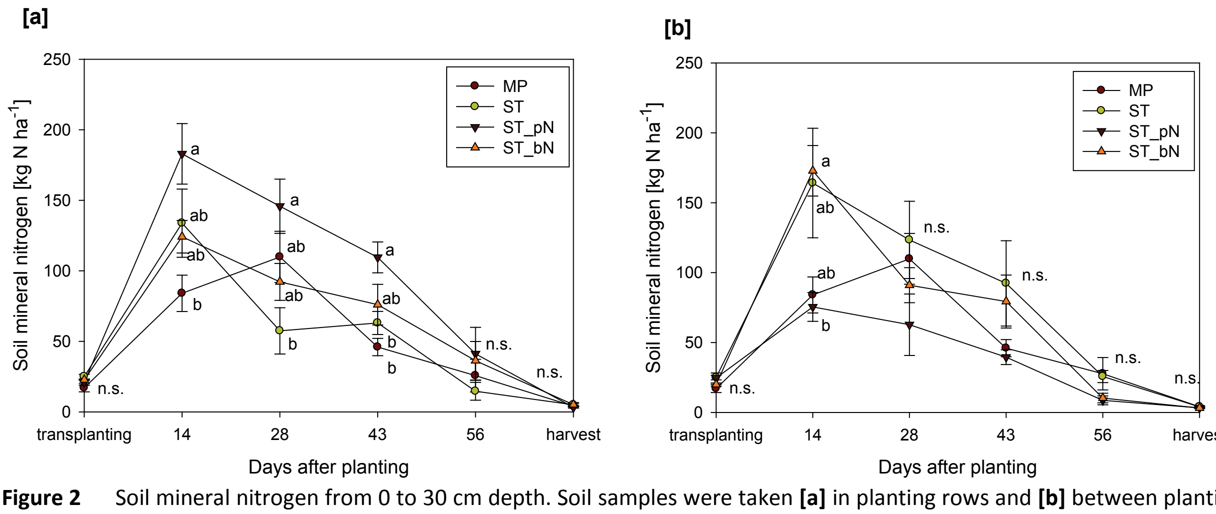

Figure 2 Soil mineral nitrogen from 0 to 30 cm depth. Soil samples were taken **[a]** in planting rows and **[b]** between planting rows. Soil treatments were MP: mouldboard ploughing; ST: strip-tillage; ST_pN: intensive strip-tillage with double tillage and band-placed nitrogen fertilization; ST_bN: intensive strip-tillage with double tillage and broadcast nitrogen fertilization. No significant differences for values with same letters, $P < 0.05$. Comparison only for each sampling date, n.s.: not significant

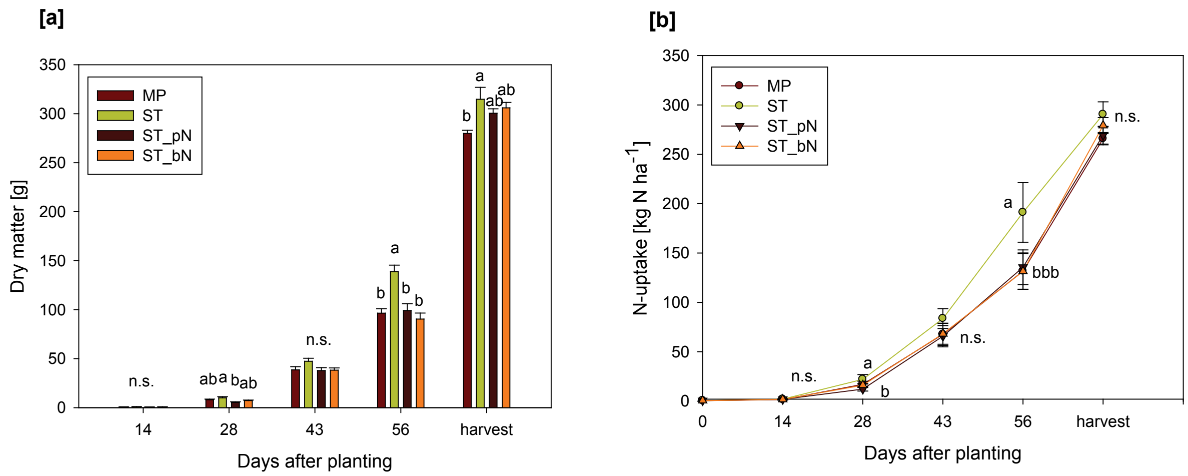

Figure 3 **[a]** Average dry matter yield per cabbage plants [g] for different sampling dates. **[b]** N-uptake of cabbage plants across the cultivation duration. Soil treatments were MP: mouldboard ploughing; ST: strip-tillage; ST_pN: intensive strip-tillage with double tillage and band-placed nitrogen fertilization; ST_bN: intensive strip-tillage with double tillage and broadcast nitrogen fertilization. No significant differences for values with same letters, P < 0.05. Comparison only for each sampling date, n.s.: not significant

Table 2 Absolute yield in t ha^{-1} of 2011 and 2012 in mouldboard ploughing plots and in comparison with the relative yield of strip-tillage treatments.

Yield	**Relative yield (%)**		
Mouldboard ploughing (t ha^{-1})	Strip-tillage	Strip-tillage intensive band-placed nitrogen-fertilization	Strip-tillage intensive broadcast nitrogen- fertilization
64.9	110 % *	104 % $^{n.s.}$	105 % $^{n.s.}$

* signicficantly different to mouldboard ploughed plots, p<0.05

n.s.: no significant differences to the mouldboard ploughed plots

Conclusion

Non-woven fabrics can be used as an erosion control measure, if the climate conditions are suitable. For areas with high summer temperatures and wet conditions, risk of fungal diseases increases especially under fleece. However, yield potential can be higher under agrotextiles because of decreasing risk of insect pests.

The strip-tillage experiments have shown that this technique is an innovation with an optimal protection against soil erosion with similar yields compared to conventional mouldboard ploughed plots. The results of N-uptake and yield in strip-tillage plots showed, that the nitrogen availability is guaranteed for cabbage plants, independently from the application system (broadcast or band-placed application). The risk of nitrate leaching can be reduced in strip-tillage system because of a more continuous mineralisation of nitrogen and better N-uptake compared to mouldboard ploughing system.

In conclusion, agrotextiles can be a component to reduce the risk of soil erosion for individual fields and farmers under specific conditions; however, other measures, such as strip-tillage, are more suitable to protect soils and ensure high yield for long term vegetable cultivation.

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(9) Minerals and wastewater treatment products effectively increase P sorption capacity in acidic sandy soils.

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Abstract: *As a result of decades of excessive phosphorus fertilization, most acidic sandy soils in Flanders (Belgium) and the Netherlands are phosphorus (P) saturated. Many of these soils are under intensive vegetable rotations. This saturation entails a risk of significant P leaching to groundwater resulting in environmental problems. A study was undertaken to test several soil amendments in terms of their potential for increasing P sorption capacity of the soil, with a view to decreasing the risk of P leaching.*

In this study eight amendments, including five minerals (olivine, biotite, zeolite, gypsum and bauxite), one waste water treatment residual (dried Fe-sludge) and 2 amendments designed for P fixation in water (Phoslock® and Sachtofer) were evaluated for their ability to fix P in soil with different P level, by assessing P leaching in incubation experiments.

The preliminary results showed that all amendments reduced P leaching to varying degrees, and the success depended on the amount of product applied and the pre-treatment of the product (for the minerals). This research opens perspectives for combating P leaching losses in a relatively simple and cheap way.

Keywords: *P saturation, P leaching, Fe-bearing minerals, P fixation,*

Introduction

Phosphorus (P) losses from heavily fertilized agricultural soils cause severe environmental problems in Flanders, the northern part of Belgium (De Bolle et al., 2013). Elevated P concentrations in surface waters contribute to the deterioration of surface water quality (Agyin-Birikorang et al., 2007). In the EU, especially in Belgium, The Netherlands and Denmark, many of the acidic sandy soils have a high Phosphate Saturation Degree (PSD) and are subjected to strict P fertilization restrictions, what ultimately should result in P depletion or P mining. However, with current crop rotations, it will take many decades to bring P levels back to environmentally safe levels, because P mining efficiency decreases rapidly with time (Callahan et al., 2002; Sharma et al., 2007). One possible alternative management option would be to increase the P fixation capacity of the upper soil layers with addition of materials rich in aluminium (Al), iron (Fe) and/or calcium (Ca), because Ca-rich materials tend to remove P by Ca phosphate precipitation, whereas Al- and Fe-rich materials can precipitate and absorb P (ligand exchange) (Callahan et al., 2002; Chardon et al., 2012; Stoner et al., 2012). The amendments that appeared most promising from the above screening experiments were tested for their ability to reduce P leaching from a soils during a batch leaching experiment under controlled conditions in the laboratory. This has, to our knowledge, never been investigated in this way before.

The reduction in P solubility is the main reason why these amendments are now tested in the soil, however one needs to be aware of all the elements which are brought in the soil with these products. A disadvantage is the release of toxic metals, which tends to be a potential concern when using industrial by-products as soil amendments, next to their advantages of being widespread available and being cheap (Buda et al., 2012). The objective of this study was to make an evaluation of the effectiveness of 8 soil amendments to reduce P leaching from a sandy soil.

Materials and methods

One acidic sandy soil from Belgium with a PSD of 107% in the upper 30 cm was used in the experiment. To increase the reaction rate (or weathering) of the amendments, they were pre-treated physically (ball milled, BM)and/or chemically. Out of the conclusions drawn from a screening experiment (De Bolle, 2013) following products were tested in the fixation experiment at their most efficient addition rates (R), namely Blank, Olivine (R3), olivine + 1 h HCl (R3), biotite (R3), biotite + 1 h HCl (R3), zeolite (R3), zeolite + 1 h HCl (R3), gypsum (R2), bauxite (R2), Dried Fe sludge (R1, R2, R3), Phoslock® (R2, R3) and Sachtofer (R2, R3), whereby R1 is 0.1%, R2 is 0.5% and R3 is 1.5% amendment to soil. The amendments were thoroughly mixed with 80 g of pre-incubated soil (volumetric moisture content of 23.5%) and put into a PVC column (height 10 cm, inner diameter 4.6 cm). The bottom of the tubes was closed with a polyester sieve (250 µm MW) and a paper filter (a Whatman filter, 589/3) on top of the sieve in order to prevent soil loss during the fixation experiment. The experiment was performed in triplicate for each amendment per soil and also three unamended control samples were included. Eighty ml of $CaCl_2$ (0.005 M) was added to each column and allowed to infiltrate. The leachate was collected and this was repeated eight times. On the leachates the concentration of $P_{inorganic}$ (P-$CaCl_2$ method) was measured.

Results

A cumulative loss of $P_{inorganic}$ of 13.3 ± 1.9 mg P kg^{-1} was found in the control sample (Figure 1). The dynamics of the $P_{inorganic}$ loss as a function of time found for the amended samples was comparable to the control. The gypsum R2 treatment resulted in higher $P_{inorganic}$ loss compared to the control. The zeolite R3 resulted in a higher amount of $P_{inorganic}$ loss over the entire experiment in comparison with the control. On the contrary, the addition of the chemically pre-treated minerals resulted in the highest P fixation of all tested minerals in the tested soil.

A lower $P_{inorganic}$ loss was found with the addition of dried Fe-sludge or the specially designed products Phoslock® or Sachtofer. The Fe-sludge R2 or R3 and Phoslock® R3 treatments, resulted in the highest P fixation of the industrial by-product and the specially designed products. A comparable amount of $P_{inorganic}$ was fixed in the Sachtofer or bauxite treatment.

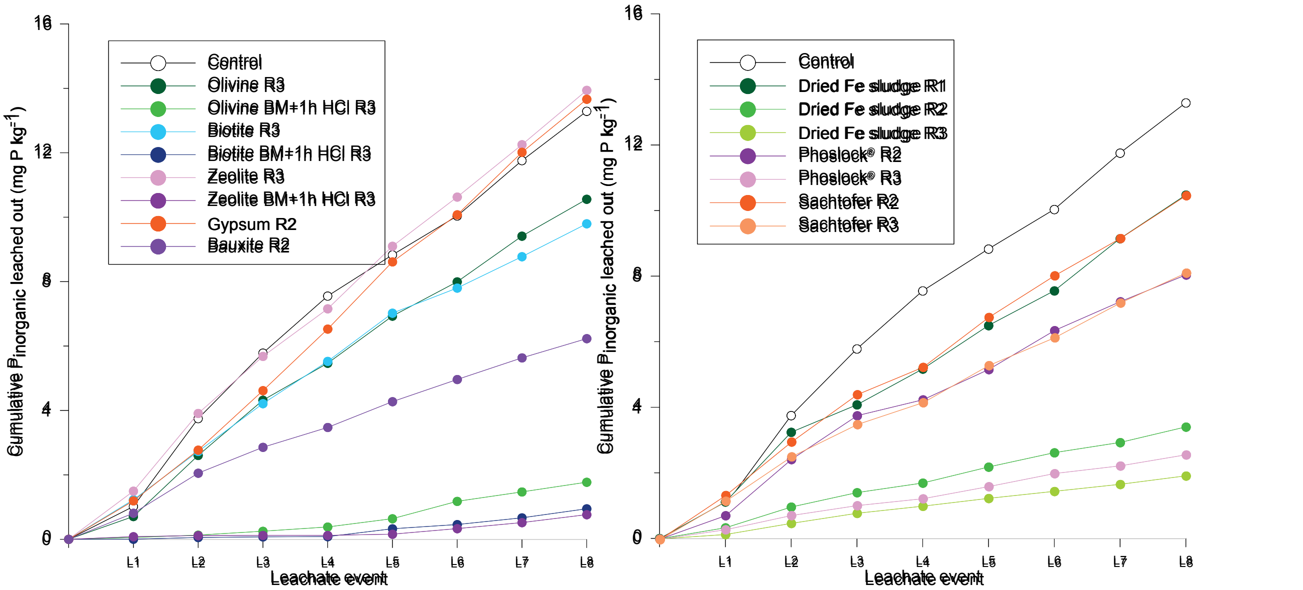

Figure 1. Cumulative amount of $P_{inorganic}$ (mg P kg^{-1}) leached out over the eight leachate events with addition of minerals (a), industrial by-product and specially designed products (b)

Discussion

The P build up in acidic sandy soils with low P retention capacity such as in the investigated soil, poses a potential risk of P leaching and contamination of the ground and surface water. Reducing the P solubility and increasing the P retention capacity in the soil are considered as the best management practices to reduce P leaching risks (O'Connor et al., 2005). The gypsum R2 treatment gave a higher cumulative P loss, compared to the control sample, which is in agreement with the findings of Summers et al. (1996), who found a slight increase in P leaching on a sandy soil after addition of gypsum. This was attributed to the amount of P in the gypsum (0.15%) or to the displacement and competition between sulphate and phosphate ions for binding sites. Rechcigl et al. (2000) reported that gypsum and lime amendments had no effect on the P concentrations in runoff. Gypsum and lime products have been widely used to increase the pH on agricultural soils and these products have also been used to reduce P loss in heavily manure-impacted soils (Callahan et al., 2002; Cox et al., 2005; Watts and Torbert, 2009). A possible explanation of the lack of P fixation by gypsum in these soils could be the fact that they were acidic and sandy, where previously gypsum amendments were shown to be efficient on clay and clay loam soils (Ekholm et al., 2012; Uusitalo et al., 2012). Gypsum addition increases the pH of acidic soils, thereby solubilizing more P fixed to Al or Fe than could be bound by the added Ca, and consequently results in an increase in soluble P. In the tested soil the zeolite treatment had none or a negative effect on the P fixation capacity but to a lesser extent than gypsum. The effect of zeolite addition to the soil thus corresponded to its effect in water, i.e. generally a poor P sorption capacity (Wium-Andersen et al., 2012).

The chemically pre-treated minerals were most effective in terms of P fixation capacity in the soil that were very rich or rich in P. They were able to fix almost all $P_{inorganic}$ during the eight consecutive leaching events. The reason that chemically pre-treated minerals were able to fix P more efficiently is due to the fact that pre-treatment is an enhanced way of mineral weathering, which results in a strong increase in sorption sites for P. Bauxite addition decreased the total $P_{inorganic}$ loss but was not able to fix all P in the soil. This is in agreement with other experiments where bauxite is found to be an efficient amendment in terms of P fixation (McDowell and Nash, 2012). The pH increase after bauxite addition is also in agreement with other experiments (McDowell and Nash, 2012).

The dried Fe sludge, originating from waste water treatment, was already able to fix P at the lowest addition rate (R1). The products that are designed for P fixation in water bodies, namely Phoslock® and Sachtofer also gave promising results, especially Phoslock® R3.

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(10) Sustainable nutrient management in soil-less culture in Dutch greenhouse horticulture

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Abstract: *Since the expansion of soilless culture in the Netherlands in the mid-eighties of the previous century, emission of nutrients and plant protection products (PPP's) used in the root environment was considered as a huge problem. Eventually, the government and growers organisations reached an agreement which aimed at reducing the N, P and PPP emissions. For soilless culture, reuse of drainage water or closed growing systems became obligatory. Recently, the regulation changed by shifting the focus on reaching emission targets for N rather reaching 100 % closure of the systems. Yet, recirculation is still the key issue for reaching the goal of zero emission by 2027. These closed systems will potentially lead to substantial reduction of mineral leaching to the environment, however, they require adequate water quality and nutrient management. Moreover, satisfactory disinfection to control root diseases and removal of organic components is needed. In practice, substantial loss of water and minerals still occurs occasionally, when growers decide to flush the system and drainage water is partially discharged to the surface water or sewage system, causing emission of nutrients and PPP's. There are several reasons for growers to discharge e.g. accumulation of Na, mismanagement in EC or pH or nutrient supply, and serious problems with soil borne diseases or growth inhibition. This paper will give an overview of the state of the art of systems for nutrient solution recycling, and the requirements for water treatment, water quality and nutrient supply and strategies to obtain the highest efficiencies for nutrient and water use.*

Keywords: *Recirculation, Na accumulation, Discharge, Emission, Growth Inhibition*

Introduction

Protected cultivation in the Netherlands covers over 10 000 ha, mostly concentrated in the western part of the country with a high density of glasshouses. Almost 80 % of the area is soil-less culture. Glasshouse crops are intensively grown, with high inputs of capital and labour and high production levels. As the mineral uptake is proportional to the total yield, these high production levels involve high inputs of fertilisers. In comparison to open field vegetable crops, the annual fertiliser application is eight to ten times higher (Sonneveld, 1993). Apart from the high crop demand, the high fertiliser inputs are necessary to keep high osmotic pressure levels in the root environment to prevent lush growth and for enhancing product quality (Sonneveld, 2000). However, these high fertiliser applications and levels in the root environment increase the risk of leaching and emission of N and P into ground - and surface water. The problem of water pollution by minerals increased seriously with the introduction of soil-less culture from the early 1980's on. The fertiliser requirement increased as consequence of the higher yields in soil-less culture (Voogt, 2004). The main reason for the higher emission in substrate culture was, however, the practice of high irrigation frequency and quantity to compensate for the heterogeneity of the output of the irrigation system (Sonneveld and Voogt, 2009). It is therefore and as a consequence of the high density of greenhouses in most areas that the Dutch government decided, by the end of the 1980-ies, to start with comprehensive regulations and legislations to reduce the pollution of the aquatic environment in horticultural areas (Ministry, 1989). A complicating factor is that the costs of fertilisers and water in these intensive growing systems are low compared to the total costs (Ruijs, 1995). Savings on these items are therefore in general not an incentive to implement concepts and measures regarding sustainability.

This paper will give an overview of the state of the art of systems for nutrient solution recycling, and the requirements for water treatment, water quality and nutrient supply and strategies to obtain the highest efficiencies for nutrient and water use.

Legislation

In the late 1980s, the problem of high nutrient concentrations in surface waters in and near greenhouse areas were signalled. To diminish the problems of nutrient losses, closed growing systems were stimulated by governmental policy. Because of insufficient effect of the stimulation programme, the policy was adjusted and replaced by regulations (Roos-Schalij *et al*., 1995). From November 1996 reuse of drainage water was obligatory for soil-less crops. Enforcement of this regulation was assigned to the Polder boards. (A polder board is a semi-governmental, local body, set up to maintain the integrity of the water defences around polders and responsible for water quality) However, due to the large number of enterprises, local conditions as well as the impracticability of the control, the operation was unsuccessful. Therefore, the important stakeholders (central and local government, environmental groups and the growers' organization) organized themselves in the GLAMI committee, Dutch acronym for "Greenhouse Horticulture and Environment" (GLAMI, 1997). This resulted in an official agreement, covering the regulations and details concerning the obligation for recirculation (Infomil, 2002). The key issues in the regulation were:

- Obligation of reuse of drainage water
- Permission of temporarily discharge drainage water if Na concentrations exceed a certain crop specific level.
- Obligation of rainwater collection of at least 500 m^3/ha or sufficient water from sources with comparable quality as rainwater.

However, during the late 1990s and early 2000s, some developments induced the central government to change policy again. This was driven on the one hand by the implementation of European Nitrate Directive (ND) and the Water framework Directive (WD) and on the other hand by the disappointing results of the water quality monitoring by the Polder boards in areas with many greenhouses and the evaluation of the nutrient emissions (Baltus and Volkers-Verboom, 2005). As a result, the GLAMI committee (now 'Platform Sustainable Greenhouse Horticulture') changed the agreement from 'prescription of means and requirements' towards 'prescription of targets' in the period 2005 – 2010. The new agreement defines specific goals for emissions, instead of a list of obligations. Obviously the main route for emission are the water flows, which is mainly the discharge of drainage. So all measures taken to reduce the amount of discharge also will reduce the emission of P – and other nutrients - as well as the emission of PPP's to surface waters and groundwater. Therefore the new agreement has chosen for defining N norms for emission, achieving a reduction of discharge and by that also for P and PPP's. The final target is zero emission from Greenhouse Horticulture to be achieved by the year 2027.

The agreement was translated into new regulations: "Activiteitenbesluit Glastuinbouw" (Infomil, 2012). From January 1st, 2013 growers are responsible for reaching the emission goals. However, the polder boards still have the legal means of enforcement as growers are obliged to officially register fertiliser use and the discharge quantity so that the quantity of N emission can be determined.

The main points of the regulations are:

- Crop specific norms for the emission of N (Table 1), which will be yearly decreased until 0 in 2027.
- Grower need to make a yearly report, with the registered water use, discharge and fertiliser use.
- Obligation for rainwater collection will be dismissed
- Discharged water may be used for other sectors like field vegetables.

For some crops, however, no economically feasible soil-less growing system was available (Ruijs, 1994). For soil grown greenhouse crops the solutions were directed towards improvement of the irrigation en fertilisation management, to avoid irrigation surpluses (Voogt, 2004).

Table 1. Maximum acceptable yearly emission of N in discharged drainagewater in kg ha^{-1} yr^{-1} *(Infomil , 2012)*

	2013 & 2014	2015- 2017	>2018
Other vegetables	25	25	25
Anthurium, Container crops, Bedding plants	50	33	25
Orchid (Cymbidium)	75	50	38
Tulip, Annual	100	67	50
Tomato, Herbs	125	83	67
Cucumber, Potted plants, Propagation ornamentals	150	100	75
Strawberry, Eggplant, Sweet pepper	200	133	100
Rose, Gerbera, Propagation vegetables	250	167	125
Pot orchids (Phalaenopsis)	300	200	150

Bottlenecks

Surplus irrigation in substrate cultures is necessary due to the unequal distribution of water and nutrients by the irrigation system and differences in transpiration of individual plants and spots in the greenhouse (Sonneveld and Voogt 2009). Closing the system can easily be done by the collection of runoff by a gutter system and reuse it in the system (Voogt and Sonneveld, 1996). The closed systems increase water- and nutrient use efficiency and reduce the risk of emission of nutrients and PPP's. However, there are some bottlenecks accompanying the recirculation of nutrient solution.

1) Recirculation can lead to rapid spread of spores of root pathogens, viruses, bacteria or nematodes from infected plants throughout the system. Sometimes serious problems and outbreaks of root diseases in closed growing systems are reported.
2) Salinity can be a problem, since residual salts present in the irrigation water or added by fertilisers accumulate in the system if the concentrations in the inputs are higher than the apparent uptake concentration. This is enhanced by the low buffer capacity of the system, due to the low volume and the inertness of the growing media.
3) As constrained by the salinity problem, only water of perfect quality is suitable (Table 2). This means that the major traditional water sources like surface water and well- water in the Netherlands are unsuitable, except for the well water in the east part of the country.
4) In some crops, mainly cut roses, the reuse of drainage water occasionally causes growth inhibition. It has been suggested that the accumulation of (organic-) compounds in the system or a build-up of microbiological activity causes infection and deterioration of the harvestable flowers.
5) Since the root environment is restricted all essential nutrients should be supplied, in the right quantity as well as in the required mutual ratios. A supply higher than needed by the crop will lead to rapid accumulation and a supply with lower concentrations than required will lead to rapid depletion.
6) Despite the high water and nutrient use efficiency potential of the closed system, discharge of the circulating nutrient solution is needed frequently due to the accumulation of Na^+, Cl^- or other elements. Growth inhibition is an obvious reason to refresh the recirculation water by discharge of drainage, but sometimes also done as precaution, even if growth inhibition is not yet observed. Some growers even discharge the drainage tank because of too high EC or pH. The discharge causes loss of nutrients and in some cases loss of PPP's. Since the discharge is applied in short time it causes serious environmental problems.

Table 2. Guide values for water quality for closed growing systems *(Sonneveld and Voogt, 2009).*

Class	EC mS cm^{-1}	Na mmol l^{-1}	Cl mmol l^{-1}	
1.1	<0.5	<0.2	<0.2	Suitable for all crops
1.2	<0.5	0.2 – 0.5	0.2 – 0.5	Suitable for salt sensitive crops
1.3	<0.5	0.5 – 1.0	0.5 - 1.0	Suitable for salt tolerant crops or crops with high Na uptake

Sustainable management

Irrespective of the fact that reuse of drainage water is not anymore obligatory under the current legislation, the aim for emission reduction and the final goal of zero emission requires closed growing systems. Therefore, the reuse of the nutrient solution should be maximized by solving the problems with recirculation, to avoid discharge. As a certain discharge is unavoidable, the remaining nutrient solution to be discharged can be purified. The following measure can be taken to alleviate the above mentioned bottlenecks.

Soil-borne diseases

Prevention is obviously the first priority, taking strict hygiene measures for the preparation of the greenhouse and the growing system at the start of the crop. Next, disinfection of drainage water is highly recommended and has been practiced for many years. There are many ways for disinfection (Van Os, 2010). UV radiation is the most popular water treatment, chemical treatments with peroxide and chlorine becoming more commonly used. Despite the high effectiveness of the UV treatment, serious problems and outbreaks of root diseases in closed growing systems are still reported such as the 'Thick Root Syndrome' with cucumber (Gaag *et al*. 2002) and more recently with 'Crazy roots' caused by *Agrobacterium* (Ludeking, 2009).

Water quality and salinity

To prevent the accumulation and salinity problems, water sources low in Na and Cl should be selected for closed systems (Voogt and Sonneveld, 1996). For closed growing systems, the input concentrations for Na and Cl will be determined by the maximum uptake concentration which is reached at the maximum acceptable Na or Cl concentration in the root environment. For all crops so far known, Na is always the limiting factor, since Na and Cl is usually present in waters in more or less the same molar ratio, the suitability of water sources will be determined by Na (Voogt and van Os, 2012). Next to Na and Cl, virtually all nutrient-ions could be the limiting factor for suitability of water sources, if the concentrations present are higher than the average uptake rate of plants. In practice, this is mainly the case with Ca, Mg and SO_4. In some (well-)water sources also some micro-nutrients like Mn or B could be a problem. The ions in this category are nutrients and have to be taken into account when preparing the nutrient solution. The concentration present in the source water should be deducted from the required concentration in the nutrient solution. General guidelines for water quality have been developed (Table 2) however, since the tolerance for salinity and also the uptake differ substantially among crops, the guidelines must be interpreted for specific situations (Sonneveld and Voogt, 1994). Despite all measures, Na accumulation will be a remaining problem, since for some crops the capacity for Na uptake is very low. Therefore some discharge is hardly avoidable, to keep Na within an acceptable level. The lowest volume of necessary discharge will then be achieved if the Na uptake by the specific crop is maximized. This can be reached if the Na concentration in the root environment is kept at the highest acceptable Na concentration in the root environment. This level coincides with the minimum required concentration for nutrients (Voogt and van Os, 2012).

Substrate and fertilisers

Although the main input of residual salts is by the irrigation water, to some extend also other inputs like substrates and fertilisers contribute to the Na accumulation. Sometimes the growing medium can have high Na levels, like coir if this is not properly pre-treated (Verhagen, 1999) or composts used in peat mixtures for potted plants. Some fertilisers have relatively high Na levels, for instance some of the Fe chelates and some K sources like in KNO3, K2SO4 and KH2PO4, or even liquid alkaline K sources like KOH or K2CO3. However, the total contribution of Na from either substrate or fertilisers are rather negligible if compared to the potential for Na input by the irrigation water (Voogt, unpublished data).

Growth inhibition

The sometimes observed growth inhibition is not straightforward identified but yet a major problem. So far, no relation with salinity, nutrition, pathogens or any known micro-organism has been observed. It is assumed that the growth inhibition in rose is connected with the prolonged recirculation of drain water and might be caused by accumulation of growth inhibiting substances in the water (Ehret *et al*. 2005). Both the accumulation of (organic-) compounds in the system and a build-up of microbiological activity, causing infection and deterioration of the vegetation, have been suggested as possible causes. Obviously, growth inhibition should be prevented as it is a driving force for discharge. Recently Van der Maas *et al*. (2013) showed that growth inhibition has a micro-biological cause, most likely of bacterial origin. Disinfection of recirculating water with existing techniques such as UV, ozone or heat treatment inactivated the growth inhibition. Parameters as the O_2 concentration in the root environment or oxidative stress might be useful as early warning for growth inhibition.

Nutrient management

Closed growing systems entail that the inputs of nutrients should match the output or uptake by the crop (Voogt and Sonneveld, 1997). The relevance of this constraint is enhanced by the restricted rooting volume and the inertness of the growing media, making the water- and nutrient buffer limited. The supply of nutrients should therefore be tuned adequately to the crop requirements, to prevent rapid accumulation or depletion of nutrients. In line with the development of closed growing systems in the 1990's, nutrient solutions for specific crops in closed systems have been developed (Sonneveld and Voogt 2009). These are designed to keep to the nutrient status in the root environment optimal for soil-less cultures with recirculation under the current growing conditions. Factors to be considered are: the specific uptake ratios of the crops, substrate characteristics, crop growth stage and climatic conditions. According to water quality, analytical results of the root environment or other parameters adjustments to the nutrient composition can be made easily. It is not sufficient to derive the nutrient requirements from crop uptake data only. Some crops will deplete the nutrient solution almost completely for specific nutrients, not necessarily meaning a great demand, which is demonstrated for rose and strawberry (De Kreij *et al*., 1985; van Bastelaere, 1993). Opposite effects were found with sweet pepper, since for this crop relatively high B levels in the root environment are needed, to achieve sufficient uptake (Voogt and Bloemhard, 2013). To characterize the differences in nutrient uptake and demands, the accumulation factor is a useful parameter which has been elaborated in Voogt and Sonneveld (1996). The uptake during the growing period changes, as crop stages require different nutrient ratios. A clear example of crop stage depending shift in uptake ratios is shown in Fig 1. The change in K:Ca ratio of the uptake of a tomato crop is rapid and substantial and if no adjustments are made in time, rapid depletion occurs resulting in K deficiency (Voogt, 2002).

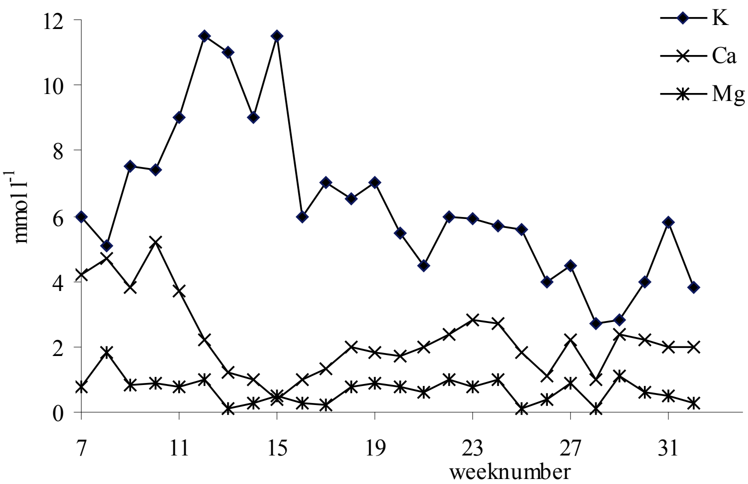

Figure 1. Uptake of K, Ca and Mg of a year round crop of tomato in a closed growing system, planted in week 1, first yield in week14, expressed in mmol l^{-1} *(from Voogt (1997).*

To avoid mismatch of nutrient supply and uptake, a tuned supply is necessary in the first place and secondly, proper control by taking regularly samples for nutrient analysis from the root environment in the second place. These analysis are the basis for adjustments to the fertiliser recipes and have been proven to work quite well in common practice in the last twenty years. As part of the trend of having more control over all growth processes, there is also need for more direct measurement of nutrients in the root environment. Recently hand-held analytical devices for nutrients became available (Blok et al. 2012). New developments in micro- electronica, like capillary electrophoresis (Van der Lugt, 2013) open the way for the long desired wish of on-line nutrient measurements (Gieling, 2001).

Purification of discharge water

Taking the measures as discussed above will help to reduce discharge as much as possible. Nevertheless discharge will be unavoidable occasionally. For instance, when sodium levels exceed the crop-specific threshold values, nutrients are out-of-balance, technical failures appear, or growth inhibition is observed or feared. The pollution with nutrients and ppp's can be reduced substantially by purification before discharge. Recently, van Ruijven *et al*. (2013) evaluated purification techniques for drainage water. Four technologies were tested. It proved that ozone as well as UV with H_2O_2 combination proved to be able to remove the PPPs with an effectiveness of approximately 80%. Activated carbon filter after ozone treatment improved effectiveness up to 100%.

Discussion and conclusion

Although soil-less culture with closed systems are common practice in the Netherlands, reaching complete closure still faces serious bottlenecks. An important issue is the Na accumulation. Due to the high quality requirements (Table 2) many water sources are unsuitable. In practice, only rainwater and in the eastern part of the country, deep well-water is suitable. Sufficient rainwater storage capacity that makes it possible to bridge the gaps of dry periods should be available. However, the space for sufficient rainwater collection buffers is lacking or very expensive. Moreover, even with extreme large buffers the availability of rainwater is uncertain due to the unpredictable climate (Fig 2) (Voogt *et al*. 2012). Therefore growers need installations for desalination by reverse osmosis (RO) as back-up. In addition, due to coastal influence the Na concentration in the collected rainwater is sometimes too high (Voogt and Sonneveld, 1996). Also in case of ill-tuned RO installations the residual salt concentration can be too high. This makes Na accumulation and consequently occasional discharge a remaining problem.

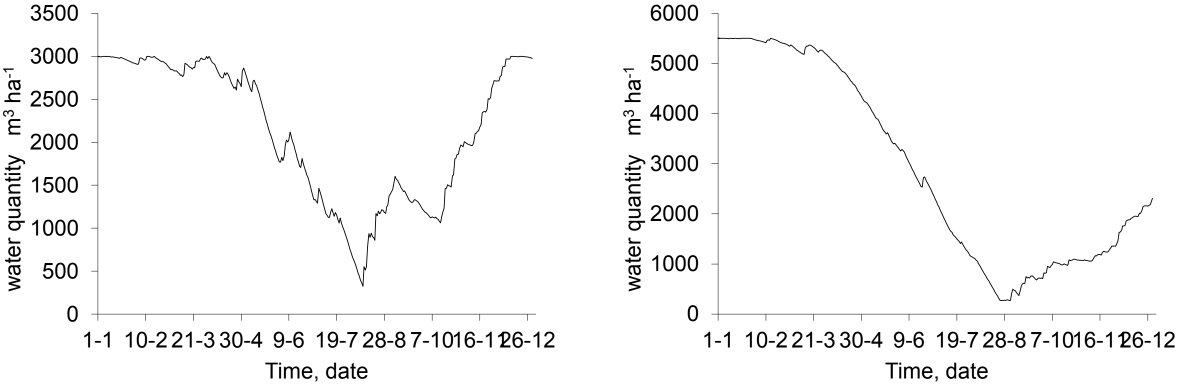

Figure 2 Required basin capacity (m^3 ha^{-1}) and available water (m^3 ha^{-1} day^{-1}) in a rainwater basin during a normal year (left) and an extreme dry year. Results of simulation for a year round tomato crop in closed system, with the model Watersteams *(Voogt et al, 2012).*

With the state of the art automation and monitoring, an uncontrolled EC or pH of the drainage should be no excuse for discharge, as being avoidable. This would be also true for mismatch of nutrients, if the right recommendations and frequent analysis are accomplished. This will be facilitated by hand-held analytical devices already in the market. With the development of continuous on-line nutrient determination, any mismatch of nutrients are no longer a problem. Moreover, it opens new perspectives for managing the crop nutrient uptake.

In the prevailing regulations for soil-less greenhouse crops in the Netherlands, the focus for reaching the WFD and ND targets was shifted from obligatory recirculation to emission targets going down to zero by 2027. So growers should make their own assessments how they will meet these targets today and in the coming years. Reduction the discharge of drainage water is inevitable. Some growers have to invest in alternative water sources to assure sufficient water of good quality, whilst others have to focus on disinfection with advanced techniques or elimination of growth inhibition factors. Nevertheless, there will always be a remaining quantity to be discharged. With advanced purification technologies all PPP's and even nutrients can be removed. However, it is questionable if these steps are economically feasible for individual growers. Clustering of greenhouse holdings and cooperation for the purification of water is probably more obvious. Implementation of a yearly gradual reduction of the N-emission norm urges the greenhouse industry and individual growers to develop innovations to maximise reuse of the drainage by solving problems that lead to discharge, and to purify the inevitable remaining discharged water.

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(11) Quantification of nutrient rich wastewater flows in soilless greenhouse cultivations

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Abstract: *Despite far-reaching recirculation of nutrient solutions, important nutrient enrichment of surface water is still frequently observed near greenhouses with soilless cultures of vegetables and ornamental plants. In order to quantify nutrient rich wastewater flows, 13 farms with greenhouse vegetable or ornamental crops are monitored intensively during a 2-year-period. Results of the first year (2012) show that only 25% of the soilless cultivation systems is completely closed and 92% of the farms where nutrient rich wastewater was generated, produced less than 50m³ per hectare. Only 1 farm produced up to 435m³ waste water due to frequent discharge of nutrient water because of accumulation of sodium. Important causes for the generation of nutrient rich wastewater are i)removal of nutrient water because of imbalance of nutrient elements, e.g. sodium and ii) wash water of filter systems. Imbalance of nutrient elements can be prevented when water of high quality i.e. containing little ballast salts is used. Therefore, rain water is advised as the best water source for recirculation systems. Recirculation of wash water is possible but in most situations requires a sedimentation step. The amounts of wash water can also be reduced by use of new techniques such as ECA-technology and SAF-filters. If a drainage system is placed beneath the greenhouse construction this drainage water can contain higher nutrient concentrations due to leakage of the recirculation system or historical enrichment of the soil by previous cultivation systems. Annual drainage water volumes can reach up to 100 m³ per hectare. Consequently, discharge of this drainage water can lead to important enrichment of the surface water. Based on the monitoring results, growers are advised on good fertigation techniques to prevent or significantly reduce the production of nutrient rich waste water flows.*

Keywords: *recirculation, closed system, wash water, sand filters, removal nutrient solution*

Introduction

In order to meet the European Water Framework Directive (WFD, 2000) a dense monitoring network was set up in Flanders to measure the impact of agriculture and horticulture influence on chemical water quality of surface water. At the start of the monitoring system, almost 60% of the monitoring points exceeded the limit of 50 mg/l nitrate at least once per year. These measuring points were indicated as “red points”. By 2010, the number of measuring points that exceeded the nitrate limit, had decreased to almost 32%. Europe demands that this number decreases to only 16% in 2014 and 5% in 2018. In 2011, the Coordination Centre for Information and Guidance for Sustainable Fertilization (CVBB) was established to identify the sources of nitrogen enrichment of surface water due to agriculture and horticulture activities. Despite far-reaching recirculation of nutrient solutions, important nutrient enrichment of surface water is frequently observed near greenhouses with soilless vegetable and ornamental crops. Actions of CVBB showed that in 10% of the red points there is an important or exclusive influence of soilless cultivation systems with direct discharge of nutrient rich wastewater into the surface water bodies. Especially in the summer period, when water levels in those water bodies are low, the impact of discharged nutrient rich water or wastewater can be high. Therefore, a 2-year demonstration project was established to identify and quantify nutrient rich wastewater flows present in horticulture. In the following step, the project aims to implement available actions and techniques to avoid discharge of these nutrient rich wastewater flows. In a last step, end-of-pipe solutions are listed. Possibilities of application of wastewater flows on grassland are examined. In addition, the implementation of an anoxic moving-bed bioreactor for purification of nutrient rich wastewater flows was examined for cases where a complete reduction of nutrient rich wastewater is impossible. In the following, the results of the quantification of wastewater flows are presented.

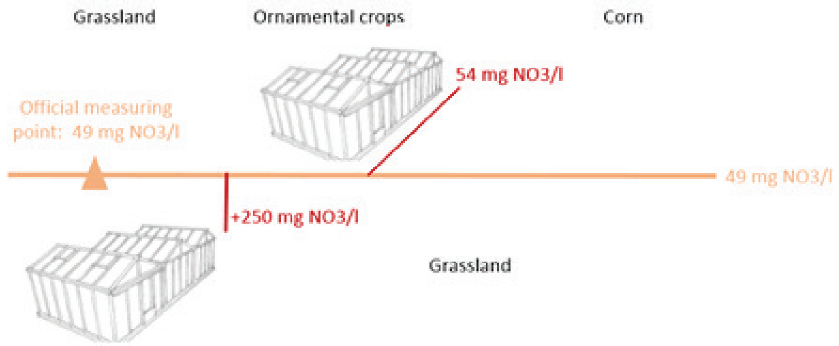

Figure 4 Overview of nitrate concentration of surface water upstream of the measuring point in March 2012. Measurements were carried out during rainfall. Although nitrate concentrations of surface water nearby the greenhouses is above 250 mg per litre, this does not influence the measurement at the official measuring point because of dilution by big amounts of water with a lower concentration (CVBB, 2012).

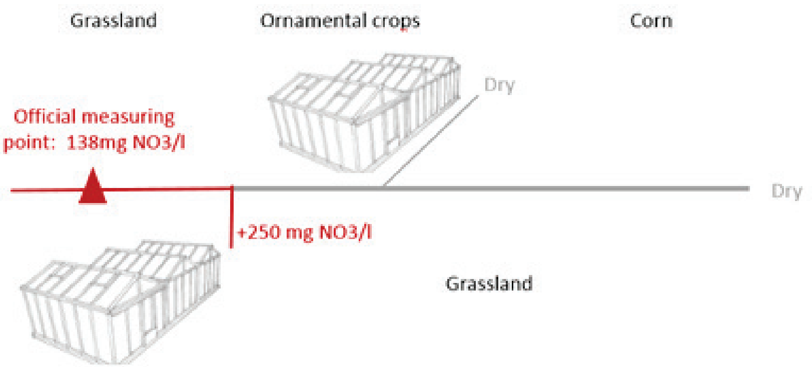

Figure 5 Overview of nitrate concentration of surface water upstream of the measuring point at April 2012 after a longer dry period. The nitrate concentration of surface water nearby the greenhouse is not diluted and therefore it influences the measuring point (CVBB, 2012).

Materials and Methods

To identify and quantify nutrient rich wastewater flows, 13 greenhouses with vegetable or ornamental crops are monitored intensively during a 2-year-period starting from June 2012. The group of monitored greenhouses exists of 10 greenhouses with soilless vegetables (6 greenhouses with tomato, 3 greenhouses with sweet pepper, 1 greenhouse with cucumber) and 3 greenhouses with potted plants (azalea and gerbera). Selection criteria include the presence of new techniques that lead to lower wastewater production (e.g. SAF-filters or Electro Chemical Activation – ECA – technology), presence of flow meters, characteristics of used water sources. Characteristics of the different greenhouses are summarized in Table 2. Flow charts were established for each greenhouse and discussed with the growers. Possible wastewater flows were indicated and, if necessary, additional flow meters were placed to measure nutrient rich wastewater flows. Water use and nutrient rich wastewater production were registered on a monthly base. Additional water samples were taken to establish the nitrate concentration of different wastewater flows.

Table 2 Characteristics of the monitored greenhouses

Greenhouse	Greenhouse (Ha)	Cultivation system (1)	Watersources (2)	Substrate (3)	Desinfection systems (4)	Filter systems (5)	Point of interest for project
Tomato 1	2,8	DW	RW, GW	RW	H	FSF	Use of groundwater, recirculation of wash water
Tomato 2	9,1	G	RW,GW	RW	H	FSF	No wastewater production
Tomato 3	3,6	G	RW	RW	UV	SFSF, SAF	Use of SAF-filter, recirculation of wash water
Tomato 4	3,2	DW	RW	RW	UV	FSF, MMF	Recirculation of wash water
Tomato 5	1,2	G	GW	RW	SSF	SSF	Use of groundwater
Tomato 6	3,5	G	RW	RW	UV	FSF	No wastewater production
Cucumber	1,2	DW	GW	RW	UV	FSF, MIF	Use of groundwater
Sweet Pepper 1	2,2	DW	RW	RW	-	FSF	Recirculation of wash water
Sweet Pepper 2	7,0	DW	RW, GW	RW	ECA	SAF	Use of ECA and SAF-filter
Sweet Pepper 3	4,4	DW	RW, GW	RW	ECA	FSF	Use of ECA
Azalea	3,8	CF	RW, GW	P	UV	FSF	
Gerbera	0,8	G	GW	CC	ECA	FSF	Use of ECA and groundwater
Potted Plants	2,0	EF	RW	P	ECA	-	Use of ECA

(1) Cultivation system: G = gutters, DW = drainwater tube, EF = eb and flood, CF = containerfield
(2) Water sources: RW = rain water, GW = ground water, TW = tap water
(3) Substrate: RW = rockwool, CC = coconut, P = peat
(4) Desinfection: UV = Ultraviolet , SSF= slow sand filter, ECA = Electro Chemical Activation technology, H = heating
(5) Filter systems: SSF = slow sandfilter, FSF= fast sandfilter, MMF = multimedia filter, MIF = microfilter, SAF = automatically cleaning filters

Results and discussion

Figure 3 gives an overview of the annual nutrient rich wastewater production per hectare for each greenhouse. The variation between farms is remarkable. Only 25% of the observed soilless cultivation systems seemed completely closed. At 9 of the observed greenhouses, an annual wastewater production below 25 m³/ha was assessed. Two greenhouses had an annual wastewater production between 25 and 50 m³/ha. Greenhouse Tomato 5 produced up to 435 m³/ha wastewater. Important sources of wastewater are 1) discharge of nutrient recirculation water due to imbalance of nutrient compounds, 2) nutrient wash water of filter systems, 3) discharge due to technical malfunctions, 4) removal of drain water at the end of the season and 4) rinse water of the irrigation system containing nitric acid. Results of the first year show that production of nutrient rich wastewater can occur occasionally (e.g. rinse water of the irrigation system) to daily (e.g. wash water of filter systems).

In most cases, sodium accumulation was decisive for discharge of nutrient water out of the recirculation system. Figure 3 shows a high variation in discharged volume from only 2 to 435 m³/ha. Due to structural problems of rain water storage, greenhouse 'Tomato 8' had to use 100% of ground water – containing high sodium concentrations – for irrigation, which is reflected in the amount and frequency of nutrient water discharge. Nitrate concentrations of discharged water are identical to those of drain water.

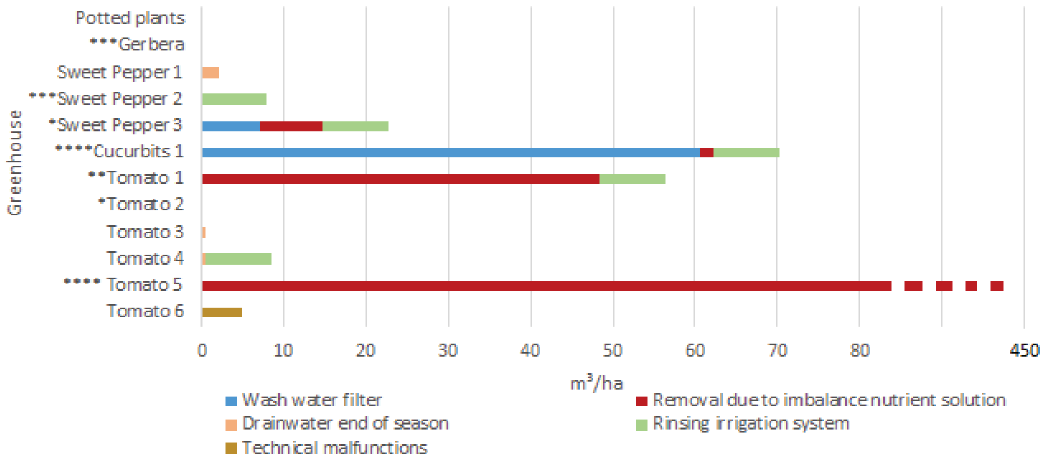

Figure 6. Overview of the annual nutrient rich wastewater production of the different wastewater sources in m³ per ha for each greenhouse. The use of groundwater is indicated by an asterix:* = less than 20% use of groundwater, ** = 20-50%, ***= 50-75%, **** 75-100%.

Table 3. Average nitrate-N and nitrate content of drain water samples of tomato, cucumber and sweet pepper (S. Deckers, 2009)

	NO_3-N concentration (mg/l)		NO_3 concentration (mg/l)	
	Average	Standard deviation	Average	Standard deviation
Tomato	413	125	1825	553
Cucumber	284	98	1255	433
Sweet pepper	307	90	1357	398

Wash water of filter installations

Greenhouse 'Tomato 5' did not produce any wash water due to the well functioning slow sandfilter system installed on the farm. The remaining 12 greenhouses produced nutrient wash water on a daily to weekly basis (Figure 4). Production of nutrient rich wash water was registered in 8 of the 13 greenhouses. The amount of produced wash water is influenced by many factors including 1) the present filter- or desinfection system, 2) washing settings, 3) concentration of floating particles in the water source, and 4) filter capacity.

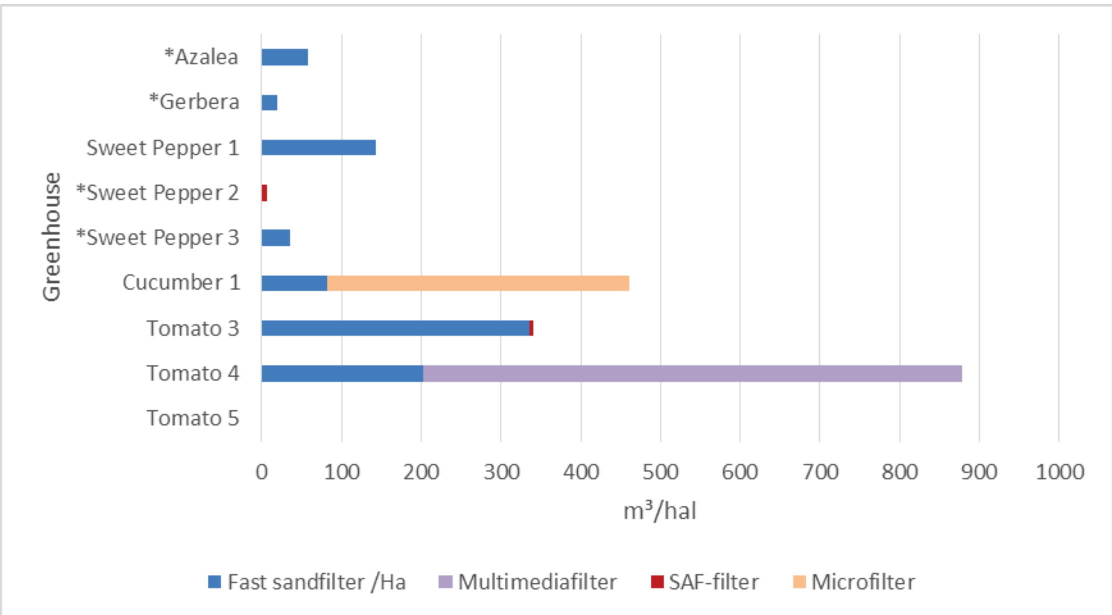

Figure 7. Annual nutrient wash water production of filters in m³ per hectare for different filters systems and greenhouses. Greenhouses with ECA technology are indicated by an *.

Dispite this high variation, automatic cleaning filters like SAF-filters clearly generate less wash water than other filter systems. The use of ECA leads to lower wash water production because organic pollution like fragments of biofilms are reduced and filters need to be back washed less frequently. Only 2 of the greenhouses still discharge wash water from their filter system. The discharged annual volumes of wash water were respectively 7 and 36 m^3/ha, which are relative small volumes compared to those produced by the other greenhouses. The 10 remaining greenhouses reuse their wash water, sometimes after a sedimantation step (Figure 5). Daily wash water production volumes of up to 3 m^3/ha were registered. Nitrate concentration of wash water was measured for washing of sand filters of soilless cultures of vegetables. Samples were allways collected in sedimantation pits and had an average concentration of 360 mg nitrate per litre.

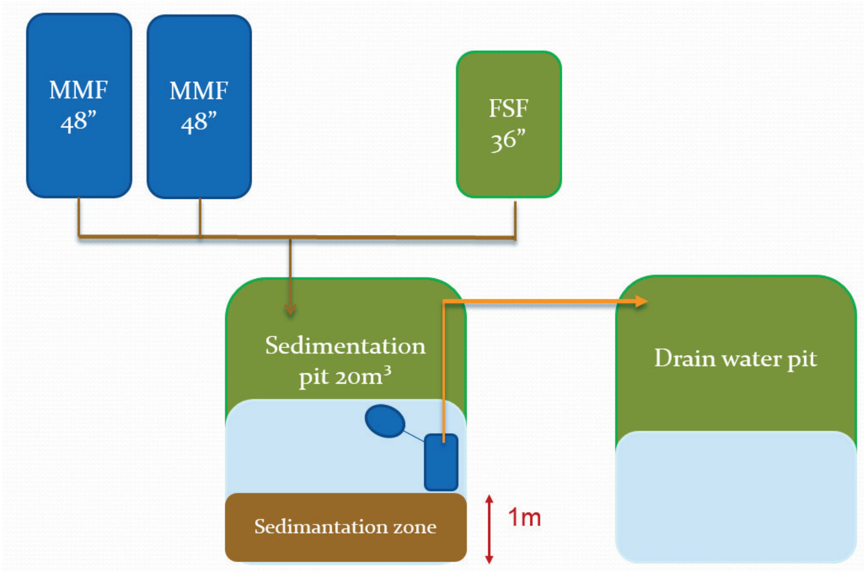

Figure 8. Recirculation of wash water of filter systems as present in greenhouse ‘Tomato 3’. Wash water flows in a sedimentation pit and, after 20 hours, is pumped in the drain water pit. The pump is placed 1 meter above the bottom of the pit to avoid suction of sediment.

Removal of remaining drain water at the end of the season still occurs at 3 of the 13 observed greenhouses. At some of the greenhouses, nutrient water is removed by external companies. Volumes varied from 2 to 5 m^3/ha and nitrate concentration is comparable to that of drain water. For disinfection of the drip systems, 5 of the 13 greenhouses still used nitric acid. On average, 8 m^3/ha rinsing water – with an average concentration of 625 mg N per litre – was used.

Discharge of nutrient water due to technical malfunctions

At 3 of the 13 greenhouses discharge of nutrient water occurred due to technical failure of pumps or filter systems. The amounts of discharged water varied from 1 to 48 m^3/ha. Structural malfunctions of rain water basins or storages caused indirect waste water production, as more groundwater had to be used and sodium accumulation occurs. In 2012, rainwater use was completely impossible in 2 greenhouses, while storage capacity for rainwater had decreased to only 45% in a third greenhouse.

Drainage water

Nitrate concentration of drainage water was registered in the greenhouse ‘Sweet pepper 1’. Drainage water is defined as water from a ground water collection system under the greenhouse. Normally, drainage water is collected when the ground water table reaches the level of the collection system. Drainage water should not be confused with drain water which is the term used for redundant nutrient water. In Figure 6, the evolution of nitrate concentration in drainage water is presented. The measured nitrate concentration occasionally exceeds the limit of 50 mg per litre. Although drainage water amount was not registered, measurements of drainage water production beneath a nearby greenhouse with comparable conditions indicated annual drainage volumes up to 1000 m^3/ha.

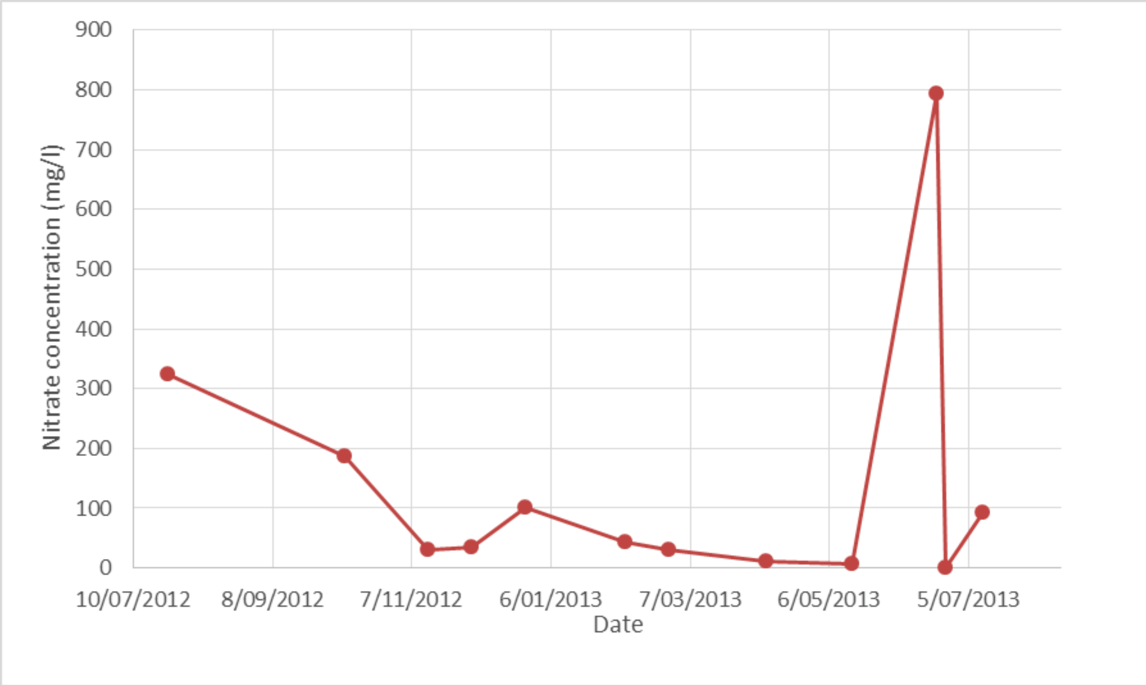

Figure 9 Evolution of the nitrate concentration of drainage water beneath greenhouse 'Sweet Pepper 1'. The limit value of 50 mg/l is exceeded several times during the last year.

Conclusion

Despite far-reaching recirculation of nutrient solutions, important nutrient enrichment of surface water is still frequently observed near greenhouses with soilless cultivation systems. Only 25% of the observed greenhouses was found to be completely closed. The origin and volumes of nutrient rich wastewater flows is very specific for each greenhouse. In 90% of the observed greenhouses, waste water production was below 25 to 50 m³/ha. Important nutrient rich wastewater sources are removal of nutrient water due to imbalance of nutrient elements like sodium and wash water of filter systems. Imbalance of nutrient elements can be prevented when water of high quality is used. Therefore, rain water is the best water source for recirculation systems. Consequently, sufficient rain water storage is necessary and special attention is needed for structural health of the water storage. Recirculation of wash water is possible but requires a sedimentation step in most situations. The amount of wash water can be reduced using new techniques like ECA-technology and SAF-filters. In almost 50% of the greenhouses, nitric acid was used for rinsing the irrigation system. Also here ECA-technology can be an interesting alternative. At 25% of the observed greenhouses, nutrient rich wastewater was discharged due to technical malfunctions.

If a drainage system is present under the greenhouse, this drainage water can contain higher nutrient concentrations due to leakage of the recirculation system or historical enrichment of the soil by previous cultivation systems. This drainage water can cause important nutrient enrichment of surface water. When drainage water contains higher nitrate concentrations, it should be recycled or purified in order to avoid nutrient enrichment of surface water.

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S. Deckers; Bodemkundige Dienst België

(12) Improving irrigation and nitrogen management in California leafy greens production

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Abstract: *The Salinas Valley, located on the coast of central California, is the most intensive leafy greens production region of North America. Lettuce, broccoli, cauliflower, celery and spinach production occur nearly year around, with two or more crops produced annually in most fields. This intensive cropping schedule minimizes the use of catch crops. Consequently, nitrate loss from vegetable fields represents a serious threat to environmental water quality. In more than a decade of N management research we have collected extensive data on N cycling in this vegetable production system, and have developed and demonstrated improved irrigation and fertilization practices that reduce environmental N loading. To aid in the adoption of these more efficient practices an on-line tool, called CropManage, has been developed. The software estimates irrigation and N fertilizer requirements on a field-by-field basis. The grower provides baseline information (field location, soil type and planting date), and inputs fertilizer and irrigation data as the crop progresses. The N fertilizer algorithm generates recommendations based on the crop N uptake requirement, current soil* NO_3*-N status, and estimated soil N mineralization. The irrigation scheduling algorithm uses real-time reference evapotranspiration data, crop coefficients based on the planting configuration, and soil water holding characteristics to estimate the appropriate irrigation interval and volume of water to apply. CropManage was evaluated by growers in 10 commercial lettuce fields in 2012, and their assessments have been used to improve the functionality of the tool.*

Introduction

The Salinas Valley of California produces > 90,000 ha of leafy green vegetables annually, with lettuce (Lactuca sativa L.) dominating crop rotations (> 50,000 ha). Intensive, nearly year around production of leafy vegetables, with minimal use of catch crops, has resulted in significant NO_3-N degradation of both surface water and ground water. Extensive research has been done on irrigation and N fertility management of lettuce in this region (Bottoms et al., 2012; Breschini and Hartz, 2002; Gallardo et al., 1996; Hartz et al., 2000). The use of two management practices, pre-sidedress soil nitrate testing and evapotranspiration (ET)-based irrigation scheduling, has been shown to dramatically improve N use efficiency and limit N loss to the environment. To date, adoption of these practices has been slow. Among the reasons for slow adoption is the significant management time required to generate and evaluate the required field data, and to integrate irrigation and fertilization events into the complex set of field operation required to grow these crops. It is much easier for busy farm managers to implement standardized, calendar-based irrigation and fertilization schedules. However, pending regulatory action by the regional Water Quality Control Board is providing an incentive for growers to improve their management practices to limit nitrate loss.

We are developing an online tool to assist growers in determining appropriate water and nitrogen fertilizer applications on a field-by-field basis. The software automates steps required to calculate crop water needs from reference evapotranspiration (ETo) data, and estimates the fertilizer N requirement of lettuce using soil NO3-N data and modeled crop N uptake. The web application also helps growers track irrigation schedules and nitrogen fertilizer applications on multiple fields and allows users from the same farming operations to view and share records.

Methods

In collaboration with the University of California Agriculture and Natural Resources (UCANR) Communication Services personnel, we launched a preliminary version of a web-based software program for managing irrigation and nitrogen fertilization in lettuce production on Sept 1, 2011. The software application, named CropManage (*https://ucanr.edu/cropmanage/login/*), is hosted and maintained on the UCANR Communications server in Davis, CA. Using a web browser, users can access the software through smart phones, tablet and desktop computers.

CropManage was designed to be intuitive for growers and farm managers to use. The user interface and menu structure were designed and developed in consultation with collaborating growers, and follows common practices that they use to maintain records of fertilizers, soil tests, and irrigation. The web application uses a secure login procedure so that only individuals with permission can view and/or edit water and nitrogen fertilizer records of a particular farming operation. After logging on, a screen displays a list of ranches/farms that the user has permission to access. By following the hyperlink for an individual ranch, the user can view a list of all active and/or past plantings associated with the ranch.

A database manages information associated with ranches, fields and plantings, which are used to drive the irrigation and N fertilizer models. The database also facilitates combining and displaying data from multiple sources such as user entries, California Irrigation Management Information System (CIMIS, *http://wwwcimis.water.ca.gov/cimis*) weather stations, and field sensors. It also minimizes the necessity for reentering information. To establish a new ranch, data must initially be uploaded, which includes lists of field names, associated acres and soil types, as well as a list of nearest CIMIS stations. Each ranch in CropManage requires one user to serve as a "virtual farm manager" who has administrative responsibility to grant other users permission to view and/or edit ranch data and also to customize settings for the ranch. To add a planting (new crop) to a ranch, one selects the appropriate field, and enters lettuce type, planting/harvest dates, planted acres, bed spacing, and irrigation system characteristics. The planting "home" screen displays summary tables of soil tests, fertilizer applications, and watering schedules. When the user enters intended dates to fertilize and/or irrigate, the summary tables are updated with recommended fertilizer N rates (Table 1) and water volumes (Table 2). Data in tables can be exported into an excel spreadsheet file.

Table 1 Example fertilization summary table displayed in CropManage.

Date	Event	Soil NO_3-N test value (mg kg^{-1})	N fertilizer recommendation (kg ha^{-1})	Actual application: Fertilizer type	Fertilizer amount (liters ha^{-1})	Kg N ha^{-1} applied
5/06/12	1st sidedress	10	41	15-8-4	190	80
5/24/12	1st drip fertigation	20	5	28-0-0-5	57	52
5/29/12	2nd drip fertigation	22	11	28-0-0-5	38	35
6/09/12	3rd drip fertigation	26	0	28-0-0-5	38	35
6/11/12	4th drip fertigation	26	0	28-0-0-5	19	18
6/16/12	5th drip fertigation	20	53	20-0-0	38	24
Total			110			244

Table 2 Example irrigation summary table displayed in CropManage.

Date	Irrigation method	Recommended irrigation interval (days)	Recommended irrigation duration (hours)	Recommended irrigation amount (cm)	Actual water applied (cm)	Crop ET (cm)
04/19/12	sprinkler	N/A	N/A	N/A	2.2	--
04/21/12	sprinkler	1	1.1	0.8	1.3	0.6
044/23/12	sprinkler	1	1.1	0.9	1.5	0.6
04/27/12	sprinkler	3	0.8	0.6	1.6	0.5
04/29/12	sprinkler	1	1.0	0.8	1.3	0.6
05/09/12	sprinkler	5	1.2	0.9	3.7	0.8
05/24/12	drip	7	5.3	2.0	3.0	1.8
05/29/12	drip	7	3	1.1	1.9	1.0
06/03/12	drip	5	5.1	2.0	2.7	1.8
06/09/12	drip	4	6.4	2.4	2.8	2.5
06/15/12	drip	4	9.2	3.5	1.9	3.2
06/19/12	drip	4	6.3	2.4	2.0	2.1
06/23/12	drip	4	5.5	2.1	2.3	1.9
06/26/12	drip	4	4.2	1.6	1.3	1.4
Total				21.2	29.5	18.9

CropManage also has the option of automatically importing, analyzing, and displaying flow meter data, allowing growers to conveniently track the volume of water applied to their fields. Flow meters capable of producing a voltage pulse output proportional to the flow rate are interfaced with a datalogger that records flow at 2 minute intervals. The dataloggers are equipped with internet cell phone access, which permits flow data to be downloaded onto a computer in the Monterey County, Cooperative Extension office. The ANR server in Davis is scheduled to upload and analyze flow meter data files from the county computer four times per day. Because of the complexity involved, we foresee that a service such as an irrigation mobile lab or crop consultant would set up the flow meters in commercial fields for growers.

In addition to storing and displaying records of soil tests, irrigations, and fertilizations, the software algorithms recommend N fertilizer rates and water applications appropriate for the stage of lettuce growth. The N fertilizer algorithm develops recommendations based on an N uptake curve for lettuce (Bottoms et al., 2012), current soil NO_3-N concentration (top 30 cm depth), as well as estimated soil N mineralization. Future work will incorporate NO_3-N concentration of the irrigation water into the N fertilizer recommendation. To create a fertilizer recommendation, the user must enter the intended fertilization date, a soil NO_3-N value, and estimated days until the next fertilization event. The model uses this information to determine the amount of N fertilizer needed to maintain the soil at a predefined threshold of soil nitrate. The soil nitrate threshold varies from 20 ppm NO_3-N at the early stages of growth to 15 ppm NO_3-N later in the crop.

The irrigation scheduling algorithm uses CIMIS ET_o data, crop coefficient values for lettuce, soil water holding capacity, and the application rate of the irrigation system to estimate the appropriate irrigation run time and volume of water to apply to maximize lettuce growth and minimize deep percolation. The algorithm is based on the canopy model of Gallardo et. al. (1996) for estimating evapotranspiration of lettuce:

$$\text{Canopy cover (\%)} = \text{Gmax}/(1 + \exp(A + B\times \text{day}/\text{Maxday}) \qquad \text{eqn. 1.}$$

where Gmax is the maximum canopy cover, A and B are fitted parameters in Table 3, day is the number of day after planting and Maxday is the total days between planting and harvest. Parameters for this model were determined for iceberg and romaine lettuce types grown on 40 and 80-inch wide beds by taking overhead near-infra red canopy photos in numerous fields at 10 to 15 day intervals during the crop cycle.

Table 3 Parameters for estimating canopy cover (eqn. 1) for various lettuce types and planting configurations.

Bed width	Lettuce	Plant rows	Number of	Model coefficients			
(cm)	type	per bed	fields monitored	Gmax (% cover)	A	B	R^2
100	iceberg	2	7	83	6.78	-11.61	0.77
200	iceberg	5	2	92	6.83	-12.77	0.93
200	iceberg	6	2	89	8.23	-14.11	0.97
100	romaine	2	2	85	3.88	-7.68	0.94
200	romaine	5	3	86	7.07	-10.73	0.96
200	romaine	6	7	82	7.06	-10.95	0.94

Canopy cover is converted to a crop coefficient (K_c) by a modified version of the equation published by Gallardo et al. (1996):

$$K_c = (0.63+1.5\,C - 0.0039C^2)/100 \qquad \text{eqn. 2.}$$

where K_c is the crop coefficient, ranging between 0 and 1, and C is percent canopy cover. Evaporation from the soil surface is also estimated by the method described by Gallardo et al. (1996) and used to develop the final K_c value.

To obtain a recommended irrigation volume and interval, the user enters the date of the next irrigation and the software automatically obtains ET_o data from the nearest CIMIS weather station and uses the algorithms described above to estimate the crop coefficient. Historical ET_o data are used when current data are unavailable. The software also allows a grower to use reference ET_o data from the 'spatial CIMIS' feature of the CIMIS network; this feature estimates ET_o at specific GPS locations through interpolation of data from nearby weather stations (Hart et al., 2009). The recommended irrigation volume is based on the estimated crop ET adjusted for irrigation system uniformity and the desired leaching fraction, which are initially set by the grower.

Maximum soil moisture tension values known to slow growth of lettuce (-30 kPa) are used to optimize the recommended irrigation interval. The maximum allowable depletion of moisture between irrigations is determined using algorithms relating volumetric soil moisture to soil moisture tension and for estimating rooting depth.

Results

We evaluated the CropManage software in 10 commercial lettuce fields during the 2012 production season. Portable flowmeters were installed on the main irrigation pipe in each of these fields so that the grower could view the volume of water applied during individual irrigation events, and compare actual and recommended volumes of applied water. Participating growers were responsible for monitoring soil nitrate levels of their fields, mostly using the quick nitrate test (Hartz, 1994), and entering these values and fertilizer applications amounts into CropManage. Participants provided assessments of the software application that were used to improve the ease-of-use and the functionality of the online tool. We also conducted 2 demonstration trials comparing yield of lettuce grown under standard and CropManage recommended water or nitrogen management practices. One trial comparing the CropManage fertilizer N recommendation with the grower standard practice resulted in similar commercial yields using almost 30% less N fertilizer. The other trial comparing the irrigation recommendation of CropManage with the grower standard practice resulted in a 12% savings in water following the CropManage irrigation schedule during the drip irrigated phase of the crop, and equal commercial yields between treatments.

Conclusions

Web-based software appears to be a useful tool for delivering decision support models to growers in a format that they can use for their daily operations, and provides a rapid means to extend new research findings to the agricultural community. Our preliminary work has demonstrated that CropManage can potentially help growers reduce production costs by applying less fertilizer and water, and minimize environmental water quality impacts of vegetable production. The software tool also provides a convenient means for growers to keep records of their practices, which may help them demonstrate that they are meeting water quality regulatory objectives. Our immediate challenge is to expand CropManage to include all the major vegetables crops produced in this region. As more geo-referenced weather and soil data become available on the web, the accuracy of models for guiding cropping decisions can be improved. We are working to better integrate soil survey and remote sensing data into future versions of CropManage.

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(13) Anoxic Moving-Bed BioReactor (MBBR) and phosphate filter as a robust end-of-pipe purification strategy for horticulture

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Abstract: *Throughout Europe, the wide application of soluble fertilizers gives rise to a wastewater-related nutrient problem in the greenhouse industry. When 'closing the loop' with the aid of water and nutrient management strategies is impossible, only an end-of-pipe solution remains to solve this global environmental problem. In this paper, the development of a combined system comprising an anoxic Moving Bed BioReactor (MBBR) and a phosphate adsorption filter was studied as a possible alternative for the disposal of nutrient-rich wastewater on grassland. The most important operational parameters of these purification technologies have been examined in detail with the aim to guarantee a high nutrient removal efficiency. For the anoxic MBBR process, the removal efficiency during winter operation and the influence of the type of carbon source was thoroughly investigated. For the optimal operation of the phosphate chemisorption process main attention was paid to the influence of the influent pH and the introduction of intermittent periods of rest, in order to maximize the adsorptive capacity of the iron grains.*

Keywords: *Denitrification, chemisorption, nitrate uptake rate,*

Introduction

The agricultural use of nitrates has been a major source of water pollution in Europe. To limit their emission, the EU issued the Nitrates Directive (1992), which has subsequently been integrated in national legislations by the member states. In response to this Directive, vulnerable zones were established, in which the standard of 11,3 mg NO_3-N/l is exceeded. In some regions a correlation exists between the presence of greenhouses (often soilless crops) and exceedances of the nitrate standard in surface water. A way to limit the emission of nitrates in the environment is the use of good farming practices to avoid the production of nutrient-rich wastewater but this is not always possible. In Belgium the generated wastewater can be applied on grassland but growers do not always have sufficient grassland available. In this case, an end-of-pipe treatment is the only alternative.

The anoxic denitrification used in this study is based on the Moving-Bed BioReactor (MBBR) technology. In an MBBR, plastic carriers that provide a surface area for biofilm development, are kept in constant motion in the solution. This results in a compact installation with a limited growth of biomass. The choice for this type of installation is driven by the fact that denitrifying biofilms are generally preferable above suspended biomass because of an optimization of the bioreactor's active volume and the avoidance of sludge settling problems (Dupla et al., 2006). Moreover, MBBR installations possess intrinsic advantages over other typical biofilm-based systems. For example, trickling filters are not volume-efficient, rotating biological contactors often suffer from mechanical problems, and fluidized bed reactors exhibit hydraulic instability. The MBBR technology has already been widely studied for the treatment of both municipal and industrial wastewater, and also in particular for the denitrification of water from marine aquariums (Dupla et al., 2006). Also, a lot of effort was put in the dynamic modelling of Moving Bed Bioreactors, e.g. by Plattes et al. (Plattes et al., 2006, Plattes et al., 2007 and Plattes et al., 2008) and Lin (Lin, 2007). The usefulness of the MBBR technology for the denitrification of high-strength nitrate wastewater was studied at an industrial relevant scale by Aspegren et al. (Aspegren et al., 1998) and Chudoba et al. (Chudoba et al., 1998). The study of Chudoba et al. (1998) confirms a nitrogen removal efficiency beyond 80% at a loading rate of 0.6 kg NO_x-N/m^3. It can therefore be concluded that the MBBR technology may offer a market-ready solution for the high nitrate concentrations that are found in the nutrient-rich wastewater of horticulture companies.

In addition to the presence of high nitrate concentrations (250 mg NO_3-N /l), also moderate PO_4-P concentrations (< 25 mg PO_4-P/l) are expected in the nutrient-rich wastewater from horticulture, which also needs to be removed. Often metal salts are dosed to wastewater to precipitate ortho-phosphate as an insoluble salt. A major drawback of this treatment technique is the dependency of the optimal metal salt dosage on the influent PO_4-P concentration. Therefore, in this paper, a technology based on phosphate adsorption was applied as a technically simple alternative. It concerns a specific chemical adsorption (or also called chemisorption) process. In general, a solid adsorption process requires less post-processing compared with a conventional physicochemical phosphate removal process, for which a highly efficient separation of the formed phosphate sludge is still necessary. The adsorbent applied in this research is granular iron with a sand core. This material is derived from rapid sand filters used for the deferrization in the production of drinking water from groundwater, and is considered as a solid waste product for the drinking water company. During the quick sand filtration process, the iron grain is formed through the adsorption of Fe(II) onto the sand core, and in the presence of oxygen the adsorbed Fe(II) is in situ oxidized to Fe(III) (= the adsorptive removal of iron from the groundwater). At the same time also a biological deferrization can take place. During the biological deferrization, Fe(II) is oxidized biologically and, thereafter, it is intra-cellular or extra-cellular precipitated. In this way, a deposition of Fe(III) compounds occurs onto the sand core, which steadily grows. The grain diameter will thus increase with time, resulting in an increasing height of the sand bed. Periodically, part of the granules have to be removed from the sand bed and are discharged as solid material. This iron beads are also called iron oxide-coated sand (IOCS) and can be used for adsorption of a variety of pollutants (e.g. arsenic and phosphate) from wastewater (Sperlich, 2010). Moelants et al. (2010) already demonstrated the potential of iron-rich grains from industrial deferrization installations to adsorb phosphate from municipal wastewater on laboratory scale. In this study the feasibility of the use of a combined anoxic biological denitrification reactor and a phosphate filter to treat nutrient rich (especially nitrogen an phosphorous) so that the treated water meets the environmental standard and can be discharged in the surface water. The most import research objective of this paper is to translate lab scale experience to good practices and optimal working conditions for industrial scale applications.

Materials and Methods

Phosphate and nitrate analysis

Phosphate concentration was measured by the ascorbic acid method in accordance to the procedure set by the United States Environmental Protection Agency (EPA). Nitrate concentrations were monitored with an ion selective electrode (Hach Lange, type IntelliCAL™ ISENO3181) and some samples were analyzed by a HPLC based method to verify the anion and cation composition of the water.

MBBR technology on lab scale

The denitrification reaction was characterized by a nitrate recording test run during which the nitrate uptake rate is measured as a function of time (Ekama et al, 1986). This Nitrate Uptake Rate (NUR) batch test is often carried out in a temperature controlled (20°C), stirred reactor on a laboratory scale, in which a known volume of activated sludge is brought into contact with a carbon source and nitrate-nitrogen, and this without the addition of oxygen. The decrease in concentration of nitrate-nitrogen is followed in time. In a conventional NUR-test, the COD present in the wastewater itself is used as a carbon source for denitrification. In our experimental work, two frequently used external carbon source were used, i.e. sodium acetate and molasses. The denitrification process is often divided in three separate phases as a function of the time (Sage et al., 2006)

1. In a first phase, the maximum rate of denitrification is achieved by the consumption of rapidly degradable COD (S_S) as the electron donor.
2. In a second phase, the slowly biodegradable COD (X_S) fraction is used. At this stage, it is clear that the rate of denitrification is substantially lower than in the first phase.
3. In the last phase, comprises the so-called endogenous denitrification in the absence of a carbon source.

The experimental set-up for the anoxic titrimetric biosensor in this paper is similar to the one described in Petersen et al., 2002. The pH in the denitrification reactor is kept constant between 7.1 and 7.15 by a pH-STAT titration in which hydrochloric acid (0.05 M) is dosed. A double-walled reactor of 1 l is kept at a constant temperature of 20 °C by circulating cooling water through the double wall jacket of the reactor. To evacuate all CO_2 formed during the denitrification process; the reactor is flushed with nitrogen gas (0.5 l/min) by a diffusor during the whole experimental period. Plastic carrier elements of the type AnoxKaldnes™ (K3) are used instead of activated sludge, which is usually used in the classical NUR experiments. 40 AnoxKaldnes^{TM} carrier elements were circulated in the reactor of 1 litre (= 30%) by a 200 l/h submersible circulation pump. In order to ensure a sufficiently high denitrifying active biomass concentration at the surface of the plastic carriers, they were sampled from the pilot MBBR plant in which they were allowed to generate a full-grown denitrifying biofilm for at least 2 weeks.

Phosphate adsorption experiments on lab scale

Two types of laboratory test where performed to characterize the adsorption capacity of the used iron grains with sand core. First the Langmuir and Freundlich adsorption kinetics were determined by simple batch tests in which 10 g of granular substrate material (S) was brought in contact with 100 mL samples with different PO_4-P concentrations between 10 and 3000 mg PO_4-P/l.

Langmuir equation: $q_t \approx q_{t,MAX} \frac{bC_A}{1+bC_A}$ and after linearization: $\frac{C}{q_t} = \frac{1}{q_{t,MAX}} C + \frac{1}{b.q_{t,MAX}}$

Freundlich equation: $q_t = \frac{X}{M} = Kf * C^{1/n}$ and after linearization: $\ln(q_t) = \frac{1}{n}\ln(C) + \ln(Kf)$

q_t: adsorption capacity [g P/kg S]

$q_{t,MAX}$: maximum adsorption capacity [g P/kg S]

b: the Langmuir constant expressing the affinity of the substrate for P [l/mg]

C: the equilibrium phosphorus concentration in the solution [mg P/l]

X: mass of adsorbed component [g P]

M: adsorbent mass [kg S]

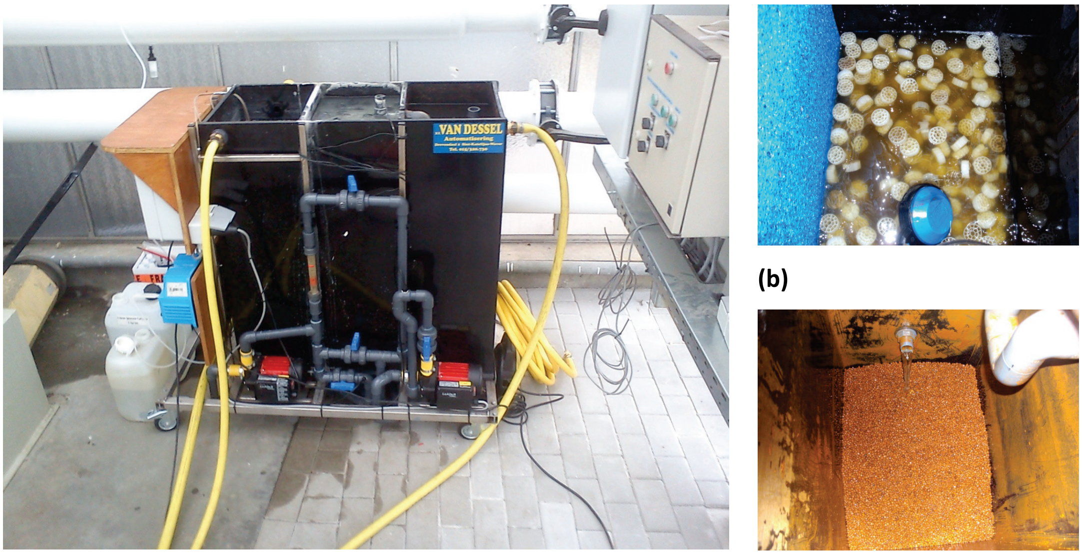
K_f: Freundlich constant for a given adsorbate and adsorbent

n: Freundlich constant for a given adsorbate and adsorbent

Afterwards, laboratory scale column experiments were performed to verify the kinetics and determine the influence of some operational parameters on the breakthrough time of the column. Each column was filled with a predetermined mass of dry iron grains and was fed with a phosphate solution with a concentration of 25 mg P-PO_4 /l via a membrane pump with adjustable flow rate.

Pilot plant MBBR and phosphate filter

The pilot plant installation used in this study consists of three separate reactors, which are operated in a semi-batch mode. The first reactor operates as a buffer tank, in which the influent water was sampled. The second reactor is the MBBR denitrification reactor and has a total volume of 120 l of which 20% (by volume) is filled with the AnoxKaldnes™ carrier elements. This is approximately equivalent to 25 carrier elements per litre of reactor volume. A pump ensures the constant circulation of the plastic elements in the liquid of the reactor. Because of the lack of readily biodegradable COD in the influent the addition of an external carbon source for denitrification is necessary. A sodium acetate based commercial carbon source (BIOAid®, Dow Chemical Company) is used and is dosed at a 5 mg COD/mg NO_3-N ratio in the MBBR. To compensate the H^+ consumption during the denitrification reaction, the pH is kept constant at 7.3 – 7.5 by addition of HCl (5%). After 4 hours the water is gravimetrically transported from the MBBR to the phosphate filter by a PLC controlled valve, which periodically opens for 15 min. In this way every 4 hours, 40 l of denitrified wastewater flows to the phosphate filter, resulting in a daily average flow of 240 l. The phosphate filter consists of granular iron with a sand core and contains about 30 kg (dry weight) of this material. At the bottom of the reactor, the granular filter material is supported by a plastic filter medium. To prevent clogging of the filter, the system is periodically aerated with a low-pressure air blower. An overview of the mobile pilot plant is provided in Figure 1.



(b)

(a) (c)

Figure 1: (a) Overview of pilot plant with anoxic denitrification on the basis of a Moving-Bed BioReactor (MBBR) and a phosphate filter. (b) Top view MBBR. (c) Top view phosphate filter.

Results and discussion

The denitrification kinetics of the MBBR technology were investigated based on the pH-STAT laboratory experiments and maximum denitrification rates of 80 mg NO_3-Nl ·h were reached. These values are high, compared to typical denitrification on the basis of activated sludge. Based on the experimental data reported by Sage et al. (2006), a maximum denitrification rate of 25 mg NO_3-N/(l·h) is expected from NUR experiments with acclimatized activated sludge. Because the wastewater only contains a limited concentration of COD, a considerable amount of external carbon source should be added. Several carbon sources were investigated on laboratory scale (results not included). Eventually, a commercially available carbon source based on acetate was selected as the most cost-effective alternative. In Figure 2 the denitrification rates when using molasses and sodium acetate as a carbon source are compared with each other at a COD/NO_3-N ratio of 5. The higher denitrification rates generated by the acetate can be explained by the biological degradability of both substrates. The simple chemical structure of acetate leads to readily degradable COD and this in contrast to the more complex chemical structure of molasses, resulting in a slower biodegradability. Also, the effect of reduced temperature during the winter months (Figure 3) and the filling grade of the MBBR (Figure 4) were simulated on lab-scale and investigated.

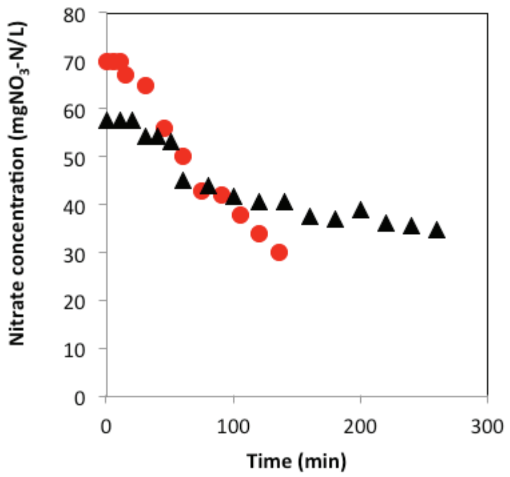


Figure 2: Comparison of sodium acetate and molasses as a carbon source for MBBR denitrification. (**Δ** = Molasses and **O** = sodium acetate).

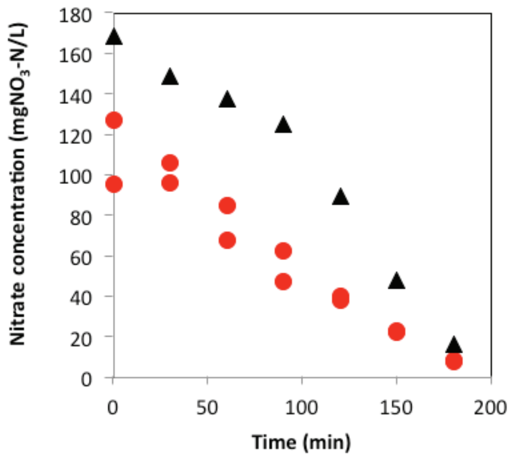


Figure 3: Effect of reduced temperature during the winter months. (**Δ** = 20°C and **O** = 5°C).

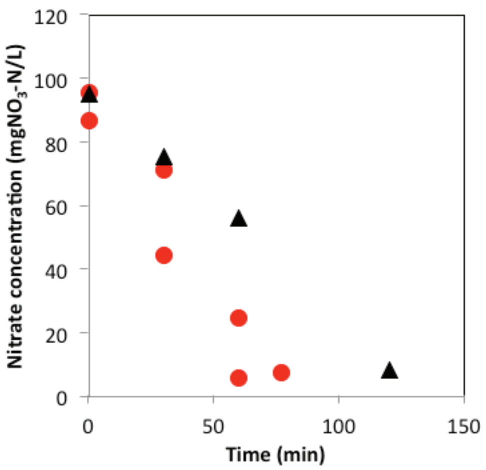


Figure 4: Effect of carrier filling grade on the denitrification rate. (**Δ** = 30% filling grade and **O** = 60% filling grade).

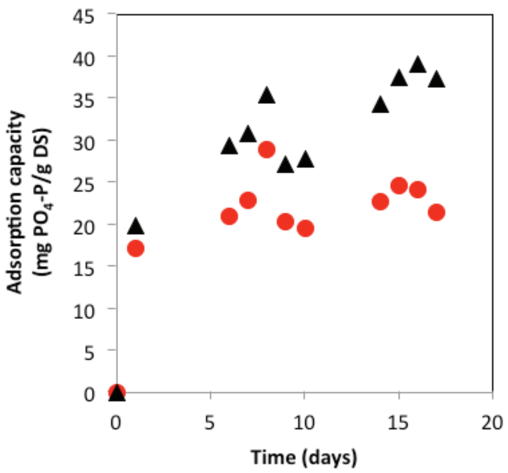


Figure 5: Effect of residence time on the phosphate adsorption capacity of the iron-rich sand grains. (**Δ** = first batch and **O** = second batch).

For the reduction of phosphorus, the potential of the iron rich granular substrate was assessed on lab-scale by batch experiments. The kinetic evaluation of the results of these batch tests resulted in the estimation of the maximum P sorption capacity ($q_{t,MAX}$) of the granules from deferrization sand filters from different drinking water facilities. A mean value of 21 mg PO_4-P/g DS was found for $q_{t,MAX}$ for the iron grains with sand core. All the results of the kinetic study and the physical properties of the different grains are summarized in Table 1. The physical properties of the grains were determined on the basis of sieve analysis experiments and grain sizes D10, D50 and D60 are obtained. The D refers to the size or apparent diameter of the grains, while the subscript (10, 50, 60) denotes the percent (by mass) that is smaller than that diameter, e.g. D10= 2937 µm means that 10% of the sample grains have a diameter smaller than 2937 µm. Additionally, the effect of the residence time and initial pH of the batch experiments on the PO_4-P adsorption capacity was studied. The results are depicted in Figure 5 and Figure 6.

Table 1: Overview of the result of the kinetic study of the granules from different deferrization sand filters. [*] = $[(mg_{PO4-P}^{(1-\frac{1}{n})} * l^{(\frac{1}{n})})/g_{korrels}]$, (1) = first batch, (2) = second batch.

Location	D10 [µm]	D50 [µm]	D60 [µm]	Initial PO_4-P conc. in grain [mgPO_4-P/gDS]	Density [kg/l]	$q_{t,MAX}$ [mgPO_4-P/gDS] Langmuir	K_f [*] Freundlich	q_t @ 25mg/l [mgPO_4-P/gDS] Langmuir	q_t @ 25mg/l [mgPO_4-P/gDS] Freundlich
Balen (1)	2937	3990	4215	1,84	3.358	17.434	1.011	5.330	3.941
Balen (2)	584	2334	2525	/	2.560	23.117	0.4317	3.975	3.196
Grobbendonk	332	481	507	3,03	1.721	27.639	0.6151	2.669	2.021
Herentals	1310	1878	2070	13.91	2.757	19.783	0.2350	2.284	1.902
Mol	2173	2870	3019	3.03	1.365	18.517	0.2527	3.086	3.562

During the adsorption (chemisorption) of phosphate on the iron-rich sand grains the following reactions occur (Equation 1, 2, 3 and 4):

$$Fe(OH)_3 + H_3PO_4 \rightarrow FePO_4 + 3H_2O \quad (1)$$
$$Fe(OH)_3 + H_2PO_4^- \rightarrow FePO_4 + 2H_2O + 1OH^- \quad (2)$$
$$Fe(OH)_3 + H_1PO_4^{2-} \rightarrow FePO_4 + 1H_2O + 2OH^- \quad (3)$$
$$Fe(OH)_3 + PO_4^{3-} \rightarrow FePO_4 + 3OH^- \quad (4)$$

Depending on the pH, the ortho-phosphate is present in the aqueous solution in one or, more likely, consecutively in two forms. At a pH lower than 5 mainly reactions (1) and (2) take place; at a pH between 5 and 9, reactions (2) and (3) occur; and finally at a pH between 9 and 14, (3) and (4) are the main reactions. If only reaction (1) occurs, there is no pH change. A pH change is only to be expected when reaction (2), (3) or (4) occur. The pH increases during the chemisorption process is due to the additional OH-ions, which are produced in these reactions. In an acidic environment (low pH) protonation occurs at the hydroxyl groups on $Fe(OH)_3$ at the adsorption surface of the grain. As a result, $-OH^{2+}$ groups are formed. These $-OH^{2+}$ groups are easier to be replaced at the binding sites by anions such as PO_4^-. This protonation is not applicable in an alkaline environment (high pH), where the hydroxyl (-OH) must be replaced by PO_4^-. This latter process is more difficult than the exchange with the above-discussed $-OH^{2+}$ groups. Therefore, the adsorption capacity in an alkaline medium is much lower than in an acidic environment (Song et al, 2011; Sperlich, 2010). When the experimental results of Figure 6 are further examined in detail, the influence of the pH on the adsorption capacity can be clearly identified as described above. At a pH=8 or higher, the adsorption capacity drops significantly, because of the presence of hydroxyl groups which are more difficult to exchange than in the $-OH^{2+}$ groups. For a pH value < 8, an increased adsorption capacity was observed, with a maximum adsorption capacity lower than a pH of 6. For an initial pH lower than 2, the pH change will be very limited as a result of the phosphate adsorption. Ortho-phosphate is at this low pH primarily present as H_3PO_4 and only partially present in the diiociated form of $H_2PO_4^-$. The pH increase is limited because only a limited amount of OH^- ions is formed, mainly because mainly reaction (1) will take place. For an initial pH between 2 and 7, the pH will increase as more ortho-phosphate is adsorbed to the grains. This is because mainly the ortho-phosphate is present as H_2PO_4, and therefore OH-ions are produced as a result of reaction (2). Finally, the pH stabilizes around a pH of 7 to 8. For an initial pH between 7 and 12, the adsorption takes place in an alkaline environment and a low adsorption capacity is obtained. Reaction (3), which is dominant in this pH range, ensures that even more OH-ions are formed in this case than in the pH range of 2 to 7. The pH stabilizes here around 9. For a pH higher than 9, the pH decreases because of the presence of Fe^{2+} ions on the surface of the grains. The outer layer of the grains is not fully oxidized to Fe^{3+}, and therefore the following reaction (5) takes place. During the formation of $Fe(OH)_3$ OH-ions are incorporated, which ensures that the pH drops.

$$4\ Fe^{2+} + O_2 + 2H_2O + OH^- \rightarrow 4\ Fe(OH)_3 \qquad (5)$$

For a pH of 13 or higher, a very low adsorption capacity is determined and it is obvious that the low adsorption capacity leads to a small effect on the pH.

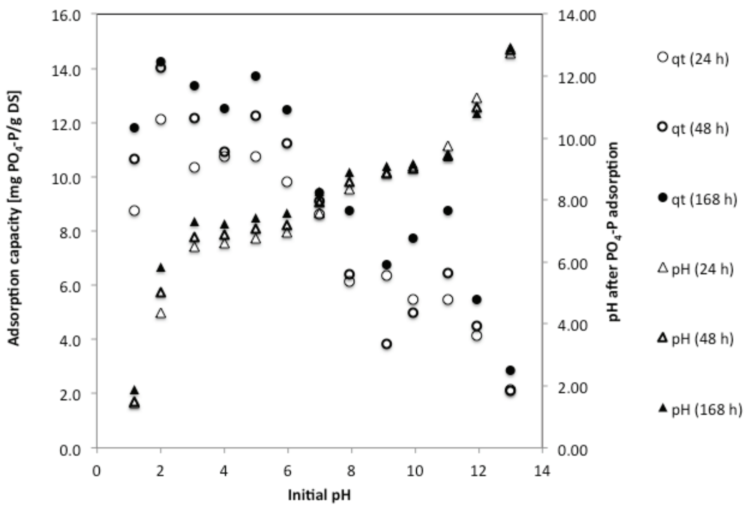


Figure 6: Effect of initial pH on adsorption capacity of PO_4-P on the iron grains.

Based on the results of the performed kinetic study a PO_4-P adsorption capacity (q_t) of only 2 to 6 mg PO_4-P/g granular substrate can be expected in the phosphate filter, which is fed with an influent concentration of 25 mg PO_4-P/l. In this way, the breakthrough time of this type of phosphate filter can be predicted. In a second step in the research a bench-scale column adsorption experiment was performed to verify the adsorption capacity and to investigate whether the PO_4-P adsorption capacity could be augmented by the operational conditions of the filter. There was an attempt to achieve an increased adsorption by the use of intermediate rest periods. In this strategy the column was fed 8h per day and in this way the column was left to stand for 16h per day. In Figure 7 it can be clearly established that these rest periods cause a significant improvement of the adsorption capacity, making it possible to reach the maximum adsorption capacity, as determined in the batch experiments on lab scale. The underlying cause can be explained by the interparticle diffusion of PO_4-P towards the core of the grain during the rest periods. This will result in fresh and free adsorption sites, leading to a slower saturation of the grains.

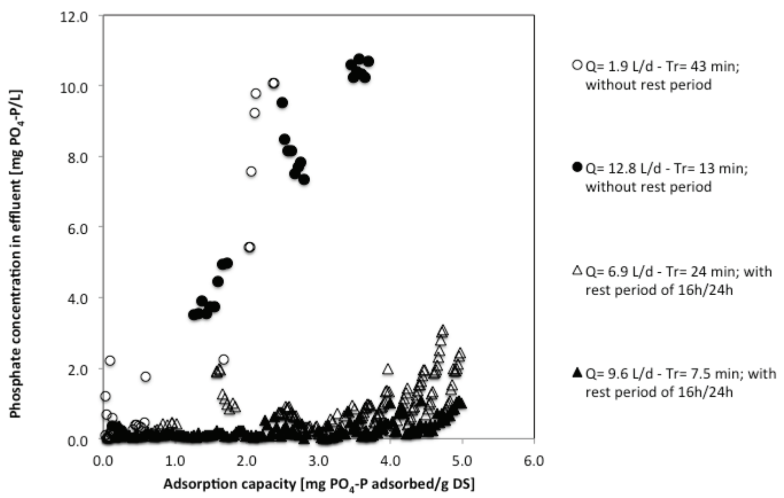


Figure 7: Effect of intermediate rest periods on the adsorption capacity of PO_4-P on the iron grains.

In order to verify the above-mentioned conclusions, pilot experiments were carried out on nutrient-rich wastewater from a tomato grower and from a rose grower. The effluent had almost always a nitrate concentration that was far below the discharge limit, with an average concentration of 6 mg NO_3-N/L. With the aid of the phosphate filter the discharge standard could just not be achieved. By further optimization based on the inclusion of rest periods and longer residence times in the reactor, an attempt will be made to reduce the effluent concentration of 2.5 mg PO_4-P/l to below the discharge limit of 1 mg PO_4-P/l. An overview of a detailed characterization of the water flowing through the pilot plant can be found in Table 2. Samples were taken at various points in the pilot plant in which the sample, which has been taken in the buffer tank, can be considered as the nutrient-rich waste water. The sample from Reactor 3 – Top of the PO_4-P filter is the denitrified wastewater and the sample taken from Reactor 3 – Bottom of the PO_4-P filter is passed through the phosphate filter where a large part of the dissolved phosphorus is adsorbed on the filter material.

Table 2: Overview of the characterization of different samples from the pilot plant.

Location of sampling	pH [/]	EC [µS]	Cl^- [mg/l]	NO_3-N [mg/l]	SO_4^{2-} [mg/l]	Mg^{2+} [mg/l]	Ca^{2+} [mg/l]	K^+ [mg/l]	Na^+ [mg/l]	PO_4-P [mg/l]
Reactor 1 - buffer	6.62	1074	7	97	90	24	105	95	6.9	11.0
Reactor 2 - MBBR	8.08	15430	528	/	60	15	57	/	/	6.8
Reactor 3 – Top of PO_4-P-filter	9.20	7380	457	/	78	10	21	174	/	14.7
Bottom of PO_4-P filter	8.62	2070	255	6	188	29	88	188	271.7	2.5

Conclusions

Based on the research discribed in this paper, the application of the combined treatment strategy of an Anoxic Moving-Bed BioReactor (MBBR) and phosphate filter can be considered as a worthy alternative for the spreading on grassland of the nutrient-rich wastewater derived from horticulture on grassland. Assuming, e.g., a constant flow rate of 1 m^3/day and an average incoming concentration of 100 mg NO_3-N and 25 mg PO_4-P/l, and requiring that the effluent concentrations have to remain below the environmental nutrient discharge standards, an anoxic MBBR reactor volume of 85 to 175 l and a phosphate filter volume of 700 l is required. Based on the adsorption kinetics found in this study, the breakthrough time of the phosphate filter can be estimated at 4 to 6 months. The cost associated with the dosing of the necessary carbon source for denitrification can be estimated as 0.21 € per m^3 of run-off water. Further research is needed to study the possibility of the re-use of the phosphate saturated iron grains as a fertilizer for the plants.

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(14) Strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield: a comparative meta-analysis

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Abstract: *Nitrate leaching (NL) is an important N loss process in irrigated agriculture that imposes a cost on the farmer and the environment. A meta-analysis of published experimental results from agricultural irrigated systems was conducted to identify those strategies that have proven effective at reducing NL and to quantify the scale of reduction that can be achieved. Forty-four scientific articles were identified which investigated four main strategies (water and fertilizer management, use of cover crops and fertilizer technology) creating a database with 279 observations on NL and 166 on crop yield. Management practices that adjust water application to crop needs reduced NL by a mean of 80% without a reduction in crop yield. Improved fertilizer management reduced NL by 40% and the best relationship between yield and NL was obtained when applying the recommended fertilizer rate. Replacing a fallow with a non-legume cover crop reduced NL by 50% while using a legume did not have any effect on NL. Improved fertilizer technology was the least effective of the selected strategies at reducing NL. Overall, we recommend a sequential approach in which the primary approaches used should be optimization of water and fertilizer management. More innovative methods including the use of cover crops and improved fertilizer technologies may offer additional reductions in NL, but may not always result in a net financial benefit. Ultimately, the costs and benefits of NL reducing strategies should be assessed for a specific system, to ensure the best choice is made for the farmer and the environment.*

Keywords: *Diffuse water pollution, effect size, nitrogen, nitrogen use efficiency, water quality.*

Introduction

Irrigated agriculture represents 16% of total cropland in the world and over 40% of crop production. Water application contributes to crop diversification and, provided proper crop production practices are used, may enhance sustainability of rural areas. However, irrigated agriculture has considerable potential for contaminating surface and groundwater because crops are abundantly fertilized to achieve high yield potentials (Diez et al., 2000). Current legislation in developed countries aiming at preserving good water quality has made it imperative to reduce quantities of nitrate delivered from cropland to ground and surface water. While the mechanisms of N losses in irrigated and rainfed agriculture are common, the strategies and options to secure ecological sustainability and economic viability may differ considerably (Vázquez et al., 2006). Therefore, a meta-analysis (MA) of the available information on strategies to reduce NL losses from agricultural irrigated systems was conducted. The main objective was the identification of those strategies that have proven effective at reducing NL losses and quantification of the scale of reduction in N losses that can be achieved by the various strategies and their effect on crop yield and N use efficiency (NUE). A more detail description of this work is available in Quemada et al. (2013).

Materials and Methods

A survey of peer-reviewed published literature was conducted to identify articles that reported NL in irrigated agricultural systems using the ISI-Web of Science. This provided 234 articles published from 1963 to 2012 in journals from the Journal Citation Report. Papers were scrutinized and included in the MA if they met the following criteria: i) study for at least one growing season under field conditions; ii) NL was measured in terms of N mass lost; iii) experimental design sufficiently detailed to determine critical aspects of the treatments, irrigation and fertilizer management; iv) studies reflected typical regional practice. After the screening, a total of 44 articles was used in the MA.

Data on the variable NL were extracted from the selected articles that compared the various mitigation strategies. When available, data on crop yield (Y), N applied as fertilizer (Nap) were also collected for each observation. In addition, we calculated NUE as the Y per unit of Nap (kg kg^{-1} N). The total number of observations on NL in the database was 279. From these observations, 166 contain data on Y. To build the data-sets Information was compiled from the selected articles to characterize the environmental (soil type, climate) and management factors (crop and irrigation technology). Four main strategies for NL control were identified based on a review of the selected articles (Improved water management (IWM), Improved fertilizer management (IFM), Use of cover crops (UCC) and Improved fertilizer technologies (IFT)) and further subdivided into various treatments (Table 1). Each observation in the data-set was assigned to one strategy and treatment.

Table 1 Categories (strategies and treatments) to control nitrate leaching in irrigated land defined from the analysis of selected articles and the number of observations per treatment.

Strategies	Treatments	Observations
Improved water management (IWM)	Adjust water application to crop needs	24
	Deficit irrigation	16
	Improved irrigation schedule	25
	Improved irrigation technologies	12
	Mulched soil	5
Improved fertilizer management (IFM)	Use recommended fertilizer rates	40
	Reduction in the recommended fertilizer rate	40
	Optimized timing of fertilizer application	16
	Fertigation	10
Use of cover crops (UCC)	Replacing winter fallow by a non-legume CC	39
	Replacing winter fallow by a legume CC	20
Improved fertilizer technologies (IFT)	Controlled release fertilizer	13
	Nitrification inhibitor	19

Data were analyzed using MA techniques to study the response of NL and the other variables to the strategies and treatments that had been identified. For each observation data were presented as averages of the replicates in the field study and the number of replications was not used for weighting. The effect size for each observation was calculated as the response ratio ($r = Xe/Xc$), where Xe is the experimental treatment mean and Xc is the control mean of each variable. To perform the MA, a square root transformation of the response ratio was used, $R = \mathrm{sqrt}(r) = \mathrm{sqrt}(Xe/Xc)$, to normalize the data distribution. The transformed values were used to compare the effect sizes across all the strategies and treatments using resampling and back transformation of these average values provided the difference in the magnitude of the effect sizes (Hedges et al., 1999). Mean effect sizes were calculated for each variable of interest and data-set category, and bias-corrected 95% confidence intervals (CI) were generated by a bootstrapping procedure (5000 iterations). Means were considered significantly different from zero if the 95% CI did not overlap zero, and different from one another if their 95% CIs interval were non-overlapping (Hedges et al., 1999). We also analyzed the mean response ratios of the environmental (soil type and climate) and management (crop and irrigation type) factors describing the field experiments of the data-set.

A subset of the database from the observations in treatments *Use recommended fertilizer rates* and *Reduction in the recommended fertilizer rate* was created to conduct a detailed analysis into the relationship between NL and Nap. The number of data pairs (NL versus fertilizer Nap) remaining in the analysis after separating observations was 150. N fertilizer rates were divided into 6 groups: no N fertilizer, four groups of approximately the same size every 100 kg N ha^{-1} up to 400 kg N ha^{-1} applied, and a sixth group for Nap > 400 kg N ha^{-1}. In an attempt to relate Nap and crop demand, in the same data subset the fraction of recommended N rate applied was calculated by dividing the actual Nap by the recommended rate for the study. The data pairs were split into five groups: no N fertilizer, less than the recommended rate, the recommended rate, less than twice the recommended rate, twice the recommended rate or more. Relative Y was calculated as the Y obtained at a particular Nap rate divided by the Y obtained at the recommended N rate. Means were calculated for all database subsets and 95% CI around the means were generated by a bootstrapping procedure.

Results

The scientific literature selected represented a global data-set, the geographical distribution of the selected articles being as follows: North America (44%), Europe (38%), Asia (14%) and South America (4%). The NL observations focused on the strategies of improved water (82) and fertilizer management (106) dominated the literature (Table 1). The Use of cover crops was the only crop diversification approach to reducing NL included in the analysis. Improved fertilizer technologies received moderate attention in the literature, but most articles dealing with this topic found in the literature passed the criteria to be included in the data-set. The effect of environmental factors was of little relevance for our data-set, so we focused on the mean effect size of the management strategies to control NL that were identified in the comprehensive analysis.

Influence of management strategies on nitrate leaching

All management strategies selected for the MA reduced NL, but with varying degrees of success (Fig. 1). The largest effect was achieved by IWM (58%) which was significantly different from the other strategies. Improved fertilizer management (39%) had a larger effect than IFT (24%), and the effect of UCC was in between these two strategies. The potential of specific practices to reduce NL in irrigated agriculture is confirmed by these results, with water management highlighted as the most effective strategy. Within the IWM, the treatment Adjust water application to crop needs had the largest effect (Fig.2a). Deficit irrigation, improved irrigation schedule, improved irrigation technology and plastic mulching also decreased NL but to a lesser extent. Use of recommended fertilizer rates reduced NL relative to excessive application by 43% (Fig. 3). A reduction in the recommended fertilizer rate produced a further decrease in NL of 50% compared to using the recommended fertilizer rate. The number of available observations in these two treatments was about half the total in the IFM group and sufficient for a more detailed analysis to improve understanding of the relationship between adjusting N fertilizer rates and NL. The mean NL from treatments that did not receive N fertilizer was 16 kg NO_3-N ha^{-1} per measurement period, and then it increased with Nap up to a mean NL of 106 kg NO_3-N ha^{-1} for application rates above 400 kg N ha^{-1} (Fig. 4a). There was a NL linear increase up to applications equal to the recommended rate, but if Nap exceeded recommended fertilizer rate then the NL losses were enhanced (Fig. 4b). Surprisingly, fertigation, a practice specific to irrigated systems that allows improved timing of fertilizer application, did not have a significant effect on controlling NL.

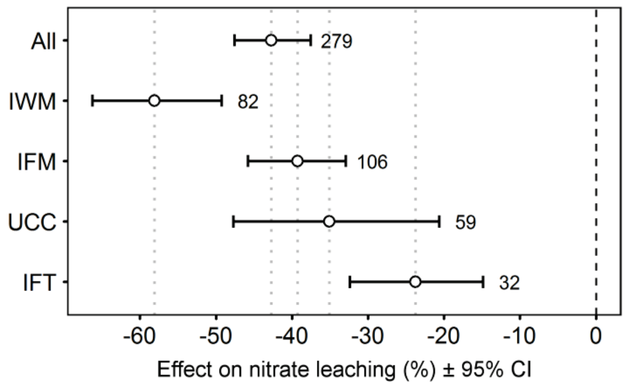

Figure 1 Overall effect of all management strategies (All) and effect of each category on nitrate leaching in units of percent change from the control. IWM: improved water management; IFM: improved fertilizer management; UCC: use of cover crops; IFT: improved fertilizer technologies. Mean values and 95% CI of the response ratios are shown. The number of observations is shown on the right of the CI.

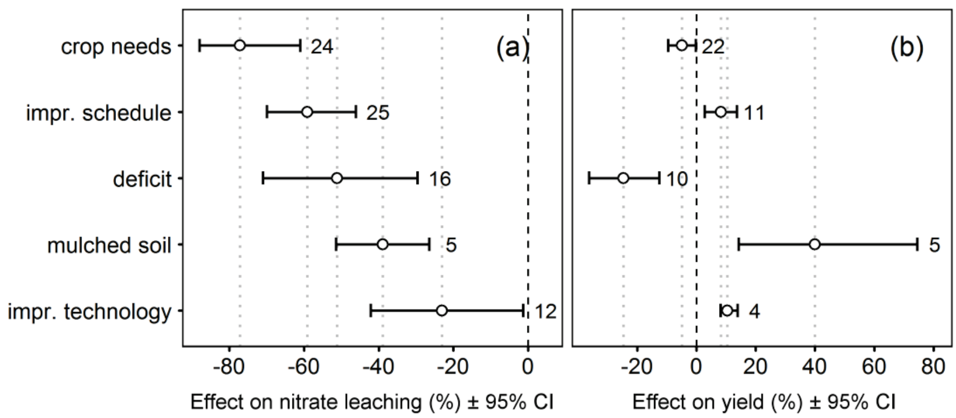

Figure 2 Effect of the strategy IWM and various treatments within the strategy on nitrate leaching (a) and crop yield (b) in units of percent change from the control. Mean values and 95% CI of the response ratios are shown. The number of observations is shown on the right of the CI.

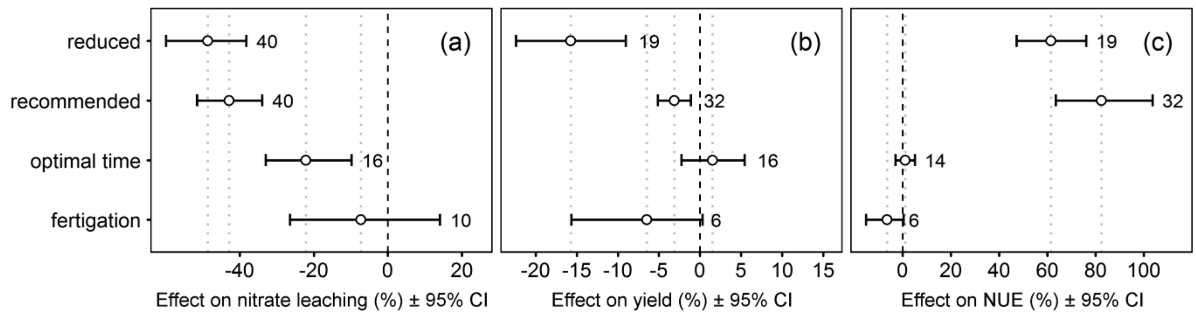

Figure 3 Effect of treatments from the strategy Improved fertilizer management: Use recommended fertilizer rate (recommended), Reduction in the recommended fertilizer rate (reduced), Optimized timing of fertilizer application (optimal time) and Fertigation on the control of nitrate leaching (a), crop yield (b) and N use efficiency (c). Mean values and 95% CI of the response ratios are shown. The number of observations is shown on the right of the CI.

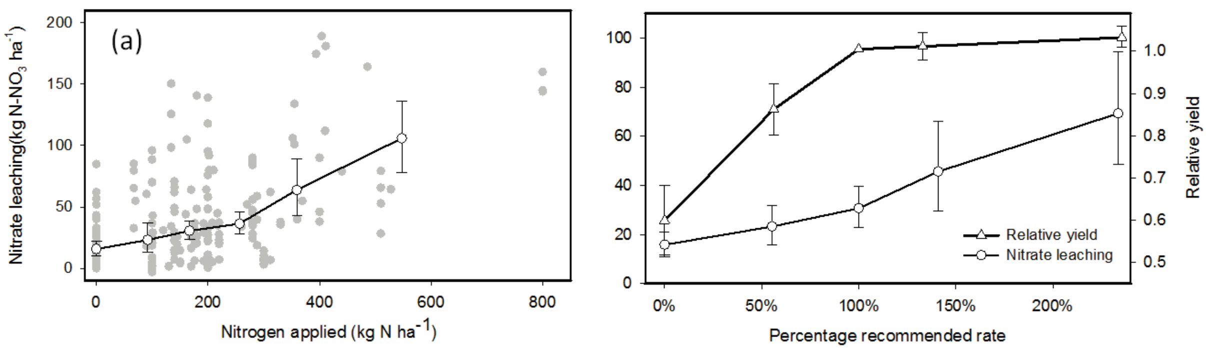

Figure 4 Nitrate leaching from observations in the treatments Use recommended fertilizer rate and Reduction in recommended fertilizer rate versus the nitrogen applied as fertilizer (a) or the percentage of the recommended N rate (b). Plot (a) points represent the raw data from all treatments and the circles show mean values for each fertilizer rate class. Plot (b) shows mean nitrate leaching (circles) and relative yield (triangles) at each class of percentage of recommended rate. Bars on all plots are the 95% CI around the mean effects.

The effect of UCC was affected by the CC type (Fig. 5a). While replacing fallow with a non-legume CC decreased NL by 50%, using a legume CC did not reduce NL. The results for legume CC are not conclusive, with an increase in NL in nine out of 20 observations, and a decrease for the other 11. On average, IFT decreased NL by 27% with no differences observed between CRF and NI (Fig. 6a).

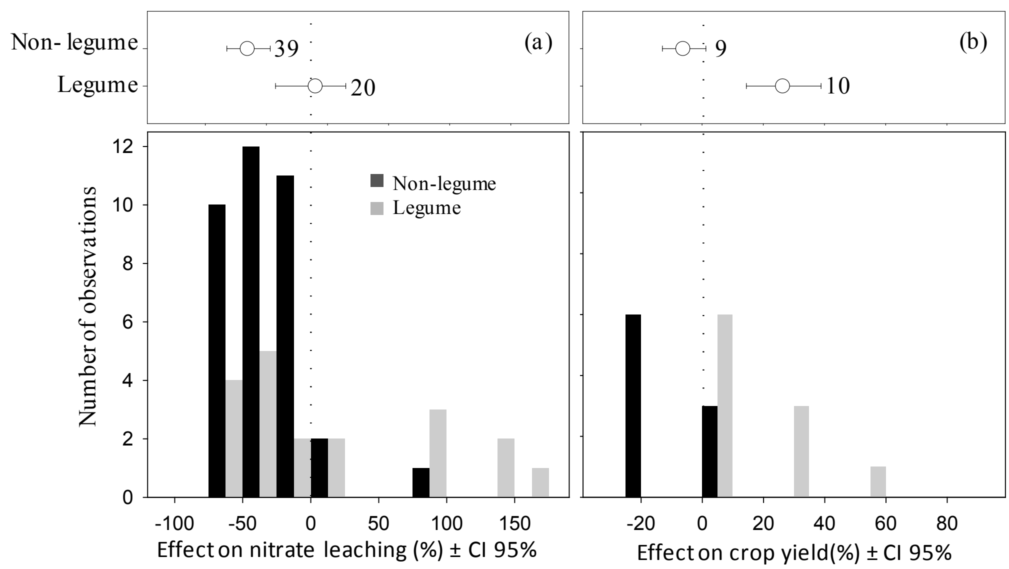

Figure 5 Effect of using legume and non-legume cover crops on nitrate leaching (a) and yield (b). Upper panel plots show mean values and 95% CI of the response ratios. Lower plots show the frequency distribution of observations for each percentage range with respect to the control.

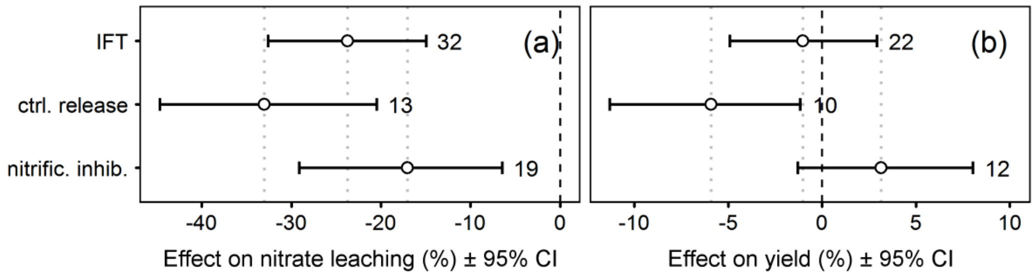

Figure 6 Effect of the strategy Improved fertilizer technology (IFT) and the treatments Controlled release fertilizer (ctrl. release) and Nitrification inhibitor (nitrific. inhib.) on nitrate leaching (a) and yield (b). Mean values and 95% CI of the response ratios are shown.

Influence of management strategies on crop yield

Improved water management did not reduce Y relative to excessive irrigation (Fig. 2b). While most crops under deficit irrigation decreased their Y, the proper scheduling of water application increased Y. Mulched soil had a beneficial effect on Y.

The mean Y from treatments that did not receive N fertilizer was 63% of the Y obtained in the recommended N rate treatments (Fig. 4b). Above the recommended rate, only a very slight crop response to Nap was observed. As a consequence, in the strategy Improved fertilizer management the largest mean effect on NUE was observed for the treatment Use recommended fertilizer rates, in which an increase of over 80% can be achieved relative to excessive applications (Fig. 3c). Reducing the Nap with respect to the recommended rate allowed a further increase of 60% NUE. Treatments Fertigation and Optimised timing of fertilizer application did not have an effect on total Y or NUE.

Replacing a fallow with a legume CC had a positive effect on Y in all observations (Fig. 5b). If the fallow was replaced by a non-legume CC, in more than half of the observations there was a Y decrease in the subsequent cash crop and the mean effect on Y was not significant. Overall, the strategy IFT did not have an effect on Y (Fig. 6b). The use of CRF even had a negative effect on Y.

A total of 16 different cash crops were studied in the field experiments selected for the data-set, with 63% of observations assigned to cereals and 37% to vegetables. The mean effect of the strategies to control NL was larger for the cereals (48%) than for the vegetables (33%). Within a given irrigation type adopting a strategy to control NL had a positive effect. The largest effects were achieved when mitigating strategies were implemented for surface irrigation and smallest effects for drip irrigation, with sprinkle and central pivot systems presenting intermediate opportunities for reductions in NL.

Discussion

The reduction in NL attained by Adjust water application to crop needs depends on the original degree of excessive application, but according to our results it is the treatment with a larger effect and can lead to reductions in NL of over 80%. In the six articles for this treatment, excessive irrigation varied from 10% to 30% over crop needs. Overwatering is a common practice to compensate for soil variability and to ensure that potential Y is achieved in the whole field, but because N losses are enhanced it is often accompanied by over fertilization which leads to a vicious circle with deleterious environmental effects. Water and N use efficiency were highly related in all articles from this treatment and adjusting water to crop needs was a good strategy to optimize environmental quality without sacrificing Y.

Deficit irrigation, a common practice where water is scarce, allowed for a further reduction in NL relative to adjusting water application to crop needs. When Y is reduced because of deficit irrigation, N fertilizer application should also be reduced to match the reduced crop demand; otherwise enhancement of residual N could increase NL risk during the non-growing season. Even if water application was not reduced with respect to crop needs, Improved irrigation schedule allowed for NL control and increased Y. This practice was particularly relevant in vegetable crops where irrigation frequency was a major management variable to ensure survival of plantlets and controlling NL during the crop establishment period (Vázquez et al., 2006). A further reduction in NL can be attained with appropriate use of soil or plant moisture sensors to control irrigation that may allow better adaptation of water application to crop demand (Zotarelli et al., 2011).

Mulching, apart from numerous other agronomic advantages, enhanced crop N uptake due to an increase in soil temperature and N and water use efficiency leading to a reduction in NL (Vázquez et al., 2005). In addition to that, mulching protects the bed from direct infiltration of rainfall during the cropping season that may cause occasional NL (Romic et al., 2003).

The strategy IFM attained a reduction in NL of almost 40%, making it an additional priority when implementing policies to control nitrate pollution. Application of N fertilizer to an irrigated system increased NL, even applying N at the recommended rate doubled NL compared with unfertilized controls. The best relationship between Y and NL is obtained when applying the recommended N fertilizer rate. Values below the recommended rate, while reducing leaching, also reduce Y. Fertilizing above the recommended rate will lead to an increase in NL without a significant increase in Y. It is advisable for future articles to report crop N uptake and the different sources of N supply (deposition, irrigation water, soil) when studying NL, so an approach based on N surplus could be conducted in addition to the recommended rate.

Fertigation did not reduce NL in comparison with side-dressing granular N fertilizer application. Frequent fertigation of vegetables (i.e. associated with drip irrigation) has often been recommended in the literature with the aim of increasing NUE and reducing losses, due to better synchronization between N availability and crop N uptake (Stark et al. 1983). However, in our study we selected data-pairs that used identical amounts of irrigation water and N, and in most cases, no significant effects on NL, Y or NUE were found for fertigation. Our strict selection criteria for fertigation experiments may have resulted in an underestimation of the potential of this technology. Studies with valid comparisons of fertigation and conventional applications are needed.

The reductions in NL that resulted from replacing a fallow with a CC may have been related to some or all of the following factors: increased evapotranspiration, decreased water percolation below the root zone, a modification of nitrate concentration in the soil solution moving down the soil profile, and N uptake by the CC (Gabriel et al., 2012). As expected, non-legume CC had a greater effect than legumes and their performance was very consistent. Nevertheless, in most studies replacing fallow with a legume CC increased soil N retention without a significant increase in NL, suggesting an enhancement of organically bound soil N. In accordance with this process the results of this MA show that in irrigated systems the use of legume CC can increase Y and NUE without enhancing NL risk, if subsequent crops are able to exploit the N released from legume CC residues (Gabriel et al., 2011).

The use of IFT, such as nitrification inhibitors (NI) and controlled released fertilizers (CRF), contributes to mitigating NL. The main reason is the slower release of nitrate to the soil solution achieved via these technologies when compared with conventional fertilizers. The efficiency of NI and CRF is higher under conditions that favour drainage or under high inputs of N fertilizer (Cui et al., 2011). As a whole, the use of IFT was moderately effective for controlling NL and had little effect on Y. Currently prices for NI and CRF are substantially greater than those for conventional fertilizers. The cost gap depends on raw material prices and varies greatly, but while NI is in a range that is attractive for agricultural use, the CRF are only under exceptional conditions economical in agriculture.

One of the goals of the MA was to learn from the experiences in areas already using irrigation to avoid repeating pollution problems in newly irrigated areas. Care should always be taken when extrapolating results, but the MA allows for results to be extrapolated with more confidence than is possible when looking at individual studies. The inclusion of data from four zones of climate and different soil textures should reduce bias and enhance the reliability of the results. Nevertheless, other soil characteristics that may be relevant such as depth, stone content or soil organic matter content have not been included in the MA. Also, topography and hydrological characteristics of the study sites are rarely described in the studies and have not been included. Consequently, care should be taken when extrapolating the results and attention paid to local conditions and information.

Conclusion

This study has highlighted the potential of four different strategies for reducing NL from irrigated cropping systems, providing information for policy development designed to mitigate nonpoint source pollution. Improving water management practices offers the greatest potential for reductions in NL to groundwater, and matching irrigation supply to crop needs should be the primary water management technique implemented. Further reductions in NL can be achieved if scheduling is improved. Reductions in NL can also be achieved with deficit irrigation, but at the cost of crop yield.

Improved fertilizer management reduced NL by a mean of 40% relative to management where fertilizer use was not optimized, indicating that this should also be a priority when designing policies to mitigate NL. Our results suggest that a combination of optimal water management and applying recommended fertilizer rates should also be the most profitable choice for the farmer, and therefore appear to be “win-win” choices for reducing NL.

Other strategies, while providing some benefits in reducing N losses, should only be recommended once the primary approaches of improving water and fertilizer management are implemented. The use of leguminous CC does not reduce NL with respect to the fallow but increase Y and NUE, opening the option of reducing N fertilizer application. The use of non-leguminous CC offers some potential with reductions of NL by 50% compared with bare fallow. However, CC requires an additional labor and seed input by the farmer, which may not be compensated by the minor gains in yield obtained by cover crop use. Likewise, the use of fertilizer technologies like NI and CRF, while reducing NL by 20-30% compared with standard fertilizers, may incur an additional cost for the farmer. CRF may slightly reduce yields while the use of NI does not increase them relative to standard fertilizer, making the economic case for using improved fertilizer technologies to reduce NL less convincing.

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(15) Optimization of N fertilisation through fertigation and green manuring: case studies in processing tomato

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Abstract: *In conventional cropping systems fertigation with drip irrigation represents an efficient tool to optimize vegetable crop nutrition and limit nitrogen pollution to the environment. In fact this technique allows to split and adjust the rate according to crop requirements during the growth cycle, to localize the fertilizers and thus to improve N use efficiency.*

In organic systems green manure crops can have a strategic role both to reduce the risk of nitrate leaching and to supply N for a subsequent cash crop so improving the environmental sustainability and self-sufficiency of the system.

Recently, there has been an increased interest in fertigation in organic agriculture due to the availability of reliable water soluble organic fertilizers as well as in cover crops in conventional agriculture mainly due to a rise in the price of fertilisers and to the increased awareness of environmental issues. As a consequence, within a sound strategy for a conservative horticulture, fertigation and green manure crops could be suggested as complementary tools in order to guarantee both adequate vegetable crops N nutrition and environmental benefits.

Nitrogen dynamics in crop-soil system when fertigation, green manuring and fertigation+green manuring were applied in processing tomato is discussed on the basis of published and unpublished evidences from field experiments carried out in the last decade in Central Italy. Particular attention is given to N leaching risk as affected by fertigation frequency, green manuring by legumes and grass species as pure stands or mixtures, and green manures coupled with fertigation.

Keywords: *vegetable crops; nutrient management; localization; cover crops, leaching*

Introduction

The availability of nitrogen is a key factor for ensuring optimum crop growth, high yield and a good quality of the marketable product. Mineral and organic fertilisers are applied in order to balance the gap between the N crop requirement for economically optimal crop development and yield and the soil N availability.

About 40 to 60% of the current human population depends upon crops grown with synthetic nitrogen fertilizers (Davidson et al., 2012). In 2010 the annual application of mineral fertiliser N was about 105 Mt at the global scale and about 11 Mt in Western and Central Europe (IFA, 2013); fruit and vegetables account for about 15% of the total at the global level and for 7.5% in EU-27 (Heffer, 2009).

The increasing demand and competition for cheap food, the relatively low cost of fertilisers compared to the price of the crop product, and the unapparent effect of a supra-optimal availability of nitrogen on the yield and quality of vegetables have encouraged over-fertilisation of field vegetables over the past few decades. As a consequence, scientific and public concerns have been raised about accumulation in edible portions of vegetables by nitrates (Maynard et al., 1976) and environmental pollution (Grizzetti et al., 2011).

Developing integrated approaches to nitrogen management in cropping systems is crucial to optimize N fertilization and to protect environment and human health (Agostini et al., 2010).

Determination of sound fertilizer N rates to meet crop N requirements of vegetable crops can be based on different approaches and/or methods (Agostini et al., 2010; Thompson et al., 2013):

(a) methods based on soil mineral N content (e.g. Nmin and KNS methods);
(b) methods based on evaluation of the crop nutritional status which include conventional tissue lab analysis, tissue quick tests (e.g. SAP test) and non-destructive monitoring by optical sensors (e.g. SPAD, DUALEX4 LAV, etc.);
(c) N balance approach that calculates/estimates N inputs (e.g. soil Nmin at the beginning of crop cycle; N from soil organic matter, crop residues, manure, rainfall, irrigation water, etc.) and N outputs (e.g. N crop uptake, leaching, N immobilization, denitrification, volatilization, etc.) in the “soil-plant-atmosphere” system;
(d) models to simulate, test and explore the N dynamics in soil-plant system at a single crop level or/and at a whole crop rotation scale, and user-friendly Decision Support Systems (DSS) based on simulation model.

Irrespective of the approach followed, detailed information has to be available on crop N uptake for optimal growth and yield both in terms of total crop N demand and N uptake rate during the different phenological phases.

Moreover, there are many agronomic options in fertiliser N management that affect N use efficiency (Benincasa et al., 2011):

- species and cultivars;
- environmental factors (air and soil temperatures, rainfall, soil texture, etc.);
- crop management (crop rotation, crop density and spatial arrangements, N fertilization rate, N application methods and timing, water management, etc.);
- type of fertiliser (organic, mineral, slow release fertilizers, etc.) or other N sources (crop residues, green manures, etc.).

Galloway et al. (2008) suggested that an increasing fertilizer N use efficiency may reduce fertilizer N use at the global level by 15 Mt per year (i.e. over 10% of the total estimated anthropogenic N release into the wider environment).

Within this theoretical frame several researches were carried out at the University of Perugia, Italy, Department of Agricultural and Environmental Sciences with the aim to study different scientific aspects related to the N management in vegetable crops. This keynote is focused on results of the researches carried out in processing tomato (always with cv. Perfectpeel) where crop N requirements, apparent recovery of fertilizer N, critical N dilution curve, crop N status assessment, fertigation, organic fertilization, green manuring and cropping systems have been analysed.

Why processing tomato as a case study? There are at least five main reasons:

- it is one of the most important vegetable crops at the global level (5.2 Mha, 34 Mt), in Mediterranean area (1.4 Mha, 14 Mt), in EU (8 Mt) and in Italy (90,000 ha, 5.3 Mt, as 7-years average) (WPTC, 2013);
- it is an high N-demanding crop (Tei et al., 2002);
- localised fertilization like drip fertigation is widely applied;
- N fertilization can affect the quality of marketable product (Branthôme et al., 1994; Colla et al., 2003);
- it is generally inserted in 3-4-year crop rotations with a winter cereal as a previous crop.

Crop N demand and assessment of crop N status

In processing tomato, as for other crops, plant N concentration declines during the crop cycle. The species-specific relationship between the total above-ground dry biomass (DW, t ha^{-1}) and critical N concentration (%Nc, the minimum N concentration required for maximum plant growth) has been found to be $\%Nc = 4.53\ DW^{-0.327}$ for total-N, and $\%Nc = 3.90\ DW^{-0.270}$ for reduced-N (Tei et al., 2002). These relationships stand for above-ground dry biomass varying between 1.2 and 12.4 t ha^{-1} and for stages of development ranging from the onset of fruit growth (~ 40 days after transplanting) to maturity. As a consequence, a “critical uptake” curve ($Nupt = 45.3\ DW^{0.673}$), i.e. the relationship between crop total-N uptake (Nupt, kg N ha^{-1}) and accumulated dry matter in the aerial biomass (DW, t ha^{-1}) at critical N concentration, can be derived: for above-ground DW reasonably ranging 10 to 14 t ha^{-1} the N uptake ranged between 210 and 270 kg N ha^{-1}.

As the crop cycle can be modelled by a sigmoidal function, the length of the three growth phases (i.e. exponential, linear and final) in the studied processing tomato (cv. Perfectpeel, growth cycle length of about 15 weeks, 3-year average) was 4, 7 and 4 weeks with an N uptake rate of about 0.7, 4.9 and 1.6 kg ha^{-1} d^{-1}, respectively (Tei et al., 2005); about 80% of the total N demand is taken up during the linear growth phase. Average N crop demand is 2.2 kg N t^{-1} fresh fruit mass (Tei et al., 2002, 2005; Benincasa et al., 2011).

All these results are perfectly in line with results found by Hartz and Bottoms (2009) in California: in particular, the rate of biomass development and N uptake peaked during the period between early fruit setting and early red fruit development (a period of about 6 weeks) during which N uptake averaged 4 to 5 kg ha^{-1} d^{-1}.

Apparent recovery (REC; Greenwood et al., 1989) of broadcast N-fertiliser declined approximately linearly with the increase in N rates (Tei et al., 1999): with 200 kg N ha^{-1} rate (i.e. N rate allowed maximum marketable yield and growth close to the critical curve), REC was 0.62, mineral nitrogen left by the crop in the soil at final harvest was about 70 kg ha^{-1}, and N in crop residues amounted to about 100 kg ha^{-1} (i.e. about 40% of the total crop N uptake).

Taking the critical N curve (Tei et al., 2002) as the reference, results by Farneselli et al. (2010) showed that the sap test (based on sufficiency ranges proposed by UC Davis, Anonymous, 1997) is a reliable tool for assessing the N nutritional status in processing tomato for about 2/3 of the crop cycle (i.e., until the fruit ripening phase) that represents the crucial time for N fertilizer management in that vegetable crop, while the use of the SPAD chlorophyll meter was a less sensitive and less reliable method. These results are really in contrast with results by Gianquinto et al. (2006) who defined reliable SPAD threshold values for optimal yield and by Hartz and Bottoms (2009) who found that petiole NO_3-N did not reliably discriminate between crops with adequate or deficient N availability and pointed out that current petiole NO_3-N sufficiency guidelines (Lorenz and Tyler, 1983) were unrealistically high. More recently, the utilization of VIS-NIR spectrophotometry in portable devices has been also proposed as a powerful tool to assess the nutritional status of tomato plants (Ulissi et al., 2011).

Fertigation

Several studies (see for example Phene, 1999; Singandhupe et al., 2003; Battilani, 2006; Zotarelli et al., 2009) demonstrated that fertigation allows high water- and N-use efficiency while N losses to the environment are minimised. The benefits are due to N rate splitting according to the crop requirement at any growth phase and to the localised placement of fertiliser close to the roots.

In Italy, fertigation is the standard method of nutrient applications to vegetables: this technique is applied on about 70% of the open field vegetable production area and on most processing tomato crops.

Achieving maximum fertigation efficiency requires knowledge of crop-specific water and nutrient requirements at any site throughout the growth cycle and attention to the timing of water and N delivery to meet crop needs. Obviously, there is a strong interaction between fertilization and irrigation: an efficient N fertilization requires an efficient irrigation, particularly in the Mediterranean regions, and so DSSs were developed to manage fertigation (Battilani et al., 2003).

At a given water and nutrient supply, irrigation and/or fertigation frequency affects water volume and N rate per each application and thus soil moisture and nutrient concentration in the rhizosphere between irrigations with consequent changes in crop growth, N uptake and yield (Cook and Sanders, 1991; Locascio and Smajstrla, 1995).

High fertigation frequency keeps constant soil moisture and nutrient concentration near the root zone (Silber et al., 2003). Some authors (Cook and Sanders, 1991; Locascio and Smajstrla, 1995; Silber *et al.,* 2003) have found that in processing tomato grown on a sandy soil, daily or weekly fertigation significantly increased yield compared to less frequent fertigation even if no significant difference was recorded between daily and weekly intervals. However, the benefit of high-frequency fertigation should be carefully studied because of increased water waste due to both evaporation from the constantly wet soil surface and the large portion of the irrigation cycle used for system charge and flush (Simonne et al., 2006). The emitter discharge rate and the rates of water and N application affect the wetting pattern and water movement; in particular an increase of the water application rate allows more water distribution in a vertical direction for a given volume applied in a sandy soil (Farneselli et al., 2008b).

Results from experiments carried out in processing tomato grown on clay-loam soil (Farneselli et al., 2007, 2008a) suggest that an high fertigation-irrigation frequency (i.e. three times a week application) increased the N uptake and the apparent N recovery (i.e. 0.82 with three times a week fertigation vs. 0.51 with once-a-week fertigation) only when N supply was very high and exceeded crop critical requirements (i.e. for luxury N consumption) while for optimal and sub-optimal crop N status no significant difference was detected in comparison to once-a-week application. Results seem to support the hypothesis that root growth was reduced by a high fertigation-irrigation frequency, so affecting water and N dynamics (i.e. water and N distribution between soil layers, and N partitioning between solid phase and soil solution).

Benincasa et al. (2007), in a field experiment on processing tomato grown in a clay-loam soil with 1.3% SOM and drip irrigated once per week, compared localized mineral N fertigation to the organic fertilization with poultry manure broadcast at transplanting. As expected, there was a clear effect of N rate, but no appreciable effect of the fertilizer-N form and distribution methods on either the N accumulation and the residual N in the soil or the shoot DW and marketable yield so that in the end the NUE was unaffected.

The use of Decision Support Systems (DSS) for crop fertigation management can significantly help to improve water and nutrient use efficiency of the crop: for example, the application of DSS FERTIRRIGERE (Massa et al., 2013), compared with the cropping practices of local growers (Tuscany, Italy), increased nitrogen use efficiency up to 102% and water use efficiency up to 21%, and the total crop water footprint decreased 11.5 m^3 t^{-1} (about 27%); moreover, the yield value increased while the cropping costs decreased thus resulting in a higher average net income of about 700 euro ha^{-1}.

Cover crops and Green Manuring

Covers crops are reliable tools for reducing soil erosion and N leaching and for managing soil fertility both in organic and conventional farming systems (Thorup-Kristensen et al., 2003; Macdonald et al., 2005; Boldrini et al., 2007a, 2007b; Tosti, 2008; Benincasa et al., 2008).

Winter cover crops of legumes and non legumes, pure or mixed, can be grown to catch N and so prevent N leaching and/or to be incorporated into the soil as green manure to increase soil organic matter and to supply N to the following spring cash crops (Odhiambo and Bomke, 2001; Thorup-Kristensen et al., 2003; Guiducci et al., 2004; Benincasa et al., 2004, 2008). Such “nitrogen effect” results from two combined processes: on one side the uptake of N by the cover crop during its growing cycle and, on the other side, the release of N by mineralisation of biomass incorporated into the soil.

Grass cover crops are the most efficient in immobilizing soil N and in reducing N leaching during the winter but when incorporated into the soil as green manure they can reduce N availability for the initial growth of succeeding cash crop due to their high C/N ratio (Benincasa et al., 2004, 2008). Green manures for supplying N are usually based on leguminous species able to accumulate considerable amount of nitrogen: in Central Italy field experiments found values up to more than 300 kg ha^{-1} for faba bean and hairy vetch (Benincasa et al., 2010) but high inter-annual variations may occur which is hard to explain based only on soil and weather conditions (Benincasa et al., 2008). The net contribution in terms of nitrogen input to the system (i.e. the nitrogen derived from atmosphere through symbiotic N fixation) was estimated to be 70-80% of the total nitrogen supplied by legumes (Seddaiu et al., 2007).

Recent researches found that adopting mixtures between legumes and non legumes can be an efficient tool to merge the advantages of the single species in the cover crop practice achieving both environmental and agronomic benefits (Tosti, 2008); moreover mixing grass and legumes allows to modulate N supply and release from green manures to a subsequent crop (Boldrini et al., 2006;). The use of mixtures of hairy vetch (*Vicia villosa* Roth.) and barley (*Hordeum vulgare* L.) with high proportion of vetch (i.e. barley at 25% of its full sowing rate + vetch at 75% of its full sowing rate, 100 + 150 seeds m^{-2}) allowed an optimal N nutritional status of processing tomato without promoting luxury N consumption (Tosti et al., 2008)**,** a very good development of the photosynthetic structures of the crop, an optimal homogeneity in the ripening of the processing tomato fruits (i.e. less unmarketable fruits), and good yield, similar to those obtained with the application of mineral fertilization (200 kg N ha^{-1}) or with pure vetch green manuring (Tosti et al., 2012).

Moreover, using barley - vetch mixture proved to be a very effective strategy for the management of winter cover crops because: 1) it represented a “buffered system” where barley and vetch complemented each other very well, allowing a stable N accumulation with adequate C/N ratio of the incorporated biomass; 2) mixture also worked as a “buffering system” for the agro-ecosystem, because, as pure barley, it assured a continuous reduction of the NO_3-N concentration in the water solution during fall-winter and during the critical period between cover crop killing and the establishment of the following cash crop (Tosti, pers. commun.)

In conventional agriculture, although there is often a reluctance by farmers to adopt voluntarily the practice of using cover crops because of extra time and cost demand (for establishment, removal or incorporation, seed cost, management of weeds, pests, and diseases) an increasing interest has been recently shown due to a rise in the price of fertilisers and to the increased awareness of environmental issues.

However N fertilization should be managed within a whole crop rotation rather than within a single crop. At this regards Farneselli et al. (2013a) reported results from a Long Term Experiment in Central Italy started in 1998 and still in progress where a 6-year rotation is applied in an organic (ORG) and in a conventional (CONV) low-input system. The rotation is characterized by the following basic sequence of crop groups: legume crop (soybean, field bean or common pea) - vegetable crop (pepper or melon) - winter cereal (soft or durum wheat) - summer cereal (maize) - processing tomato - winter cereal (soft or durum wheat). In ORG vegetables and maize are fertilized by fall-winter green manures (hairy vetch + barley or barley + pea) integrated if necessary by application of N fertilizers allowed in the organic farming system while in CONV all crops are fertilized by applying mineral fertilizers. Results confirms that:

a) as compared to the conventional crop cultivation, organic tomato provided similar yields, used supplied N more efficiently and left lower residual N after harvest, with lower related risks of pollution;

b) system sustainability for both organic and conventional cultivation depends greatly on the management of soil N availability and post-harvest residual N. In other words, appropriate crop rotations are essential in both systems, with cover crops in fall-winter to prevent leaching loss of mineral N. With this regard green manure crops have a strategic role for organic cultivation since they either trap and recycle mineral N or supply *ex novo* legume N derived from atmosphere to the soil, with benefits in mitigation of N pollution and improvement of self-sufficiency of the system;

c) on the other side, green manures can represent a “weak ring” of crop rotation in an organic system because the environmental sustainability of the crop rotation greatly depends on the fine tuning of their N immobilization-release processes.

Combination of fertigation and green manuring

Within a sound strategy for a conservative horticulture, fertigation and winter cover crops could be suggested as complementary tools in order to guarantee both adequate vegetable crops N nutrition and environmental benefits during fall-winter season and crop growth cycle.

In a 2-year field experiment where processing tomato was fertilised by green manuring of winter cover crops (i.e. hairy vetch and barley as pure stands or mixtures), fertigation or green manures+fertigation, Farneselli et al. (2013b) found that the incorporation of cover crops with high C/N ratio as pure barley and mixture barley-vetch, although supplied very low amounts of N for a subsequent tomato crop, contributed to fix N into the soil and reduced the environmental impact related to the mobility of nitrogen along the soil profile during fall-winter period and crop fertigation.

Conclusion

The fertilizer cost is not generally considered by vegetable growers as a critical item to reduce fertilizer use.

In processing tomato extensive scientific and technical knowledge on crop N demand, crop N status assessment, fertigation, use of cover crops and DSS are currently available and could be implemented by farmers to optimize crop N fertilization but most of them are not used under the current voluntary because they involve additional costs or risks to farmers, who are unlikely to adopt them without some form of support, incentive, or regulation.

However, nitrogen fertilization should be managed at a whole crop rotation scale rather than within a single crop for obtaining a maximum efficacy and efficiency in the environmental protection.

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(16) Nitrogen management by use of in-season living mulch in organic cauliflower production

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Abstract: *Consumers expect that the production of organic vegetables is less harmful to the environment compared to conventional vegetable cropping. However, vegetables with a high nitrogen demand such as cauliflower may cause intensive leaching of nitrate to natural waters. In addition, organic growers face difficulties in providing adequate amounts of organic fertiliser in order to attain high yields. In organic cropping systems, the use of an in-season living mulch may decrease the need for fertiliser and the risk of nitrate leaching. It may also improve nitrogen nutrition for next season's crop. The aim of this study was to investigate the effect of growing an in-season living mulch of grass-clover on cauliflower yields, nitrate leaching over winter, and soil nitrogen availability the following spring. A field experiment was performed on a sandy loam soil using two cultivars of cauliflower and with or without grass-clover as living mulch. The mulch was sown in rows between the rows of cauliflower, and two levels of fertilisation (dried chicken manure) were applied. Plant samples were taken for evaluation of yields, biomass and nitrogen content. Evaluation of inorganic N-content in the soil was done at planting, at harvest, in late autumn and in spring by taking soil samples to a depth of 1.5 m. Results show that high yields of cauliflower can be maintained, whereas no effects on nitrate leaching could be observed in a cropping system with an in-season living mulch of grass-clover.*

Keywords: *intercropping; vegetable production; nitrate leaching; crop growth; nitrogen fertiliser*

Introduction

Most consumers expect that the production of organic vegetables is less harmful to the environment compared to conventional cropping. However, leaching losses of nitrate may be high in organic production. In order to reduce nutrient emissions to the environment, new organic cropping systems have been developed where the main crop is intercropped with an in-season living mulch. This is done to better exploit ecosystem services such as attracting beneficial insects, suppressing weeds, increasing biodiversity and decreasing nitrate losses (Kremen and Miles, 2012). In a previous study, overwintering grass-clover has been found to work well as an in-season living mulch when incorporated in rows in late autumn and root pruned (0.2 m depth) and cut aboveground before the main crop is planted in spring. The living mulch formed a "green bridge" between growing seasons over two years, while nitrate leaching was decreased, and high yields and product quality of the main crop were maintained (Thorup-Kristensen et al., 2012). However, the competition between the main crop and the living mulch poses a challenge in providing sufficient amounts of nutrients to the main crop when growing vegetables such as cauliflower, which have a high nitrogen (N) demand and a short growing season. The aim of this study was to investigate the effect of growing an in-season living mulch of overwintering grass-clover on cauliflower marketable yields and potential nitrate leaching over winter.

Materials and Methods

A field experiment was performed on a sandy loam soil at Aarhus University, Research Centre Aarslev in Denmark, as part of the Interveg-project. The experiment was laid out in a randomised block design with three replications and a plot size of 10 m x 3.2 m. Two cultivars of cauliflower (Chambord F1 hybrid, Goodman open pollinated) were grown both with and without rows of living mulch intercropped between the rows of cauliflower. The design was a substitution design where the rows of living mulch replaced every third row of cauliflower. The living mulch was an overwintering grass-clover that was incorporated in strips (the crop + living mulch system: C+L) or fully incorporated (the sole crop system: S) in December 2012 in both systems. The rows of living mulch were cut aboveground and root pruned below ground (0.2 m depth) before planting the cauliflower to control interspecies competition (Båth et al., 2008). The cauliflower was planted 31. May and harvested from 3. until 20. August 2012.

The plots were fertilised with two different levels of dried chicken manure. The amount of fertiliser was adjusted based on the inorganic N found in the soil at planting and in June to a total of soil inorganic N of 240 and 290 kg N ha^{-1}.

After harvest the living mulch was left to grow until spring. Plant samples were taken for evaluation of marketable and non-marketable yield, and for analysis of dry matter and N content. Soil samples (to 1.5 m depth) were taken to evaluate the inorganic N content at planting, harvest (23. August), late autumn (20. November), and spring (April 2014).

The field experiment was conducted according to the rules of organic management which exclude the use of inorganic fertilisers or pesticides. Insect nets were used for pest management.

Results and Discussion

The results showed that high marketable yields were obtained of 19 and 12 Mg ha^{-1} in the S and C+L systems, respectively. The lower yield of the C+L system was caused by the fact that every third crop row was replaced by a row of living mulch. When calculated per meter row, there were no differences in marketable yields or total biomass production between the two systems. The fertiliser treatments had no effects on yield or harvest quality, which showed that the lower level was sufficient to obtain optimal yields. The yield results for cultivars were not unequivocal. Soil inorganic N levels were higher in the S system at planting compared to the C+L system with levels of inorganic N in the top soil of 15 and 9 mg N g^{-1}, respectively. The levels decreased gradually in the 0.3-1.5 m soil layer to 1 mg N g^{-1} in both systems. At harvest inorganic N-levels in the soil were similar for both the S and the C+L systems, and for both fertiliser treatments. Inorganic N-levels varied in the range of 2-6 mg N g^{-1}. The highest concentrations of mineral N were found in the top soil layer and decreased with increasing depth. In late autumn there were no differences in N-levels between both cropping systems. Neither were there differences between both levels of fertilisation. The levels of soil inorganic N varied in the range of 4-7 mg N g^{-1} (Figure 1). Thus contrary to the expected, there was no effect of growing an in-season living mulch of grass-clover on soil inorganic N content.

Effect of fertiliser and cropping system on soil inorganic N in late autumn

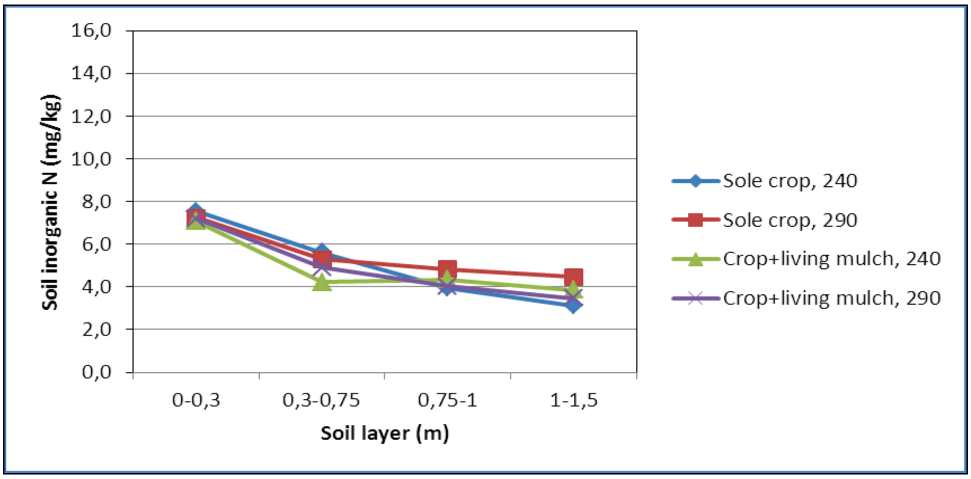

Figure 1 Soil inorganic N in November at the start of the leaching season under a sole crop of cauliflower or cauliflower intercropped with a living mulch of grass-clover at two levels of fertilisers (240 and 290 kg N ha^{-1}).

Conclusion

In an organic cropping system, and using an intercropping with an overwintering living mulch of grass-clover, high yields and quality can be obtained in an N demanding and short seasoned crop like cauliflower. However, the use of a substitution design where every third row of cauliflower was replaced by a row of living mulch significantly reduced the yield per hectare, which was not compensated by increased marketable yields per meter row. Fertiliser levels could be reduced to 240 kg N ha^{-1} without jeopardizing yields. Also, there were no clear effects of the living mulch on the potential nitrate leaching during winter. The results of this trial can be used for further development of organic cropping systems including living mulches using ecosystem services for the benefit of organic vegetable production and the environment.

Acknowledgements

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(17) Spatial and temporal variability of rooting characteristics and catch crop effectiveness

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Abstract: *Growing catch crops is an effective measure for reducing nitrate-N leaching during autumn and winter. In this study we investigated 1) how effective different catch crop types are over time, 2) how deep they can extract N with their rooting system and 3) the effect of field conditions. The two catch crops under investigation were Italian ryegrass (Lolium multiflorum Lam.) and white mustard (Sinapis alba L.). They were sown the 29th of August 2008 at three different locations (headland, normal and wet conditions) in a sandy loam field plot (Terric Anthrosol) in Merelbeke (Belgium) on wheat stubble. At each location, a randomised block design was established with three replicates. Apart from the catch crops, there was a third treatment with bare plots. Mineral N in the soil profile (0-90 or 0-210 cm) and above and below ground biomass parameters were measured in September, October, November and February. N-uptake in October was higher for white mustard than for ryegrass because of the fast early crop development. This difference had disappeared in November. The nitrate-N content in the 0-90 cm soil profile (residual N) did not change between October and November for white mustard and fallow, but decreased for ryegrass in that period. The maximum rooting depth for both crop types was 50-60 cm, except for the headland where, depending on the precise location, the crops could only extract N from the 0-25 or 0-45 cm top soil. Remineralisation from white mustard in winter was demonstrated.*

Keywords: *compaction; white mustard; Italian ryegrass; nitrogen*

Introduction

Catch crops are considered to be an effective measure to prevent nitrate-N leaching to surface and groundwater during autumn and winter. Nitrate leaching can be reduced by 100 kg N/ha and more depending on sowing date, weather conditions and catch crop type (Relaes, 2000; Ver Elst, 2007). Catch crops do not only reduce nitrate concentrations in the upper layers, they may also ‘pump’ nitrogen (N) that is already leached to deeper layers upwards (Thorup-Kristensen et al., 2003). After decay, the N that was taken up by the catch crops can be used again by the succeeding crop and is as such not lost from the system. The deeper the rooting system of the catch crop, the more effective for reducing nitrate leaching risks deeper in the profile. This was illustrated by Kristensen and Thorup-Kristensen (2004) who found a significant reduction in nitrate concentration in the 1-2.5 m soil layer (21 to 33 kg /ha) for fodder radish that rooted until 2.4 m deep compared to Italian ryegrass and winter rye that rooted until 0.6 and 1.1 m deep, respectively. Compacted soil layers offer greater mechanical resistance to root growth, reduce aeration and modify soil water contents. This mostly leads to reduced N uptake by crops (Lipiec and Stepniewski, 1995). A soil penetration resistance of 3 MPa is often considered as the critical threshold beyond which roots cannot grow anymore but this threshold appears to be crop dependent (Glinski and Lipiec, 1990).

In Flanders, soil samples for nitrate-N concentrations in the 0-90 cm soil layer need to be taken between the 1st of October and the 15th of November in the framework of the Manure Decree (to comply with the Nitrate Directive). The results are an indication for potential leaching losses over winter. The nitrate-N levels may not exceed 90 kg N/ha in non-focus areas and non-sandy soils. Catch crops can lower nitrate-N levels but it is the question if they can still lower nitrate-N contents during the course of the sampling period. If so, having samples taken at the end of this period would be more favourable for the farmers who have sown catch crops.

The objectives of this study were to assess 1) how effective different catch crop types are over time, 2) how deep they can extract N with their rooting system and 3) the effect of field conditions on catch crop growth and effectiveness. The two catch crops under investigation were Italian ryegrass (*Lolium multiflorum* Lam.) and white mustard (*Sinapis alba* L.). It was our hypothesis that white mustard, with its tap root, would be more efficient in extracting N from deeper soil layers than Italian ryegrass and that root growth depth and N uptake would be lower when soil conditions are less favourable such as in compacted soil. This extended abstract summarises the findings of Coorevits (2009).

Materials and Methods

Experimental site and set-up

This study was conducted on an arable field plot of the Institute of Agricultural and Fisheries Research (ILVO) at Merelbeke, on which in the summer of 2008 winter wheat was harvested. Average yearly precipitation is 887 mm and average yearly temperature is 10.6°C (1992-2009 period, ILVO meteorological station Lemberge/Merelbeke). The weather conditions during the experimental period (August 2008 – February 2009) are shown in Figure 1.

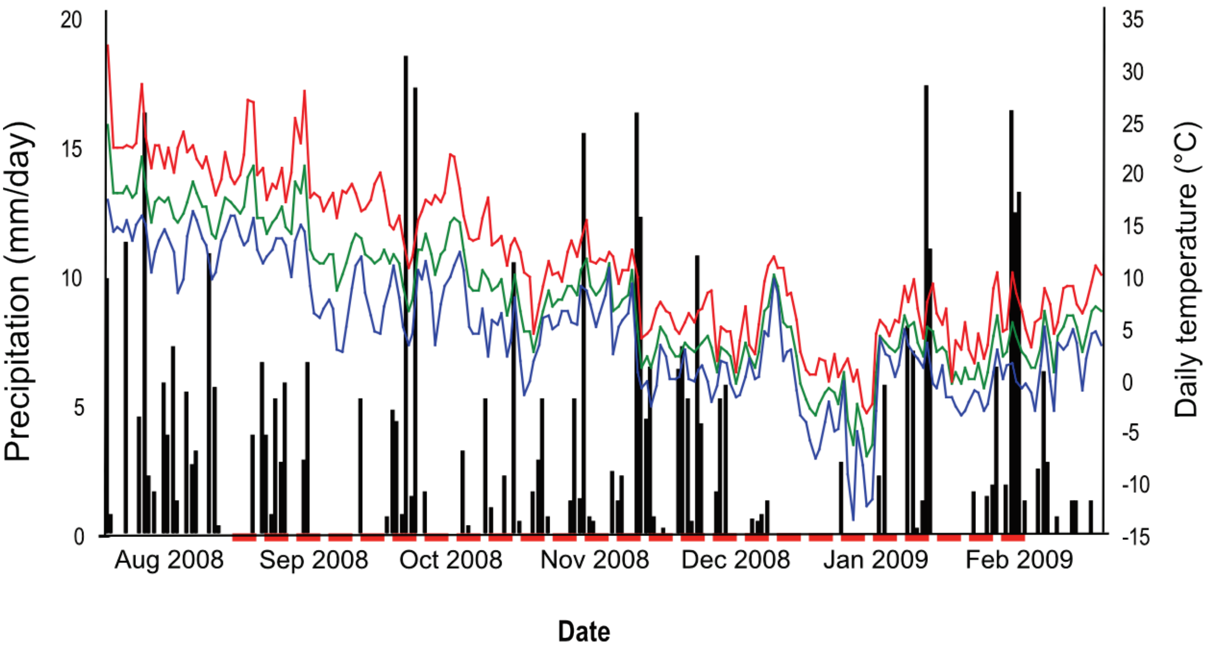

Figure 1 Weather conditions during the experiment (ILVO station at Lemberge, Merelbeke). Bars: daily precipitation; curves: daily maximum, average and minimum temperature; dashed line at the X-axis: experimental period.

The effectiveness to extract N compared to a control (bare soil) was investigated for two catch crop types, being Italian ryegrass (*Lolium multiflorum* Lam.) and white mustard (*Sinapis alba* L.) in a randomized block design with three replicates. This experiment was conducted on three locations of the field plot, being 1) head land (Block A), 2) normal field conditions (Block B) and 3) more wet field conditions (Block C) (Figure 2). This difference in soil drainage conditions was also visible on the Belgian soil map (AGIV, 2009) as it classifies Block A and B as moderately dry and block C as moderately wet. It was our hypothesis that the root growth of the catch crops would be hampered by compaction (Block A, headland) and less favourable drainage conditions (Block C) and that this would reduce catch crop effectiveness. Plots sizes were 3x10m² for Block A and 3x15m² for Block B and C. As crop growth was heterogeneous in block A, samples in each plot were both taken in places with normal (Anorm) and places with reduced growth (Ared).

The winter wheat stubble was tilled with a stiff-tooth cultivator (20 cm deep) and clod breaker the 26th of August 2008. This was repeated the 28th of August after which 27 kg N/ha was added with a calcium-ammonium-nitrate fertilizer. A combined tillage with a stiff-tooth cultivator (25 cm deep), clod breaker and rolling harrow was conducted the 29th of August and white mustard and Italian ryegrass were sown on the same date. The fallow plots were treated with herbicides the 17th of October 2008.

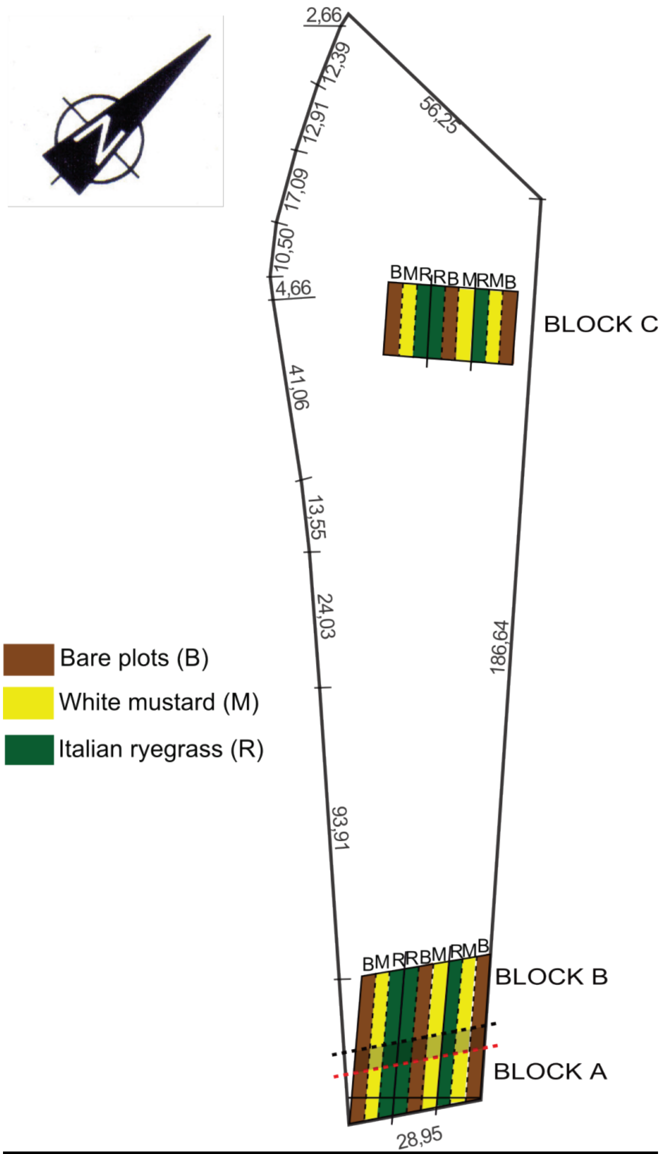

Figure 2 Experimental design. Numbers at the field plot edges are distances in meter.

Soil analysis

The soils of blocks B and C were well characterised by augerings and a soil profile description (FAO, 2006). Soil texture was determined with the sedimentation method (ISO 11277:1998 (E)). Chemical soil characteristics at the start of the experiment were measured on the 0-30 cm layer of each block: 1) plant available nutrients in ammonium lactate extract (ICP-OES, Varian VISTA-PRO), 2) pH-KCl (ISO10390:1994), 3) total organic carbon (TOC; dry combustion, Skalar Primacs SLC) and 4) total N (modified Kjeldahl method; EN 13654-1). Penetration resistance was measured with a penetrologger (Fieldscout SC900 soil compaction meter, Spectrum Technologies Inc.) in March 2009 (one measurement per plot). The penetrologger records penetration resistance every 2.5 cm to a depth of 45 cm.

Soil samples for initial mineral N concentration (6 subsamples for one composite sample) were taken the 28th of August 2008, i.e., before fertilization and one day before sowing. An overview of the other soil sampling dates in each block is given in Table 1. Of these sampling dates one was early October and one mid November, so that the results are representative for the start and the end of the campaign for measuring residual nitrate-N concentrations (Manure Decree). Four subsamples for one composite sample per plot were taken each time on Block B and C. On Block A, because of the smaller plot sizes, only 3 subsamples for one composite sample were taken close to the plots of recent crop measurements. Samples were taken per 30 cm to a depth of 210 cm in August and for the other sampling dates to a depth of 90 cm for Block A and C and to a depth of 210 cm for Block B. Soil mineral N was determined in a 1M KCl extract according to ISO TS14256-1:2003 with a Foss Fiastar 5000 continuous flow autoanalyser.

Crop growth and nutrient uptake

Aboveground biomass was determined on all sampling dates (Table 1) within a 1m² frame per plot for block B and C and within a 0.25m² frame for block A. Dry matter yield was measured after drying at 70°C for at least 24h. Crop N content was measured according to the Kjeldahl method (ISO 5983-2:2005(E)).

Root growth characteristics were measured twice in block A and C and three times in block B (Table 1) on cores (diameter 8 cm, length 15 cm) of a root auger (Eijkelkamp). One sample was taken per plot on the place of aboveground biomass measurements and in the row. The samplings were continued 15cm below the deepest root detected. The maximum rooting depth was recorded. Soil samples were frozen until roots were separated from soil by washing over a 0.5 mm sieve. Afterwards, root length was determined with the modified Newman line-intersect method (Oliveira et al., 2000). For larger root samples, root lengths were measured on one fourth of the sample. Coorevits (2009) determined that this leads to a relative standard deviation (= standard deviation/ total root length of the sample) of 10% or less. After root length measurement, roots were dried at 65°C for 48h to determine dry matter root biomass.

Table 1 Overview of the soil and crop samplings in each block

	Soil samples			Root samples			Aboveground biomass		
Time Block	A	B	C	A	B	C	A	B	C
Mid-September		x			x			x	
Early October	x	x	x	x	x	x	x	x	x
Mid-November	x	x	x	x	x	x	x	x	x
Mid-February	x	x	x				x[a]	x[a]	x[a]

[a] only aboveground biomass of Italian ryegrass as white mustard was killed by frost

Statistical analysis

Data were statistically analysed with the software STATISTICA (Statsoft, inc., 2008). Differences between the blocks (A, B, C) for penetration resistance were analysed with a one-way ANOVA analysis. For the other parameters a two-way ANOVA analysis was used with the factors 'block' (levels A, B, C) and 'catch crop treatment' (levels fallow, Italian ryegrass, white mustard). For crop growth characteristics block A is split into Anorm and Ared. The evolution of mineral N (NH_4^+-N + NO_3^--N) was analysed with a 'repeated measures analysis of variance' with the different sampling data as 'within effects'. Tukey HSD was used as posthoc test for balanced designs and the Unequal N HSD for unbalanced designs (unequal numbers). Treatments were considered to be significantly different if p<=0.05.

Results and Discussion

Soil characteristics

The soil of the field plot could be classified as an Terric Anthrosol. Soil texture of the top layer (0-30 cm), both in block B and C, is light sandy loam (Belgian classification) or sandy loam (USDA) with 58.0-59.9% sand (50-2000µm), 33.9-35.7% silt (2-50 µm) and 6.2-6.3% clay (<2 µm). Chemical soil characteristics are summarized for each block in Table 2. The largest differences between blocks were found for plant available P and K contents, which decreased from block A to block C.

Table 2 Chemical soil characteristics of each block at the start of the experiment

	pH-KCl	%C	%TN[a]	Plant available nutrients (mg/100g dry soil)				
				P	K	Mg	Ca	Na
Block A	6.9	1.0	0.151	21.4	36.9	22.6	110.8	5.2
Block B	6.8	1.0	0.109	14.7	29.0	18.9	88.7	5.5
Block C	6.2	1.1	0.106	10.9	23.1	19.9	94.5	5.2

[a] Total nitrogen as determined by modified Kjeldahl method

The penetration resistance was significantly higher in block A compared to blocks B and C for the 15-30 cm layer and reduced root growth was already expected in this layer in block A (Figure 3). In block B and C we expected reduced root growth from 30-45 cm onwards and a more pronounced effect in block B. Despite of what expected no differences in penetration resistance were found between subplots with normal (Anorm) and reduced (Ared) crop growth.

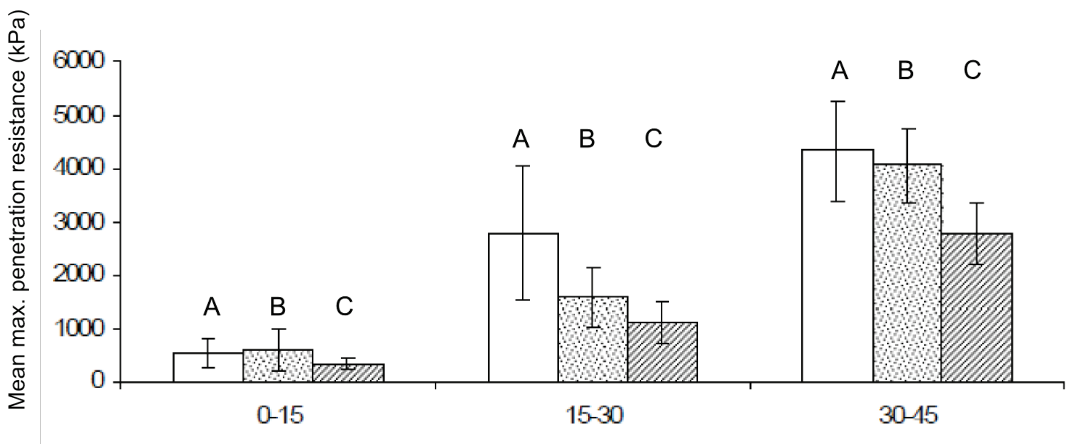

Figure 3 Mean maximal penetration resistance (kPa) within each block (letters A, B, C) at 3 depths (cm). Error bars are standard deviations.

Spatial and temporal variability of catch crop growth and N uptake

At the last measuring dates (Table 1), aboveground catch crop dry biomass was between 3.0 and 3.5 Mg/ha, except for lower biomass yields for Italian ryegrass in block C (2.8 Mg/ha) and for both catch crops in the places with reduced growth in headland (Ared). Aboveground biomass in November was not significantly different between catch crop types within the blocks. There were also no significant differences detected between blocks Anorm, B and C.

The temporal evolution of aboveground biomass N uptake is illustrated in Figure 4. Initially, white mustard was more efficient for N uptake than ryegrass (September and October measurements), leading to a significantly higher N uptake by white mustard than by ryegrass in October. Afterwards, the growth of white mustard was slowing down due to colder weather conditions, while ryegrass continued to accumulate N in the aboveground biomass (November measurement). No statistical differences between white mustard and ryegrass N uptake were detected in November anymore. There were also no differences between blocks except for Ared which had reduced N uptake, i.e. 20-30 kg/ha for Ared compared to 53-72 kg N/ha for the other blocks. White mustard died due to frost over winter (no measurement in February) and ryegrass growth clearly slowed down resulting in an equal or only slightly higher N uptake after winter (February) compared to before (November).

Maximum rooting depth was significantly lower for both Anorm and Ared (25-45 cm) compared to blocks B and C (50-60 cm). This was expected from the results of the penetration resistance (Figure 3). Rooting depth was significantly higher for white mustard compared to ryegrass in October ($p=0.045$), but this difference disappeared in November. Rooting depth for white mustard was thus not as high as expected. Perhaps this is due to high penetration resistance or due to sufficient N availability in the top layer, not forcing roots to grow deeper. In October, root length was not significantly different for the factors block nor for catch crop type. In November root length of ryegrass was significantly higher than of white mustard ($p<0.001$). This difference was the highest in block B and C. Root mass was not significantly different between blocks nor between catch crop types. However, white mustard has a tap root which accounts for approximately 60% of the root mass. Without this tap root, the root mass of ryegrass is ca. twice that of white mustard.

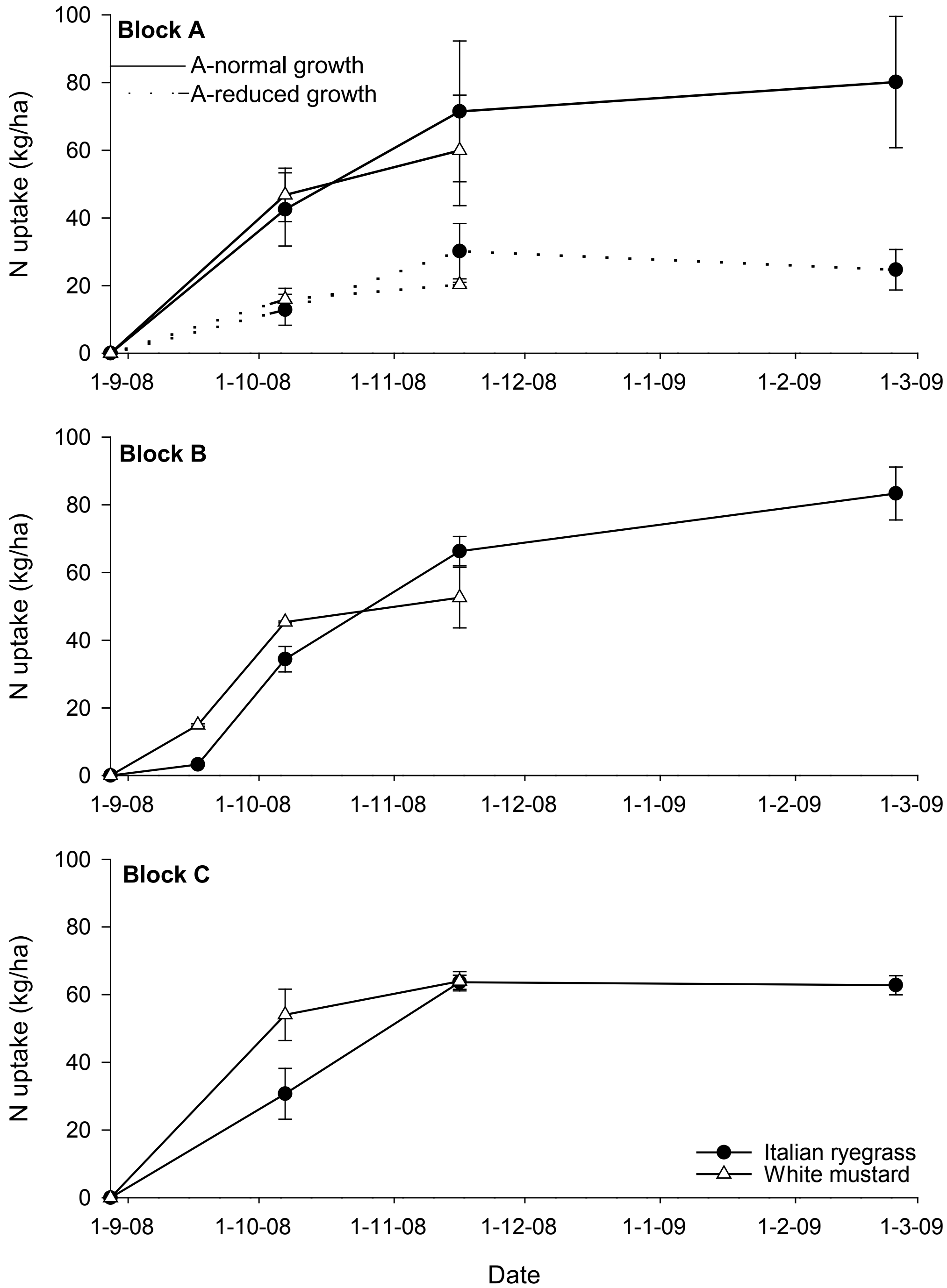

Figure 4 N uptake in the aboveground biomass (kg/ha) for the different catch crop types and locations in the field (blocks). Error bars are standard deviations.

Spatial and temporal variability of soil mineral N

Only soil mineral N results of block B (Figure 5) are provided here as soil samples to a depth of 210 cm were taken in this block (as opposed to a depth of 90 cm) and the soil was sampled 4 instead of 3 times. Results of the other blocks are similar, except for the initial mineral N content in the 90-210 cm layer, which was 71 kg N/ha for Block A, 100 kg N/ha for block B, but only 21 kg N/ha for Block C. In the latter block we presume that higher groundwater levels already leached the available nitrates.

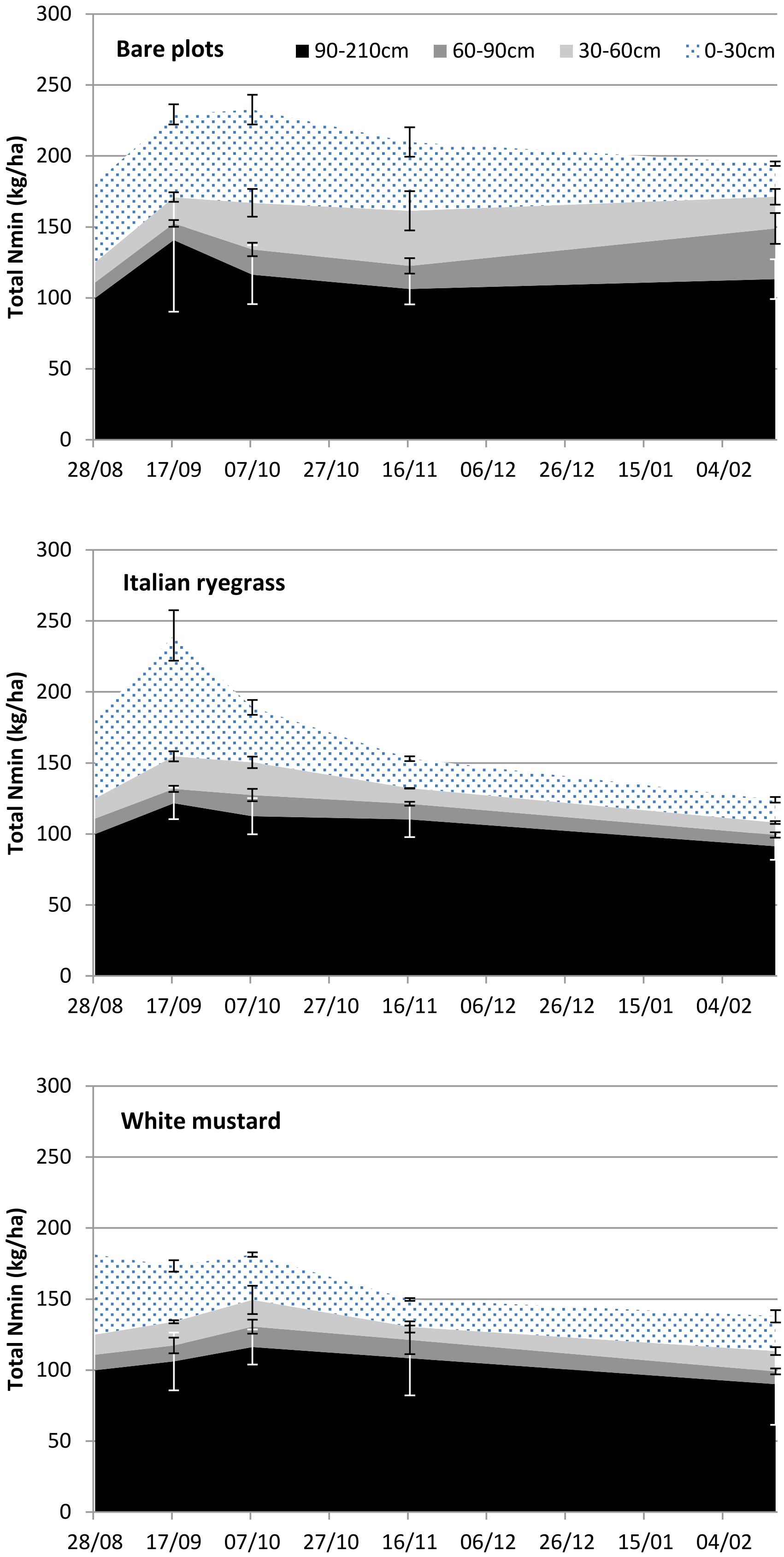

Figure 5 Temporal variability of mineral N (NH_4^+-N + NO_3^--N) content (kg/ha) in the different soil layers of block B for bare plots and treatments with Italian ryegrass and white mustard. Error bars are standard deviations.

For the bare plots of Block B, the peak in September is caused by an outlier in the 90-210 cm layer. If this outlier is removed, mineral N is still increasing but the peak is more clearly reached in October. Between sowing and October, the increase in mineral N in the 0-90 cm layer of the bare plots, caused by mineralisation, was 35 kg N/ha for block B , 53 kg N/ha for block C and 11 kg N/ha for block A. The lower mineralisation rate in block A can be attributed to higher soil compaction (Figure 3). In the bare plots of block B, there is a redistribution of mineral N over winter, i.e. the N content decreases in the 0-30 cm layer, increases in the 30-60 cm layer until November after which there is a decrease and increases in the 60-90 cm and 90-210 cm layer after November. The decreasing mineral N in the entire soil profile (0-210 cm) after November indicates how much N is lost from the system through gaseous or leaching losses (i.e., at least 15 kg N/ha). Considering all five measuring times, the share of NH_4^+-N in the soil mineral N ranged for Block B between 19 to 58% in the 0-30 cm layer, 13 to 50% in the 30-60 and 60-90 cm layers and between 15 to 37% in the deeper soil layers.

From mid-September onwards, Italian ryegrass starts to get effective as catch crop reducing the mineral N content in the 0-30 cm layer and as such preventing leaching losses to the underlying soil layers and accumulation of mineral N in these layers over winter. The results for white mustard are similar, except for the fact that white mustard shows already to be effective after a few weeks (mid-September sampling date). This is supported by the higher N uptake in September (15 kg N/ha in the aboveground biomass) compared to Italian ryegrass (3 kg N/ha) but cannot entirely explain the differences between white mustard and ryegrass/fallow. A second difference with Italian ryegrass is that soil mineral N in the upper layer (0-30 cm) is slightly increasing over winter (although not significantly), instead of the observed decrease in the fallow and ryegrass plots. We presume that frozen plant parts started to mineralize after the frost period in January 2009, when the temperature rose again to maximum temperatures of 5-10°C. Even at temperatures of 2°C, Cookson et al. (2002) found that N mineralisation from crop residues, in this case clover, is possible. It is estimated (by comparison with fallow) that remineralisation of white mustard between November and February is at least 30 kg N/ha. Despite crop residue mineralisation, no differences in soil mineral N between the catch crop types were detected in February, similar to the observations in November. As there were significant differences with the fallow treatment in November, except for Ared, both catch crop types were effective.

With this research, we also wanted to assess the effect of sampling time and catch crop type on the nitrate-N content in the 0-90 cm layer, which is measured in the framework of the Manure Decree. Our samplings were in the beginning of October and mid-November, marking the start and the end of the official measuring period. Sampling time did not affect the fallow and white mustard treatments (p>=0.10) (Table 3). For Italian ryegrass, the nitrate-N content was significantly lower mid-November compared to early October in block B and C (decrease of 24-29 kg N/ha) as ryegrass continued to grow in that period. Nitrate-N contents in the fallow treatments are high and approximate the legal limits of 90 kg N/ha. Growing catch crops, both ryegrass and white mustard proof to be effective to lower nitrate levels when sown at the end of August.

Table 3 Soil nitrate-N contents (kg $NO3^-$-N/ha; 0-90 cm) at the start and the end of the legal soil nitrate measurement campaign in 2008.

	October 7			November 15		
	Fallow	Italian ryegrass	White mustard	Fallow	Italian ryegrass	White mustard
Block Anorm	68.2	35.3	24.2	65.4	22.1	15.3
Block Ared		28.0	17.8		26.4	20.3
Block B	84.4	39.6	24.7	79.4	15.7	15.8
Block C	98.7	37.2	11.4	86.0	8.5	6.5

Conclusion

When sown at the end of August, white mustard has the capacity to develop quickly and can reduce mineral N contents in the soil already by mid-September. The crop continues to grow and extract N from the soil profile until early October. Italian ryegrass grows more slowly but continues to take up N until mid-November. The time of sampling for nitrate-N in the framework of the Manure Decree is not important when soil is bare or when white mustard is sown, but when Italian ryegrass is sown, sampling at the end of the sampling period (mid-November) is more favourable for farmers.

The mineral N content in the 90-210 cm soil layer, which has high potential to be leached to surface or ground water, is considerable in comparison with the mineral N content in the 0-90 cm soil layer. Deep rooting crops are needed to extract this N and bring it to the surface again. In our study, rooting depth (50-60 cm) was not as high as expected, especially not for white mustard. Less favourable soil conditions, such as in headland, further reduce the rooting depth and the capacity of catch crops to extract N from the soil in deeper soil layers.

Acknowledgements

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(18) Strategies to reduce nitrogen leaching by summer catch crop in vegetable greenhouse of North China

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Abstract: *Continuing monoculture, excessive fertilization and irrigation has led to high risk of the dominant nitrogen (N) leaching in the greenhouse. Control N fertilizer input is one of the efficient strategies to reduce N leaching, however, the high manure application and N mineralization is difficult to avoid total N leaching. In the study, catch crop was introduced into vegetable greenhouse as a biological tool to reduce N loss in China. Although root growth was not deeper and stronger than the cereal field, the effects of N extraction by aboveground of catch crop from the soil was significant, with N uptake of 150-180 kg N ha^{-1} in aboveground part and soil N_{min} in the soil profile of 0-180cm decreased by 303-343 kg N ha^{-1}. The analysis of ^{15}N isotopic technique implied that N immobilization from N_{min} to organic N contributed to the difference between the reduction of residual soil N_{min} and N uptake. Catch crop planting significantly increased organic N content and the ratio of dissolved organic nitrogen (DON) to dissolved total N in 0-60 cm soil depth, which accounted for 20-30% of the total soluble nitrogen. Nitrate leaching was dominant in vegetable field with high N_{min} residue and selecting some special catch crop, i.e. sorghum, maybe significantly in inhibiting the process of ammonium transforming to nitrate through biological nitrification. Our study highlights the need for considering both N_{min} and DON to account for the strategies of catch crops to control N leaching, which is a critical requirement for efficient vegetable production while avoiding environmental damage.*

Keywords: catch crop, summer maize, leaching, nitrate, dissolved organic nitrogen, vegetable greenhouse

Introduction

China's vegetable production has experienced a rapid growth in the last several decades. By 2011, China's total vegetable production reached 561.7 million Mg (1Mg = 10^6 g), which accounted for 51.6% of the world's production (FAO, 2013). Furthermore, the growing demand for healthier foods has stimulated vegetable production in the nation. The area under vegetable production accounts for 11.6% of the total land area of agricultural production in China (National Bureau of Statistics of China, 2010; FAO, 2013). For conventional planting, continuous cropping, repeated doubled-cropping rotation, the large input of chemical fertilizer and water input have brought limits to plant growth and caused soil degradation and nitrogen leaching (Chen et al., 2004; Ju et al., 2006; Zhang et al., 1996). The seasonal N inputs of greenhouse and open field were 2088 and 464 kg N ha^{-1}, respectively. These N inputs derived from manure and chemical fertilizers are 7.2-and 2.4-fold greater than the mean N removal by the crops. In greenhouse and open field vegetable production systems, the manure N input accounted for 53.7% and 37.8% of the total N input, respectively. Recent investigations reveal that nitrate-N concentrations in shallow wells (>15 m) around greenhouses in Huimin, Shandong, North China Plain, ranged from 9 to 274 mg N l^{-1}, with 99% of the surveyed wells exceeding the limit of 10 mg N l^{-1}, and more than half of the samples (53%) exceeded 50 mg N l^{-1} (Ju et al., 2006). A fertilizer recovery rate of less than 10% was found where excessive mineral fertilizer and manure had been applied (Zhu et al., 2005).

Recommendations taken into consideration of plant nutrient demand and rootzone nutrient supply has been used to minimize the excessive supply of nutrients into the rootzone. When the N target value method based on soil testing and side-dressings in the rootzone, some nitrogen loss is still evident (Guo, et al., 2008a; He et al., 2007; Ren et al., 2010). Using the technique of rootzone N management, the N fertilizer input could be reduced by 53% in a four-season greenhouse cucumber experiment (Guo et al., 2008b). However, significant losses of nitrate-N in drainage water continue to occur under a furrow irrigation regime because of excessive nutrient supply from long-term over application of organic manures and chemical fertilizers to the greenhouse.

Catch crop planting may be a pathway to reduce nitrate leaching (Ju et al., 2006; Snapp et al., 2005; Thorup-Kristensen et al., 2003). Using crops during the fallow period to reduce nitrogen leaching was first proposed in 1993 (Thorup - Krisenten et al., 1993). Crops used to capture nitrogen in the soil to prevent nitrogen leaching are called catch crops, while crops used to improve the soil fertility for the next season are called green manures. Similarly in America cover crops are described to play a dual role by providing ground cover to prevent wind and water erosion and carbon input to enhance soil quality. Carbon input from cover crops and crop residue play a vital role in agroecosystems, insuring long-term economic benefits with minimal impact on soil, water and air quality (Reicosky and Forcella, 1998). In Europe, catch crops are mainly planted in fall and winter, and most commonly used species are ryegrass, rye, hairy vetch, fodder radish, white mustard and clover (Thorup - Krisensen et al. 2003). A number of crops with deep root systems and high N uptake have been evaluated as winter cover crops to scavenge residual NO_3^- during the winter in Europe (Kuo and Jellum, 2002; Logsdon et al., 2002; Meisinger et al., 1991; Weinert et al., 2002). In this article catch crop refers to plants growing after the main crop harvest, to take up nitrogen, which otherwise would be lost by leaching losses, to benefit the next crop without substantially changing the planting system.

Catch crop use in vegetable production of North China

Planting crops during the fallow period in China has a long history. In Wei dynasty (533-544), an agronomic book named Qi Min Yao Shu described the stimulating effect of planting crops, such as legume during the fallow period on the yield of the main cereal crops. These historic records showed that increasing legume crops in rotation had been found an effective way to maintain long-term soil fertility before one thousand four hundred years ago in China. In China, areas such as Gansu with one growing season grew winter catch crop, mostly *violet orychophragmus* but hairy vetch is also used (Zhang et al., 2011).

In greenhouses on the North China Plain a double-cropping system with a winter-spring season (WS season) from February to June and a second autumn-winter season (AW season) from September to the following January or alternately a single cropping system consists of a overwinter season from September to May are typical (Fig 1). Thus, these systems all have a fallow period in summer within two or three months. Nitrate leaching is unavoidable due to high soil inorganic N in the root zone at harvest (He et al., 2007; Song et al., 2009; Strock et al., 2004). The continuously warm and moist conditions inside the greenhouse are favorable for very high N mineralization rates (Guo et al. 2010). These may contribute to large amounts of potentially leachable nitrogen in fallow period (Addiscott et al., 1991; Powlson, 1993). Additionally the plastic covers are often removed from the greenhouses and the land is often subject to excessive irrigation and large rainfall events during the summer fallow season in north China (Chen et al., 2005). Hagedorn et al. (1997) showed that under heavy rains, topsoil mineral N decreased by 50–70% within the first two weeks. Thus, reducing the nitrogen leaching without changing the cropping pattern becomes an issue to be solved for a sustainable development of the greenhouse vegetable production. Consequently, summer catch crop planting is a possible pathway to reduce nitrate leaching (Ju et al., 2006).

<table>
<tr><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sept</td><td>Oct</td><td>Nov</td><td>Dec</td><td>Jan</td></tr>
<tr><td></td><td colspan="4">Winter-Spring Season</td><td colspan="2">Summer Fallow</td><td colspan="4">Autumn-Winter Season</td><td></td></tr>
<tr><td colspan="4">Overwinter Season</td><td colspan="4">Summer Fallow</td><td colspan="4">Overwinter Season</td></tr>
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Fig 1 Typical greenhouse cropping systems in Northern China

Function of summer catch crop

The benefits of catch crops are primarily focused on their capacity to reduce nitrate leaching. Catch crops effectively absorb 19 g/m^2 of N in the soil solution, (Vos and Van der Putten, 1997), reduce 75% of NO_3^--N leaching loss, decreased 50% in the second year (Gustafson et al., 2000). In cereal rotations , compared to fallow, catch crop planting can reduce nitrogen leaching by more than 90% (Macdonald, 2005). Min et al. (2011) reported that sweet corn planting reduced mineral nitrogen concentration in the leachate from 94 to 59 mg/L, and the surface soil NO_3^--N accumulation from 306 to 195 mg/kg in vegetable production in south China. There are many other benefits of catch cropping beyond those of reducing N loss. These include increasing yield of main crop by altering the soil microbial community structure (Klose and Tabatabai, 2000) and promote crop seeding stage growth ,control or mitigate seeding disease occurs (Zhao, 2011). Some root exudates released from the catch crop may threaten pathogenic organisms; the planting of green garlic in summer fallow period could reduce the accumulation of bacterial pathogens (Wu et al., 2006). Spring onion in planted in the summer may increase the number of bacteria and actinomycete, reduce the number of fungi, improve the ratio of Bacteria/Fungi greatly, reduce the number of *Fusarium* by 69.17% (Li et al., 2006) and slow down the soil acidification (Zhang et al., 2009a). Leaf vegetables and sweet corn can obviously reduce the accumulation of nutrients in the soil and inhibit the formation of secondary salinity (Li et al., 2008). Soil conductivity in 0～20 cm soil layer was significantly decreased by 41.4% by planting catch crop(Xi et al., 2011). Cultivation of catch crops for so-called green manure can be useful management practice for enhancing soil biological activity as evaluated by enzymatic activity (Piotrowska and Wilczewski, 2012).

Characteristic of summer catch crop vs. vegetable greenhouse

For the special situation during the summer fallow period, the summer catch crop should have a short growing period, resist high temperature and waterlogging, with a large biomass and deep rooting system (Guo, 2008b). Kuo et al. (1995) found that rye and annual ryegrass (*Lolium multiflorum* Lam.) with extensive root systems significantly reduced NO_3^- concentrations in soil leachates in comparison with fallow soil, whereas hairy vetch actually increased the leachate NO_3^- concentrations. Ideally, crops with rapid biomass accumulation and high N uptake capacity (especially C_4 plant species) were selected as summer catch crops (Snapp et al., 2005). Deep rooted catch crops could reduce the residual nitrogen leaching by absorbing the nitrogen in deep soil layers, and by incorporating the catch crop residue into the soil, the absorbed nitrogen could be used for the next crop after the mineralization of crop residue (Thorup – Kristensen et al., 2006). The C_3 and C_4 crops differ in a number of important traits including photosynthesis, plant growth rate as well as root and biomass production. The C_4 crops, such as sweet corn, silage maize or waxy maize are suitable for summer catch crop according to its biological characteristics (Ren, 2003).

Strategies to reduce N leaching by summer catch crop

The benefits of using catch crops as a biological method to reduce nitrogen leaching are widely adopted. This article mainly summarizes the following strategies to reduce NO_3^--N leaching by catch crops (Fig 2).

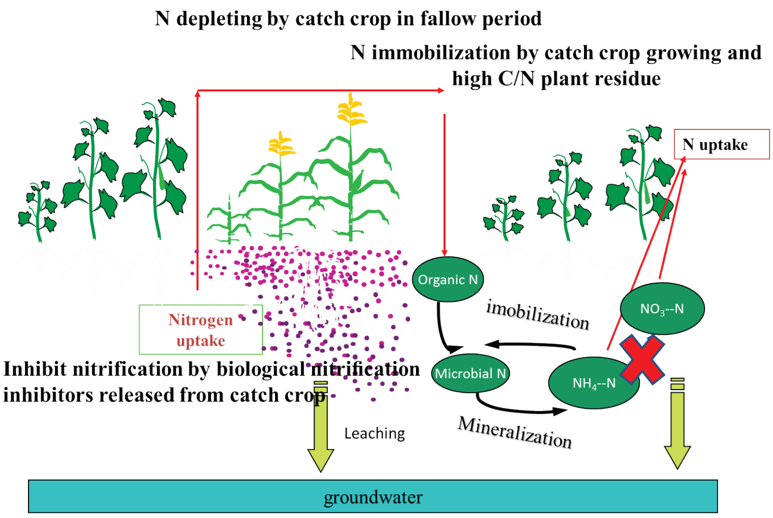

Fig 2 Strategies to reduce nitrogen leaching by summer catch crop

Extraction effects of summer catch crop by N uptake

Taking up and storing soil active N in plant tissue during the leaching-prone fallow period with heavy precipitation (Thorup-Kristensen et al., 2003) and absorbing and transpiring water and thus lessening water percolation (Weinert et al., 2002) are important mechanisms for catch crops to reduce potential N leaching.

Table 1 Nitrogen uptake by catch crop in greenhouse vegetable fields of China

Location	Catch crop	N uptake by above –ground part (kg N ha^{-1})	References
Beijing	Sweet corn	154-184	Guo, 2007
Beijing	Sweet corn	329	Zhang et al., 2009b
	Sorgham hybrid sudangrass	166	
	Herbst bloodleaf	157	
	Water spinach	101	
	Wheat	64	
Beijing	Sweet corn	162	Xi et al., 2011
Beijing	Sweet corn	128	Zhao et al., 2010
Beijing	Maize	173	Jiang, 2009
Hebei	Sweet corn	212	Ji et al., 2010
Beijing	Water spinach	48	Xie, 2010

Immobilization of nitrate to organic N during the catch crop growing stage

In our experiments, the reduction in soil mineral nitrogen was greater than could be explained by by the uptake of N by the sweet corn (Guo et al., 2008b). This leads to the assumption that the capacity of the catch crop to reduce N leaching risk was not based on N uptake alone. The results of an ^{15}N-labeling experiment indicate that more organic N was retained in the 0–0.9 m soil layer under sweet corn than fallow. Parkin et al. (2006) speculated that living rye plants may have increased immobilization of N in the organic N pools in their roots according to a partial N balance determined from measurements of NO_3^--N leaching, N_2O and NH_3 emissions, cover crop N uptake and Ni remained in the soil. Therefore, catch crops can perhaps improve N retention capacity by root decomposition and root activity. Large differences in N transformations have been found between bulk soil and rhizosphere (Whalen et al., 2001). Under the influence of the live roots of sticky corn, soil microbial biomass C and N increased significantly compared with the fallow treatment in a soil column experiment (Wang, 2011). Rhizodepositon may explain the difference (Landi et al., 2006). Root N deposition may contribute to increasing soil organic N directly. Molina et al. (2005) used the NCSWAP/NCSOIL model to simulate root N deposition of maize in a long term field experiment. The results showed that 54 kg N ha^{-1}, which accounted for 18.5% of total N uptake, was released into the soil by N rhizodeposition. Fifty percent of this loss was transformed into soil organic matter; 30% of this loss was in the form of soil organic N, and the remaining 20% of this loss was still in the form of root N deposition (Molina et al., 2005). Root exudates of non-leguminous plants usually have a high C/N ratio, which may lead to soil N immobilization (Huggins and Pan, 1993). Bolinder et al. (1999) concluded that the transformation rate of underground C (including C in root tissue and exudates) to soil organic matter (16–30%) was higher than that of aboveground C to soil organic matter (8–20%). Hence, C rhizodeposition from sweet corn added to the potential immobilization of inorganic N in soil, which may be converted into soil organic N later. The contribution of N rhizodeposition that transforms inorganic N to the soil organic N pool could also be a factor to consider for reducing nitrogen leaching by catch crop.

However, catch crop planting could also increase the leaching of dissolved organic nitrogen (DON). DON is increasingly recognized as an important component of nitrogen cycling and biological processes in the soil-plant ecosystem (Table 2). Based on recent research, DON is also an important part of soil nitrogen in vegetable plantation ecosystem (Yang et al., 2007). In organic fertilizer, most of soluble nitrogen is in organic form. DON accounted for 70.5% - 74.7% of soluble total nitrogen and 4.3% - 74.7% of total nitrogen for different organic fertilizer (Zhao, 2007). Such high DON input with manure in the greenhouse could be a potential source for nitrogen loss. Catch crop planting can definitively reduce soil NO_3^--N leaching, but it is not clear if it will also reduce the leaching of DON , or through the contribution of root secretion and microorganisms increase the DON leaching. Another experiment was carried out to examine how the summer catch crop influences N transformation and DON leaching. The results showed that planting catch crops and incorporating the residue into the soil was more efficient in reducing the nitrogen leaching, besides the increase in the ratio of DON/DTN (Kang et al., unpublished). But the mechanism of this are still unclear, and need to be should be taken into account in future studies.

Table 2 The proportion of different N form through leaching loss N in greenhouse vegetable fields of China

Location	n	Proportion of different N form in Total N (%)			References
		Nitrate N	Dissolved inorganic N	Dissolved organic N	
Shouguang, Shandong	6	-	84.0	16.0	Wang, 2010
Shunyi, Beijing	1	78.0	78.8	21.2	Wang, 2010
Yixing, Jiangsu	5	88.5	91.0	9.0	Min et al., 2012
Wuxi, Jiangsu	3	93.0	93.2	6.8	Lu, 2012
Average		86.5	86.7	13.3	

N immobilization after incorporation of catch crop residues

Management of catch crop residue is another important part in promoting nutrient recycling. The nitrogen transformation of catch crop residue and the nitrogen effectiveness for next crop are also commonly concerned. Upon destruction or incorporation into the soil, nitrogen is mineralized from the catch crop and made available to a following main crop. The efficiency of transfer of nitrogen from a catch crop to a main crop depends on many factors, including the time of destruction or incorporation, the net mineralization rate (depending on the properties of the organic material such as its C/N ratio and soil conditions) in relation to the temporal pattern of the nitrogen requirement of the main crop (Vos and Van der Putten, 1997). C/N ratio is an important factor determines the nitrogen release of catch crops. Crops with a low C/N ratio would rapidly mineralize and release nitrogen for next crops at an early stage (Norman et al., 1990); Crops with a high C/N ratio may stimulate microbial growth, fix nitrogen for a long period and reduce the effectiveness of nitrogen in the soil (Wylandet al., 1996). As a result, the catch crop with a moderate C/N ratio can help to keep the nitrogen cycle in a relatively stable state (Dupont et al., 2009). Thorup-Kristensen et al. (2003) reported that soil inorganic N content varies strongly depending on winter precipitation when no catch crop is grown, and the use of cover crops ensures a rather stable delivery of N to the subsequent crops, regardless of winter precipitation. In intensive vegetable production in China, large amounts of basal fertilizer, consisting of manure such as chicken manure, are usually applied. Combines with the high irrigation rate, the available nitrogen from this fertilizer is leached out easily at the early stage of the crop when the demand of nitrogen is lower. If a crop residue with higher C/N ratio would be incorporated into the soil, nitrogen could be immobilised at the early stage, while in the middle and later stage, the fixed nitrogen would release to supply the crop growth. If the C/N ratio is too high, the residue may reduce the available nitrogen in the soil and inhibit crop growth (Jensen, 1997).But some results indicated that this effect does not exist (Guo et al., 2008b).

Biological nitrification inhibition from catch crop

Nitrification represents an important biological process in the nitrogen cycle, which regulates NO_3–availability to plants and microbes and influences N losses from ecosystems as NO_3–or gaseous compounds (N_2O, NO x and N_2) (Castaldi and Aragosa, 2002). Nearly 90% of the N-fertilizer applied worldwide is in NH_4^+form (or is converted into NH_4^+ from urea hydrolysis), which is rapidly oxidized to NO_3^- by soil nitrifying bacteria (Mason, 1992; Sahrawat, 1980; Strong and Cooper, 1992). Soil organic N also goes through the nitrification process, making it liable to N loss by the same pathways as the fertilizer N does (Dinnes et al., 2002). Maintaining N in NH_4^+ form is sufficient to limit N losses by leaching. Nitrification inhibitors are compounds that delay bacterial oxidation of NH_4^+ by depressing activities of soil nitrifying bacteria. In theory, reducing nitrification under conditions where there is a high risk of N loss from NO_3– leaching or denitrification, should improve N-use efficiency (NUE) (Hughes and Welch, 1970). But several limitations or constraints have affected the widespread adoption of chemical nitrification inhibitors.

Several researchers have observed a slow rate of nitrification in soils of certain tropical grassland and forest soils (Sylvester-Bradley et al., 1988). This led to the hypothesis that plant roots may influence nitrification by releasing phytochemicals that can affect soil nitrifying bacteria activity (Fillery, 2007). Biological nitrification inhibitors (BNI) is the ability of certain plant species to release organic molecules/compounds from their roots that have a targeted suppressive effect on soil nitrifying bacteria (Subbarao et al., 2006a, b, 2009).

An evaluation of tropical forage grasses, cereal and legume crops indicated a wide range in their BNI-capacity. The highest BNI capacity was found in *Brachiaria* and *Sorghum bicolor* (Subbarao et al., 2007). If these plants can be used as catch crops N leaching may be reduced by inhibiting nitrification, but this will need confirmation in further studies.

Perspective

Summer catch crops introduced in a typical greenhouse two-crop rotation showed the potential of reducing N losses in a period with high risk of leaching losses. Mineral N was not only stored in above- and below-ground biomass, but also immobilized into organic N in the rhizosphere, but may also be retained as NH_4^+-N as a result of BNI. This review has highlighted the importance of addressing all possible pathways of N loss when investigating the possible benefits of catch crop use. All in all, catch crop could play an efficient role to reduce N loss and soil function degradation，improve soil quality and realize the sustainable development of greenhouse vegetable production in China.

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(19) Why do we have to increase P use efficiency and recycling in cropping systems?

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Abstract: *Phosphorus (P) is an essential, non substitutable nutrient for plants. Moderate P deficiency limits yield by reducing leaf growth, light interception and photosynthesis. In soils, P availability for living organisms is limited because it is strongly bound to soil particles. Since the end of the second world war, agricultural soils from western Europe have received large amounts of P as mineral and organic fertilisers. Today, the P content in soils is often above the minimum requirement for maximum yield. When overused, P can be a major water pollutant triggering eutrophication. Moreover, mineral P fertilisers derive from phosphate rock, which is a non-renewable resource whose future scarcity, decreasing quality and increasing cost threatens agricultural production and food security. Europe has very limited phosphate rock reserves, and depends on imports from a small number of countries, leaving it exposed to geopolitical issues. These emerging issues strengthen the need for a more sustainable use of P in agricultural systems, including more efficient use and recycling.*

Keywords: phosphorus; nutrient; eutrophication; natural resource

Introduction

Phosphorus (P) is at the same time an essential, non substitutable nutrient for plants, a pollutant for continental aquatic ecosystems and a non renewable resource. A major environmental concern about P is that it triggers eutrophication of continental aquatic ecosystems. This is especially the case in areas with high P surpluses, due to intensive livestock or cropping systems. Recently, a concern has emerged about the finite nature of global P resources (Cordell et al., 2009; Van Vuuren et al., 2010). These new challenges reinforce the need for a more sustainable use of P in agricultural systems, including more efficient use, reducing losses and recycling. Horticultural systems are often characterised by P surpluses and P accumulation in soils because of high P fertilisation rates and low exports (Chan et al., 2007; Yan et al., 2013). The objective of this communication is to review the current knowledge on P, and identify the most challenging and promising ways for a more sustainable use of P in cropping systems.

Phosphorus is an essential, non substitutable nutrient, whose availability for plants is limited because it is bound to soil particles

Phosphorus is taken up by roots as orthophosphate ions ($H_2PO_4^-$ or HPO_4^{--}) present in the soil solution. Most plants contain P in concentrations varying between 0.1 and 0.4 % in dry matter (Ott and Rechberger, 2012). Phosphorus plays a key role in the energetic cell cycle as part of the ADP/ATP system. It is also involved in several other key molecules like DNA, RNA, sugar phosphates and phospholipids. Moderate P deficiency limits biomass production by reducing leaf growth and subsequent light interception. A reduction of the CO_2 assimilation rate per unit leaf area was also reported on P deficient plants, but several authors have demonstrated that the leaf growth reduction generally occurs before, and to a greater extent, than the reduction of the net photosynthesis per unit leaf area (Hart and Greer, 1988; Fredeen et al., 1989) (Fig. 1). Additionally, P deficiency may alter the marketable yield through specific effects on physiological or morphological processes (e.g. initiation of tuber formation on potatoes, early vegetative growth rate, maturity control).

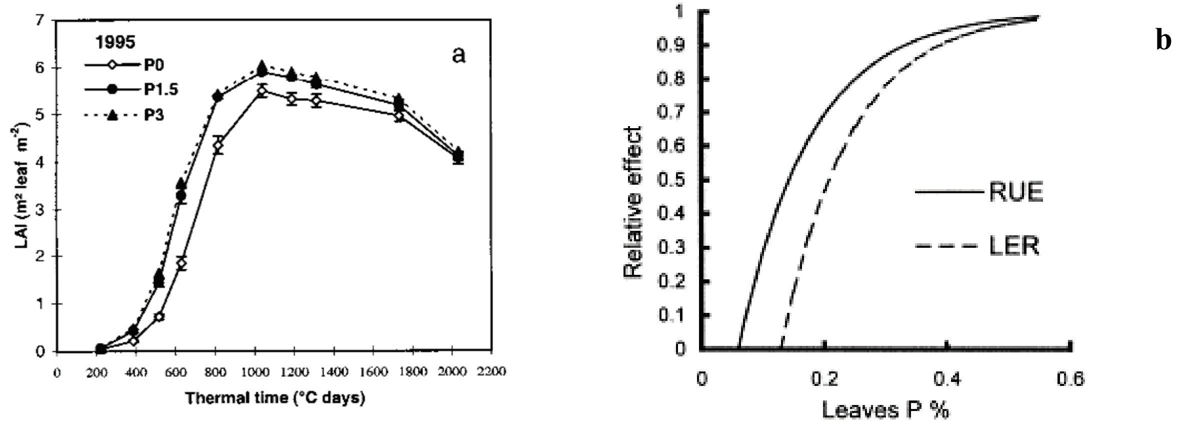

Figure 1: (a) Leaf area index (LAI, m^2 green leaf $(m^2\ soil)^{-1}$) of a maize crop under three P treatments: low P (P0), intermediate P (P1.5) and high P (P3) (Plenet et al., 2000); (b) Relative effect of the P concentration in leaves on the relative values of RUE (Radiation use efficiency) and LERs (leaf elongation rates) (Rodriguez et al. 2000).

Soils contain between 100 and 2500 mg P per kg of dry soil, that is between 350 and 8750 kg of P per ha in the 0-0.25m ploughed layer. However, the main part of the P in soils is bound to soil particles or included in minerals or organic molecules. Therefore, from a functional point of view, the key compartment is the soil solution because plants can only absorb dissolved P. Because of the very low solubility of orthophosphates, the amount of P contained in the soil solution is very low (between 0.05 and 2 mg P L^{-1}, which represents between 0.04 and 1.6 kg P per hectare if we consider a volumetric water content of 0.33 $m^3\ m^{-3}$). Although roots can only absorb dissolved P, the main part of the P taken up by plants originates from the soil solid phase. A major process involved in the soil-root P transfer process is P desorption from the soil solid phase and transport by diffusion towards the root surface. Because of the very low diffusivity of P in soils, transport by diffusion is often the limiting step, so that P gradients appear around roots (Fig. 2). Additional rhizospheric processes like proton and organic acids extrusion or phosphatase production are known to contribute to P mobilisation around roots, especially under low P availability. Since P is a very poorly mobile nutrient in soils, P uptake is highly dependent on the root length density and other root features (e.g. root hair density and length). By increasing the surface exchange between the root system and the soil, symbiots like myccorhizae may act as major contributors to P uptake.

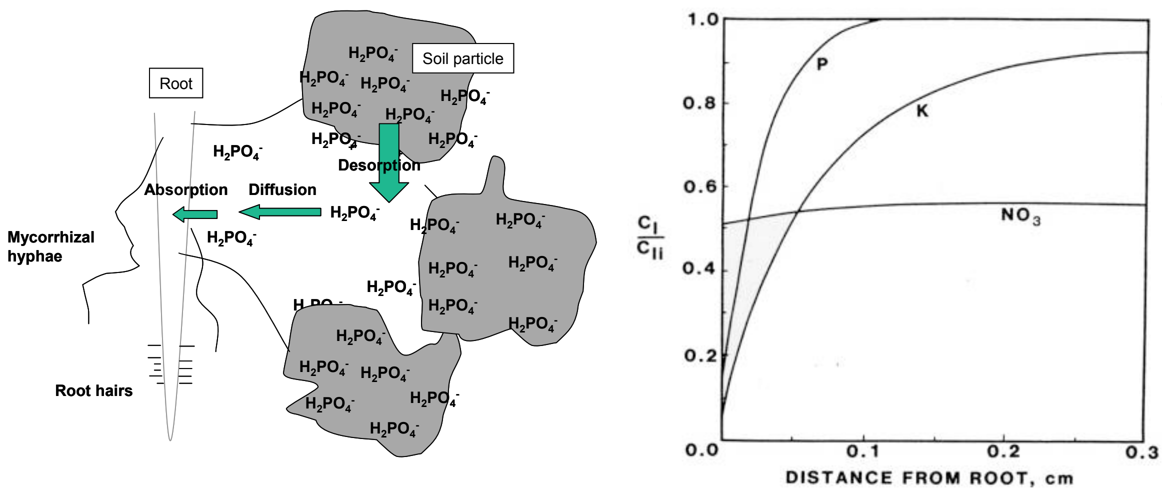

Figure 2: (a) Simplified representation of the main processes involved in P mobilisation and uptake by roots. For clarity, additional processes like organic P mineralisation and P mobilisation by rhizospheric processes other than P depletion were not presented (b) Calculated relative concentration (solution concentration, C_l, at 10 days as a proportion of the initial concentration, C_{li}) perpendicular to the root, where NO_3^-, $H_2PO_4^-$ and K^+ are calculated as if all supplied by diffusion (Barber, 1995)

P availability still limits crop yields on more then 40% of the world's arable land. In western Europe, P availability in agricultural soils has been considerably increased since the end of the second world war as a result of the use of mineral and organic P fertilisers. In many soils P concentrations are now above the minimum value that is required for maximum yield. Mineral P fertiliser rates have decreased since the early 70s, with no negative effects on yields because of high P stocks in soils. Fertilizer-P recommendation systems are generally based on soil testing and fertilizer recommendation programs to control build-up and maintenance of P levels. The general strategy consists of bringing soil-P test values to a recommended target value, and to maintain it by replacing crop off-takes (Fig. 3). Although very helpful for mid-term management of P stocks, this method suffers from several limitations. It is based on the assumption that a minimum concentration of P in soils is required to ensure maximum yield. This neglects dynamic aspects, whereas P demand and uptake capacity may considerably vary during plant cycle with critical stages (e.g. on maize, Fig. 4). Moreover, soil P tests by chemical extraction are poor indicators of the actual P bioavailability and no consensus exists between countries (Jordan-Meille et al., 2012). A key challenge for the future is to improve P recommendation systems (e.g. more mechanistic soil P tests, fertilisation strategies that are better adapted to crop specificities). A promising way to reduce P fertiliser use in cropping systems is to combine lower P content in soils with specific targeted fertilisation techniques like P localisation to ensure sufficient P nutrition during critical stages. Increasing P uptake capacity of cultivated species (e.g. by plant breeding on root system architecture) is also a challenge for the future.

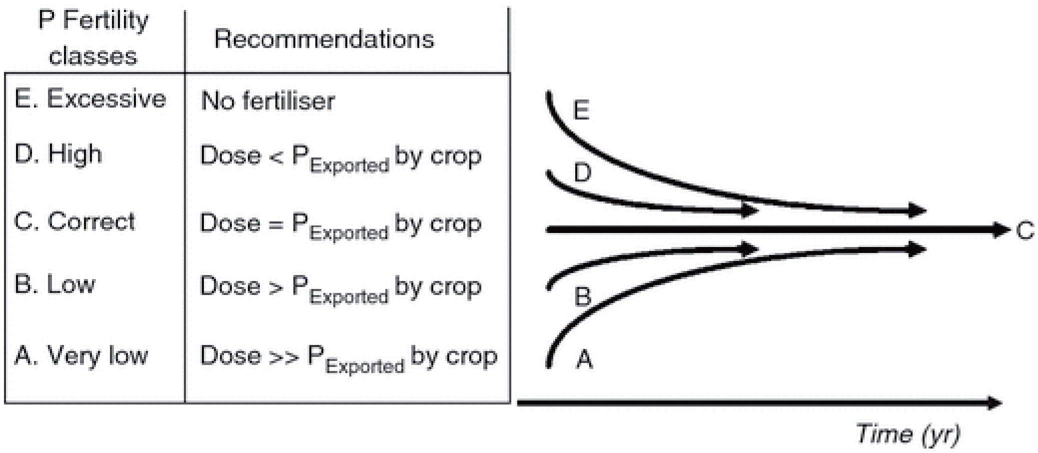

Figure 3: P fertilizer strategy in most European countries (Jordan-Meille et al., 2012)

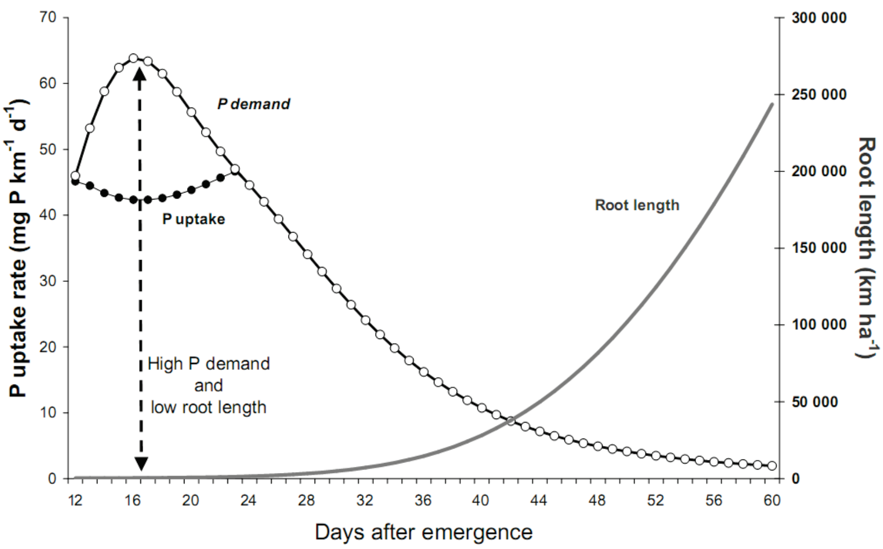

Figure 4: Simulated daily P demand per unit of root length (in mg P km^{-1} d^{-1}), simulated P uptake (in mg P km^{-1} d^{-1}) and root length (in km ha^{-1}) of maize as a function of the number of days after emergence (in Mollier, 2013)

When overused, P is a major water pollutant triggering eutrophication

Because of its very low solubility in water, P is often the limiting factor of plant growth in aquatic ecosystems. Therefore any additional supply of P is likely to promote eutrophication and algal bloom. Phosphorus reaching water bodies may be of urban, industrial or agricultural origin (e.g. for the Seine watershed, Table 1). Because of recent progress in wastewater collection and treatment, the amount of P reaching aquatic ecosystems having an urban or industrial origin has decreased. Therefore, the relative contribution of agriculture has tended to increase. Compliance with the Water Framework Directive will require substantial reductions in agricultural P losses, especially in Northern Europe.

Table1: Origin and fate of phosphorus in the Seine watershed (France) (adapted from Nemery and Garnier, 2007)

<table>
<tr><th>Origin</th><th></th><th colspan="3">P flows (year 2000)</th></tr>
<tr><th></th><th></th><th>Tons of P per year</th><th colspan="2">% of total</th></tr>
<tr><td rowspan="2">Point sources</td><td>Urban and industrial, downstream of Paris</td><td>3930</td><td>43</td><td rowspan="3">77</td></tr>
<tr><td>Urban and industrial, upstream of Paris</td><td>2922</td><td>32</td></tr>
<tr><td rowspan="4">Non-point sources</td><td>Urbanized areas</td><td>206</td><td>2</td></tr>
<tr><td>Forests</td><td>59</td><td>1</td><td rowspan="3">23</td></tr>
<tr><td>Agricultural soils, by leaching</td><td>51</td><td>1</td></tr>
<tr><td>Agricultural soils, by runoff and erosion</td><td>1900</td><td>21</td></tr>
<tr><td colspan="2">Total from point and non-point sources</td><td>9068</td><td>100</td><td>100</td></tr>
<tr><td colspan="2">Measured P flow at the outlet of the Seine river</td><td>8009</td><td></td><td></td></tr>
</table>

Phosphorus loss from agricultural soils is a complex function of climate, topography, soil type and land management and varies both temporally and spatially. Phosphorus transfer from soils to water bodies mainly occurs via runoff and erosion. Phosphorus leaching may occur in some specific situations (e.g. sandy soils). The identification of "critical source areas" is a prerequisite for implementing cost-effective mitigation measures. Several "Phosphorus indices" have been proposed to assess the risk of P loss from fields to surface waters. Most of them are based on simple arithmetic computations of source (soil test P, P application as manure and fertilizer,…) and transport factors (erosion, surface runoff, subsurface drainage, connectivity,…) (Buczko and Kuchenbuch, 2007; Heckrath et al., 2008). This approach is capable of delineating critical source areas for P export within a watershed. Various mitigation strategies have proved to be efficient for reducing P losses, including on-farm strategies (decreasing soil P content, minimum tillage, contour cultivation, tramline modification, grass buffer strips, continuous crop cover,…) and edge-of-field strategies (e.g. natural or constructed wetlands). Some of them may also serve other environmental objectives (e.g. reducing erosion and transfer of pesticides; increasing C storage). However, P accumulated in vegetated buffer strips or wetlands may be released later, so that the long term benefit of such strategies is questionable (Dorioz et al., 2006). Therefore, a strict control of P sources (lower P content in agricultural soils, adapted P fertilisation techniques) is a key component of any successful mitigation strategy for reducing P losses.

Mineral P fertilisers derive from phosphate rock, which is a non-renewable resource: in the long run there is no alternative to better P recycling

Mineral P fertilisers derive from phosphate rock, which is a non-renewable resource. Many studies have raised concern about rapid depletion of the world's P reserves. Some authors have suggested that global P production will peak around 2035, after which, demand will be higher than supply, leading to increasing costs. Other studies conclude that P rock reserves will be available for the next three centuries. Europe relies on P imports from a few, potentially unstable countries (Morocco, Tunisia, Syria, Russia), leading to potential vulnerability in the supply and cost of P fertilisers. Thus, Europe must reduce its dependency on P imports to ensure a competitive agriculture sector and future food security. Recent studies have analysed the P cycle at regional, national and European scale, which is a prerequisite to explore strategies for more efficient use of P, reduced wastage and better recycling. P enters Europe as rock phosphate, fertilisers, imported food, feed and non-food products and circulates within different sectors: agriculture, industry, households and waste. An improved P efficiency is possible at several steps of the whole P cycle (e.g. improved waste water treatments, reduce food losses). Despite interconnections with other sectors, agriculture is a key driver of P flows and budgets through mineral P fertiliser use, crop uptake, animal feedstuff production and trade, and manure production and disposal. Thus, a more sustainable use of P strongly relies on progress in the agricultural sector. Increasing P use efficiency and reducing P losses in agricultural systems may be achieved through a wide range of techniques, as mentioned in previous sections. Phosphorus in animal manure is disposed of on agricultural soils, but regional specialisation of agricultural systems hampers an optimal recycling of P (see fig 5, the example of two French regions: Brittany, an intensive animal farming region, and Centre, an intensive crop farming region; In Brittany the P budget is highly positive, especially because of feed imports, whereas in Centre the P budget is equilibrated but relies on mineral P imports). A key challenge for the future is to reduce agriculture dependency on imported mineral P. This may be achieved either by agronomical or technological processes (i.e. recycling soil P stores, using P-rich by-products as fertilisers, manufacturing P fertilisers from wastewaters by struvite crystallization,…) and/or by redesigning agricultural systems and their localisation to facilitate recycling. This will obviously necessitate trade-offs with other key issues like N and C cycle management and greenhouse gas emissions or public health issues associated with recycling of organic products.

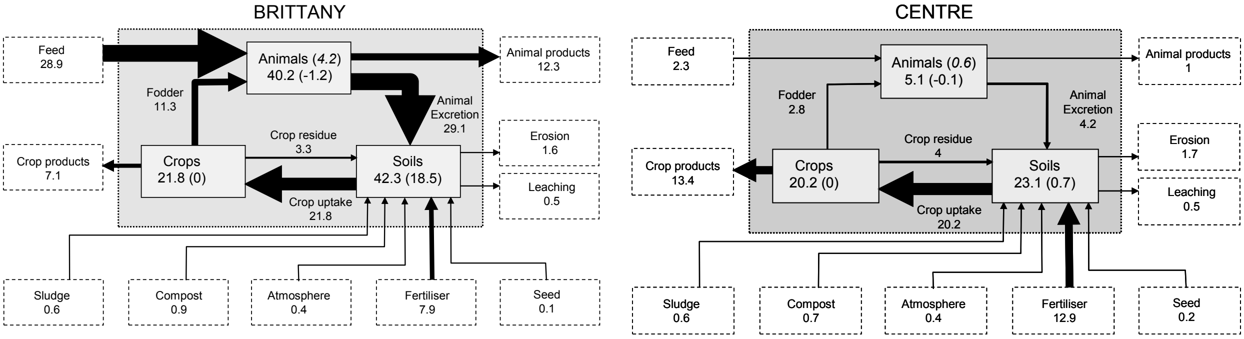

Figure 5. Phosphorus stocks (values in italics), flows and balances (values in parentheses) for two French regions: Brittany and Centre. All values are in kg P ha^{-1} yr^{-1} averaged for the years 2002-2006 (in Senthilkumar et al., 2012).

Conclusion

Phosphorus was first considered and studied as a nutrient, then as a pollutant and recently as a non renewable resource, with an associated shift from micro to macro scale approaches. Proper management of this nutrient in cropping systems at the field scale is a key step for ensuring food production, reducing losses to the environment and reducing depletion of P reserves.

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(20) Phosphorous placement for bulb onions – rates and distances

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Abstract: *In the production of direct sown bulb onions it is normal practice to place a starter fertilizer close to the seeds at sowing. However, in some cases the distance between the starter fertilizer and the seeds becomes too short resulting in salt stress and reduced seedling emergence. The objectives of this experiment were to examine the influence of various fertilizer types, fertilizer rates, and distances between fertilizer and seeds on seedling emergence and plant production. At sowing of bulb onions in early spring in five years 2008-2012, a range of P and NP fertilizers were tested alone or in combination. The treatments resulted in large differences in plant emergence and size of plant seedlings. Starter fertilizers containing N applied in the highest amount and close to the seeds resulted in seedling damages and reduced emergence percentage. The damage was less severe when the amount of starter fertilizer was reduced or when the distance between fertilizer and seeds was increased. Placement of starter fertilizers without N close to the seeds showed less damaging effects. Placement of 44 kg P per ha in a distance of 4-5 cm resulted in high yield. Reduced yield was obtained when the P rate was reduced and when the distance between fertilizer and seeds was larger than 5 cm or especially when the fertilizer was placed close to the seeds. Combining low P amounts close to the seeds and higher P amounts in 4-5 cm distance of the seeds increased the plant production, especially in moist soils.*

Keywords: *Starter fertilizers; plant density; plant production*

Introduction

At direct sowing in April the soil is still cold, and therefore, young plants have difficulties in uptake of sufficient phosphorus (P) (Sheppard and Racz, 1985; Costigan, 1986). Consequently, it is normal practice to place a phosphorus fertilizer in a distance of 5-6 cm from the onion seeds. Usually, this starter fertilizer is an ammonium phosphate placed 4-5 cm below and 3-4 cm aside the seeds.

In some cases, however, the distance between the starter fertilizer and the seeds becomes too short resulting in reduced seedling emergence. The distance may also become too far resulting in reduced growth, due to lack of phosphorus.

Previous studies have shown that the phosphorus uptake is increased if the starter fertilizer consists of a mixture of phosphorus and nitrogen (N) (Miller and Ohlrogge, 1958; Henriksen, 1985; Strasser and Werner, 1995). Later studies showed that the phosphorus uptake and plant growth increased further if the starter fertilizer also included sulphur (Gordon and Pierzynski, 2006).

The optimum distance between the starter fertilizer and the onion seeds has been shown to be 5-10 cm (Cooke et al., 1956; Mulkey et al., 1979; Henriksen, 1985). Shorter distances may be harmful to young plant roots and result in reduced plant growth.

Analysis of the soil showed that the soil pH and the concentration of ammonium were increased in the vicinity of a fertilizer band of ammonium phosphate (Creamer and Fox, 1980; Werner and Strasser, 1993; Thomas and Rengel, 2002). However, this harmful effect of ammonium is influenced by the soil type and the soil acidity.

To overcome problems in reduced seedling emergence and reduced plant growth it was hypothesised that root damages can be avoided by use of starter fertilizers with a reduced amount of nitrogen. To test this, we compared a range of starter fertilizers in various rates and in various distances from the seeds.

Materials and Methods

Field experiments with different starter fertilizers in various rates and in various distances from the seeds of direct sown bulb onions (*Allium cepa* L.) were conducted on a sandy loam soil in five years 2008-2012. All years, the previous crop was spring barley.

At sowing, which took place in the beginning of April each year, the topsoil contained, in mg kg^{-1} dry soil, 18-33 P, 132-165 K, and 39-93 Mg. The pH was 6.0-6.7 and the top 0.5 m contained 19-35 N-min kg ha^{-1}. The soil analysis was performed according to VDLUFA (1991). Phosphorus was extracted with 0.5 M $NaHCO_3$ (Olsen et al. 1954) and 20-30 P mg kg^{-1} dry soil is classified as low to moderate.

The starter fertilizer, which was applied in the same field operation as sowing, was placed in a band in various distances from the seeds and in various rates as described in table 1 and table 2. Plants were established in 1,6 m width beds with 5 rows and at a density of 23 seeds m^{-1} row corresponding to 70 seeds m^{-2}. Besides the starter fertilizer, 124 kg N, 16 kg P, 132 kg K, 75 kg S, and 25 kg Mg ha^{-1} were applied each year. Plants were irrigated and disease controlled according to normal practice.

Table 1. Types and rates of fertilizers applied in 2008, 2009 and 2010, and distances to the seeds.

	2008	2009	2010
Fertilizers with percentages of N-P-K-S			
	Monoammonium phosphate 12-23-0-0	Monoammonium phosphate 12-23-0-0	Monoammonium phosphate 12-23-0-0
	Diammonium phosphate 18-20-0-3	Diammonium phosphate 18-20-0-3	
	Humifirst 16-5-0-0	Humistar 20-15-0-0	
	Triple superphosphate 0-20-0-3	Triple superphosphate 0-20-0-3	Triple superphosphate 0-20-0-3
	TurboSeed 0-21-26-0	TurboSeed 0-21-26-0	
P rates in kg ha^{-1}			
	0, 11, 22, 44	0, 11, 22, 44	0, 11, 22, 44
Distances in cm below the seeds and aside the seeds			
	0, 5x5	0, 2x3, 5x5	0, 2x3, 4x3, 5x3

Table 2. Types and rates of fertilizers applied in 2011 and 2012. The percentage of N, P, K, and S is indicated.

2011		2012	
Fertilizers placed close to the seeds	Fertilizers placed in 4x3 cm distance from the seeds	Fertilizers placed close to the seeds	Fertilizers placed in 4x3 cm distance from the seeds
Triple superphosphate 0-20-0-3	Diammonium phosphate 18-20-0-3	Triple superphosphate 0-20-0-3	Diammonium phosphate 18-20-0-3
PowerStart Food 0-13-4-0		PowerStart Food 0-13-4-0	
PowerStart Feed 9-9-0-0		OnionStart 0-13-4-0	
P rates in kg ha^{-1}		P rates in kg ha^{-1}	
0, 5	0, 17, 39	0, 5	0, 17, 39

The influence of the starter fertilizers on the plant density was measured after plant emergence. Plants were harvested at 80% top fall-down. The net plot size was 10 m^2. The onions were field cured for around two weeks and then dried artificial at 25℃ for two weeks. Subsequently the onions were size graded.

The experiments were arranged in randomized complete block designs with two replicates. Analysis of variance was performed on each variable using the Statistical Analysis System (SAS Institute Inc., 2011) and the effects were tested using the General Linear Models procedure.

Results and Discussion

When the fertilizer contains nitrogen and the rate of fertilizer was high (22 and 44 kg P ha^{-1}), placement of starter fertilizers in the seed row resulted in a significant reduced plant emergence compared to placement in a distance of 2x3 cm (2 cm below the seeds and 3 cm aside the seed row) or 5x5 cm (Figure 1). At a reduced amount of N-rich starter fertilizer (11 kg P ha^{-1}) placed in the seed row, the plant emergence was less reduced. In-row placement of triple superphosphate or TurboSeed, which do not contain nitrogen, reduced the plant density in one of two years.

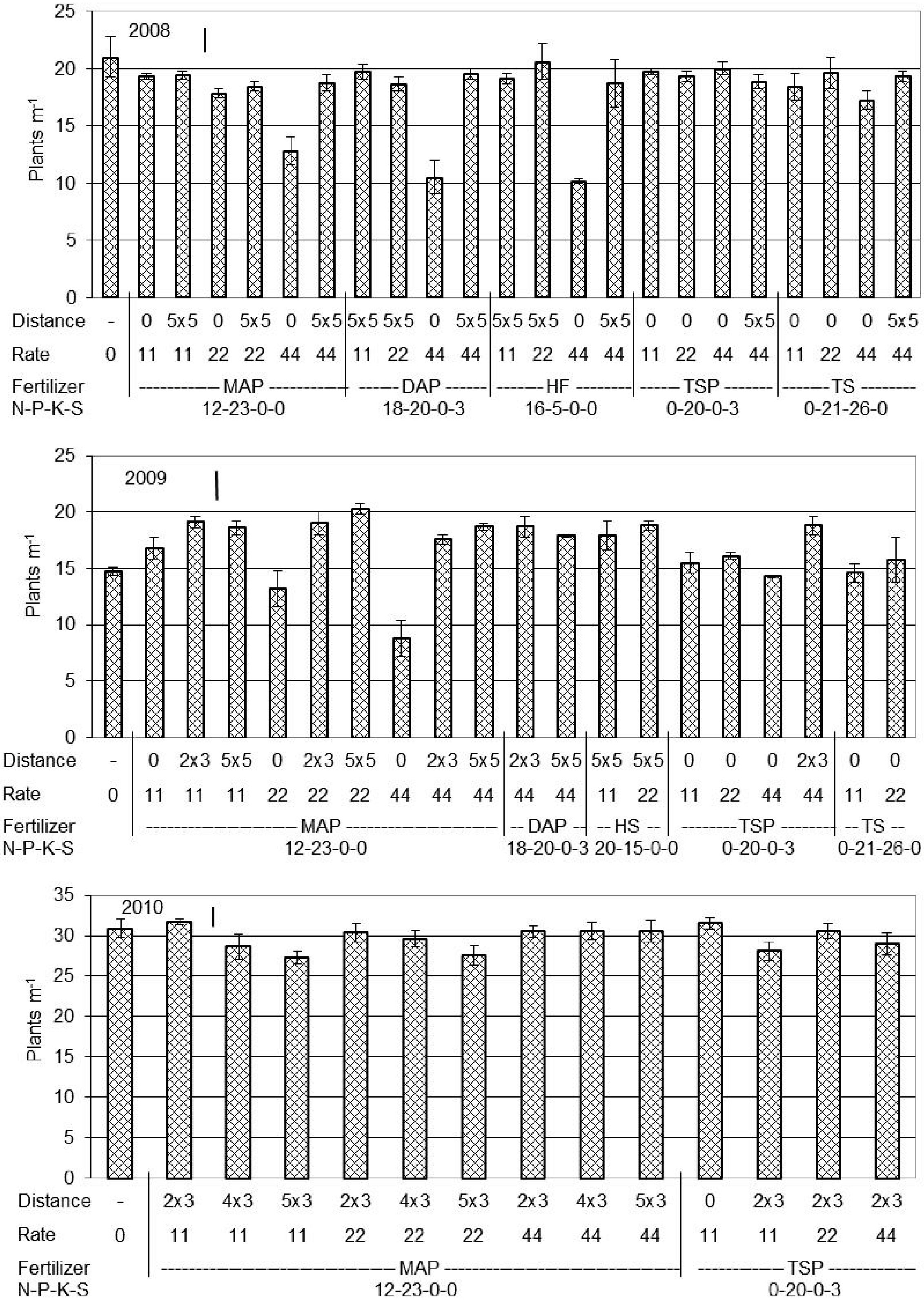

Figure 1. Plant density in plants per row meter as influenced by a range of starter fertilizers in various rates (P kg ha^{-1}) and in various distances from the seeds (cm below the seeds x cm aside the seeds). The starter fertilizers were monoammonium phosphate (MAP), diammonium phosphate (DAP), triple superphosphate (TSP), Humifirst (HF), Humistar (HS), and Turboseed (TS). The bar in top of each figure represents the LSD value.

The reduced plant emergence was probably caused by ammonia toxicity that adversely harms the young plant roots. Zhang and Rengel (2002) showed that the ammonium concentration in soil solution was highly increased in a distance of several cm from a band of diammonium phosphate. Toxicity was, however, very much influenced by soil type and soil acidity (Zhang and Rengel, 2003).

At a distance of 2x3 cm or 5x5 cm, the plant density was unaffected by the rate and type of starter fertilizer in 2008 and 2009. In 2010, however, the plant density tended to decrease as the distance between fertilizer band and seeds increased. This response that was seen at a P rate of 11 and 22 kg ha^{-1} is unknown.

The low plant density obtained when high rates of nitrogen-rich starter fertilizers were placed in the seed row resulted in significant lower final onion production compared to placement in a distance of 2x3 cm or 5x5 cm (Figure 2). Due to the low density, these onions were large in size. Placement of lower rates of nitrogen-rich starter fertilizers in the seed row did not reduce the onion production. However, the proportion of large onions was larger after placement of nitrogen-rich starter fertilizers in the seed row compared to placement in a distance of 5x5 cm. This finding could be due to some early growth stress.

The advantage of P placement in onions has previously been proved by Cooke et al. (1956), Mulkey et al. (1979), and Henriksen (1985). Their overall conclusion is that plant production was influenced more by placement than the rate of application. Later, the effect of fertilizer placement in onions has been shown to be influenced by the soil P status (Costigan, 1988; Stone, 1998) and the soil moisture (Rahn et al., 1996). The effect of placement was reduced in fertile soil or in dry soil. In the present experiments, placement increased plant production in three of five years and was not clearly related to soil P. In 2010, plant production was not influenced by placement although the soil P was classified as low (18 mg P kg^{-1} dry soil).

In 2009, the onion production increased at increased rate of mono-ammonium phosphate placed in distances from 2x3 cm to 5x5 cm from the seeds. However, this result was not seen in 2008. A closer examination on the optimum distance between fertilizer band and the seeds showed that the highest plant production was obtained when the distance was 2-3 cm below the seeds and 2-3 cm aside the seeds (data not shown). In 2010, the P rate increased plant production at distances 2x3 cm and 4x3 cm, but not at 5x3 cm.

The influence of distance between fertilizer and onion seeds has been examined by Mulkey et al. (1979), who found that the optimum distance was 2,5 and 5 cm directly below the seeds after placement of 22 and 44 kg ha^{-1} P with triple superphosphate, respectively. The plant production decreased at increased lateral distance between the P fertilizer and the seeds.

Placement of starter fertilizers in a short distance (e.g. 3-4 cm) from the seeds may be risky. If something goes wrong, the seeds may be sown too close to the placed fertilizer band and the young plants may be damaged. Therefore, the distance should be not less than around 5 cm unless it is possible to fully control the distance. This is not the case with the placement equipment that is used at present, but should be possible with new technical solutions.

Results from 2008-2010 showed that in-row placement of starter fertilizers without nitrogen was less harmful compared to nitrogen-rich fertilizers, especially at low rates. In 2011-2012, therefore, 5 kg ha^{-1} P was applied in the seed row. However, placement of 5 kg ha^{-1} P with PowerStart, OnionStart, or triple superphosphate did not significantly increase the onion production (Figure 3). But combining this low-rate in-row starter fertilizer with a high-rate nitrogen-rich starter fertilizer placed in a distance of 4x3 cm from the seeds resulted in increased onion production. The highest production was obtained when a total of 44 kg ha^{-1} P was applied.

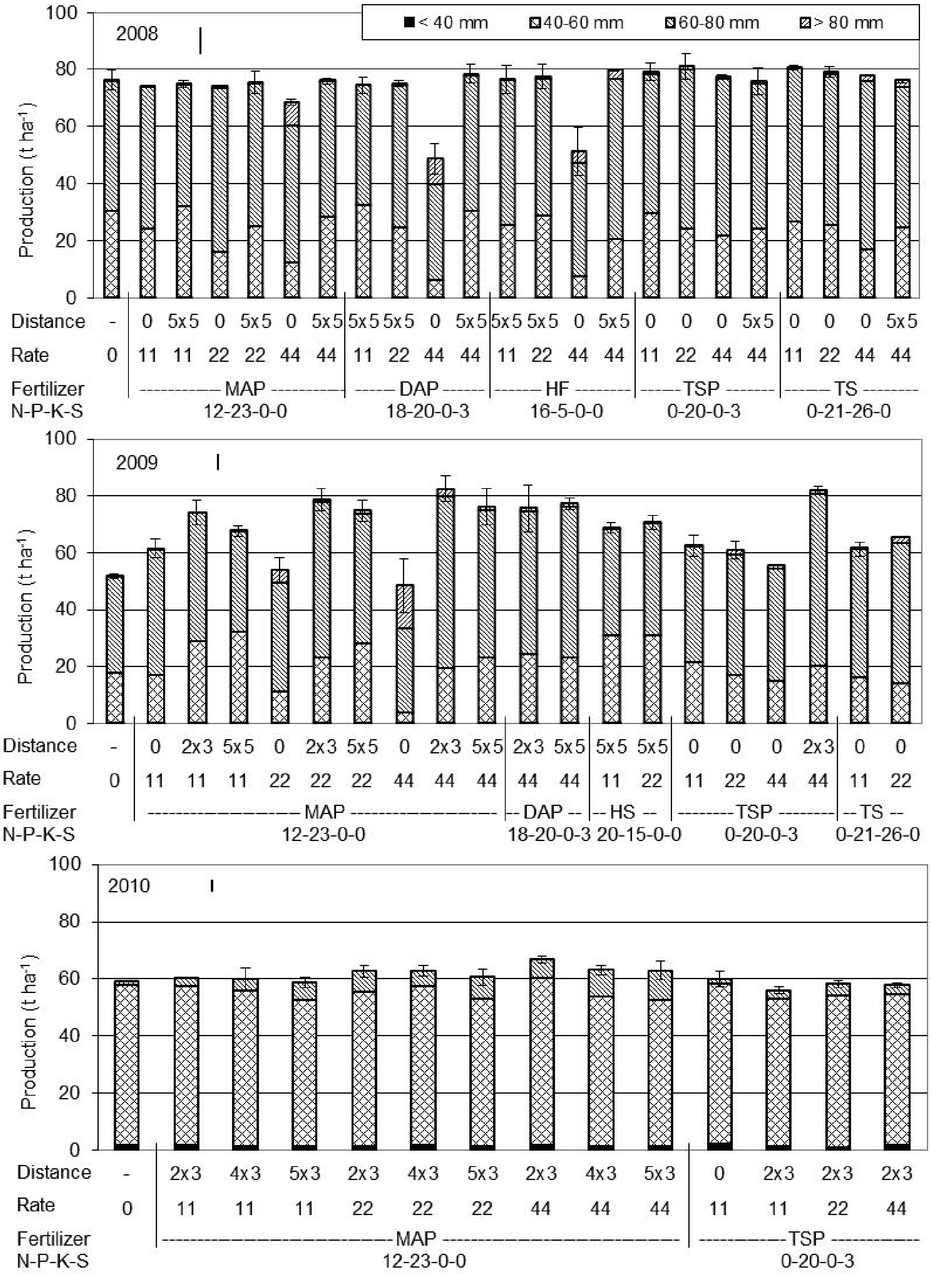

Figure 2. Plant production and size distribution of onions applied starter fertilizers in various rates (P kg ha^{-1}) and in various distances from the seeds (cm below the seeds x cm aside the seeds). The starter fertilizers were monoammonium phosphate (MAP), diammonium phosphate (DAP), triple superphosphate (TSP), Humifirst (HF), Humistar (HS), and Turboseed (TS). The bar in top of each figure represents the LSD value.

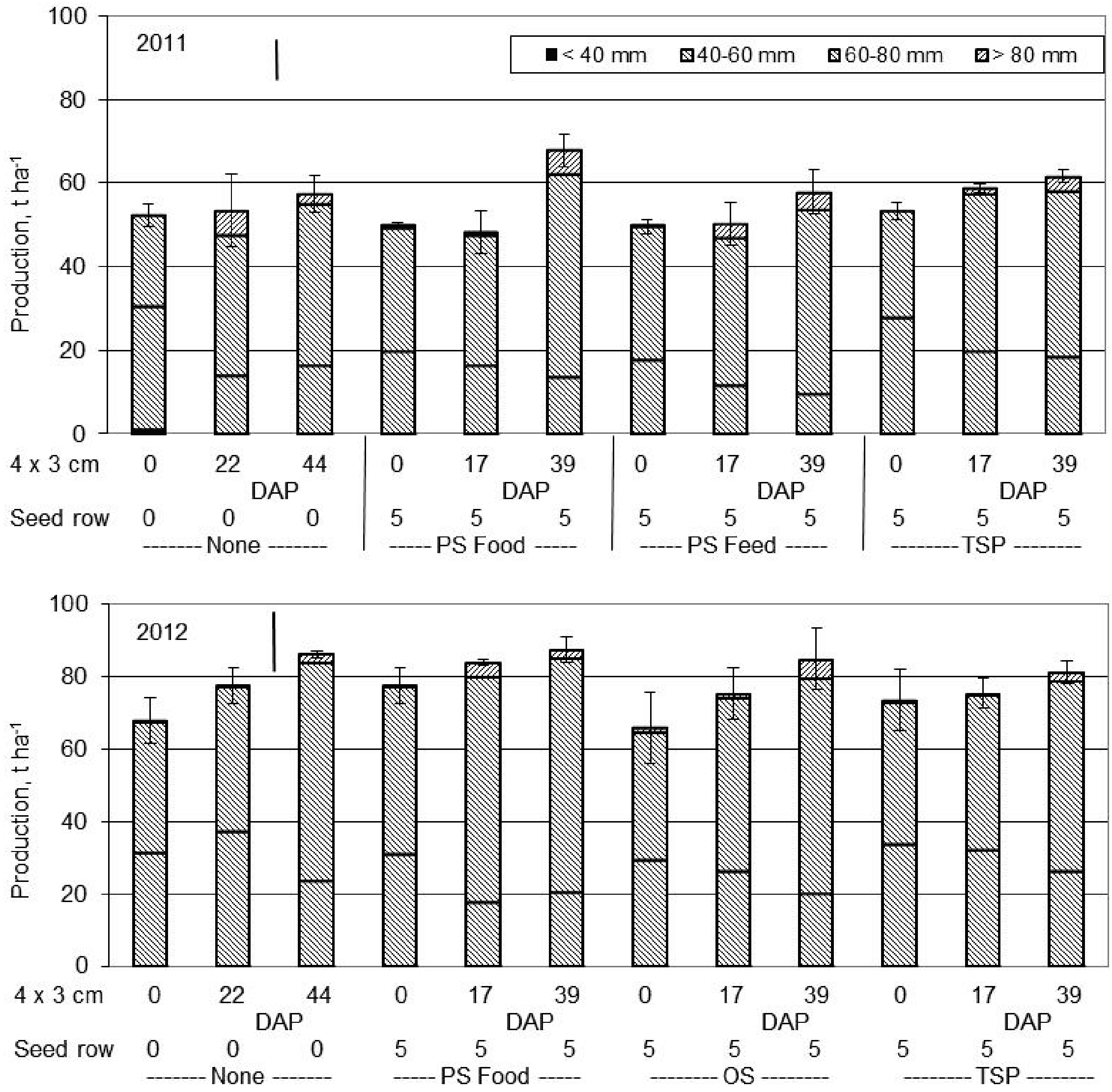

Figure 3. Plant production and size distribution of onions in relation to various combinations and rates (P kg ha^{-1}) of starter fertilizers placed in the seed row and diammonium phosphate (DAP) in a distance of 4 cm below the seeds and 3 cm aside the seeds. The starter fertilizers placed in the seed row were PowerStart Food, PowerStart Feed, OnionStart (OS), and triple superphosphate (TSP). The bar in top of each figure represents the LSD value.

Conclusion

N-rich starter fertilizers at a rate of 44 P kg ha^{-1} placed close to the seeds resulted in seedling damages and reduced emergence. Reduced P rate or increased distance to the seeds resulted in reduced seedling damages. Placement of 44 P kg ha^{-1} in a distance of 4-5 cm resulted in the highest yield in three of five years. Reduced yield was obtained when N-rich starter fertilizers was placed close to the seeds or when the distance between fertilizer and seeds was higher than 5 cm. Combining low P amounts placed in the seed row and higher P amounts in 4-5 cm distance of the seeds did not increase plant production compared to placement of all P in 4-5 cm distance.

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(21) The phosphorus cycle in North-West European agricultural soils

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Abstract: Phosphorus (P) concentrations in NW European surface waters generally exceed ecological thresholds. The Nitrates Directive and the Water Framework Directive have asked EU Member States to address this problem. The resulting monitoring networks and P concentration standards differ widely between Member States. Because agriculture is considered to have a large impact on the surface water P concentrations, the diffuse P losses from soils with high P contents are targeted. Attempts have been made to reduce the soil P concentration under the threshold above which P losses increase exponentially. However, agro-economic interests should also be taken into account. A target zone of soil P concentrations with optimum crop yields and limited P losses can be defined. In order to reach or stay in this target zone, fertilisation recommendations should be adapted to include the risk for P losses. Soil P application standards are ideally differentiated to soil P concentrations. In this way, soils with large P concentrations should receive less P in order to reduce the P losses and soils with small P concentrations can receive more P to ensure satisfactory crop yields.

Keywords: *surface water, P losses, P standards*

Introduction

Algal blooms, the result of excess phosphorus (P) in the water, decrease the ecological status of surface waters in Europe. Because P is the limiting nutrient for primary production (Correll, 1999), actions to decrease P concentrations in surface water are being taken under the European Nitrates Directive and the Water Framework Directive. It is unclear, however, whether the main proposed action, i.e. reducing P fertilisation by lowering agricultural P application standards, is an efficient tool to reduce P concentrations in surface water. Moreover, questions have arisen in relation to the impact of reduced phosphorus application on crops and soil. A literature study on P processes in soil and plant and on legislation aims to shed light on these uncertainties and propose guidelines for efficient measures to reduce P concentrations in surface waters.

Materials and Methods

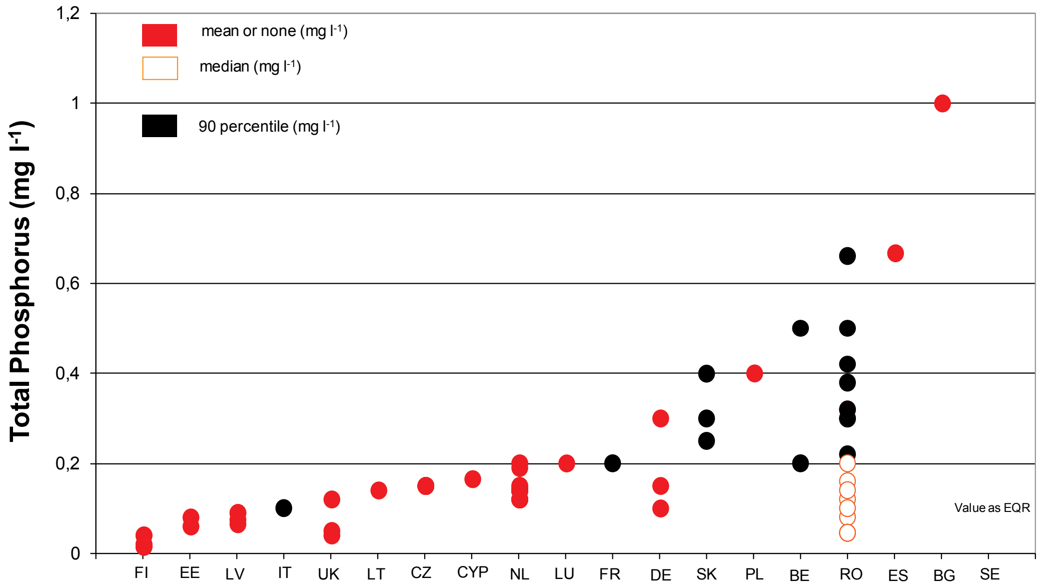
A literature study was performed on the P cycle in agricultural soils. The focus of the literature study was on Flanders (Belgium), but other European countries were also considered.

Results and Discussion

Phosphorus in surface waters

Phosphorus concentrations in many European surface waters are above ecological thresholds, resulting in algal blooms (Sharpley and Rekolainen, 1997). The Water Framework Directive of the European Union (2000) aims to reach a good ecological status or potential for the surface waters by 2015. Member States are requested to define ecological reference conditions and ecological classifications (very good, good, moderate, poor and bad) for each surface water type present in the country. Relationships between chemical/physical conditions and ecological status can then result in P concentrations related to the ecological class boundaries. The P concentration for the good/moderate boundary then becomes the P standard for that specific surface water type. In an attempt to harmonise the P standards in the different Member States, a non legally-binding document, 'Guidance Document' (Anon., 2009) was published. An intercalibration exercise between the Member States was also performed between 2004-2007. Despite these initiatives, P standards between Member States differ and are difficult to compare given the differences in kind of concentration (total versus ortho phosphorus concentration), statistics (mean, median or 90th percentile), water type, time of measurement (summer or year mean), etc. Claussen et al. (2012) did attempt a comparison in spite of these differences (Figure 1). Phosphorus standards for surface waters in Flanders are not present in the study of Claussen et al. (2012) but are listed in Table 1 (Anon., 2010).

a)



b)

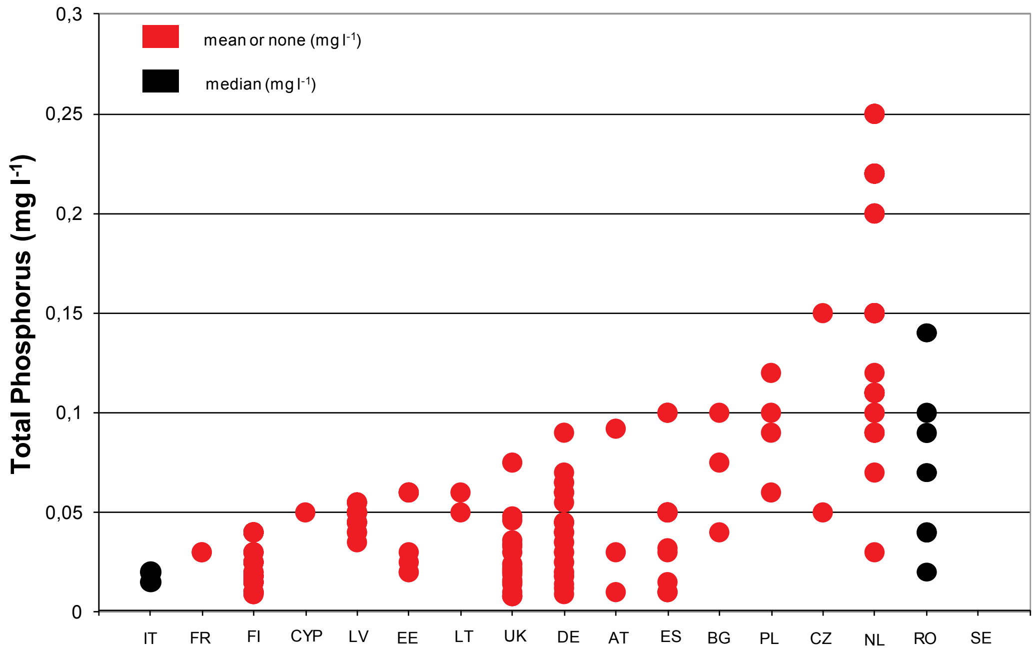


Figure 1 Phosphorus standards (moderate/good boundary) for total phosphorus concentration in Europe for (a) rivers and (b) lakes. Arrangement from left to right is not necessarily in order from good to bad because differences can be attributed to different water types, climate, statistical interpretation, etc. (from Claussen et al. (2012)).

Table 1 Phosphorus standards for surface waters in Flanders (Anon., 2010)

Parameter	Water type	P standard (mg/l)
Total P concentration (summer mean[a])	Rivers	0.14
	Lakes	0.03-0.11
Ortho P concentration (year mean)	Large rivers, brackish waters, estuarial waters	0.14
	Small and very large rivers	0.12
	Brooks	0.10
	Brooks in the Campine	0.07
	Lakes	/

[a] between April 1[st] and September 30[th]

Not only P concentration standards, but also the monitoring networks vary between the Member States. Guidelines for the monitoring required for the Water Framework Directive are listed in a non-legally binding Guidance Document (Anon., 2003). Monitoring is also required for the Nitrates Directive, but guidelines for the monitoring of the effect of the action programmes are not present in the Draft Monitoring Guidelines (Fraters et al., 2011). As a result, monitoring networks differ widely. Densities of the networks are largest in Belgium and smallest in Finland (Table 2).

Table 2 Densities of ground and surface water monitoring networks for the Nitrates Directive in European countries (van Grinsven et al., 2012)

	Groundwater (points/1000 km²)	Surface water (points/1000 km²)
Belgium	99	38
Germany	3	1
Denmark	34	5
France	5	3
Ireland	1	3
The Netherlands	33	13
United Kingdom	13	33
Finland	0.2	0.4
average	**13.7**	**7.4**

The phosphorus standards are generally exceeded in a lot of European countries. Recent evaluations reveal that 60% of the measuring points in the monitoring network of the Nitrates Directive in Flanders have average phosphorus concentrations above the P standard (*Vlaamse Landmaatschappij*, 2012). This percentage is 57% for The Netherlands (Klein et al., 2012). Agriculture is considered to be a large contributor to the P pressure on surface water (Sharpley and Rekolainen, 1997). The estimated share of agriculture in the phosphorus load of surface water in Flanders is 44% (Van Steertegem, 2013). Fifty-four percent of the P load of surface water in the Netherlands originates from soil leaching and runoff (van der Bolt, 2012). In order to reduce the surface water P concentrations to meet the Water Framework Directive goals, agriculture seems to be the main target sector for P measures.

Phosphorus in agricultural soils

Due to historically large P fertiliser additions, P levels in agricultural soils are high in northwestern Europe. Phosphorus losses from soils (runoff and leaching) are considered to increase with increasing soil P concentrations (Tunney et al., 1997; Rubaek et al., 2010). Often a threshold soil P concentration is observed above which P losses increase exponentially (McDowell and Sharpley, 2001) (dashed line in Figure 2). Although it is recognised that transport and hydrological factors are also important for soil P losses (Haygarth and Jarvis, 1999), the high soil P concentrations seem to be the main target for reducing the large impact of agriculture on surface water P concentrations.

But not only soil P losses are influenced by soil P concentrations. Crop yield and quality are also largely affected by the available soil P concentrations (solid line in Figure 2). Farmers are reluctant to decrease P fertilisation because they fear that the resulting smaller soil P concentrations will induce smaller crop yields. In fact, none or only minimal crop yield reductions are expected within ten years if P inputs are smaller than P export numbers, given the large soil P reserves in northwestern Europe (Jungk et al., 1993; Gallet et al., 2003). Effects occur faster for grasslands, especially for plant P concentrations (Ehlert et al., 2008). Whether effects on crop yield and quality occur largely depends on the P input-export difference and the initial soil P concentration (position on the solid line in Figure 2).

A target zone is defined (Figure 2) to assure optimum crop yields and minimal soil P losses. Grassland studies in Ireland (Tunney, 2002) suggest that threshold values for rapidly increasing P losses are at the upper end of the range for optimum grassland production. This small target zone is therefore the optimal soil P concentration range from both an agro-economical and an ecological point of view. Soils with P concentrations smaller than the target zone (left side of Figure 2) have sub-optimum yields and can increase the soil P concentration by P fertilisation with limited ecological risk. Soils with P concentrations larger than the target zone (right side of Figure 2) can reduce the P losses by P fertilisation reduction, i.e. smaller input than export, without risks for crop yield reductions. Soils within the target zone ideally stay in the target zone by balancing P inputs and exports (equilibrium fertilisation).

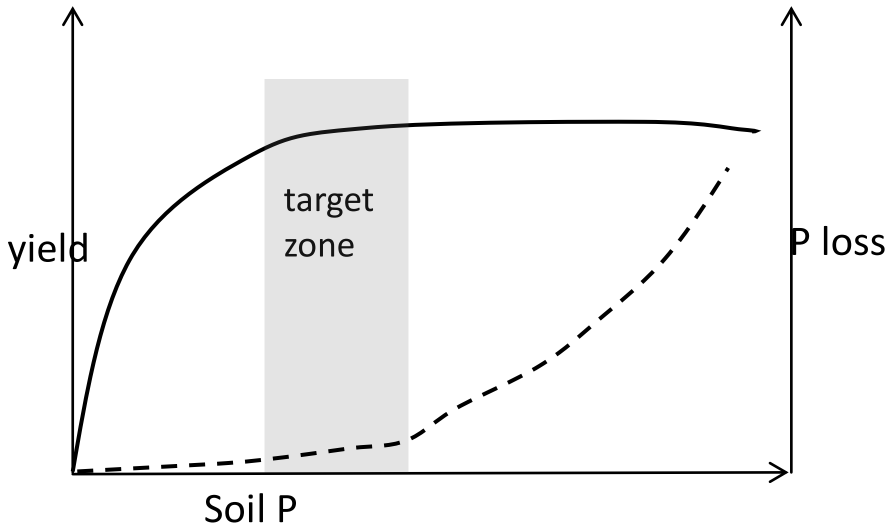


Figure 2 Crop yield (solid line) and soil P loss (dashed line) vary with increasing soil P concentration. A target zone with optimum yields and limited P losses is defined.

Reaching the target zone for soil P concentration: fertilisation advice and application standards

The target zone defined in Figure 2 is the optimum for agriculture and environment considered together. Fertilisation advice systems mainly consider agricultural interests, and the target zone recommended by fertilisation advisers therefore does not always equal the target zone defined in Figure 2. Target zones for P fertilisation advice differ widely across Europe (Jordan-Meille et al., 2012). For instance, the phosphorus concentration range for the fertilisation target zone in Flanders is 2-3 times higher than for the fertilisation target zones of other European countries using the same soil P test (ammonium lactate extraction). Moreover, recommended fertilisation P doses for the fertilisation target zone in Flanders (Maes et al., 2012) are generally larger than the P doses exported by the crops (Ehlert et al., 2009; Anon., 2011) resulting in steadily increasing soil P concentrations. This can be visualised by a movement to the right on the curves in Figure 2.

Some European countries have P fertilisation standards whose aim is to reduce or limit soil P concentrations (Table 3). In Sweden and Slovenia, only standards for organic P fertilisation exist. However, most countries do not have any P application standards.

Table 3 Phosphorus application standards in European countries

Country (region)	Differentiation	P fertilisation standard (kg P_2O_5/ha/yr)
Belgium (Flanders)	Crop	65-95 (55-90)[a]
The Netherlands	Soil and agricultural system[b]	55-120
Ireland	Soil and crop	0-286
Sweden	-	50[c]
Slovenia	-	120[c]
France (Brittany)	Type of farm	183-218

[a] First numbers: for 2013-2014. Numbers between brackets: proposed standards from 2017 on. Standard for phosphate saturated soils: 40 kg P_2O_5/ha/yr; [b] Agricultural system: grassland or arable crops; [c] Standards only for organic P fertilisation.

The P application standards in Flanders are differentiated to the cultivated crop. Since the amount of P exported by the crop depends on the kind of crop (Ehlert et al., 2009), crop differentiation of the application standards is necessary to attain equilibrium conditions. In fact, P application standards in Flanders are slightly smaller than crop export doses resulting in slightly negative soil P balances (Anon., 2011). This results in a very slow movement to the left in Figure 2, regardless of the initial soil P concentration. Soils with excessive soil P concentrations will therefore maintain high soil P concentrations for many years (not environmentally optimal), while soils with sub-optimum P concentrations will remain to the left-hand side of the target zone in Figure 2 (not agro-economically optimal). In contrast, P application standards in the Netherlands are differentiated to the soil P concentration. Soils with large P concentrations have smaller P application standards than soils with small P concentrations. This results in a movement to the right for soils located on the left-hand side of the target zone in Figure 2, and a movement to the left for soils located on the right-hand side of the target zone. Standards in the Netherlands therefore better account for the agro-economical and environmental issues than the standards in Flanders do. Standards in Ireland are differentiated both to crop and soil P concentration. The application standards in Ireland can be much larger than in the Netherlands and in Flanders, but soils with excessive P contents can be restricted to no P fertilisation at all (Table 3).

Despite the attempts to reduce P fertilisation, phosphorus concentrations in surface waters remain high. Models predict only small decreases in surface water P concentrations due to fertilisation reduction (van der Bolt et al., 2008; Groenendijk et al., 2012). The question thus arises whether alternative measures (e.g. water bodies and drainage management and chemical and hydrological measures) would not be more cost-efficient to reach the Water Framework Directive goals (Schoumans and Kruijne, 1995; van der Bolt et al., 2008). It is also questioned whether point sources are not the main contributors of P loads towards water bodies (Jarvie et al., 2006; Greene et al., 2011). The conclusion that in many cases even after several decades of P nutrient mitigation no improvement in water quality is observed, calls for a more holistic approach of eutrophication management (Jarvie et al., 2013).

Conclusion

Actions need to be taken to reduce the high phosphorus concentrations in European surface waters. The Nitrates Directive and the Water Framework Directive introduced monitoring networks and P concentration standards in Europe, but large differences between Member States exist. It appears that diffuse P losses from agricultural soils with large P contents have large impacts on surface waters. To increase the chance of success, measures to reduce this impact should take both agro-economical and environmental interests into account. Phosphorus fertilisation advice systems should therefore also consider the risk for P losses, and P application standards are preferentially differentiated for the soil P content in order to reach the target zone for optimum crop yield and limited P losses.

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(22) The effect of different fertilizer types on soil P conditions, crop yield and P leaching potential

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Abstract: *A history of excessive fertilization in Flanders' intensively managed agriculture, causes severe nitrogen (N) and phosphorus (P) losses to water bodies. The local government took action from the 1990s onwards, by introducing restrictions to N and P fertilizer use. These restrictions also limit the supply of organic matter to the soil, while the soil organic matter level of many agricultural soils is suboptimal in Flanders. Moreover, P is an immobile nutrient and P fertilizer efficiency is low as only a minor part is directly available for plant up-take. We compared the effect of three compost types, cattle slurry, farmyard manure and mineral fertilizers on crop yield, soil organic carbon content, P availability, P export and P leaching in a long-term field experiment with arable, vegetable and fodder crops. Organic fertilizer doses were calculated every year for equal C input, and were always combined with mineral NPK. Total N supply fulfilled the demands of the crops and total P input was set equal to 100kg* P_2O_5*/ha.yr. As expected, farmyard manure and compost are the best options to enhance the total organic carbon level of the soil. Cattle slurry and mineral fertilizers tended to produce lower crop yields. P plant availability increased in the farmyard manure treatment, but did not lead to extra P export. Probably the soil delivers already sufficient P to the crops, and increasing P availability is not necessary. In a column leaching experiment in unsaturated conditions based on soil samples of this field experiment, increased potential P leaching was observed in the farmyard manure treatment. We conclude that evolution in soil organic carbon level and P plant availability, but also potential P leaching is dependent on organic fertilizer type. Compost shows to be an interesting product, as it can gradually increase TOC level, without increasing potential P leaching losses. Moreover compost has a positive effect on crop yield.*

Keywords: *long-term field experiment; P leaching experiment; P plant availability; potential plant available P ; total organic carbon level*

Introduction

Northern Belgium (Flanders) has a history of intensive agriculture and a large livestock. Large amounts of animal manure were spread on agricultural land, with increasing soil N and P status as a result. Crop yields increased, as did nutrient losses to the environment. P transfer from agricultural land to water bodies can lead to eutrophication. Surface water contamination with P became a major problem (Chardon & Schoumans, 2007). In response to this problem, the Flanders' government introduced several 'manure action plans' to reduce the nutrient losses, mainly by restricting inorganic and organic fertilizer doses. Despite these restrictions, P concentrations in surface and ground water decreased little. This could be expected, since allowed P fertilization remained until 2011 still higher than crop requirements. Anno 2013 P fertilization is further restricted to meet crop requirements. Although this does not lead to further soil P accumulation, the soil P status of most soils is very high and continues to be a source of P losses.

In the last two decades, the soil organic carbon content decreased due to changes in management such as increasing plough depth (dilution effect), higher harvest indices, but also a decreased use of animal manure (Sleutel et al., 2006). To maintain the soil organic carbon content at optimal level and subsequently soil quality, action is needed. Possibly there is an opportunity with organic fertilizers that have a high C stability. Also organic fertilizers with higher C/P ratios are interesting for supplying C while respecting the P fertilizer limits.

Significant P losses through P leaching are always ascribed to the high P status of soils, which is proven several times in field and lab experiments. P status of soils is the basis of the Van der zee principal of P saturation. We were interested if also fertilizer type and soil organic carbon content can influence the potential P leaching. In several studies column leaching experiments are used to estimate the effect of certain fertilization management types (Lookman, 1995; Siemens et al., 2008; Ashjael et al., 2010) on potential P leaching.

The objective of this research is to study the effects of long-term use of different types of animal manure, compost and mineral fertilizers on crop yields, P availability, soil carbon content and potential P leaching.

Materials and Methods

FIELD EXPERIMENT

In 2005, a long-term field experiment was started in Melle (experimental site of Ghent University, 50°59'N, 03°49'E, 11 m above sea level), Belgium. Prior to the experiment the field was cultivated with monoculture maize for 8 years with mineral fertilization only. The soil contains 11.7% clay (0-2 μm), 52.0% silt (2-50 μm) and 36.3% sand (>50 μm), and its texture can be classified as sandy loam (Belgian classification) or silt loam (USDA). The experiment is a randomized complete block design with 4 replicates comparing 8 fertilizer treatments: MIN (only mineral fertilizers), FYM (farmyard manure), CSL (cattle slurry), VFG (vegetable, fruit and garden waste compost), CMC1 (farm compost, low C/N), CMC2 (farm compost, high C/N), NF+ (no fertilizer) and NF- (fallow). NF+ and NF- can be considered as control treatments (Leroy, 2008). The crop rotation consisted of fodder beet (*Beta vulgaris* L.) in 2005, winter wheat (*Triticum aestivum* L.) in 2005/2006, phacelia (*Phacelia tanacetifolia* Benth.) in 2006/2007, red cabbage (*Brassica oleraceae* L. var. *rubra*) in 2007, perennial ryegrass (*Lolium perenne* L.) in 2008, forage maize (*Zea mays* L.) in 2009, fodder beet in 2010, red cabbage in 2011, potatoes (*Solanum tuberosum* L.) in 2012, Rye (*Secale cereale* L.) in 2012/2013 and forage maize in 2013. The above ground crop residues including the catch crops phacelia and rye, were removed by hand after harvest. The dosage of the CSL treatment is yearly calculated with a N balance method. The other organic fertilizer treatments are set equal to the CSL treatment for C input (2000-3000 kg C/ha.yr). Mineral N was applied to correct for differences in plant-available N of the organic amendments. If P and K supply through organic fertilizers was below 100 kg P_2O_5/ha.yr and/or 300 kg K_2O/ha.yr respectively, additional mineral P and K fertilizers were added to become an equal P and K supply in every fertilized plot. Since no organic fertilizers were added in treatment MIN, P and K were entirely supplied in form of mineral fertilizers. In all cases, the organic amendments and mineral fertilizers were incorporated to a depth of 30 cm using a spading rotary tiller just before planting or sowing. During the experimental period, the NF- plots were kept fallow by removing weeds manually. During the field trial DM (dry matter) crop yield, TOC (total organic carbon) level and pH-KCl were measured on several occasions. In 2011 and 2012, P plant availability (0.01M $CaCl_2$ extract; P-$CaCl_2$), potential plant available P (ammonium lactate extract, pH 3.75; P-AL) and P export were intensively measured. Hot water extractable P was also measured (HWP), similar to hot water extractable C (HWC) as a simple method to measure the labile P fraction of the soil. The data of the soil samples were analysed using One way ANOVA's and Scheffé's test.

SOIL COLUMN EXPERIMENT

On December 13th 2011, soil samples (0-30 cm) were taken with an auger in 3 replications of all 8 treatments. The soil samples were thoroughly mixed and stored in closed plastic bags (0-4°C). On January 9th 2012 a soil column experiment in unsaturated conditions was started with soil samples of CSL, FYM, MIN, NF- and VFG. Since a limited number of glass fibre filters were available, a second leaching experiment in the same circumstances was started May 9th 2012 , for soil samples from the treatments NF+, CMC1 and CMC2. FYM and NF- were also included, to check the repeatability of the leaching experiment.

Out of each bag, the equivalent of 1.374 kg dry soil was transferred to a soil column, to conduct the experiment. This quantity was chosen based on the chosen soil bulk density (1.4 kg/dm³) and the dimension of the soil columns for the leaching experiment.

The percolation equipment consisted of a vacuum pump, a peristaltic pump, 15 glass fibre filters (porosity 10-16 µm), 15 filtrate bottles and a digital pressure gauge. The glass fibre filters served as soil columns, and were placed on the filtrate bottles. These bottles were connected with tubes to the pressure gauge and the vacuum pump. The set-up was based upon the study of Lookman (1995). On top of the soil a common paper filter was placed. Afterwards, the glass fibre filter was covered with parafilm. The peristaltic pump permanently provided an aqueous mixture of 'artificial rain' (pH 5.45), which consisted of 0.02 mM SO_4^{2-}, 0.04 mM Cl^- , 0.02 mM Ca^{2+}, 0.003 mM K^+, 0.02 mM Na^+. This composition was based upon the composition of 'artificial rain' used by Lookman (1995) and the composition of rain nearby Chimay (Belgium), measured by André et al. (2006). The water flow rate was 2.85 ml/h. This water flow was only interrupted whenever a water sample was taken. The digital pressure gauge controlled the vacuum pump, so that the pressure in the whole system was held at 10 kPa below atmospheric pressure (= pressure of a sandy soil at field capacity). Thus the soil columns were held permanently in unsaturated conditions. The entire system was installed in the dark, at a constant temperature of 18.0 ± 0.5°C. As the soil was not at field capacity at the start of the leaching experiment, it took several days before field capacity was reached and the first drops of water leached at the bottom of the column. After 7 days, the first water sample in the filtrate bottles was collected. From then on a water sample was collected twice a week. The TP concentration in the water samples was measured with ICP-OES immediately after collection. A subsample was taken from each water sample, which was filtered over a membrane filter of 0.45 µm. The Total Dissolved P (TDP) and Total Dissolved C (TDC) were measured respectively as the total P and total C concentration in the filtrate by ICP-OES. Also the total Fe concentration in the filtrate (0.45 µm) was measured. Orthophosphate (OP) concentration was measured via Ion Chromatography (IC) in the filtrate (0.45 µm). The leaching experiment lasted 36 days, and a rainfall of 200 mm/m² was simulated.

The TP, TDP, TDC and OP concentrations in the water samples are calculated as a function of the percolated water : Total Pore Volume (ΔV/TPV) ratio. The TPV is estimated as followed:

$$\text{TPV}(\%) = 100 \times \left(1 - \frac{1.4}{2.65}\right) = 47.17\%$$

With 1.4 kg/dm³ as the soil bulk density in the columns and 2.65 kg/dm³, as the soil particle density. Given a sample volume of 981.8 ml, the TPV corresponded to 463.1 ml per soil column. Statistics (One way ANOVA's) of the leached P were based on the slope of cumulative percolation curves.

Results and Discussion

CROP YIELD

In 2006, the winter wheat yield was not measured, because the crop yield was completely destroyed by lodging. Only in 2005, 2008 and 2013 significant ($p<0.05$) differences in DM crop yield were observed (figure 1). However in 2005 this was probably only due to the lower yield of fodder beet, which was a result of soil compaction due to tillage of a very wet soil (very high precipitations), in combination with the addition of liquid manure (Leroy, 2008). In 2008, the fertilizer strategy did not allow to give a 2nd and 3rd N fraction to the perennial ryegrass. Probably, all available inorganic N was assimilated by the crop before the first cut. We presume that in the CMC1, CMC2 and FYM treatments there was a higher N delivery through an enhanced N mineralization after the first cut. In 2013, only the rye yield was included. As rye served as catch crop, it was not fertilized. Because the temperature in autumn of 2012 was rather high, and the rye was sown early September, we expected to see an effect of N mineralization. Indeed MIN and CSL, the treatments with the lowest expected N mineralization had lower crop yields for rye.

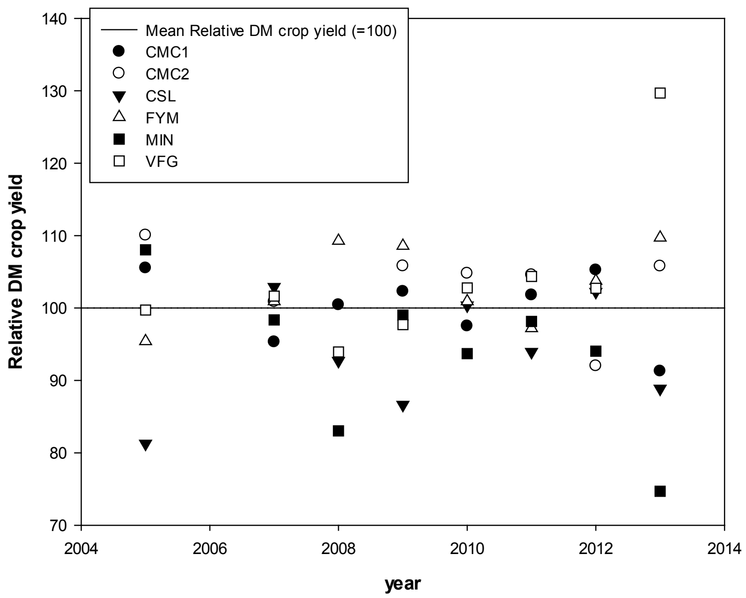

Figure 1 The DM crop yield per year, relative to the mean DM crop yield of the fertilized treatments (MIN: only mineral fertilizers; FYM: farmyard manure; CSL: cattle slurry; VFG: vegetable, fruit and garden waste compost; CMC1: farm compost, low C/N; CMC2: farm compost, high C/N).

Although yearly differences in crop yield were rather small, the use of mineral fertilizers (MIN) and cattle slurry (CSL) led in most years to lower crop yields than compost (VFG, CMC1 and CMC2) and farmyard manure (FYM). When calculated over the entire period of the field trial (2005-2013), significant differences ($p<0.05$) are observed in the overall mean relative DM crop yield:
CSL^{a} (94)<MIN^{a} (94)<CMC1^{ab} (100)<FYM^{ab} (103)<VFG^{ab} (104)<CMC2^{b} (106). The DM crop yield of the control treatment NF+ fluctuated from 31 (maize, 2009) to 75% (potatoes, 2012) of the mean DM crop yield of the fertilized treatments.

TOTAL ORGANIC CARBON & pH-KCl

At the start of the field experiment the TOC level was 1.01%. In the control treatment NF+ and the mineral fertilizer treatment MIN, only root and stubble residues could contribute to the soil organic carbon. All aboveground biomass was removed each year. The TOC level of MIN and NF+ differed little from NF- (table 1), but the addition of organic fertilizers led to a clear increase of the TOC level. Although C input was equalized for all organic fertilized treatments, there was a clear and sometimes significant ($p<0.05$) influence of the organic fertilizer type used. VFG compost and cattle slurry led to the highest and lowest increase in TOC, respectively. As expected, C mineralization of the different organic fertilizers is different due to differences in C stability. Also mineralization processes of soil organic matter will change over time after a given fertilizer strategy is introduced.

Table 1 Soil parameters of the field experiment, measured in 2011 and/or 2012 for all treatments (TOC: Total Organic C level; P-$CaCl_2$: P plant availability, 0.01M $CaCl_2$ extract; HWP: hot water extractable P; P-AL: potential plant available P, ammonium lactate pH 3.75 extract; DS: dry soil). The letters indicate significant different groups (Scheffé-test, p<0.05).

Treatment[1]	TOC 2011 (%)	pH-KCl 2012	P-$CaCl_2$ 2011 (mg P/kg DS)	P-$CaCl_2$ 2012 (mg P/kg DS)	HWP 2012 (mg P/kg DS)	P-AL 2012 (mg P/100g DS)
NF-	0.97[a]	5.53[ab]	2.6[ab]	3.3[ab]	17.5[ab]	22.9[a]
NF+	1.05[ab]	5.48[ab]	2.0[a]	2.4[a]	17.0[ab]	24.0[a]
MIN	1.03[a]	5.37[a]	2.0[a]	3.3[ab]	17.2[ab]	24.0[a]
CSL	1.13[bc]	5.62[ab]	2.2[ab]	3.6[ab]	18.5[ab]	23.8[a]
FYM	1.24[de]	5.78[bc]	3.4[b]	4.9[b]	24.1[b]	28.9[a]
CMC1	1.21[cd]	5.62[ab]	1.8[a]	2.7[ab]	16.6[a]	22.9[a]
CMC2	1.27[de]	5.80[bc]	2.4[ab]	2.6[ab]	16.9[ab]	24.2[a]
VFG	1.32[e]	6.06[c]	2.5[ab]	3.4[ab]	17.0[ab]	27.1[a]

[1] MIN: only mineral fertilizers; FYM: farmyard manure; CSL: cattle slurry; VFG: vegetable, fruit and garden waste compost; CMC1: farm compost, low C/N; CMC2: farm compost, high C/N; NF+: no fertilizer; NF-: fallow

The use of mineral fertilizers alone (MIN), clearly led to a decreased pH level. Use of CMC2, VFG compost and farmyard manure (FYM) led to the highest pH levels. There were no lime applications during the experiment. Addition of organic material and subsequent mineralization can both lead to acidification or increase in pH, depending on the composition (Cong and Merckx, 2005). Moreover, composts and farmyard manure to a lesser extent, contain large amounts of stable organic C which can buffer the soil against acidification. Above, all composts used in this experiment had a pH-H_2O> 7.0 and contained also a minor amount of lime (CaO). Nevertheless, only the use of VFG compost brought the soil pH close to the optimal pH range for a sandy loam soil (6.20-6.60; Maes et al., 2012).

P PLANT AVAILABILITY & POTENTIAL PLANT AVAILABLE P

We estimated P plant availability as P in the soil solution (0.01M $CaCl_2$ extract on fresh soil) at the moment of soil sampling. The range of P plant availability is largely influenced by soil type, Al and Fe concentration in the soil and the (long-term) fertilizer application history. Moreover, within this range, large fluctuations caused by changes in soil temperature, soil moisture content and crop type, in time may occur. Therefore it is only meaningful to compare the P plant availability of the treatments at one point in time and not between years. Both in 2011 and 2012 the P plant availability was higher for FYM. Compared to the other treatments, this was not always significant due to high variability in these measurements. It seems that farmyard manure delivers more P. It is not known whether this is caused by increased P mineralization, P desorption or the P type available in farmyard manure. HWP, as a measurement of the labile soil P fraction, indicates also a higher capability of rapid P delivery to the soil solution in the FYM treatment. P-AL is only part of the total P content of the soil and is an estimate of P available for crop growth on the mid-term (years). It is thought that 10% of the potential plant available P becomes available for crop growth in one growing season (Legrand et al., 2012). The potential plant available P is way higher than the recommended optimal range of 12 to 18 mg P/100g DS (Maes et al., 2012). Moreover, this recommended optimal range is already amongst the highest in Europe (Jordan-Meille et al., 2012). There are no significant differences between the treatments in 2011 and 2012. However, when calculated over both years together, FYM is significantly higher level ($p<0.05$), compared to all other treatments, except for VFG. Because of practical considerations there was no correction for P input in 2005, 2009 and 2010 between the treatments. In those years, the P input was the highest for the FYM treatment. Although, the other fertilized treatments differed also in P input, the differences found in potential plant available P (table 1) were small.

P EXPORT

In 2011 the mean P concentration in the red cabbage and the above ground crop residues ranged from 0.412 (MIN) to 0.448% (VFG) and from 0.297 (CSL) to 0.317% (MIN), respectively and were not significant. There were some differences in P export due to differences in DM crop yield, but again not significant: CSL (48 kg P/ha)< MIN (51 kg P/ha)< FYM (53 kg P/ha)< CMC1 (54 kg P/ha)< CMC2 (55 kg P/ha)< VFG (58 kg P/ha).

Also in 2012 no significant differences were found in the P concentration of potato tubers: range from 0.219 (CMC1) to 0.264 % (FYM). The P export was CMC2 (25 kg P/ha)< MIN (27 kg P/ha)< CSL (28 kg P/ha)< CMC1 (30 kg P/ha)< VFG (31 kg P/ha)< FYM (33 kg P/ha) and not significantly different amongst the treatments.

Organic fertilizers such as composts may enhance the soil structure, stimulate the root growth and therefore also the capability of crops to take up P. In conditions of P shortage this can be critical. The potential plant available P in this field experiment was probably high enough to deliver as much P as the crop needs. Although the P plant availability was the highest for FYM both in 2011 and 2012, the P concentration of the plant tissue was only the highest in 2012. There was no extra uptake of P in the FYM treatments, probably because there was already enough P available in the soil. Above, P can be present in the soil solution, but is only actual available when plant roots grow towards the P source.

To fully test the effect of organic fertilizer types on crop yield, P export and P plant availability, a similar field experiment, with P fertilization at a suboptimal level is required.

POTENTIAL P LEACHING

In figure 2 the cumulative TP leaching of the first leaching experiments is shown. It is clear that the treatment FYM led to a significantly increased ($p<0.05$) potential P leaching. It is remarkable no differences are observed between the control treatment (NF-) and the fertilized treatments (VFG and CSL), except for FYM. The second leaching experiment confirmed the first experiment. Again Cumulative TP leaching was increased for FYM, compared to CMC1, CMC2, NF- and NF+. In the NF- treatment there is no P export and no P input, which results in a constant P leaching potential over the whole period. In the NF+ control plots, there is a negative P balance. No P fertilizer used, but P is exported by crop harvest. However this P export is lower, compared to the fertilized treatments, due to the restricted crop growth mainly caused by N and K shortage. Therefore a fertilizer stop is not an efficient way to mine P, as there were no differences in potential P leaching between NF+ and CMC1, CMC2, VFG, CSL and MIN.

CMC1, CMC2 and especially VFG compost seem to have the most opportunities. These compost types provide the soil of the largest increase in TOC level, without increasing the potential P leaching. Moreover compost tends to increase crop yield compared to fertilizing with cattle slurry (CSL) and mineral fertilizers (MIN).

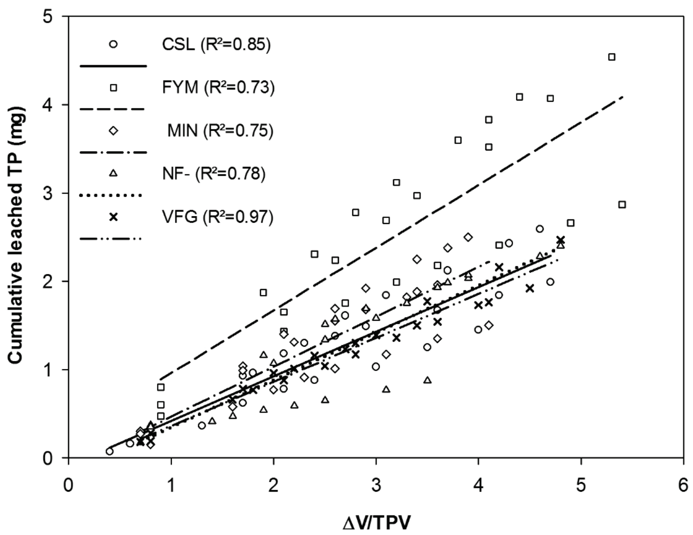

Figure 2 The Cumulative TP leaching in the first leaching experiment. The horizontal axis is the amount of water percolated through the soil columns expressed in percolated water volume per TPV (total pore volume). (CSL: cattle slurry; FYM: farmyard manure; MIN: only mineral fertilizers; NF-: fallow; VFG: vegetable, fruit and garden waste compost).

Probably the extra P available in the soil solution of the FYM treatments is simply not used by the crops, but contributes to the leachable P source of the soil. In previous leaching experiments a significant correlations between P plant availability and potential P leaching was found. To validate the results of the leaching experiments, P-AL and HWP were also measured 10 cm below tillage depth (30-40 cm). Both parameters were slightly, although not significantly, increased (HWP: $p=0.3$; P-AL: $p=0.2$) in case of the FYM treatments, and therefore confirm our results.

The composition of the total P leached was not influenced by the fertilizer treatments. Approximately, 80 to 90% and 45 to 60% of the P leached as TDP and OP, respectively. There were no differences in TDC leaching between treatments.

Conclusion

The use of composts and farmyard manure had a slightly positive effect on the crop yield over the whole period of this field experiment. Although the C input was equalized for the different composts, cattle slurry and farmyard manure, the evolution in TOC level is mainly influenced by the C stability. The application of farmyard manure led to a clear increase in P plant availability (extracted with 0.01 M $CaCl_2$) and there is also indication of increasing potential plant available P (P-AL, extracted with ammonium lactate pH 3.75). However, this seems not to cause higher crop yields or P export. On the contrary, the potential P leaching is significantly increased by farmyard manure.

The results show that different organic fertilizer types have different effects on P plant availability and potential P leaching. The present study shows that compost is a highly valuable product in soils with a high P status and a suboptimal TOC level. Compost gradually increases the TOC level, without any increase in potential P leaching losses.

It would be interesting to confirm this by repeating the leaching experiment in a few years from now, but also test other long-term field experiments or even farmer's fields for differences in P plant availability and potential P leaching.

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(23) A more trustworthy P recommendation by implementing the intensity, buffering capacity, quantity concept into agricultural practice

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Abstract: *The basis of current fertilization recommendations as a function of soil P status was established mostly in the 1950's – 1960's. To establish the soil P status, dozens of different soil P tests have been developed and were tested in many field trials. Up to now almost everywhere a single soil test is used which differs between countries and regions. The last decades the agro-economic environment has altered; environmental protection has become a topic and P resources proved exhaustible. This requires a more precise P fertilization recommendation that makes better use of the state of the art regarding soil chemical knowledge and laboratory methods (e.g. increased precision and decreased duration and costs of analyses but with minimal cost increases for the farmer). Though, replacing existing soil tests and recommendations would imply a very significant effort with respect to introducing new tests and recommendations by fertilization trials in practice. However, with a more mechanistic approach less field testing is required to develop an improved recommendation system than based on an empirical approach. We have used a soil chemical approach to study and predict the dynamic behaviour of P release by the soil as a result of P removal (P uptake by the crop). With a at least two soil parameters (P-Al and P-CaCl$_2$) it was possible to describe what is directly available for plant uptake (P intensity), the capacity of the soil to replenish this directly available P by the soil when P is removed (or added) to the soil (the P buffer capacity) and what is the total capacity for P replenishment (P quantity). We will describe the stepwise introduction of the intensity, buffering capacity, and quantity concept into agricultural practice, and into proposed legislative measurements in the Netherlands.*

Keywords: *soil phosphorus; fertilization recommendation; crop based; soil based; soil test*

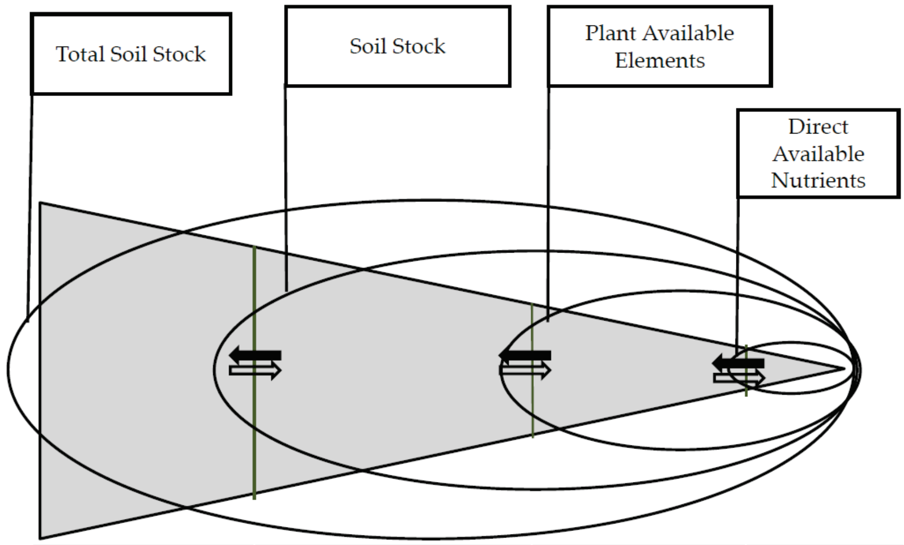
Introduction

An adequate soil phosphorus (P) status guaranteeing an adequate P supply to growing crops is crucial for optimal crop production. To obtain insight in crop nutrient requirements and optimal soil fertility status, field trials have been performed from the 19th century onwards. At that time, soil testing – first for research purposes – started too. First 'total' soil stocks were measured. Daubeny (1845) took the difference between 'active' and 'dormant' fractions of nutrients into consideration and Dyer (1894) was the first to use the term (plant) available elements. The search for suitable extractants relating soil status to crop yield and quality has resulted in a wealth of soil tests which are different for different countries and regions and they extract different amounts in the soil. The amount of extractable P of some well-known soil tests decreases in the order P-total > P-oxalate > P-Al > P-CAL > P-Olsen > Pw > P-CaCl$_2$ (0.01 M 1:10 CaCl$_2$ dried soil; Houba et al., 1990) > P-CaCl$_2$ (0.01 M 1:2 CaCl$_2$ non-dried soil) (Van Noordwijk et al., 1990; Neyroud & Lischer, 2003; Figure 1). Harsher extracting agents like for example P-Al represent soil quantity and can be used for long-term fertilization strategy (soil based), while mild extracting agents such as P-CaCl$_2$ represent soil intensity and can be useful for immediate fertilizer recommendations (crop based).

Despite the numerous available soil tests, generally only one soil test is used as a basis for fertilization recommendations. That two or more soil P tests may provide more insight into the soil P status and its relationship with crop response to P fertilization, has been suggested repeatedly (e.g. Kuipers, 1951; Van der Paauw, 1971; Ehlert *et al.* , 2003; Quintero *et al.*, 2003). In the Netherlands already in the 1930's two soil tests were offered to farmers, one for plant available P (so called intensity characteristic), and one for soil P stock (so called quantity). Although the combination of soil tests was helpful, farmers rarely used both methods and usually chose one or the other, mostly for reasons of cost (Van der Paauw, 1971).

At present, environmental protection has become a topic (e.g. Csathó *et al.*, 2009), and P resources proved exhaustible (Heffer *et al.*, 2006; Cordell *et al.*, 2009). As a result Dutch legislation has set limits to the amount of P-fertilizer that may be applied to a field. Even important, farmers are interested in improved allotment of P but doubt the fertilization recommendations (Reijneveld et al., 2013a). So there seems room for improved P recommendations. Still, most recommendations have been largely unaltered since the 1970's till only recently. Mostly because implementing new insights - like the intensity, buffering capacity, quantity concept – into agricultural practice seems hard, to a large extent because replacing existing soil tests and recommendations would imply a significant effort with respect to deriving new (empirical) relationships based on fertilizer trials in practice. The same would apply for environmental evaluations. However, if empirical recommendations can be improved by using a more soil chemical based mechanistic approach it will lead to a better understanding of P behaviour in soil and therefore requires a limited number of field trials (validation trials). This became clear form the work of Bussink et al. (20011a,b). In addition, the problem of costs for measuring more than one parameter have decreased the last decades due to modern analysis methods (increased precision and decreased duration and costs of analyses); Houba et al. (1990; 1994) and Van Erp (2002) proposed introducing the use of 0.01 M $CaCl_2$ as single extractant to assess readily plant available nutrients and from 2004 onward this was gradually introduced in practice in the Netherlands (e.g. Ros et al., 2011; Van Rotterdam – Los et al., 2012; Anonymous, 2013).

The objectives of this paper are i) to provide an overview of the intensity, buffering capacity, and quantity concept and ii) describe the stepwise introduction of this concept into agricultural practice, and into proposed legislative measurements in the Netherlands.



Method	← P-total →	← P-Al →	← P-$CaCl_2$# →	← P-$CaCl_2$^ →
Result	250 mg P_2O_5 100 g^{-1}	40 mg P_2O_5 100 g^{-1}	1.5 mg P kg^{-1}	0.5 mg L^{-1}
Kg ha^{-1}	3400 P	545 P	4.7 P	2.5 P
	Soil Quantity		**Soil Intensity**	

0.01 M 1:10 $CaCl_2$ in dried soil (e.g. Houba et al., 1990)
^ 0.01 M 1:2 $CaCl_2$ in non-dried soils

Figure 1 The soil quantity, buffering capacity, and intensity concept presented visually for P. The several fractions can also be represented by other methods, for example, soil stock is represented by P-Al but could also be represented by P-Olsen. The arrows indicate the buffering and binding processes which depend among others on Fe, Al, and Ca (anno 2013 estimated by the ratio P-Al/P-$CaCl_2$). To get an impression the amounts of P per hectare in the soil layer 0 – 25 are present (soil density of 1.25 kg dm^{-3} is assumed)

Intensity, buffering capacity, quantity concept

Mechanistic approach

To understand dominant soil processes involved in the translocation of P from soil to crops and the corresponding reaction rates, we have performed literature studies, pot, and field experiments. The research started with the realization that a single soil test is a rather poor approximation of the dynamic processes involved in the translocation of P from soil particles through the soil solution to plant roots. Although a simplification too, the soil P supply potential can be described much more accurate using the terms intensity, buffering capacity, and quantity. Intensity is defined as (a measure for) the P concentration in the soil solution (C_p). The soil solution is the compartment from which roots absorb nutrients and as a result P availability at a certain moment in time is determined by C_p. However, the amount of P in the soil solution is generally very low compared to a crops P demand. As a result C_p is replenished from P adsorbed to soil particles. The capacity of the soil to resist a change in C_p is defined as the soil's buffering capacity (BC). The soil P that is associated with the buffering of C_p is defined as the P quantity (Q_P). Q_P is not some well-defined P form or fraction (e.g. Koopmans et al. 2004). We will assume Q_P to resemble the fraction of P that is reversibly bound to the surface of soil particles, mainly Fe-, Al (hydr-)oxides and Ca-phases.

Phosphorus intensity, P quantity, and buffering capacity are integrated in a soil specific sorption isotherm. The buffering capacity combines the soil P intensity and P quantity as it is directly related to the slope of this isotherm (Barrow, 1967). The methodology that is derived to increase the accuracy with which the soil P supply potential can be predicted is based on the soil specific sorption isotherm. This is approached by studying the soil P desorption and the decrease in C_p during continuous removal of P by an artificial sink (Fe oxide-impregnated (P_i) paper) which is repeatedly replaced during a certain period. The release of P from the soil is modeled using a sorption isotherm (Langmuir). The two soil specific parameters of this isotherm are related to data derived from standard soil tests.

The results show that the soil P supply potential can be predicted with various degrees of accuracy (Van Rotterdam-Los, 2010, Van Rotterdam et al, 2009, 2012). To be able to make a prediction of the soil P supply potential a minimum of two parameters is needed; a measure for the reversibly adsorbed P (Q_P) and a measure for the P concentration in solution (C_P). For the Dutch situation P-Al (ammonium acetate lactate, Egnér et al., 1960) and 0.01 M P-$CaCl_2$ (Houba et al., 2000), were used to approximate Q_P and $C_{p,}$ respectively. The measure for C_P is an indication of the rate with which P can be removed from the soil. The P-Al over P-$CaCl_2$ ratio is used to predict the buffering capacity, but to increase the accuracy of this prediction for soils that don't have a high buffering capacity (and the isotherm is thus non-linear), a measure for the reactive surface area (e.g. Fe_{ox} ,Al_{ox} and Ca) of the soil must also be taken into account.

The combination of using two soil tests approximating P intensity and P quantity and interpreting the results based on the intensity- quantity – buffering capacity concept is a leap forward compared to using one single extractant to predict the potential of soils to supply P to a growing crop.

Verification of the methodology

The above described methodology was tested in pot experiments and verified in field trials. The pot experiments showed that the same mechanisms apply when P is removed using an artificial soil sink compared to when is removed by a growing crop (in this case grass) .

The concept was tested further in field trails (Bussink et al., 2011a, 2011b). Changing from only P-Al (the standard soil test for grassland) to a combination with P-$CaCl_2$ and the ratio P-Al over P-$CaCl_2$ results in an increase in the explained variance in P content of grass and in a more accurate P fertilization recommendation for grassland. An example is shown in Table 1. It shows that the new fertilization recommendation may change considerably when besides P-Al, also P-$CaCl_2$ is taken into account compared to when only P-Al is considered. At low P-$CaCl_2$ the new fertilizer recommendation may increase slightly whilst at a high P-$CaCl_2$ it may decrease to zero. The measured P content in the grass (Table 1) shows that this is valid as the measured P content is considerably higher than the target of 3.7 g P kg-1 dry weight. The concept was also tested for among others maize and is currently validated for potatoes.

Table 1 Comparison between the old and new P-fertilization recommendation for grassland (first mowing cut) for (as example) four fields in the same region.

Field	Soil test results		P recommendation (kg P_2O_5 ha^{-1})			
	P-Al mg P_2O_5 $100g^{-1}$	P-$CaCl_2$ mg P kg^{-1}	Old	New	P-content grass g P kg DM^{-1}	Actual P applied kg P_2O_5 ha^{-1}
A	35	1.0	45	55	3.1	48
B	33	4.1	45	15	4.6	19
C	20	0.2	70	79	2.7	20
D	23	6.0	70	15	4.1	20

Implementing a more trustworthy recommendation

Farmers' perception of soil P tests and recommendation

Compliance with fertilizer recommendations would in the long run have resulted in soil P values in the agronomical optimal ranges. However, agricultural land with above optimal P status has become significant in many countries. For example, 50% of arable fields in Sweden have soil P status 'high' or 'very high' (Eriksson et al., 1997) and in Belgium about 80% of arable land is considered fairly high to high (BDB, 2005). In the Netherlands average soil P status increased from the agronomical classification '(ample) sufficient' to '(fairly) high' during the period 1971 – 2004

(Reijneveld et al., 2010). An explanation could be that soil tests are not valued by farmers. However, in some recent questionnaires (Nesme et al., 2011; Reijneveld et al., 2013a) it was found that farmers find soil P status most important on the soil report and first consider the results of soil tests when making a fertilization scheme (above among others extension services). At the same time, the value of the soil P test used to establish plant available P was questioned by the majority of the farmers and they indicate to strive for supra-optimal soil P values. So, - as mentioned – there seems to be room for a more trustworthy recommendation.

Implementing new soil tests and recommendations

Soil Pw test (see Reijneveld et al., 2010) was used in the Netherlands from 1968 – 2004. It represents both the intensity and, due to the very large solution to soil ratio, is highly influenced by the buffer capacity (Van Noordwijk *et al.*, 1990; Figure 1). Because it is just one extraction it is not possible to distinguish between intensity from quantity. Direct replacement of one soil P(w) test with a combination of other soil tests based on the intensity, buffering capacity, quantity concept, was difficult since Pw was the basis of all fertilization recommendations (except grassland) and environmental evaluations for manure policy used it too. So, a stepwise approach was followed (see also Reijneveld et al., 2013b).

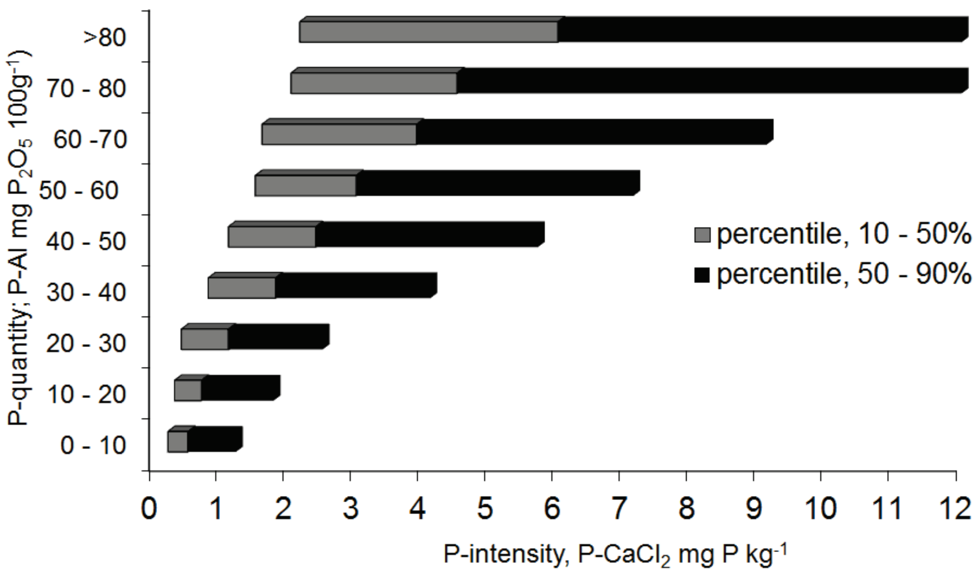


Figure 2 Distribution of P-intensity (P-$CaCl_2$, mg P kg^{-1} soil) per P-quantity category (P-Al, mg P 100 g^{-1} soil). The median (percentile 50%) is situated between percentile 10 – 50% en percentile 50 – 90% (Figure from Reijneveld & Oenema; 2012; n = 5172, marine clay soil; 2009 – 2010)

From 2004 onwards, in addition to the conventional soil P(w) test, the results of additional soil P tests for intensity, quantity, and later buffering capacity were reported to farmers while the fertilizer recommendations were not directly altered. For grassland the same procedure was followed, with the advantage that the quantity characteristic (P-Al) did not alter. At the same time the concept was tested further in pot experiments and field trials (e.g. Bussink *et al.*, 2007; Van Rotterdam *et al.*, 2009). These experiments proved successful and were presented to the Fertilization Committees. Early 2011 the new concept was approved for maize, 7 years after introducing the multiple soil P test values to the farmers. In the meantime, farmers and their advisors had become familiar with the new soil P test values. For example, already in the first years (2004 – 2005) farmers and extension services noticed that the amount of plant available P per P-Al category ranged significantly (Figure 2). After >5 years of experience with the new soil tests, introducing the new P fertilization recommendation was a relatively small step. Subsequently, the new P recommendation for grassland was approved early 2012, and further validation trials for arable crops were set up, again with the advantage that the concept has led to a better understanding of P behaviour in soil and therefore requires a limited number of validations trials.

Discussion & Conclusion

In more than 3 decades (from 1970 – 2004) no significant changes in soil P tests, nor P recommendations were implemented into agricultural practise (Anonymous, 1999). Although numerous new insights in soil testing and fertilizer recommendations reflecting more efficient use of P became available, these new insights were hard to implement into agricultural practice. Mainly because replacing existing soil tests and recommendations would imply a very significant effort with respect to (costly) fertilization trials in practice. The more mechanistic approach that was followed by Van Rotterdam – Los (2010) resulted in a well-founded and generally applicable methodology for prediction the potential of soils of supply P. Several validation field trials confirmed the concept and enlarged the acceptance. As a results, farmers saw the number of soil test to predict soil P processes increase from 1 to ≥ 3, but more important, average expected yield remained the same, with on average lower P recommendations. For maize for example, the mean fertilization recommendation was 15 kg P_2O_5 ha^{-1} lower with the new concept (Anonymous, 2013), although the allotment over different fields can differ significantly (so, some fields obtain higher recommendations while other fields get a zero recommendation).

Another advantage of multiple soil tests for P is the possibility to make a distinction between soil-based (i.e. soil fertility, investments for the longer term) and crop-based (plant nutrition, investments for a single crop season) fertilization strategies. This may be extra helpful for management (fertilization) decisions on leased fields.

The concept can also be used for other nutrients (for example combining K-$CaCl_2$ with K-CEC), and other countries (for instance: much used P-Olsen can be used as quantity characteristic instead of P-Al).

The concept can be further improved when soil tests predicting P binding capacity in the form of Fe- and Al (hydr-)oxides and Ca-precipitates can be analysed routinely, thereby improving the buffering capacity prediction which now is approximated only by the P-Al/P-$CaCl_2$ ratio. Near Infra-Red (NIR) spectroscopy is therefore a promising technique; not only for these hydoxides but also for basic soil characteristics like SOM, CEC, exchangeable cations, texture etc. (e.g. Malley et al., 1999; ISO 17184, 2013). The measurement technique itself is fast and relatively cost effective The use of Fe- and Al (hydr-)oxides and Ca-precipitates data will also give insight in the environmental risk of P leaching to the subsoil and can be used in environmental evaluations as well, including water (quality) authorities.

Finally, maximum P applications in the Netherlands are based on soil P status. Until now, soil status is determined on basis of P-Al (grassland) on Pw (open cultivation). The new routine analyses might prove helpful when determining maximum allowable P applications per hectare. Government in the Netherlands has the intention the use quantity and intensity characteristics to classify soils and establish P applications from 2015 onwards.

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(24) Future fertilizer legislation will require adapted nutrient management strategies in German vegetable production

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Abstract: *In the framework of implementing the EU Nitrates Directive in Germany, the German fertilization legislation is under consideration. It is to be expected that after the amendment of the Fertilization Ordinance growers will have to cope with stricter rules regarding nitrogen (N) fertilization. To identify management strategies suited for the new legislation we used scenario calculations with agro-ecosystem models. Not surprisingly, the model results indicated that the highest N losses occurred when crops with high amounts of harvest residues were grown in autumn and most of the residue N was lost overwinter. The most promising model strategies included the use of winter catch crops. We tested these strategies in field experiments with three catch crops at three sites in three years. Our experimental results indicated that on average catch crop strategies do not solve the problem of high N losses in intensive field vegetable production systems.*

Keywords: *nitrogen balance, fertilizer legislation, crop rotation, catch crops*

Introduction

In Germany fertilization is governed by the Fertilization Ordinance (Düngeverordnung). This ordinance describes rules of good agricultural practice for calculating nutrient requirements, timing of fertilizer applications, soil sampling etc. Vegetable growers assert that the most difficult rule to comply with is the fixed amount of allowable nitrogen (N) surplus. Simplified, the N surplus is calculated as the difference between N input (organic and mineral fertilizers) and N output (N in harvested products). Currently, the allowable N surplus is 60 kg N ha^{-1} $year^{-1}$ for all field crops plus an extra allowance for vegetable crops. This extra allowance can be up to 120 kg N ha^{-1} $year^{-1}$ depending on the vegetable species. The extra allowance will soon be lowered to 0 kg N ha^{-1} $year^{-1}$ for most vegetable crops. In the case of a few exceptions, mostly brassica crops, it will be set to 60 kg N ha^{-1} $year^{-1}$. How can growers cope with this much stricter rule? Scenario calculations with agro-ecosystem models indicated that that the highest N losses occurred when crops with high amounts of harvest residues were grown in autumn and most of the residue N was lost overwinter. The most promising model strategies included the use of winter catch crops. We tested these strategies in field experiments with three catch crops at three sites in three years.

Materials and Methods

The experimental set up was described in detail by Nett et al. 2011. Briefly, at each experimental site, crop rotation experiments were performed that lasted approximately 1.5 years and comprised, a preceding crop in the summer of the first year, a catch crop (CC) over the winter, and a succeeding crop during the summer–autumn period of the next year. The preceding crop was cauliflower in all cases. The catch crops tested were: winter rye (*Secale cereale* L.), fodder radish (*Raphanus sativus* L. var. *oleiformis* Pers.), bunch onion (*Allium cepa* L.) and sudangrass (*Sorghum sudanense* Stapf).

A balance of N for each crop rotation experiment was calculated on the basis of N input into, and N output out of the crop rotation.

The input was defined as the sum of

1) N in above-ground crop residues of the cauliflower crop
2) soil mineral nitrogen (SMN) in the depth section 0–90 cm at time of cauliflower harvest
3) mineral N fertilization between cauliflower harvest and harvest of the succeeding crop
4) N mineralization from soil organic matter between cauliflower harvest and harvest of the succeeding crop

The N output was defined as the sum of

1) N in aboveground plant biomass of the succeeding crop at harvest
2) SMN in the depth section 0–90 cm at this time.

The difference in N input minus N output was referred to as the apparent N loss. To assess the impact of the CC, the difference between the apparent N loss of a certain CC treatment minus that of the corresponding control treatment, i.e. the treatment without a CC at the same site and sowing date and for the same experiment, was calculated. Henceforth, this difference will be termed CC effect.

Results and Discussion

Nitrogen balance

On average across all sites, experiments, and treatments, the N input into the crop rotations amounted to 386 kg ha^{-1}. About half of this input could be attributed to cauliflower crop residues, one quarter to the initial SMN content (from the soil depth section 0–90 cm), and the final quarter to N from mineral fertilization. Of the total N input, on average 47% was recovered in the total N output, corresponding to an apparent absolute N loss of 203 kg ha^{-1} (n = 139).

Catch crop effects on apparent N losses

On average for all treatments, the CC effect (Fig. 1) was −13 ± 6 kg ha^{-1} (n = 97). This reduction of apparent N loss due to CC use was small in comparison to the total apparent N losses of the control treatments, which amounted to 217 ± 17 kg ha^{-1} (n = 42), but significantly different from zero according to a one-sample t-test (P = 0.024).

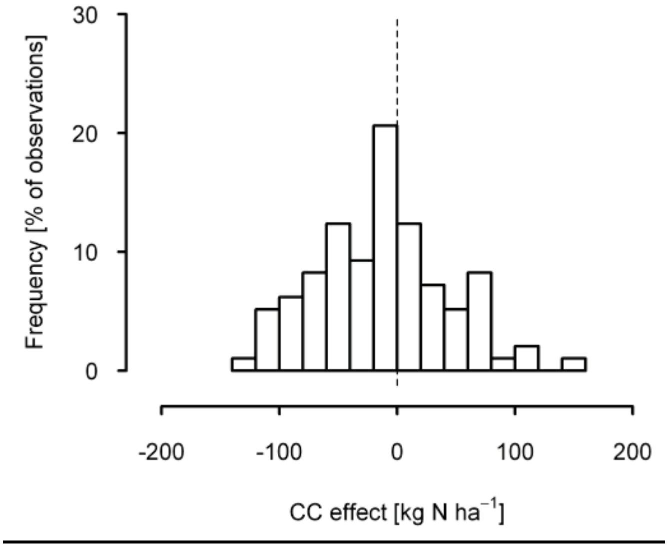

Figure 1 Frequency distribution of the “catch crop effect” (definition see Material and Methods), n = 97

Nitrogen balance and cauliflower crop residues

The average N input across all experiments was as high as 386 kg ha^{-1}, half of which could be ascribed to the cauliflower crop residues. This demonstrates how important residues from crops like cauliflower and broccoli are for the N balance of whole vegetable crop rotations. These amounts were in the upper range of figures summarized by Feller et al. (2010), who compiled data from many field experiments and reported average values for cauliflower crop residues of between 153 and 180 kg N ha^{-1}. On average, only half of the total N input was recovered at the end of the crop rotation suggesting that the other half, a high absolute amount of 203 kg ha^{-1}, may have been lost.

Conclusion

The typical intensive German vegetable crop rotations investigated in this study were particularly prone to N losses due to the high input of mineral N fertilizers, as well as the high amount of SMN and crop residue N left after harvest of the cauliflower crop. However, based on the large data set obtained from performing field experiments, at three different sites, over 2–3 years, and after applying several CC treatments, we conclude that the use of winter CCs, in combination with conventional mineral N fertilization does not solve the problem of high N balance surpluses in these systems. This was evidenced by the small effects of the CCs on the N balance surpluses in comparison with the much higher total N balance surpluses, as well as by the high uncertainty associated with these CC effects. For these sites, alternative measures, such as the removal of harvest residues or vegetable–cereal rotations may be more effective in reducing N losses compared to a CC strategy.

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(25) Management of vegetable crop residues for reducing nitrate leaching losses in intensive vegetable rotations

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Abstract: *Crop residues of field vegetables are often characterized by large amounts of biomass with a high N-content. Even when these are incorporated in autumn, high rates of N mineralization and nitrification still occur causing important N-losses through leaching. Crop residues thus pose a possible threat to maintaining water quality objectives, but at the same time they are a vital link in closing the nutrient and organic matter cycle of soils. Appropriate and sustainable management is needed to fully harness the potential of crop residues. In this research, two fundamentally different management strategies are investigated, namely i) removal of crop residues followed by a useful and profitable application or ii) on-field treatment of crop residues in order to prevent N losses and maintain soil quality. We here present the experimental set-up of the project, results will be presented during the conference.*

Keywords: *Immobilizing materials; incorporation; cover crops; valorisation; economic*

Introduction

Crop residues constitute an important link in soil nutrient and organic matter cycles and aid in maintaining soil quality and fertility (Wilhelm et al., 2004, Blanco-Canqui and Lal, 2009). The combined above- and belowground biomass of crop residues is often greater than the biomass of the harvested crop. Vegetable crop residues take a particular position relative to arable crops due to often large amounts of biomass and high N-content. Economically important vegetable crops such as cauliflowers may leave 50 ton ha^{-1} or more of fresh material as crop residues with a N -content of up to 200 kg N ha^{-1} (Rahn et al.1992). Vegetable crop residues are characterized by low C:N ratios (De Neve and Hofman, 1996) and mineralize rapidly (Fox et al., 1990, Trinsoutrot et al., 2000). During summer generally more than 80% of N present in cauliflower crop residues will be mineralized within 8 weeks (De Neve and Hofman, 1998). An important amount of vegetable crops are harvested during late autumn and despite decreasing soil temperatures during autumn, high rates of N mineralization and nitrification still occur (De Neve and Hofman, 1996). Crop residues may thus lead to considerable N-losses through nitrate leaching during winter (Chaves et al., 2007). Hence crop residues pose a possible threat to maintaining water quality objectives. However, at the same time crop residues are a vital link in closing the nutrient and organic matter cycle of soils. Appropriate and sustainable management is needed to harness the full potential of crop residues (Askegaard et al., 2011).

Materials and methods

On-field management of crop residues

The field experiments in this research are set up in 'long term' experiments (18 months), and 'short term' experiments (2-6 months), all located in the intensive vegetable growing region in Flanders (Belgium). All field experiments were designed in fully randomized blocks with four replicates.

Long term experiments

Two long term experiments are set up to investigate the effect of alternative crop rotations on soil mineral N -content compared to conventional vegetable crop rotations. The potential of including either non-vegetable crops or cover crops in vegetable crop rotations is assessed. In the long term experiments the vegetable crop residues are treated in a conventional manner, i.e. incorporated into soil after harvest. The first alternative crop rotation examines the inclusion of Italian ryegrass (*Lolium multiflorum*) in cauliflower (*Brassica oleracea var. botrytis*) rotations. Per location two treatments, namely (i) cauliflower – Italian ryegrass (sown in August) and (ii) cauliflower – cauliflower – Italian ryegrass (sown in October) are compared to the conventional cauliflower – cauliflower combination. Following spring one or two cuttings of grass is harvested and removed. The remaining organic material is incorporated and a new cauliflower crop is planted. The field experiments are established at three locations with a different soil texture (sand, sandy loam and loam) in order to evaluate the effect of soil texture on nitrate leaching. The second alternative crop rotation examines the use of two cover crops (Italian ryegrass or winter rye (*Secale cereale*) after a cauliflower crop. Similar as for the first alternative rotation two rotations, namely (i) cauliflower – cover crop (sown in August) and (ii) cauliflower – cauliflower – cover crop (sown in October) are compared to a conventional double cauliflower rotation. However in contrast to the first alternative rotation the cover crop will be incorporated during spring instead of harvested. Again three locations with different soil textures (sand, sandy loam and loam) are chosen to take into account the influence of the latter. Field-acquired results will be used in a simulation model (EU_Rotate_N) to fully evaluate the influence of alternative crop rotations on soil N dynamics and crop yields in the long term.

Short term experiments

Several crop residue management strategies are assessed through means of short term field experiments. A first set of field experiments assesses the effect of conventional crop residue incorporation compared to no-incorporation or total removal of crop residues for cauliflower, leek (*Allium porrum*) and headed cabbage (*Brassica oleracea convar. capitata var. Alba*). Two cauliflower crops, one headed cabbage crop and one leek crop were grown on a sandy loam soil. Another three fields with cauliflower are set up on a sandy soil. Following harvest of crop residues a cover crop (winter rye, Italian ryegrass or black oats (*Avena strigosa*)) was sown and compared to leaving the field fallow.

A second set of field experiments examines the effect of three immobilizing materials on N-losses. At two fields on a loam and a sandy loam soil cereal straw (12 t ha^{-1}), corn straw residue (12 t ha^{-1}) or immature green waste compost (50 t ha^{-1}) was mixed with cauliflower residues and subsequently incorporated. The three treatments are compared to incorporation of cauliflowers residues without immobilizing materials.

The potential of cover crops undersown is evaluated at a third set of field experiments. On a sandy loam soil three cover crops (Italian ryegrass, winter rye or phacelia (*Phacelia tanacetifolia*)) were sown 4 week after planting of a cauliflower crop and compared to a treatment without understorey.

A future field experiment will assess the potential of in situ stabilisation of vegetable crop residues. To this end, a mixture of structural materials (straw, wood chips and bark) is brought onto the field and combined with the crop residues of cauliflower. This mixture will subsequently be structured in ridges on the field. The influence of soil quality on soil N mineralisation rate will also be evaluated.

Finally, we will assess the influence of differences in soil quality on the N dynamics after crop residue incorporation on an experimental field where large differences of soil quality were created due to different combinations of organic matter management and soil cultivation over a five year period.

Removal of crop residues

The feasibility of mechanical crop residue removal during late autumn is examined for cauliflower, headed cabbage, celery and leek crops. The potential amount of mechanically removable vegetable crop residues was examined for cauliflower (December), celery (October) and leek (September). Mechanical removal of headed cabbage crop residues took place in August and November. Crop residues of headed cabbage were collected manually (total removal) and mechanically and the mechanical removal efficiency was determined. Organic matter, dry matter, N - and P -content was measured for all crop residues. Mechanical removal of celery crop residues will take place in autumn 2013.

Following crop residue removal the potential of ensilaging, composting or anaerobic co-digestion of vegetable crop residues followed by reapplication on the field is assessed.

Four crop residues (leek, celery, cauliflower and headed cabbage) were mixed with corn straw residues in a 50/50 vol% composition and 42L of this mixture was ensilaged in 15L buckets (Agriton) specially designed for this purpose. Before ensilaging, the bulk density, organic matter, dry matter, N- and P-content was measured for the starting materials. Ensilaging of celery crop residues with a higher crop residue/ straw ratio will be repeated in autumn 2013.

In the composting scenario two compost piles (12 m long × 3 m wide) with crop residues of leek or headed cabbage residues, mixed with additional materials, were set up at the end of November in open air on a concrete floor, with a mixture of 20 vol% crop residues, 30 vol% wood chips, 30 vol% bark and, 20 vol% straw. Temperature and CO_2 levels in the composts were monitored and the compost piles were mixed, turned and covered or rewetted when necessary. Before composting bulk density, organic matter, dry matter, N- and P-content was measured for the starting materials and the feedstock mixture. Next autumn two compost piles with celery residue (one on a concrete floor, one on a grassfield) will be set up with the same composition as previously described.

Evaluation of energetic valorisation of vegetable crop residues by means of anaerobic co-digestion will take place in autumn 2013. The fertilizer value of digestate derived from vegetable crop residues and possible reapplication to the field will be assessed.

Plant and soil sampling

General soil properties were determined at all fields before the start of the experiment. During the experiment soil samples were taken monthly with an auger in three layers: 0-30 cm, 30-60 cm, 60-90 cm. These samples were analysed for ammonium-N and nitrate-N after 1 M KCl extraction in order to determine soil mineral N profiles. Crop and crop residue (leaves and stalks) samples were collected at harvest. Four subsamples were taken per treatment. All plant samples were dried, ground and analysed for N and P content.

Economical evaluation

The economic feasibility of all evaluated crop residue management strategies will be assessed and compared to conventional practice. Farm in- and outputs affected by the concerned crop residue management strategy as well as the influence of farm specific differences and market situation will be taken into account.

Conclusion and perspectives

Appropriate crop residue management may contribute to improved soil and water quality, help meet the Nitrates Directive requirements and possibly imply a new source of valuable organic material for off-field use. Results of the evaluated vegetable crop residue management strategies will be presented at the symposium at the poster sessions.

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(26) Integrated nitrogen management – a strategy to improve nitrogen efficiency in intensive field vegetable production

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Abstract: *Nitrogen use efficiency is low in regions with intensive field vegetable production. Weak points involved in low N use efficiency are (i) poor root growth, (ii) large amounts of N left in the field in crop residues and (iii) excessive N fertilisation, due to quality standard demands of the market. We conducted field experiments to identify the most effective measures to improve N use efficiency and to develop integrated N management strategies in field vegetable production. In this contribution, effects of the combination of prediction of N fertiliser demand, crop rotation and crop residue management on vegetable yield and quality, N balances and nitrate leaching are assessed. Based on the results achieved under experimental field conditions, model calculations were performed to evaluate the effects of the implementation of integrated N management strategies in farmers practice on a regional scale (vegetable growing area of Palatinate). Results show that accurate prediction of N fertiliser demand is a prerequisite to grow vegetables in an environmentally friendly way. Nevertheless, yearly N leaching losses are still too high from the environmental point of view. Accurate fertilisation has to be combined with the inclusion of cover crops in the rotation to further reduce N leaching. Export of crop residues should be adopted with caution, particularly due to the fact that export of crop residues also negatively affects soil humus content. Our results indicate effective measures to improve N use efficiency in agriculture and may be used as a basis to develop integrated N management strategies in vegetable production.*

Keywords: N balance, nitrate leaching, prediction of fertilizer demand, crop residues, crop rotation

Introduction

Nitrogen (N) is the most limiting nutrient for crop production in many of the world's agricultural areas. To meet the food needs of a growing world population, global use of N fertilizers increased largely during the past decades (Byrnes and Bumb, 1998). However, the efficiency of fertilizer N is frequently small, with often less than 50% of the applied N taken up by the crop (Wiesler, 1998). This may cause severe yield limitations where there is a lack of N fertilizers and may increase the risk of environmental pollution of both air (NH_3, N_2O) and water (NO_3^-), particularly where high N fertilizer doses are applied to achieve maximum yields and / or crop qualities. N use efficiency is particularly low in areas with high inputs of organic fertilizers (i.e. intensive livestock farming) and in regions with intensive field vegetable production. Under these conditions, several weak points may be involved in low N use efficiency, namely (i) poor root growth caused by both soil structure problems and cultivation of shallow rooting vegetable species, (ii) large amounts of N left in the field in crop residues, which are subjected to leaching over winter, and (iii) excessive N fertilization, due to quality standard demands of the market, such as size and colour of the produce (Armbruster et al., 2008). To improve N use efficiency in agriculture, numerous measures have been tested and recommended in the past decades, including improved fertilizer, soil and crop management strategies (Wiesler et al., 2001). We conducted field experiments to identify the most effective measures to improve N use efficiency in field vegetable production. These measures were used to develop integrated N management strategies in field vegetable production. Based on the weak point analysis given above, various crop rotations, different methods of crop residue management and different systems of predicting N fertilizer demand were compared.

Materials and Methods

The field experiments were conducted between 2004 and 2010 at two study sites in a vegetable production region in southern Germany. Climatic conditions for both sites are comparable with mean annual air temperature of 10 °C and mean annual precipitation of 600 mm. Soils differ significantly at both sites. The soil at the first site (agricultural experimental station “Rinkenbergehof” of the LUFA Speyer) is a gleyic cambisol developed from loamy sand with a low field capacity of 10%. The soil at the second site (agricultural experimental station “Queckbrunnerhof” of the DLR Rheinpfalz) is a haplic luvisol developed from loam and has a field capacity of 20%. Four crop rotations ((i) vegetable monocropping, (ii) vegetable followed by a summer cover crop, (iii) vegetable followed by a winter cover crop and (iv) vegetable followed by cereal) were compared at both sites (Table 1). At the site “Rinkenbergerhof” three methods of crop residue management ((i) incorporation immediately after harvest, (ii) delayed incorporation after harvest, (iii) export from the field) were compared. At both sites two methods of predicting N fertilizer demand ((i) application of fixed N rates), (ii) N-Expert: taking into account the soil mineral N supply) were compared. A third method ((iii) SPAD: chlorophyll meter measurements) was tested at the site “Rinkenbergerhof”. At both sites a randomized block experiment (split-split-plot design at “Rinkenbergerhof”; split-plot design at “Queckbrunnerhof”) with four replicates including all treatments was established.

Susceptibility to nitrate leaching is highest in rotation 1 (vegetable mono-cropping with two vegetable crops per year, cauliflower in 2004 and 2007, lettuce in 2005, blanched celery in 2006, spinach in 2008, rocket in 2009, welsh onion in 2010) and reduced in rotations 2 (cultivation of one vegetable crop per year followed by the deep rooting summer cover crop sorghum, grown until November), 3 (cultivation of one vegetable crop per year followed by the deep rooting winter cover crops barley or rye, grown until may) and 4 (cultivation of one vegetable crop per year followed by the deep rooting cereals winter wheat or barley, grown until maturity in july). Regarding crop residue management, a reduced susceptibility to nitrate leaching was expected in treatment II.3, in which all crop residues were removed from the field. N fertilizers were applied according to (1) “farmers practice” (application of fixed N rates based on long-term experiences of farmers), (2) the N-Expert system (application of variable N rates taking into account the soil mineral N supply according to soil tests and the estimated mineralization of crop residues; Feller et al., 2007) and (3) SPAD chlorophyll meter measurements (N top dressing not before the leaf colour drops below 95% of that of highly fertilized control plants grown in a “fertilizer window”). Marketable yield, N uptake and nitrate concentration in seepage water (installation of suction tubes at 105 cm soil depth, sampling of suction water in 2 weeks intervals) were measured and N balances (N import with fertilizers minus N export with the marketable produce) and nitrate leaching (based on nitrate concentrations in the suction cup water and seepage water according to application of a soil water balance model) were calculated.

Based on the results achieved under experimental field conditions, model calculations were performed to evaluate the effects of the implementation of integrated N management strategies (accurate prediction of N fertiliser demand; growing cover crops; export of crop residues) in farmers practice on a regional scale. Based on statistical data (vegetable areas and species; Statistisches Landesamt Rheinland-Pfalz, 1992-2008) N-balances were calculated for the vegetable growing area of Palatinate for different strategies. Additionally potential nitrate concentrations in soil water for strategies were calculated. For this seepage water amounts were estimated from climate and soil data. Model calculations are conducted according to the assumptions of the model “Stoffbilanz” (Gebel et al., 2010).

Table 1: Experimental treatments at the two experimental sites.

I	**Crop rotation**
	1. Vegetable mono-cropping (vegetable / vegetable)
	2. Vegetable followed by a summer cover crop (vegetable / summer cover crop)
	3. Vegetable followed by a winter cover crop (vegetable / winter cover crop)
	4. Vegetable followed by a cereal crop
II	**Management of crop residues (only site “Rinkenbergerhof”)**
	1. Incorporation immediately after harvest
	2. Delayed incorporation after harvest (only until 2007)
	3. Export from the field to be used in a biogas plant
IV	**Estimation of N fertilizer demand**
	1. Farmers practice (application of fixed rates)
	2. N-Expert (taking into account the soil mineral N supply)
	3. SPAD chlorophyll meter measurements (only site “Rinkenbergerhof”)

Results and Discussion

Table 2 shows that the prediction of N fertilizer demand highly influenced N fertilizer rates. Compared with the application of fixed N rates according to farmers practice, application of variable N rates taking into account the soil mineral N supply according to soil tests (N-Expert) reduced N fertilization considerably, with N rates ranging between 60% and 78% of those applied according to farmers practice. A further reduction of the amount of N application could be achieved by the use of the SPAD chlorophyllmeter.

Table 2: Nitrogen fertilizer amount [kg N ha^{-1}] of each vegetable crop (average of planted) according to method of fertilizer demand estimation. Values in brackets show data for site "Queckbrunnerhof".

Crop	Farmers practice	N-Expert	SPAD
Cauliflower	338 (325)	203 (208)	167
Blanched celery	300 (300)	222 (208)	184
Lettuce	166 (166)	106 (116)	97
Spinach	180 (180)	140 (108)	103
Rocket	150 (150)	109 (94)	91
Welsh onion	240 (250)	172 (150)	135

Regardless of huge differences in N fertilizer application, percentage of marketable plants of vegetables from seedlings (cauliflower, blanched celery and lettuce: means of 4 years, 3 species and 1 – 2 crops per season) was hardly affected by the method of N fertilizer recommendation (Figure 1). Compared with vegetable mono-cropping, growing of summer or winter cover crops increased the percentage of marketable plants. This might indicate soil structure problems, arising with long-term vegetable mono-cropping. Likewise, long-term export of crop residues without any compensatory supply of organic material seems to cause yield losses, due to negative effects on the soil humus content.

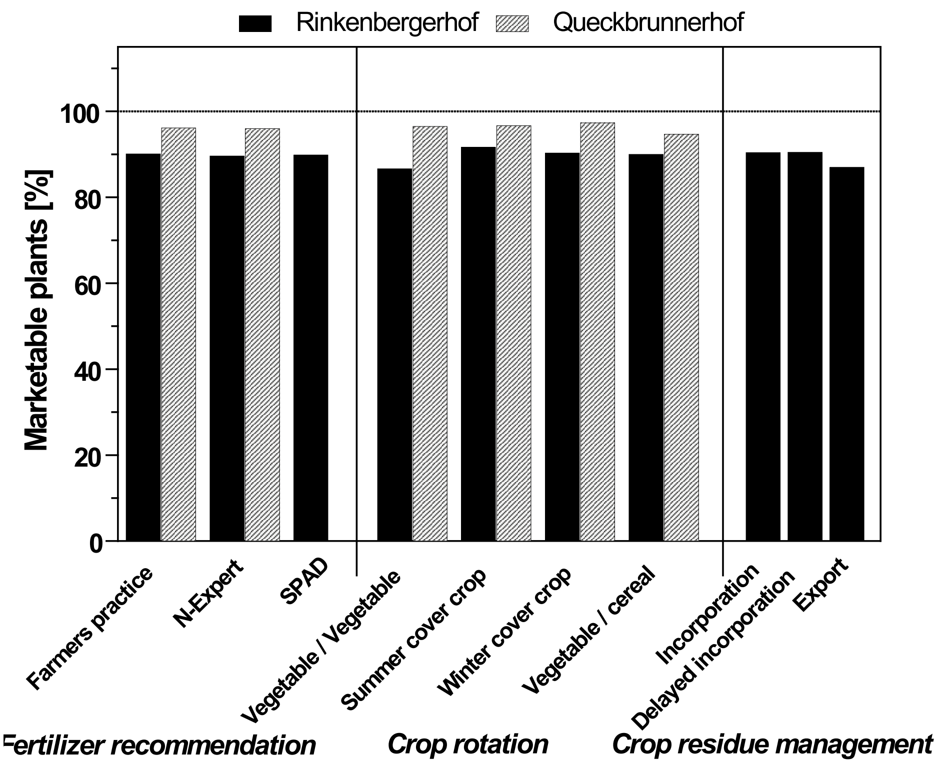

Figure 1: Percentage of marketable vegetables from seedlings (cauliflower, blanched celery and lettuce: means of 4 years, 3 species and 1 – 2 crops per season) as influenced by the method of estimating N fertilizer demand, crop rotation and crop residues management (100 % = all plants marketable).

Fresh matter yield of vegetables from seeds (spinach, rocket and welsh onion) was reduced by application of SPAD fertilizer recommendation method at the sandy site "Rinkenbergerhof" (Figure 2). This might be due to shorter vegetation times (spinach and rocket) and problems with the standardisation of SPAD measurement for all tested species from seeds. Obviously the SPAD method was less applicable for vegetables from seeds. Compared with vegetable mono-cropping, growing of summer or winter cover crops increased and export of crop residues decreased marketable yield of vegetables from seeds. The significant yield decrease of the vegetable /cereal crop rotation at the site "Queckbrunnerhof" was due to technical problems with accurate straw incorporation at the experimental plots.

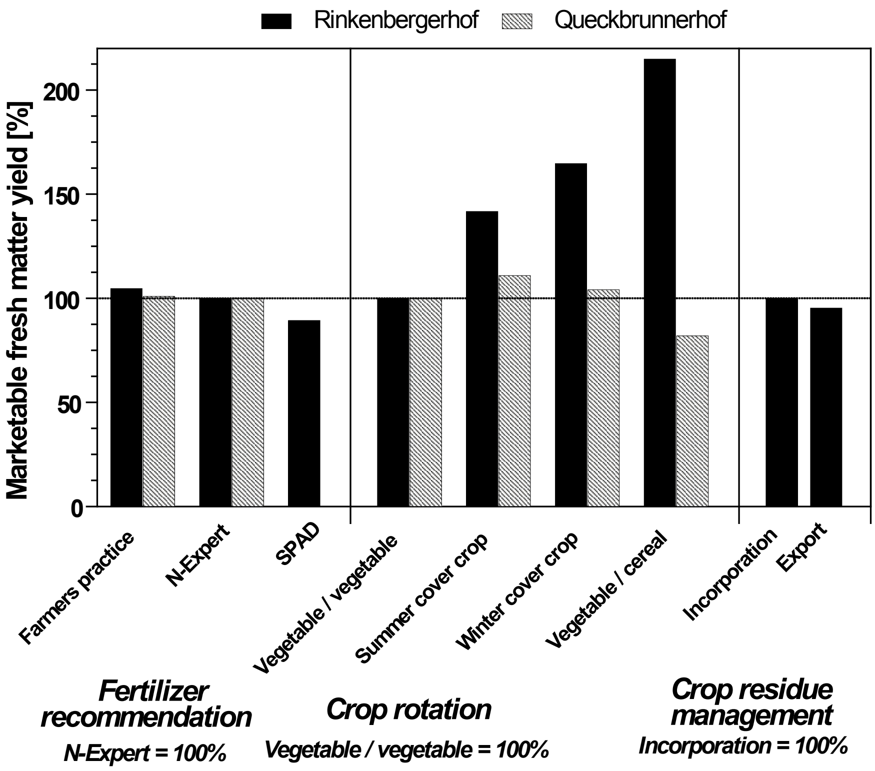

Figure 2: Marketable vegetable fresh matter yield of vegetables from seeds (spinach, rocket and welsh onion: means of 3 years, 3 species and 1 – 2 crops per season) as influenced by the method of estimating N fertilizer demand, crop rotation and crop residues management. All data in relative numbers: Fertilizer recommendation “N-Expert” = 100%; Vegetable / vegetable crop rotation = 100%; Incorporation of crop residues = 100%.

Nevertheless the results clearly indicate the potential to reduce N fertilizer rates while maintaining both high yields and the required quality standards of vegetables. In addition to soil tests, the use of the crop as an indicator of site-specific soil N supply seems promising for vegetables from seedlings (i.e. cauliflower, blanched celery), particularly under conditions where the mineralization of high amounts of N in crop residues or cover crops contribute above average to N uptake of the crop.

Nitrate-N leaching in the years 2005 to 2010 (installation of suction cups after the first vegetable rotation in autumn 2004) clearly reflected the different amounts of N applied in the various N fertilization treatments. N fertilization according farmers practice resulted in extremely high leaching losses in the range of 216 to 460 kg N ha^{-1} yr^{-1} at the sandy site “Rinkenbergerhof” and 96 to 546 kg N ha^{-1} yr^{-1} at the loamy site “Queckbrunnerhof”, respectively (Figure 3). Losses could be reduced by more than 50% when N fertilizer application was based on soil tests. Similar results were obtained by the use of the SPAD chlorophyllmeter at the site “Rinkenbergerhof” (not shown). A further significant reduction in nitrate-N leaching could be achieved when the accurate prediction of fertilizer N demand (N-Expert) was combined with an environmentally friendly crop rotation, such as the vegetable /cereal crop rotation (Figure 4). Export of N-rich crop residues resulted in an additional reduction of leaching (not shown).

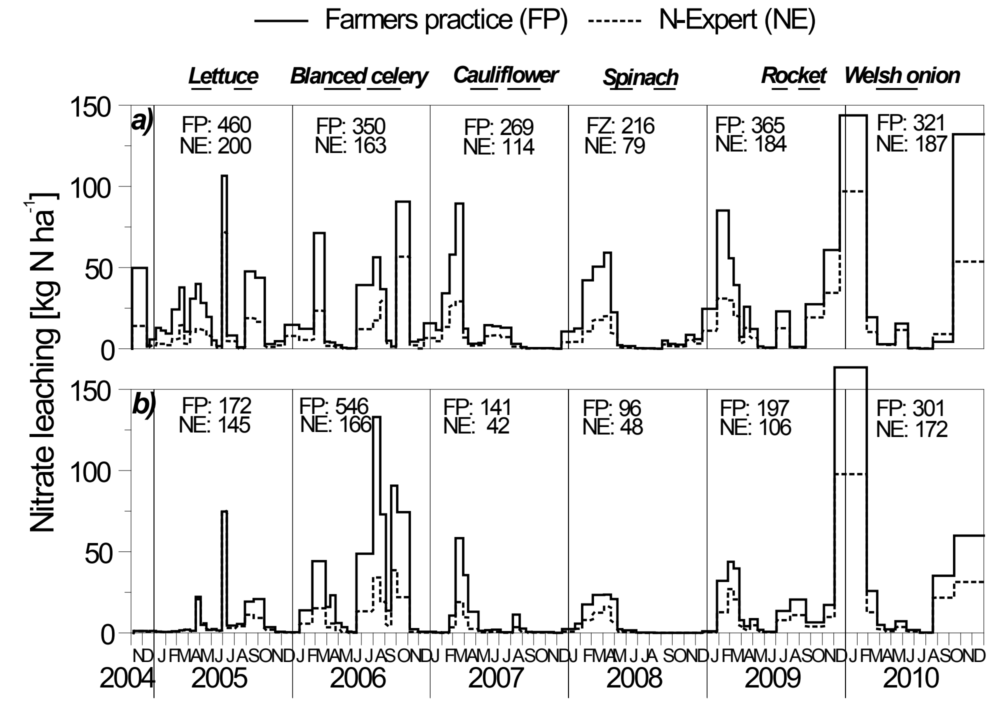

Figure 3: Nitrate-N leaching at 105 cm soil depth in the vegetable monocropping rotation as affected by the method of estimation N fertilizer demand (a) sandy site “Rinkenbergerhof”; b) loamy site “Queckbrunnerhof”). Numbers given in the figure indicate the yearly sums of nitrate-N leaching.

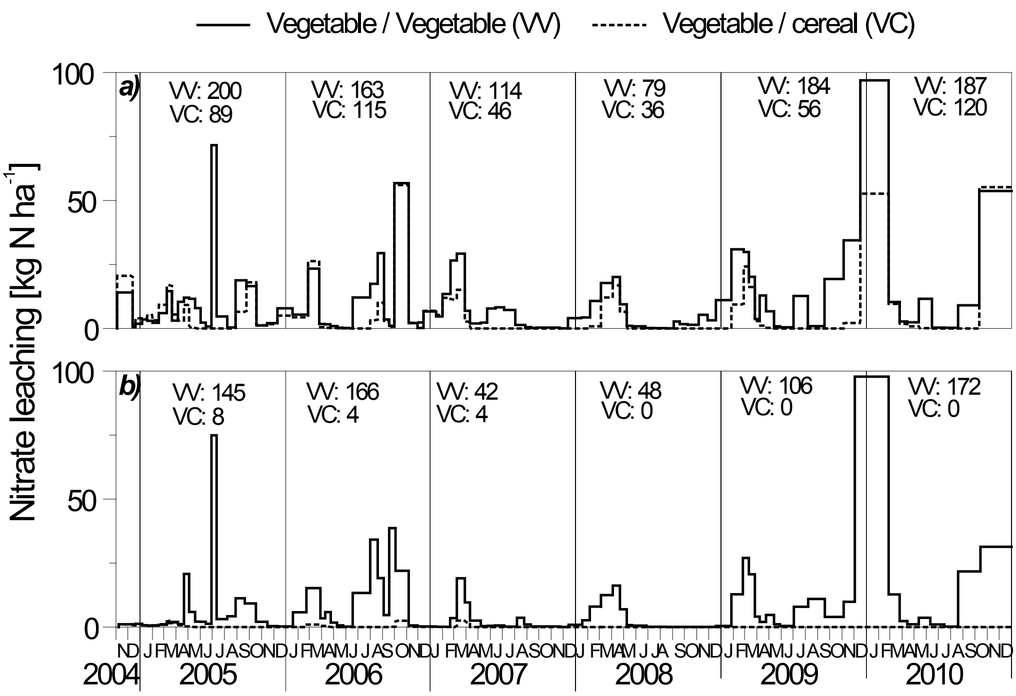

Figure 4: Nitrate-N leaching (kg N ha^{-1}) at 105 cm soil depth in treatment with N application according to N-Expert as affected by crop rotation (vegetable / vegetable compared with vegetable /cereal) (a) sandy site “Rinkenbergerhof”; b) loamy site “Queckbrunnerhof”). Numbers given in the figure indicate the yearly sums of nitrate-N leaching.

Model calculations for the vegetable growing area of Palatinate showed that solely accurate prediction of N fertilizer demand reduced potential nitrate concentrations in the groundwater by approximately 50% (Table 3). If additionally crop residues of vegetables with high amounts of N in crop residues (i.e. cauliflower, broccoli, zucchini) were removed on 20% of those areas (scenario C1) or summer cover crops were grown at 20% of the vegetable area (scenario C2), a further decrease by 10 – 12% (25% if cover crops were additionally removed: scenario C3) of the potential nitrate concentration in the groundwater area was achieved.

Table 3: Potential nitrate concentrations in soil water (without denitrification losses) and in groundwater (assumption of 50% denitrification losses) of the vegetable growing area of Palatinate for different model scenarios. All numbers in mg l^{-1} nitrate (NO_3^-) for the year 2000.

	Scenario	**Potential nitrate concentration [mg l^{-1} NO_3^-]**	
		Without denitrification losses	Assumption of 50% denitrification losses
A)	"Farmers practice" N fertilizer demand	386	193
B)	"N-Expert" N fertilizer demand	188	94
C)	"N-Expert" N fertilizer demand		
	C1) export of crop residues (20 %)[a]	165	83
	C2) summer cover crops (20 % of area)	172	86
	C3) summer cover crops (20 % of area) and export of cover crops	146	73

[a] Export of crop residues of vegetables with high amounts of N in crop residues (i.e. cauliflower, broccoli) at 20% of those areas.

Conclusion

Conclusions may be drawn from Table 4, summarizing the most effective measures / measure combinations to reduce N balance surpluses and nitrate leaching in vegetable production. Table 4 shows that accurate prediction of N fertilizer demand by soil or plant tests is a prerequisite to grow vegetables environmentally friendly. Nevertheless, yearly N leaching losses in the treatments N-Expert and SPAD (> 150 kg N ha^{-1} at the sandy site "Rinkenbergerhof" and > 110 kg N ha^{-1} at the loamy site "Queckbrunnerhof", respectively) are still too high from the environmental point of view. When N fertilization according to N-Expert is combined with the inclusion of cover crops in the rotation, N balance surpluses and N leaching losses can be further reduced. This effect is even more pronounced when N fertilization demand is estimated on the basis of chlorophyllmeter measurements, indicating that this method has particular advantages under conditions of high mineralization rates, e.g. from crop residues or cover crops. Finally, export of crop residues after harvest may result in very low N surpluses or even negative N balances. However, this measure should be adopted with caution, particularly due to the fact that export of crop residues also affects soil humus content negatively. Results presented in Table 4 indicate effective measures to improve N use efficiency in agriculture and may be used as a basis to develop integrated N management strategies in vegetable production.

Table 4: Nitrogen balance and nitrate-N leaching at 105 cm soil depth as influenced by the method of predicting N fertilizer demand, crop rotation and crop residue management (means over experimental years: N balances 2004-2010, N leaching 2005-2010; n.d. = not determined). Values in brackets show data for site "Queckbrunnerhof".

Prediction of N fertilizer demand	Crop rotation	Crop residues	N balance [kg N ha^{-1} yr^{-1}]	N leaching [kg N ha^{-1} yr^{-1}]
Farmers practice	Vegetable / vegetable	incorporation	288 (265)	330 (242)
N-Expert	Vegetable / vegetable	incorporation	126 (86)	154 (113)
SPAD	Vegetable / vegetable	incorporation	100 (n.d.)	156 (n.d.)
N-Expert	Summer cover crop	incorporation	79 (91)	79 (46[a])
N-Expert	Winter cover crop	incorporation	62 (53)	87 (n.d.)
N-Expert	Vegetable / cereal	incorporation	98 (54)	77 (3)
SPAD	Summer cover crop	incorporation	54 (n.d.)	n.d. (n.d.)
SPAD	Winter cover crop	incorporation	47 (n.d.)	n.d. (n.d.)
SPAD	Vegetable / cereal	incorporation	79 (n.d.)	n.d. (n.d.)
N-Expert	Vegetable / vegetable	export	30 (n.d.)	141 (n.d.)
N-Expert	Summer cover crop	export	-29 (n.d.)	n.d. (n.d.)
N-Expert	Winter cover crop	export	-36 (n.d.)	n.d. (n.d.)
N-Expert	Vegetable / cereal	export	37 (n.d.)	n.d. (n.d.)

[a] Period 2008 – 2010 only

Acknowledgements

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(27) KNS[1] – Based advisory system proves to be a useful tool in reducing residual nitrate content of horticultural soils in the fall

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Abstract: *The past 15 years practical research considering nitrate uptake of different horticulture crops led to an adaptation of the German KNS (Kulturbegleitenden N_{min} Sollwerte-System) advisory system to Flemish circumstances. Between 2006 and 2011 this Flemish advisory system was validated on 60 different fields spread over Flanders. On those 60 fields two different fertilization strategies were applied. One part of the field received nitrogen fertilization following the advisory system. Here soil samples before and during the culture were used in order to determine the given nitrogen doses. Depending on the culture, nitrogen fertilization was applied in a number of different fractions and nitrogen doses were always based on the analysis of a soil sample. On the other part of the field, the farmer was asked to fertilize his crop according to his own insights. The selection of cooperating farmers was done by the Flemish research centres (practical agricultural research in open air horticulture) and was based on the care and precision of farmers' fertilization practices. Only farmers already using 'good agricultural practices' were allowed. On both parts of every field nitrate content in the soil and obtained yields were closely surveyed. From the results of the comparison a number of conclusions can be drawn:*

- *Farmers applied larger N–fertilizer doses compared to the KNS-system.*
- *Average residual nitrate content in the fall was higher on the fields fertilized by the farmers.*
- *Both farmers and practice centres struggled to achieve the legally obliged residual nitrate content of 90 kg NO_3-N in their soils (soil layer between 0 and 90 cm depth) during the fall.*
- *On 11 of the 60 fields the farmers achieved higher yields.*

[1] *KNS (Kulturbegleitende N-min – sollwerte)–system, developed by IGZ (Institut fur gemuse und zierpflanzenbau) and DLR (Dienstleistungszentren landlicher raum) Rheinland - Pfalz, republished and digitalized by IGZ and named N-expert.*

Keywords: *horticulture, fertilisation advice, residual nitrate, fractionated fertilisation.*

Introduction

Open air horticulture in Flanders and Europe faces a difficult adaptation due to the European nitrate directive. European legislation states that nitrate (NO_3^-) content in surface waters must not exceed 50 mg NO_3^-/l. It is hard to conciliate the practice of open air horticulture with this objective. Due to the properties of vegetable cropping a high nitrogen (N) content in the soil is often necessary. Most vegetables are harvested in a vegetative state, meaning that N-uptake and supply must be plentiful in order to achieve good yield and quality. Furthermore many vegetable species have a poorly developed and shallow root system which causes a low N-uptake efficiency. Compared to arable crops vegetables produce a significantly higher economical yield. This yield is very closely related with the quality of the produced vegetables. Small nitrogen shortages can rapidly lead to significant decreases in crop quality. In order to reduce the risk of crop failure most vegetable farmers apply high doses of N fertilizer (animal manure as well as chemical fertilizer) often exceeding the actual demand of the crop.

Many Flemish soils have a history of intensive fertilization with animal manure, mostly pig slurry. Vegetable cropping also produces large amounts of easily decomposable crop residues. Therefore N -mineralization from decomposing non-recalcitrant organic material can be significant and hard to predict. In order to adjust N-fertilization to real crop demands, while taking in account unpredictable mineralization rates of the soil and crop residues, an elaborated advisory system is needed. The Flemish research centres chose to adapt the principles of the German KNS-system to the Flemish agricultural situation as the KNS-system uses soil sampling during crop growth and fractionated N-fertilizer gifts during cultivation.

Material and Methods

Since the 1980s the German 'Institute fur Gemuse und Zierpflanzenbau' developed and refined an advisory system for N-fertilization in open air horticulture. Originally called KNS-system (Kulturbegleitende N-min Sollwerte system) the system was further developed, digitalized and renamed the N-expert system. Using N-uptake curves for all relevant crops, the system allows to calculate the expected N-uptake between the current stage of the crop and the harvest time. This allows using soil samples taken during the growing period to correct the mineral nitrogen stock in the soil. The use of soil samples taken during the growing period also makes it possible to account for all mineralization that occurred during the period before sampling.

This was one of the main reasons for the Flemish research centres to use the principles of the KNS- system when developing a proper advisory system adapted to Flemish cultures and agricultural practices. Uptake curves for all relevant cultures were taken from the KNS-system and when necessary adaptations (N-uptake, expected yield) were made by experienced advisors. Supplementarily a number of relevant parameters were added to the system. Farmers are asked to supply the advisor with these parameters (combined with a soil sample) when a fertilization advice is demanded.

Using the expected N-uptake of the crop and the results of the analysis of the soil sample, an advice is calculated. Based on an intensive study of existing literature and by using the information supplied by the farmers, an estimation of expected mineralization from soil organic matter, organic fertilizer and crop residues is made and deducted from the advice.

Necessary parameters can be divided in 3 categories:

- Soil parameters: texture of the soil, the pH and the carbon content in the soil.
- Field history: the amount and type of organic fertilizer - applied during the current and the past year- must be known, as well whether a catch crop was sown the previous year .
- Field usage: With respect to the usage of the field the farmer is asked whether horticulture is the main agricultural activity on the field or not (to account for higher mineralization due to higher quantities of instable organic material), what the previous cultures were and whether crop residues of the preceding culture were already incorporated at the time the soil sample was taken.

During a period of 4 years (from 2006 until 2009) the Flemish advisory system was validated on site. 15 professional field vegetable farmers were asked to cooperate in a comparative study. The cooperating farmers were selected from the pool of farmers already cooperating with the field research of the research stations. Each of the 3 Flemish research centres selected 5 fields accounting for a total of 15 fields. The cooperating farmers were chosen in order to obtain an optimal geographical distribution and an optimal coverage of soil types (on which horticulture is conducted) existing in Flanders.

For each farm a field was selected on which intensive horticulture cropping would be conducted for the following 4 years. Validation of the advisory system was done by dividing these fields in two halves. A first part of the field received N-fertilization following the farmers' insights. On the second part of the field N-fertilization was applied following the advice given by one of the practice centres. Furthermore, all actions on this part of the field were conducted following the best possible agricultural practices (e.g. when possible catch crops were sown, …).

Both parts of the field were intensely surveyed in order to compare soil N-content, yield and quality in both parts of the field. General soil properties were determined and all relevant actions on both parts of the field were registered. On yearly basis, up to 7 soil samples were taken on every part of each field (always on the same date) in order to determine soil mineral N-content. At the beginning of each culture a soil sample was taken in order to formulate a first fraction of the advice. During every culture 2 soil samples were taken, the first sample was used to define the second fraction of the fertilization advice. A soil sample was also taken whenever a culture was harvested and during the fall a supplementary soil sample was taken in order to determine residual NO_3^--content in the soil.

Results

Fertilizer doses applied

Table 1 shows the applied fertilizer doses for every culture. Applied fertilizer is calculated on a yearly basis and the 15 fields surveyed for 4 years are considered as 60 individual fields. All applied fertilizer doses are given in kg effective N per hectare (N-fertilizer value).

Table 4: Fertilizer doses applied and residual nitrate content in the soil on the farmers' fields and on the fields fertilized following advice of the research centres.

Culture	nr of fields	farmers			research centres			Relative (centres versus farmers)	
		effective N (kgN/ha)		residual N (kg N/ha)	effective N (kgN/ha)		residual N (kg N/ha)	total effective nitrogen	residual nitrate
		organic	total		organic	total			
Lettuce (3x)	4	24	284±58	179	8	226±38	202	80%	113%
potatoes	3	91	156±36	67	22	139±49	45	89%	67%
Endive-leek	2	61	455±10 1	203	19	255±33	139	56%	68%
cauliflower	3	101	282±40	304	26	166±57	240	59%	79%
cauliflower (2X)	3	18	356±11 0	328	5	269±111	170	76%	52%
cauliflower-leek	5	65	335±96	215	22	224±40	116	67%	54%
cauliflower-radicchio	1	21	312	143	0	110	77	35%	54%
cauliflower-fennel	2	84	343±13 5	249	14	159±12	165	46%	66%
broccoli	1	102	183	41	0	50	50	27%	122%
lettuce (iceberg)	2	0	150±0	126	21	161±14	54	107%	43%
iceberg - head cabbage	2	0	202±74	142	10	189±26	47	94%	33%
turnip-rooted celery	2	80	190±44	182	0	75±35	94	39%	52%
leek(seedlings) - carrots	1	0	126	209	16	142	197	113%	94%
leek	12	87	233±68	183	15	168±39	107	72%	58%
leek-endive	1	63	328	210	32	196	6	60%	3%
spinach	2	0	136±37	118	10	111±121	125	82%	106%
spinach-beans	1	83	164	58	0	140	54	85%	93%
spinach-cauliflower	1	79	200	109	0	289	59	145%	54%
spinach-leek	4	59	303±31	255	36	209±71	199	69%	78%
spinach-beans	1	79	79	412	0	163	231	206%	56%
Brussels sprouts	1	78	226	60	16	265	20	117%	33%
beans	2	89	105±7	163	39	65±64	128	62%	79%
sugar beet	1	43	124	100	0	93	67	75%	67%
wheat	1	50	223	15	0	158	13	71%	87%
carrots-beans	1	0	50	174	0	101	221	202%	127%
onion	1	0	37	57	0	57	69	154%	121%

Of the applied organic fertilizer, only the mineral N released during the first year after application is taken in account when calculating the given dose. Depending on the type of organic fertilizer different N-fertilizer values are used. These percentages (legally standardized) represent the amount of mineral N that becomes available during the first year after application.

- mineral fertilizer : 100%
- pig slurry : 60 %
- cow slurry : 60 %
- litter: 30%
- compost : 15 %

In almost all cases farmers appear to be giving higher amounts of effective nitrogen in the form of organic fertilizer. This is partly due to the more intensive use of pig slurry. About 1/3 of the farmers applied pig slurry, 1/3 of the farmers did not apply any organic manure and 1/3 of the farmers applied solid manure or compost. The research centres did not apply any organic fertilizer in half of the cases. For the other half of the fields, compost was applied in most cases.

In general, fertilizer doses applied by the farmers were higher than the doses advised by the practice centres. Especially when crops with a high N-demand are considered reductions in applied N were achieved by following a fertilisation advice.

The standard deviation per culture(s) on the doses given by the farmers is significantly higher than the standard deviation on the applied doses following the given fertilization advices. This is mostly due to outliers, fields on which the farmer applied too much fertilizer. On some fields farmers applied up to 550 kg effective N/ha for a rotation of leek and fennel. Most high outliers were due to intensive application of pig slurry. For some cultures, the advices given by the research centres also showed relatively high standard deviations caused by differences in mineralisation, soil type and history of the field.

Crop Yield

Figure 1 gives an overview of the relative crop yields obtained when using N-fertilizer doses advised by the KNS-system compared to yields attained on the same field when using N-fertilizer doses according to farmer's practice. Only total marketable yield was considered. Differences in crop quality were not considered. Only fields where yield determination could be done appropriately and at the same moment for both parts of the field are shown in the figure. Comparison between the 'farmer's practice' and the 'research centres' shows a slightly higher yield for the Farmers' practice in most of the cultures. On 32 of 47 fields the farmers obtained the higher yield. On 11 fields these differences were statistically significant at p = 0,05 (Duncan).

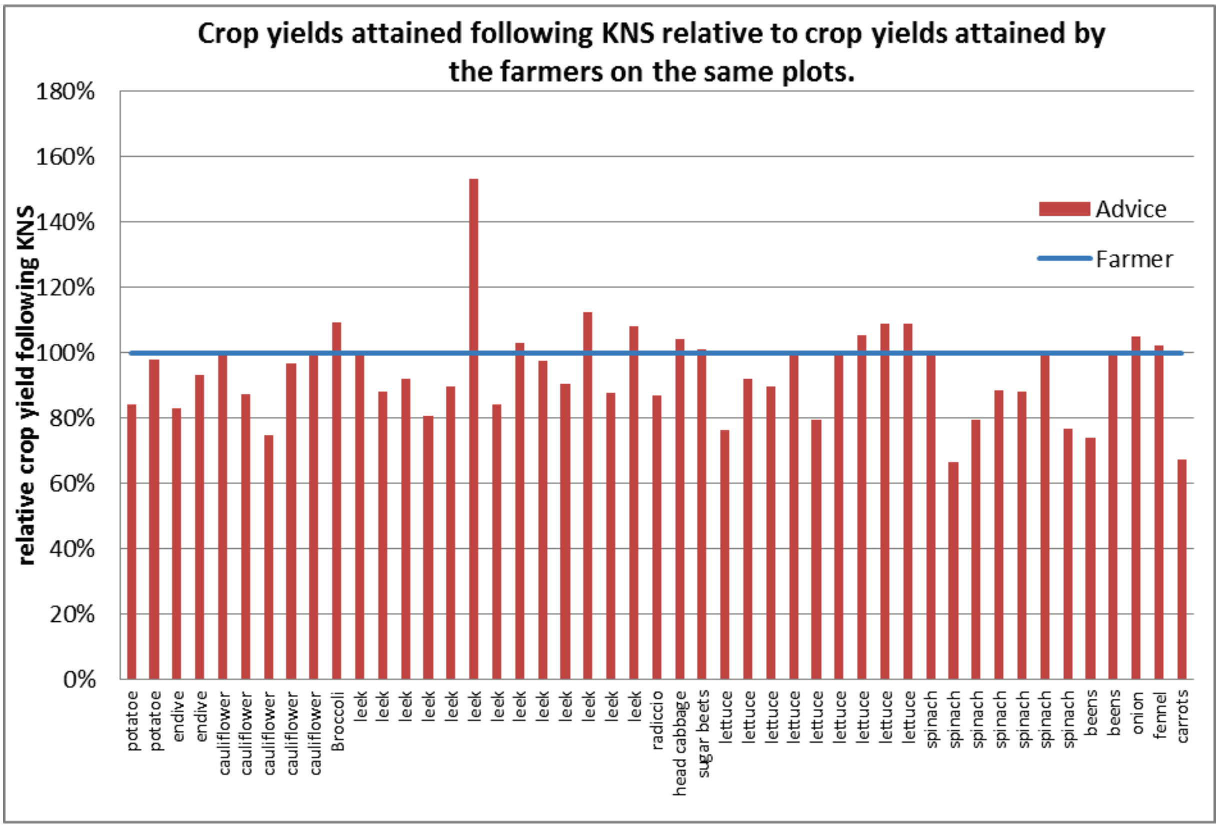

Figure 10: Crop yields of plots fertilized following the advice of the centres. Yields are expressed relatively to the yield of the farmer on the same field.

Residual nitrate content in the fall

Between the 1st October and 15th of November, residual NO_3^{-} content in the 0-90 cm soil layer was determined on all fields. Soil samples were taken on the same day for both parts of the field (fertilization according to farmer's practice and the KNS-system).

Residual NO_3^--content measured in the fall in the 0-90 cm soil layer of every field is given in Table 1. Figure 2 gives a cumulative distribution of the residual NO_3^--content measured in every field. Three different curves are shown : the residual NO_3^--content in the fields fertilized by the farmers and the residual NO_3^--content in the fields fertilized according to the KNS-system with in- and exclusion of the fields with significantly lower yields (at p = 0.05)).

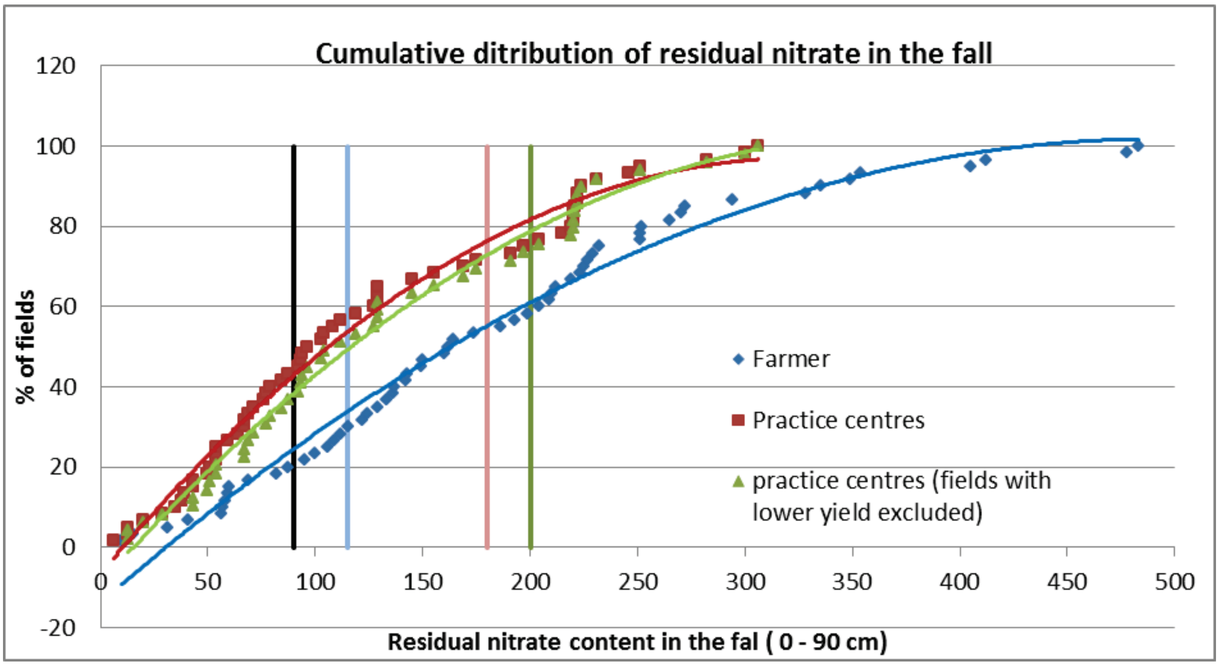

Figure 11: Residual nitrate in the fall: cumulative distribution of all measured (layer between 0 cm and 90 cm) residual nitrate contents in both fields fertilized by the farmer and fields fertilized following advice.

This figure clearly shows the differences between the fertilization strategies followed by the farmers and fertilization following the advices of the practice centres. Only 24% of the fields fertilized according to farmer's practice attained the legally obliged maximum residual NO_3^--content in the 0- 90 cm soil layer. This percentage amounts up to 43% for all the fields managed according to the KNS-system. When only the fields without a significant yield reduction are considered this percentage drops to 38%. Furthermore a significant number of fields has very high residual NO_3^--nitrate contents exceeding 300 kg NO_3-N/ha. Most of these fields received high quantities of organic fertilizers.

The vertical lines on the figure show the different legal thresholds in horticulture (90 kg NO_3-N/ha, 110 kg NO_3-N/ha, 180 kg NO_3-N/ha and 200 kg NO_3-N/ha) representing increasing sanctions when exceeded. When the final threshold is exceeded, the farmer is obliged to sow a catch crop on this field. He also must reduce his fertilizer dose to 40 % on this field the following year, his company will have an administrative audit, and he will be controlled more intensively in the future. 40% of the farmers exceeds this highest threshold. When advice of the KNS-system was followed, only 21% of the fields (yield reductions are excluded) exceeded the highest threshold.

Summary

High residual NO_3^--contents in horticultural soils remain a problem in autumn. Using an advisory system in order to adjust fertilization to crop requirements leads to a reduction in applied effective N for most cultures. Furthermore, this reduction in N applied mostly leads to a reduction of the residual NO_3^--content in the fall. The possible reduction in effective N applied appears to be higher when cultures with high N demand are considered. Residual NO_3^-- contents measured in the fall follow a similar tendency.

An important negative consequence of these lower fertilizer doses are the lower yields that might occur. As shown in Figure 1, a small reduction in total marketable yield did occur in many cases. On a considerable amount of fields this reduction was statistically significant at p = 0.05. Even when following the advisory system, residual NO_3^--content in the soil remains high. The legal threshold of 90 kg NO_3-N/ha (0-90 cm) in the fall remains very difficult to attain in horticulture. When following the advisory system, only 38% of the fields obtained this threshold.

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(28) Strong effect of compost and reduced tillage on C dynamics but not on N dynamics in a vegetable cropping system

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Abstract: *Organic matter supply by compost and the way it is incorporated are important issues for sustaining soil quality in horticulture. Our research question was how compost application and reduced tillage would affect soil N dynamics and fertilizer N availability. To this end a multiyear field trial on a sandy loam soil with a vegetable crop rotation was set up. Soil tillage in spring was executed either with a moldboard plough or with an Actisol cultivator designed for non-inversion soil tillage. Farm compost was applied each autumn, starting in 2008, at 3 different rates, i.e. 0, 15 and 45 Mg per hectare. In 2011 leek (Allium porrum) was cultivated as test crop. Top mineral N dressing (0, 30 or 60 kg N ha^{-1}) eight weeks after planting was added as a third factor. After three years significant differences between treatments were observed with respect to pH, total organic C and hot water extractable C content in the 0-10 cm soil layer. Only a few significant differences in N dynamics between treatments were registered. Residual N at the end of the growing season only varied due to differences in top mineral N dressing. The resulting higher C stocks did not appear to affect the risk of nitrate leaching.*

Keywords: *soil management; soil condition; soil organic matter; N availability; N use efficiency*

Abbreviations: *SOM: soil organic matter; C: carbon; N: nitrogen; ANM: apparent net N mineralization; TOC: total organic carbon; HWC: hot water extractable carbon; BD: dry soil bulk density; NUE: N use efficiency; Nmin stock: stock of soil mineral N; CT: conventional tillage (ploughing), RT: reduced (non-inversion) tillage; C0, C1, C2: 0, 15 and 45 Mg farm compost ha^{-1}; s1, s2, s3: sampling moment 1, 2, 3.*

Introduction

Compost application and reduced tillage are carbon (C) saving practices due to supply of stable organic matter and suppression of organic matter oxidation by minimizing soil inversion and soil structure disruption, respectively (Alluvione et al., 2013). These cultivation measures may also improve soil quality by favoring nutrient status, soil structure and soil organisms. Bernard et al. (2012) observed an increased microbial population and activity by compost application. Release of nutrients from compost in the surrounding soil increases nutrient availability and microbial activity (Duong et al., 2013). Aggregates in the surface layer are more stable in case of no-till or reduced tilled soils, which is associated with an increased organic matter content (Cannell, 1985). A higher level of organic matter content at the soil surface in a reduced tillage system favors a different range of organisms compared to a plough-based system in which residues are buried (Rasmussen and Collins, 1991). Nitrogen (N) is a key-element in plant nutrition, however, excessive N use and low N use efficiency in vegetable cropping has led to environmental problems which should be solved by the implementation of national or regional programs in the frame of the European Nitrates Directive.

Repeated compost application is expected to increase the N availability due to an increase in the N mineralization potential of soil organic matter (SOM). On the other hand, freshly applied not fully matured compost (high C/N) may cause temporary immobilization of N due to readily available C sources. Addition of stabilized organic matter by regular compost application may favor the physical properties of the soil and hence plant growth and nutrient uptake. D'Hose et al. (2012) reported a positive yield effect of yearly applied farm compost at optimum fertilizer N supply, which indicated a better soil condition for crop growth as a result of repeated compost application. Soil tillage practices may change both spatially and temporally the N turnover processes in the soil. D'Haene et al. (2008) related a higher mineralization rate in the 0-15 cm top soil under reduced tillage, compared to conventional tillage, to the higher stratification of the total N percentage in the 0-30 cm arable layer.

Our research hypothesis was that changes in soil quality, as a result of compost application and reduced tillage, would affect N availability in the soil and N use efficiency of a top mineral N dressing due to changes in N turnover processes. A related research question was if the supposed change in N availability would occur to an extent that (1) fertilization schemes should be adapted and (2) levels of residual N could considerably raise, with consequently a higher risk of nitrate leaching. A field trial was set up in September 2008 with different combinations of compost application rates and soil tillage practices, in order to create a variety in soil conditions. In the third growing season, 2011, differences in soil quality parameters and N dynamics were assessed.

Materials and Methods

Experimental set-up and crop monitoring

A two-factorial soil management experiment was installed on a sandy loam soil at 50°57'N and 3°15'E (Meulebeke, Belgium) in September 2008. The soil was tilled either conventionally (CT) by ploughing or according to reduced tillage (RT) with an Actisol cultivator designed for non-inversion soil tillage. Tillage depth was approximately 30 cm for both tillage practices. Farm compost was prepared at ILVO in a windrow composting system based on equilibrated mixes of crop residues, wood chips, bark and hay of grass and clover (Steel et al., 2012). All compost used for the trial was well ripened (high $N\text{-}NO_3^-$ to $N\text{-}NH_4^+$ ratio) and had a high organic matter content (40-70 % on dry matter). Compost was applied each year in autumn, starting in 2008, at 3 different rates, i.e. 0, 15 and 45 Mg ha^{-1} (C0, C1 and C2). The split-plot trial design had soil tillage as main plot and compost application as subplot factor. Individual subplots were 6 by 18 m.

In the third year of the experiment (2011), leek (*Allium porrum*, cultivar Harston) was planted on the fourth of July, after chopping the spring cover crop (*Sinapis alba*). Mineral N fertilizer (calcium ammonium nitrate, 27% N) was used as base mineral N dressing of 70 kg N ha^{-1} immediately before planting leek. Based on mineral N availability in the 0-60 cm soil layer, three N doses, i.e. 0, 30 and 60 kg N ha^{-1}, were applied as top mineral N dressing (calcium ammonium nitrate, 27% N) eight weeks after planting on three randomized sub-subplots (split-split plot design). At that time, four times two meters of leek were harvested in two different rows within the subplot. At the end of the growing season (first half of November), three times two meters of leek were harvested in three different rows within the sub-subplot. Each time, whole plants including a part of the root system were harvested. Fresh weight was recorded after thoroughly washing the plants. To determine leek dry matter content, subsamples of a few whole plants were dried in a ventilated oven at 70°C during at least 48h. The N content was determined on ground dried plant material according to the Kjeldahl method (ISO 5983-2). Dry matter yield and crop N uptake were calculated for both sampling moments.

Assessment of soil quality and N dynamics

Total organic carbon (TOC), hot water extractable carbon (HWC) content, dry soil bulk density (BD) and pH-KCl were determined in the 0-10, 10-30 and 30-60 cm soil layers under the standing leek crop in August.

Plant N availability during the growing season was assessed by determining the mineral N stock and its distribution in the 0-90 cm soil profile. The soil layers 0-30, 30-60 and 60-90 cm were sampled separately at three different sampling moments for analysis of the mineral N content, i.e. s1: 14/06/2011 (before fertilization and soil tillage preceding leek planting), s2: 24/08/2011 (seven weeks after leek was planted) and s3: 08/11/2011 (at the time of crop sampling in autumn). Stocks of soil mineral N (Nmin stock) and the ratio between the Nmin stock in the upper 0-30 cm layer and the Nmin stock of the whole soil profile were calculated. Balances of plant available N were calculated by subtracting N supply from N recovery balance sheet items, all expressed in kg ha^{-1}. Recovered N is crop N uptake in the considered balance period and residual mineral N in the soil profile. N supply consists of the initial Nmin stock and mineral N fertilizer input. The balance result represents the apparent net N mineralization (ANM) from SOM and organic matter applied through fertilization but may also include some N losses (Feller and Fink, 2002). The N content of the leek plantlets were considered to be negligible. The N balances were calculated for three periods: an overall balance for the period from s1 until s3 and two partial balances for the periods from s1 until s2 and from s2 until s3.

The N use efficiency (NUE) of the top mineral N dressing, either 30 or 60 kg ha^{-1}, was determined by subtracting the N $uptake_{s2\text{-}s3}$ on the non-fertilized sub-subplots from the N $uptake_{s2\text{-}s3}$ on the fertilized sub-subplots and dividing this by the mineral N dose.

The net N mineralization from the soil sampled in summer (s2) for both the 0-10 and 10-30 cm soil layers was measured during an incubation in the laboratory (apparent net N mineralization in a laboratory test, ANM_{lab}). Soils were incubated in PVC-tubes (Ø 4.63 cm, filling height 12 cm and bulk density 1.4 g cm^{-3}) in duplicate. Before filling the tubes, demineralised water was added to obtain a gravimetric moisture content of 16.8% (w/w) equivalent to 50% water-filled pore space. After thorough mixing, the tubes were filled and covered with a single layer of gas-permeable Parafilm® M Barrier Film (Pechiney Plastic Packaging) to minimize water loss. After an incubation of three weeks at 15°C and 70% relative humidity, entire tubes were destructively sampled and analyzed.

Soil analyses

The soil pH was measured potentiometrically in a 1M KCl solution (1:5 v/v) according to ISO 10390. TOC content was measured on oven-dried (70 °C) soil samples by dry combustion at 1050 °C with a Skalar Primacs SLC TOC-analyzer according to ISO 10694. For soils with pH-KCl > 6.5, inorganic C was measured separately; none of the samples had inorganic C levels higher than the limit of quantification. HWC was extracted following a method of Haynes & Francis (1993). Soil samples (equivalent to 5 g oven dry weight) were weighed into 50 ml polypropylene centrifuge tubes and 25 ml of demineralized water was added. The tubes were capped and left for 16 h in a hot-water bath at 70 °C. At the end of the extraction period these tubes were centrifuged and the supernatants were filtered over a Machery-Nagel mn640d filter. Total C in the extract was measured using a CCD simultaneous ICP-OES (VISTA-PRO, Varian, Palo Alto, CA).

To determine BD, three undisturbed soil cores (100 cm^3) were taken on each sub-plot with an auger (Eijkelkamp Agrisearch Equipment) at approximately 5 cm, 20 cm and 45 cm below the soil surface (ISO 11272) for the 0-10 cm, 10-30 and 30-60 cm layer, respectively.

Statistical methods

Split-plot anova (Gomez and Gomez, 1984) with soil tillage as main plot factor and compost application as subplot factor was applied. When soil layer or mineral N top dressing were involved as a third factor a split-split-plot anova was conducted. If significant interaction effects were found between factors, data analysis was continued either per variant of one or both of the interacting factors or by comparing all six combinations of both factors. Normality of parameter data was checked using the Kolmogorov-Smirnov test. The Scheffe method was applied for multiple comparison of the means.

Results and Discussion

Soil quality assessment

The TOC in the 0-10 cm soil layer was significantly higher for C2 than for C0 ($p < 0.05$)(table 1). No differences in TOC contents were observed between compost application rates in the 10-30 and 30-60 cm layers. However, a tendency for increased TOC in the 10-30 cm layer with increasing compost doses was observed ($p < 0.1$). The average TOC content in the 0-60 cm layer was significantly higher for C2 than for C0 ($p < 0.05$) with an intermediate value for C1 (results not shown).

Soil tillage as such did not significantly affect TOC content in the different soil layers. Only for the 0-10 cm soil layer, TOC under RT tended to be higher than TOC under CT ($p < 0.1$). RT did not reduce TOC in the 10-30 cm soil layer compared to CT. Van den Bossche et al. (2009) observed a higher SOM retention in the upper soil layer for RT compared to CT due to differences in incorporation depth of (external) organic matter and in soil disturbance. In our experiment, RT resulted in a significantly higher TOC content in the 0-10 cm soil layer than in the 10-30 cm layer ($p < 0.001$), whereas in case of CT, TOC content of both upper layers was almost equal and not significantly different.

$HWC_{0\text{-}10cm}$ data from the six combinations of tillage practice and compost application were compared (figure 1). For RT-C2 plots, on which a considerable amount of compost was kept in the surface layer by RT, $HWC_{0\text{-}10cm}$ was significantly higher than for all other treatments ($p < 0.05$). Neither the compost, nor the tillage factor affected HWC in 10-30 and 30-60 cm soil layers. The average HWC content in the 0-60 cm layer was significantly higher for C2 than for C0 ($p < 0.05$), with an intermediate value for C1 (results not shown). D'Hose et al (2010) reported significantly higher HWC contents on farm compost amended plots in a multiyear field experiment.

$pH\text{-}KCl_{0\text{-}10cm}$ was significantly affected by compost application and significantly higher on the compost amended plots C2 than on the non amended C0 plots ($p < 0.05$)(table 1). The average pH-KCl value of the three soil layers was significantly higher for C1 and C2 plots than for C0 plots ($p < 0.01$, C0: pH-KCl 5.7 and C1, C2: pH-KCl 6.0). No significant effect from the soil tillage factor was found. D'Hose et al. (2010) found a significantly higher pH-KCl in the arable layer (0-23 cm) on plots receiving annually 50 m^3 farm compost ha^{-1} compared to non-amended plots, i.e. 0.4 pH units more in a time span of six years (2004-2009). With regard to the 0-10 cm soil layer, the difference between C2 and C0 plots was of the same order of magnitude (0.4 pH units) for an annual recurrent application in a time span of only 3 years (table 1). Steel et al. (2012) reported that the most important short-term effect of the farm composts applied in this field trial on the soil was a pH increase irrespective the feedstock materials used in the compost. BD was not affected by either compost application or tillage.

Table 1 Mean values of considered soil quality parameters per soil tillage practice and compost dose for each individual soil layer; values between brackets are standard deviations; significant differences are indicated by p-values and by different lowercase letters; TOC: total organic carbon, HWC: hot water extractable carbon, BD: dry soil bulk density; CT: conventional tillage (ploughing), RT: reduced (non-inversion) tillage; C0, C1, C2: 0, 15 and 45 Mg farm compost ha^{-1}

	layer cm	CT	RT	Anova p-value	C0	C1	C2	Anova p-value	Scheffe p-value
TOC	0-10	0.88	1.05	< 0.1	0.90 [a]	0.95 [ab]	1.04 [b]	< 0.001	< 0.05
%		(0.06)	(0.13)		(0.11)	(0.11)	(0.13)		
	10-30	0.90	0.93		0.87	0.91	0.95	< 0.1	
		(0.08)	(0.09)		(0.08)	(0.10)	(0.05)		
	30-60	0.61	0.61		0.59	0.62	0.62		
		(0.05)	(0.12)		(0.07)	(0.13)	(0.07)		
HWC	0-10	580	689		567	618	719		
ppm		(73)	(112)		(74)	(68)	(119)		
	10-30	605	626		594	605	647		
		(75)	(125)		(127)	(104)	(69)		
	30-60	428	491		436	459	482		
		(39)	(118)		(72)	(107)	(99)		
pH-KCl	0-10	5.7	5.8		5.5 [a]	5.9 [ab]	5.9 [b]	< 0.01	< 0.05
		(0.2)	(0.4)		(0.2)	(0.4)	(0.1)		
	10-30	5.9	6.1		5.8	6.0	6.1	< 0.05	
		(0.3)	(0.3)		(0.3)	(0.3)	(0.1)		
	30-60	6.0	6.0		5.9	6.1	6.1	< 0.05	
		(0.2)	(0.3)		(0.2)	(0.3)	(0.2)		
BD	0-10	1.42	1.37		1.45	1.40	1.34		
g cm^{-3}		(0.13)	(0.11)		(0.13)	(0.11)	(0.12)		
	10-30	1.49	1.51		1.48	1.54	1.48		
		(0.15)	(0.12)		(0.09)	(0.17)	(0.14)		
	30-60	1.71	1.71		1.67	1.73	1.72		
		(0.10)	(0.07)		(0.08)	(0.11)	(0.03)		

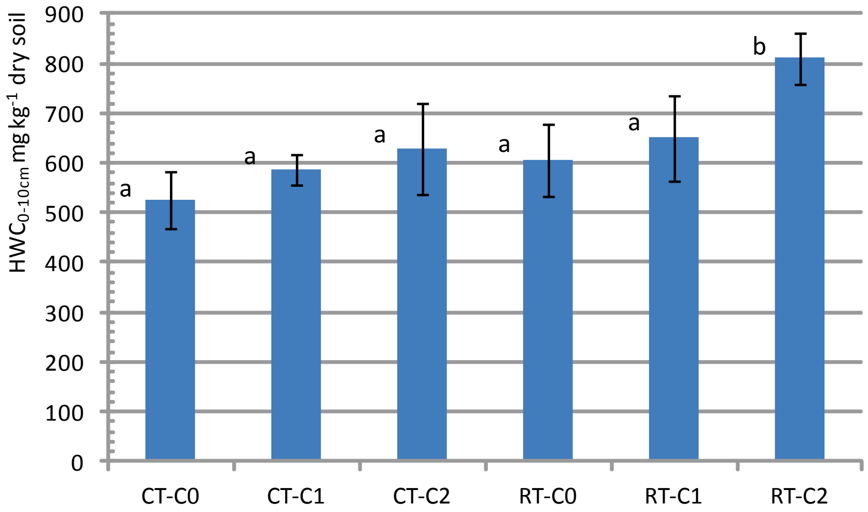

Figure 1 HWC for each combination of compost dose and soil tillage practice; significant differences are indicated by different lowercase letters. Values are averages of measurements in 4 replicates. Error bars represent the +/- standard deviations. HWC: hot water extractable carbon; CT: conventional tillage (ploughing), RT: reduced (non-inversion) tillage; C0, C1, C2: 0, 15 and 45 Mg farm compost ha^{-1}

Obviously, differences between compost doses for pH-KCl, TOC and HWC were most striking in the 0-10 cm soil surface layer, however, differences seemed not to be strictly limited to this upper layer. The increase in TOC was proportional to the compost dose, whereas pH-KCl increased by compost application but irrespective of the dose. For HWC, only the highest compost dose could make a clear difference and that only on RT plots.

N availability, N uptake and dry matter yield

Compost application did not increase N availability in the soil profile at any sampling moment in the growing season. Neither dry matter yield nor total N uptake at s2 and s3 were affected by compost application despite the beneficial impact of compost application on some soil quality parameters, especially in the 0-10 cm top layer. Soil tillage type did not affect N availability in the soil profile at any time. However, in contrast with the factor compost application, soil tillage type affected soil condition and consequently youth growth and crop development, as was proven by a significantly higher dry matter yield for CT, compared to RT, both at s2 and s3 ($p < 0.05$). At s2, CT yielded on average 1.01 Mg dry matter ha^{-1}, whereas RT yielded 0.85 Mg ha^{-1}. Total N uptake tended to be higher for CT ($p < 0.1$). The higher dry matter yield at s3 in case of CT (6.58 Mg ha^{-1} versus 6.20 Mg ha^{-1} for RT) was not related to a higher N availability or N uptake. At s3, N uptake just tended to differ ($p < 0.1$) between plots with different top mineral N dressing (table 2). N availability was a non-limiting factor for crop yield in our experiment.

Mineral N dynamics

Neither the soil tillage nor the compost factor affected Nmin stocks at any sampling moment. However, at s3, significant differences appeared due to differences in top mineral N dressing ($p < 0.001$). The residual mineral N up to a depth of 90 cm was significantly higher ($p < 0.001$) on plots with the highest level of top mineral N dressing (60 kg N ha^{-1}) than for both other fertilization levels, i.e. 0 and 30 kg mineral N ha^{-1} (table 2).

Table 2 Overall N balance (s1-s3) and partial N balances (s1-s2, overall and s2-s3, per top mineral N dressing) and the respective supply and recovery items, average results in kg ha^{-1} (0-90 cm); significant differences are indicated by different lowercase letters; standard deviations between brackets; ANM: apparent net N mineralization; Nmin sx 0-90: mineral N stock in the 0-90 cm soil layer at sampling moment x; base, top N fert: base, top mineral N fertilization

ANM	N SUPPLY			N RECOVERY	
s1-s2	Nmin s1 0-90	base N fert		N uptake s1-s2	Nmin s2 0-90
125 (37)	58 (17)	70		36 (4)	218 (37)
s2-s3	Nmin s2 0-90		top N fert	N uptake s2-s3	Nmin s3 0-90
-7 (47)	218 (37)		0	134 (27)	76 ^{a} (18)
-21 (46)	218 (37)		30	146 (21)	80 ^{a} (17)
-13 (42)	218 (37)		60	151 (30)	114 ^{b} (34)
s1-s3	Nmin s1 0-90	base N fert	top N fert	N uptake s1-s3	Nmin s3 0-90
118 (36)	58 (17)	70	0	170 (27)	76 ^{a} (18)
104 (34)	58 (17)	70	30	182 (22)	80 ^{a} (17)
112 (35)	58 (17)	70	60	187 (30)	114 ^{b} (34)

Soil tillage type affected the ratio $Nmin_{0\text{-}30\ cm}:Nmin_{0\text{-}90\ cm}$ at s2. A significantly higher part of $Nmin_{0\text{-}90\ cm}$ was found in the 0-30 cm soil layer in case of RT (52.3%) compared to CT (45.1%)($p < 0.05$). Compost application did not affect the distribution at s2. Neither soil tillage type, nor compost application affected the ratio $Nmin_{0\text{-}30\ cm}:Nmin_{0\text{-}90\ cm}$ at s1 and s3. At s3, this ratio was affected by top mineral N dressing ($p < 0.001$) with a significantly higher part of $Nmin_{0\text{-}90\ cm}$ in the 0-30 cm soil layer in case of a mineral N dressing of 60 kg ha^{-1} ($p < 0.01$).

N use efficiency of top mineral N dressing

NUE from top mineral N dressing did not differ between plots with different compost application or soil tillage practice. Reduced tillage did not affect the recovery of fertilizer ^{15}N applied as top mineral N dressing on winter wheat in a field experiment by Giacomini et al. (2010). No significant difference between the NUE at both doses of top mineral N dressing was observed. The average NUE of the top mineral N dressed plots was only 34% but a large variation was observed (standard deviation +/- 86%). A high N availability at s2, as well as its high variability have complicated the assessment of NUE.

Top mineral N dressing hardly contributed to plant N uptake and crop growth. By comparing average N uptake and residual N values of plots which received either 30 or 60 kg N ha^{-1} top mineral N dressing (table 2), it became clear that the N utilization of the additional 30 kg N ha^{-1} was low or non-existent and just increased residual N to a non-acceptable level in the frame of legislative standards imposed by the European Nitrates Directive, as implemented in Flanders, Belgium. The significantly higher part of $Nmin_{0\text{-}90\ cm}$ in the 0-30 cm soil layer in case of a mineral N dressing of 60 kg ha^{-1} was directly related to the low N use efficiency from the extra 30 kg top mineral dressing. A fertilization dose of 100 kg mineral N (70 kg base + 30 kg top mineral N dressing) in combination with approximately the same amount of apparently available N by mineralization did guarantee a steady and healthy crop growth, resulting in a good crop yield in the next spring. Growers should be fully aware of this mineralization potential, which - in this case study - encountered half of the crop requirement.

Apparent net N mineralization in the field and in the laboratory

For $ANM_{s1\text{-}s2}$, the N balance result for the period from s1 until s2, no differences were found between compost doses and soil tillage types. Data analysis for N balance results that comprise the autumn period (s2-s3 and s1-s3) revealed no significant effects from any of the factors soil tillage, compost application and top mineral N dressing except that $ANM_{s2\text{-}s3}$ tended to be higher if compost was applied on CT plots ($p < 0.1$). This may be interpreted as a sign that C sequestration by compost application will increase N availability through increase of soil organic N content and mineralization in the medium to long term as reported by Chalhoub et al. (2013). Due to autumn application of stable compost in our experiment, N availability of the last application by biodegradation was probably low in the next growing season.

A positive ANM occurred in the s1-s2 period (71 days) at a rate of 1.8 kg ha^{-1} day^{-1}. This quite high native soil N availability may explain that no effect from compost application on N availability was perceived. A similar observation and suggestion was made in a study of Alluvione et al. (2013). In the next survey period s2-s3 (76 days) a negative ANM occurred at a rate of -0.2 kg ha^{-1} day^{-1}, which indicates that apparently net N immobilization took place over this period, on average 14 kg ha^{-1}. N losses might lower ANM and cause a negative balance result. N losses by leaching may be neglected in our field experiment given the period of crop growth with no excess precipitation. To a limited extent, gaseous losses of the superficially applied ammonium nitrate might have occurred. In the field experiment of Giacomini et al. (2010) with fertilizer ^{15}N, top dressed as N solution containing urea, ammonium and nitrate, the unrecovered fertilizer N in the plant-soil system was approximately 30% (i.e. 32 kg N ha^{-1}) and was attributed to ammonia volatilization. The soil on that experimental site had a $pH_{(H2O)}$ of 7.6 and contained 0.02 g g^{-1} $CaCO_3$. No inorganic C was found at our site and therefore, ammonia volatilization is less probable. Whole plant N uptake was used for calculating the N balance, however, only a limited part of the root system of the leek was harvested. N immobilized in the non-harvested part might have lowered $ANM_{s2\text{-}s3}$. The N mineralization from SOM in this period was possibly not negative, however, considerably lower than in the first half of the growing season.

A significant interaction occurred between the layer and soil tillage factor with regard to their effect on ANM_{lab} with soil sampled at s2 ($p < 0.001$). For the 0-10 cm layer, ANM_{lab} was significantly higher in case of RT (7.9 mg kg-1 dry soil) than in case of CT (5.4 mg kg^{-1} dry soil)($p < 0.01$), whereas for the 10-30 cm layer, it tended to be the opposite (RT: 3.0 mg kg^{-1} dry soil versus CT 4.3 mg kg^{-1} dry soil) ($p < 0.1$). $ANM_{lab\ 0\text{-}10cm}$ was significantly higher than $ANM_{lab\ 10\text{-}30cm}$ for both soil tillage practices, however, this layer effect was much more pronounced for RT than for CT ($p < 0.001$ and $p < 0.05$, respectively). This is all in line with the observed difference in distribution of soil organic matter between both tillage practices. $TOC_{0\text{-}10cm}$ was significantly higher than $TOC_{10\text{-}30cm}$ on RT plots, by which readily decomposable SOM was likely to be greater in the 0-10 cm than in the 10-30 cm soil layer. This explains the more pronounced difference in N release between both soil layers in the lab experiment for RT, compared to CT. D'Haene et al. (2008) studied RT and CT fields with comparable soil type and crop rotation. The N mineralization rate derived from an incubation experiment with undisturbed 0-15 cm top soil was on average a 1.55 times larger for RT than for CT fields. The ratio that we have found in our lab experiment with disturbed 0-10 cm top soil was of the same order of magnitude, i.e. 1.46. Kandeler et al. (1999) have also found an acceleration of N mineralization in the 0-10 cm layer with a reduction of tillage intensity, from ploughing, over reduced to minimum tillage.

Based on the clear stratification of SOM and potential mineralization (lab experiment) in the 0-30 cm soil layer of RT plots, on one hand, and on the equivalent mineral N stocks on RT and CT plots, on the other hand, we presume a similar mineralization rate in the 0-30 cm soil layer for both soil tillage types. Oorts et al. (2007) did also not detect differences in N mineralization kinetics between long-term no-till and conventional tillage by taking frequent measurements of nitrate contents from different soil layers. Finding a higher part of the mineral N stock in the arable layer at s2 in case of RT might be related to the localization of the N mineralization near the soil surface.

In case of CT, a significant effect from the compost factor on ANM_{lab} appeared ($p < 0.05$). This observation in the lab experiment is probably in line with the tendency of higher apparent net mineralization in the field in the second part of the growing season (ANM_{s2-s3}) if compost was applied on CT plots ($p < 0.1$).

Conclusion

Soil quality was mainly affected by compost application. By contrast, the few observed differences in N dynamics seemed to be related to differences in soil tillage practice and occurred only at s2. On the short term overall N flows seem not to differ between soil management practices. Variation in available N in the plant-soil system could only be attributed to differences in top mineral N dressing, of which the highest level obviously caused excess residual N. There is no need to adapt N fertilization advice systems and no risk appeared of a higher N residue level due to a higher organic C content from repetitive compost application for the range of studied situations.

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(29) Fertilization of flower bulbs and hardy nursery stock in open field production in the Netherlands

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Abstract: *A substantial part of flower bulbs and nursery stock crops in the Netherlands are grown on sandy soils. In these regions the European quality standards for groundwater and surface waters are often exceeded. Therefore in 2006 new legislation was introduced with application standards for N, P and animal manure. These restrictions necessitates growers to implement measures that increase the efficiency of applied nutrients and in addition reduce the risk of leaching.*

The nutrient need of crops as well as measures to reduce leaching and effects on soil fertility are discussed. Also the adoption rate by growers will be presented and if relevant how this rate can be increased. Special attention will be paid to soil organic matter management.

Keywords: *ornamentals, N and P requirements, water quality*

Introduction

The extent of open field production of ornamentals, flower bulbs and hardy nursery stock, amounted in 2012 to 23,500 and 17,000 ha, respectively (Productschap Tuinbouw, 2013). For both crops fertilizer guidelines are available (van Dam and van Reuler, 2013; Aendekerk, 2000). Due to the great variety of species these guidelines are mainly based on expert knowledge and only partly on field trials.

A great part of these crops are grown on sandy soils. In these regions the European quality standards for groundwater and surface waters are often exceeded. Therefore in 2006 new legislation was introduced with application standards for N, P and animal manure. These restrictions necessitates growers to implement measures that increase the efficiency of applied nutrients and in addition reduce the risk of leaching.

The nitrogen application standard depends on crop species and soil type. The phosphate application depends only on the phosphate content as indicated by the amount that can be extracted with water – Pw (LNV, 2009). The amount of nitrogen and phosphate that can be applied through animal manure is limited to 170 kg and 85 kg per ha, respectively. The amount of nitrogen applied needs to be multiplied by a so-called activity coefficient in order to obtain the available nitrogen which is indicated by the nitrogen application standard.

The nitrogen application standards aim at reducing the nitrogen surplus being the balance between:

N in plant material + N application + N deposition + N mineralization - N export by harvested products = N surplus

On sandy soils this surplus is limited to 76 kg nitrate/ha in which case the nitrate concentration in groundwater will be < 50 mg/l (Schroder et al., 2004).

The system of application standards are applied at farm level so farmers have some liberty to vary the amounts applied at a certain field and/or crop.

Materials and Methods

In on-farm experiments on sandy soils the fertilization requirements of lilies, Zantedeschia, young fruit trees, conifers, shrub roses and Buxus were studied.

Table 1. On-farm experiments with flower bulbs and hardy nursery stock crops

Crop		Year	N rates kg N/ha	Reference
Flower bulbs	Lily	2011-2012	0;70;140;210;280	Slootweg et al., 2013
	Zantedeschia	1995-1998; 2011	0;50;100;150;200 0;150	Van Leeuwen and Van Reuler, 2012
Nursery stock	Young fruit trees	2007-2010	0;20;100;140;180	Van Reuler et al.,2013
	Shrub roses	2007-2009	0;50;100;150;200	
	Conifers	2007-2009	0;40; 80; 130;160	
	Buxus	2007-2009		
	-1th year		0;25;50;100;175	
	-2th year		0;50;100;150;225	

Experiments were executed in three repetitions. The response to nitrogen application of the nursery stock crops were analysed by the quadratic response and the 'broken stick'' methods (VSN, 2008).

The nitrogen content of the planting material and the harvested product of all treatments were measured. Nitrogen deposition was estimated according data of Compendium voor de Leefomgeving (2013). In this way the nitrogen surplus could be calculated.

In a field experiment with three different types of sand the decomposition rate of soil organic matter was studied (Pronk et al., 2012).

Results and Discussion

Flowerbulbs

According to the fertilizer guidelines for flower bulbs the nitrogen fertilizer application rate is determined as: N application rate = Target value – amount of available N in the topsoil. The target value represents the estimated uptake plus a certain buffer. This buffer is needed to overcome unexpected losses.

Lily

The actual fertilizer recommendation for lily on sandy soils is 155 kg N/ha. Field experiments have found this rate to be sufficient for recently introduced new varieties.

Zantedeschia

The actual fertilizer recommendation for Zantedeschia amounts to 110 kg N/ha. In fertilizer trials at three locations the optimal rate appeared to be 170 kg N/ha.

Hardy nursery stock

Young fruit trees

The cultivation of young fruit trees takes two years. In the first year no response to nitrogen fertilization was found. In the second year at two of three locations a response to nitrogen fertilization was found. The optimum N rate proved to be 130 kg N/ha while also the same amount is exported with the harvested crop. If we assume that about 60% of the N applied is absorbed by the crop then about 50 kg N/ha more N is exported then applied.

Conifers

In first year after planting the growth is limited. In the second and third year more than 100 kg N per year is absorbed. With a recommended fertilizer recommendation of 130 kg minus the amount of available N in the topsoil it is clear that more N is exported then applied.

Bush roses

The actual fertilizer recommendation for bush roses is 100 kg N minus the amount of available N in the topsoil. Application rates higher 100 kg N/ha did not result in improved yield levels.

Buxus

The fertilizer recommendation for bigger sized plants is 150 kg N minus the amount of available N in the topsoil. In the first year after planting 134 kg N was absorbed and in the second year after planting 172 kg N/ha. If we assume that about 60% of the applied N is absorbed then more N is exported then absorbed. Consequently in the long term the inherent fertility will decrease and yield level lowered.

Soil organic matter

In dune sand about 6% of the soil organic matter was decomposed in the first year when no organic material was applied. In cover sand the decomposition rate was 3.7%. During later years the decomposition rates decreased but the difference remained.

Conclusion

Flowerbulbs

Lily

The results of the fertilizer trials with the new lily cultivars indicated that there is no need to adapt the actual fertilizer recommendation.

Zantedeschia

Results of field experiments indicate that the fertilizer recommendation for Zantedeschia needs to be increased from 100 to 170 kg N/ha.

Hardy nursery stock

Young fruit trees

The nitrogen fertilizer recommendation for young fruit trees is adequate in the year of planting. In the second growing season the recommendation amounts to 130 kg N/ha and approximately equals the amount of nitrogen that is exported with the harvested crop at the end of the second growing season. However, if an uptake efficiency of N of 60% is assumed, the soil fertility decreases in time and production levels will decrease accordingly.

Conifers

The nitrogen exported with the harvested large conifers is much higher than the amount applied according to the standard application rate for this crop. In time this will result in a decrease of the soil fertility and subsequently in production losses.

However, the question arises how many growers only grow large conifers or whether a combined cultivation of small and large plants is more common.

Bush roses

The field trials do not indicate that the standard application rates for nitrogen for bush roses need to be adjusted.

Buxus

The nitrogen recommendations for the first and second growing season of Buxus are adequate, but nitrogen requirement of large plants is higher than the recommendations But again the question arises how many growers only grow large sized Buxus.

Soil organic matter management aiming at maintaining the actual organic matter content while respecting the legislation regarding nutrient application, is a great challenge. Especially when field experiments demonstrate that the decomposition rate at coarse calcareous sandy soils along the coast is about 6% and 3% for cover sand soil common for the central and eastern part of the Netherlands.

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(30) An integrated model for the management of nitrogen fertilization in leafy vegetables

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Abstract: *Optimal nitrogen (N) supply is crucial for high yield, produce quality and crop sustainability of leafy vegetables. In spinach (Spinacia oleracea L.), N availability in the root zone is positively correlated with biomass production, tissue minerals and antioxidants content, and other commercial quality attributes such as leaf colour and wrinkledness. An erroneous N supply may cause crop N deficiency or overfertilization, which in turn results in waste of fertilizers with increased production costs and environmental impact. Nevertheless, growers very often supply N at constant rate based on empirical protocols, without taking into consideration climate variables and crop rotations. During a four-year long study (2007-2011), we assembled, calibrated and validated an integrated model (DSS, decision support system) that simulates N concentration in the root zone (daily basis) and gives information on the amount of N that should be delivered to the crop for maintaining the desired (i.e. optimal) N mineral content in the root zone. Simulations run on the basis of climate parameters, chemical-physical soil characteristics, and crop characteristics. Main outputs of the DSS are: crop cumulated biomass and N uptake, soil water balance and nitrogen balance. The DSS was tested on spinach grown in open field, in sandy-loam soil, under Mediterranean climate conditions. A significant linear correlation was found between simulated and measured data. The DSS was effective to support the management of N fertilization: in some cases, it allowed a reduced N supply in comparison to standard protocols applied by local growers, with no significant reduction in yield and quality.*

Keywords: *nitrogen, spinach, modelling, environmental impact*

Introduction

A well balanced nitrogen (N) fertilization is a key factor to obtain both high yield (Y) and quality in leafy vegetable cultivation since the mineral status of the root zone positively influences plant growth, tissue composition, external qualities such as leaf colour and shape (e.g. the typical wrinkledness of savoy spinach), and post-harvest quality. On the other hand, an excessive N fertilization can become even harmful for the crop, leading to a reduced biomass Y and quality (e.g. Chen et al., 2004; Wang and Li, 2004). Nitrate can accumulate in edible organs of leafy vegetables, especially when N is supplied as a nitric form, thus representing a risk for the consumer's health (Chen et al., 2004; Wang e Li, 2004; Zhang et al., 2005; Stagnari et al., 2007). Moreover, nitrate may induce the euthrophication of water bodies and limit the availability of drinking water. Following the implementation of EU Nitrate Directive (676/1991), in Italy some areas affected by nitrate pollution have been designed as Nitrate Vulnerable Zones (NVZs). Spinach is an important crop in some Italian regions such as Tuscany, Lazio and Apulia both for fresh and processed (frozen) produce. In the last years, the increase of production costs and the constraints set by EU regulations reduced the local growers capacity to compete on the global market. In this scenario, the optimization of non-renewable inputs, such as N fertilizers, becomes a crucial factor for improving crop environmental sustainability and grower's incomes, supporting local production and market, as well as employment in agriculture and agro-industries. In this work, we assembled, calibrated and validated an integrated model (DSS, decision support system) that simulates N concentration in the root zone (daily basis) and gives information on the amount of N that should be delivered to the crop to maintain the desired (i.e. optimal) N mineral content in the root zone and limit the loss of fertilizers. The DSS is an aggregated model that could be used for other leafy vegetables, such as lettuce, after a crop-specific calibration of few parameters.

Materials and Methods

Experimental trials.

Eight separate experiments were conducted in the autumn-winter and winter-spring season from 2007 to 2011 in a private farm located in a coastal area of Tuscany (Val di Cornia, Italy). Spinach (*Spinacia oleracea* L.) was sown and cultivated following the standard practice of local growers based on: direct sowing on raised beds (crop density of 30 pl. m^{-2}); pre-sowing application of mixed organic and mineral fertilizers followed by 2 top-dressings with ammonium nitrate and calcium nitrate; irrigation if needed. Nitrogen was supplied to the cultures from 0 to 160 kg ha^{-1} in the attempt of having a wide range of N concentrations in the root zone profile explored by the roots (0-40 cm), thus obtaining a total 24 different combinations (treatments, T). Twenty Ts were used for the calibration of a coefficient for the estimation of plant growth as a function of the actual mineral N (N_{min}) concentration in the root zone (Massa et al., 2013); eight of these Ts were used for the calibration of a mechanistic growth model for the estimation of plant N uptake under optimal N_{min} condition in the root zone. Then, four Ts were used for the validation of the whole DSS that simulates the N balance in the root zone. During the cultivation, four plant destructive analyses (including final harvest) were conducted to measure biometric parameters such as fresh and dry weight (FW and DW respectively), leaf area index (LAI), specific leaf area (SLA) and number of true leaves in three replicates during the cultivation cycle and four replicates at harvest. Nitrogen content in the root zone and DW of plant material was also determined for the computation of N balance. Air and soil temperature, radiation, wind speed, rainfall and air humidity were collected on hourly basis, using a meteorological station (Pessl Instruments GmbH, Weiz, Austria) located in the experimental area.

Growth and N uptake model.

Crop growth simulation was represented by the daily increment of dry matter as calculated on the basis of the daily carbon assimilation using the following equation:

$$P_n = (RUE*PAR*(1-C_{LR})*(1-\exp(-k*LAI)))*T_{lim}$$

where, P_n (g m^{-2} day^{-1}) is the net photosynthesis as expressed as the net quantity of CO_2 assimilated by the crop, RUE (g MJ^{-1} m^{-2} day^{-1}) is the radiation use efficiency for CO_2 assimilation, PAR (MJ m^{-2} day^{-1}) is the photosynthetically active radiation, C_{LR} (dimensionless) is the light reflection coefficient (Marcelis et al., 1998), k (dimensionless) is the canopy extinction coefficient (Marcelis et al., 1998) and T_{lim} (dimensionless) is a coefficient, which varies from 0 to 1, estimated as a function (beta function) of the minimum, maximum and optimal growth temperature for the crop (Yin et al, 1995; Confalonieri et al., 2006); T_{lim} was estimated according to Yamori et al. (2005). P_n is then converted to dry matter using the following equation:

$$GR=Cf*(30/44*Pn)*N_{lim}$$

where, GR is the daily growth rate of the crop (gDW m^{-2} day^{-1}), Cf (dimensionless) represents the assimilate-to-dry matter conversion efficiency (Marcelis et al., 1998) and N_{lim} is a coefficient that varies from 0 to 1 as a function of N_{min} in the root zone (Massa et al., 2013). Daily GR rate is then partitioned between roots (GR_r) and aboveground biomass (GR_s) by a constant coefficient of partitioning. Finally, LAI of the successive day is calculated by multiplying the GR_s by the SLA. The initial LAI was estimated empirically on the basis of the data collected during the field trials and is function of plant density. Crop N uptake (N_U) is obtained by multiplying the crop cumulated DW by N concentration in plant tissue.

DSS framework.

To run simulations, the DSS needs some parameters to be entered by the user: i) climatic variables such as mean air temperature, global radiation, soil temperature (optional), potential evapotranspiration (optional); ii) chemico-physical characteristics of the soil such as clay and sand content, bulk density (optional), water content at field capacity (optional), total N or alternatively organic matter content, C/N ratio, N mineral content (N-NO_3 and N-NH_4), limestone content; iii) cultivation system parameters such as the date of sowing and soil analysis, the date of harvest of previous crops and their actual Y.

The DSS developed is based on a database, a user interface and an aggregated model that simulates the daily actual N concentration in the root zone ($N_{min,}$ expressed as mg per kg of soil DW) as a result of the N balance calculated as follows:

$$N_{min\,(t)} = N_{S(t-1)} + N_{M(t)} + N_{CR(t)} + N_{OF(t)} + N_{R(t)} + N_{I(t)} + N_{U(t)} - N_{L(t)} - N_{V(t)} - N_{D(t)} + N_{F(t)} \text{ (mg kg}^{-1}\text{DW)}$$

The simulation starts with the initial N mineral content in the root zone (N-NO_3 and N-NH_4) that must be entered as an input coming from a soil analysis (not older than two months from the beginning of the crop cycle).

Nitrogen obtained from the mineralization (N_M), of the organic matter pool, is simulated on the basis of the average N content in the organic matter (5%), using a function proposed by Mary and Guèrif (1994): with this function, the rate of the organic matter mineralization is influenced by air temperature, soil chemical-physical characteristics, percentage of organic matter in the soil and its C/N ratio (input data).

Nitrogen coming from the crop residues (N_{CR}), left in the field by previous crops, is simulated at the net of N immobilized during the transformation of crop residues into stable organic matter in the soil; these quantities are estimated on the basis of temperature, chemico-physical characteristics and water content in the root zone using a simulation model based on the studies of Verbruggen (1985). The DSS takes only into consideration crop residues blended with the soil within six months before the date of the soil analysis. The residual effect of organic fertilizers supplied to previous crops (N_{OF}) is also taken into account in the computation of N balance using an empirical approach that calculate a fixed fraction of N supplied on the basis of: i) the type of manure; ii) the number of days elapsed from the organic fertilization to the beginning of the current cultivation; iii) the percentage of N in the organic fertilizer. A database present in the DSS contains information about N content of crop residues (60 different crops) and 15 different manure types (Cisternino et al., 2010).

Nitrogen delivered to the crop with rainfall (N_R) and irrigation water (N_I) is calculated on the basis of rainfall depth, at the net of water runoff (see below), and irrigation water supplied by growers both multiplied by their N concentration.

Crop N uptake (N_U) from the soil is simulated as previously described in this section.

Nitrogen denitrification (D_N) and volatilization (D_V) are estimated empirically and considered of minor importance if BMPs (Best Management Practices) are adopted by growers. In case of use of volatile fertilizers such as ammonia, the percentage of volatilization should be taken into account by the growers/users.

Nitrogen leaching (N_L) occurs in the simulations only when the net rainfall plus irrigation water exceed field capacity; it is simulated using an adaptation of the formula originally proposed by Massa et al. (2011), for cultivation in substrate, and below reported:

$$N_{min}^{AL} = N_I^C + \left(N_{min}^{BL} - N_R^C\right) \cdot \exp^{\left(\frac{WL \cdot kl}{WR}\right)}$$

where, N_{min}^{AL} and N_{min}^{BL} (g m^{-3}) are the N_{min} concentration in the root zone after leaching and before leaching events, respectively, N_R^C (g m^{-3}) is the concentration of N in the rainfall, WL (m^3) is the volume of water leached out from the root system, WR (m^3) is the volume of water in the root zone at the leaching time and kl is an empirical coefficient that varies with the soil texture (Stockle and Nelson, 2002). Finally, the difference between the concentration of N_{min} before and after a leaching event is the quantity of N lost through the water drained out from the root zone. Water balance is simulated in the root zone day by day taking into account: i) rainfall depth as entered by the user; ii) surface water runoff, which is the fraction of rainfall that does not seep into the soil, as estimated with the method proposed by USDA (NRCS, 2003); iii) the effective evapotranspiration estimated on the basis of the potential evapotranspiration (entered by the user or optionally estimated by the Hargreaves' formula (Hargreaves and Allen, 2003) and crop evapotranspiration coefficients (Allen et al., 1998). When the water content of the soil reaches a critical threshold for the crop, the DSS gives a suggestion about the volume of water to be delivered through irrigation to restore the field capacity in the root zone. On the contrary, when the water balance exceeds the field capacity, the excess water drains out from the root zone determining a N leaching as previously described.

Finally, on the basis of the N balance simulated in the soil, the DSS gives a suggestion on the quantity of N_F (kg ha^{-1}) to be supplied to the crop whenever the concentration of N_{min} in the root zone surpasses a certain critical threshold below which the potential Y of the crop begins to decrease (Massa et al., 2013). It is required to the user to enter the percentage of $N\text{-}NO_3$ and $N\text{-}NH_4$ in the fertilizer used since the DSS can simulate de-nitrification process, using the approach proposed by Stockle and Nelson (2002), to have a better estimation of the N_L.

Results and Discussion

The DSS was calibrated using only those Ts in which N status of the root zone was deemed optimal for the crop (Massa et al., 2013). Major efforts were addressed to the calibration of the growth and N uptake model that was originally developed in this work. The calibration of the model yielded a significant relationship between predicted and measured values. The analysis of regression conducted on predicted versus measured DW and N_U showed negligible intercepts, slopes close to 1, high correlation coefficients and statistical significance (R^2=0.94 for DW in the range of 0.01-2.4 t ha^{-1};R^2=0.93 for N_U in the range of 0.44-92.45 kg ha^{-1}; n=40 and p<0.001 for both). Only minor adjustments were required for the other models already validated by other authors as reported in the M&M section.

The validation of the DSS was conducted on four trials, two of which were set up to have suboptimal N_{min} concentration in the root zone (N-) while the other two trials were maintained at optimal N_{min} level in the root zone (N+) (Massa et al., 2013). In Fig. 1 a good agreement between simulations and measurements is shown. The DSS was effective in following N_{min} variation in the root zone and only small differences could be found between simulated and measured values that showed a significant relationship (Fig. 2). Notwithstanding the accuracy in simulating N_{min} the DSS was not so accurate in simulating plant DW (and other biometric parameters, i.e. FW and LAI) that was slightly overestimated during the first periods after sowing, while a slight underestimation occurred late in the culture and close to the harvest (data not shown). This tendency was more evident in N- treatments, probably due to small changes in dry matter percentage and SLA, that can occur under suboptimal N_{min} concentration in the root zone as suggested by previous studies (Massa et al. 2013). The same tendency was confirmed for N_u. However, this last quantity was acceptably simulated by the DSS showing a significant relationship between simulations and measurements (Fig. 2).

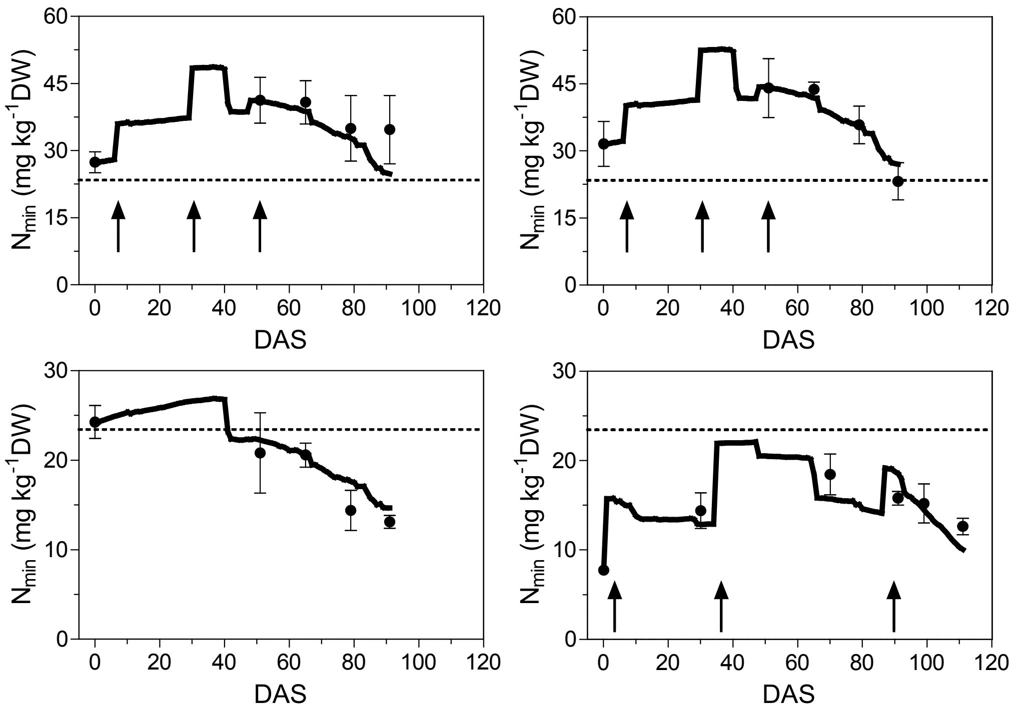

Figure 1 Simulated (line) and measured (points; mean of three replicates ±SE) N_{min} concentration in the root zone of four different cultures of spinach grown under optimal N conditions (N+; graphs on the top) or suboptimal N conditions (N-; graphs on the bottom). Data are plotted versus days after soil sample analysis (DAS). The dotted line represents the critical threshold below which there is a decrease in the potential yield. Arrows show the supply of N fertilizers.

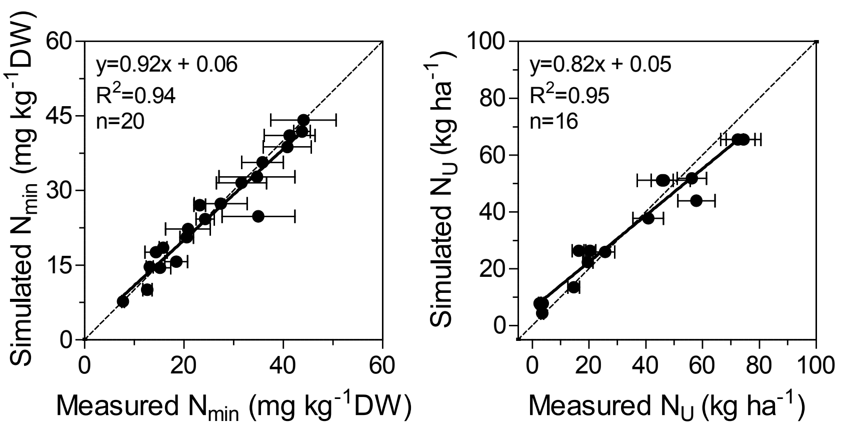

Figure 2 Linear regression (full lines) of simulated versus measured total N mineral concentration in the root zone (N_{min}) or N plant uptake (N_U). Values are the mean of three replicates ±SE. Dotted line represents the 1:1 line.

Although the experiments here reported were considering only spinach, the developed DSS could be adapted for other similar crops by small adjustments. The use of the DSS could improve the N use efficiency in the management of N fertilization. To asses this hypothesis, in the period 2010-2011 we carried out a parallel experiment on spinach in which we compared the N fertilizer supply, as suggested by the present DSS, with the standard protocol adopted by specialized growers (Val di Cornia, Tuscany, Italy). The use of the DSS allowed to save 10 and 40 kg ha^{-1} in two separated trials without any significant reduction in Y and quality, thus resulting in a significant increase in N use efficiency (+19% on average) and possibly in higher farmer incomes.

Conclusion

Further studies are required to better assess the effectiveness of the developed DSS especially under suboptimal conditions of N_{min} in the root zone. In general, the DSS showed an acceptable capability in simulating the N_{min} concentration in the root zone and plant N_U as well. This work highlights once again that the computation of nutrient and water balance in the soil and the monitoring of the crop trough soil analysis can help to achieve higher crop sustainability from both environmental and economic point of view. To these purpose, the developed DSS could be a valuable tool for an optimized management of N fertilization in leafy vegetables.

Acknowledgements

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(31) Nitrate nitrogen residues, soil mineral nitrogen balance and nitrogen fertilizer recommendation in vegetable fields in Flanders

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Abstract: *In vegetable crops, an accurate nitrogen fertilization based on soil analysis is essential, both to optimize crop yields and to reduce nitrate residues after the crop and nitrate leaching during winter. The nitrate residue in autumn is determined by several factors. Crop N requirements and N uptake patterns play a significant role, as well as N stocks at the start of the cropping period, N mineralization from soil organic matter and plant residues and N fertilization. The calculation of soil mineral N balances taking into account the different N inputs and outputs in a crop can be very useful to detect the possible causes of excess nitrate-N residues after the crop. In this study, the major bottlenecks of vegetable growing in Flanders in terms of N fertilization and nitrate-N residues are discussed, based on the calculation of soil mineral N balances in three different vegetable fields with cauliflower and leek.*

Keywords: *N-index; nitrate-N residues, mineral nitrogen balance, cauliflower; leek; catch crop*

Introduction

In agricultural fields, a clear correlation exists between the nitrate-N residue in the soil (residual nitrate-N in autumn) and the risk of nitrate leaching to ground- and surface water during winter. The higher the nitrate residues are, the higher the risk of nitrate leaching will be. For this reason nitrate-N residues are monitored yearly in Flanders and agricultural parcels have to meet certain criteria in terms of maximal allowed nitrate-N levels in the soil measured from October 1st until November 15th. An extensive analysis of the available nitrate residue measurements in Flanders from 2001 to 2008 demonstrated the impact of fertilization practices and policy measures (Tits *et al.*, 2012). In all crops a significantly decreasing trend was observed over the years, coinciding with the increasing application of good fertilization practices by the farmers.

An increasing amount of nitrate-N residue analyses after vegetable crops is performed since 2009. In several vegetable crops, nitrate-N residues are often too high. In parcels with cauliflower and leek for example, average nitrate-N residues of resp. 159 and 159 kg N/ha were measured in 2011, whereas the maximum allowed limit was 90 kg N/ha (VLM 2012). Moreover, a higher percentage of the residual nitrate is often situated in the deeper soil layers. This can indicate that too much nitrogen is applied at the start of the growing season, when crop requirements are more limited. Part of this nitrogen leaches out to the deeper soil layers and, due to the shallow rooting of these crops, becomes unavailable for later crop uptake. Consequently this nitrogen can leach to the groundwater. More specifically for vegetables, the high nitrate residues and their unfavourable distribution in the soil profile after vegetables can also be explained by several other factors, such as the specific cropping periods, N uptake curves and shallow rooting of these crops, the incorporation of crop residues, high N mineralization capacity of the soil, etc.

To reduce nitrate-N residues after vegetable crops and nitrate-N leaching during winter, an accurate N fertilization based on soil analysis is an essential first step and will also optimize crop yields. Often a distinction is made between 'basic fertilization', to be applied at the start of the growing period, and 'supplementary fertilization', to be applied during the growing period in order to meet the specific crop requirements.

Finally, the calculation of soil mineral nitrogen balances taking into account the different N inputs and outputs in a crop can be very useful to detect the possible causes of excess nitrate-N residues after the crop.

This paper explores the link between nitrate-N residue levels on one hand and fertilization practices and cropping techniques on the other hand, by calculating soil mineral nitrogen balances in typical Flemish vegetable crop rotations (cauliflower and leek). The results of three demonstrative fields are discussed, starting from the crop N requirements, response and surplus curves and taking into account typical crop characteristics such as rooting depth, cropping and harvesting period, crop residues etc.

Materials and Methods

The N-index expert system

Since 1958, the Soil Service of Belgium (SSB) has carried out yearly numerous field trials on mineral and organic N fertilization. In 1977 this N research resulted in the development of a N fertilization expert system called N-index (Geypens *et al.*, 1994; Vandendriessche *et al.*, 1996). The N-index estimates the amount of N becoming available during the growing season for a specified crop on a specific parcel. For the calculation of the N-index several factors are taken into account: the measurement of the mineral N stock (0-90 cm) at the beginning of the cropping period, the calculation of expected N mineralization and N losses during the growing period. Based on the N-index a N fertilization recommendation is formulated taking into account the N requirements of the specific crop. If appropriate, fractionation is formulated aiming at an economically optimal crop production and at the same time a minimal nitrate-N residue after the harvest. Since the seventies, this expert system has been continuously maintained and refined. In 2012 statistics and trends of N stocks and recommendations in Flanders were calculated and published for the main arable crops (Maes *et al.*, 2012).

As for vegetables, more than 30 000 N fertilizer recommendations were formulated in the last 15 years (1998-2012). The samples originated from the whole of Flanders, but especially from the sandy loam and sandy soils in West-Vlaanderen (the major vegetable-growing area in Flanders).

Nitrate-N residue measurements

In Flanders, nitrate-N residues in the soil profile are used as an indicator for the risk of nitrate-N leaching from agricultural soils to surface and ground water. The nitrate-N residue is defined as the amount of nitrate-N present in the soil profile (0-90 cm) during the period October 1st to November 15th and is expressed as kg $N.ha^{-1}$. It is measured every year on a selection of agricultural parcels, commissioned by the Flemish Land Agency. When an excessive nitrate-N residue is measured, exceeding the maximal level, certain measures are imposed to the farmer in order to help him to reduce the nitrate-N residue on his parcels in the future.

Calculation of soil mineral N balances

The soil mineral N balance of a parcel is defined as the expected amount of mineral N in the soil profile at the end of the growing season and is calculated for a defined period. The mineral N stock in spring (at the start of the growing season) plus the various N inputs (expressed in nitrate-N) minus the various N outputs results in the expected nitrate-N residue (= mineral N balance). The different N inputs and outputs are schematically represented in Figure 12.

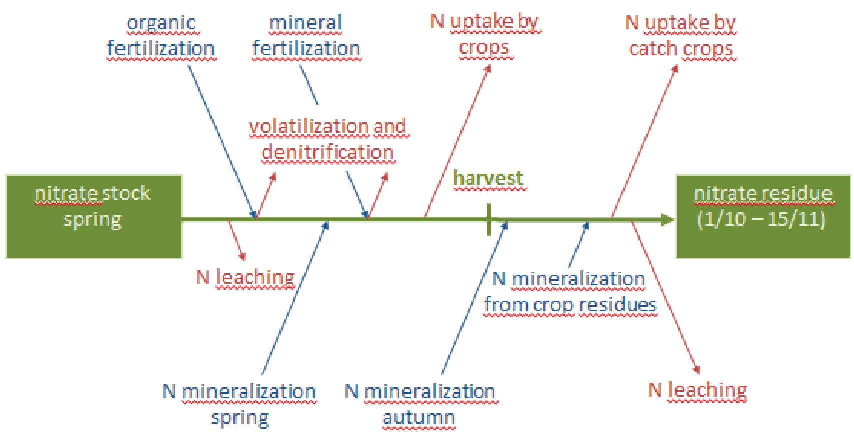

Figure 12 Schematic representation of the soil mineral N balance in crop fields (source: Soil Service of Belgium).

For the calculation of soil mineral N balances, the following factors are taken into account (Soil Service of Belgium, 2008; Vandelannoote, 2008):

Input of mineral N:

- Mineral N stock in spring (or at the beginning of the cropping season): measured on soil samples (N-index analysis)

- N mineralization from soil organic matter during the growing season: calculated based on the expected N mineralization of soil organic matter in function of the C content and the soil texture, determined by Herelixka *et al.* (2002).
- N mineralization from non-removed crop residues (including catch crops): estimated from the measurement of the amount and N content of the residues or from average data based on literature, research and field data.
- N from mineral fertilization.
- N from organic fertilization: only the effective N for the balance period (i.e. the amount of N that becomes available for the crop in the period between the soil sampling in spring and the measurement of the nitrate residue in autumn) is taken into account. This amount is estimated based on the analysis of the applied organic fertilizer and the period of application or on average data on the N content of different organic fertilizers.
- N deposition.

Output of mineral N:

- N uptake by crops and catch crops: estimated from the measurement of the amount and N content of crop biomass or from average data based on literature, research and field data. N leaching: calculated by the Burns model (1975).
- N denitrification: in normal conditions, average yearly denitrification losses are limited to maximum 30 kg N.ha^{-1}.year^{-1}. Higher values may occur in case of excessive N fertilization, extremely high soil organic matter contents and/or high soil clay percentages in combination with relatively wet soils (limited oxygen content).

Follow-up of demonstrative fields

In 2007-2008, demonstrative fields with cauliflower and leek were set up in the main vegetable production regions in Flanders (sandy and sandy-loam region) (Soil Service of Belgium, 2008; Vandelannoote, 2008).

Different parameters were monitored and measured in these fields: the overall soil fertility at the start of the growing season, the mineral nitrogen stock at the start of the growing season, the fertilizer applications (time, type, amount), the N content of applied organic fertilizers, the N content of harvested crop and crop residue and the nitrate-N at the end of the growing season (nitrate residue).

At the end of the growing seasons, soil mineral N balances were calculated for each of the fields.

Results

In the next paragraphs the soil mineral N balances of 3 demonstrative fields with cauliflower and leek followed in 2007 (Soil Service of Belgium, 2008) are summarized.

In the first field (Sint-Amands), after cauliflower in 2006, a cauliflower crop followed by a catch crop ray-grass was cultivated in 2007. The cauliflower was planted on June 6th and harvested between the end of August and the beginning of September. The soil mineral N balance was calculated for the period from April 30th to September 27th.

In April, a mineral N stock of 88 kg N.ha^{-1} was measured (45 kg in the layer 0-30 cm, 29 kg in the layer 30-60 cm, 14 kg in the layer 30-60 cm).

Based on a soil C content of 2,1% and a sandy soil, the expected N supply from mineralization of soil organic matter from April to September was 165 kg N.ha^{-1}.

The N fertilization recommendation was 145 kg N.ha^{-1}.

At the start of the growing season, 20 tonnes.ha^{-1} green compost was applied on this field. The green compost was not analysed, but taking into account the average composition of green compost in Flanders and an average N mineralization percentage of 10%, this amount corresponded to 16 kg effective N.ha^{-1}. As for mineral N fertilization, 190 kg N.ha^{-1} was applied.

The cauliflower crop was harvested between the end of August and the beginning of September. Residues of the harvested cauliflower crop were analysed and contained 130 kg N.ha^{-1}. Since the nitrate-N residue was measured only at the end of September, part of the crop residues had mineralized and had to be taken into account in the nutrient balance: 40 kg N.ha^{-1}.

The real N uptake by the crop was not measured. Based on average data from literature, a N uptake of 250 kg N.ha^{-1} was estimated. After the cauliflower crop, ray-grass was planted as a catch crop. However, the nitrate-N residue was measured shortly after the sowing of the grass, so the N uptake by the catch crop was negligible.

Based on regional climatic data on precipitation and evapotranspiration, it was estimated that no leaching losses took place in this field.

As a result, the soil mineral N balance of this field was 245 kg N.ha^{-1}, whereas the measured nitrate-N residue in October was 311 kg N.ha^{-1}, resulting in a balance deviation of 67 kg N.ha^{-1} (**Fout! Verwijzingsbron niet gevonden.**).

Table 5 Calculation of the soil mineral N balance in a demonstrative field with cauliflower-ray-grass in Sint-Amands (source: Soil Service of Belgium, 2008).

N inputs	kg N.ha^{-1}	N-outputs	kg N.ha^{-1}
Mineral N stock in the soil profile (April)	88	N uptake by the crops	250
Expected N mineralization from soil organic matter	165	N uptake by catch crops	0
Expected N mineralization from crop residues	40	N losses through leaching	0
Applied mineral N fertilization	190	Nitrate-N residue (September 27th)	**311**
N supply from applied organic fertilization	16		
Total input (incl. N stock)	499	Total output (incl. residue)	561
		Expected residue (input – output)	**249**
		Balance deviation	-62

In the second demonstrative field (Pittem), after carrots in 2006, two successive cauliflower crops were cultivated in 2007. The soil mineral N balance was calculated for the period from March 1st to October 20th.

In March, a mineral N stock of 138 kg N.ha^{-1} was measured in the soil profile, with the following distribution: 54 kg N.ha^{-1} in the layer 0-30 cm, 59 kg N.ha^{-1} in the layer 30-60 cm and 25 kg N.ha^{-1} in the layer 60-90 cm. The N recommendation for the first crop was 169 kg N.ha^{-1}.

Based on a soil C content of 1,3% and a sandy-loamy soil, the expected N supply from mineralization of soil organic matter from March to October was 110 kg N.ha^{-1}.

At the start of the growing season (April), 30 t.ha^{-1} cattle manure was applied on the field. Taking into account the analysis results of this manure, this amount corresponded to 81 kg effective N.ha^{-1}. As for mineral N fertilization, 169 kg N.ha^{-1} was applied for the first crop.

The first cauliflower crop was planted on May 3th and harvested on July 13th. It was marketed to the vegetable processing industry, so only the cauliflowers were harvested, the leaves remaining entirely on the field. As a consequence, the harvest residues of the first cauliflower crop containing a considerable amount of N (207 kg N.ha^{-1}) accounted for an important N supply for the second cauliflower crop. In the soil mineral N balance it was considered that 60% or 124 kg N.ha^{-1} was mineralized before the end of October and therefore had to be taken into account.

At the harvest of the first crop, an average nitrate-N reserve of 115 kg N.ha^{-1} was measured. The N recommendation for the second crop was 112 kg N.ha^{-1}. In practice, a mineral fertilization corresponding to 140 kg N.ha^{-1} was applied for the second crop.

Due to unfavourable conditions, the second crop was only planted on July 30th. It was harvested in November, so the crop was still on the field when the nitrate-N residue was measured and a catch crop could not be planted anymore.

Based on the analysis of crop samples at harvest (harvested part and crop residues), 292 kg N.ha^{-1} was absorbed by the first cauliflower crop and 180 kg N.ha^{-1} by the second crop.

Based on measurements of soil moisture content and N reserves in the soil profile, it was estimated that N leaching took place in the period around July 20th. The leaching losses were calculated with the Burns model (Burns, 1975) at 44 kg N.ha^{-1}.

As a result, the soil mineral N balance of this field was 247 kg N.ha^{-1}, whereas the measured nitrate-N residue in October was 224 kg N.ha^{-1}, resulting in a balance deviation of 23 kg N.ha^{-1} (Table 6).

Table 6 Calculation of the soil mineral N balance in a demonstrative field with cauliflower-cauliflower in Pittem (source: Soil Service of Belgium, 2008).

N inputs	kg $N.ha^{-1}$	N outputs	kg $N.ha^{-1}$
Mineral N stock in the soil profile (March)	138	N uptake by the crops	472
Expected N mineralization from soil organic matter	110	N uptake by catch crops	0
Expected N mineralization from crop residues	124	N losses through leaching	44
Applied mineral N fertilization	309	Nitrate-N residue (October)	**224**
N supply from applied organic fertilization	81		
Total input (incl. N stock)	762	Total output (incl. residue)	739
		Expected residue (input – output)	**247**
		Balance deviation	23

In the third demonstrative field (Zonnebeke) leek was cultivated in 2007, preceded by white cabbage in 2006. The white cabbage had been harvested in October 2006. The leek was planted on July 7th 2007 and harvested in February 2008.

The soil mineral N balance was calculated for the period from April 24th to October 10th.

In April, a mineral N stock of 132 kg $N.ha^{-1}$ was measured (43 kg in the layer 0-30cm, 39 kg in the layer 30-60cm, 50 kg in the layer 30-60cm).

Also in April, after the soil sampling, 20 $tonnes.ha^{-1}$ cattle manure was applied on this field. Taking into account the analysis results of this manure, this amount corresponded to 52 kg effective $N.ha^{-1}$.

In July, a second N sample was taken in order to calculate the N fertilization recommendation for the leek crop. At that time, a N stock of 157 kg $N.ha^{-1}$ was measured (56 kg in the layer 0-30cm, 71 kg in the layer 30-60cm, 30 kg in the layer 60-90cm).

Based on a soil C content of 1,4% and a loamy soil, the expected N supply from mineralization of soil organic matter from April to September was 90 kg $N.ha^{-1}$. However, the field had a pasture history before 2000, so a more important mineralization could be expected.

Given the considerable N stock, the high mineralization capacity of the soil and the slow initial growth of leek, no N fertilization was recommended at the start of the growing season.

In September, the N stock was measured again in order to estimate the possible need of an additional fertilization. The mineral N stock was 223 kg $N.ha^{-1}$ and again, no fertilization was recommended.

Nevertheless, in October a mineral N fertilization of 21 kg $N.ha^{-1}$ was applied on the field in order to improve the yield and yield quality (green colouring of the leaves) .

No analysis of the crop was done, but based on average data for leek with a growing period of 3 months, the N uptake by the crop from July to October was estimated at 110 kg $N.ha^{-1}$.

The leek being harvested only in February, no catch crop was cultivated.

Based on measurements of soil moisture content and N-reserves in the soil profile, it was estimated that N leaching took place in the period around July 20th. The leaching losses were calculated with the Burns model (Burns, 1975) at 36 kg $N.ha^{-1}$.

As a result, the soil mineral N balance of this field was 149 kg $N.ha^{-1}$, whereas the measured nitrate-N residue in October was 147 kg $N.ha^{-1}$, resulting in a balance deviation of 2 kg $N.ha^{-1}$(Table 7).

Table 7: Calculation of the soil mineral N balance in a demonstrative field with leek in Zonnebeke (source: Soil Service of Belgium, 2008).

N inputs	kg $N.ha^{-1}$	N outputs	kg $N.ha^{-1}$
Mineral N stock in the soil profile (April)	132	N uptake by the crops	110
Expected N mineralization from soil organic matter	90	N uptake by catch crops	0
Expected N mineralization from crop residues	-	N losses through leaching	36
Applied mineral N fertilization	21	Nitrate-N residue (October)	**147**
N supply from applied organic fertilization	52		
Total input (incl. N stock)	296	Total output (incl. residue)	293
		Expected residue (input – output)	**149**
		Balance deviation	2

Discussion

The nitrate-N residue in autumn is determined by several factors. Crop N requirements and N uptake patterns play a significant role, as well as N stocks at the start of the cropping period, N mineralization from soil organic matter and plant residues and N fertilization. Of all these factors, only the N fertilization can be controlled directly by the grower, in terms of dosage, time and method of application. Accurate fertilization recommendations taking into account measured N stocks as well as all the other factors can therefore greatly contribute, not only to an optimal crop yield and quality but also to minimizing nitrate-N residue levels and nitrate-N leaching.

In the cauliflower field of Sint-Amands, the N fertilization recommendation was 145 kg $N.ha^{-1}$. The effective N fertilization was 206 kg $N.ha^{-1}$, which corresponds to an excess fertilization of 61 kg $N.ha^{-1}$. Moreover, mineralization of N-rich crop residues in September supplied an extra and late amount of mineral N in the soil profile. In such a case, a catch crop can be used to reduce the nitrate-N residue. In Sint-Amands however, ray-grass was used as a catch crop. This catch crop could not reduce the nitrate-N residue measured at a relatively early date (end of September), because of its slow initial growth and consequently poor N uptake. A phacelia or mustard catch crop would have been a better choice in this situation.

In the cauliflower field of Pittem the first cauliflower crop started with a sufficient mineral N stock in the soil profile, especially in the upper layer (0-30 cm), leading to a high yield. After the harvest of the first crop, the N stock was insufficient for the second crop, so a supplementary N fertilization of 112 kg $N.ha^{-1}$ was recommended. The high nitrate-N residue in October was mainly explained by an excessive mineral N fertilization for the second crop and an important N supply from the residues of the first cauliflower crop, of which mineralization still took place in autumn. Furthermore, the total N requirement of cauliflower is estimated at 220 to 250 kg $N.ha^{-1}$. The N uptake by the second crop was significantly lower than expected (180 kg $N.ha^{-1}$), due to the delayed planting date and unfavourable growth conditions in late summer and autumn. Sowing of a catch crop to reduce the nitrate-N residue was not possible anymore in November (after the harvest of the second crop).

In the leek field of Zonnebeke, mineral N stocks and mineralization were high. Despite a limited N fertilization, the nitrate-N residue in autumn was high. The total N requirement for leek is estimated at 200 to 225 kg $N.ha^{-1}$, but due to its slow initial growth, only 20% of this requirement is absorbed in the first month after planting. This means that leek cannot absorb all the N present in the soil profile at the start of the growing season and a high N fertilization at this time is undesirable. In September-October the crop is still absorbing a considerable amount of N. As a consequence, a sufficient N supply is required during this period, risking higher nitrate residue levels. In Zonnebeke, a supplementary N-dose of 21 kg $N.ha^{-1}$ was applied at the end of the balance period, to improve the yield and yield quality (green colouring of the leaves).

Conclusion

In this study, the major bottlenecks of vegetable growing in Flanders in terms of N fertilization and nitrate-N residues are discussed, based on the calculation of soil mineral N balances in three demonstrative fields with cauliflower and leek.

In many vegetable parcels in Flanders, considerable amounts of animal manure (slurry) have been applied in the past, leading to the accumulation of a pool of easily degradable organic nitrogen. The exact estimation of the mineralization of this pool is complicated, partially due to more frequent soil cultivations in vegetable fields, in comparison to common arable fields.

In addition, N mineralization from crop residues can be considerable for vegetables (up to 150 kg $N.ha^{-1}$ in many cases) and occurs in a short period after harvest.

Due to the shallower root systems of vegetables, they are not capable to absorb N in deeper soil layers. N availability at the right time and N distribution in the soil profile is therefore extremely important. The N uptake of vegetables can be seriously affected by deviating weather conditions: drought periods can seriously affect crop growth and reduce N uptake; wet periods can cause leaching of N to deeper soil layers (60-90 cm) where it comes out of the reach of the plant roots.

Vegetable crops such as cauliflower and leek are often cultivated as a second crop. Since they are harvested during their vegetative stage, they still show a considerable N uptake even in late autumn, requiring a high N supply in this period and risking high nitrate residues. Moreover, at the time of harvest they leave behind rapidly degradable crop residues.

Sowing of catch crops after the harvest of vegetable crops could contribute to the reduction of nitrate-N residues, but this is not always practically possible, due to the late harvest time of the vegetables.

The influence of all these factors was clearly demonstrated by the calculated mineral N balances in the demonstrative fields. Calculation of soil mineral N balances is frequently used as a tool to demonstrate to the farmers the impact of their field practices and the possible techniques to reduce nitrate-N residues.

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(32) Soilless cultivation of outdoor horticultural crops in The Netherlands to reduce nitrogen emissions

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Abstract: *Many horticultural crops in open field production in The Netherlands do not meet the demands of the EU Water Framework Directive and EU Nitrates Directive mainly because of too high nutrient emissions. No solutions are available within the conventional cultivation systems to reduce nutrient emissions sufficiently while maintaining financial returns and crop quality. Addionally, growers have difficulties to manage their crops e.g. to comply with new market requirements, to have sufficient labour available or manage soil borne pest and diseases. Therefore, new soilless cultivation systems are being developed and tested for various horticultural crops (lettuce, leek, cabbage, strawberry, apple, blue berry, flower bulbs and tree nursery crops). A structured design method was used. First, an analysis was made of the conventional cultivation systems. Secondly, a brief of requirements was set up for all crops. Thirdly, various crop specific systems were designed, selected, engineered and tested on a small scale during several years. The sustainability and profitability of the selected systems are assessed in detail on all sustainability aspects (Planet, People, Profit). Almost all crops can be grown on a system without soil. Most promising systems are: deep flow systems for lettuce, leek and cabbage; NFT systems for strawberry and systems with substrate in pots, gutters or troughs for flower bulbs, tree nursery crops and fruit crops. The profitability and sustainability of the systems is currently under investigation, some first results are shown. Some leading growers have already installed prototypes of these new systems on their own farms.*

Keywords: *cultivation systems, recirculation, design, sustainability, profitability*

Introduction

Due to high nutrient emissions, many crops in open field production in the Netherlands do not meet the requirements of the EU Water Framework Directive (WFD) and EU Nitrates Directive (ND). Additionally, growers are facing difficulties complying with new market requirements, such as minimal pesticide residues, quality requirements and constant deliver. Moreover, growing crops is often labour intensive, working conditions are demanding and soil borne diseases are difficult to manage. Within conventional cultivation systems, only a few methods are available to reduce emissions without affecting crop productivity and quality (de Haan *et al*., 2010; de Haan *et al*., 2009).

At the end of 2009, the research program 'Soilless cultivation of outdoor crops' was started in a unique cooperation between government, research and trade and industry. This research and innovation program has the aim to develop soilless cultivation systems which comply with the EU WFD and ND for nine different (groups of) crops: leafy vegetables, leek, cauliflower, strawberry, blue berries, apple, tree nursery crops, flower bulbs and summer flowers. Essential are the prerequisites that the cultivation systems not only prevent emission, but also provide growers with other benefits (e.g. higher labour efficiency, better product quality or new market opportunities) and that the systems are profitable and accepted by society.

A structured method was used to design and develop new cultivation systems for each crop, followed by three years of experimental development. Adjacent to the technical design and development of the cultivation systems, relevant general subjects (e.g. water use and recirculation, food safety, acceptance by society) were studied.

Materials and Methods

A structured method was used to design and develop new cultivation systems derived from other methods used in the design of open field production systems (de Haan and Garcia Diaz, 2002; Vereijken, 1997), protected cultivation systems (van Henten et al., 2006) and animal husbandry systems (Groot Koerkamp and Bos, 2008). A system innovation approach was used; the essence of this approach is a balance between the use of well-funded theory, future oriented innovation and the involvement of different stakeholders as growers, suppliers, sales parties, government authorities and NGO's. For each of the crops, a working group was established, consisting of researchers, growers, advisors and sometimes other stakeholders. The working groups acted as steering committees for the research program, providing professional knowledge, advice and feedback.

At the start of the program, an analysis was made of the conventional cultivation systems, taking into account technical as well as environmental, societal and legal aspects. With this analysis, a list of system requirements was developed for each crop, containing a variety of requirements focusing on sustainability, profitability, product quality and plant growth. During the first year, using the system requirements, various cultivation systems were designed, engineered and tested on a small scale on experimental farms. Those cultivation systems that sufficiently met the system requirements were selected for further development and experimentation. This process was repeated once or twice until only the one or two most promising cultivation systems were selected. This final system was further optimized (e.g. on fertilization, use of growing media) and laid out on a larger scale, preferably at the farm of a commercial grower.

The selected cultivation systems are currently assessed in details on all sustainability aspects (Planet, Profit, People). A comparison is made on all sustainability aspects between soilless cultivation systems and conventional cultivation systems. For all sustainability aspects, themes are identified (e.g. greenhouse gas emissions, energy use, profitability, competitiveness, labour (conditions) and food quality). For each theme, indicators are used to determine the performance of both soilless cultivation systems and conventional cultivation systems. In this paper a quantitative comparison between both systems is made for some crops on yield (units per ha and number of cultivations) and cost price (€ per unit). Besides a generalized comparison is made on product quality, emission reduction, energy use and greenhouse gas emissions, adaptation to climate change, pesticide use, food safety, labour conditions and societal acceptance. A more detailed comparison of the sustainability of soilless and conventional cultivation systems is made in Breukers *et al*. (2013).

In addition to the development of soilless cultivation systems and the sustainability assessments, relevant general subjects were studied:

- Desk research on water flows and reduction of emission in outdoor soilless systems to understand emission risks and the need to control rainfall surplus (Van Os *et al*., 2013).
- HCCP analyses of the vegetable production systems to identify possible food safety risks (Van der Lans and Van der Voort, 2013).
- Focused interviews on societal acceptance of the soilless cultivation systems and the products with the aim to incorporate viewpoints of society in the design and development of the soilless cultivation systems.

Results and Discussion

Key elements of designed systems

The systems designed are specific for each crop dependent on the crop type and main challenges to tackle for the specific crop (Table 1). Three years of design, development and testing of new cultivation systems make clear that all crops can be grown on the chosen soilless cultivation systems. Selection of systems strongly depends on crop characteristics, crop value and type of product produced. For perennial crops, systems with substrate are selected. For crops with a short cultivation cycle and vegetable crops, mainly water systems are selected. Water systems are also selected for vegetables and strawberries because of the cleanliness of the system. Where bulbs or roots are the main product (flower bulbs, perennial plants) systems with substrate are selected.

The developed soilless cultivation systems can be considered relatively simple in comparison to greenhouse production. This is caused by the requirement of profitable systems in combination with lower crop values of outdoor crops compared to greenhouse crops.

Deep Flow (DF) systems are developed for crops with short growing cycles (2-4 cycles per year) as vegetables (lettuce, leek, cabbage, spinach) and summer flowers. DF systems consist of a water layer of 10-30 cm with floaters in which the plants are planted (Figure 1). This type of systems uses no or only small amounts of substrate and provides a clean production system. DF systems are robust as failure of the system does not directly lead to plant loss. Besides, DF systems offer possibilities for easy logistics by transport over water. Main disadvantage of the system is the large water volume, making disinfection of the water practically impossible and resulting in high emissions when discharge of water is needed. Another disadvantage of the system is the high energy use needed to pump the water.

Growing strawberry in troughs using peat substrate without recycling of water and nutrients is an existing cultivation system in The Netherlands used on about 150 hectares. Advantages of this system are better labour conditions (easy harvest) and product quality (dry fruits and less rotting). An NFT system was developed for strawberry (Figure 2), using water to reduce the use of peat substrate to a minimum. To make recirculation possible without the spread of diseases (e.g. *Phytophtora*)a slow sand filter in combination with chemicals (*dimethomorf,* Paraat) was successfully tested. Main bottlenecks of the NFT system are the use of a large water volume, resulting in costly disinfection of the water and a high energy use.

Table 1. Overview of systems developed and crops in which they are applied. The main advantages next to direct yield and quality increase and the main remaining research questions per system are provided

Main system type	System type	Crops	Main advantages (next to production)	Main remaining research questions
Water systems	Deep flow system	Vegetables (e.g. lettuce, leek, cauliflower, spinach) Summer flowers	• Clean produce • Better planning of production • Possibilities for mechanization	• Energy use • Disease management (lettuce, leek) • Rainfall surplus management • Logistics of cropping system
	Nutrient Film Technique (NFT)	Strawberry	• Easy harvest • Minimum substrate use	• Disease management • Reduction of water volume
Substrate	Sand bed	Flower bulbs Apple trees Perennial ornamental plants	• Growth steering (apple) • Disease free substrate	• Substrate constitution and thickness • Disease management • Weed control • Water management
	Troughs, pots or crates above the soil	Blue berries Tree nursery crops Summer flowers	• Shortening start period (blue berries) • Extending growing season (blue berries and summer flowers) • Labour conditions	• Frost resistance of perennial crops

Figure 1 Deep flow system for lettuce

Figure 2 NFT system for strawberry

Figure 3 Substrate system for apple

Figure 4 Tree nursery crops in troughs

Sand beds in the soil were developed for apples, flower bulbs and perennial ornamental plants (Figure 3). Substrate systems provide isolation against frost, stability and robustness, with an excellent growth. In addition, growth regulation is possible for apple by steering water content and fertilization.

For tree nursery crops, substrate systems in troughs were developed (Figure 4). These systems provide better labour conditions, the possibility to harvest within one year, faster growth and better quality of the trees. For blue berries, a substrate system in pots above the soil was developed, resulting in faster growth. Crates with substrate were developed for summer flowers (multi annual), providing possibilities to relocate the flowers (inside and outside) and accelerate or delay production during the growing season, leading to a longer production period.

Sustainability of the developed systems

Yield and product quality

Yield increase using soilless cultivation systems is large for vegetables (Table 2). With the exception of cauliflower, product quality (% product class I) is better using soilless cultivation systems (data not shown). By unknown causes, the quality of cauliflower decreases in the end of the cultivation period. Less pesticides are used in the soilless cultivation system, resulting in lower risks for residues.

For the tree nursery crops grown on troughs it is estimated that growth is about twice as fast as compared to conventional cultivation. For blue berries, the time to establish a producing crop is halved from 4 to 2 years.

Table 2. Yield of vegetable crops in conventional and soilless cultivation systems

Crop	Conventional cultivation system		Soilless cultivation system	
	yield per ha per year	Average number of cultivations per year	Yield per ha per year	Average number of cultivations per year
Head lettuce	85.000 heads	2	684.000 heads	5.5
Leek	65 ton	1.5	285 ton	4
Cauliflower	21.000 heads	1	39.600 heads	3
Strawberry	20 ton	1	60 ton	1.5

Profitability

For all crops reviewed, cost price of conventional cultivation is lower than soilless cultivation (Table 3). The increase in costs is caused by high investment costs for the new cultivation system and high energy costs. Increase in production and reduction in land use and other costs is not sufficient to compensate for the cost increase. The cost estimations have large uncertainties as the soilless cultivation systems are still in development; the current scale of the system is small and mechanization not developed. When size of systems is increased and mechanization is developed, costs are expected to decrease. Besides, further optimization of the system will increase production and/or decrease costs. Energy reducing options are currently investigated. Therefore we expect that in the future for leek, lettuce and strawberry a profitable system is possible. For cauliflower, the production increase is too small to have a perspective on a profitable system. Higher product quality or (more) continuous delivery could result in better prices when using soilless cultivation systems. However we expect that the increase in product price will be small and will be available for a short period only.

Table 3. Producing costs in conventional and soilless cultivation systems in € per head or kg product

		Conventional cultivation system	Soilless cultivation system
Head lettuce	€ per head	0.17	0.30
Leek	€ per kg	0.49	0.56
Cauliflower	€ per head	0.52	1.73
Strawberry	€ per kg	2.20	3.10

Emission reduction

The soilless cultivation systems were mainly developed to drastically reduce emissions of nutrients and pesticides. Systems for blueberries and tree nursery crops were developed to minimize drainage without recirculation. It appears that nutrient emissions can be reduced with more than 50% in these systems.

In the other systems water is recirculated. Large reductions in emission are expected. However, it is still difficult to give an accurate estimation of the emission reduction of these systems as the need for discharge of water in the developed systems is still unknown. The need for discharge is firstly depending on the rainfall surplus of the system. If the rainfall surplus is entering the system, discharge is needed on a yearly basis. Therefore it is important to a) adapt the systems avoiding that rainwater is able to enter the systems, b) cover the system when no crop is present or c) use purification of the discharge via reversed osmosis. This is especially necessary in the deep flow systems (vegetables) and the sand beds (flower bulbs, perennial plants). In systems with smaller sand beds, troughs or pots, the rainfall surplus is more limited (van Os *et al.*, 2013).

Besides, the occurrence of pests, diseases and harmful root exudates in the recirculation water make it necessary to discharge the water leading to emissions. Disinfection and purification of water can reduce the need for discharge and reduce emissions but will increase the costs.

Finally there are emission risks because of leakage of the ponds and subsequent leakage of the solution to surface - and ground water bodies. These kind of accidents have to be prevented by a well-designed system and good maintenance.

Other sustainability aspects

In Deep Flow and NFT systems, the energy use and greenhouse gas (GHG) emissions are much higher compared to conventional cultivation due to the need to pump the water and due to the material use for the system. In tree nursery crops, the energy use and greenhouse gas emissions are lower compared to conventional cultivation due to more efficient use of inputs and machinery.

Reductions in pesticide use per crop unit is very large, varying from 75 to 100%. For vegetable crops, reductions in pesticide use per area vary between 75% and 100% as well. For three nursery crops however, the reduction is absent calculated on an area basis. Reduction is caused by higher planting densities, absence in use of herbicides and pesticides for soil borne diseases and lower amount of infections observed. Based on this, it is assumed that in soilless cultivation systems, disturbances in growth are less, leading to less stress and less infections.

The identified food safety risk for vegetables were small. The main food safety risks consist of the possibility of crop protection equipment to leak on the crop and into the pond water, risks on microbiological infections, parasites, viruses and heavy metals or pesticides in the water. Based on these food safety risks periodic testing of water in each growing system is a minimum requirement. Besides, regular refreshment/ disinfection of the pond water and cleaning the plates of algae is needed (van der Lans & van der Voort, 2013).

Labour conditions are better in soilless production systems compared to conventional systems. Examples are better working heights in the systems for strawberry and tree nursery crops. Harvesting of strawberries can be done standing instead of on the knees and harvesting of the trees nursery crops can be mechanized. In the Deep Flow systems it is possible to take the harvest to a central processing place instead of harvesting in the field.

Citizens (in their roles as citizens, neighbours and consumers) evaluate cultivation systems and products produced by these systems mainly on the basis of taste, health, freshness and quality. These criteria consider citizens as the most important buying criteria. Possible degradation of the landscape is considered to be the most important disadvantage of soilless cultivation systems. To incorporate viewpoints of society and increase social acceptance of soilless cultivation systems, natural materials (e.g. wood) and colours should be used, the systems need to blend in with their (natural) environment and they need to be neat and tidy. Citizens are inquisitive to the origins of soilless cultivation systems, therefore communication on and around farms with soilless cultivation systems is advised.

Remaining questions and challenges

Almost all soilless production systems are still in development: the troughs system for tree nursery crops is the only system that is currently being applied in practice by several growers on a commercial scale. One lettuce grower and one blueberry grower have invested in small scale commercial system. Several other growers are testing new cultivation systems on a small scale. They have the expectation to scale up within a few years.

The main challenges still left are improving the robustness and disease suppression of the cultivation systems. This seems especially important for the DF systems and the sand beds. In the DF system new diseases in leek and lettuce have appeared which reduce yield and product quality. In the sand beds, disease suppression is an important item as well. For apple, the question is if nematodes in the substrate can be kept at sufficient low levels during the whole cultivation period of 8 years or more. Connected to this is the need to reach minimal emissions of nutrients and pesticides. Optimal disease suppression diminishes the needs for discharge of water or investments in disinfection techniques.

To reduce emissions control of rainfall surplus is also necessary. Ideas developed to control rainfall surplus will be tested such as covering of the system outside production periods, discharge of rainfall before it enters the nutrient solution.

In DF and NFT systems options to reduce energy use are needed. Solutions to reduce energy use and GHG emissions are reducing the flow rate of the water, decrease the depth of the water layer, pumping air instead of water and the use of sustainable energy sources as wind and sun energy.

For perennial crops as fruit crops and tree nursery crops frost resistance of the systems is important. There are still many questions about the cause of frost damage. Many factors may play a role in the cause, such as wind, temperature, moisture and dehydration.

Next to the main challenges above, there are many optimization questions in e.g. optimizing fertilization, substrate choice, mechanization and water application. In the next years, we are planning to help growers further to implement and upscale their systems to reliable, sustainable and profitable systems.

Conclusion

Soilless cultivation of outdoor horticultural crops is technically feasible and expected to be profitable for high value crops. It gives new possibilities for growers to grow better products for new market sectors with higher yields. New cultivation systems are still in development and many technical challenges have yet to be overcome to realise reliable, sustainable and profitable systems. Besides to the technical challenges, market opportunities have to be developed and the advantages and disadvantages of the developed systems have to be communicated to authorities and citizens. Soilless cultivation has the potential to reduce nitrate emissions drastically. However, how much reduction is possible with these recirculation systems is still under investigation. Development of new cultivation systems also results in new knowledge that can be applied in conventional production systems. Soilless cultivation systems give opportunities to improve sustainability of cultivation on many themes. Therefore it can be a solution for more countries depending on their specific challenges.

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(33) Opportunities provided by the European Innovation Partnership "Agricultural Productivity and Sustainability" and its Operational Groups

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Abstract: *European Innovation Partnerships (EIPs) are a new approach to EU research and innovation. EIPs are challenge-driven, focusing on societal benefits and a rapid modernisation of the associated sectors and markets. EIPs streamline, simplify and better coordinate existing instruments and initiatives and complement them with new actions where necessary. This should make it easier for partners to co-operate and achieve better and faster results compared to what exists already. Therefore, they build upon relevant existing tools and actions.*

The agricultural EIP aims to foster a competitive and sustainable agriculture and forestry sector that 'achieves more from less' input and works in harmony with the environment. It will contribute to ensuring a steady supply of food, feed and biomaterials, both existing and new ones, working in harmony with the essential natural resources on which farming depends. For achieving this aim, the EIP needs to build bridges between research and practice.

The innovation model under the agricultural EIP goes beyond speeding up the transfer from laboratory to practice through diffusion of new scientific knowledge (referred to as the "linear innovation model"). The EIP adheres to the "interactive innovation model" which focuses on forming partnerships -using bottom-up approaches and linking farmers, advisors, researchers, businesses, and other actors in Operational Groups. This will generate new insights and ideas and mould existing tacit knowledge into focused solutions that are quicker put into practice. Such an approach will stimulate innovation from all sides and will help to target the research agenda.

Operational Groups will bring together farmers, researchers, advisors, businesses, NGOs and other actors to implement innovative projects pursuing the objectives of the EIP for Agricultural Productivity and Sustainability. Operational Groups can be supported by various funding sources.

Rural Development Policy and the Union Research and Innovation Framework "Horizon 2020" will provide particular opportunities for setting up Operational Groups in the period 2014-2020 and incentivize interested actors who engage in actions on developing, testing and applying innovative approaches. The two policies complement each other in giving emphasis to different objectives and main target groups. In addition, Rural Development Programmes are normally applied within a specific programme region, whilst research policy must go beyond this scale by co-funding innovative actions at the cross-regional, cross-border, or EU-level. Other policies, such as Cohesion and Education Policy, might offer additional opportunities.

Initiating the agricultural EIP

The agricultural European Innovation Partnership (EIP) aims to foster a competitive and sustainable agriculture and forestry sector that 'achieves more from less' input and works in harmony with the environment. It will contribute to ensuring a steady supply of food, feed and biomaterials, both existing and new ones, working in harmony with the essential natural resources on which farming depends. For achieving this aim, the EIP needs to build bridges between research and practice (farmers, businesses, advisory services, etc).

The innovation model under the agricultural EIP goes beyond speeding up the transfer from laboratory to practice through diffusion of new scientific knowledge (referred to as the "linear innovation model"). The EIP adheres to the "**interactive innovation model**" which focuses on forming partnerships -using bottom-up approaches and linking farmers, advisors, researchers, businesses, and other actors in **Operational Groups**. This will generate new insights and ideas and mould existing tacit knowledge into focused solutions that are quicker put into practice. Such an approach will stimulate innovation from all sides and will help to target the research agenda. Innovation under the EIP may be technological, non-technological, organisational or social, and based on new or traditional practices.

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Rural Development Policy and the Union Research and Innovation Framework "Horizon 2020" will provide particular opportunities for setting up Operational Groups in the period 2014-2020 and incentivize interested actors who engage in actions on developing, testing and applying innovative approaches. The two policies complement each other in giving emphasis to different objectives and main target groups. In addition, Rural Development Programmes are normally applied within a specific programme region, whilst research policy must go beyond this scale by co-funding innovative actions at the cross-regional, cross-border, or EU-level. Other policies, such as Cohesion and Education Policy, might offer additional opportunities.

EIP Actions funded under Rural Development

The aims of the EIP and the functions of Operational Groups are described in Art 61 –63 of the proposal for a Rural Development Regulation for the programming period 2014-2020 (COM (2011) 627-3). Article 62 of the draft regulation refers to "interested actors such as farmers, researchers, advisors and businesses involved in the agriculture and food sector" as members of Operational Groups. The EIP Communication (COM(2012) 79) mentions in addition NGOs as possible members.

Operational Groups are built around concrete innovation projects, on the initiative of the interested actors. The composition of an Operational Group may vary from project to project in function of the project pursued. Operational groups shall draw up a description of the innovative project, the expected results, the approach towards implementing the project, and the decision making process work of the Operational Group. Furthermore, Operational Groups have to commit themselves to disseminate the results of their work via the EIP network.

Operational Groups may pursue "the development of new products, practices, processes and technologies in the agriculture, food and forestry sectors"(Art 36 (2)(a)) and "pilot projects"(Art.36 (2)(b)). Further possible areas of action include joint work processes, short supply chains, joint climate change actions, collective environmental projects etc. The projects of Operational Group may involve the testing and adaptation of technologies and processes to specific geographical and environmental contexts.

Member States could use eligibility conditions and selection criteria in order to prioritise support to certain types of projects or areas of action, or to certain compositions of operational groups. Alternatively, Member State could rely on bottom-up initiative in defining content and objectives of the projects pursued by Operational Groups. Of course, projects must fall in any case into the scope of the EIP as stipulated in Article 61: they must promote a resource efficient, productive, low emission, climate friendly and resilient agricultural sector in harmony with essential natural resources on which farming depends.

Actions under Article 36 benefit from an increased EAFRD co-financing rate. Support can cover both **the setting up and running of Operational Groups and the funding of their operations**. Article 36 provides also for the setting up of innovation brokering in order to help with the establishment of operational groups, including finding the partners and refining the conceptualisation of innovation projects.

The funding of the setting up and running of Operational Groups may be combined with support under other rural development measures such as knowledge transfer and information actions(Art. 15), advisory services (Art. 16), investment in physical assets(Art.18), farm and business development (Art. 20), forestry investments (Art. 27), producer groups (Art. 28) etc. Investments done in the framework of EIP Operational Groups may profit from a higher support rate. Operational Groups may also use funding instruments outside rural development policy, especially those of the EU's research policy.

The Farm Advisory System

The Farm Advisory System (FAS) was set up as a component of the CAP reform of 2003. Member States were obliged to have an advisory system in place which helped farmers complying with cross-compliance requirements via the provision of technical advice. The establishment and use of the FAS is supported by the Rural Development Policy (see above). In the current period 2007-2013, the advisory activity covers at least the Statutory Management Requirements (SMR) and the standards for Good Agricultural and Environmental Condition (GAEC) but may cover other issues if Member States who want to do so. Advisors can play a major role in enhancing innovation, by forming part of operational groups or in serving as an interface between research and practice.

Innovation Brokers

Raising awareness and animating the participation in innovative actions are key for the successful implementation of the EIP. Single actors might have difficulties in finding partners and getting an Operational Group project started. An "innovation broker" could help this process by acting as a go-between, discovering innovative ideas, connecting partners, finding funding sources and preparing project proposals. Ideally, innovation brokers should have a good connection to and a thorough understanding of the agricultural world as well as well-developed communication skills for interfacing and animating.

EIP Actions funded by Research and Innovation Policy ('Horizon 2020')

Horizon 2020 is the financial instrument for research and innovation in Europe. A budget of € 4.5 billion is proposed to support the societal challenge: "Food security, sustainable agriculture, marine and maritime research and the bioeconomy".

The proposed Horizon 2020 regulation foresees the implementation of the Societal Challenge "Food security, sustainable agriculture marine and maritime research and the bio-economy". Beyond the funding of applied research to provide the necessary knowledge base for innovative approaches, Horizon 2020 provides for practice-oriented formats such as "**multi-actor approach**" and “**thematic networks**” which will "ensure interactions between researcher, businesses, farmers/producers, advisors and end-users". This approach fully matches with the concept of Operational Groups.

The undertakings of Horizon 2020 in support of "Operational Groups" will be translated into specific instruments and practical approaches via the annual work programmes and calls for proposals. Current thinking involves projects integrating a continuum from basic to applied research and demonstration, multi-actor approaches, cross-border initiatives such as thematic networks, as well as supporting innovation brokers and innovation centres as intermediates to connect farmers and other actors with research.

The Standing Committee for Agricultural Research, which coordinates agricultural research across the European Research Area, with representatives from Member States including from Candidate and Associated Countries has engaged in assisting the EIP through contributing to the development of innovative Horizon 2020 instruments and providing advice via a dedicated working group on Agricultural Knowledge and Innovation Systems (AKIS).

Knowledge exchange - the EIP network

As a key instrument of the EIP, a Brussels based network facility will work as an intermediary enhancing communication between science and practice and fostering cooperation. This "EIP Service Point" will encourage the establishment of Operational Groups and support their work through focus groups, seminars and workshops, the establishment of data bases (on relevant research results and good practice examples), support for partnering, and help desk functions.

A particularly important action format of the EIP Network is the so-called Focus Group which is established to share knowledge and practical experience from concrete innovative projects. Focus Groups will in particular build upon the outcome of Operational Groups.

The EIP network will facilitate the effective flow of information in order to ensure that successful projects of Operational Groups do not remain singular events but contribute to advancing and mainstreaming of innovative approach beyond the local and regional level.

(34) Benchmark study on innovative techniques and strategies for reduction of nutrient losses in horticulture

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Abstract: *Open field or greenhouse production of vegetables and ornamental plants is challenging because of the need to balance high productivity and sometimes late harvests with reducing nutrient losses to the environment. Growers urgently need to find and implement more sustainable strategies for the intensive production of vegetables, potatoes, flowers and ornamental trees. On request of the European Commission - DG Environment, a consortium of research institutes and extension research centers in Flanders (ILVO, UGent, Inagro, PCS, PCG and PSKW) performed a benchmark study to evaluate innovative techniques for nutrient management in horticulture in Flanders and other regions in Belgium, The Netherlands, France, Spain, Italy, Germany, Denmark, Switzerland and Poland. The benchmark focuses on the current knowledge of sustainable and innovative techniques of vegetable and ornamental plant production. The techniques are related to both conventional and organic agriculture, are used both for vegetables and ornamentals, and do include applications for all horticultural systems (open air and greenhouse, in soil and soilless). The selected techniques focus on innovative fertilization, crop residues management, crop rotation, organic matter management and soil quality practices in horticulture. The necessary information was gathered by visits to the selected regions. The benchmark resulted in an overview of promising techniques on this subject compiled in a report with fact sheets on cultivation and fertilization techniques for vegetable and ornamental plant production. The position of Flanders relative to other European regions concerning the implementation degree is assessed as well. For new techniques ready for implementation, we evaluated the applicability and the economic and technical feasibility for Flanders. These results will be used for an action plan for horticulture in Flanders.*

Keywords: *implementation degree; fact sheets, research and extension need, action plan, economic and technical feasibility*

Introduction

Production of field or greenhouse vegetables or ornamental plants is challenging because of the need to balance high productivity and sometimes late harvests on the one side and reducing nutrient leaching to the environment on the other side. High concentrations of nitrate or phosphate can cause eutrophication of the surface and coastal water. Leaching of nitrate or phosphate to the groundwater can pose a problem for drinking-water production. Growers need to find and implement more sustainable strategies for the intensive production of vegetables, potatoes, flowers and ornamental trees. On request of the European Commission - DG Environment the Flemish Land Agency contracted a consortium of research institutes in Flanders (ILVO, UGent, inagro, PCS, PCG and PSKW) to perform a benchmark study to evaluate innovative techniques for nutrient management in horticulture in Flanders and other European regions.

Materials and Methods

Innovative techniques and strategies for reduction of the nutrient losses in horticulture were collected and evaluated for different regions in Belgium, The Netherlands, France, Spain, Italy, Germany, Denmark, Switzerland and Poland. These regions were selected as being important for horticultural production. This benchmark results in an overview of potential techniques on this subject. The position of Flanders relative to other European regions is evaluated, and an action plan for horticulture in Flanders will be developed. The project thus contains 3 important steps:

1. Fact sheets: characteristics of potential innovative techniques
2. Benchmark: degree of implementation, and assessment of potential application in Flanders
3. Action plan for horticulture in Flanders: actions related to the results of the benchmark

The necessary information was gathered by visits to the selected regions between October 2012 and August 2013. A list with potential techniques and strategies within this benchmark study was made based on Smit *et al.* (2011), with other techniques from Derden *et al.* (2005), Vandenberghe *et al.* (2007 and 2009), and de Haan and Dekker (2005). The contacted regions were asked to choose relevant techniques from this list for filling the questionnaires.

The benchmark is based on standardized questionnaires, i.e. one questionnaire for each technique or strategy for nutrient loss reduction in horticulture. For making the questionnaire we consulted related studies of Anonymous (2012), Claeys *et al.* (2007), Derden *et al.* (2005), Reijnders (2007), Schoumans *et al.* (2012), Smit *et al.* (2011), Vandenberghe *et al.* (2007 and 2009) and Willems *et al.* (2012). The fact sheets based on these questionnaires are available as a book, distributed together with the NUTRIHORT Book of Abstracts and the NUTRIHORT Proceedings (Amery *et al.*, 2013).

These techniques are related to 6 groups:

- Crops and crop rotations
- Cultivation constructions
- Fertilizer application
- Fertilizer type
- Irrigation
- Determine the N need

In total 55 questionnaires were collected. These questionnaires were categorized depending on the degree of implementation. For 38 questionnaires the innovations were already applied in practice for at least some of the regions. For these questionnaires, we assessed the degree of implementation in the visited regions and in Flanders. For the other 17 techniques, research is still ongoing and implementation by growers has not yet started.

Innovations already applied in practice

The 38 fact sheets for innovations already applied in practice were clustered in 19 techniques applicable in horticulture (Table 1). For assessing the degree of implementation of these 19 techniques in horticulture a questionnaire on implementation degree was filled in August and September 2013 by the contact persons in the visited regions (based on expert judgement). The techniques were assessed for the 5 subsectors:

- horticulture open air: vegetables
- greenhouse horticulture soil bound: vegetables
- greenhouse horticulture soilless: vegetables
- floral and ornamental soil bound horticulture
- floral and ornamental soilless horticulture

Implementation degree is assessed in 4 classes:

1. class 1: not implemented
2. class 2: implemented at <2% of the farms
3. class 3: implemented at 2-20% of the farms
4. class 4: implemented at >20% of the farms

Implementation degree can be assessed on different scales (e.g. % of area, number of farms, …). By using a scale based on implementation degree in % of the farms we assess whether farmers know the techniques or not.

Innovations not yet applied in practice

For the innovative techniques not yet applied, we evaluated the coverage of these topics by ongoing research and assessed their applicability for Flanders based on:

- technical feasibility (score between -2 and 2):
  - -2: at least 3 major bottlenecks
  - -1: less than 3 major bottlenecks but more than 1 major or two small bottlenecks
  - 0: at maximum 1 major or two small bottlenecks
  - 1: only one small bottleneck
  - 2: no bottlenecks
- economic feasibility:
  - -2: Yearly costs >5% of turnover
  - -1: yearly costs are between 2 and 5% of turnover
  - 0: yearly costs are between 0.5 and 2% of turnover
  - 1: yearly costs are between 0.1 and 0.5% of turnover
  - 2: yearly costs <0.1% of turnover

Results and Discussion

The 55 techniques are related to both conventional and organic agriculture, are used both for vegetables and ornamentals, and include applications for horticulture in open air and greenhouse horticulture (both cultures in soil and soilless cultures).

For the 55 fact sheets, 39 fact sheets are related to horticulture open air (vegetables), 16 to greenhouse horticulture soil bound (vegetables), 17 to greenhouse horticulture soilless (vegetables), 17 to floral and ornamental soil bound horticulture and 12 to floral and ornamental soilless horticulture. Twenty fact sheets were filled for conventional farming, 3 fact sheets were specific for organic farming and 29 fact sheets are applicable for both farming systems. Concerning the focus of the fact sheets, 52 sheets were related to N and 26 were related to P.

The categorization over the action domains was:

- cropping technique (e.g. substrate): 9
- crop choice/rotation plan: 8
- fertilisation planning (timing, level & analyses): 20
- fertiliser type: 16
- fertilisation technique: 21
- crop residues: 9
- water supply: 11
- drain water (recirculation, treatment,…): 12
- catch crops: 8
- other: 3

This distribution illustrates that the cases used for filling the fact sheets are mostly related to more than one action domain. There was no clear relation between the score for technical feasibility and the score for economic feasibility (assessed for 48 fact sheets), nor between the expected N and P loss reduction (assessed for 20 fact sheets). We did observe a relation between technical feasibility on one hand, and N loss reduction (assessed for 41 fact sheets) or P loss reduction (assessed for 28 fact sheets) on the other. Very large N and P loss reduction (>50% loss reduction) was expected in case of application of drain water processing techniques or for drain water reuse, and when closed cultivation constructions are applied.

Innovations already applied in practice

In tables 2 to 6 an overview is given of the implementation degree in different European regions for innovations that are already applied in practice in the five defined subsectors. Below, the implementation of these techniques in Flanders is discussed briefly.

Growers are obliged to apply technique 7, 8 and 18 due to the nutrient legislation in Flanders (High implementation). The N-Expert (which is a further development of the KNS-system) is already applied in several regions (Germany, Flanders, Denmark, Poland, …). Collaboration in research on N advice systems based on soil sampling between these regions may help for gathering the necessary knowledge on different crops and soil types to improve the advice systems. The use of catch crops can be applied in several variants. This is related to the difference between using crops as catch crop or as green manure.

Concerning crops and crop rotations in vegetables open air systems, Flanders has a low implementation degree for crop rotations, the use of local varieties, and removal of crop residues, an intermediate implementation degree for reduced or ploughless tillage, and a high implementation degree for catch crops (Table 2). Due to intensive crop production and the high prices for agricultural land the implementation of “smart” crop rotations in Flanders is low. Searching for better combinations of shallow rooting and deep rooting crops might be an alternative. Removal of catch crop residues is not yet generally applied in the visited regions. For the techniques related to fertilizer type: most techniques are already implemented in vegetable production in open air in Flanders except for fertigation (Table 2). Fertigation (technique 16) is less applicable in Flanders, as the need for irrigation in vegetable production in open air is not high (occasional irrigation). However, fertigation in combination with mulch is applied for strawberry in Flanders.

In order to decrease the N and P losses to surface and ground water, the amounts of N and P to be used as organic or mineral fertilizer on agricultural and horticultural land are strictly regulated. This may affect soil quality as manure, compost and other organic fertilizers might be valuable tools for maintaining or increasing the carbon content in the topsoil. Increasing the soil organic C level and overall soil quality by using compost seems to be a promising technique in intensively managed horticultural soils and is already implemented in Flanders.

In greenhouse soil-bound vegetable production in Flanders, implementation is high for technique 8, 9, 13, intermediate for technique 14, 15, and low for 3, 11, 12 and 17 (Table 3). The use of catch crops is not feasible in the current system of soil-bound vegetable production in the greenhouse (Table 3) due to continuous cropping, e.g. up to six crop cycles for lettuce. For greenhouse soilless horticulture (vegetables) implementation is high for technique 7, 8, and 9, intermediate for technique 12, and low for 3, 10, 11, 14 and 17 (Table 4).

A high implementation degree was noticed for technique 3, 8, 9, 10, 12, 13, 14 and 18 in floral and ornamental soil bound horticulture in Flanders (Table 5). The implementation degree is low for technique 1, 17 and 19. In comparison with soil bound vegetable production in open air, the implementation degree in floral and ornamental soil bound horticulture is higher for techniques 3, 12 and 14, and lower for 1 and 2 (Tables 2 and 5). The use of catch crops is not feasible in perennial floral and ornamental soil bound horticulture due to restricted crop rotations (land is expensive).

For floral and ornamental soilless horticulture in Flanders, the implementation degree is high for technique 7, 8, 9, 12 and 14 (Table 6). The implementation degree of techniques 3, 7, 8 and 9 in floral and ornamental soilless horticulture in Flanders is similar to that of soilless vegetable production in the greenhouse (Tables 4 and 6). For techniques 10, 11, 12, 14 and 17, however, the implementation degree is higher in soilless production of ornamental crops: more than 20% of the growers of ornamental crops on substrate use commercial organic fertilizers and controlled release fertilizers (Table 6).

Remarks on the implementation and on-going research in Flanders for these innovate techniques are given in Table 7. We conclude that most of the innovative techniques are already applied in practice or are still under research in Flanders.

Innovations not yet applied in practice

The techniques not yet applied in practice are listed in Table 8. For these techniques, we assessed the applicability in Flanders and the related on-going research in Flanders (Table 8). The technique of fact sheet NL14 ‘Scientific base for N fertilization recommendation’ is based on modelling only. It would be valuable for Flanders to improve the current parcel-bound advice systems based on soil sampling with plant determinations and application of models rather than using only models for fertilization recommendation.

End of pipe water treatment techniques (e.g., fact sheet NL18, NL19, FL01 and FL03) for processing nutrient rich waste water from soilless crops allow for closing the water cycle. We believe that ‘Modified Ion Exchange’ (fact sheet FL01) might be a solution for drain water treatment, once the process of ‘harvesting’ and reusing nutrients is completely developed. Contamination might be the most important bottleneck in reusing nutrients, on top of the cost of constructing a sufficiently scaled plant and eventual operation costs of such a plant.

Table 1. Clustering of the fact sheets on implemented innovative techniques (numbers in brackets refer to oral and poster presentations during Nutrihort)

Category	Number	Technique	Fact sheet	Examples technique (fact sheets)	Presentation at Nutrihort
Crops and crop rotations	1	Crop rotation	BR01	designing smart crop rotations	(26), (44), (64)
	2	Catch crops	BR02	Smart use of N-fixing green manure	(14), (15), (16), (17), (18), (24), (38), (40), (60), (65), (71)
			CH02	Winter legumes as green manure crop	
			IT02	Mixture of legumes and non-legumes as cover crop	
			WA02	Management of intercropping period after vegetables crops to reduce N losses through leaching	
			NL09	Catch crop	
	3	Local varieties	IT03	local varieties	
	4	Management of crop residues after harvest	NL04	Removal of N-rich crop residues after harvest in early autumn	(25), (26), (70), (73), (74)
	5	Reduced or ploughless tillage	WA06	Ploughless tillage	(8), (28), (62)
Cultivation constructions	6	Closed cultivation constructions	NL12	Soilless cultivation of nursery stock crops - U system	(32), (53)
			NL20	Floating cultivation	
			NL08	Soilless cropping	
Drain water recirculation	7	Drain water recirculation	BR07	Reuse of drain water (recirculation)	(10), (11), (51)
			CH06	Drain water re-use	
Fertilizer application	8	Fertilization planning	NL10	Fertilization planning	(37), (38), (46), (79), (89)
	9	Split the N dose for a higher efficiency	WA03	Split the N dose for a higher efficiency	(6), (46), (83), (87)
	10	Fertilizer placement	DE03	Row or point fertilization	(7), (20), (46), (87)
			NL06	Placement of starter P fertilizer in the row or near individual plants	
			NL11	Placement of starter N fertilizer in the row or near individual plants	
Fertilizer type	11	Foliar N fertilisers as top dressing	BR06	Use foliar N fertilisers as top dressing	(14), (82)
	12	Commercial organic fertilizers	CH03	Commercial organic fertilizers	(76)
	13	Ammonium-stabilized fertilizers	DE01	Use of ammonium-stabilized fertilizers	(46)
	14	Controlled release fertilizers (CRF)	DE02	Use of controlled release fertilizers (CRF)	(39), (46), (83)
	15	Compost application as fertilizer	BR09	Use of compost/mycorhizes in association with reduced fertilisation	(22), (28), (62), (67), (72)
			CH01	Phosphorus fertilisation with green waste compost	
	16	Fertigation	NL01	Fertigation	(12), (14), (15), (49), (55), (60), (88)
Irrigation	17	Irrigation based on moisture sensor	NL05	Irrigation based on moisture sensor	(5), (10), (12)
			SP01	Enviroscan (+Triscan)	
			CH04	Irrigation (and also fertilization) management according to soil moisture in strawberry cultivated in soil	
			CH05	Irrigation (and also fertilization) management according to substrate moisture or drain volume in soilless raspberry	
Determine the N need	18	Determine the N need by soil determinations	BR03	Equiterre: Advice according to precipitation, pre-crop and crop earliness	(4), (6), (26), (27), (31), (44), (59), (66), (84), (85)
			BR05	Determining N mineralization	
			DE04	N-Expert / KNS - system	
			WA01	Use of a recommendation program for the fertilisation	
			NL03	Determine the N need for the crop and farm	
			NL02	Measuring or estimating the mineral N supply from the soil	
	19	Determine the N need by crop determinations	BR04	Measuring nitrogen in plant juice	(4), (6), (26), (42), (47), (48), (86)
			WA04	Determine the level of the additional mineral dressing by use of crop determinations	

Table 2. Implementation degree of innovative techniques[1] in vegetables open air systems in Flanders (FL), The Netherlands (NL), the region of Almeria in Spain (SP), Italy (IT), Switzerland (SW), Denmark (DK), the Pfalz region in Germany (DE), the Brittany region in France (FR) and Poland (PL).

Number	Technique	not implemented	implemented at <2% of the farms	implemented at 2-20% of the farms	implemented at >20% of the farms
1	Crop rotation		NL, FL, SP	DE	WA, SW, PL, IT, DK, FR
2	Catch crops	WA, SP	IT	SW	FL, NL, PL, DK, DE, FR
3	Local varieties	DK, FL, WA, DE, SP	IT, NL, SW		
4	Management of crop residues after harvest	WA, FL, NL, DK, SP, SW, DE	IT	PL	
5	Reduced or ploughless tillage	WA, SP, DE	FL, NL, SW, DK	IT	
6	Closed cultivation constructions	WA, PL, SW, DK, DE	FL, NL, SP		IT
8	Fertilization planning			WA, SP	FL, NL, SW, PL, IT, DK, DE
9	Split the N dose for a higher efficiency	PL	WA		FL, NL, SW, IT, DK, SP, DE
10	Fertilizer placement	WA	PL, DE	NL, SW	FL, IT, DK, SP
11	Foliar N fertilisers as top dressing	WA	NL, PL, IT	FL, SW, DK, SP	DE
12	Commercial organic fertilizers	WA	NL, IT	FL, SW, DK, SP, DE	PL
13	Ammonium-stabilized fertilizers	PL	WA	SW, DK, SP	FL, NL, IT, DE
14	Controlled release fertilizers (CRF)	WA, PL	FL, IT, DK, DE	NL, SW, SP	
15	Compost application as fertilizer	WA, NL	IT, DK, SP, DE	FL, SW, FR	PL
16	Fertigation	PL	FL, WA, NL, DK	SW	IT, SP, DE
17	Irrigation based on moisture sensor	FL, WA, PL, DK	NL, SW, IT, DE	SP	
18	Determine the N need by soil determinations		SP	WA, SW, IT, DK	NL, PL, FL, DE, FR
19	Determine the N need by crop determinations	FL, PL, DE, FR	WA, NL, IT, DK, SP	SW	

[1] Only techniques relevant for vegetable open air systems are discussed.

Table 3. Implementation degree of innovative techniques[1] in greenhouse soil-bound horticulture (vegetables) in Flanders (FL), The Netherlands (NL), the region of Almeria in Spain (SP), Switzerland (SW, only organic horticulture), Italy (IT) and Poland (PL).

Number	Technique	not implemented	implemented at <2% of the farms	implemented at 2-20% of the farms	implemented at >20% of the farms
3	Local varieties	FL, NL	IT, SW	SP	
8	Fertilization planning			SP, SW	FL, NL, PL, IT
9	Split the N dose for a higher efficiency	PL		SW	FL, IT, SP
10	Fertilizer placement	FL, NL, PL		SW	IT, SP
11	Foliar N fertilisers as top dressing	NL, SW	FL, PL, IT		SP
12	Commercial organic fertilizers		PL, IT	SP, FL	NL, SW
13	Ammonium-stabilized fertilizers	NL, PL		SP	FL, IT
14	Controlled release fertilizers (CRF)	PL	FL, NL, IT, SP		
15	Compost application as fertilizer		NL, PL, IT, SP	FL	SW
17	Irrigation based on moisture sensor	FL, PL, SW	NL, IT	SP	

[1] Only techniques relevant for vegetable greenhouse soil-bound systems are discussed.

Table 4. Implementation degree of innovative techniques[1] in greenhouse soilless horticulture (vegetables) in Flanders (FL), The Netherlands (NL), the region of Almeria in Spain (SP), Italy (IT) and Poland (PL).

Number	Technique	not implemented	implemented at <2% of the farms	implemented at 2-20% of the farms	implemented at >20% of the farms
3	Local varieties	FL, NL, IT	SP		
7	Drain water recirculation		PL, SP	IT	FL, NL
8	Fertilization planning			SP	FL, NL, PL, IT
9	Split the N dose for a higher efficiency	PL			FL, IT, SP
10	Fertilizer placement	FL, NL, PL			IT, SP
11	Foliar N fertilisers as top dressing	NL, IT	FL, PL, SP		
12	Commercial organic fertilizers	IT, PL	SP	FL	
14	Controlled release fertilizers (CRF)	FL, IT, PL	SP		
17	Irrigation based on moisture sensor	FL, PL	SP	NL, IT	

[1] Only techniques relevant for vegetable greenhouse soilless systems are discussed.

Table 5. Implementation degree of innovative techniques[1] in floral and ornamental soil bound horticulture in Flanders (FL), The Netherlands (NL), the region of Almeria in Spain (SP), Switzerland (SW, only organic horticulture), the Brittany region in France (FR), Italy (IT) and Poland (PL).

Number	Technique	not implemented	implemented at <2% of the farms	implemented at 2-20% of the farms	implemented at >20% of the farms
1	Crop rotation	FL, SP, SW		IT	NL, PL
2	Catch crops	IT, SP, SW		FL, NL	PL
3	Local varieties	IT, NL	SP, SW		FL
5	Reduced or ploughless tillage	SP	FL, NL	IT	
6	Closed cultivation constructions	NL, PL, SP	FL		IT
8	Fertilization planning			SP, SW	FL, NL, PL, IT
9	Split the N dose for a higher efficiency	PL		SW	FL, NL, IT, SP
10	Fertilizer placement	PL		SW	FL, NL, IT, SP
11	Foliar N fertilisers as top dressing		NL, PL, IT	PL, FL, FR	
12	Commercial organic fertilizers		NL, IT	SP	FL, PL, SW
13	Ammonium-stabilized fertilizers	PL, NL		SP	FL, IT
14	Controlled release fertilizers (CRF)		SP	NL	FL, PL, IT
15	Compost application as fertilizer		PL, SP	FL, SW, FR	NL
16	Fertigation	PL	FL, NL		IT, SP, SW
17	Irrigation based on moisture sensor	FL, PL, SW	NL, IT, SP		
18	Determine the N need by soil determinations	SW	SP	IT	FL, NL, PL
19	Determine the N need by crop determinations	FL, NL, PL, SP, SW	IT		

[1] Only techniques relevant for floral and ornamental soil bound horticulture are discussed.

Table 6. Implementation degree of innovative techniques[1] in floral and ornamental soilless horticulture in Flanders (FL), The Netherlands (NL), the region of Almeria in Spain (SP), the Brittany region in France (FR), Italy (IT) and Poland (PL).

Number	Technique	not implemented	implemented at <2% of the farms	implemented at 2-20% of the farms	implemented at >20% of the farms
3	Local varieties	FL, NL, IT	SP		
7	Drain water recirculation	SP	PL		FL, NL, IT, FR
8	Fertilization planning			SP	FL, NL, PL, IT
9	Split the N dose for a higher efficiency	PL			FL, NL, IT, SP
10	Fertilizer placement	PL		FL	NL, IT, SP
11	Foliar N fertilisers as top dressing	IT	NL, PL, SP	FL, FR	
12	Commercial organic fertilizers	PL, IT	NL, SP		FL
14	Controlled release fertilizers (CRF)	IT	SP	NL	FL, PL
17	Irrigation based on moisture sensor	PL	SP	FL, NL	IT

[1] Only techniques relevant for floral and ornamental soilless horticulture are discussed.

Table 7. Remarks on implementation and ongoing research in Flanders for innovate techniques already applied in practice (ADLO-LV: Division of Durable Agricultural Development of the Flemish Ministry of Agriculture and Fisheries)

Number	Technique	Remarks on implementation and ongoing research and extension
1	Crop rotation	This is a topic within the research project "Management of vegetable crop residues for reducing nitrate leaching losses in intensive vegetable rotations" financed by VLM in the framework of the 4th Flemish Action Plan.
2	Catch crops	There is related project in the framework of the 4th Flemish Action Plan on effect of catch crops after cereals. This is also a topic within the research project "Management of vegetable crop residues for reducing nitrate leaching losses in intensive vegetable rotations" financed by VLM in the framework of the 4th Flemish Action Plan. Furthermore ADLO-LV finances a demonstration project on the use of catch crops as a tool to reduce residual N in field vegetables. At the practical research centres, catch crops have been a constant research topic: species, sowing data, destruction data, productivity, effects on subsequent crop, mineralisation, etc.
3	Local varieties	Is a research need, but should be applied in a broader context, i.e., rooting and nutrient use efficiency as criteria in variety choice. In soil bound ornamental and floral horticulture the use of local varieties is widespread but the incentive is not a reduction of nutrient leaching. Rooting depth is currently investigated for several vegetable crops in the Ecofert 2 project, financed by IWT.
4	Management of crop residues after harvest	Ongoing research "Management of vegetable crop residues for reducing nitrate leaching losses in intensive vegetable rotations" financed by VLM in the framework of the 4th Flemish Action Plan.
5	Reduced or ploughless tillage	Ongoing research at ILVO (2 field trials). Is already applied in extensive vegetable production and in the production of forest planting stock (the implementation will probably increase in the near future).
6	Closed cultivation constructions	There are still technical (rain water, high volume of nutrient solution) and economic bottlenecks. Flanders will follow the ongoing research in The Netherlands. In Flanders one grower is testing the U system (disadvantage according the grower: compared to (pot-in-)pot system additional handling is needed at harvest to cut the chunk) and some growers use hydroculture for tulips.
7	Drain water recirculation	Recirculation is current practice and in fact compulsory. An ongoing demonstration project "Greenhouse growing without nutrient rich waste water", financed by ADLO-LV, demonstrates techniques to reduce the amount of waste water (= drain water that can not be recirculated) and informs on how remaining waste water should be discharged (e.g. by applying on grassland). Slow sand filters and UV filters are used for desinfectation of drainwater. New desinfection methods (e.g. ECA water) for ornamental plant production are tested and demonstrated.
8	Fertilization planning	Compulsory for growers with fields where very high N residues were found during the random sampling of the government at the end of the year.
9	Split the N dose for a higher efficiency	Compulsory, part of the advise after soil sampling.
10	Fertilizer placement	Not relevant for greenhouse soil bound and soilless vegetable production in Flanders. Important to have more extension activities on this topic. Point fertilization in ornamental crops grown in containers: risk for root-damage as a higher concentration will be near the roots compared to the standard practice where fertilizer is mixed with the potting soil. Extensive research was done at the practical research station for field vegetables, where it is now common practice.
11	Foliar N fertilisers as top dressing	For all techniques on fertilizer type: it is important to have demonstration activities and practical research on how to combine these fertilizers without increasing the N leaching. There is an ongoing demonstration project on this topic. As new fertilizer products are launched regularly, ongoing demonstration is an important need. In ornamental horticulture the use of foliar N-fertilisers is widespread, the incentive however is to adjust fertilization near the end of the season (more than reducing N-leaching, although this incentive becomes more important in soil bound cultures).
13	Ammonium-stabilized fertilizers	Extensive research has been done in the past on the practical research centres, is currently subject of demonstration and already broadly applied.
14	Controlled release fertilizers (CRF)	Not relevant for greenhouse soilless vegetable production in Flanders
15	Compost application as fertilizer	Ongoing research at ILVO (2 field trials). At the practical research stations for vegetables long run trials (more than 10 years) are going on. Results are very good for years and use of compost is a standard recommendation to reduce N residue. In Flanders green waste compost is ready available and commonly used in field vegetables.
16	Fertigation	Is applied in open field cultures of strawberries and zucchini. In ornamental horticulture it is applied by a couple of forestry growers (early adopters), while it is a common technique for Chrysanthemum growers (but they are only few compared to forestry). It is tested in field vegetables in the Ecofert 2 project.
17	Irrigation based on moisture sensor	This is the topic of the REDUNG project funded by IWT and to be started in autumn 2013, focussed on vegetables. In soilless horticulture the technique is mainly implemented in the greenhouse, not in open air cultures.
18	Determine the N need by soil determinations	This is the topic of the ADLO-LV demonstration projects "Optimal and durable fertilization with innovative techniques" and "KNS and efficient N in Flanders". These projects demonstrate the application of KNS in vegetables. There is a project financed by VLM in the framework of the 4th Flemish Action Plan to update the KNS-system used in Flanders based on literature and results of past field trials. Additionally, the Ecofert 2 project funded by IWT develops a dynamic advice tool that integrates all historical data of a field with model based expected extraction and mineralisation, for determination of crop N demands for selected field crops.
19	Determine the N need by crop determinations	This has been developed for greenhouse cultivation of lettuce (see contribution) and for potatoes (as a control on the base fertilisation). It might be an alternative for soil sampling, but further research is necessary.

Table 8. Assessment of applicability in Flanders of innovative techniques ready for implementation (white: relevant, grey: not relevant for a subsector). Technical feasibility: -2: at least 3 major bottlenecks, -1: less than 3 major bottlenecks but more than 1 major or two small bottlenecks, 0: at maximum 1 major or two small bottlenecks, 1: only one small bottleneck, 2: no bottlenecks. Economic feasibility: -2: Yearly costs >5% of turnover, -1: yearly costs are between 2 and 5% of turnover, 0: yearly costs are between 0.5 and 2% of turnover, 1: yearly costs are between 0.1 and 0.5% of turnover, 2: yearly costs <0.1% of turnover)

Technique	Fact sheet	Technique/strategy name	horticulture open air	greenhouse horticulture soil bound	greenhouse horticulture soilless	floral and ornamental soil bound horticulture	floral and ornamental soilless horticulture	Remarks (Flanders)	Presentation at Nutrihort	technical feasibility	economic feasibility
Crops and crop rotations: mulching	IT01	Mulching and organic fertilization						What is the effect of specific climatic conditions? In Flanders mulched plants may grow further, which techniques are available to avoid this?	(40)	1	1
Determine the N need based on plant determinations	DE05	N-Tester: Small portable chlorophyll meter						Is used in Poland for tomatoes. Is related to technique 19. A research need is for combining soil analyses, plant determinations and models for optimal determination of N need.	(4)	0	1
	DE06	N-sensor: detection of chlorophyll amount of crops								0	0
	DE07	ImageIT: Digital images to calculate the ground coverage								0	1
Determine the N need based on a model	NL14	Scientific base for N fertilization recommendation						Should be used in combination with soil analyses and plant measurements	(4), (30)	-1	1
Determine the N and water need based on a model	SP05	Simulation model of daily crop growth, nutrient uptake and evapotranspiration (Vegsyst)							(52)	-1	1
Irrigation based on a combination of techniques	NL16	Emission management system using lysimeter, moisture sensor, model, software						This is the topic of the REDUNG project funded by IWT and to be started in autumn 2013, focussed on vegetables. There is a need to test this system for floral and ornamental horticulture.	(10)	1	0
Irrigation based on a model	NL17	waterstreams						Is currently tested in the demonstration project "Greenhouse growing without nutrient rich waste water", financed by ADLO-LV.	(10)	1	1

Table 8 (Continued)

Technique	Fact sheet	Technique/strategy name	horticulture open air	greenhouse horticulture soil bound	greenhouse horticulture soilless	floral and ornamental soil bound horticulture	floral and ornamental soilless horticulture	Remarks (Flanders)	Presentation at Nutrihort	technical feasibility	economic feasibility
Drain water treatment	NL18	Advanced oxidation						Is currently tested as the nutrient legislation is a driving force for applying this technique to close the cycle. Drain water surplus is only an issue in older greenhouses with unsufficient storage capacity for rain water, and a need for using groundwater (with higher EC).	(10), (11), (13)	1	-1
	NL19	Membrane destillation, elektrodialysis and capacitive de-ionisation								-1	-1
	FL01	Modified Ion Exchange								-1	0
	FL03	Anoxic Moving Bed Bioreactor (MBBR) + phosphate chemisorption filter								0	1
Fertilizer type: N-immobilizing substrate	BR08	Use of substrate that temporarily immobilises N							(41), (77)	-1	0
Fertilizer type: mineral fertilizer	NL07	Replacing sludge manure by mineral fertilizer							(68)	2	1
Soil amelioration with compost	WA05	Composting rejected trees for soil amelioration						Tree growers have woody material available. The problem with composting rejected trees will be the increased risk for infection (when composting process is not successful). Growers will not use compost that contains rejected material from other growers.	(28), (62), (67)	0	0
Cultivation constructions	NL13	pot-in-pot system						This system is not implemented in Flanders but some growers show interest. The system is already popular in Italy and the USA. Although the system in not very flexible (fixed container size) its potential for implementation in Flanders is higher than that of the U system.		1	0
Determine the P need by soil determinations	NL15	Scientific base for P fertilization recommendation							(23)	2	1

Conclusion

This benchmark focuses on the current knowledge of sustainable and innovative techniques of vegetable and ornamental plant production. The selected techniques are related with innovative fertilization, crop residues management, crop rotation and catch crops, organic matter management and soil quality practices in horticulture, and drain water reuse and treatment in soilless cultures.

Most of the innovative techniques are already applied in practice or still under research in Flanders and other regions. The stringent nutrient legislation in Flanders proved to be an important driving force for implementation of innovative techniques, both for open air and greenhouse horticulture.

At the same time, many research projects focus on horticulture and several demonstration projects are running. The results of these collaborative projects by basic and practical research institutes are communicated to all stakeholders involved. The practical research centres have direct and intensive communication lines to the growers through spoken, written and electronic communication. By doing this, fine tuning of techniques can be improved, and may lead to faster implementation by farmers. Fine tuning is an on-going need for practical research related to extension. Techniques should be adapted to specific regional conditions as small changes in climatic conditions between regions can affect the applicability. Some of the future research and extension needs can be organised within European collaboration, as issues are relevant for several of the visited regions.

Most techniques focus on reducing N losses. Much less attention goes to reducing P losses from greenhouse or open air horticulture, and maintaining or increasing organic carbon levels in horticultural soil. However, in the nutrient legislation in Flanders and the Netherlands P application standards are reduced yearly and P is now in many cases the limiting element for organic fertilizer application. We should take care that the reduction of P application standards do not negatively affect the organic carbon levels in arable soils.

The benchmark study allows to define the most important future research needs:

- Research should focus on a combined assessment of crop N demand, based on soil sampling, crop determinations and models. The issue of crop determinations is valuable if these techniques are able to detect N shortages early enough.
- The use of local varieties and/or varieties with a higher nutrient use efficiency is a research need. Rooting depths and nutrient use efficiency should be used as criteria in variety choice.
- For removal of crop residues, being a valuable option for significant reduction of N leaching, a link with the bio-based economy is essential to have a promising application for growers: collected residues should be reused as bio-resource. However, more research is needed as also negative effects of crop residue removal on soil structure or applicability under bad weather conditions are to be evaluated. There is a need for developing special harvest equipment as well.
- Optimal use of catch crops, soil improvers and organic fertilizers, manure and compost for combining a reduction of P losses with a sufficiently high organic carbon level in arable soils.
- End of pipe water treatment techniques for processing nutrient rich waste water from soilless crops.

In addition to the conclusions of NEV2013, the main management practices (or combinations of these practices) that can reduce risks of water pollution in horticultural areas are:

- Accurate prediction of fertilizer demand (combining foliar and soil water tests with models);
- Precision techniques, in view of calibrating timing and doses of fertilizer applications;
- Crop residues management (removal from the field or other variants);
- Optimization of crop rotations (deep/shallow roots) and use of local varieties and/or varieties with a higher nutrient use efficiency;
- Use of catch crops in certain situations; and
- Closing the water cycle by combining drain water reuse with water treatment techniques.

The next step is an action plan for horticulture in Flanders related to the application of innovative cultivation and fertilization techniques for vegetable and ornamental plant production, including a list of research and extension needs and planning, and policy recommendations on nutrient legislation to protect natural resources (in particular improving the water quality) from horticulture.

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(35) Benchmark study on nutrient legislation for horticultural crops in some European countries

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Abstract: *A benchmark study on nutrient legislation for horticultural crops in some European countries has been done by a consortium of Flemish institutes involved in nutrient management of horticultural crops. Therefore, the members of the consortium visited horticultural institutes and contacted persons responsible for nutrient legislation in some EU countries and Switzerland. By filling out a questionnaire and discussions with the responsible researchers and governmental people, the members of the consortium got well documented information of the nutrient legislation in these countries. This paper gives a summary of the different nutrient legislations for horticultural crops in the various countries. It ends up with points of discussion with the aim to clarify some points in the various legislations as well as to come up with ideas about harmonisation where obvious.*

Keywords: *benchmark; horticultural crops; Nitrates Directive; nutrient legislation*

Introduction

On December 12th 1991, the EU issued the Directive "Concerning the protection of waters against pollution caused by nitrates from agricultural sources", the so-called Nitrates Directive 91/676/EEC (Anonymous, 1991). The objectives of this Directive are:

- reducing water pollution caused or induced by nitrates from agricultural sources;
- further preventing such pollution.

The Nitrates Directive sets forward the maximum allowed NO_3^- concentration in ground- and surface water at **50 mg NO_3^-/L**. To obtain this goal, Member States should take several measures like:

- Designation of Nitrate Vulnerable Zones (NVZ): Regions where waters are affected by pollution and waters which could be affected by pollution if no actions are taken, have to be designated by Member States as NVZ. These NVZ can include the total territory or only parts of the country.
- Establishment of action programs: One of the consequences of the appointment of NVZ is the establishment of action programmes. These action programmes comprise:
  - prohibition of application of certain fertilisers during some periods;
  - installation of sufficient storage capacity of livestock manure;
  - limitations concerning the use of fertilizers;
  - control and sanctions on nutrient application;
  - establishment of a Code of Good Agriculture Practices, compulsory for areas with an action programme, otherwise it is on a voluntary basis.
- Establishment of monitoring programs. Member States must implement suitable monitoring programmes to assess their effectiveness. They must monitor the nitrate content of waters (surface waters and groundwater) at selected measuring points. This enables to establish the extent of nitrate pollution in the various waters.

Besides the Nitrates Directive, the EU establishes a framework for Community action in the field of water quality in a much broader context, the so-called Water Framework Directive (WFD) (Anonymous, 2000). The aim of this Directive is to protect surface waters, groundwater, transitional waters and coastal water. The overall goals are:

- the protection and enhancement of the status of aquatic ecosystems;
- the promotion of sustainable water use;
- the enhanced protection and improvement of the aquatic environment through specific measures for progressive reduction of discharges, emissions and losses of priority substances;
- prevention of further pollution of aquatic systems;
- contribution to the mitigation of effects of flooding and drought.

Concerning nutrients besides nitrates, there is more emphasis on the fate of phosphorus.

Monitoring sites show (rather) high concentrations of nutrients (N and P) in surface and ground water in the horticultural regions of Flanders. Therefore, the Flemish government started a project which includes (a) a benchmark study on nutrient legislation for horticultural crops in some European countries, (b) a benchmark study on innovative techniques to minimise nutrient losses to the environment in horticultural cropping and (c) the organisation of a conference where both items can be discussed. Here, we will focus on the nutrient legislation for vegetables and other horticultural crops in various EU countries or regions with an important horticultural industry, and compare the different measures mentioned in the introduction. If special measures are taken for horticultural crops, they will also be discussed. We will focus on those countries which we have visited or gathered information during the benchmark study. These countries are Belgium (Flanders and Wallonia), Denmark, England/United Kingdom, France, Germany, Italy, The Netherlands, Poland, Spain and Switzerland. As the legislation with respect to the Nitrates Directive is in most countries a regional matter, the results are only applicable for the region mentioned.

Designation of Nitrate Vulnerable Zones (NVZ)

As a whole, from the 28 EU countries, 10 countries have designated their total area as NVZ, i.e. Austria, Denmark, Finland, Germany, Ireland, Lithuania, Luxembourg, Malta, Slovenia, the Netherlands. The level of environmental impact does not always explain why a country chooses to designate the whole country as NVZ. Otherwise, The Netherlands would not be in the same group as Finland because there is a great difference in nutrient load between both countries. Some countries tried to avoid discrimination between different groups of farmers, they want e.g. to raise environmental awareness among all farmers and therefore they commit themselves to uniform environmental standards. On the contrary, all the other EU countries have designated only certain areas. However, under pressure of the European Commission, the vulnerable zones were extended the last years in practically all countries. As an example, in Belgium, Flanders is totally vulnerable since 2007 while Wallonia has designated in 2013 about 57% of the total land area as NVZ (Table 1). Overall in the EU, about 45% of the total land area has been designated as vulnerable zone in 2012.

Table 1. Vulnerable zones in the studied countries in 2008 (European Commission, 2010)

Country or region	Total vulnerable (x)	Partly vulnerable (% of agricultural area)
Belgium		67.8
- Flanders	x	
- Wallonia		42
Denmark	x	
France		45.6
- Brittany	x	
United kingdom		38.7
Germany	x	
Italy		12.6
The Netherlands	x	
Poland		1.5
Spain		12.6
- Andalusia		About 10 (in 2013)
- Murcia		About 14.5 (in 2013)
Switzerland		Local, around lakes and drinking water sources

Action programs

In some countries, there are national action programs for the whole country but different regions come up with additional and more restricted measures. In other countries, the national government provides only general guidelines and the different region develop the detailed legislation. The action programs of the different regions within one country can be quite different. Although most countries recognise that high nitrogen losses occur especially in horticulture, only a few countries or regions have taken supplementary measures for the cultivation of horticultural crops until now.

Prohibition periods of nutrient applications

In all EU countries, there is a period where no nutrients may be applied in open air cultures. These periods can differ substantially between countries, depending on climatic conditions and thus on risks of nutrient losses. In some countries, there are specific measures for vegetables (Table 2). From this table, it can be concluded that Flanders, together with the Netherlands have the most severe prohibition period although in Flanders and to a certain extent also in The Netherlands there are particularly exceptions for horticultural crops. In southern countries the risk for leaching is lower and growing season larger, and thus the prohibition period are managed differently. in most countries prohibition periods are shorter when catch or winter crops are sown. The prohibition period is mostly much shorter for solid manures and they vary between grassland and other crops. In some countries, there are adapted prohibition periods for horticultural crops which grow during winter.

Table 2. Prohibition periods of nutrient applications for agricultural crops and specific measures (exceptions) for horticultural crops

Country or region	General prohibition period	Adapted prohibition periods for horticultural crops - adapted application rates
Belgium - Flanders	1 Sept. - 15 Feb. On heavy clay soils 15 Oct. - 15 Feb. Champost and FYM[1] 15 Nov. - 15 Jan.	For fruit trees and late vegetables: 15 Nov. - 15 Feb. (max 40 kg N for fruit trees and max 100 kg N for vegetables between 1 Sept. and 15 Nov.) For early vegetables 1 Sept. -15 Jan. (max 50 kg N between 15 Jan.-15 Feb.)
- Wallonia	Mineral N Grassland: 15 Sept. - 31 Jan. Other crops: 15 Oct. - 15 Feb. Organic N Grassland: 15 Sept. - 31 Jan Other crops: 1 July - 15 Feb. Exception: Catch crop or winter crop (limited till 80 kg N/ha): 15 Sept. – 15 Feb.	No (limited area of horticultural crops)
Denmark	Mineral N No restrictions Liquid manures Grassland and oil seed rape 1 Oct. - 1 Feb. Other crops 1 June - 1 Feb. Solid manure No restrictions except on bare soil from 1 June to 1 Nov.	No (limited area of horticultural crops)

Table 2. Prohibition periods of nutrient applications for agricultural crops and specific measures (exceptions) for horticultural crops (continuation)

Country or region	General prohibition period	Adapted prohibition periods for horticultural crops - adapted application rates
France - Brittany	Mineral fertilizers: Grassland 1 Oct. - 31 Jan. Crops sown in autumn or at the end of the summer: 1 Sept. - 31 Jan. Crops sown in spring: 1 July - 15 Feb. Liquid manure, poultry manure: Grassland: 15 Nov. - 15 Jan. Crops sown in autumn or at the end of the summer: 1 Oct. - 31 Jan. Crops sown in spring: 1 July - 31 Jan. Crops sown in spring, preceded by green manure: from 1 July until 15 days before sowing green manure, and from 20 days before destruction or harvest of green manure until 31 Jan. Solid manure: Grassland: 15 Dec. - 15 Jan. Crops sown in autumn or at the end of the summer: 15 Nov. - 15 Jan. Crops sown in spring: 1 July - 31 Aug. and 15 Nov. - 15 Jan. Crops sown in spring, preceded by green manure: from 20 days before destruction or harvest of green manure until 15 Jan.	No
England	Mineral fertilisers Grassland: 15 Sept. - 15 Jan. Other crops: 1 Sept. - 15 Jan. Liquid manure Grassland: 1 Sept. - 31 Dec. on shallow or sandy soils, 15 Oct. - 31 Jan. on other soils Other crops: 1 Aug. - 31 Dec. on shallow or sandy soils, 1 Oct. - 28 Feb. on other soils Solid manure No prohibition period	For some crops grown in winter like a number of horticultural crops, 40-100 kg N/ha (depending on the crop) may be applied during the prohibition period
Germany	Grassland: 15 Nov. - 31 Jan. Other crops: 1 Nov. - 31 Jan. After harvest of the main crop, no N fertilisation except when there is a catch crop or a winter crop or straw will be incorporated (maximum 80 kg total N/ha or 40 kg NH_4^+ N/ha) FYM all year round	Mineral fertilizers for crops which take up N during winter Solid manure the whole year for start of trees

Table 2. Prohibition periods of nutrient applications for agricultural crops and specific measures (exceptions) for horticultural crops (continuation)

Country or region	General prohibition period	Adapted prohibition periods for horticultural crops - adapted application rates
Italy		
- Piemonte	<u>Mineral fertilizers</u> 15 Nov. - 15 Feb. <u>Liquid manure</u> Grassland + winter crops: 15 Nov - 15 Feb. Other crops: 1 Nov. - 28 Feb. <u>Solid manure</u> Grassland: 15 Dec. - 15 Jan. Other crops: 15 Nov. - 15 Feb.	
The Netherlands	<u>Mineral fertilizers</u> 16 Sept. – 31 Jan. <u>Liquid manure</u> 1 Sept. - 15 Feb. <u>Solid manure</u> 1 Sept. - 31 Jan. Arable land on clay and peat: no restrictions	Ground-covered horticultural crops. For hyacinth and tulips exception during the period 16/01 to 31/01
Poland	<u>Mineral N fertilizers</u> Grassland: 15 Aug. - 1 March Arable land: 15 Nov. – 1 March <u>Liquid manure and urea</u> Grassland: 15 Nov. – 1 March Arable land: 15 Nov. – 1 March <u>Solid manure</u> Grassland: 30 Nov. – 1 March Arable land: 15 Nov. – 1 March	
Spain		
- Andalusia	Not in fallow period unless cover crop is present. Not before 15 days before planting or sowing.	No
- Murcia	Perennial crops: from 1 Nov. - 29 Feb.	Vegetables: at least during 3 months of the year, between the crops. In case of 3 crops, 1 month between each crop.
Switzerland	In one region, between 15 Dec. and 15 Feb.	No

[1] Champost= composted substrate from mushroom production; FYM= farm yard manure

<u>Compulsory storage capacity of livestock manure</u>

The storage capacity of animal manures should go hand in hand with the prohibition period for applying fertilisers. But, this is not relevant for horticulturalists.

<u>Limitations on nutrient applications</u>

In Nitrate Vulnerable Zones, the maximum amount of N applied by animal manure is restricted to 170 kg N/ha·y, except if there is a derogation. There are no derogations for horticultural crops in any country. This maximum amount is a severe restriction in countries with a high animal density. The consequence is that large amounts of animal manure can’t be applied on arable land which is a kind of recycling and thus by far the most economic way. The surplus of animal manures has to be transported to other farms, treated or processed which implies supplementary costs to the farmers. The maximum allowed N and P_2O_5 applications per ha for the visited countries or regions are given in Table 3a, b and Table 4, respectively. The list is limited to the most important horticultural crops cultivated in Flanders. For nitrogen, these maximum allowed application rates can be expressed in efficient N or in total N. For Flanders, both approaches are allowed. The used working coefficients for the most important fertilizers are given in Table 5 for some countries.

In Denmark, each year a spreadsheet is produced containing maximum allowed N rates and advised doses for P and K for all crops. The maximum allowed N rates are differentiated based on crops and crop systems (open field and greenhouse), soil type, previous crop, use of irrigation, yield (for vegetables only applied for carrots), crop duration and year. The maximum allowed N rate is thus calculated as the N norm minus the pre-crop effect plus the year-to-year change due to the weather conditions. The year-to-year change depends on the residual mineral N in autumn (based on a monitoring network) and the weather circumstances in the preceding winter, but usually the year-to-year change is zero. In Table 3a, the data for 2013 are given but the changes between the years are small. Maximum allowed N rates can also be changed on demand of the growers' organisation after scientific evaluation. All fertilisation in Denmark is reduced by 10-15% compared to the economic optimum.

In Germany there are no maximum norms for N and P. The allowed fertilisation is based on a simple input output balance where the input is solely the N and P_2O_5 fertilisation and N gathered by legumes. The output is the N removed from the field by harvested products. There is a N surplus foreseen for vegetables which vary between 50 and 160 kg N/ha above the general allowed N surplus for arable crops of 60 kg N/ha (Bundesministerium der Justiz, 2006).

In Brittany, France, efficient N application rates are calculated by an established N balance forecast model which takes into account planting time, crop N requirement, N supply from soil organic matter and from previous crop. This calculation is valid for most crops, only for crops for which an operational version of the N balance method is not available, maximum efficient N rates are defined.

In Andalusia, the application standards are expressed as kg N/ton expected marketable yield. The maximum allowed N application rates is the expected marketable product multiplied by this application standard.

The maximum allowed N rates for horticultural crops can vary substantially between countries. In Flanders, the horticultural crops are divided in 3 groups and each group has a common maximum allowed N fertilisation rate. In other countries there is a N rate per crop. The highest maximum allowed N rates are in England and Murcia which is rather strange because of the different climatic conditions. For leguminous crops like peas and beans, Flanders allows higher N rates than most of the other countries which allow no or a very restricted N fertilisation. Also the maximum N rates for strawberries are high in Flanders. In Murcia, the N rates for cabbages and cauliflowers are high.

In several countries there are no restrictions on P_2O_5 apllication rates (table 4). Most severe restrictions are in Fladners and the Netherlands, based on crop type and soil P status (especially in the Netherlands).

If there is more than one vegetable crop per year, the question arises if the maximum allowed N and P_2O_5 fertilisation rate per crop given in Table 3 can be added. For N, in some countries the total addition for two or more crops per year is allowed (e.g. Spain), in other countries (e.g. Flanders) there is a reduction. For regions or countries with maximum P_2O_5 fertilisation rates per ha and year there is no supplementary P fertilisation allowed.

Table 3a. Maximum allowed N rates (kg/ha) as efficient N for some horticultural crops in the studied countries

Crops	Belgium Flanders[1]	Denmark[2, 3]	France[4] Brittany	England	Italy Piemonte	Italy Marche	The Netherlands[5]	Spain Murcia[6]	Switzerland
Vegetables open air									
Asparagus	125	150		180	210	180	75-85		
Beans	125			280	50-70		50	40-80	0 (30)
Broccoli	250	190-215			180	150	235-270	225-300	220
Brussels sprouts	250	215-240		370			265-290		260
Cabbages	250	160-285		370	250		260-320	320-400	160-260
Carrots	125	100-125[7]		180	195	150	110		110-130
Cauliflower	250	230-255		370	225	200	210-230	300-390	260
Celeriac	180	190-235			200	200	185-200		180
Cucumber	180				225	150	175-190		140
Endive	180						170-180		
Leaf parsley	180	180-205							
Green celery	250		300	280	250	200	185-200	280-340	190
Head lettuce	180	140-165		280	130	120	105-180	120-180	90-110
Leaf parsley	180	180-205							
Leek	250	200-225		370	126		225-245		200
Onions	125	140-165		280	160	120	120	150-200	130
Peas	125	0	50				30		0 (30)
Pumpkin	180	110-135					175-190		
Radish	125			180			80		110
Salsify	125						170		120
Spinach	180	95-120			125	120	145-260	150-200	130-180
Strawberries	250	80	80		160	150	155-170		
Red beet	125	155-180			190	130			
Root parsley	180	140-165							
Zucchini	180	125-150		280	190	200	175-190	100-140	130
Other crops	180	240-265							

Table 3a. Maximum allowed N rates (kg/ha) as efficient N for some horticultural crops in the studied countries (continuation)

Crops	Belgium	Denmark[2, 3]	France[4] Brittany	England	Italy		The Netherlands[5]	Spain	Switzerland
	Flanders[1]				Piemonte	Marche		Murcia[6]	
Ornamentals open air									
Azalea	180								
Begonia	180						145-150		
Chrysanthemum	180								
Rose tree	180								
Fruits in general						130			
Apples and pears	180	140					165-175	120-200	
Ornamental trees	180	0-110							
Greenhouse horticulture[8]	No limits						No limits		
Cut flowers		1100							
Lettuce		900							
Sweet pepper								285-390	
Tomatoes		2350						450-480	
Other vegetable crops		800							
Pot plants		950							
Container plants		550							

[1] Figures for Flanders on sandy soils are 10% lower than those given in Table 3a
[2] Range of values depending on soil texture and use of irrigation
[3] For each crop, it is specified whether the N released by the previous crop has to be taken into account. The amount of N released is a crop-specific value.
[4] Figures for Brittany; maximum efficient N rates for crops for which an operational version of the N balance method is not available. For all other crops, efficient N application rates are calculated by an established N balance forecast model which takes into account planting time, crop N requirement, N supply from soil organic matter and from previous crop.
[5] Two values: depending on soil texture and time of vegetation period
[6] The grower has to estimate the expected yield within the range mentioned in the legislation and define the expected N need within the range. When for celery, broccoli, cauliflower, baby lettuce, other lettuce, melon and watermelon the production cycle is expected to be relatively long, the N application may be increased by 15%.
[7] N rate is for a yield of 40 Mg/ha, can be increased by 0.1 kg N per 100 kg/ha extra yield
[8] N amounts on a yearly basis

Table 3b. Maximum allowed N rates (kg/ha) as total N for some horticultural crops in the studied countries

Crops	Belgium		Spain	Poland[3]
	Flanders[1]	Wallonia	Andalusia[2]	
Vegetables open air				
Beans	195	250		30
Broccoli	320	250		250
Brussels sprouts	320	250		250
Cabbages	320	250		300
Carrots	195	250	5 kg N/t	150
Cauliflower	320	250	5 kg N/t	350
Celeriac	250	250		
Cucumber	250	250		200
Green celery	320	250		250
Head lettuce	250	250	5 kg N/t	150
Leek	320	250		250
Onions	175	250	4 kg N/t	200
Peas	195	250		30
Radish	195	250		140
Salsify	195	250		120-180
Spinach	250	250		150
Strawberries	320	250	5kg N/t	50
Zucchini	250	250		
Ornamentals open air				80-250
Azalea	250	250		
Begonia	250	250		
Chrysanthemum	250	250		
Rose tree	250	250		150
Fruits in general	250	250	7 kg/t	60-80
Apples and pears	250	250	7 kg/t	60
Ornamental trees	250			80-150
Greenhouse crops	No limits	250		
Cut flowers		250	1000 kg/ha (carnation)	
Cucumber			4 kg N/t	
Eggplant			7 kg N/t	
(Sweet) pepper			5 kg N/t	
Tomato			6-12 kg N/t short/long	
Zucchini			7 kg N/t	

[1] Figures for Flanders on sandy soils are 5-8% lower than those given.
[2] Expressed in kg total N/ton expected marketable fresh production
[3] Maximum allowed N rates (kg /ha) as total N for Nitrate vulnerable zones in Poland. Except for the EU regulation (maximum dose of 170 kg N/ha of animal manure) there are no maximum N doses outside the nitrate vulnerable zones. Farmers can voluntarily choose for a 'sustainable farming package' in which they obtain some extra subsidies in exchange for a more sustainable management. In this management, the allowed maximum N rates are 10 to 50% lower than in the nitrate vulnerable zones, depending on the crop.

There are several countries with no restrictions on P_2O_5 fertilisation. The best option seems to be a P fertilisation based on crop type and soil P content like in the Netherlands.

Table 4. Maximum allowed P_2O_5 rates (kg/ha) for some horticultural crops in the studied countries

Country or region	Maximum allowed rates in kg P_2O_5/ha·y	
Belgium		
- Flanders	Based on kind of crops: 65-95 kg P_2O_5/ha·y Horticultural crops: 65 kg P_2O_5/ha·y – A further reduction to 55 kg P_2O_5/ha·y is planned from 2015 on Soils with P-saturation degree >35%: 40 kg P_2O_5/ha·y	
- Wallonia	No restrictions	
Denmark	No restrictions, crop and soil specific recommendation for P and K	
France	No general restrictions	
- Brittany	80-95 kg P/ha·y	
England	No restrictions	
Germany	A maximum P_2O_5 surplus of 20 kg/ha·y on the input-output balance	
Italy	No restrictions	
The Netherlands	Based on crops (grassland or other crops) and soil P content: 55-120 kg P_2O_5/ha·y	
	Pw (mg P_2O_5/100 g)	Max rate for horticultural crops (kg P_2O_5/ha·y)
	<25	120
	25-36	85
	36-55	65
	>55	55
Poland	No restrictions	
Spain		
- Andalusia	No restrictions	
- Murcia	No restrictions	
Switzerland	Only around a few lakes – based on the crop and soil P content On field basis	

The working coefficients for the various organic manures are the highest in Denmark and the lowest in England (Table 5). No official working coefficients were reported for Wallonia, Italy, Poland, Andalusia and Switzerland. A study on variation of manure N efficiency throughout Europe by Webb et al. (2011) reports that a matrix with N efficiencies from organic manure ranging from 24 to 84% depending on animal, soil type and application time is available in Italy. In Poland manure efficiency for slurry and solid manure is 50-60 % and 30, respectively (Webb et al., 2011). It is amazing that so large differences in efficient N can occur.

Table 5. Working coefficients the first year after application for different types of N fertilisers (% of total N)

Kind of N fertiliser	Belgium Flanders	Denmark	France[1] Brittany	England	Germany	The Netherlands	Spain Murcia
Liquid livestock manure	60	70-75	40-70	40 (cattle) 50 (pork) 30 (poultry)	50-60	60-70	75 (pork)
Solid livestock manure	30	65	10-45	10 - 30	25-30	40-55	45-70[3]
Champost	30					25	
Other fertilizers with low mineral N release	30						
N from excretion by grazing	20	70			25	45	
Compost	15	45	5-45[2]			10	18
Other organic fertilizers	60	45				50	
Liquid fraction of separated manure	60	85				80	
Effluent from biological treatment of manure	100						
Mineral fertilizers	100	100	100	100	100	100	100

[1] Figures for Brittany: working coefficients vary according crop type and application period
[2] Values depend on the type of compost
[3] Values are differentiated for solid cow, pork, goat and sheep, and chicken manure. Values are defined for 2 years. Second year: 15 % for liquid livestock manure (pork), 15-30% for solid livestock manure, and 18 % for urban residue compost

Control and sanctions on nutrient applications

The control on nutrient applications is mostly done on paper. However, in some countries or regions, there are supplementary measures like measurements of residual NO_3^- in the soil profile in autumn in Flanders, Wallonia and Baden-Wurtemberg (Germany). Sanctions for applying too much nutrients are diverse (Table 6).

Table 6. Control and sanctions on nutrient applications

Country or region	Control	Sanctions
Belgium		
- Flanders	Control on paper and random control on farm. Control at field level. Maximum residual NO_3-N levels are established depending on crop, soil type, situated in focus zone or not. Random sampling by government (see below)	Administrative fines if more N is applied than the standards (1€/kg·ha exceeded N or P_2O_5) Depending on exceeding of the residue standard, compulsory measures in the following year: take samples for residual N, make fertilization planning, reduction of application standard of 30 or 60%
- Wallonia	Calculation of produced organic N/quantity allowed N on all fields on farm basis Residual NO_3-N analyses in autumn	Administrative fines and direct payment cuts (cross compliance)
Denmark	Control on paper + farm visits	No
France	Growers have to elaborate a provisional fertilization plan and ought to register fertilization practice for each field in a vulnerable zone. Growers with more than 3 ha in a vulnerable zone ought to do a soil analysis of residual mineral N after winter and of soil organic matter or N total in the arable layer, at least for one of the three most important crops in the vulnerable zone. Data of these analyses may be used by G.R.E.N. (Groupe Régional d'Expertise Nitrates) and must be available for inspection bodies.	Direct payments cuts if administrative data are not available or incorrect; direct payment and juridical fines if standards are exceeded.
England	Control on paper	Direct payments are cut (cross compliance)
Germany	A nutrient balance is made up on farm level. All nutrient inputs and outputs on farm level are recorded. On field level, the nitrogen balance is calculated on typical uptake figures. On average over all fields of the farm, the nitrogen balance should be lower than -60kg N/ha for arable crops, vegetables above this 60 kg N/ha a further surplus is allowed between 50 and 160 kg N/ha. (DuV §6. (2.1)) In the case of phosphate, the same calculation is made (on farm level). On average over all fields of the farm the phosphate balance may not be lower than -20 kg P2O5/ha. (DuV §6. (2.2)) Balances must be calculated before March 31 of the following year. In case of nitrogen, the average of the last three years (actual year plus the last two) is significant, for P the average of the last five years is significant (actual year plus last five).	Misdemeanor for willful or negligent act (fine possible)
Italy		
The Netherlands	N and P balances on paper Soil analyses for P	Administrative fines

Table 6. Control and sanctions on nutrient applications (continuation)

Country or region	Control	Sanctions
Poland	No	No
Spain		
- Andalusia	Control on paper (very few)	None in practice Possible reduction or exclusion within CAP
- Murcia	Control on paper	Possible reduction or exclusion within CAP
Switzerland	Use of equilibrated fertilisation based on own declaration on farm level	Reduction of direct payment to the farmer

<u>Code of good agricultural practice</u>

This code includes the measures mentioned before and some supplementary measures. The code is compulsory for these areas where an action plan is established, otherwise it is on a voluntary basis in all countries.

Establishment of monitoring programs

Each EU country must monitor the nitrate concentrations in surface and ground water. The sampling density is quite different between countries and/or regions (Table 7). By far the largest density for surface and ground water monitoring is in Flanders. The density in Flanders is about 150 and 60 times higher compared to the density in Germany, for surface and groundwater respectively.

Table 7. Sampling density (for whole land surface) for surface and ground water in the studied countries in 2008 (European Commission, 2010)

Country or region	Surface water (points/1000 km^2)	Groundwater (points/1000 km^2)
Belgium	37.8	98.9
- Flanders	75.5	158
- Wallonia		52
Denmark	5.1	34.3
France	3.2	4.9
United Kingdom	32.6	12.5
Germany	0.5	2.5
Italy	7.0	18.2
The Netherlands	13.4	33.3
Poland	10.9	4.0
Spain	5.0	8.1
Switzerland		

Besides the density of measuring points, there are also large differences in monitoring frequency, differences in locations (large catchments, small catchments or ditches and trenches) where surface water sampling points are located, differences in depth of groundwater sampling etc. All these makes it difficult to evaluate and compare the water quality concerning NO_3^- contents between the different countries.

The location of sampling points for surface water can have a large influence on the NO_3^- concentrations. Small ditches in intensive agricultural areas have higher NO_3^- concentrations than rivers in large catchments. This is illustrated by results obtained in Flanders where besides 800 sampling points in small ditches (MAP monitoring network), there are also 200 sampling points in large water bodies (for monitoring related to WFD). For winter year 2011-2012 (July-June), the average NO_3^- concentration in large water bodies is about 75% of the average in small ditches (MAP measuring points) and as a consequence there are only 6% of the sampling points which exceed 50 mg NO_3^-/l at least once a year in the large water bodies compared to 28% in the MAP monitoring points (Table 8). This implies that countries with especially sampling points in large rivers can come up with much better results than Flanders although the real situation is possibly the same or even worse. To compare different countries, it is necessary to make a distinction between the results in small ditches in the agricultural area and those in large catchments.

Table 8. Average NO_3^- concentrations and percentage of samples of the operational monitoring network in Flemish water bodies and the MAP monitoring network in surface water with at least one exceeding of the 50 mg NO_3^-/l from July 2011 till June 2012 (VLM, 2012).

	Average NO_3^- concentration (mg/l)	% sampling points at least once in a year above 50 mg NO_3^-/l
Large water bodies	14	6
MAP points	19	28

The same holds for the ortho-P concentrations in surface waters although the differences between small catchments in the agricultural area and large catchments are somewhat smaller in relative terms (Table 9).

Table 9. Average ortho-P concentrations (mg ortho-P/l) in large catchments and small ditches in Flanders (winter year July 2011 - June 2012)

Large Catchments	Small ditches
0.38	0.30

Additional measures specific for horticulture

<u>Regulations about discharge water of soilless culture</u>

One of the problems in soilless culture is how to solve the problem of drainage water which may contain large amounts of nutrients. Details are given in Table 10.

Table 10. Regulations for discharge water of soilless cultures in greenhouses

Country or region	Compulsary collection	Compulsory storage capacity	Disposal in open water allowed	Application on agricultural fields allowed
Belgium				
- Flanders	Yes	Yes	No	Yes
- Wallonia	No	No	Yes	Yes
Denmark				
France				
- Brittany[1]	No	No	No	No
England	No	No	No	No
Germany	No	No	No	Yes
Italy				
The Netherlands	Yes	No	Yes	Yes
Poland	No	No	Yes, when < 50 mg NO_3/l	Yes
Spain				
- Andalusia	No	No	Yes	Yes
- Murcia	No	No	Yes	Yes
Switzerland	Yes	No	No	Yes

[1]for Brittany, no additional measures in the Nitrates Directive related legislation, however, maximum nutrient levels for disposal in open water exist.

Other specific measures

NO_3 N residues in the soil profile in autumn

In Belgium, the residual NO_3-N in the soil profile (0-90 cm depth) at the end of the growing season is regulated. In Flanders, the NO_3-N residues are measured on behalf of the government on random samples of about 17.000 fields between 1 Oct and 15 Nov. Depending on soil type, crop and if the field is situated in focus zone or not, the accepted threshold values vary. For vegetables and ornamental crops in non-focus zone, is it 90 kg N ha^{-1} and in focus zone it is 85 kg N ha^{-1}. Focus areas are defined around measuring points of the monitoring network where the soil or surface water NO_3^--content do not meet the standard (at least one exceeding of 50 mg NO_3/l·y). If residue threshold values are exceeded the farmer has to fulfil accompanying, compulsory measures in the next year.

These measures are: analyses of N_{min} in spring and autumn, take advice on fertilisation, make a fertilisation plan and register, sow catch crops, reduction of N fertilisation standards with 30 % or 60%. Depending on the level of the exceeding of the residue standard the farmer has to fulfil from only the first to all the measures. In Wallonia, the NO_3-N residues are measured on pilot farms between 15 Oct and 30 Nov. Threshold values per year are based on group of crop (8 categories) and sampling day. If threshold values on two of the three sampled fields of a farmer is exceeded, the farmer will be monitored for at least two years. Three new fields are measured and assessed in each year. A positive assessment must be obtained in two consecutive years in order to stop taking part in the observation programme. If, on the other hand, a farmer has three negative assessments (consecutive or not) he must pay a fine. The threshold values change from year to year depending on the residual mineral N on reference parcels. These reference parcels were also introduced last year in Flanders with the same aim (but threshold values changing between year were not yet introduced).

N fertilisation advices

From 2013 on, each horticultural farmer in Flanders must have at least per year and per field or per ha, a fertilisation advice based on a soil sample, delivered by an official recognised institute. The advice must include all sources of N that become available to the plant during the crop such as N_{min} of the soil, precipitation, mineralisation from soil organic matter, mineralisation from crop residue from the previous crop, mineralisation from organic manure application, etc.

N surpluses

In Germany, a general N surplus of the input output balance is 60 kg N/ha·y and 20 kg P_2O_5/ha·y for arable crops. For vegetables, the values for nitrogen surpluses depend on the kind of the crop and are between 50 and 160 kg N/ha·y above the general allowed surplus for arable crops of 60 kg N/ha.y.

Points for discussion during the workshop at NUTRIHORT

- Nitrate Vulnerable zones
    - To what degree are horticultural areas included in NVZ in the different countries?
    - Should not all countries be recommended to become NVZ?
- Prohibition period of nutrient applications
    - Are there exceptions of the general prohibition period for late autumn, winter and early spring horticultural crops?
    - Do you think this is needed?
    - What is an adequate prohibition period?
- Limitations on nutrient applications
    - Are the maximum allowed N rates best expressed in total N or in efficient N?
    - Is it valuable to know the average N and P_2O_5 concentrations of the harvested products as well as of the crop residues?
    - Should we come up with a general table for these concentrations for the most important horticultural crops?
    - Is it worth to come up with average or at least ranges of yields for vegetables per country?
    - What is the best method, either a maximum nutrient rate or a calculation based on nutrient concentrations and yields?
    - Which figures of table 3a and b are strange?
    - How do we solve the problem of two or more crops per year concerning the use of nutrients?
    - What arguments have the countries which don't have maximum allowed application rates for P_2O_5?

  - Should we try to harmonise to a certain extent the working coefficients of the various organic fertilizers? Is this valuable?
- Control and monitoring
  - How severe is the control in the different countries? Can it be better?
  - Have some farmers already paid important fees?
  - Can we ask the EU to have comparable samplings for ground and surface water?
  - Can we ask the EU for a thorough scientific study of the monitoring networks? Networks should be comparable as to assure that the corresponding legal pressure on the farmers, based on the results of those networks, is equitable?
  - How will we solve the problem of sampling points in large catchments versus small catchments? Is there an agreement of sampling depth for groundwater? Can we ask for common criteria for sampling points and sampling frequencies?
  - What kind of supplementary measures may be emphasized for horticultural crops?
  - Etc.

Conclusions

This is an attempt to compare the nutrient legislation in a selection of European countries, especially focused on horticultural crops. It was a difficult task because the legislations are rather complicated. Besides a lot of exceptions are included in most of the legislations. Therefore, it is not excluded that some of the data in the various tables are not totally correct and have to be adapted. Nevertheless, some general conclusions can be drawn:

- The area of Nitrate Vulnerable zones are quite different between countries. The question is if all areas with problems concerning water quality are already included in the vulnerable zones in the different countries. One can ask themselves if a general Code of Good Agricultural Practices, with a minimum set of measures, should not be compulsory in all EU countries. In this way, potential discrimination between farmers should be at least partly avoided.

- Prohibition periods of nutrient applications are quite different between countries, depending of the pressure on the environment and climatic conditions. The prohibition periods are the longest in Flanders and the Netherlands, countries or regions with the highest environmental pressure.

- Maximum allowed N application rates are expressed as efficient N in some countries and in others as total N. In Andalusia, Spain, the fertilisation standards are set in kg N/ton produced fresh, marketable yield. Constructing tables per country or region with mean N concentrations and mean yields or ranges of yield per crop should clarify differences in maximum allowed N fertilisation rates.

- Some harmonisation of N working coefficients of various organic fertilisers may be suggested.

- P fertilisation limits are only introduced in a limited number of countries although the P concentration in surface waters in a lot of regions is too high to prevent eutrophication. Maximum P rates should be based on the P content of the soil and the sensitivity of the different crops for P.

- Monitoring programs between countries show large differences in sampling density, monitoring frequency, sampling locations (small ditches versus large catchments), depth of groundwater sampling, etc. Evaluation and comparison of the water quality in the different countries is therefore very difficult. The EU should harmonise this on a scientific basis.

- Although in all countries or regions horticultural crops are responsible for possible high N losses by leaching, only a few countries or regions take specific actions for these crops. Flanders is by far the region with the most developed legislation on this with measures at farm and field level. Additionally, control and sanction policy is very well developed and proofed to be effective in the field.

- One of the outcomes of the conference should be to propose common actions to reduce the N losses in an equitable way and reduce the often large differences between legislation and its implementation in practice throughout Europe.

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(37) Nitrates Directive in Flanders' horticulture: towards nutrient management through participation

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Abstract: *In the first decade, measures taken to implement the Nitrates Directive in Flanders were mainly focused on livestock breeding. Impact on horticulture in this stage was very limited. With the introduction of the nitrate residue instrument (NO_3-N measurement in autumn in the soil up to 90 cm depth), however, horticulture was pushed to implement environmental aspects in their nutrient management. Since water quality remained insufficient, the focus of the action programs shifted towards measures targeting more directly on improving water quality. From this moment on also greenhouse horticulture has taken up responsibility in close cooperation with the government. This collaboration was the basis for further alliance in preparation of the current action program. The participatory approach has initiated research initiatives on different aspects of horticulture and several demonstration activities. Participation of the stakeholders has introduced also changes in legislation. Specific fertilization standards where defined for vegetables according to their nitrogen uptake capacity, replacing general values. Furthermore, since 2013 fertilization on vegetable crops is only allowed when based upon fertilization advices. Changes in nitrate management policy have had their effects. The mean nitrate residue on vegetable crops has dropped 36% since 2007. Nevertheless it's too early to draw conclusions on the enhanced participatory approach in the current action program. However, it's already clear that this strategy creates a higher level of awareness among horticulturists regarding the effect of nutrient management on water quality, and facilitates acceptance of stricter regulation in order to meet the objectives set in the Nitrates Directive.*

Keywords: *legislation; evolution; water quality; nitrate residue; cooperation*

Introduction

During the 1980's the need arose to develop a policy to mitigate nitrate losses from agriculture to the environment, both in Europe as in Flanders, due to intensification of livestock production. This concern initiated legislative action with the creation of directive 91/676/EEc concerning the protection of waters against pollution caused by nitrate from agricultural sources (i.e. the Nitrates Directive) on European level and the decree of January 23rd, 1991 concerning the protection of the environment against pollution caused by the production and the use of fertilizers on the Flemish level (De Clercq et al., 2001; Dejongh & Van Windekens, 2002).

The first years of manure policy in Flanders focused mainly on the redistribution of livestock manure from areas with a production surplus to areas with a deficit of livestock manure, based on farm balances. Fertilization standards were very general and set on a relative high level when compared with today's standards (VLM, 2002).

Table 8 Overview of fertilization standards in 1991 (VLM, 2002)

Crop	Nitrogen from animal manure fertilization standard (kg N/ha)	Phosphorous fertilization standard (kg P_2O_5/ha)
Grass	400	200
Maize	400	200
Other crops	400	150

A first review of the legislation, called 'Mestactieplan I' (MAP I, Manure Action Programme), was adopted in 1995. The main objective of the changes was to gradually lower maximum fertilization standards to reach an environmental sound level by 2002. To realise this, a standstill in manure production was introduced: it could not raise above the production levels of 1992. Therefore no new environmental permits were delivered and farms situated in regions with a production surplus could not grow. Furthermore a first designation of nitrate vulnerable zones was carried out, limiting the fertilization standard for livestock manure to 170 kg N/ ha according to the Nitrates Directive, except for grassland (i.e. 200 kg N/ha). Fertilization standards were differentiated and gradually lowered to attain environmental justifiable fertilization levels by 2002. (Vlaamse Raad, 1995; Dejongh & Van Windekens, 2002; VLM, 2002)

Since the improvement in water quality was insufficient and the number of livestock was still growing, a new round of adaptations to the manure legislation was carried out in 1999 – 2000. With this set of changes a clear shift was made from a manure redistribution policy to a manure policy which was based on a three-pronged approach. The first level was a source-oriented approach whereby the limitation of animal production and the usage of low-nutrient feeds. A second aspect was rational fertilization which was based on more restrictive fertilization standards and the instrument of nitrate residue (NO_3—N measurement in autumn in the soil up to 90 cm depth). The third aspect was the more prominent role given to manure processing (VLM, 2000; VLM, 2002)

Although the three-pronged approach succeeded in balancing both the nitrogen and phosphorus surplus from livestock production on a Flemish level, water quality remained unsatisfactory. Additionally, the region of Flanders was convicted of an insufficient implementation of the Nitrates Directive by the European Court in 2005. These elements lead to the conception of a new action program in which the whole of Flanders was designated as a nitrates vulnerable zone and the focus shifted from a manure policy to a policy aiming at the improvement of the water quality. This changes affected legislation in a way that the Decree of 1991 was replaced by the Decree of December 22nd, 2006 concerning the protection of waters against the pollution caused by nitrate from agricultural sources (VLM, 2006)

During this third action program water quality improved too slow so further measures were taken in the fourth action program (2011-2014). As a result legislation evolved to a nutrient management policy by emphasizing the concepts of balanced fertilization.

Nutrient legislation and policy in Flanders clearly developed from a manure redistribution policy over a manure policy towards a nutrient management policy. This evolution is also reflected in the subgroups of farmers targeted by nutrient policy. In the first decade focus was directed towards livestock production whereas at the start of the new millennium also the end-users of nutrients gradually became more involved. The concepts of rational and balanced fertilization and the introduction of the nitrate residue instrument obliged arable farmers and horticulturists to become more aware of the fertilization of their crops.

Until 2006, both soil-bound horticulture and greenhouse horticulture were not strongly affected by nutrient legislation. However water quality in specific horticultural areas clearly demonstrated the need for reinforced measures to be taken up by horticulture as is shown in Figure 1.

Materials and Methods

Participation in greenhouse horticulture

As it was clear that the use of fertilizers in horticulture lead to an exceeding of the water quality standard of 50 mg nitrate per litre in several monitoring sites, government and sectorial organisations agreed to take action. At first instance, greenhouse horticulture has taken up responsibility in close collaboration with the government in 2006 in preparation of the third action program.

This process of participation started with the establishment of a Task Force Horticulture by the former Flemish minister of environment Kris Peeters and his colleague of agriculture Yves Leterme. The purpose of this Task Force Horticulture was to look for ways in which horticulturists could contribute to a better quality of the water.

The Task Force Horticulture consisted of a wide range of organizations: farmers' organizations, biological farming organizations, private advisors on fertilization, distribution centers of vegetables, universities and practical research centres in horticulture. Also representation of several divisions of the Flemish government: the Flemish Land Agency, the Flemish Environment Agency, the Department and Agency of Agriculture and Fisheries, the Environmental Inspection, the Public Waste Agency of Flanders.

In the period 2006-2008, the Task Force Horticulture met 5 times. Two meetings in 2006 resulted in a contribution to the third action program of Flanders (2007-2010). Concrete measures resulting from this participatory process were requirements concerning the yearly declaration of fertilizer use by greenhouse horticulturalists and an obligation to have storage capacity for six months' for drainage water. The further elaborations of these measures into Flemish legislation were the subject of the next 3 meetings. From this moment the Flemish Land Agency took action to bring the legislation to the horticulturist (Cochez & Jacobs, 2013).

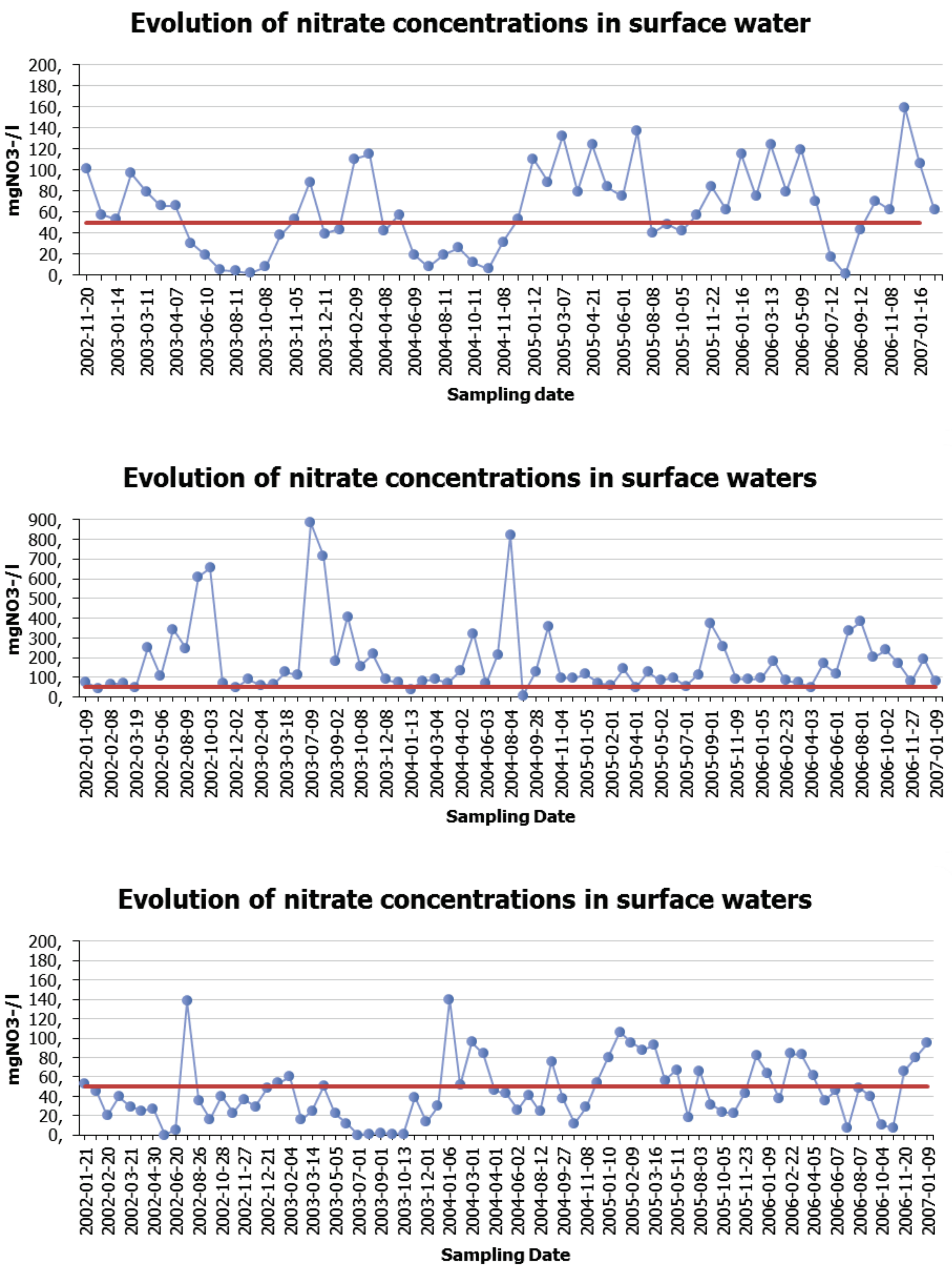

Figure 1 Evolution of nitrate concentration 2002 - 2006 of MAP-monitoring points in three horticultural areas. Point ID 964050 in Staden, point ID 263100 in Sint-Katelijne-Waver and point ID 79150 Hoogstraten (VMM, 2013)

Participation in soil-bound horticulture

As already stated, the first confrontation of horticulture with manure legislation was the introduction of the nitrate residue measurements. The nitrate residue measurements are measurements of the nitrate concentration in the soil to a depth of 90 cm taken in autumn. This gives an indication of the possible leaching of nitrate to ground and surface water during winter. This instrument is a keystone in the Flemish nutrient policy.

Despite the fact that nitrate levels in horticulture are high (Bries & al., 2008), it is found that they create a high level of responsibility and raise awareness among growers concerning the nutrient management on the farms. Although legal nitrate residue threshold values in the soil during autumn are considered very strict, these were derived in close collaboration with farmers' representatives, universities and practical research centers.

In preparation of the fourth action program the need arose to further differentiate maximum fertilization standards based on the concepts of balanced fertilization. Since vegetable crops were still considered other crops in terms of maximum fertilization standards, differentiation took mainly place with respect to horticulture.

As the framework for participation in horticulture was laid out during the previous action program, this collaboration between stakeholders, research and government was taken up in a slightly different form, since the focus was on soil-bound horticulture this time. This process resulted in the creation of three groups of vegetable crops in function of their nitrogen uptake with corresponding fertilization levels.

In addition nitrogen fertilization on most vegetables is forbidden since January 1st, 2013, unless it is based upon a fertilization advice. The legislation on this aspect, was made up in close collaboration between government and the stakeholders, so it's a balanced agreement which gives a clear and minimal legal framework that leaves room for advisory services to identify additional needs for fertilization advice in cooperation with the farmers.

Results and Discussion

Figure 2 gives an overview of the evolution of the mean nitrate residue levels in leek, cauliflower and Brussels sprouts. The first conclusion that can be drawn is a huge difference in nitrate residue levels between different years. The weather conditions during growth have an important role in this variability.

Secondly a clear difference between crops can be derived: whereas Brussels sprouts generally have low mean nitrate residue levels in autumn, it is more difficult to obtain the threshold value in leek and cauliflower. Moreover for this two crops 2012 is the first year, the mean nitrate residue level is below 90 kg NO_3^--N/ha.

Despite the variability between different years a downward trend can be seen in mean nitrate residue levels. This indicates an improvement in nutrient management and fertilization techniques have taken place due to implementation of the nitrate residue instrument in Flemish legislation. Since the nitrate residue is a criterion for the amount of nitrate leaching to the ground and surface water these trends must trigger an improvement in water quality.

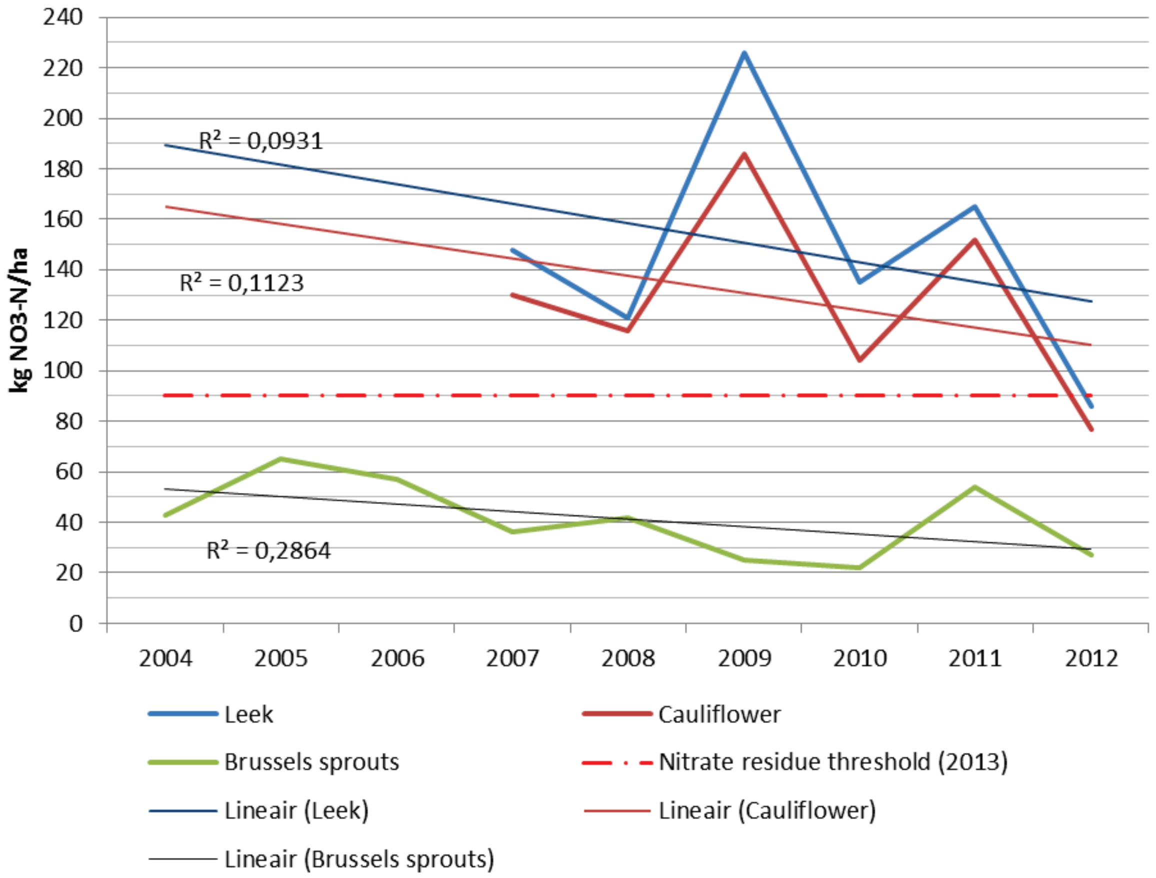

Figure 2 Evolution of the mean nitrate residue levels in leek, cauliflower and Brussels sprouts (VLM, 2013)

In Figures 3, 4 and 5, water quality data from three randomly selected surface water monitoring points in horticultural areas are analyzed for trends before and after the participatory approach was introduced in nutrient legislation. In the selected sampling points in Staden (Figure 3) and Hoogstraten (Figure 5), clearly a trend change has occurred: whereas before 2007 monitoring showed even an increase in nitrate levels of the surface water, changes in legislation triggered a decrease in nitrate levels after 2007. In the sampling point in Sint-Katelijne-Waver (Figure 4) however, the decreasing trend of the first period continues. Remarkable in this figure are the high peak concentrations of nitrate that occur in summer, which lead us to suspect this sampling point is under influence of a greenhouse where untreated drainage water is discharged.

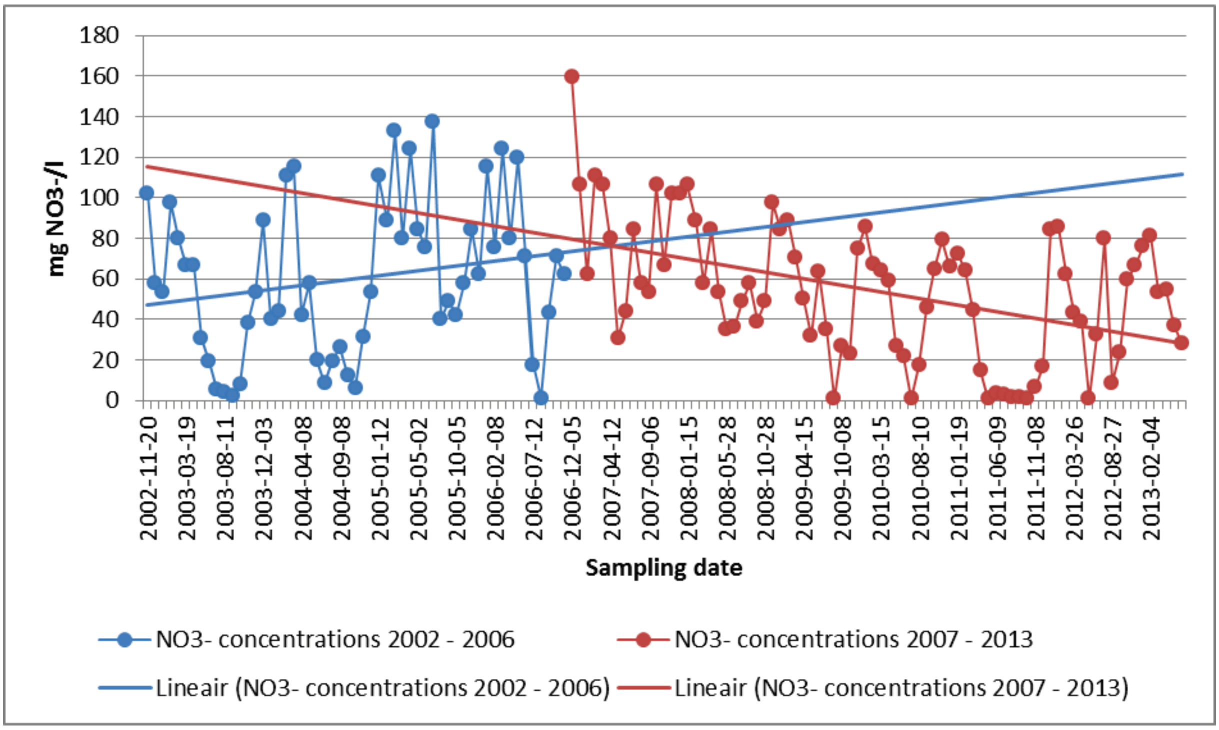

Figure 3 Trends in nitrate concentration between 2002 - 2006 and 2007 - 2013, MAP monitoring point 964050 Staden (VMM,2013)

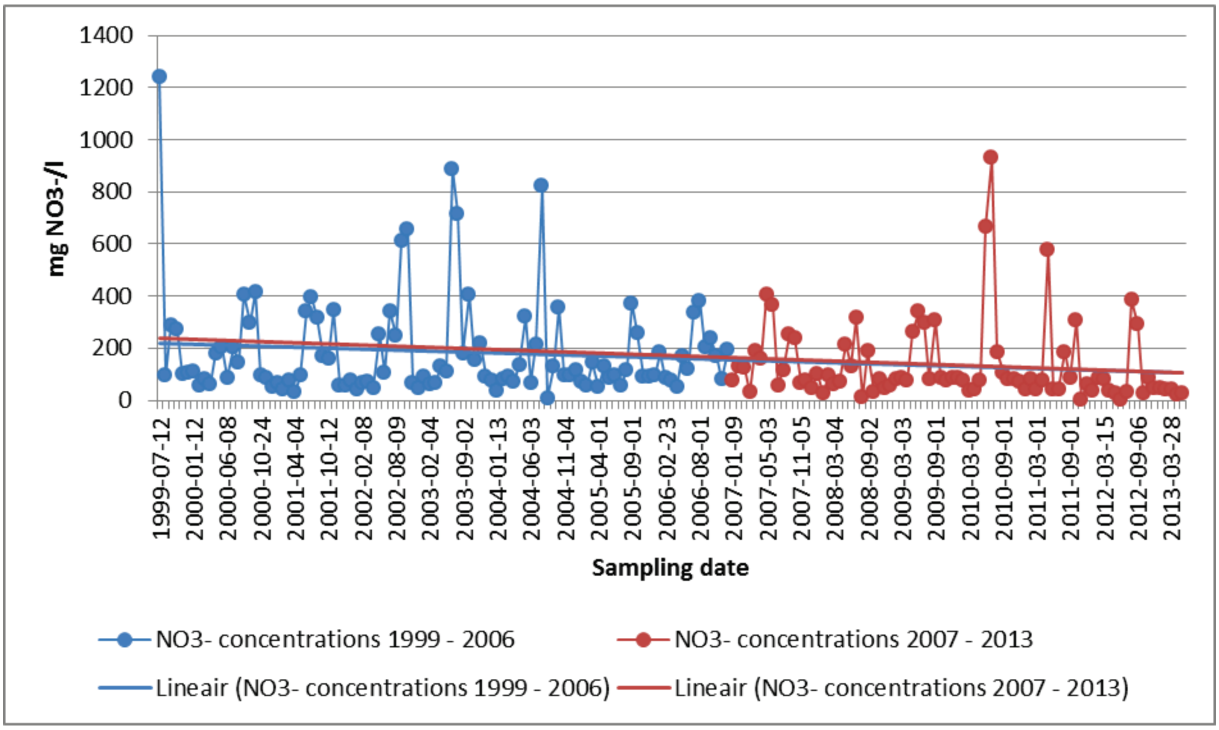

Figure 4 Trends in nitrate concentration between 2002 - 2006 and 2007 - 2013, MAP monitoring point 263100 Sint-Katelijne-Waver (VMM,2013)

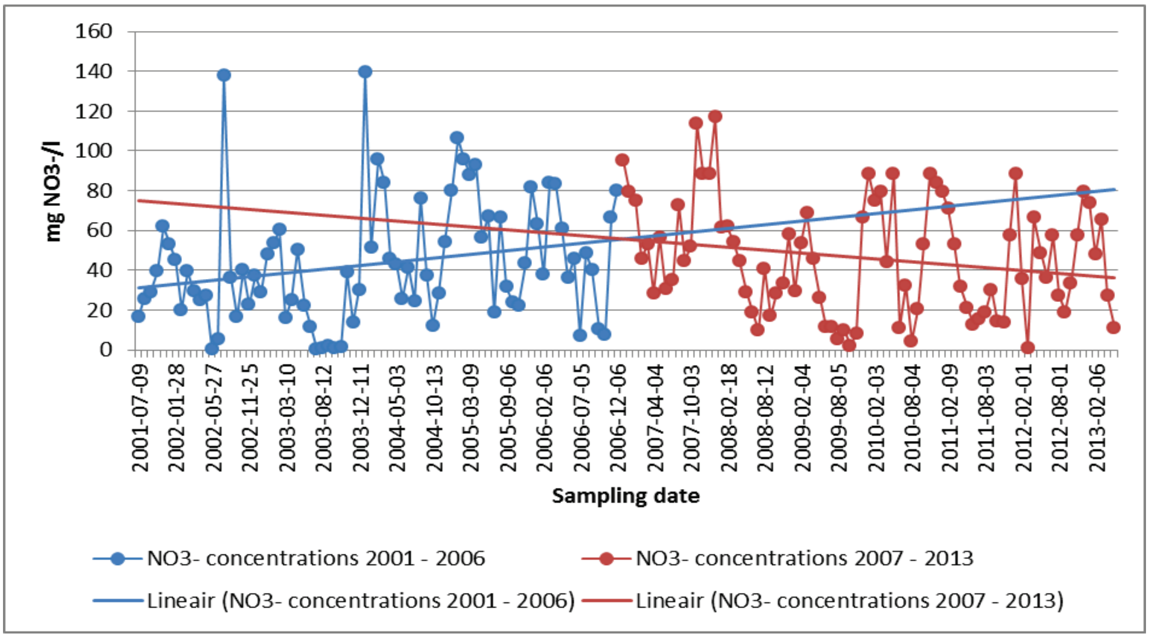

Figure 5 Trends in nitrate concentration between 2002 - 2006 and 2007 - 2013, MAP monitoring point 79150 Hoogstraten (VMM,2013)

Conclusion

The gradually more restrictive but also participatory character of nitrate legislation in horticulture has had its effects. Nitrate residues in horticulture have diminished and also water quality has improved in specific horticultural areas. To see effects of the obligated fertilization advices it's too early but it can be expected to have a positive effect on nutrient management efficiency and thus on water quality.

In twenty years of manure policy, legislation in Flanders has gradually become more restrictive on the use of nutrients in horticulture. In the same time an evolution towards a more participatory approach has occurred. It can be concluded that in a first stage more restrictive measures are most effective but in later phases a more important role can be played by rational fertilization and sustainable nutrient management. Also a more participatory approach enhances awareness among stakeholders which helps meeting the objectives.

However for the purpose of this exercise only three randomly selected monitoring sites are analyzed. To draw up more decisive conclusions about the effects of participatory approach in horticulture, a more extensive analysis of water quality data is needed.

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(38) Emission control of soil nitrogen content in water protection areas in Baden-Württemberg, Germany

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Abstract: *Vegetable production in water protection areas in Baden-Württemberg (BW) is subject to regulations according to the decree SchALVO (Schutzgebiets- und Ausgleichsverordnung). To remediate groundwater consistent constraints in addition to the existing standards of good agricultural practice are imposed. It fulfils the Water Framework Directive (WFD) as 'additional program of measures'. SchALVO is compulsory in water production domains with 359.500 hectare in agricultural use. The constraints depend on soil type, altitude, distance to water sources and the nitrate concentration of groundwater in three classes (normal area <35-50, problem-area 35-50, remediation area >50 mg NO_3 L^{-1}). Measures in vegetable cropping include fertilizer use; crop choice; dates for establishing catch crops; time windows for tillage; and others. Residual soil nitrate-N is monitored in 0-90 cm between October 15th and November 15th. Farmers get financial compensation for meeting a threshold of 45 kg N ha^{-1}. SchALVO was amended in 2001 and monitoring was restricted to areas at risk (problem- and remediation areas) which resulted in an increase of residual nitrate-N. Since 2006 the residual nitrate-N reaches a level of 70 to 80 kg N ha^{-1}. For 2011 a detailed analysis of nitrate-N residues on 141 vegetable growing sites was done and results presented. Generally the effect of measures according to SchALVO is influenced by site specific characteristics as well as weather conditions. The results of the monitoring program are used to check compliance with the requirements and are a valuable instrument for the extension services to derive recommendations for vegetable farmers. Additionally SchALVO measures provide valuable experience to implement voluntary measures according to WFD in horticultural practice in BW.*

Introduction

In Germany (GE) the fertilizer decree (Düngeverordnung) implements the EU action programme according to the nitrate directive at federal (national) level (DüV, 2007). For this purpose all 16 federal states of Germany are designated as a vulnerable zone. These codes of good agricultural practice in accordance with DüV are strengthened in water protection areas (WPA) by water laws in each federal state to remediate nitrate contamined groundwater. Only Baden-Württemberg (BW) in the southwest of GE decided to establish regulations and settlement of claims in WPAs centrally managed by the government. This was due to the fact that WPA amounts for 26% of the state area with 359.000 hectare of agricultural land and 1.250 independent water supply companies. Thus agricultural and horticultural crop production is restricted by the decree of SchALVO (Schutzgebiets- und Ausgleichsverordnung) (UM, 2001). This central regulation was launched in 1988 and ensures consistent constraints and financial compensation. Fund inputs are from the so called "water cent" with 0.05 € per m^3 water paid by consumer.

SchALVO was amended in 2001 and is accepted as additional program to fulfil the water framework directive (WFD) (UM, 2009). Measures of SchALVO are compulsory and address all agricultural pollutants (pesticides microbial, nitrate-nitrogen). Generally the rules depend on soil type, distance to water sources, crop and altitude and the pollution status of groundwater. The latter is classified in three categories according to its recent concentration of nitrate and the development of concentration over time. Thus normal areas (<35-50 mg NO_3 L^{-1}), problem-areas (35-50 mg NO_3 L^{-1}) and remediation areas (>50 mg NO_3 L^{-1}) are specified which cover 70%, 25% and 5% of the agricultural used land, respectively. With amendment of SchALVO in 2001 restrictions in normal areas became less severe; this area is still covered by the codes of good agricultural practice according to DüV. In areas at risk (problem- and remediation areas) the higher levels of nitrate in groundwater gradually lead to more restrictive measures. Crop specific rules limit vegetable production and include use of industrial fertilizers (timing, split application, fertilizer type, and placement), crop choice and rotation (deep rooting crops, catch crops, and greening at fixed dates); time windows for tillage depending on elevation, and others. Each year soil samples are taken in autumn to verify compliance with SchALVO. Results of this emission control are summarized in the "Nitratbericht" (LTZ, 2012) and are used for advice of agricultural and horticultural farmers.

Materials and Methods

Monitoring the residual nitrate-nitrogen (N) content of soils takes place from October 15th to November 15th. The distribution of sampling sites follows the "guidelines for site selection" (LTZ, 2010a). Soil sampling focuses not only on sites being at risk for nitrate leaching but also on sites for which farmers applied for compensation of constraints. Designation of sampling sites is supervised by local authorities in accordance with the official "guidelines for soil sampling" (LTZ, 2010b). Analysis of soil nitrate-N follows the method manual of VDLUFA (VDLUFA, 1991) at the Landwirtschaftliches Technologiezentrum Karlsruhe (LTZ). Data of nitrate-N content of soils in the years 1991 to 2011 were analysed by the computer application 'SchALVO-Manager' with special focus on vegetable cropping. Data from 2011 were analysed in detail and will be shown. For each site data is available on soil covering at soil sampling, e.g. main crops, catch crops or soil tillage. Since 2001 records on soil type were no longer enforced. On account of the lower sample size of sites with vegetable growing the data were not analysed for regional differentiation.

To verify compliance with SchALVO requirements nitrate-N content of the soil is evaluated according to the risk of leaching. On light soils (e.g. S, Sl, lS, SL) the sum of nitrate-N content in 0-90 cm is compared with the threshold of 45 kg N ha^{-1}. On heavy soils (e.g. sL, L, LT, T) the soil depth of 0-30 cm and 30-60 cm are evaluated separately. If the threshold is exceeded the farmer has to keep records on all management measures on farm level. Improper transport and storage of the soil samples as well as errors in soil analysis are taken into account by setting the legal justiciable limit up to 70 kg N ha^{-1}. Each year the farmer in WPA has the possibility to apply for flat rate compensation (agriculture: 165€ ha^{-1}) or site specific compensation on proof (horticulture, between 100 and 1200€ ha^{-1}). Financial compensation for the sampled site is refused if results are higher than the legal limit. In special cases fines are imposed for infringement of measures.

Results and Discussion

In the first 12 years of SchALVO emission control took place on all sites in WPA (80.000 sites, 100% of WPA). Since amendment of SchALVO in 2001 monitoring focuses solely on areas at risk (problem- and remediation areas) which cover 30% of WPA. Thus the number of soil sampling sites declined from 80.000 to 17.000. In 2011 276 sites with horticultural crops were monitored in comparison to 900 sites before 2001 (tab. 1).

Table 1 Soil sampled sites in water protection areas (WPA) of Baden-Württemberg according to SchALVO emission control 2011

2011	soil sampled sites in WPA (problem- and remediation areas)	
	number	area (ha)
Baden-Württemberg	17.000	26.000
horticulture*	276	300
- vegetable crops**	141	141

*horticulture = vegetables, asparagus, ornamental crops, tree nursery

The results of monitoring nitrate-N content from 1991 to 2011 are shown in figure 1. The years with effects on soil nitrate-N content due to weather conditions, e.g. precipitation (leaching) and temperature (higher mineralization) are marked with arrows. Implementation of SchALVO distinctly decreased the residual soil nitrate-N content of vegetable cropping sites in autumn. The reduction of soil sampling sites on areas at risk resulted in an increase of nitrate-N content with vegetable crops. Since 2006 nitrate-N content remained on a level of 70 to 80 kg N ha^{-1}. In comparison to cereals vegetables are evaluated as groundwater harmful crops (data not shown).

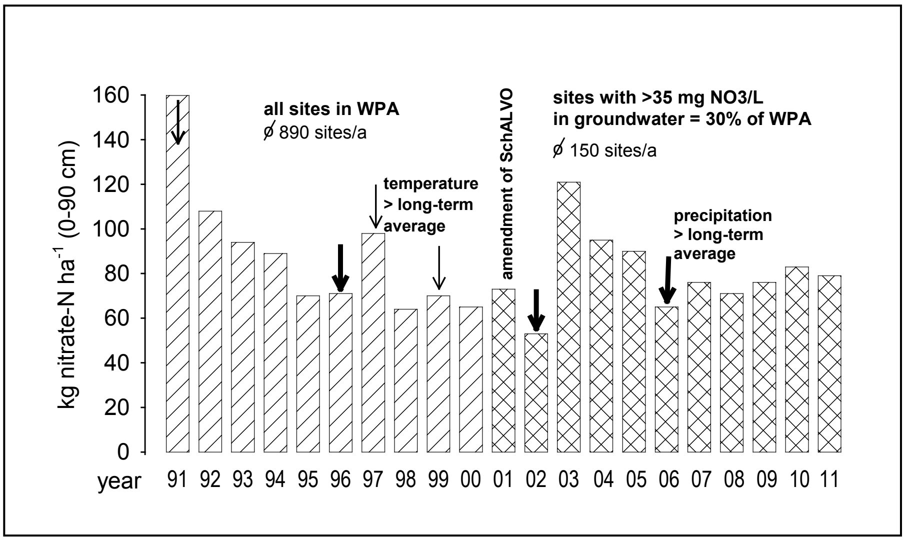

Figure 1 Effect of SchALVO on residual soil nitrate-N content (0-90 cm, weighted average) of vegetable growing sites from 1991 to 2011.

The nitrate-N content of vegetable cropping sites was classified in four classes to evaluate the impact on groundwater (tab. 2). The threshold value (45 kg N ha^{-1}) was met on 57% of sites with vegetable cropping. Generally 75% of all sites reached less than the legal limit of 70 kg N ha^{-1}. However on 25% of the sites financial compensation was refused due to exceeding the limit. The consultants in WPA use these results to advice the farmers individually.

Table 2 Distribution of soil nitrate-N (kg N ha^{-1}) in classes in per cent *(number of sites)*

2011	class of nitrate-N (kg N ha^{-1})*				
main crop	<45	46-70	71-90	>90	100% *(number)*
horticulture**	58 *(159)*	18 *(51)*	7 *(18)*	17 *(48)*	*(276)*
vegetables	57 *(80)*	18 *(25)*	5 *(7)*	21 *(29)*	*(141)*

*arithmetical weighted average of soil mineral nitrate-N: light soils 0-30 cm, heavy soils 30-60 cm.

**horticulture = vegetables, asparagus, ornamental crops, tree nursery

To find reasons for the still high level of residual nitrate-N on sites with vegetable crops a detailed analysis of representative data from 2011 was done (fig. 2-3). With vegetable crops 50 to 75% of residual nitrate-N is left below 30 cm soil depth. This might be due to missing compliance with SchALVO measures or residual nitrate-N which is left by the pre-crop or mineralized and leached nitrate-N from crop residuals (tab 3). Nitrate-N content varied from 57 to 122 kg ha^{-1} depending on vegetable crop specie (fig. 2). Shallow rooting vegetables (e.g. lambs lettuce, spinach, green onions) and herbs release high residual nitrate-N in autumn with the risk of leaching over winter. With cabbage residual nitrate-N was lower than with other species because soil sampling was done before mineralization of N from incorporated crop residues. These results confirm findings on missing crop rotation to deplete especially lower soil depths by agricultural crops. It could be recommended not to plant vegetable crops on sites with more than 60 kg ha^{-1} below 30 cm.

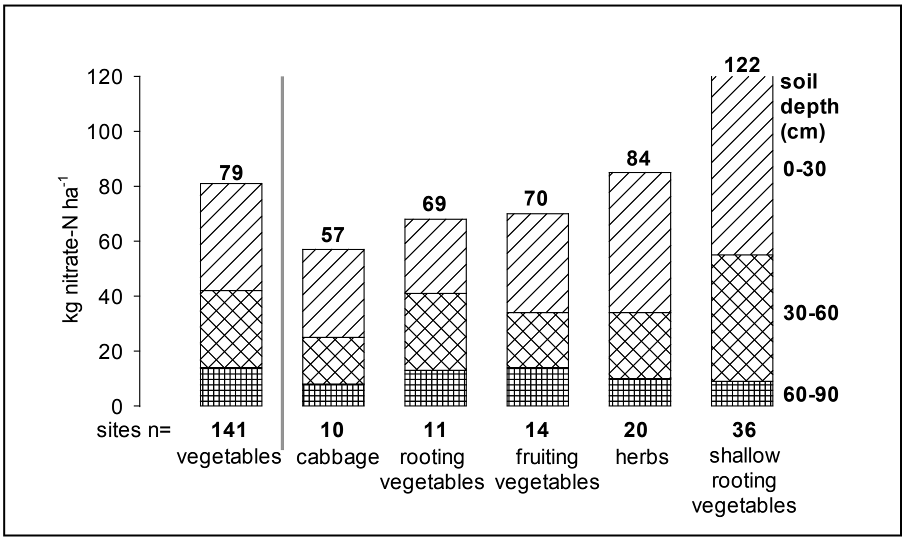

Figure 2 Soil nitrate-N content (0-90 cm, weighted average) in 2011 on sites with vegetable cropping in problem- and remediation areas.

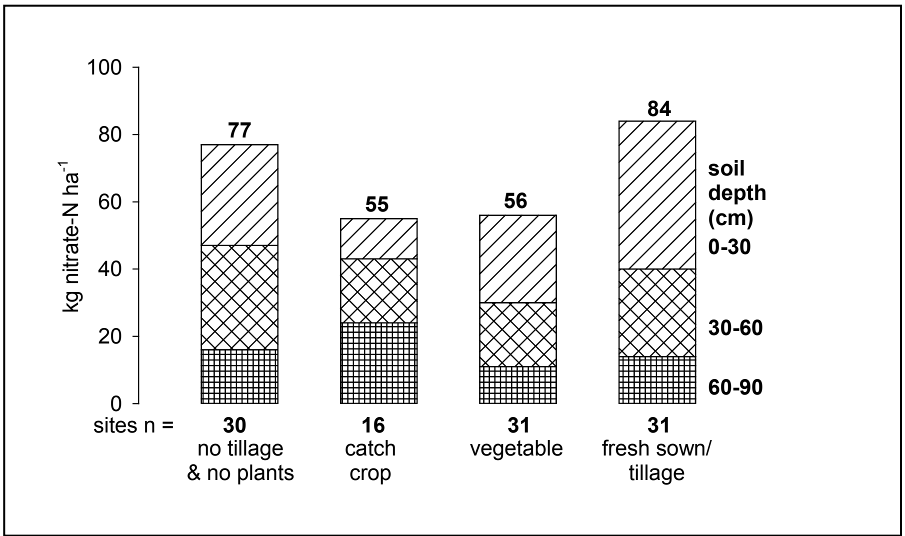

Figure 3 Soil nitrate-N content (0-90 cm, weighted average) in 2011 on sites with vegetables as main crop and soil cover at sampling date in problem- and remediation areas (50 sites without information about soil cover).

Analysing the data according to soil cover at sampling date is shown in figure 3. Soils covered with plants (catch crops, vegetable) left the lowest residual nitrate-N content in the soil profile. Fresh sown crops or soil tillage resulted in higher N content mainly due to higher mineralization rates. This confirms the implemented measures of SchALVO concerning soil tillage and greening.

Finally a survey was carried out among the consultants in WPA to analyse and discuss reasons for farmers to exceed the threshold and legal limit of nitrate-N content according to SchALVO (tab. 3). This leads to intensive advice to the farmers changing their practice.

Table 3 Reasons for exceeding the residual nitrate-N limit of 45 kg N ha^{-1} according to SchALVO at emission control – results of a survey among consultants of local authorities 2011 (n=8)

▪ not complying with SchALVO requirement e.g. missing fertilizer split application or early soil tillage
▪ ignoring SchALVO requirements because farmer did not apply for financial compensation (resulting in less motivation)
▪ time window of soil sampling shortly after fertilizer application with late planted crops
▪ soil tillage at harvest (e.g. onions, leek) improves N mineralization at soil sampling date
▪ shallow rooting plants not depleting the lower soil layers (crop rotation)
▪ freshly incorporated crop residues before sampling date

Conclusion

SchALVO measures successfully reduced soil mineral N content in vegetable crop production. Since 2006 nitrate-N residues vary between 70-80 kg N ha^{-1} in 0-90 cm. Representative data from 2011 showed that 57% of sites have met the threshold of 45 kg ha^{-1}. Exceeding this limit may be due to less depletion of N in the subsoil or late harvesting crops or not complying with SchALVO requirements. Low tillage of the soil and catch crops are important measures to capture N in vegetable fields. These results are used to verify compliance with SchALVO measures. Moreover they are an important tool for the official extension services in order to convince farmers to change their cultural practice in WPA. The long standing experience of SchALVO additionally supports implementation of voluntary measures according to WFD.

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(39) Nitrate-leaching from container grown nursery crops on a closed culture system in open air

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Abstract: *Belgian tree nurseries often use a closed culture system with plantcontainers in open air. Although runoff is captured and stored, excessive rainfall might necessitate overflow to surface water. Hence, the EU Nitrates Directive (91/676/EEG) limiting NO_3-concentration to 50 mg/l indirectly applies on NO_3-concentration in the drain storage basin. To ascertain if standard practice on nurseries answers to the Directive, representative data on NO_3-leaching from containers are needed. Therefore, experiments were conducted on a containerfield with lysimeters allowing collection and monthly analysis of drain (i.e. water passing through and around containers). Experiments covering one growing season of Prunus laurocerasus "Otto Luycken", Fagus sylvatica, Lonicera nitida "Maigrün", Thuja plicata "Atrovirens" or Viburnum tinus were repeated over five years to reckon with climatic variations influencing plant growth and drain characteristics. As controlled released fertilizers (CRF) are generally used, different brands of CRF were applied at recommended doses. Despite varying growing conditions, water-drain fluctuated around 33% of total water-input. NO_3-leaching averaged 14% of total NO_3-input and never exceeded 30%. Based on these numbers and taking into account the applied NO_3-concentration, average water-input and field coverage (to estimate runoff of unpolluted water), growers are now able to predict the NO_3-concentration in their drain storage basin. Experiments demonstrated that most Belgian tree nurseries with a closed culture system in open air are able to produce high quality plants without violating the EU Nitrates Directive. In addition, results provide background for substantiated advice to growers and future experiments on reducing NO_3-leaching.*

Keywords: *EU Nitrates Directive; controlled released fertilizers (CRF); drain; runoff; tree nursery*

Introduction

In Flanders (Belgium), 541 ha is used for of container cultivation of ornamental shrubs and trees in open air (EROV, 2013). Apart from some growers specialised in *Buxus* sp. or *Laurus nobilis* cultivars, most tree nurseries are characterised by a wide assortment of woody ornamentals and conifers, and a wide range of container or pot sizes. In general, growers use controlled released fertilizers (CRF) mixed with the substrate during the (re)potting process.

While overwintering occurs under a plastic tunnel or in the greenhouse, plants grow on outdoor containerfields during the frost-free period. Based on preliminary results of a questionnaire on (re)use of water, approximately 50-60% of Flemish tree nurseries use a closed culture system in open air (Mechant, pers. commun.). Plastic film on the topsoil prevents leaching of water to the soil and runoff can be captured. During the outdoor season, runoff water has passed through or around plant containers and is therefore defined as drain. In closed culture systems, drain is stored and reused for irrigation after mixing with fresh water at a common drain:fresh water ratio of 1:2. Consequently, a substantial reduction in fresh water consumption can be achieved. This is interesting for growers who depend on limited or expensive water resources. The most important (ecological) benefit of a closed culture system, however, is the prevention of nutrient leaching to surface water. The latter is essential in regard to legislation on nutrient enrichment of water bodies like the EU Nitrate Directive (91/676/EEG) that limits NO_3-concentration in surface water to 50 mg/l.

Despite the closed culture system, drain might accidently overflow to surface water. Besides technical errors, an excessive drain volume after downpours is the main cause for overflow. Indeed, drain consists of both irrigation- and rainwater and, hence, its volume is quite unpredictable. Consequently, the EU Nitrate Directive indirectly applies on NO_3-concentration in the drain storage basin.

To give growers adequate advice on necessary drain storage capacity and to ascertain if standard practise on nurseries complies with legislation, representative data on NO_3-leaching from the field and NO_3-concentration in drain storage are needed. Therefore, experiments to collect these data were conducted at PCS Ornamental Plant Research.

Materials and Methods

Lysimeter-experiments were conducted on an experimental containerfield at PCS Ornamental Plant Research in Destelbergen, Belgium. The set-up allowed volume measurement, expressed as l/m², of [1] rain water, [2] total water-input (*i.e.* rain and irrigation) and [3] drainwater (Figure 1). In addition, NO_3-concentration of drain was monthly determined. Based on these data, water- en NO_3-drain percentages were calculated. Lysimeters were 0.36 m² (0.55 m x 0.65 m) and at 100% field coverage they carried 10 2.0-litre, 12 1.5-litre or 16 0.7-litre containers, equivalent to 56.0, 50.4 or 30.4 litre substrate/m² respectively.

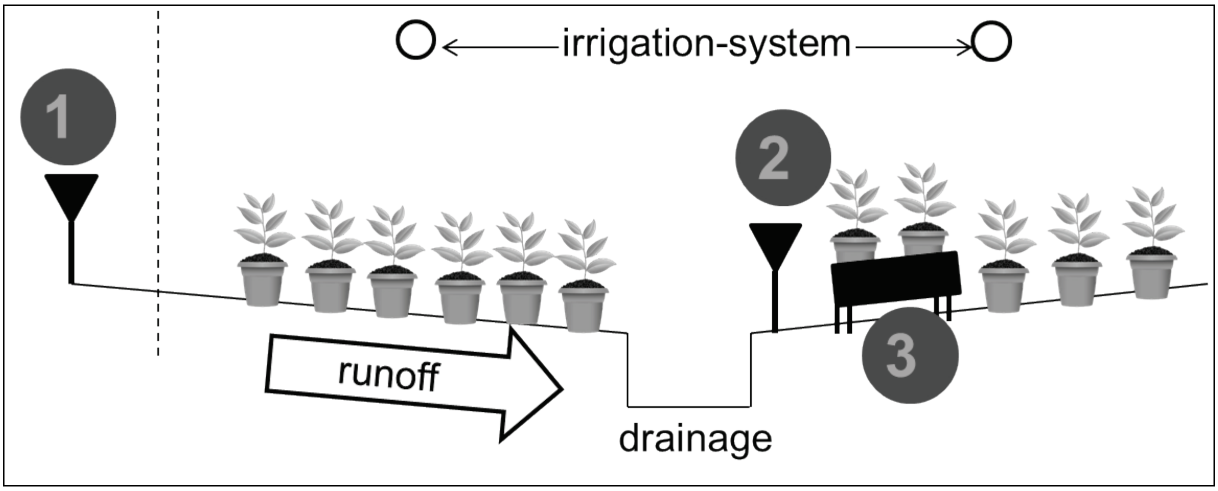

Figure 1 Set-up of lysimeter-experiment on outdoor containerfield allowing volume-measurement of rain (1), rain + irrigation (2) and drain (3).

To reckon with climatic variations influencing plant growth and drain characteristics like nutrient release from CRF, drain volume and NO_3-concentration in drain, the lysimeter-experiment was repeated over five years (Table 1). Each experiment covered one outdoor season of *Prunus laurocerasus* "Otto Luycken"*, Fagus sylvatica, Thuja plicata* "Atrovirens" or *Viburnum tinus.* Although research focus shifted each year, all experiments included treatments that were fertilized with CRFs at recommended doses. Examined CRF-brands were Osmocote, Basacote and Horticote and N-NO_3 input varied between 600 to 933 g/m³, corresponding with 4 to 6 kg CRF/m³. Because experiments were not designed to compare different CRFs, no details on this aspect are given.

Table 1 N-NO_3-input of treatments with CRF in lysimeter-experiments between 2008-2012

Year	Crop	Exp. code	N-NO_3-input (g N/m³ substrate)	Plant container		N-NO_3-input (g N/m²)
				size (l)	#/0.36 m²	
2008	*Fagus sylvatica*	F8-01	600	2.0	10	33.6
2009	*Thuja plicata*	T9-01	750	1.5	12	37.8
		T9-02	750	1.5	12	37.8
		T9-03	900	1.5	12	45.3
	Viburnum tinus	V9-01	750	1.5	12	37.8
		V9-02	750	1.5	12	37.8
		V9-03	900	1.5	12	45.3
2010	*Prunus laurocerasus*	P10-02	675	0.7	16	20.5
		P10-01	750	0.7	16	22.8
		P10-03	810	0.7	16	24.6
2011	*Prunus laurocerasus*	P11-01	720	1.5	12	36.3
		P11-06	720	1.5	12	36.3
		P11-04	750	1.5	12	37.8
2012	*Prunus laurocerasus*	P12-02	833	1.5	12	41.9
		P12-01	853	1.5	12	42.9
		P12-07	883	1.5	12	44.5
		P12-10	933	1.5	12	47.0

Results and Discussion

Total drain volume, NO_3-concentration in drain (averaged over the outdoor season), and water- and NO_3-drain percentages are summarized in Table 2.

Table 2 Drain characteristics of treatments with CRF in lysimeter-experiments between 2008-2012

Exp. Code	N-input (g N/m²)	Total drain volume (l H_2O/m²)	H_2O-drain (%)	Average NO_3-concentration (mg NO_3/l)	NO_3-drain (%)
F8-01	33.6	336	37.9	131.4	29.7
T9-01	37.8	183	24.5	128.2	14.0
T9-02	37.8	183	24.0	160.0	17.5
T9-03	45.3	190	23.7	186.5	17.7
V9-01	37.8	179	30.7	84.4	9.1
V9-02	37.8	174	28.4	95.9	10.0
V9-03	45.3	181	28.5	123.8	11.2
P10-02	20.5	352	46.5	23.4	9.2
P10-01	22.8	412	49.2	28.7	11.7
P10-03	24.6	372	50.1	31.4	10.8
P11-01	36.3	206	27.2	67.2	8.6
P11-06	36.3	215	28.5	113.2	15.2
P11-04	37.8	229	29.7	50.8	7.0
P12-02	41.9	257	31.4	168.4	23.3
P12-01	42.9	268	33.1	98.6	13.9
P12-07	44.5	272	34.3	73.8	10.2
P12-10	47.0	261	32.4	99.5	12.5
Average			***32.9***		***13.6***

Over all experiments, drain volume averaged 32.9% of total water-input and varied between 24% (2009) and 50% (2010). As variation in H_2O-drain was biggest between years, rainfall and irrigation were determined as the most influencing factors of drain volume. Especially downpours, which frequently occurred in 2008 and 2010, induce an increase in drain volume because they quickly saturate the substrate. Once the substrate is water-saturated, all additional water will directly pour through the container as drain. A second factor influencing drain volume is the crop and its water demand. This was clearly illustrated in 2009, where drain volume of *V. tinus* (objects V9-01, V9-02 and V9-03) was on average 5% higher than that of *T. plicata* (objects T9-01, T9-02 and T9-03), indicating that the latter made better use of the same water-input. Within the same year and crop, only small differences in drain volume were found between treatments. These variations could be attributed to natural variation and possible differences in the rooting system of plants due to variable CRF-treatment. The effect of substrate volume (*i.e.* container size and number of containers per lysimeter) could not be measured, but most likely it also influenced H_2O-drain as a small substrate volume (*e.g.* 16 0.7-litre containers) will be faster water-saturated than a large volume (*e.g.* 12 1.5-litre containers).

NO_3-leaching averaged 13.6% of total NO_3-input and never exceeded 30%. Table 2 clearly indicates that a high drain volume does not necessarily result in a high NO_3-drain percentage. NO_3-leaching merely depends on factors influencing nutrient release from CRFs, like temperature and soil moisture. When nutrient release is followed by a high water-input (*e.g.* downpour), plants lack time for nutrient uptake and NO_3 is leached with drain. Other factors influencing NO_3-drain are CRF-type and plant quality, as illustrated below. Despite identical N-NO_3- and H_2O-input, identical factors influencing CRF nutrient release and similar H_2O-drain percentage, NO_3-drain of object P11-01 (8.6%) was significantly lower than NO_3-drain of object P11-06 (15.2 %). P11-01 had a mix of two CRFs (2.5 + 2.0 kg) with residual activity of 6 and 9 months respectively, while P11-06 was fertilized with 4.5 kg CRF with 6 months residual activity. The different CRF-types resulted in a more gradual nutrient release in object P11-01, thus increasing the opportunity for nutrient uptake by the plants and decreasing NO_3-leaching. At the end of the experiment, visual assessment scored plants of P11-01 better in quality than those of P11-06. Although this higher plant quality mainly resulted from higher nutrient uptake due to differences in fertilization, the better root system of P11-01 will have further contributed to an increased nutrient uptake and lower NO_3-leaching.

NO_3-concentration of drainwater (Table 2) collected in the lysimeters represents NO_3-leaching from a 100% covered containerfield. In practice, however, containerfield coverage will average 70-90% depending on the amount of empty sections that occur during the season due to the typical wide assortment and quick turn over of some crops. On empty sections H_2O-drain will be 100% and NO_3-concentration most probably will equal zero. Consequently, NO_3-concentration will decrease when field coverage is low due to a diluting effect in the basin. Table 3 illustrates the effect of containerfield occupation degree on the average NO_3-concentration in the drain storage basin. Growers should adjust the calculation of NO_3-concentration in their basin according their average field occupation. With a field coverage of 70%, the average NO_3-concentration in drain was below the 50 mg/l limit for three quarter of the objects, indicating that it is possible to produce high quality plants without violating the EU Nitrate Directive but also that overflow to surface water is often not a realistic option.

Table 3 Effect of field occupation on NO_3-concentration in drain water storage

Exp. code	**N-input (g N/m²)**	**Average NO_3-concentration (mg NO_3/l)** at containerfield occupation degree of			
		100%	**90%**	**80%**	**70%**
F8-01	33.6	131	102	79	62
T9-01	37.8	128	88	63	**47**
T9-02	37.8	160	109	78	57
T9-03	45.3	187	127	91	66
V9-01	37.8	84	62	**47**	**35**
V9-02	37.8	96	69	51	**38**
V9-03	45.3	124	89	66	**49**
P10-02	20.5	**23**	**19**	**15**	**12**
P10-01	22.8	**29**	**23**	**19**	**15**
P10-03	24.6	**31**	**26**	**21**	**17**
P11-01	36.3	67	**48**	**35**	**26**
P11-06	36.3	113	81	60	**45**
P11-04	37.8	51	**37**	**28**	**21**
P12-02	41.9	168	124	94	71
P12-01	42.9	99	74	56	**43**
P12-07	44.5	74	56	**43**	**33**
P12-10	47.0	100	74	56	**43**

Conclusion

Although drain volume and NO_3-concentration in drain are influenced by multiple factors, we can conclude that a H_2O-drain of 30-35% and NO_3-drain of 12-17% are good indicators for drain characteristics of Belgian tree nurseries on containerfields regardless of crop, container size, container density and climate.

Combined with N-NO_3-input and the actual field coverage, these indicators allow an estimation of NO_3-concentration in the drain storage basin. When the estimated NO_3-concentration in the basin exceeds 50 mg/l, action should be taken to prevent overflow of drain to surface water. First of all, storage capacity of the drainwater basin could be increased. A larger basin does not only prevent overflow, but also allows collection of unpolluted water from the (almost) empty field before the start of the season (*i.e.* decreased average containerfield occupation degree). If enlarging storage capacity is not feasible, an overflow to the irrigation water basin could be considered. Another option is to (partly) dispose of drain by overflow to constructed wetland (prior to discharge to surface water or reuse) or by spreading on (grass)land.

In addition, the results provide background for substantiated advise of extension workers to growers and for future experiments on reducing NO_3-leaching (*e.g.* effect of mixing CRFs with different residual activity thus mimicking a split N-input).

Finally, the results confirm that growers, who have a closed culture system, use CRFs at recommended doses and take additional action when their drain storage basin has limited capacity, are able to produce high quality plants without violating the EU Nitrates Directive.

Acknowledgements

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POSTER PRESENTATIONS

(40) In Line Roller Crimper technology in organic vegetables production to mitigate nitrate leaching risk

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Abstract: *The use of the In Line Roller Crimper (ILRC) technology to terminate cover crops could reduce nitrate leaching risk in vegetable cropping systems. Two 2-year field experiments were carried out, growing zucchini after rolled cover crops (barley and common vetch in central and southern Italy, respectively). In central Italy no cover crop, green manure and in-line till/roller crimped barley were compared on zucchini yield, yield quality, weed control and N dynamic in the soil–plant system. Zucchini cultivated by the ILRC yielded 69% more than the crop preceded by the green manure and similarly to the control. Yield quality did not differ among the treatments. Weed above ground biomass was lower than the control in the green manure and in the ILRC treatments. The N use efficiency in the ILRC treatment was twice as high in comparison with the control treatment and 29% higher compared with the green manure treatment. In southern Italy, the effects of vetch management strategies as green manure (GM), using a roller-crimper (RC) and different organic fertilizers (municipal solid waste compost, anaerobic digestate and a commercial organic fertilizer) on organic zucchini yield and quality were investigated. The vetch cover crop increased marketable zucchini yield by 26.6% compared to the fallow (FA) treatment, indicating that using this fertility building crop could reduce the off-farm N fertilizer input. Averaging over two years of the experiment, the marketable zucchini yield increased when RC mulch and GM were used. The concentrations of mineral N in the soil at harvest were 19, 27 and 28 mg kg^{-1} for the RC, FA, and GM treatments, respectively. Research findings suggest that ILRC technology was able to increase the zucchini N utilization efficiency in both the experiments, and to mitigate the risk of nitrate leaching.*

Keywords: *organic farming; cover crops; zucchini; N use efficiency.*

Introduction

Cover crops play an important role in organic farming and, in properly designed rotational systems, are able to provide fundamental ecological services to enhance agro-ecosystem sustainability (Uchino et al., 2011). The conservation no-till systems, based on the use of a roller crimper to terminate cover crops, have been receiving growing interest for their capability to control weeds and provide additional crucial ecosystem services (e.g. soil temperature control, fossil fuel origin energy saving, water saving, and soil erosion reduction) (Altieri et al., 2011). However, studies reported in the current scientific literature have been carried out principally on grain production systems (Davis, 2010; Delate et al., 2012; Mirsky et al., 2012), whereas fewer papers have focused on vegetable crops (Leavitt et al., 2011; Luna et al., 2012). A number of well known agronomic constraints and risks related to the no-till roller crimper approach, such as the cover crops re-growth during the subsequent main crop cycle, and the nitrogen (N) immobilization (Luna et al., 2012), could even more limit the success of this technology in the organic vegetable cropping systems, mainly because of the low competitive ability of vegetable species. In order to overcome the constraints of the no-till roller crimper technology, an alternative reduced tillage system has been recently developed. This in-line tillage/roller crimper (ILRC) system is based on the use of a novel machinery, obtained slightly modifying a common roller crimper. In particular, a sharp vertical disk and a coulter (or chisel) were in-line installed at front and rear of the roller, respectively (*Fig. 1*). This machinery allows to flatten the cover crops and, simultaneously, to obtain a transplanting furrow, leaving a mulch layer covering the soil surface, thus providing the expected agronomic and ecological services (e.g., weed control, soil protection, etc.). At the same time, since the cover crop is not chopped and plowed-down (i.e., green manure), its biomass mineralization rate is slowed down. In fact, only the cover crop roots as well as the cover crop tissues localized at the soil-mulch interface are subjected to a rapid decay, while most of the cover crop biomass mineralizes slowly, thus releasing nitrogen over time.

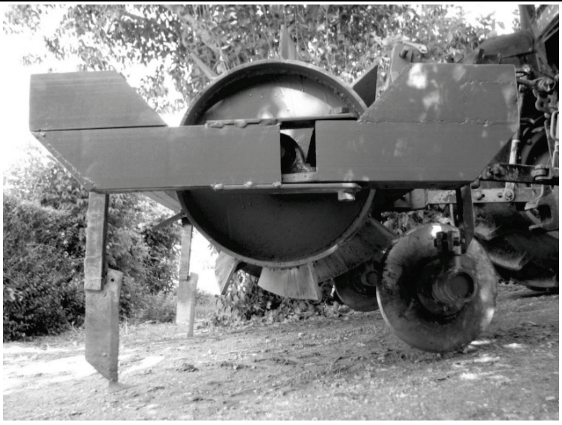

Figure 1 Modified roller crimper for transplanting bed preparation (in-line tillage)

The objective of this research was to test the feasibility of the ILRC system in organically managed vegetable cropping systems in Mediterranean conditions, particularly to mitigate nitrate leaching risk. Therefore, two 2-year field experiments were carried out in 2010 and 2011, growing transplanted zucchini (*Cucurbita pepo* L.) after rolled cover crops (barley and common vetch, in central and southern Italy, respectively).

Materials and Methods

Central Italy field experiment setup

A 2-year field experiment was carried out within a 4-year crop rotation at Monsampolo del Tronto (AP) (42°53’ N, 13°48’ E) in central Italy, on the experimental farm of the C.R.A., Vegetable Research Unit. The climate is “thermomediterranean”, as classified by UNESCO-FAO (1963). According to Soil Taxonomy (USDA, 1996), the soil at the field trial site was Typic Calcixerepts fine-loamy, mixed thermic.

The experimental design was a strip-plot with three replicates, where two factors, the cover crop (barley, *Hordeum vulgare* L.) management and zucchini hybrids (Dietary and Every), were tested. Strips (21 m × 8 m) were used to test the cover crop management factor. The following treatments were compared: (i) control (no cover crop), (ii) green manure of barley, and (iii) flattened barley mulch obtained by ILRC. Within the strips, the plots (24 plants per plot) were used to compare the two hybrids. Barley was sowed on the 4th and 29th of November in 2009 and 2010, respectively. It was terminated on the 6th and 9th of May in 2010 and 2011, respectively, then its aboveground biomass was measured. In the ILRC treatment, the residues of the flattened barley mulch were incorporated into the soil after the zucchini crop. The zucchini was manually transplanted on the 10th of May both in 2010 and 2011. In 2010, the harvest started on the 14th of June and ended on the 2nd of August. In 2011, the harvest started on the 13th of June and ended on the 29th of July. The crop was irrigated with 830 m^3 ha^{-1} and 701 m^3 ha^{-1} of water in 2010 and 2011, respectively. Off-farm fertilizers, allowed in organic farming, were distributed as 116, 47 and 32 kg ha^{-1} of N, P_2O_5 and K_2O, respectively (50% of the total dose at transplanting, and 50% split along the cropping cycle).

In each year, the zucchini yield was measured collecting fruits 3 times per week along the harvest period, at the end of the cropping period, the total yield was calculated. Marketable yield was evaluated according to the local market standards. Yield quality parameters (i.e., fruit weight, diameter and length) and the number of fruits $plant^{-1}$ were measured on a sample of at least 5 plants per plot. At the end of the harvest period, zucchini crop residues and weeds above ground biomass were measured. Fruits, crop residues and weed samples were dried for 48 h at 70 °C to determine dry weight. Furthermore, total N content (Kjeldahl method) of each sample was determined, allowing the calculation of N uptake (N content × biomass dry weight) by the fruit yield and cropping residues, as well as by weeds. The yield N ratio (%) between the N uptake in the yield (multiplied into 100) and the sum of the N uptake in all the pools (i.e. yield, cropping residues and weeds) was calculated. Soil mineral N (NO_3^--N + NH_4^+-N, at 0–30 cm soil depth) was also determined at −2, 14, 34, 59 and 82 DAT (Days After Transplanting) in 2010, and at −4, 7, 30, 63 and 83 DAT in 2011. Soil mineral N was extracted by 2 M KCl (1:10, w/v) and measured by continual flow colorimetry according to Krom (1980) and Henriksen and Selmer-Olsen (1970) for NH_4^+-N and NO_3^--N, respectively. All the plant and soil laboratory tests were carried out in triplicate.

Results were analyzed using univariate analysis of variance (ANOVA) considering year, cover crop management and cultivar (the latter only for yield, yield quality, weed biomass and N uptake) as factors. Mean comparison was carried out according to the Least Square Difference (LSD) test and the Duncan Multiple Range Test (DMRT), both at $P \leq 0.05$

probability level, for two and more than two comparisons, respectively. The elaboration was performed using the SPSS 16.0 package.

Southern Italy field experiment setup

A 2-year rotation of zucchini-cauliflower was carried out at Metaponto (MT) (40° 24' N, 16° 48' E) in southern Italy, on the experimental farm of the C.R.A., Research Unit for the Study of Cropping Systems. The soil is classified as a Typic Epiaquert, in accordance with the Soil Taxonomy, and the climate is classified as "accentuated thermomediterranean" according to the UNESCO-FAO classification.

The experimental design was a split-plot with two factors and three replications. The main factor/plot was the vetch (*Vicia sativa* L.) cover crop management and was compared to: i) fallow (FA) (no cover crop); ii) green manure (GM), with vetch biomass chopped and plowed; and iii) roller-crimper (RC), vetch mulch obtained by ILRC. Vetch was sowed on 20 November and 2 December in 2009 and 2010, respectively, and it was terminated at the first-legume stage (15th and 17th of May in 2010 and 2011, respectively). At termination, in both years, the vetch in GM treatment was plowed in, and for FA treatment the soil was tilled at about 15-20 cm depth. Within each vetch residue management system, the application of the following off-farm organic fertilizers, allowed in organic farming, were tested: i) commercial manure (CRAI s.r.l., VR, Italy), composed of organic animal fertilizer (OAF), ii) anaerobic digestate fertilizer, based on wine distillery wastewater (WDW); iii) organic composted municipal solid wastes (MSW). These treatments were compared to an unfertilized control (N0). The organic materials (in both years) were applied to the soil about 20 days before transplanting zucchini, at 100 kg N ha^{-1} rate. This low dose took into account biological N fixation contribution of the vetch. The zucchini was transplanted on 6th and 7th of June 2010 and 2011, respectively, with plant density of about 1.4 plants m^{-2}. In both years about 2,600 m^3 ha^{-1} of water were distributed over 9 irrigation periods.

For each main plot of 20 m^2 (5 x 4 m), the total and marketable yield was determined twice a week on about 6 m^2 (8 plants) test area, in the middle of plot. Each time, a representative (about 30%) number of harvested zucchini was recorded and weighted, according to commercial standards used in this region. In 2010, harvest started on 5 July and ended on 30 July, while in 2011 it started on 6 July and ended on 8 August. Soil mineral N was determined at 17, 27, 40 and 52 DAT in 2010, and at 23, 35, 49 and 63 DAT in 2011, according to the same methodologies described for the first field trial.

Data were analyzed considering years as random, and experimental treatments as fixed factors. The effect of the treatments was assessed through the General Linear Model procedure. The means of the experimental treatments were compared using the LSD and the Student-Newman-Keuls (SNK) tests, for the values of each sampling and the mean treatment comparisons, respectively, at $P \leq 0.05$.

Results and Discussion

Central Italy

Table 1 shows the values for zucchini total yield, zucchini crop residues and weed above ground biomass. Zucchini total yield and residues were higher in 2010 than 2011, reasonably due to the total rainfall during the cropping cycle, which was 22% higher in 2010 than in 2011. In addition, the differences in the amount of barley above ground biomass between the two years (16.1 ± 0.6 t ha^{-1} and 13.9 ± 0.6 t ha^{-1} of dry matter in 2010 and 2011, respectively), probably influenced the weed above ground biomass (by 54 % higher in 2011 than 2010) and, consequently, the zucchini yield (Altieri et al., 2011). As for the cover crop management effect, both the zucchini total yield and the crop residues biomass showed the lowest values in the green manure treatment and the highest in the ILRC one. These results demonstrated the effectiveness of the mulch obtained by the ILRC technology in controlling weeds in our environmental conditions. The weed above ground biomass value was the highest in the control, intermediate in the green manure treatment and the lowest one in the roller crimper. No significant differences on the tested parameters were observed between the two tested cultivars. The release of allelochemicals could explain the low zucchini total yield and crop residues biomass in the green manure treatment compared to the control. Also N immobilization determined by the incorporation into the soil of large amount of low C/N plant materials (i.e. the barley residues) has been identified as a possible mechanism to explain the growth reduction of the green manured crops (Wells et al., 2010)

Marketable yield, marketable fruit number and fruit quality parameters are reported in *Table 2*. These parameters showed significant differences between the two years, generally being higher in 2010 respect to 2011. The cover crop management treatments also showed differences among them, being the marketable yield and number of fruits per plant of the green manure treatment both significantly lower than the control (by 37% and 34%, respectively) and the ILRC (by 34% and 35%, respectively) treatment. Fruit diameter in the green manure treatment was significantly higher than the control and the roller crimper treatments, that presented almost the same values. However, this slight difference (< 4%) was statistically but not economically significant. Marketable yield, fruit number, weight and length were significantly higher in the Every hybrid than in the Dietary one.

Table 3 reports the N uptake results, as well as the yield N ratio index. No significant differences between the two years were observed for the weed N uptake, whereas the other N uptake values were higher in 2010 than in 2011. These results were probably due to the higher presence of weeds in 2011, which reduced the zucchini yield and residues biomass. The utilization of N by the zucchini crop to produce yield was less efficient in 2011 than 2010. The cover crop management strongly affected the N uptake and distribution. Yield N uptake was lower in the green manure treatment than the control (by 55%) and the ILRC (by 53%), which showed similar values. These results are clearly linked with the observed differences in zucchini yield. Unexpectedly, the highest value of crop residues N uptake was measured in the control, on the other hand, the green manure and the roller crimper values were lower but mutually comparable. Reflecting the differences in their aboveground biomass, the N uptake by weeds was reduced in the ILRC treatment of 83% and 80% compared to the control and green manure treatment, respectively. As a consequence of the effect of cover crop management on the distribution of N in the zucchini plant–weed system, the yield N ratio showed significant higher values in the ILRC treatment respect to the other two (similar between them). These results could be explained hypothesizing that the cover crop management had an effect on N translocation from crop residues to the zucchini yield, as partially confirmed by the different N content per biomass unit measured in the cropping residues of the three treatments (results not showed). Moreover, the yield N ratio results demonstrated the ILRC technique was able to enhance, in our conditions, the efficiency of N utilization in the system. No differences on N uptake and partitioning were observed between the two tested cultivars.

Statistically significant differences for soil mineral N (results not showed) between the control and the other treatments were observed at DAT −2 and 59 in 2010 and at DAT −4 in 2011. However, in both years the ILRC technology determined the highest absolute soil mineral N values at the end of the cropping cycle.

Southern Italy

Substantial differences in vetch biomass fresh weight were found between years both as GM (36.6 ± 0.56 and 48.7 ± 11.5 t ha^{-1}, for 2010 and 2011, respectively) and RC mulch (27.6 ± 3.7 and 49.7 ± 3.2 t ha^{-1}, respectively). Also, the greatest dry matter was obtained in the treatment with vetch as GM (6.93 ± 0.38 and 6.03 ± 1.42 t ha^{-1} of dry matter in 2010 and 2011, respectively).

The total rainfall observed during the first year was much lower than in the second one (312 and 503 mm, respectively). Therefore, the climatic conditions significantly affected total and marketable zucchini yields. The two-year average of the cover crop management treatments (mean of GM and RC) showed (*Tab. 4*) an increase of 38% in marketable yield compared to the FA treatment. Within each cover crop management system, the GM treatment showed total and marketable yields higher than the FA both in 2010 (significant) and 2011 (not significant). This finding suggests cover crop termination management influence on the succeeding crop yield. The RC presented intermediate response for yield, and this was probably due to a slower rate of mineralization of vetch biomass N after the termination, while the remaining above ground biomass did not completely mineralize during the zucchini cropping cycle. A similar trend was found for the fertilization strategies. The two-year average of the organic fertilizers increased the marketable zucchini yield compared to N0 and was substantially greater in 2010 than in 2011. Among cover crop treatments, no significant difference was found for fruit weight in 2011, though significantly greater number of marketable fruits observed in GM. In particular, no significant difference was found for OAF and WDW treatments (7.0 and 7.4 fruits m^{-2}, respectively), which were greater than MSW and N0 (5.6 and 5.8 fruits m^{-2}, respectively). This result confirmed Canali et al. (2011) who found organic fertilizers and anaerobic digestates show a greater mineralization rate in the soil when compared to compost. Soil application of WDW and MSW can benefit zucchini yields and has a lower risk of environmental pollution. In 2011, no significant differences were found in total and marketable zucchini yields, fruit weight and marketable fruits number among the organic fertilizer strategies.

The mean of mineral N content in the soil was 36 and 26 mg kg^{-1} in 2010 and 2011, respectively (*Fig. 2*). In 2010, the GM treatment showed highest values of soil mineral N content in the first two zucchini growth phases, but at the end of the cropping cycle no significant difference was found among vetch residue management treatments (*Fig. 2a*). In 2011, both the cover crop vetch management treatments showed significantly lower values of mineral N than the FA treatment over the entire cropping cycle (*Fig. 2b*). This result confirmed Leavitt et al. (2011) that suggested cover crop mulches were associated with low levels of soil N in the upper 15 cm. Furthermore, in 2011, the RC treatment showed the lowest values of mineral N in the soil throughout the entire cropping cycle. This finding shows that using alternative cover crop termination methods combined with the application of organic amendments, could be an effective approach to modulate N availability to zucchini crop.

Table 1 Zucchini total yield, zucchini above soil crop residues biomass and weed biomass

	Zucchini total yield ($t\ ha^{-1}$)	Zucchini crop residues ($t\ ha^{-1}$)	Weed above soil biomass ($t\ ha^{-1}$)
Year			
2010	28.6 a	11.3 a	15.8 b
2011	8.3 b	4.4 b	24.4 a
	***	***	***
Cover crop management			
Control	18.5 ab	8.7 a	31.9 a
Green manure	13.7 b	5.1 b	24.9 b
Roller crimper	23.1 a	9.9 a	3.5 c
	**	**	***
Cultivar			
Dietary	18.1	8.7	19.1
Every	18.8	7.0	21.1
	n.s.	n.s.	n.s.
Mean	18.4	7.9	20.1

Table 2 Zucchini marketable yield, number of marketable fruits per plant, and yield quality parameters

	MY ($kg\ plant^{-1}$)	Mf ($n\ plant^{-1}$)	Mfw ($g\ fruit^{-1}$)	Mfd (mm)	Mfl (mm)
Year					
2010	3.7 a	16.7 a	222 b	41 a	211 a
2011	1.0 b	6.1 b	158 a	35 b	177 b
	***	***	***	***	***
Cover crop management					
Control	2.7 a	12.8 a	192	37 b	190
Green manure	1.7 b	8.4 b	189	39 a	197
Roller crimper	2.6 a	12.9 a	187	37 b	194
	***	***	n.s.	*	n.s.
Cultivar					
Dietary	2.0 b	10.0 b	186 b	37	200 a
Every	2.6 a	12.7 a	194 a	38	186 b
	***	***	*	n.s.	***
Mean	2.3	11.4	190	38	193

Table 3 N uptake by the zucchini and the weeds and yield N ratio

	Yield N ($kg\ ha^{-1}$)	Crop residues N ($kg\ ha^{-1}$)	Weeds N ($kg\ ha^{-1}$)	Yield N ratio (%)
Year				
2010	63.7 a	32.1 a	51.7	45.3 a
2011	17.6 b	1.3 b	54.3	29.8 b
	***	***	n.s.	***
Cover crop management				
Control	50.2 a	24.2 a	77.9 a	26.6 b
Green manure	22.8 b	14.7 b	67.6 a	20.6 b
Roller crimper	48.9 a	11.2 b	13.5 b	66.0 a
	**	*	***	***
Cultivar				
Dietary	41.2	17.9	50.6	37.4
Every	40.1	15.5	55.4	37.7
	n.s.	n.s.	n.s.	n.s.
Mean	40.6	16.7	53.0	37.6

Table 4 Zucchini total and marketable yields, fruit weight and number of marketable fruits in 2010 and 2011. Means are presented by cover crop management and organic fertilizer strategies

	2010		2011		2010		2011	
	Total yield ($t\ ha^{-1}$)	MY ($t\ ha^{-1}$)	Total yield ($t\ ha^{-1}$)	MY ($t\ ha^{-1}$)	Mfw (g)	Mf ($n\ m^{-2}$)	Mfw (g)	Mf ($n\ m^{-2}$)
Cover crop (CC)								
GM	17.5a^{z}	16.5a	12.2	8.9	231.0a	7.4a	248.3	12.5a
RC	14.8ab	13.7ab	9.8	7.5	200.6b	6.6a	224.9	9.2b
FA (control)	11.6b	10.3b	10.6	8.1	187.4b	5.4b	228.9	10.8b
	*	**	n.s.	n.s.	*	*	n.s.	*
Fertilizers (F)								
WDW	16.2a	14.9a	9.4	7.4	222.4	7.0a	204.6	9.9
OAF	17.7a	16.7a	12.9	9.6	226.2	7.4a	242.0	11.5
MSW	11.9b	10.8b	10.3	7.7	185.0	5.6b	232.7	10.9
N0 (control)	12.7b	11.6b	10.8	7.9	191.7	5.8b	256.9	12.3
	*	*	n.s.	n.s.	n.s.	*	n.s.	n.s.
CCxF	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Means	14.6	13.5	10.9	8.2	206.3	6.5	234.0	10.8

Note for tables 1-4:
In *tables 1-3*: the mean values in each column followed by a different letter are significantly different according to LSD and DMRT (two and more than two comparisons, respectively) at the reported probability level. n.s., not significant; ***, P ≤ 0.001; *, P ≤ 0.05. In *Table 4*: [z]Within vetch cover crop management and fertilizers strategies, the values in each column followed by a different letter are significantly different according to SNK at the P≤0.05 probability level.
Zucchini marketable yield: MY; number of marketable fruits per plant: Mf; Marketable fruit weight: Mfw; Marketable fruit diameter: Mfd; Marketable fruit length: Mfl. Green manure: GM; roller-crimper: RC; fallow: FA; commercial organic fertilizer animal manure: OAF: anaerobic digestate fertilizer based on wine distillery wastewater: WDW; composted municipal solid organic wastes: MSW; unfertilized control: N0.

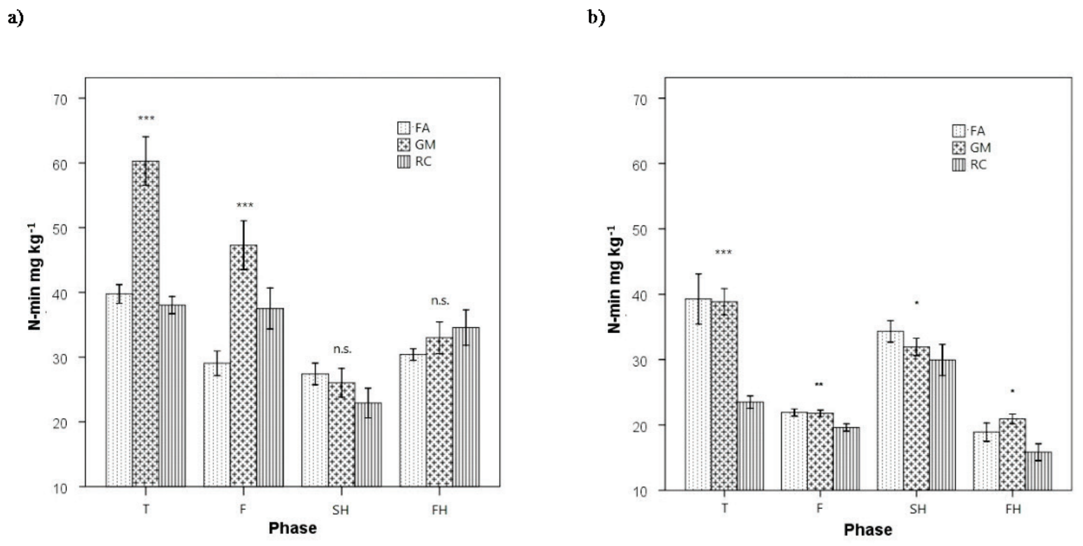

Figure 2 Effects of vetch residue management on mineral N content of the soil in 2010 (a) and 2011 (b) experimental years in southern Italy. *, **, *** = Significant at the P≤0.05, 0.01 and 0.001 probability levels, respectively. n.s.=not significant. The phenological phases of the vetch are: T =transplanting; F = flowering; SH = start of harvest; FH = final harvest.

Conclusion

The results of this study demonstrated that the ILRC technology is feasible and effectively applicable to the organically managed, specialized, vegetable cropping systems of Mediterranean areas. In central Italy, the zucchini cultivated by the ILRC yielded 69% more than the crop preceded by the green manure. Moreover, the zucchini yield quality of the ILRC treatment did not differ from that of the other ones, and the ILRC technique was very effective in weed control. In addition, our results showed that the ILRC system was able to enhance the efficiency of N utilization of the system. In southern Italy organic producers should take into account that cover crop and fertilizing strategies are notably influenced by thermo-pluviometric pattern, as observed in 2010. The RC termination of the vetch seemed to lead to a better nitrate management, thus reducing the risk of leaching. However, further study aiming to evaluate ILRC technology feasibility and effectiveness in a wider range of crops, soils and climate conditions should be promoted.

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(41) Use of textile and organic waste as a substrates for soilless cultivation of greenhouse tomato

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Abstract: *Research on the effect of organic substrates made of textile waste (wool and cotton), supplemented with coconut fiber, sawdust or flax shives, on the yield and chemical composition of greenhouse tomato variety Growdena grown in greenhouses in a prolonged cycle, was carried out in the years 2009 - 2010. Growing media made from textile waste and organic wool differed from almost all of the studied physical properties as compared to rockwool slabs. The organic substrates had higher bulk density (bulk density of the organic substrate was 105 kg/m3, while rockwool had only 62 kg/m3), a lower water content at full saturation (pF 0.0) and greater at higher potentials of 1.5 pF and 2.0 pF. The porosity of the organic substrates was only slightly less than the total porosity of the rockwool and it was higher than 90%. The substrate type had no significant effect on growth, development and yield of tomato plants. Nutritional status of N, K, Ca and Mg in all tested substrates was at a similar level, while the content of P, Fe, Mn, Cu and B was significantly higher in the leaves of plants grown in rockwool.*

Keywords: *substrate, textile waste, physical properties, yield, nutritional status*

Introduction

Rockwool is the main substrate used in soilless cultivation of tomatoes and the problem of its utilization has not yet been solved. Of all the inert substrates used in soilless cultivation, rockwool has the best physical and chemical properties. Rockwool is a homogeneous substrate; the root system develops in exactly the same conditions. This substrate provides accurate control of the amount of water, pH, EC and temperature within the root system. In organic growing media, maintaining the same conditions is practically impossible. Rockwool, like any other substrate, can be infected during the growing season with various soil-borne diseases and usually is used only once in a year-round cycle. Therefore, every year large amounts of waste material is produced. According to Pieters et al. (1998à rockwool constitutes 75% of all post-production waste in greenhouse tomato cultivation. One hectare of tomato greenhouse produce 72 m^3 of rockwool waste material along with 5 tons of plastic (Benoit and Ceustermans, 1989). In comparison to rockwool, organic growing media are fully biodegradable and can be re-used after cultivation as a fertilizer in open field vegetable cultivation (Domeno et al., 2010; Nurzyński et al., 2012). However, these substrates are characterized by high biological sorption of certain elements, especially nitrogen, because of the wide C:N ratio (Gruda and Schnitzler, 1997; Gruda et al., 2000). In soilless cultivation, this sorption has no effect on the availability of nutrients used by plants under the condition of providing the right daily amount of nutrient solution (Komosa et al., 2010). Because of the increasing need to protect the environment from greenhouses waste, research on the development of new biodegradable substrates for soilless cultivation was carried out. The main aim of this research was to determine the effect of substrates made from textile waste (wool and cotton) with addition of coconut fiber and sawdust or flax shives on the yield and chemical composition of greenhouse tomatoes.

Materials and Methods

The research on the effect of the new developed organic growing media with a fibered structure, on the yield and chemical composition of tomato, variety Growdena, was conducted in 2008 and 2010. The main elements used in the production of these new substrates were: sheep wool and cotton waste from the textile industry; stiff, long coconut fiber; pine sawdust; and flax shives. With the use of the textile needling method these materials have been used to create multilayer growing mats of a standard rockwool slab size (7,5 x 20 x 100 cm). The long and stiff coconut fiber has been used as a skeletal structure for these mats. The following types of mats have been tested:

1. wool+cotton+coconut+sawdust – (WCCS)

2. wool+cotton+coconut+flax shives (WCCFS)

3. Rockwool Grotop – Master as a control substrate (Grotop)

The materials used in the production of the mats were used in the same proportions (1:1:1:1). The mats with the substrates in which the tomatoes were cultivated have been placed on suspended gutters. Before planting, the mats were soaked in a nutrient solution with a pH value of 5,3 and EC of 3,0 mS$\cdot$cm^{-1}. After planting, the plants were systematically fertigated in accordance to required climate conditions and growth phase. Fertigation was applied on the basis of the indications of a solar integrator or with a timer every three/four hours. The water used for preparing the required nutrient solutions had the following composition ($mg \cdot dm^{-3}$): HCO_3 – 349, N-NO_3 – 0,25, N-NH_4 – 0,05, P - 0,05, K – 2,72, Ca – 101, Mg – 15,0, Na – 10,5, Cl – 12,9, S – SO_4 – 33,5, Fe – 0,042, Mn – 0,022, Cu – 0,020, Zn – 1,680, B – 0,025, EC – 0,56 $mS \cdot cm^{-1}$, pH – 7,2, total hardness – 17,6 ^{o}dH. Considering the composition of the water used, the nutrient solution used for fertigation, had the following composition: EC –2,8 – 3,5; pH-5,5; N-NO_3 - 200-250; P- 60; K-280-380; Ca-180-220; Mg 60-80; Fe-2,0-2,5; Mn-06-08; Zn-0,33; B-0,33; Cu-0,15. One mat was used to cultivate three plants, plot size was 3 m^2 in 4 replications. The plants were planted in their fixed location in mid-March and were cultivated in a prolonged cycle until the end of October. The fruits were picked twice a week to determine:

- early yield (1/3 of harvest time),
- marketable yield –tomato fruits with diameter >60 mm – extra class, 45-60 mm – I class and 35-45 mm – II class,
- total yield

Physical properties were determined according to methods presented by Aendekerk et al. (2000). The composition of the nutrient solution in the mats was analyzed every three weeks during the cultivation period. Plant nutrition status was determined at the same time, based on the amount of micro- and macro-elements in leaves. Analysis was conducted with the use of the fully grown 5th leaf, counting from the top. Total N content was determined with the Kjeldahl method, N-NO_3 content with the colorimetric method using a Scan-Plus flow analyzer, the levels of P, K, Ca, Mg, Na, Fe, Mn, Cu, Zn, B, Mo – with plasma spectrometry (ICP) using Perkin-Elmer Optima 2000 DV spectrometer. For the plant nutrient content and fruit yield, analysis of variance was performed using the Newman-Keula test to compare mean values at a significance level of α=0,05.

Results and Discussion

Organic biodegradable substrates were characterized by significantly larger bulk density in comparison to rockwool (table 1).The substrate made from wool, cotton, coconut and sawdust had the largest bulk density. Substituting sawdust with flax sheaves caused significant loss in bulk density (WCCFS). The specific density of organic substrates tested in this experiment was similar, while rockwool was significantly higher. Total porosity of organic substrates was high and amounted over 92%, while rockwool was 97,6%. The studied substrates could be characterized by very good water properties. With full saturation (pF 0), rockwool retained 91% of water while organic substrates retained significantly less water (WCCS 76,3%, WCCFS 78,3%). At a water potential of pF 1,0, the amount of water in the tested substrates was similar, while at pF 2,0 the water capacity of rockwool was ten times lower in comparison to organic substrates. Also the air capacity at pF 1.0 of the mineral wool and organic substrates were similar and did not differ significantly.

Table 1 Physical properties of biodegradable substrates and rockwool.

Substrate	Bulk density $kg \cdot m^{-3}$	Specific density $kg \cdot m^{-3}$	Total porosity %	Water capacity			Air capacity		
				pF 0 %	pF 1 %	pF 2 %	pF 0 %	pF 1 %	pF 2%
WCCS	117,7 a	1558,7 b	92,5 c	76,3 b	55,8 a	21,4 a	16,2 a	36,5 a	71,0 b
WCCFS	98,4 b	1562,8 b	93,7 b	78,3 b	64,6 a	23,7 a	15,2 a	28,8 a	70,0 b
Grotop	62,8 c	2606,2 a	97,6 a	91,1 a	66,1 a	2,0 b	10,2 b	31,5 a	98,5 a

Means marked with the same letter do not differ significantly with α=0,05.

Chemical analysis of leaves during the growing season showed a comparable nutritional status of tomato plants with the exception phosphorus (table 2). Plants grown on rockwool contained significantly more P in comparison to those grown in organic substrates. This was caused by lower availability of phosphorus in organic substrates in which the pH value in the root system remained higher during the whole cultivation period. According to Nurzyński et al. (2012), high pH value in the rhizosphere causes worse plant nutrition with P. As in the case of P, plants grown on organic substrates had a lower content of iron, manganese, copper and boron in comparison to tomatoes grown on rockwool (table 3). Despite considerable variation in the average content of mineral elements in leaves, the growth and development of plants was proper and the mineral elements content was kept on an optimal level.

Table 2 Influence of the type of substrate on the content of macro-elements in tomato leaves (2008-2010)

Type of substrate	Content (% d.m.)				
	N - total	P	K	Ca	Mg
WCCS	4,82 a	0,34 b	5,15 a	2,47 a	0,72 a
WCCFS	4,72 a	0,35 b	5,10 a	2,58 a	0,72 a
Grotop	4,62 a	0,40 a	5,34a	2,39 a	0,61 a

Means marked with the same letter do not differ significantly with α=0,05

Table 3 Influence of the type of substrate on the content of micro-elements in tomato leaves (2008-2010)

Type of substrate	Content ($mg \cdot kg^{-1}$ d.m.)				
	Fe	Mn	Cu	Zn	B
WCCS	102,53 b	213,67 b	18,72 b	50,44 a	77,73 b
WCCFS	102,35 b	244,25 b	19,89 b	51,36 a	89,61 b
Grotop	129,89 a	377,04 a	25,74 a	51,92 a	96,28 a

Means marked with the same letter do not differ significantly with α=0,05

The statistical analysis did not show any important differences in total, marketable and early yield of tomatoes grown in the tested substrates (table 4). Slightly higher total and marketable yield of fruit was obtained on rockwool in comparison to organic substrates (respectively 48,02 and 46,79 kg $\cdot m^{-2}$). Soilless tomato cultivation allows for precise control of plant nutrition status and function of the substrate is reduced to the mechanical maintenance of the root system and ensure proper air- water conditions. This gives the possibilities to use various materials as substrates. Sheep`s wool is rich in nutrients required for plant nutrition. It contains large amounts of nitrogen, carbon and sulfur. Górecki and Górecki (2010) found a significant yield increase of tomato grown on a substrates made of peat and sheep`s wool compared to pure peat substrate. Piróg and Komosa (2006) showed that the type of substrate used in soilless cultivation had no effect on yield of tomato.

Table 4 Influence of type of substrate on tomato yield cv. Growdena (2008 2010)

Type of substrate	Yield ($kg \cdot m^{-2}$)		
	Early	marketable	total
WCCS	13,99 a	44,06 a	45,78 a
WCCFS	14,16 a	43,88 a	45,50 a
Grotop	14,55 a	46,79 a	48,02 a

Means marked with the same letter do not differ significantly with α=0,05

Fruit obtained from all tested substrates had good quality, were well-filled, hard, with good internal and external staining. The concentration of mineral nutrients in tomato fruits was at the proper level, with a significantly higher nitrogen content in fruits obtained from plants grown on organic substrates (WCCS). The type of substrate used had no significant influence on the content of other mineral nutrients in the tomato fruits (table 5 and 6). According to Nurzyński (2013), tomato fruits obtained from a crop grown on a substrate made of rye straw and rape straw had a higher content of total N than those grown on rockwool.

Table 5 Influence of the type of substrate on the content of macro-nutrients in tomato fruit (2008-2010)

Type of substrate	Content ($g \cdot kg^{-1}$ d.m.)				
	N- total	P	K	Ca	Mg
WCCS	25,30 a	3,52 a	40,07 a	1,39 a	1,80 a
WCCFS	23,44 b	3,37 a	39,12 a	1,38 a	1,68 a
Grotop	23,07 b	3,59 a	41,71 a	1,41 a	1,85 a

Means marked with the same letter do not differ significantly with α=0,05

Table 6 Influence of the type of substrate on the content of micro-nutrients in tomato fruit (2008-2010)

Type of substrate	Content ($mg \cdot kg^{-1}$ d.m.)				
	Fe	Mn	Cu	Zn	B
WCCS	39,33 a	20,40 a	11,36 a	32,06 a	26,99 a
WCCFS	37,74 a	19,40 a	9,71 a	30,11 a	27,34 a
Grotop	39,08 a	23,87 a	10,75 a	30,46 a	20,82 a

Means marked with the same letter do not differ significantly with α=0,05

Conclusion

1. Substrates made from textile waste and other organic materials had different physical properties (porosity, bulk and specyfic density water and air capacity) in comparison to rockwool.

2. Plant nutrient status with N,K,Ca,Mg and Zn on all tested substrates was at the same level, while the content of P, Fe, Mn, Cu, and B were significantly higher in leaves in plants grown on rockwool.

3. There were no significant differences in tomato yield from plants grown on rockwool or organic substrates.

4.The nutrient content in tomato fruits was at a similar level with the exception of nitrogen, whose content was significantly higher in fruit harvested from plants grown in an organic substrate with the addition of sawdust.

Acknowledgements

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(42) Method using gas chromatography mass spectrometry (GC-MS) for analysis of nitrate and nitrite in vegetables

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Abstract: *Accurate analytical methods are very important to detect the contents of chemical substances in vegetables and fruit. There is particular interest in nitrate and nitrite, due to their possible benefits and harm on human health. The aim of this research is to modify the method of measurement of nitrate and nitrite by GC-MS for use in vegetables. Many procedures are available to measure nitrate (NO_3) and nitrite (NO_2). Some examples are: capillary electrophoresis, spectrophotometry using the Griess reaction, various HPLC methods and different types of isotope dilution GC-MS: with electron ionisation by nitration of mesitylene, and with chemical ionisation by derivatisation with pentafluorobenzyl bromide. However, some of these methods are mostly used in research on human health, to measure nitrate and nitrite in human biological fluids such as plasma or urine. Methods developed for analysis of vegetable samples often give variable results, for example due to interference from coloured compounds in the plant material. Therefore, we tried to modify the GC-MS method using pentafluorobenzyl bromide and chemical ionisation to optimise it for analysis of nitrate and nitrite in vegetable samples. Experiments were carried out to maximise peak area, in particular for nitrate. Factors that were tested were gas pressure, derivatisation reaction time and temperature, duration of nitrogen flushing, time of vortex after adding toluene during sample preparation, and amount of water added to separate the phases. The modified method was used to analyse contents of nitrate and nitrite in samples from a range of different vegetables.*

Keywords: *Nitrate; Nitrite; GC-MS modified; Vegetables*

Introduction

Vegetables are important constituents of a healthy diet. Adequate daily eating of vegetables can help reduce the major risk of diseases, including cardiovascular diseases, cancers, obesity and diabetes (World Health Organization, 2003). In addition, vegetables are also naturally rich in nitrate (Lundberg et al., 2004).Intervention studies have shown that short-term intake of inorganic nitrate decreases blood pressure in healthy volunteers (Siervoet al., 2013).The main risk of nitrate in vegetables is from its conversion to nitrite, creating methaemoglobin by reacting with haemoglobinafter ingestion, where the foetal haemoglobin in infants is particularly susceptible (Greer and Shannon, 2005).

Therefore, the determination of the nitrate and nitrite levels in vegetables is important in order to evaluate their safety for consumers (Correia et al., 2010).Analytical methods have an important role in nitrate and nitrite analysis of vegetable samples and there are several procedures available. For example, capillary electrophoresis can be applied to measure high amounts of nitrate in vegetables. However, the samples must be diluted because of interfering oxalate in the same vegetables such as in spinach and tomato (Jimidar et al., 1995). The most commonly used method is the colorimetric method based on the Griess reaction. This method is very popular and of low cost but it has a number of drawbacks. It is only accurate within a narrow concentration range and is therefore difficult to use for measuring the very variable nitrate content in vegetables. Also, the colour reaction is susceptible to interference from the dark colour in samples such as beetroot, red chard and cabbage. Additionally, a standard curve is needed in every test session because the changes in any conditions such as temperature affect the results. In addition, there is interference between nitrate and nitrite. Several other methods were developed for analysis of nitrate and nitrite in human samples, but they require more modification to become suitable for analysis of vegetables. Among them a GC/MS method using pentafluorobenzyl bromide (PFB-Br)and ^{15}N-labelled nitrite and nitrate as internal standards is very accurate and useful to investigate nitrite and nitrate metabolism and reactions in the human body (Tsikas, 2000). However, this method was developed for human fluids. This method measures the nitrate and nitrite contents simultaneously in the same sample based on isotope dilution. The isotope dilution means that the measured concentration values depend on the relative sizes of peaks with different molecular mass, not on the absolute size of the peaks. This makes the method exceptionally robust in relation to any external factor affecting peak size. Measurements are accurate across a range of more than 3 orders of magnitude, as long as the peaks are large enough for accurate measurement of their areas, and the volumes of sample and spiking solution are measured accurately.

The main aim of this study is to modify the PFB-Br GC/MS method to develop an improved method for analysis of nitrate and nitrite in vegetable samples.

Materials and Methods

Sample preparation:

Several vegetable samples (radish, tomato, red cabbage, red chard, mizuna, lettuce and beetroot) were used in this study; some of them have high nitrate content and others have low nitrate content. All samples were prepared by homogenising approximately 14 to 16g of vegetables mixed with 15-25ml of de-ionized water using an Ultra TurraxT-25 for at least 1 minute and allowing the separation of residue and sample solution by centrifugation.

A high amount of plant materials per sample was used to obtain a high concentration of nitrate and nitrite in the extracts and to reduce random variation caused by variable concentrations in different parts of the sample (Anderson and Case, 1999). Direct homogenisation of fresh frozen samples prevented potential problems related to insufficient hydration of dry material or sequestration of nitrate in intact plant cells.

Reagent and Chemicals:

Sodium [^{15}N]Nitrate (15N, 98%+) and Sodium [^{15}N]Nitrite (15N, 98%+) from Cambridge Isotope Laboratories, Inc. (USA). 2,3,4,5,6-Pentafluorobenzyl bromide 99%from Sigma-Aldrich (Germany). Nitrogen compressed gas (oxygen free) and methane (low ethylene) from BOC gases (UK). Toluene (reagent grade) and acetone (general purpose grade) from Fisher Scientific (UK).

For each of the following steps, two or more variants were tested to determine which version would give the best results with vegetables: gas pressure, derivatisation reaction time and temperature, duration of nitrogen flushing, time of vortex after adding toluene during sample preparation, and amount of water added to separate the phases. In each case by analysing duplicate subsamples of 5-10 vegetable extracts with each method in one session. The volumes of sample and all reagents were doubled compared with the original method, since sample volume is not a limiting factor for vegetable samples. Other variables such as column type, ionisation temperature etc. were as described by Tsikas (2000).

The aim of each comparison was to maximise the peak area of nitrate, because this determines the sensitivity of the method (how low concentrations can be measured) and the precision (random variation).

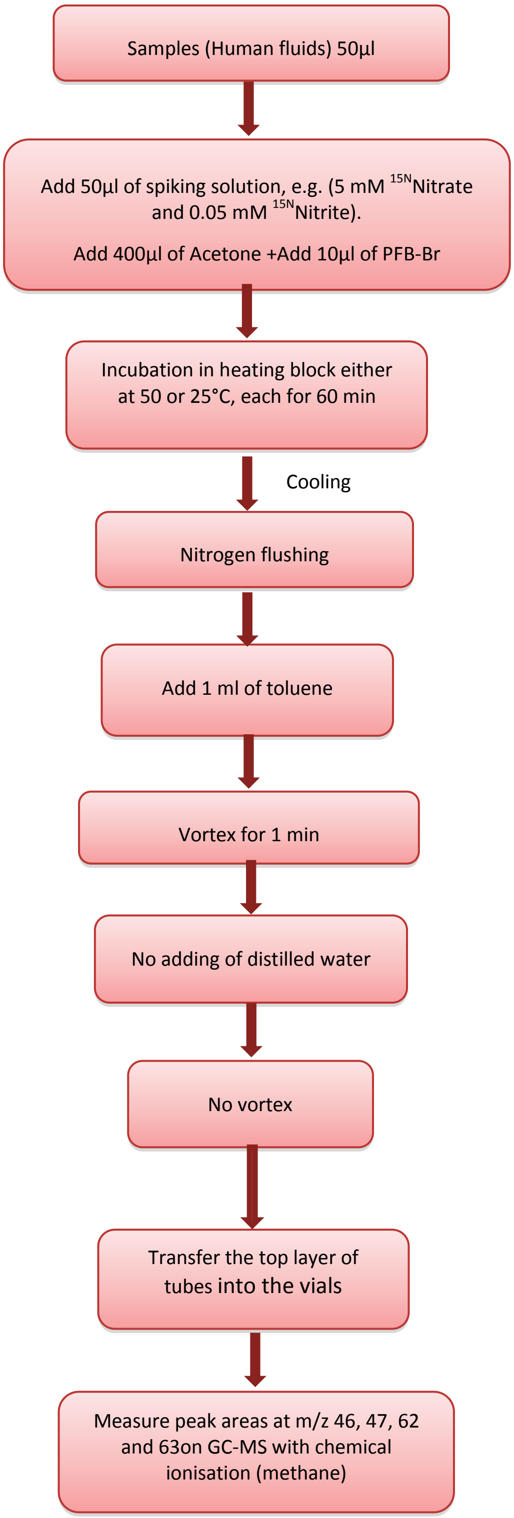
The nitrate content was calculated by the following equation:

Nitrate content (mM) = 5*[^{14}N] nitrate peak area/ [^{15}N] nitrate peak area

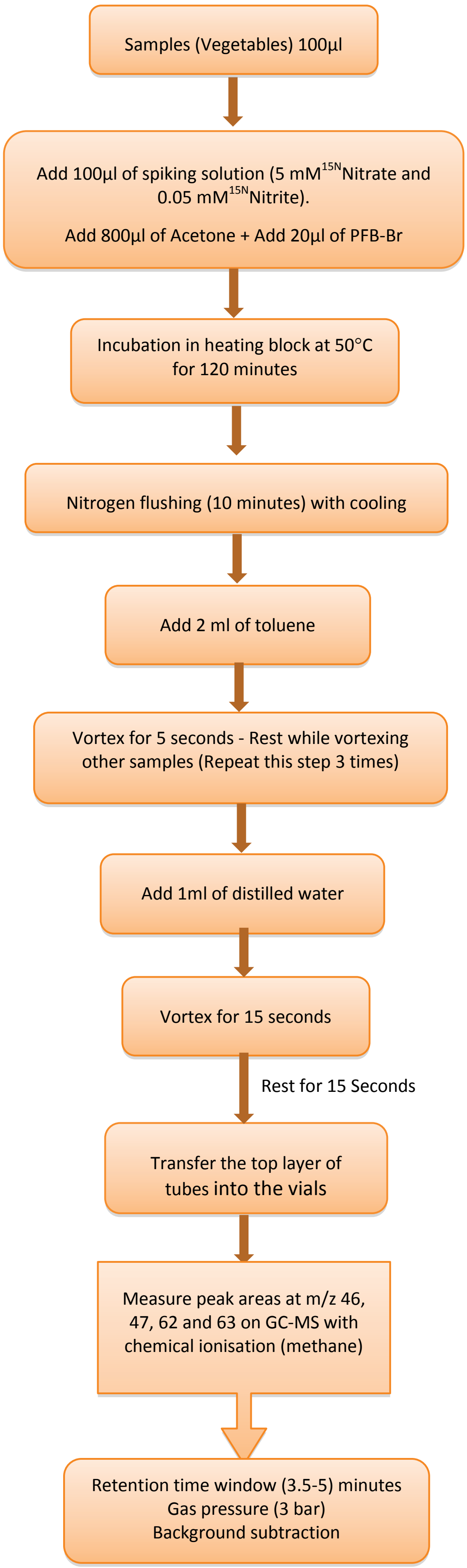
Statistical analysis was performed using the Minitab 16 software. The data were analysed using analysis of variance (ANOVA General Linear Model) and logarithmic transformation of the data. The results were presented as the back-transformed mean + SE (standard error of the mean), and significance at $p < 0.05$.

Sample preparation procedure for GC-MS:

Tsikas' method



Modified method



Results and Discussion

Gas pressure:

The pressure of the methane ionisation gas is important for the size of the peaks in the GC/MS chromatogram. Due to this, we adjusted the gas pressure through testing of different gas pressures from low (1 bar) to high (3.5 bar). The best result was obtained with 3 bar for both nitrate and nitrite (Figure 1).

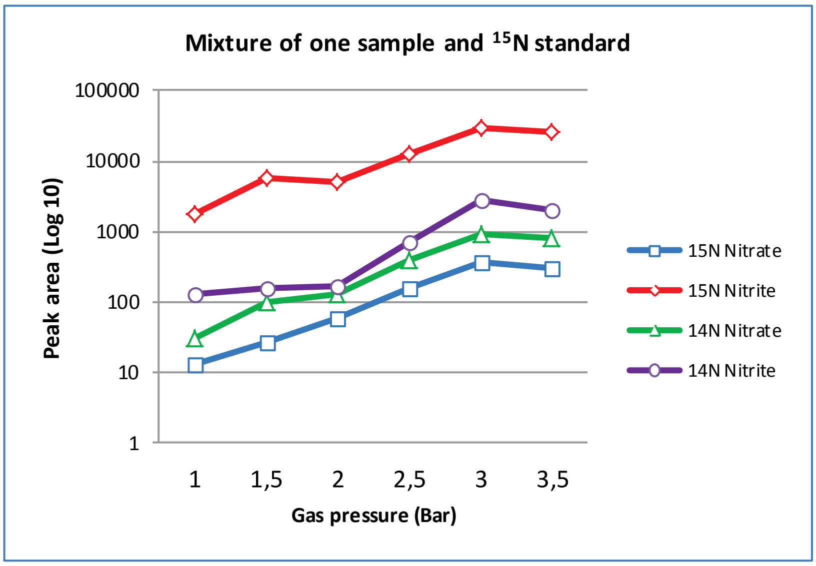


Figure 1. The effect of gas pressure on the sizes of nitrate and nitrite peaks in the GC/MS chromatograms

Retention time window:

The retention time window interval where chemical ionisation takes place during the analysis was modified through comparing different retention time windows before the first peak (which comes at 3.6-3.8 minutes). There was a significant difference between the long retention time window (RT Long 2-5 minutes) and short retention time window (RT Short 3.5-5 minutes), as shown in Figure 2.

Incubation:

Reaction time has an effect on the making of PFB-NO_3 and PFB-$NO_2$from PFB-Br during incubation on the heating block. Optimal times and temperatures of incubation on heating block were determined in three different experiments through comparing different time periods and temperatures; 50°C/120min versus 50°C/90min; 50°C/60min versus 50°C/90min; and 50°C/90min versus 60°C/60min. The results were that there was no significant difference between 50°C/90min and 60°C/60min. On the other hand, there was a highly significant difference in results for 50°C/120min and 50°C/90min and we found that the (50°C / 120min) treatment is the best condition for formation of PFB-$NO_2$and in particular PFB-NO_3. However, there was also a highly significant difference in experiment of 50°C/60min and 50°C/90min but here the peak areas of nitrite were very small so these conditions were not useful for our experiment (Figure 3).

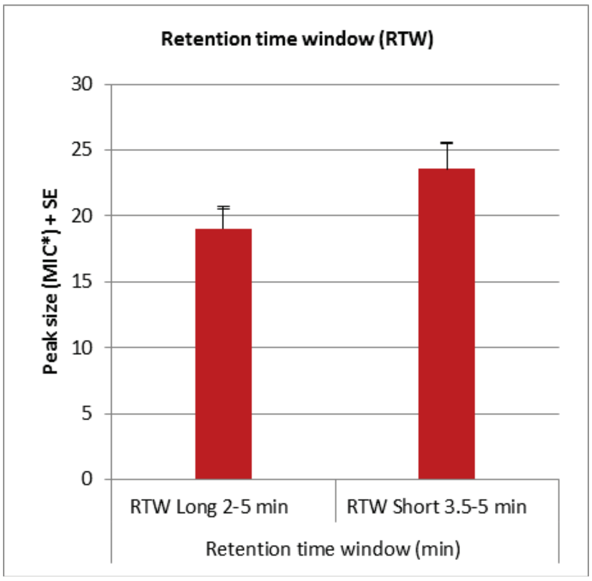


Figure 2. The difference between long and short retention time windows of GC-MS. *MIC: Multi ion current.

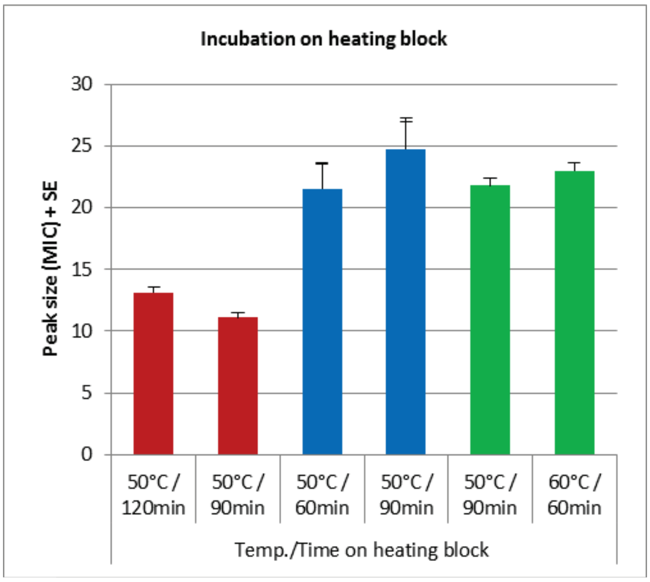


Figure 3. The effect of different time and temperature during the incubation step of sample preparation for GC-MS

Nitrogen flushing:

Dry nitrogen flush was used to remove the acetone after the derivatisation reaction was complete. However, too much or too little flushing gave samples where it was difficult to separate the phases afterwards. For this reason, we tried different periods of nitrogen flushing. Figure 4 shows that there was a highly significant difference between 10 and 20 minutes of nitrogen flushing; the best results were obtained with 10 minutes because if the mixture resides for longer time it will get dry and it may make other interfering organic compounds. No change was observed when comparing between 10 and 15 minutes of nitrogen flushing.

Adding distilled water (DW):

Adding distilled water (DW) was introduced to make it easier to separate the organic phase from the extracted samples before transferring the top layer to vials, without interfering with the reaction with acetone. The observations of adding different amounts of DW for first experiment (0.5 and 1 ml of DW) showed no significant differences. The results were the same for the second experiment (1.5 and 1 ml of DW). As a result, 1 ml of DW was chosen since it gave us a sufficient amount of supernatant phase after toluene evaporation (Figure 5).

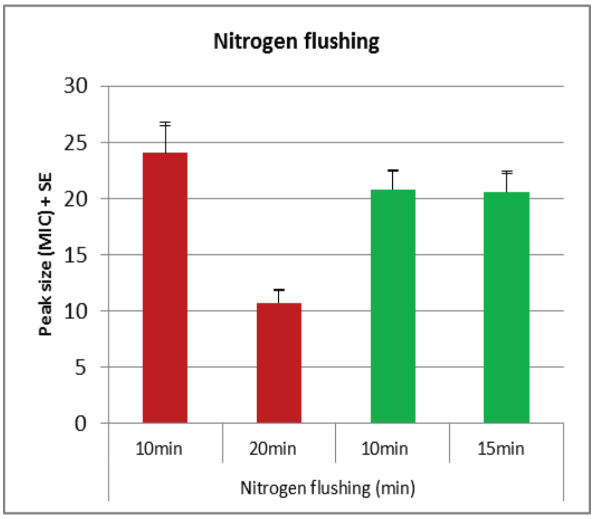


Figure 4. The effect of different time of nitrogen flushing

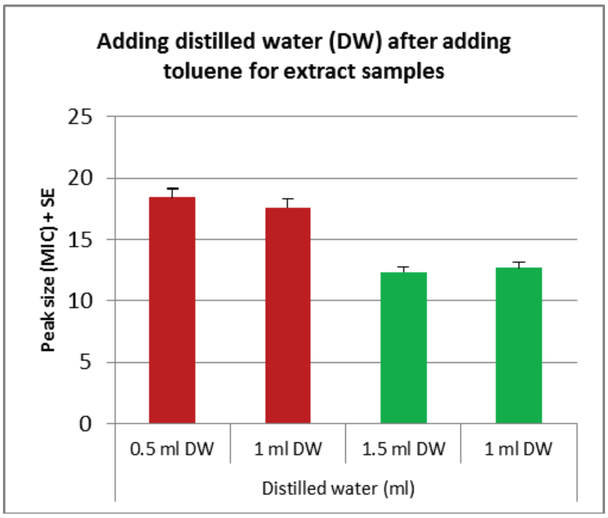


Figure 5. The effect of amount of distilled water added

Vortex after adding toluene:

Vortex mixing for samples is important to complete the chemical reaction among chemical material and different phases during sample preparation, e.g. after adding toluene or other materials. There was a highly significant difference between vortexing for 5 seconds and without vortex; the peaks of nitrite were particularly small without vortexing. On the other hand, there was no significant difference for vortexing for 60 sec and 15 sec and vortexing for 60 sec and 30 sec. The difference in effect of interval vortexing for 5 seconds and resting between vortex periods repeating 3 times was highly significant compared with vortexing for 60 seconds. This method of mixing was better than other methods tested (Figure 6).

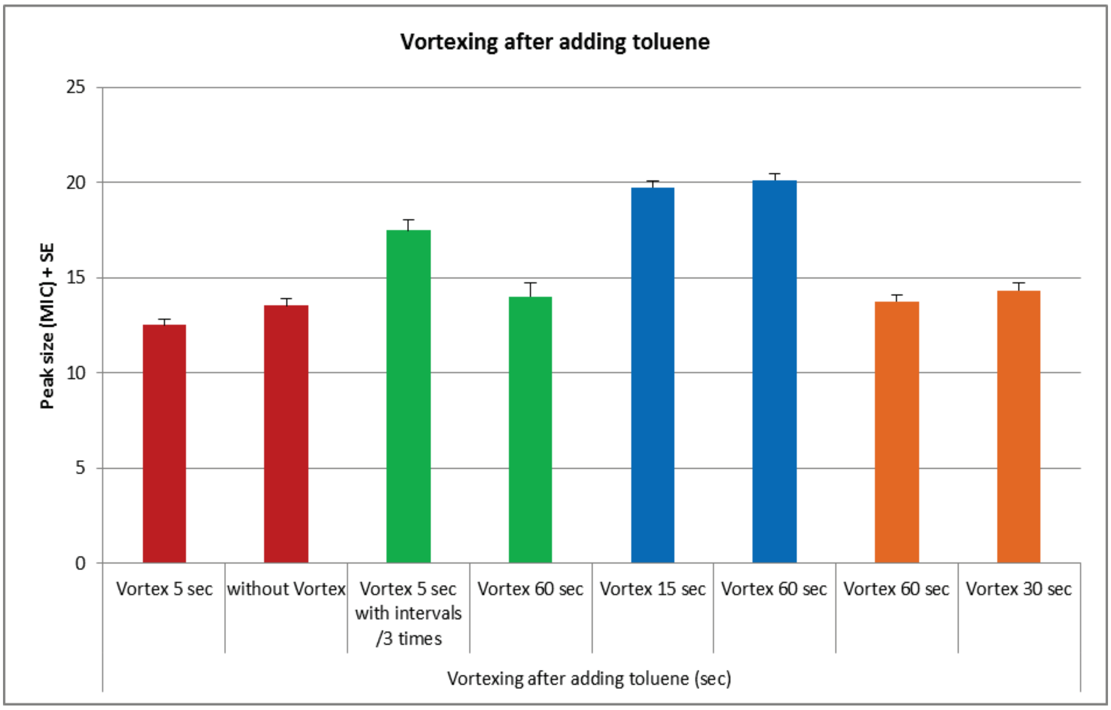


Figure 6. Mean of values for vortexing samples after adding toluene

Examples of measurement of contents of nitrate and nitrite:

In Table (1) and (2) shows a few examples of measurements by the GC/MS modified method for different types of vegetables. The nitrate content of samples was calculated from the ratios of the peak areas with known concentrations of [^{15}N]nitrate. The mass spectrometric detection was obtained in selected-ion monitoring (SIM). Since the commercially available [^{15}N]nitrate contains a small amount of [^{14}N]nitrate, a blank sample can be used to determine this background content and subtract it before calculating the concentration in the sample. This is important particularly in vegetables that have a low content of nitrate such as tomato. Additionally, nitrite content can be measured in the same way as nitrate in vegetables.

Table 1. Examples of recorded data including peak areas (SIM) of nitrate and nitrite in the GC/MS chromatograms in different types of vegetables.

Vegetables	Weight of sample (g)	Total volume (ml)	15Nitrate peak area	15Nitrite peak area	14Nitrate peak area	14Nitrite peak area
Blank			5420	12123	310	1479
Tomato	15.67	50	2893	8233	183	3414
Lettuce	20.20	40	11124	6685	89386	2708
Radish	15.25	50	7465	8043	16514	6410
Rocket	15.57	50	4840	9339	28963	2527
Red Cabbage	15.08	50	1715	2268	405	159
Mizuna	15.42	50	1721	3285	8337	514

Table 2. Examples of calculations of the amount of nitrate contents in samples and vegetables.

Vegetables	In Samples			In vegetables	
	Nitrate content (mM)	Nitrate content adjusted (mM)	Nitrate content (mg/kg)	Nitrate content (mM)	Nitrate content (mg/kg)
Blank	0.29				
Tomato	0.32	0.03	1.88	0.1	6.0
Lettuce	40.18	39.89	2473	79	4898
Radish	11.06	10.77	668	35.3	2190
Rocket	29.92	29.63	1837	95.2	5900
Red Cabbage	1.18	0.89	55.5	3.0	184
Mizuna	24.22	23.94	1484	77.6	4811

Calculated using data from Table 1

Conclusion

The modified GC-MS method is a very accurate and relatively rapid method for the determination of high and low contents of nitrate and nitrite in various vegetables. Due to its large dynamic range, there is no need for extensive dilution of samples, irrespective of initial nitrate content. There was no interference with other compounds, which can occur when using the Griess method. However, the method has a limited capacity (72 samples per 24 hours) and the equipment is very expensive.

Acknowledgements

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The research assistance of Mr. Christopher Johnson is gratefully acknowledged.

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(43) The Flemish approach to reduce nutrient losses from soilless horticulture: legislation to practice

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Abstract: *Since the manure decree of December 22th 2006, soilless horticulture growers have to take measures to prevent nutrient leakage to the environment. Monthly data from fresh surface water monitoring stations in areas with high concentrations of soilless horticulture however kept showing typically high concentrations of nitrates in summer, initially coming from soilless horticulture.*
In 2009 the Flemish Land Agency started visiting greenhouses with soilless horticulture (approx. 1,000 in Flanders) to monitor sources of nitrate leakage and to stimulate growers to take necessary measures to reduce nutrient losses. Nitrate concentrations are measured in surface water courses with colorimetric test strips showing concentrations from 10 – 500 mg/l NO_3^-. During the visit growers are immediately confronted with actual nitrate concentrations in different water flows. Although the strips give only an indication of the amount of nitrates in the water flow, this technique has proven to be highly suitable to enhance the grower´s awareness. In dialogue with the grower achievable solutions are proposed and discussed and the timing for implementation is agreed and checked. Several causes of nutrient leakage in greenhouses with soilless horticulture have been discovered since 2009. The used approach to reduce nutrient losses from soilless horticulture has recently resulted in great reductions in measured nitrate concentrations in some fresh surface water monitoring stations. On the poster the way of working will be presented, as well as different problems of nutrient leakage, reactions of horticulture growers and results.

Keywords: *Nitrates Directive; greenhouse growers; environment; recommendations; grower's awareness*

Introduction

While nitrogen is a vital nutrient for growing crops, high concentrations in water is harmful to people and nature. The EU Nitrates Directive (91/676/EEC) aims to protect water quality across Europe by preventing nitrates from agricultural sources to pollute ground and surface waters. Under the Directive, all Member States have to draw up an action programme every four years and to follow up the nitrate concentration in water bodies. Good monitoring is crucial and obliged to set up high-quality monitoring networks for ground, surface and marine waters. Flanders has a dense monitoring network.

The Groundwater Directive (2006/118/EC) confirms that nitrate concentration must not exceed the threshold of 50 mg/l. Despite the progress in water quality in Flanders, data from some fresh surface water stations show occasional nitrate levels far above 50 mg/l. Monthly data from fresh surface water monitoring stations in areas with high density of soilless horticulture typically show high concentrations of nitrates in summer, thus indicating leakage of nutrients from soilless horticulture.

In Flanders, the action programme is elaborated in the Manure Decree. Since the Manure Decree of December 22nd 2006, soilless horticulture growers have to take measures to prevent nutrient leakage to the environment. Greenhouse growers are allowed to apply drain water that is unsuitable to reuse in the greenhouse as fertilizer in outdoor agriculture. Since January 1st 2011, greenhouse growers are obligated to install minimal storage provision for drain water (Table 1). Legislation includes building codes for the construction of drain water basins.

The Flemish Land Agency has data about 1,000 horticulturists in Flanders with soilless crop systems, open air included. Data are collected from horticulturists with a minimal acreage of 50 are. The need to inform greenhouse growers about the new legislation initiated the development of a specific approach in horticulture. When visiting numerous horticulturists, the aim was to give the grower a clear, to the point and personal recommendation, and to gather additional knowledge in practice. Follow-up of growers' engagements to reduce nutrient leakage makes it necessary to deliver a written recommendation. The Flemish Land Agency decided to visit all soilless horticulture growers in the period 2009-2014.

In former experiences to measure water quality in water streams, we found out that cheap nitrate test strips can be an appropriate tool to visualise nutrient leaking to growers.

For the development and evolution of the participation of the horticulture sector, see abstract 128: "Nitrates Directive in Flanders' horticulture: towards nutrient management through participation".

Table 1 Minimal storage provision for nutrient solutions in greenhouse horticulture (* For chicory, minimal storage provision is expressed as m³/hydro-forcery)

Crop	Minimal storage provision (m³/ha)	
	without water recycling	with water recycling
Strawberries - glass cover	240	20
Strawberries - plastic cover	130	20
Eggplant	750	30
Azalea	270	45
Tree nursery	270	-
Floriculture	630	20
Other berries than strawberries	113	15
Cucumber	750	30
Other crops	750	30
Sweet pepper	750	30
Lettuce	-	30
Cut flowers	2400	400
Tomato	750	30
Chicory	36*	-

Materials and Methods

All soilless horticulturists are obliged to deliver data about used nutrients, cultivated area, crops and drain water storage provision on a yearly basis. These data are studied before visits are planned.

An air photo is used to pre-indicate potential surface water spots for water sampling (Figure 1) upstream and downstream the greenhouse/production facility if possible. If an official fresh surface water monitoring station is present in the neighbourhood, the results of the monitoring station are announced to the grower (Figure 2). Nitrogen concentrations measured at the monitoring station are discussed with the grower during the visit.

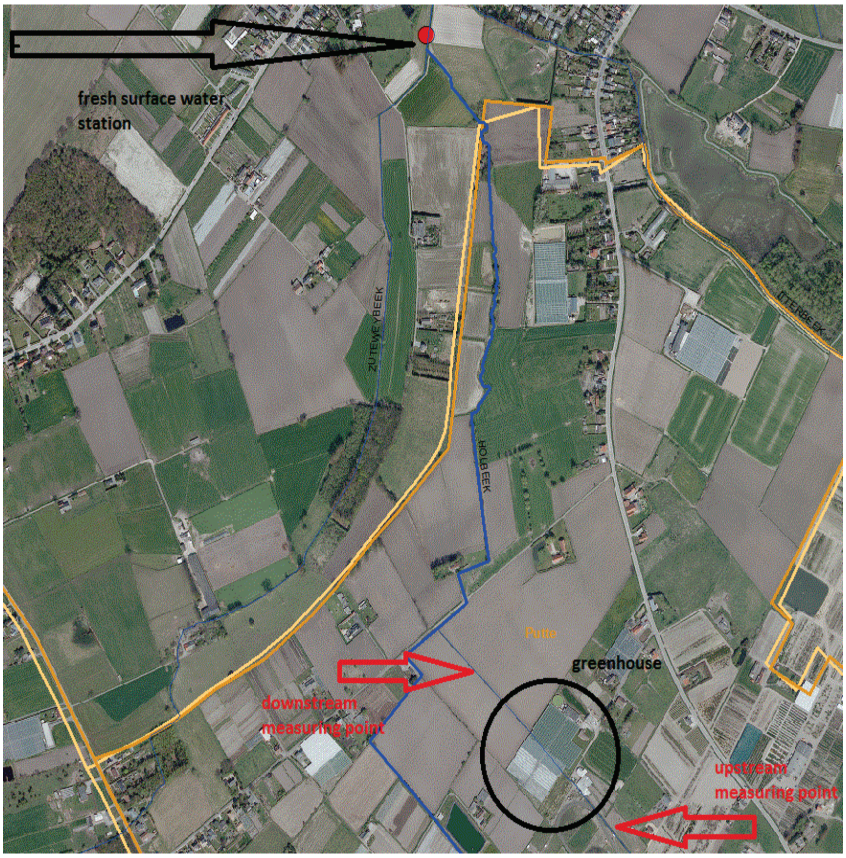

Figure 1 Air photo with indication of possible sampling spots and the nearby surface water monitoring station

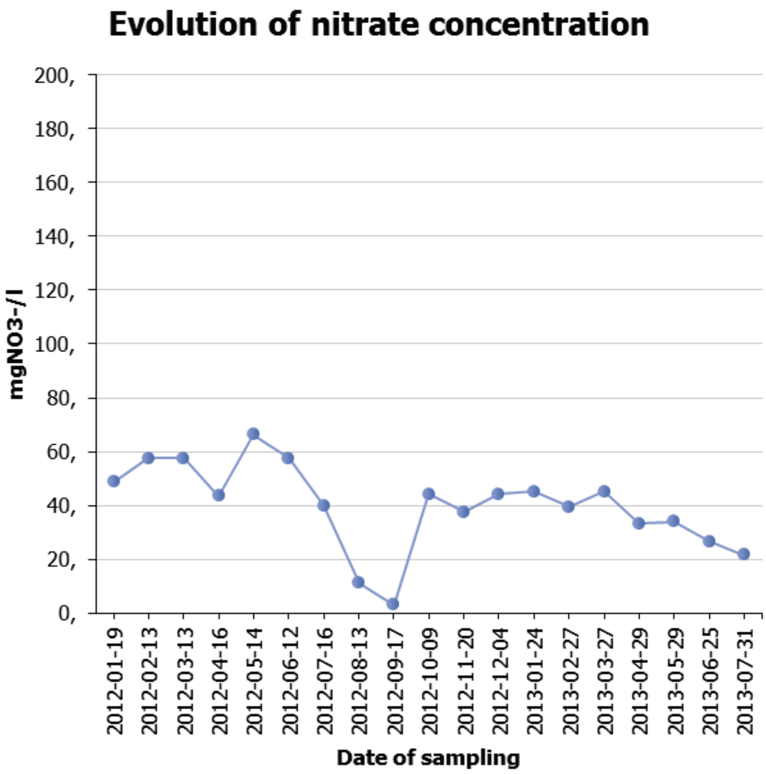

Figure 2 Example of the results of surface water monitoring (source: VMM, Flemish Environmental Organization)

Growers are contacted one week before the visit. The manufacturing of the nutrient solution, the water recycling system and water basins are explicitly observed during the visit, which takes at average one hour. The circuit of irrigation water is mapped and every section of the hydroponic system is explored e.g. nutrient unit, drippers, drain gutter, tube connections. Special attention is given to discharge water flows, which are all sampled.

Colorimetric nitrate test strips are used to rapidly detect the presence of nitrates in water flows on and around the production facility (Figure 3). It takes one minute to obtain an optical result, visualising nitrate presence from 10 to 500 mg/l. Drain water can contain up to about 1,200 mg nitrate/l. As higher levels of nitrate result in a more intense tint, the nitrate concentration of the sample can be determined by comparing the colour of the test strip to the colour scale on the test tube.

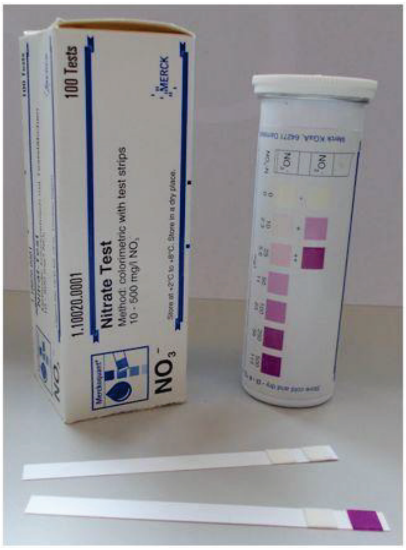

Figure 3 Nitrate test tube and tinted test strips

Together with the grower, all encountered water flows in the vicinity of the production facility and inside a greenhouse are tested. If nutrient leakage is detected, achievable solutions are proposed and discussed with the grower. Once the implementation of proposed improvements is agreed upon, a time schedule is made in dialogue with the grower in order to achieve a feasible timing.

Within two weeks after the visit, the grower receives a written recommendation including all discussion points and a time schedule to take action.

Results and Discussion

Till so far, about 600 of the 1,000 soilless growers in Flanders have been visited and received a personal written recommendation. Yearly about 200 growers are visited. In the course of these visits, widespread practices of drain water discharging and leaching were listed (Table 2).

A major result is the awareness of the grower achieved using test strips. Quiet often the grower asks to sample other water streams on or near the production facility. Most growers are affiliated with the meaning of nutrient concentration in water. Growers measure the electric conductivity (EC) of their nutrient solution through a portable EC-meter. If necessary using the EC-meter will convince the grower that the measured water flow contains nutrient solution.

Leaching of nutrients is observed in both hydroponic systems with gutters hanging above ground level and hydroponic systems standing on the ground. However, the cause of leaching is more difficult to identify in cultivation systems on agricultural foil lying on the ground. Profound investigation of the nutrient recycle system is sometimes only possible at the moment of crop renewal.

Some greenhouses are accommodated with a drainage system to evacuate ground water. Frequently high nitrate concentrations (even more than 500 mg/l) are measured in the discharged groundwater, which indicates leaching of nutrient solutions applied to the soilless crops. Straight draining of this groundwater has a major influence on nitrate concentrations in fresh surface water. Using this groundwater offers a partial solution to reduce nitrate concentrations in surface water. It is assumed that not all the polluted groundwater can be collected by the drainage tubes.

Collection of drain water in outdoor propagation fields of strawberry tray plants and ornamentals is sometimes problematic. Storage provision to collect all drain water when heavy rainfall occurs could be out of proportion. Due to the findings from visits by the Flemish Land Agency, a demonstration project, co-financed by the European Commission, is in progress to investigate technical solutions hereof.

Horticulturists of age are difficult to persuade into taking expensive measures to prevent nutrient leaching from the hydroponic system. Their greenhouse and nutrient system are often outdated. In such exceptional cases, it is recommended to return – when possible – to a soil bound system. It is presumed that soilless horticulture transposes higher amounts of nutrient solutions, resulting in a higher risk of polluting than soil bound cultures. Nevertheless, good agricultural practice is essential in both systems.

It is hard to find a linear relationship between improving nitrate measurements in fresh surface water stations and the visit because other greenhouses and/or agricultural activities can also influence nitrate concentrations in the monitoring stations. In some cases, however, no exceeding of the nitrate limit was measured since the visit (Figure 4) or at least nitrate concentration had decreased.

Table 2 Identified problem and corresponding recommendation

	Type of offence	Recommendation
Accidental leakage of drain water or nutrient solutions	The agricultural plastic foil whereupon drain water is collected is gnawed by mice, torn or even cut	Replace the foil before next cultivation
	Drain gutter is not properly draining	Replace drain gutter and/or reconstruct soil profile before next cultivation
	Tube connections of the water recycle system are leaking	Reconnect tubes properly, thus preventing any leakage before next cultivation
	Drippers cut or not properly placed in growing medium	Check position of drippers regularly, replace at once if necessary
	Nutrient solutions applied on propagation fields of strawberries (soilless) in open air without any collection of drain water	Install a system for collecting drain water and reuse drain water if possible
Major leakage of drain water	Drain water is not collected at all	Install a catch system before next cultivation or return to a soil bound cultivation system
	Drain water is only (partly) collected by the drainage system underneath the greenhouse	Install a catch system above ground level before next cultivation or return to a soil bound cultivation system
Discharge of (drain) water with high concentration of nitrate	Water from sand filter backwashing	Reuse as drain water after deposit of dirt particles or apply as fertilizer to other outdoor agricultural crops before next cultivation
	Overflow of nutrient recycle system	Definitively remove the overflow and replace by an overfill warning system
	Groundwater of the drainage system underneath the greenhouse contains high nitrate concentration caused by leakage of the hydroponic system	Until the cause of nutrient leaking is handled, apply as fertilizer to outdoor agricultural crops or reuse as drain water
	One or more valves of irrigation unit are not closing properly resulting in evacuation of nutrient solution or drain water	Avoid any outlet on the nutrient solution system to fresh surface water
	Condensate of condensing boiler (often a source of nitrite)	Discharge in an appropriate way: apply on grassland or study possibilities to (re)use it as nutrient source
Improvements on data submitted to the authorities	Inadequate or wrong data on: type of crop, type of production method (soilless, greenhouse), acreage and/or perimeter of the field plot, use and type of irrigation water, acreage of arable land or grassland.	Submit the right data in the future and call for an adjustment of earlier registrations within 14 days
	Horticulturist not registered	Submit your registration within 14 days
Obligation to install storage provision	Insufficient storage provision	Install additional provision before the next cultivation and evacuate drain water meanwhile as fertilizer on grassland or request for a water survey to demonstrate that available storage provision is sufficient for your cultivation method

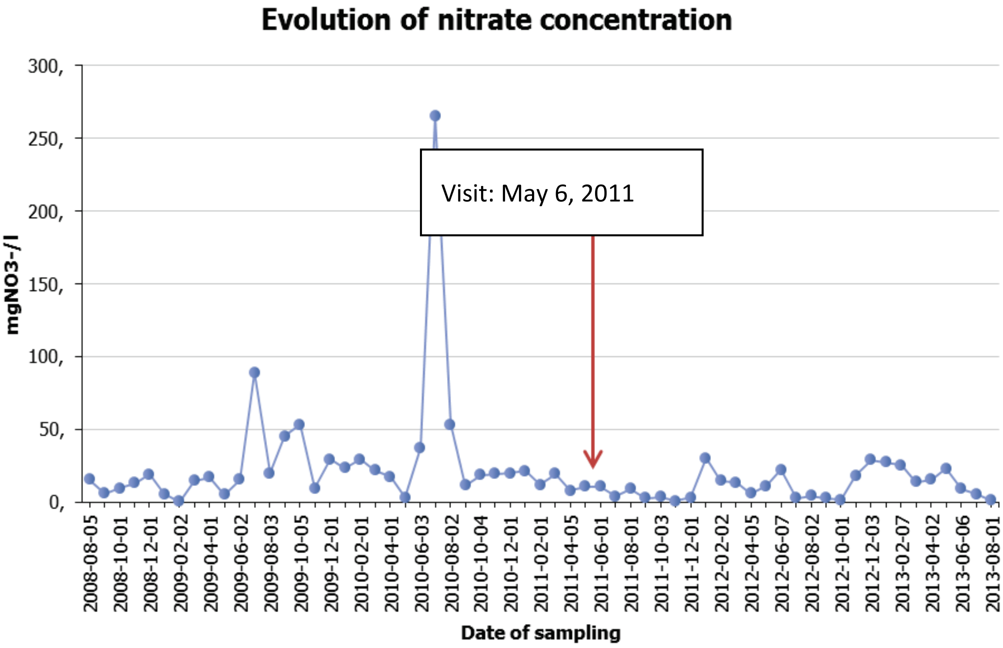

Figure 4 Nitrate concentrations measured in monitoring station downstream visited greenhouse; based upon the information of the horticulturist, the value of 265 mg nitrate per litre the 1st of July 2010 could be due to failure of the disinfection system, drain water was discharged at that time

Long-term ratification of the results has to be confirmed. Therefore, supervision on the implementation of discussed adjustments is recommended. In 2013, the control office of the Flemish Land Agency has started supervision of soilless growers. This control office works independently from the advisory office that did the visits discussed in this paper.

In July 2013 there were hot weather conditions. The Flemish Land Agency noticed horticulturists were discharging drain water in to fresh surface water due to technical problem and insufficient storage provision. The flood of drain water was too fast to process, resulting in overflow as shown in Figure 5. In these cases growers have to take short term action like spreading out on grassland.

Figure 5 Overflow recycling system for drain water during sunny and warm weather

Conclusion

The approach to use colorimetric nitrate test strips to visualize nutrient leaching makes the horticulturist aware of the environmental problem. The test strips visualize nutrient leaching and confront the grower with high nitrate levels in the surrounding of the production facility. Once growers have recognized their contribution to high nutrient concentrations in fresh surface water, many of them take up the recommendation for improvement.

Although the strips give only an indication of the nitrate concentration, this technique has proven to be highly suitable to enhance grower's awareness.

In some cases, there seems to be a direct relationship between the improved water quality and the visit.

(55) In search of the optimal N fertigation dose for ‘Conference’ pear trees

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Abstract: *Fertigation is the dispersion of fertilizers trough an irrigation system and allows a precise distribution of the nutrients in the root zone. Fertigation is often used in combination with drip irrigation in ‘Conference’ pear tree in Belgium and the Netherlands to maximize fruit yield. To optimize the efficiency of the N fertigation, the fertigation can be applied at the end of the vegetative growing period at the beginning of fruit maturing. This way vegetative growth of the pear tree is minimized while fruit yield is maximized. In search for the optimal N fertigation strategy this study discusses the effect of three different fertigation doses (0, 25 kg N, 50 kg N), applied six weeks before harvest, in a humid and a dry irrigation treatment. The experiment was conducted in three different fruit orchards with varying soil profiles and plating systems in two successive years (2008-2009). Fertigation with 25 to 50 kg N resulted in a 20 % higher fruit yield in two of the three orchards independently from the irrigation regime. Water stress induced yield decline and increased the risk of an excessive N residue in autumn. The study proves the necessity of N during fruit maturing but also discusses the risks accompanied with excessive N fertilization.*

Keywords: *Water stress, Soil Water Potential*

Introduction

Over the past years pear fruit (Pyrus communis cv. ’Conference’) has become an important part of fruit growing in Belgium and the Netherlands. Belgium is situated in the temperate climate zone with a relatively low average evapotranspiration and a high but variable rainfall from bloom (first half of April) to harvest (first half of September). Market price of fruits having a diameter of >60 mm is twice the price of smaller sized fruits (<55 mm). In dry years the price difference between large and small fruits increases significantly. The high market price for large fruit sizes has pushed the fruit growers to the implementation of irrigation systems.

The presence of an irrigation installation allows fruit growers to fertigate by solving fertilizers in the irrigation water. Fertigation allows a precise distribution of the nutrients in the root zone and increases nutrient uptake efficiency (Yin et al., 2009). Nitrogen (N) is one of the nutrients which strongly relates to fruit yield (Sanchez et al., 2002, Deckers et al., 2008, Liu et al., 2013) in different pear varieties. However over-fertilization can lead to extensive vegetative growth of the tree with consequences to fruit set decline (Sanchez et al., 2002). Furthermore excessive N fertilization leads to NO_3^--N leaching which conflicts with current environmental policies in Europe (EC 1991).

Objective of the current experiment is to test the fruit yield response to N fertilization applied by fertigation. The outcome of this experiment can be implemented in N recommendation for ‘Conference’ pear fruit.

Materials and Methods

In Belgium in the pear trees (Pyrus Communis, cv. ‘Conference’) full bloom takes place mid of April, followed by a period of intensive cell multiplication until the end of May. June and July are characterised by a period of extensive shoot growth. In August the fruits start to mature with a period of cell elongation, until harvest at the end of August or the beginning of September. Given the variety in soil profiles and planting regimes in Belgium, three different orchards (Table 1) were selected for this study: an intensively planted orchard on a dry profile on a slope situated in Bierbeek (50°49'36.35"N, 4°47'40.35"E), and two older less intensively planted orchards in Meensel-Kiezegem (50°53'40.20"N, 4°55'38.12"E) and in Sint-Truiden (50°45'59.46"N, 5° 9'24.68"E). In these three orchards a fertigation experiment was set up in 2008 and 2009.

In all orchards a drip irrigation system was installed with drippers every 20 cm with a discharge rate of 2 l/h. The orchards were also equipped with a “Dosatron” pumping unit to disperse fertilizers trough the drippers alongside with the irrigation water. One month before in bloom in 2008 and 2009 all orchards received a basic fertilization containing 30 kg N/ha using mineral fertilizers applied directly on the weed free strip below the canopy. In Bierbeek in 2008 only 20 kg N/ha was applied as basic fertilization.

In all orchards two different irrigation regimes where installed a Full Irrigation regime (FI) where Ψ_{soil} was maintained above -60 kPa due to irrigation, according to irrigation guidelines suggested by Janssens et al. (2011). Furthermore a Deficit Irrigation (DI) regime was set up where rain repelling screens were installed in the months June and July to insure root zone depletion. During the months of June and July no irrigation was supplied in the DI treatment, in the months of April, May and August the DI treatment was irrigated equal to the FI treatment.

In all orchards every irrigation regime (FI and DI) was subjected to three fertigation doses; 0 kg N/ha, 25 kg N/ha and 50 kg N/ha supplied by solving $CaNO_3$ in the irrigation water. The fertigation was applied during two weeks at the end of the shoot growing period at the end of the month of July and the beginning of August (approximately 6 weeks before harvest). The irrigation-fertigation regimes were applied in plots of four trees separated by two buffer trees. Each irrigation-fertigation combination was replicated four times in a randomized bloc design.

One day before harvest in the commercial orchard, pears of two trees per plot were harvested. N content in the fruits in every plot was analysed in 2008 and 2009, N content in the leafs was analysed in 2009 one week after the end of the fertigation. N content in the soil was analysed on one soil sample per treatment to a depth of 90 cm. Each sample was taken in the weed free strip below the canopy and consisted of minimal 10 subsamples taken in the four replications of each irrigation-fertigation combination.

In the FI and DI treatment Ψ_{soil} was monitored in one plot in the treatment which received 25 kg N/ha by fertigation. Ψ_{soil} was monitored with three “Watemark” granular matrix sensors per tree (Irrometer Co., USA) at 30 cm. The sensors were connected to a data logger which recorded Ψ_{soil} every four hours. The standard manufacturer calibration was used to compute Ψ_{soil} from the electrical resistance measured by the sensors.

Results

The irrigation had an effect on Ψ_{soil} in 2008 and 2009 (Fig. 1). In Bierbeek in 2008 and in 2009 Ψsoil declined -150 kPa in the DI treatment (Fig. 1a,b). In 2008, Ψsoil did not decrease as far as in 2009 because irrigation was resumed at the end of July at a higher rate. In 2009 there was also a decrease in Ψsoil in the FI treatment due to a malfunction of the irrigation system during one week. In Meensel-Kiezegem in the DI treatment Ψsoil decreased to below -90 kPa in 2009, in 2008 Ψsoil decreased to -60 kPa (Fig. 1c,d). In Sint-Truiden, despite similar irrigation regimes as in Bierbeek no decrease in Ψsoil occurred (Fig. 1e,f) in the DI treatment. In Meensel-Kiezegem and in Sint-Truiden the decrease in Ψsoil in the DI treatment was less pronounced compared to Bierbeek.

Irrigation had an effect on the total fruit in yield in Bierbeek (Table 1). In 2008 and 2009 fruit yield tended to be higher in the FI treatment. In the 0 kg N fertigation treatment the difference between FI and DI was significant. In Meensel-Kiezegem and in Sint-Truiden fruit yield between the FI and the DI treatment was similar.

Fruit yield varied with the applied fertigation regime in Bierbeek and in Sint-Truiden (Table 2). In Bierbeek fruit yield was highest in the 25 kg N fertigation treatment in 2008 and 2009, in the FI treatment and in the DI treatment. In Bierbeek 5 kg more fruit was harvested in the 25 kg N treatment compared to the 0 kg N treatment. In Meensel-Kiezegem no pronounced differences in fruit yield were observed when applying the three fertiation doses although yield tended to be higher in the 25 kg N treatment in both the FI and the DI treatment. In Sint-Truiden fruit yield was highest in the 50 kg N fertigation treatment in 2008 and 2009 in both irrigation regimes. In 2008 the difference was significant and conceded 5 kg between the 50 kg N fertigation treatment and the 0 kg N fertigation treatment.

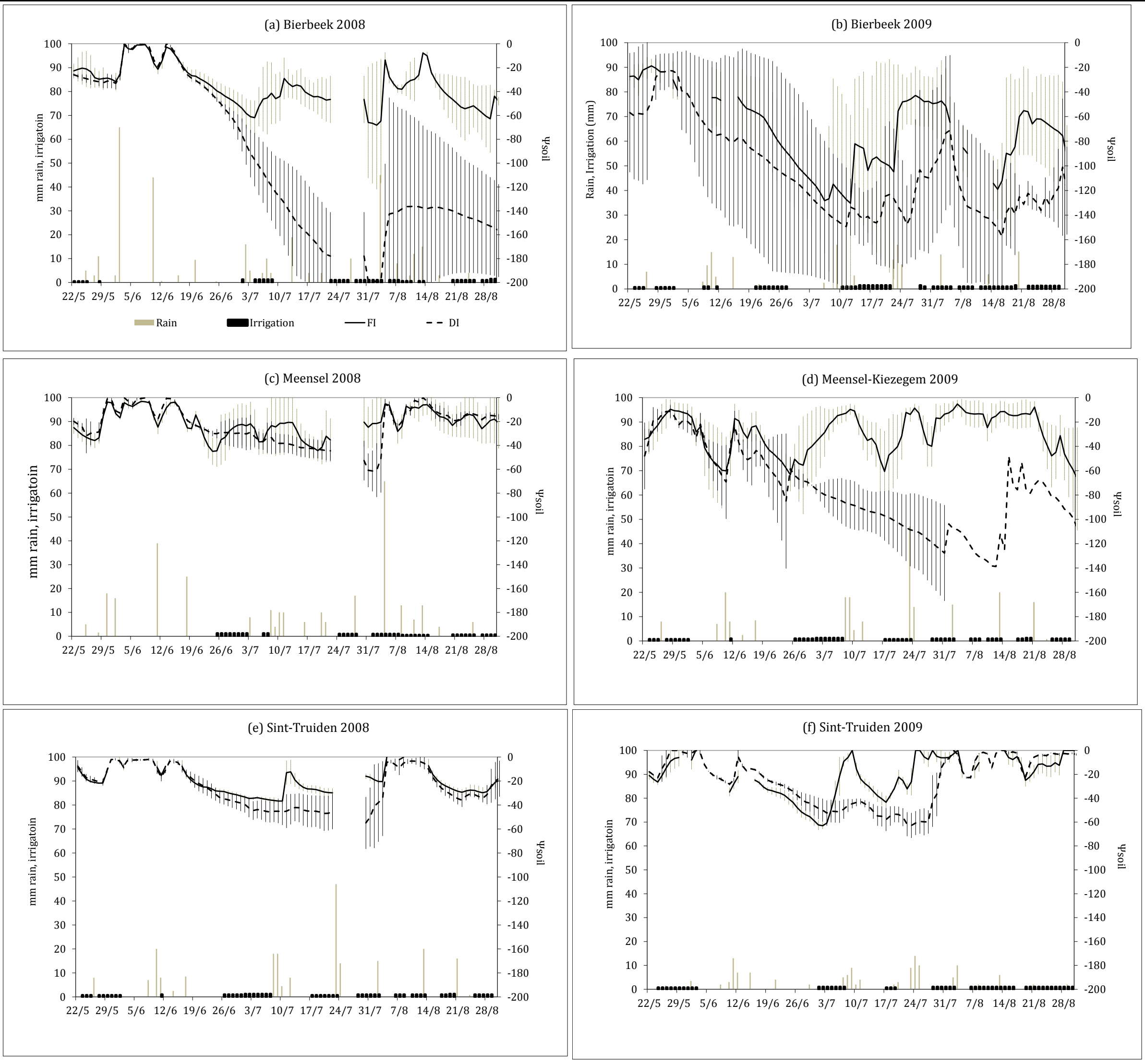

Figure 1: Evolution of Ψ_{soil} measured by three Watermark sensor at a depth of 30 cm in a reference plot per irrigation regime in the three orchards in 2008 and 2009. Vertical bars indicated standard deviation between three sensors.

Table 1: Characteristics of the three orchards

Orchard	Bierbeek	Meensel-Kiezegem	Sint-Truiden
Rootstock	Quince C	Quince Adams	Quince Adams
Planting year	2000	1996	1996
Planting Distance	3.3 m x1 m	3.5 m x 1.5 m	3.5 m x 1.25 m
Training system	Intensive V system	Free spindle	Free spindle
Average tree height	2.5 m	2 m	3.5 m
Soil texture upper soil layer (0-30 cm)	Sandy loam	Sandy loam	Loam
Carbon content upper soil layer (0-30 cm)	1.2 %	1 %	1 %
pH upper soil layer (0-30 cm)	6.8	6.1	6.4
Mineral NO_3-N content soil profile (0-90 cm) (march 2008)	66.6 kg	30.9 kg	24.1 kg
Other characteristics	Situated on a slope	Shallow ground water table (1.5 m- 2 m)	

Table 2: Fruit yield in function of the applied fertigation regime 6 weeks before harvest. The letters a,b,c, indicate a significant difference at $p < 0.05$

Orchard	Irrigation regime	Fertigation dose (July-August)	Fruit yield 2008 (kg/tree)		Fruit yield 2009 (kg/tree)	
Bierbeek	FI	0 kg N	23.94	ab	21.41	bc
	FI	25 kg N	28.89	c	22.37	c
	FI	50 kg N	25.93	abc	20.7	bc
	DI	0 kg N	22.25	a	16.59	a
	DI	25 kg N	26.95	bc	22.34	c
	DI	50 kg N	23.33	ab	19.34	ab
Meensel-Kiezegem	FI	0 kg N	27.07	a	22.58	a
	FI	25 kg N	22.46	a	24.58	a
	FI	50 kg N	21.54	a	20.75	a
	DI	0 kg N	24.68	a	21.95	a
	DI	25 kg N	24.99	a	22.97	a
	DI	50 kg N	23.29	a	23.4	a
Sint-Truiden	FI	0 kg N	14.14	a	10.03	a
	FI	25 kg N	18.14	ab	9.01	a
	FI	50 kg N	20.41	b	10.34	a
	DI	0 kg N	13.02	a	10.84	a
	DI	25 kg N	15.29	ab	12.02	a
	DI	50 kg N	18.49	b	14.63	a

N content in the fruits was lower in Bierbeek in 2009 in the DI treatment (Table 3). In 2008 the effect was less pronounced. In Meensel-Kiezegem and Sint-Truiden N content in the fruits was similar in all fertigation treatments. The lower N content in the fruits in Bierbeek in 2009 in the 0 kg N fertigation treatment is possibly related to the severe decrease in Ψ_{soil} in the DI irrigation treatment. The evaporative demand was also higher than in 2008 in the month before harvest. One week after applying the fertigation a higher N content in the leafs was observed in Bierbeek and in Meensel-Kiezegem but not in Sint-Truiden (Table 3). N content in the leafs between the 25 kg N treatment and the 50 kg N treatment was similar and higher than with the 0 kg N treatment.

Table 3: N content in the fruits (2008-2009) and in leafs (2009) (% N/g dry weight) in function of the applied fertigation regime 6 weeks before harvest. The letters a,b,c, indicate a significant difference at $p < 0.05$

Orchard	Irrigation regime	Fertigation dose (July-August)	N content in fruits 2008		N content in fruits 2009		N content in leafs 2009	
Bierbeek	FI	0 kg N	0.30	a	0.32	b	2.59	ab
	FI	25 kg N	0.31	a	0.34	b	2.68	bcd
	FI	50 kg N	0.31	a	0.33	b	2.74	cd
	DI	0 kg N	0.28	a	0.25	a	2.50	a
	DI	25 kg N	0.28	a	0.32	b	2.65	bc
	DI	50 kg N	0.29	a	0.35	b	2.79	d
Meensel-Kiezegem	FI	0 kg N	0.34	a	0.30	a	2.37	a
	FI	25 kg N	0.43	a	0.36	a	2.49	b
	FI	50 kg N	0.40	a	0.31	a	2.49	b
	DI	0 kg N	0.36	a	0.30	a	2.48	b
	DI	25 kg N	0.42	a	0.30	a	2.62	c
	DI	50 kg N	0.40	a	0.34	a	2.62	c
Sint-Truiden	FI	0 kg N	0.44	a	0.39	a	2.40	a
	FI	25 kg N	0.46	a	0.37	a	2.40	a
	FI	50 kg N	0.45	a	0.42	a	2.40	a
	DI	0 kg N	0.43	a	0.36	a	2.30	a
	DI	25 kg N	0.46	a	0.37	a	2.36	a
	DI	50 kg N	0.43	a	0.37	a	2.42	a

NO_3^--N -concentration in the soil in autumn was in accordance with the applied fertigation regimes in 2008 and 2009 (Table 4). NO_3^--N content in the soil layer 0-90 cm was higher in the 50 kg N treatment in the tree orchards in 2008 and 2009 except in Bierbeek and in Meensel-Kiezegem in 2008. NO_3^--N content in the soil in autumn tended to be higher in the DI treatment compared to the FI treatment. In March 09 there was no differentiation in soil NO_3^--N content between the fertigation treatments.

Table 4 NO_3^--N concentration in the soil in function of the fertigation regime measured at three moments in the orchards during 2008-2009

		0 kg N		25 kg N		50 kg N	
		FI	**DI**	**FI**	**DI**	**FI**	**DI**
Bierbeek	Octobre 08	16.3	14.2	25	25.9	16.5	100
	March 09	34.5	40.2	31.3	28.4	26	38
	Octobre 09	81.5	25.5	30.2	45.7	26.7	58
Meensel-Kiezegem	Octobre 08	12.6	12.2	41.3	79.1	22	55.9
	March 09	29.4	23.7	23.2	34.2	32.5	42.9
	Octobre 09	37.7	53.8	40.3	137.1	137.5	109.9
Sint Truiden	Octobre 08	44.5	39	61.8	88.6	101.4	165.6
	March 09	25.8	25.5	30.4	28.1	38	27.8
	Octobre 09	62.9	99.8	56.5	162.2	86.2	161.9

Discussion

Main objective of the current study was to detect the N needs of 'Conference' pear fruit for the optimization of fertigation schemes used in commercial orchards. Current results indicate that a fertigation dose from 25 to 50 kg N is recommended supplementary to a basic fertilization of 30 kg N one month before bloom. Furthermore the results indicate that in dry circumstances the N uptake was tempered.

The water stress response of 'Conference' in the three experimental orchards was previously discussed by Janssens et al. (2011). The orchard in Bierbeek is characterized by a dry soil profile while the soil profiles in Meensel-Kiezegem and Sint-Truiden remained longer humid. In the DI treatment in Bierbeek fruit yield was lower and also N content in the leafs and fruits was affected by the lack of water in the soil. The negative effect of water stress on N uptake was expected and is consistent with Buwalda and Lenz (1992) who reported lower N uptake rates in combination with lower water availability for the tree. Consequently with the lower N uptake a trend in a higher NO_3^--N concentration was observed in the soil in the DI treatment after harvest in Bierbeek. Which was also observed in Meensel-Kiezegem and Sint-Truiden while in these orchards no yield decline due to water stress was observed. Since Ψ_{soil} values close to -10 kPa were registered in the FI treatment of these orchards, water and NO_3^--N percolation out the root zone after rain events is a probable explanation.

Initial N content in the soils before the start of the fertilization experiments in 2008 and 2009 ranged from 30 to 60 kg/ha. Furthermore a basic fertilization of 30 kg N/ha was applied before full bloom in all treatments in both years. Nitrogen fertilization early in the season is considered important since the majority of the N uptake by pear trees occurs early in the season (Quartieri et al. 2002; Sanchez et al., 2002). The yield results in Bierbeek and in Sint-Truiden illustrate that fractionated N fertilization, in this experiment applied by fertigation, also contributes to an optimal fruit yield. The fertigation was initiated approximately 6 weeks before harvest aiming to avoid earlier vegetative growth response due to the applied nitrogen.

In Bierbeek the highest fruit yield was observed in the 25 kg N fertigation treatment while in Sint-Truiden the highest yield was observed in the 50 kg N treatment. The optimal fertigation dose seems to be orchard specific. Organic carbon content, soil temperature and pH all influence N mineralization in the orchard.

Conclusion

The present experiment illustrates how fertigation can be used to apply a fractionated fertilization in 'Conference' pear tree. The optimal fertigation dose ranged between 25 kg/ha and 50 kg/ha depending from the orchard. Water stress negatively affected the N uptake of the tree and increased the NO_3^--N content in the soil profile in the autumn.

Acknowledgements

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(56) Soil microbial fertility in olive orchards managed by a set of sustainable agricultural practices

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Abstract: *In conventional olive growing, the frequent tillage has reduced soil organic matter content. Recently, soil conservation is becoming a priority in management strategies of rural areas due to the awareness of the deterioration of this natural resource and of the difficulty of its recovery in short periods (i.e. cross compliance concept in European Union). Therefore, the conventional agronomic practices should evolve to a more sustainable olive management to improve soil quality and water saving. A better understanding of soil ecology could lead to identify agricultural management practices that support and stimulate soil organisms for beneficial purposes in agriculture. The aim of this study was to evaluate the effects of sustainable practices (grass cover and pruning residues recycling) on soil quality in a Mediterranean olive orchard. The trials were carried out in a mature olive grove (Olea europaea L. – cv Maiatica) located in Basilicata Region (Southern Italy) and managed according to two different soil management systems: the sustainable treatment (ST) and the conventional treatment (CT). Soil microbiological quality in the two systems was monitored by both microbiological cultural-dependent and molecular methods. In the ST olive orchard, soil microbiota showed a higher complexity and metabolic diversity. The adoption of 'innovative', sustainable, agricultural practices had positive effects on soil microbiota and its biodiversity which can influence soil fertility and plant growth by increasing nutrients availability and turnover. The results of this study encourage the use of sustainable agricultural practices able to enhance soil fertility and promote good-quality fruit production without detrimental effects on water and soil resources.*

Keywords: *Biolog®; Fungal identification; Olea europaea L.; Soil enzyme activities; Sustainable soil management.*

Introduction

Suitable agricultural management practices, such as minimum tillage or no tillage, recycling of carbon sources internal to the fruit grove and adequate irrigation, fertilization and pruning management, are recommended to save water, restore soil organic matter, increase soil suppressiveness against plant pathogens, and reduce erosion and environmental pollution (Lal, 2004; Postma et al., 2008; Gomiero et al., 2011; Ding et al., 2013). Sustainable and innovative soil management systems in fruit growing can determine an optimal plant nutritional equilibrium, avoid nutrients accumulation in soils and leaching risks, improve irrigation efficiency, and prevent soil erosion and root asphyxia (Sofo et al., 2010; Sofo et al., 2011). Furthermore, the optimization and innovation of low-impact agricultural techniques have positive effects on both soils and crop yields as they increase microbial biomass, activity and complexity (Kushwaha et al., 2000; Widmer et al., 2006).

In semi-arid Mediterranean agricultural lands, a new approach in fruit orchard management is imposed by environmental emergencies, such as soil degradation and water shortage (Lal, 2004; Hochstrat et al., 2006). In these areas, the use of agronomical techniques aimed at improving or preserving soil quality, health and fertility is particularly recommended (Kushwaha and Singh, 2005; Govaerts et al., 2008). In olive groves, a positive influence of sustainable orchard management systems on soil biochemical and microbiological characteristics was observed (Hernández et al., 2005; Benitez et al., 2006; Moreno et al., 2009; Sofo et al., 2010).

Metabolic microbial community diversity in the structure of soil bacterial and fungal communities can be estimated by different methods and techniques (Gomiero et al., 2011). One of the most reliable and interesting is the Biolog® metabolic assay, based on the ability of microbial isolates to oxidize different carbon and nitrogen sources (Zak et al., 1994; Singh, 2009). The community-level physiological profiles (CLPPs), obtained by the Biolog® method, has a high discriminating power among microbial soil communities from various soil environments or subjected to various treatments (Calbrix et al., 2005; Gelsomino et al., 2006; Singh et al., 2006). It is also true that this important data should be necessarily interpreted and accompanied by the use of culture-dependent methods, in order to obtain the right characterization of the microorganisms tested, and by the determination of the activities of some soil enzymes, that are important markers of soil fertility status (Nannipieri et al., 2003).

On this basis, the aim of the present study was to explore the medium-term effects (12 years) of two different management systems (namely, sustainable and conventional) on the soil microbial functional and metabolic diversity of a mature olive orchard located in Southern Italy. Rather than the effect on soil microbiota of single sustainable agronomic practices, a set of sustainable agricultural practices was considered. Finally, a new method in the assessment of fungal metabolic diversity was also tested and discussed.

Materials and Methods

The trial was carried out in a mature olive grove (cultivar Maiatica, a double aptitude variety) located in Southern Italy (Ferrandina, Basilicata Region, Italy; 40°29 ′N, 16°28 ′ E) and gr
trained and planted at a distance of about 8×8 m. From 2000, the olive orchard was divided into two plots managed according to different soil management systems: the sustainable treatment (ST) and the conventional treatment (CT). The former was conducted by soil management techniques based on the recycling of polygenic carbon sources internal to the olive orchard. Particularly, ST was permanently covered by spontaneous weeds, mowed at least twice a year. Crop residues and pruning material, produced annually, were left on the ground as mulch. The CT was managed by continuous tillage (milling at 10 cm soil depth) in order to not have any weeds on the soil. Heavy pruning was carried out every two years. Pruned residues were removed from the olive orchard.

In October 2011, soil sampling was performed in both treatments (CT and ST). For each treatment, four composite samples of bulk soil were randomly collected in the inter-row area from the top soil layer (0-10 cm) and immediately stored in sterilized plastic pots at 4°C after removing visible crop residues. Each composite sample was formed by three seven-cm-diameter cores pooled on site within a 0.50 cm-radius. This sampling type was used to minimize spatial variability, as the experimental set up refers to a whole-field trial and not to single plots (Bacon and Hudson, 2001; Tian et al., 2004).

Three replicates of 5 g-sub-samples (dry weight equivalent) of each soil sample were suspended in 45 ml sterile 0.1% sodium pyrophosphate-one quarter strength Ringer solution (NaCl 2.25 g L^{-1}, KCl 0.105 g L^{-1}, $CaCl_2$ 0.045 g L^{-1}, $NaHCO_3$ 0.05 g L^{-1}, and citric acid 0.034 g L^{-1}) and sonicated for 2 min to disperse microbial cells. Ten-fold serial dilutions of the supernatants were made in sterile Ringer solution. Aliquots were plated in triplicate on 1/10 strength TSA (Tryptic Soy Agar) medium amended with 0.1 mg ml^{-1} cycloheximide for bacterial counting, and inoculated in MEA (Malt Extract Agar) medium containing 0.03 mg ml^{-1} streptomycin and tetracycline 0.02 mg ml^{-1} in triplicate for fungal counting. Counting took place after suitable incubation period (72 h for bacteria and 120 h for fungi) at 28°C.

Sole carbon source utilization patterns of soil microbial communities, also called community-level physiological profiles (CLPPs), were assessed using the Biolog® 96-well Eco-Microplates™ (AES Laboratoire, France), containing 31 different carbon sources, for bacteria, and using Biolog® FF MicroPlates™ (AES Laboratoire, France), containing 93 different carbon sources, for fungi. Data were analysed to determine metabolic diversity indices, including average well color development (AWCD, the mean of the blanked absorbance values for all the substrates, that provides a measure of total cultural bacterial activity), Shannon's substrate diversity index (*H'*), substrate evenness (*E*, equitability of activities across all utilized substrates) and substrate richness (*S*, the number of utilized substrates) (Zak et al., 1994).

Soil enzyme activities were measured on fresh soil samples. *β*-glucosidase activity was determined according to Eivazi and Tabatabai (1988) and the units expressed as µg *p*-nitrophenol h^{-1} g^{-1} soil. The dehydrogenase assay was performed according to the method of von Mersi and Schinner (1991) and the units expressed as µg triphenylformazan h^{-1} g^{-1} soil. Fluorescein diacetate (FDA) hydrolytic activity was determined according to Green et al. (2006) and units was expressed as µg tyrosine h^{-1} g^{-1} soil; protease activity was determined according to Geisseler et al. (2009) and the units expressed as µg tyrosine h^{-1} g^{-1} soil.

The statistical analysis of data was carried out using the data analysis software system STATISTICA, version 6.0 (StatSoft Inc.; Vigonza, PD, Italy). The mean values of bacterial and fungal microbial counts, Biolog® metabolic indices (AWCD, *H'*, *E* and *S*), and soil enzyme activities (four independent replicates for each treatment; n = 4) were separated according to Student's t test at $P \leq 0.05$.

Results and Discussion

Our data evidenced significant differences between the sustainable, high carbon input soil management system (ST) and the conventional, low carbon input system (CT).

The impact of sustainable orchard management was reflected in the microbial populations. Both total cultivable fungi and bacteria were significantly higher in ST (Table 1). Particularly, the total fungal number in ST was approximately 7.4-fold higher than that found in CT, whereas the total bacterial number was 3.6-fold higher. Soil fungi, more than bacteria, strongly responded to changes induced by the presence of spontaneous cover crops and the release of biomass and pruning residues on the soil (Borken et al., 2002; Peixoto et al., 2006). The high fungal number in ST is an important benefit, making soil conditions more adequate for the development of crops. Fungi are able to colonize the rhizosphere and use root exudates as carbon source, they supply roots with easily assimilable nitrates and play a key role in the biological control of root pathogens and in the maintenance of soil health. Govaerts et al. (2008) reported that total bacterial count are generally higher when residues are retained than when they are removed and minimum tillage occurred.

Table 1 Total bacterial and fungal counts in soils sampled from the sustainable (ST) and conventional (CT) treatments. Values are means ± standard deviation (*n* = 4). Means with different letters are significantly different between the two treatments at $P \leq 0.05$, according to Student's *t* test.

	Fungi (CFU x 10^4 g^{-1} dry soil)	**Bacteria (CFU x 10^6 g^{-1} dry soil)**
ST	21.4 ± 11.8 a	35.6 ± 16.7 a
CT	2.9± 1.9 b	10.0 ± 2.6 b

Soil bacterial metabolic diversity indices estimated by Biolog® CLPP refer to the number, variety and variability of microorganisms in a given environment, including diversity within and between groups, and they are usually higher in sustainable than in conventional soils (Bucher and Lanyon, 2005; Govaerts et al., 2008). The increase in organic inputs due to cover crops presence and plant residues management can be an important discriminating element for microbial substrate utilization, according to Carrera et al. (2007). Furthermore, crop residues retention in the field and changes in soil organic matter can affect the metabolic diversity of the soil microbial communities evaluated by Biolog® CLPP (Bending et al., 2002; Govaerts et al., 2008).

Soil bacterial metabolic diversity indices are usually higher in sustainable than in conventional fields. In our experiment, the CLPP obtained by the Biolog® method was used to differentiate the soil fungal and bacterial populations of the two systems. For both bacteria and fungi, the analysis of Biolog® metabolic indices shows that total AWCD, *H'* and *S* were significantly affected by soil treatment, being higher in ST than in CT (Table 2). This indicates a higher microbial diversity and complexity due to sustainable practices. The values of *E* measured for fungi were not statistically different between ST and CT (Table 2). Considering that high values of *E* indicate the high microbial number of some groups of microorganisms, it appears that the long application of the conventional management did lead to a predominance of few groups of fungi or bacteria in the whole soil microbiota.

Indices of metabolic diversity do not necessarily reflect the composition of the bacterial communities as two communities can have similar values of metabolic diversity indices but utilize different substrates. In our case, Biolog® absorbance values identified that the AWCD values of all the principal classes of fungal and bacterial carbon substrates, were significantly higher in the ST, with only some exceptions (simple sugars, amino sugars, biogenic amines and nucleotides) for fungi. This result confirms the higher microbial metabolic activity in both the classes of microorganisms for almost all the substrates utilized.

Table 2 Fungal and bacterial metabolic diversity indices measured by Biolog® in soils sampled from the sustainable (ST) and conventional (CT) treatments. Values are means ± standard deviation (*n* = 4). Means with different letters are significantly different between the two treatments at $P \leq 0.05$, according to Student's *t* test. AWCD = average well color development; *H'* = Shannon's substrate diversity index; *E* = substrate evenness; *S* = substrate richness.

		AWCD	***H'***	***E***	***S***
Fungi	ST	0.75 ± 0.02 a	4.25 ± 0.03 a	2.48 ± 0.02 a	51.60 ± 1.52 a
	CT	0.51 ± 0.12 b	3.85 ± 0.20 b	2.41 ± 0.07 a	39.75 ± 3.86 b
Bacteria	ST	0.83 ± 0.09 a	3.20 ± 0.03 a	2.54 ± 0.07 a	18.40 ± 1.52 a
	CT	0.36± 0.07 b	2.97 ± 0.05 b	2.67 ± 0.10 a	13.00 ± 1.58 b

Biolog® FF MicroPlates™ have been efficiently used to assess carbohydrate use and assimilation and to determine metabolic profiling of soil fungi (Hobbie et al., 2003; Singh, 2009) but our study reports for the first time the utilization of these specific plates for determining the fungal catabolic profile using a procedure similar to that adopted for bacteria by Zak et al. (1994). This was possible because Biolog® FF plates, usually used for fungal identification, contain a specific tetrazolium dye that can be metabolised by fungi but not by bacteria (Preston-Mafham et al., 2002). These latter were inhibited by the antiobiotics added to Biolog® FF plates, as explained in materials and methods section.

The degree of soil microbial activity is generally well correlated with the activity of key soil enzymes (Nannipieri et al., 2003). The extra-cellular soil enzyme *β*-glucosidase is of basic importance in the soil carbon cycle, as it catalyzes the last reaction of the catabolic pattern cellulose, hydrolyzing cellobiose in glucose and making it available to microorganisms. The activity of this enzyme was observed to be higher in soils subjected to sustainable agronomic practices, where biomass turnover is enhanced and soil mineralization is lowered, and it is a reliable index of a productive soil (Eivazi and Tabatabai, 1988). In this experiment, *β*-glucosidase activity was significantly higher in ST (Table 3). Dehydrogenases isoforms are common to most microorganisms, with a predominantly intracellular localization, and they are able to oxidize organic matter. In our case, dehydrogenase activity, even though higher in ST, did not differ statistically between the two treatments (Table 3) likely because these enzymes are good indicators of the vitality of fungal and bacterial populations more than their metabolic activity (von Mersi and Schinner, 1991). The hydrolysis of FDA, not different between the two orchard systems (Table 3), summarizes the hydrolytic activity of several enzymes and it is related to the hydrolytic activities of fungi and bacteria. In this sense, the activity of the FDA hydrolase represents an overall index of the potential for release of organic nutrients from organic matrices (Green et al., 2006). Proteases are a group of hydrolytic enzymes linked to the nitrogen cycle, and their function is to catalyze the hydrolysis of proteins, oligopeptides and dipeptides, until the release of ammonia. Like the glucosidases, they represent a useful index of the evolution of soil organic matter (Geisseler et al., 2009). Indeed, in this experiment, protease and *β*-glucosidase activity were strictly related, both showing an increase in the orchard managed with sustainable agronomic practices (Table 3).

Table 3 Soil enzyme activities in soils sampled from the sustainable (ST) and conventional (CT) treatments. Values are means ± standard deviation (n = 4). Means with different letters are significantly different between the two treatments at $P \leq 0.05$, according to Student's t test.

	***β*-glucosidase**	**Dehydrogenase**	**FDA hydrolase**	**Protease**
		(Units g^{-1} soil)		
ST	187.0 ± 4.7 a	194.0 ± 19.9 a	4.4 ± 0.4 a	6.7 ± 1.5 a
CT	151.3 ± 0.6 b	163.9 ± 1.6 a	4.2 ± 0.2 a	3.1 ± 0.9 b

Interestingly, the observed improvement of soil microbial activity and diversity due to a 12-year sustainable management were similar to those observed in other fields cultivated organically with similar agronomic practices and for the same period (Nautiyal et al., 2010).

Conclusion

The results demonstrated that soil microorganisms significantly respond to a sustainable orchard management characterized by the medium-term application of endogenous sources (cover crops and pruning residues) of organic matter. The sustainable agronomic practices resulted in profound changes in the soil microbial community, that showed higher complexity and metabolic diversity. This study confirms the necessity to guide the farmers towards choices of soil management based on organic matter inputs to ameliorate soil functionality and agronomic productivity of Mediterranean orchards.

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(57) Influence of harvest time on fructan content in the tubers of *Helianthus tuberosus* L.

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Abstract: *The influence of harvest time on fructan (fructooligosaccharides and inulin) content of different varieties of Helianthus tuberosus have been investigated in this study. The determination of quantity of inulin in the tubers harvested during three years period from 2010 until 2012 was done. The extraction of fructooligosacharides was carried out with 95 % (v/v) ethanol used as a solvent. Inulin from tubers of Helianthus tuberosus was extracted by treatment with hot distilled water. The extraction efficiency of inulin and fructooligosacharides was followed by TLC analysis. The fructan content in the extracts obtained from the tubers was determined by the spectrophotometric method based on the Seliwanoff reaction with resorcinol and by HPLC-RID method. It was found that a similar amount of inulin and fructooligosacharides (45-53% of dry weight) was observed in the middle early varieties harvested 21-26 weeks after plantation and in the late variety harvested 29-33 weeks after planting. From the obtained results, we can conclude that the tubers of both varieties of Helianthus tuberosus harvested in autumn 2011 contain the highest amount of fructans (50-69 % of dry weight).*

Keywords: *fructooligosacharides, inulin, analysis, Helianthus tuberosus L.*

Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.), also known as topinambour, originates from North America and it was introduced in Europe in the early 17th century. This plant belongs to the *Compositae* (*Asteriacae*) family and together with chicory it is one of the primary sources for inulin in higher plants (Figure 1). In the past Jerusalem artichoke was cultivated as vegetable in the Mediterranean area, but today only in France and Germany it continues to be grown as a vegetable (Muzzarelli et al., 2012). In Bulgaria its tubers are consumed traditionally fresh as a salad or in conservation state as pickled vegetables.

Figure 1 Plant and tubers of Jerusalem artichoke (*Helianthus tuberosus* L.)

Helianthus tuberosus is used in some countries for small-scale inulin production, such as China and Hungary. Except for its benefits for human nutrition, this plant continues to be grown as feed material and as a crop to produce biomass for bioethanol production (Li et al., 2010).

The tubers are a good source of dietary fiber, because of the presence of inulin. It is a reserve polydisperse plant polysaccharide, member of the fructan family, consisting mainly of β-(2→1) fructofuranosyl units (Fm), and a terminal α-glycopyranose unit (1→2) (GFn) (Van Laere and Van Den Ende., 2002) (Figure 2). The degree of polymerization (DP) of inulin varies from 2 to 70 (De Leenheer and Hoebregs, 1994). Molecules with DP<12 are called oligofructoses or fructooligosaccharides (FOSs) and they are a subgroup of inulin (Niness, 1999). The dynamic of fructose-containing carbohydrate accumulation in topinambour depending on age, development stage, sort and meteorological conditions

(Bagaoutdinova et al., 2001). The inulin content in the tubers of Jerusalem artichoke varies in range of 7 to 30% on fresh weight, but in some varieties its concentrations ranges between 49.5 and 56.4% of dry matter (Praznik et al., 1998); and in others is >75% on a dry weight basis (De Leenheer and Hoebregs, 1994). The near results have been reported by Denev et al. (2010), using the modified methodology for isolation of inulin from tubers of four varieties of Jerusalem artichoke (Energina, Verona, Topstar, Spindle) grown on the territory of Bulgaria. Twenty percent of inulin chains are with DP>10 (Kays and Nottingham, 2007) and over 44% of inulin from *Helianthus tuberosus L* has DP >13 (Hempel et al., 2007). The most common is the fraction with DP 12-16 (Kocsis et al., 2007). Inulin in Jerusalem artichoke tubers ranges up to above (DP 40) (Kays and Nottingham, 2008). In tubers of topinambour Scorospelcu varieties has been found that the maximum amount of low- and high-molecular fructan can reach 75-85%, as the greater part of topinambour is a low-molecular fraction (Bagaoutdinova et al., 2001).

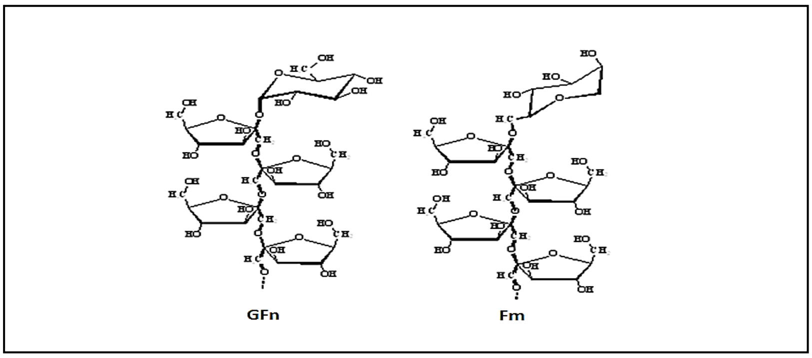

Figure 2 Chemical structure of inulin

Soluble carbohydrates present in tubers beside inulin are its derivatives, fructooligosaccharides, simple sugars (fructose and glucose) and sucrose. Due to its high nutritive value and proportions of fructans, the flour of Jerusalem artichoke tubers may be fully utilized as functional food supplement (Berghofer and Reiter., 1997). Inulin in Jerusalem artichoke has been shown to have a prebiotic effect in humans (Kleessen et al., 2007). Inulin and FOSs act as prebiotics, because it stimulates growth of *Bifidobacteria*. In large intestine it is fermented by intestinal microflora into short-chain fatty acid (SCFA), lactic acid and gases (Knudsen and Hessov, 1995). Inulin preparations used as prebiotic food ingredients in, e.g. dairy or bakery products, are mainly produced from chicory (*Cichorium intybus* L.) or Jerusalem artichoke (*Helianthus tuberosus* L.) (Hempel et al, 2007).

Likewise, inulin, whether ingested as Jerusalem artichoke tubers or as a bulking agent, is a dietary fiber and confirms a number of health advantages (Varlamova et al., 1996), e.g., reduces levels of triglycerides in the blood and increases the high density lipoprotein (HLD) to low density lipoprotein (LDL) ratio (Roberfroid, 2005, Varlamova et al., 1996), preventing cardiovascular disease and osteoporosis (Delzenne and Williams, 2002; Roberfroid, 2005). Due to its lower GI (Glycemic Index), inulin reduces blood sugar level and is helpful in the management of diabetes and blood sugar-related illness (Rumessen and Gudmand-Hoyer, 1998). The caloric value of fructosyl unit of oligofructose is between 1 and 1.5 kcal/g. This makes inulin favourable as an ingredient for dietetic food (Roberfroid, 2005). In the recent years inulin is presented also as immunomodulator and anticancer agent (Barclay et al., 2010).

In the last years, the interest in Jerusalem artichoke and potential utilisation of tubers for manufacturing functional food products has grown also in Bulgaria. The main purpose of the present investigation was to study the fructan content in tubers of some varieties and wild population of *Helianthus tuberosus* L., grown on different territory of Bulgaria. The effects of harvest time on inulin and sugar content were investigated. The knowledge about inulin and fructooligosacharides profile in the tubers of different cultivars reveals the best harvest time for their future application in food industry as source of prebiotics and in the production of functional food products with improved healthy effect.

Materials and Methods

Two middle early varieties of Jerusalem artichoke (*Helianthus tuberosus* L.) were grown in Bulgaria from the region of Berkovitca, Montana - Verona, Topstar varieties. These tubers were obtained from the local market 21-26 weeks after plantation. Scorospelcu variety tubers were supplied as topinambour flour. Two wild populations were planted in the vegetable garden in Kostievo village (42° 18′ N and 24.61° E) at 174 m above sea level, situated in Thracian valley and Chehlare (42° 25 ′N, 25° 10 ′E), mountain village at 174 m above sea level in Sredna gora, both situated in Plovdiv region. The tubers were harvested 29-30 weeks after plantation. All tubers were washed, peeled, and sliced. The air-dried tubers were finely ground and stored in screw-capped tubes, before analysis.

All used reagents and solvents were of analytical grade scale. Carbohydrate glucose, fructose, sucrose, together with high purity 1-kestose and nystose, used as standards for the identification of low molecular weight oligomers have been purchased from Sigma-Aldrich (Steinheim, Germany). Fructooligosacchrides Frutafit®CLR, HD and inulin Frutafit®TEX were supplied by Sensus (Roosendaal, the Netherlands). Frutafit®CLR contains high level of oligofructoses with the average chain length of 7-9 monomers. Frutafit®HD is with the average chain length of 8-13 monomers. Frutafit®TEX is characterized with mean degree of polymerization DP 22. Inulin Raftiline®HP (DP~25) was purchased from Orafti (Belgium).

Moisture content of the dried ground roots were determined according to AOAC 945.32 (2007).

The ground tubers were extracted three hours with 95% (v/v) boiling ethanol to obtain the low molecular carbohydrate fraction. After that the residue was treated three hours with boiling distilled water for the extraction of inulin fraction (Petkova and Denev, 2013). The fructan content in the obtained extracts were analyzed spectrophotometrically at wavelength 480 nm by resorcinol-thiourea reagent (Pencheva et al., 2012). The experiments were carried out on a Camspec M107 Vis spectrophotometer (UK).

The content of mono-, di-, fructooligosaccharides and inulin in the obtained extracts from Jerusalem artichoke tubers were analyzed by TLC in order to observe the extraction rate of fructans. Five microliters of each extract were performed on silica gel 60 F_{254} plates (Merck, Germany) with *n*-BuOH:*i*-Pro:H_2O:CH_3COOH (7:5:4:2) (v/v/v/v) used as a mobile phase. The TLC plates were dipped in the detecting reagent diphenylamine-aniline-H_3PO_4–acetone and heated (Lingyun et al., 2007).

The sugars, FOSs and inulin content in tuber extracts were analyzed by HPLC methods. Chromatographic separations were performed on HPLC Shimadzu, coupled with LC-20AD pump, refractive index detector Shimadzu RID-10A. The control of the system, data acquisition, and data analysis were under the control of the software program LC solution version 1.24 SP1 (Shimadzu Corporation, Kyoto, Japan). The separations of fructose, glucose, sucrose, 1-kestose and nystose in the ethanol extracts were performed on an analytical aminopropyl silica column SUPELCOSIL LC-NH2 (250 x 4.6 mm i.d.) equipped with a guard column (2.5 x 4.6 mm i.d.) maintained at 40 °C. An isocratic mobile phase acetonitrile/water (83/17 v/v) with flow rate 1.5 $ml.min^{-1}$ was used. Detection and identification of sugars and fructooligosaccharides were performed using RI detector that operated at 40 °C.

The determination of inulin and sugars in water extracts were performed on a Shodex® Sugar SP0810 with Pb^{2+} a guard column (50X 9.2 mm i.d.) and an analytical column (300 mm x 8.0 mm i.d.). The mobile phase used for separation was distilled water with flow rate 0.5 ml/min. The injection volume of the samples was 20 µL.

Statistical analysis was performed using MS Excel 2010.

Results and Discussion

The moisture content in the dried and ground tubers of *Helianthus tuberosus* L. were as follow: Topstar, Verona and Scorospelcu varieties - 7.89±0.07%, 8.52±0.10% and 9.66±0.19%., respectively and in the wild population from Kostievo and Chehlare: 10.90±0.09 % and 7.87±0.13%, respectively.

The results from determination of fructose, sucrose and inulin-type fructan content in the ethanol and water extracts obtained after spectrophotometric analysis with resorcinol-thiourea reagent were shown (Table 1). Comparing all the investigated *Helianthus tuberosus* plants, Scorospelcu variety contained the highest content of low-molecular fraction (45.40% dw for November 2011 and 37.22% dw for February 2012). The level of inulin in the water extracts obtained from tubers of the same variety in February 2012 decreased, but the FOSs and sugars content in the ethanol extracts increased. The wild population of *Helianthus tuberosus* in Kostievo village from September 2011 contained the highest inulin content - 43.49% dw. Except for the Scorospelcu varieties, in all Jerusalem artichoke tubers the high molecular water soluble fraction (inulin) was higher than the ethanol soluble low molecular fraction. In most of the investigated varieties or wild population of *Helianthus tuberosus* grown on the territory of Bulgaria during a period of three years (2010-2013), the total fructan content in the middle and late varieties is near to 50% dw, which confirmed the data reported in literature (Praznik et al., 1998). The highest total fructan level in tuber flour was observed in Scoruspelcu variety 69.3% dw and the lowest was present in tubers of the wild population from Chehlare village - 24.2%, respectively. The reason for this lowest content could be explained by the highest altitude or with the weather conditions in the mountain region.

The obtained results from TLC analysis showed that the extraction process in triplicate was efficient and it could be used for the fractionation of glucose, fructose, sucrose and lower molecular FOS as (kestose and nystose) with ethanol and their separation from high molecular inulin extracted with water (Figure 3). All ethanol extracts (8, 10 12, 14, 16) contained fructose (R_f = 0.55), sucrose (R_f = 0.48) and FOSs which were equivalent to standards Frutafit CLR (7-9 oligomers) and HD (8-13 oligomers). The results obtained from TLC (densitometric) analysis showed the presence of a high level of trisaccharides 1-kestose (R_f = 0.37) and tetrasaccharide nystose (R_f = 0.34) in ethanol and water extracts of tubers with the highest concentration in Scoruspelcu varieties. In the water extracts (9, 11, 13, 15, 17) except fructose, FOSs until DP 9-12 also dominated and the high molecular fraction of inulin with DP, similar to these of used as standards Frutafit TEX and Raftiline HP (DP 22-25). The wild population topinambour from Kostievo and Topstar variety contained mainly high-molecular inulin in the water extract.

Table 1 Fructan content in the extracts obtained from tubers of Jerusalem artichoke (*Helianthus tuberosus* L.) (g/100 g dw[1]) (mean ± SD[2], n=6)

Variety	Harvest time and place	Low molecular fraction (Fru[3], Suc[4] & FOS[5])	High molecular fraction (inulin)	Total fructans
Topstar	October 2010	9.32±0.69	28.99±2.41	38.3±2.16
Verona Scorospelcu	October 2010	9.41±1.07	30.79±1.55	40.2±0.68
	November 2011	45.40±2.20	23.92±1.02	69.32±2.50
	February 2012	37.32±2.57	7.36±2.75	44.68±0.18
Wild population Kostievo	November 2010	10.4±0.73	32.98±3.89	43.40±4.00
	September 2011	6.44±0.22	43.49±2.52	49,93±2.29
	Novermber 2012	6.19±1.60	36.78±3.39	42.30±1.70
Chehlare	October 2010	6.66±1.26	17.61±1.80	24.27±1.68

[1]dw – dry weight; [2]SD – standard deviation; [3]Fru- fructose, [4]Suc – sucrose; [5]FOS – fructooligosaccharides

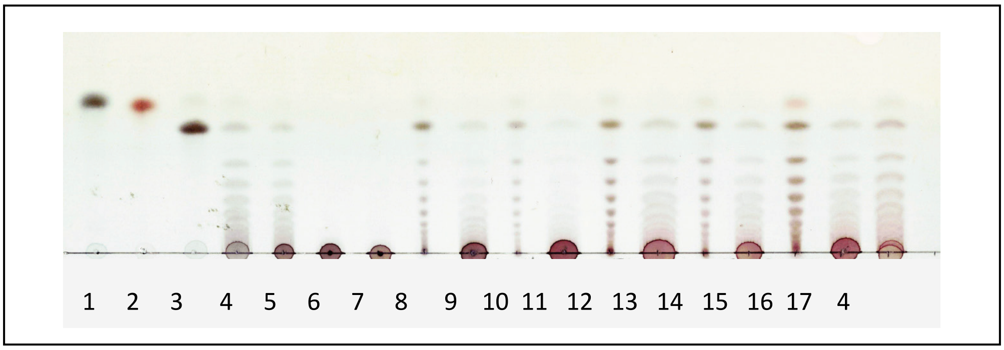

Figure 3 Thin layer chromatography of extracts from the tubers of different varieties of *Helianthus tuberosus* L. standards: 1-glucose, 2-fructose, 3-sucrose, 4 and 5-FOSs Frutafit CLR and HD, 6 and 7 - inulin Frutafit, TEX and Raftiline HP; 8, 12, 16 - ethanol extracts from varieties Topstar, Verona, Scorospelcu, 10 and 14 - ethanol extracts from wild population from Kostievo and Chehlare villages; 9, 13, 17 – water extracts from varieties Topstar, Verona, Skorospelku, 11 and 15 – water extracts from wild population from Kostievo and Chehlare villages

Some of the ethanol and water extracts of the tubers of *Helianthus tubersus* were also analysed by HPLC-RID method. The HPLC analysis of the ethanol extract from Jerusalem tubers (Figure 4) proved the results from TLC. The obtained HPLC chromatograms showed also the presence of fructose (t_R=4.63 min), glucose (t_R=5.22 min) and sucrose (t_R=7.84 min) and the presence of 1-kestose (t_R=9.86 min) and nystose (t_R=15.29 min). These tri- and tetrasaccharied possessed the best prebiotic effect and their content varies in range of 1.5 to 5.3 % dw. Their content is higher in Scorospelcu variety and the tubers could be applied as a promising source of FOSs with potential healthy prebiotic effect.

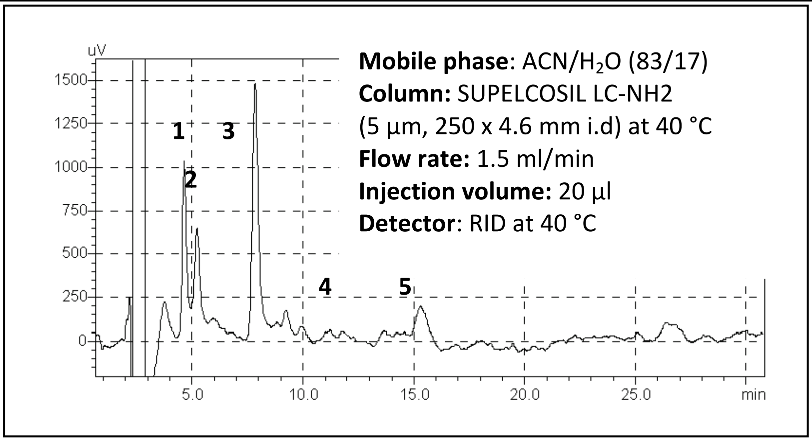

Figure 4 HPLC chromatogram of ethanol extract from tubers of *Helianthus tuberosus* L., where *1.fructose, 2.glucose, 3.sucrose, 4. 1-kestose and 5.nystose*

The water extracts obtained from tubers of *Helianthus tuberosus* showed the presence of high molecular inulin fraction, 1-kestose (t_R =11.82 min), trace of sucrose (t_R =13.10 min) and fructose (t_R=19.03 min). The quantity of the high molecular inulin fraction varies around 50-65% dw as the tubers of all varieties gathered during the autumn of these three years showed high inulin contents.

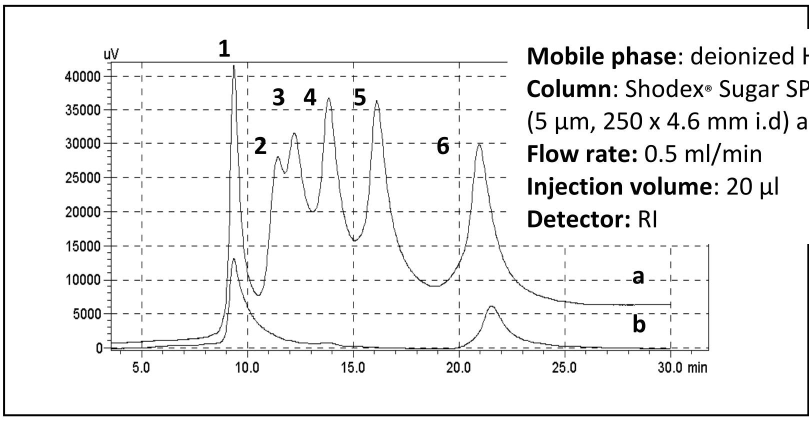

Figure 5 HPLC chromatograms of water extract obtained from tubers of *Helianthus tuberosus* L. after ethanol pretreatment: a) standard mixture, where 1. Inulin Raftiline HP (DP=25), 2. nystose, 3.1-kestose, 4. sucrose, 5. glucose and 6. fructose all in concentration 6.25 mg/ml; b) water extract from Chehlare wild population Jerusalem artichoke

Conclusion

The influence of harvest time on fructan (fructooligosacharides and inulin) content in tubers of *Helianthus tuberosus* L. from wild populations and cultivars have been investigated in this study. From the obtained results during the carried research we can conclude that the middle early varieties and the wild population of topinambour showed constant levels of inulin content - 30% dw and 35-40% dw, respectively. The tubers of these plants contained small amounts of sugars and FOSs content. Therefore they can be potential low-caloric ingredients in healthy and diabetic nutrition. The flour of Scorospelcu varieties can be used also as rich source of dietary fibre with well-pronounced prebiotic effect due to highest FOSs content in them. This variety showed the highest fructan content 69.3 dw and it will be perfect candidate for production of functional food and nutrition formula.

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(58) Influence of fertilisation and cultivation methods on the yield and essential oil content of thyme (*Thymus vulgaris* L.)

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Abstract: *The information in the literature concerning the influence of nutrient supply on the yield of biomass and essential oil of plants belonging to the Lamiaceae, in particular thyme, is very contradictory. However, it is well known that the quantity of fertilisers and their composition may influence not only the biomass and essential oil, but also the vitality and the hibernation of thyme. Therefore, a field experiment with the cv. 'Deutscher Winter' was carried out in order to investigate the effects of fertilisation during a three- years-cultivation period. Five treatments were applied ('standard fertilisation without N fertilisation', with 'double amount of N fertilisation', with 'double amount of K', 'covered with fleece', and with 'double plant density') and their effects on the content of essential oil, thymol, yield of thyme (dried leaves, leaf fraction on the plants), and influence on hibernation were analysed. The highest yield was recorded in the treatments 'covered with fleece' and at the 'double plant density with standard fertilisation' in average of the three years. The lowest yield of leaf drugs was determined in treatment 'without N-fertiliser', the highest at the 'double plant density'. The amount of essential oil was highest in the treatment 'double plant density', whereas the lowest essential oil quantity was determined when twice the quantity of N was applied. The content of thymol was highest in the treatment standard fertilisation without N-fertiliser. Concerning the vitality and effect on hibernation best results were determined in the treatments without N-fertilisation and covering with fleece. These results confirm the theory that nitrogen has a negative effect on the content of essential oil and its components as well as the vitality of the plants during the winter season.*

Keywords: *N-supply, K-supply, hibernation, plant vitality, thymol*

Introduction

Integrated cropping of *Thymus vulgaris* L. requires nutrient supply based on the uptake in relation to the yield. The nutrient supply should be carried out following the nutrient uptake and the nutrients available in the soil up to 60 cm depth, in particular in case of the mineral nitrogen content (Bomme et al., 1993). There are calculations for the necessary quantity of the macronutrients in relation to the yield and uptake of thyme. For a mean yield of 15 t ha^{-1} fresh mass, an amount of 60 kg N, 17 kg P_2O_5, 115 kg K_2O, 10 kg MgO and 40 kg CaO per hectare should be applied to most of the soil types. The nitrogen fertiliser has to be applied in two dosages, the first half of the entire amount should be applied three weeks after the germination or planting and the second half after the thyme population covered the soil completely (Bomme et al., 1993; Bomme and Nast, 1992; Bomme and Nast, 1998; Bomme and Wurzinger, 1990).

The influence of fertilisation on the (internal) quality of thyme has been in the focus of scientific research since the beginning of the field production of thyme. Currently, in the literature very contradictory information exists regarding the right amount and frequency of fertilisation, in particular concerning the amount of essential oil content of thyme. Weichan (1948) and Kästner (1966) observed in experiments with different levels of fertilisation for herbs belonging to the family Lamiaceae, the highest amount of active substances when cultivated in a clay-loamy soil. Shalaby and Razin (1992) investigated the influence of different dosages of N and P on different thyme densities on the yield and internal compounds. Their finding showed a significant influence on the plant height, fresh and dry matter, but no significant effect on the essential oil content in the leaves. Although, the total oil content in whole thyme plant (stem and leaves) was significantly influenced by the different fertilisation dosages. The highest fresh matter and total essential oil yield was obtained if 105 kg N ha^{-1}; 57 kg P_2O_5 ha^{-1}; 57 kg K_2O ha^{-1} were applied and plant density was two times higher than normal. Omidbaigi and Arjmandi (2001) investigated the influence of six different dosages of nitrogen and phosphorus on growth parameters, flowering, leaves and oil yield of thyme. Thyme with treatments of 250 kg N ha^{-1} and 200 kg P ha^{-1} were flowering 5 days later. The essential oil and thymol content was slightly influenced. Similar results were obtained for other medicinal and aromatic plants. Röhricht et al. (1999) did not discover an influence of additional phosphorus fertilisation on the essential oil content in coriander. In oregano, investigation of Kadner et al. (1999) showed that more N-fertilisation enhances the seed yield, but no significant effects on the essential oil content in oregano were detected. Trivino and Johnson (2000) detected correlations between the quantity of fertilisation and the leave yield, but no significant influence on the quantity and composition of the essential oil. Ozguven et al. (2006)

investigated the influence of 0, 40, 60 and 80 kg nitrogen fertilisation per ha on the yield and essential oil content in *Origanum syriacum* (L.). The highest fresh herb yield (19.86 t ha^{-1}) was obtained at full blooming period with a N rate of 40 kg ha^{-1}, whereas the highest dry herb yield (8.95 t ha^{-1}) was obtained at the end of blooming also with a N rate of 40 kg ha^{-1}. The highest essential oil content (6.16%) was obtained in the first year of the experiment when harvested at full blooming period with the N rate of 60 kg ha^{-1}. Similar results were described by Baranauskiene et al. (2003), they concluded that different fertilisation doses do not result in significant differences on the internal compounds of thyme herbs except the vitamin C content.

After evaluation of the cited literature, it can be concluded that past results regarding the influence of fertilisation on the growth parameters and essential oil content were contradictory.

Therefore an experiment was conducted in order to understand the effect of different nitrogen and potassium fertilisation as well as different density of the plants and using fleece as a protection cover.

Materials and Methods

Thyme cultivar, Deutscher Winter' was sown in a container filled with sieved green compost in week 8 and placed in a greenhouse. The seeds were covered with a layer of approximately 1 mm quartz sand. Three weeks after germination the seedlings were hardened in a cold frame. The experimental plot consisted of four repetitions of 8.75 m² each. The treatments were placed in a randomized block design. The plants were transplanted in week 17. Seven plants were planted together in a cluster, in six rows with 462 plants per plot in a distance of 30 x 40 cm. In the treatment ‚double plant density' the plant distance was 15 x 40 cm. In this treatment 924 plants were planted. The plants were cultivated for three years.

The experiment was set up in loamy sand (podsol) with pH 6.4 and organic carbon content of 1.4%. The average year temperature at this location was 8.7°C and the average precipitation 566 mm. Additional watering with an amount of 15 mm water was conducted if the tensiometer-value was 400 hPa.

The treatments of this experiment are described in table 1. The entire amount of additional N or K was applied between two and four times during the experimental year depending on soil analyses, plant growth and weather conditions. Harvesting of the herbs was carried out seven times, one time in the first year and three times in the second and third year.

The nutrient elements in the soil were analysed following the VDLUFA methods. Total nitrogen was analysed by using the Kjeldahl-method, nitrate by using an ion selective electrode after extraction with a potassium-sulphate solution.

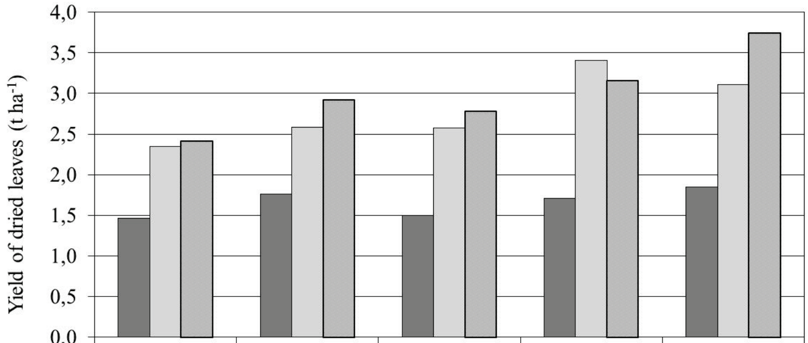
The analysis of the essential oil content was carried out by the steam-extraction method in a Neo Clevenger apparatus. Leaves of thyme (30 g) were placed in 400 ml distilled water in a 1000 ml flask, the distillation lasted 2 hours.

SPSS programme was used to calculate the data in a mono factorial analyse. Tukey-Test was used for comparison of standard aviation with a significance level of $P<0.05$. For evaluation of treatments tested parameters were ranked using a non-parametric test (Kruskal-Wallis test).

Results and Discussion

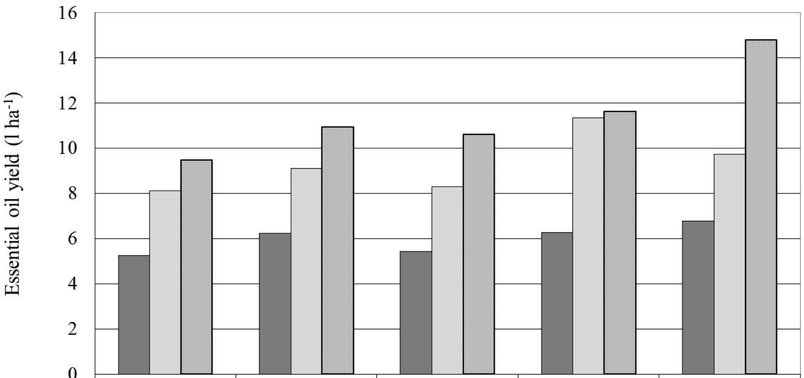
The highest yield of dried leaves was obtained during all three year in the treatment ‚Standard fertilisation + fleece cover' followed by ‚Standard fertilisation + double plant density'. The lowest herb yield was harvested in the treatment 'no nitrogen fertiliser'. Additional nitrogen and potassium fertilisation enhanced tendentially the yield of fresh herbs as well (Figure 1).

The nutritive and economical value of thyme is mainly characterised by the content of essential oil, therefore this parameter was analysed (Figure 2). Only slight differences could be detected between the treatments. In the first year of the experiment no significant effect of the different fertilisation treatments on the essential oil yield was discovered, therefore these results could not confirm the negative influence of a higher nitrogen fertilisation. Significant higher yield of essential oil in the first year, however, was detected in the treatment with 'double density of thyme plants'. In the second year protecting the plants with fleece showed significantly higher oil content than all other treatment. In the third year significantly higher essential oil yield was only detected in the treatment with the double amount of thyme plants. Beside the yield of essential oil per area, also the quantity of essential oil in 100 g dried leaves is an important parameter. In the first year of the experiment the essential oil yield in the dried leaves of thyme was in average between 2.74 and 2.83 ml 100 g^{-1}. In the second year in average of all three harvests an average yield of essential oil between 2.82 and 3.09 ml 100 g^{-1} was detected. The essential oil yield increased in comparison to the first year of the experiment with 7.58%. In the third year the essential oil content decreased distinctly to 2.63 – 2.72 ml $100g^{-1}$ dried leaves with –10.4 %. The fertilisation treatments, in particular the nitrogen fertilisation weren't influencing the quantity of essential oil and thymol content (data not shown). Similar results were obtained also from other authors (Shalaby and Razin, 1992; Omidbaigi and Arjmandi 2001; Baranauskiene et al., 2003).



	No N-fertilization	Standard + N-fert.	Standard + K-fert.	Standard + fleece cover	Standard 2x plant density
1st year	1,5 b	1,8 ab	1,5 b	1,7 ab	1,8 a
2nd year	2,4 c	2,6 c	2,6 c	3,4 a	3,1 bc
3rd year	2,42 b	2,92 b	2,78 b	3,16 ab	3,75 a

Figure 1 Dried leave yield of thyme (mean of three years) cultivated with three different fertilisations, protection with fleece and double plant density. Different letters indicate significant differences according to Tukey (P<0.05).



	No N-fertilization	Standard + N-fert.	Standard + K-fert.	Standard + fleece cover	Standard 2x plant density
1st year	5,26 b	6,23 ab	5,43 ab	6,25 ab	6,76 a
2nd year	8,13 b	9,09 ab	8,29 ab	11,35 a	9,74 ab
3rd year	9,45 b	10,91 b	10,58 b	11,62 b	14,78 a

Figure 2 Essential oil yield of thyme (mean of three years) cultivated with three different fertilisations, protection with fleece and double plant density. Different letters indicate significant differences in one year according to Tukey (P<0.05).

The aim of this study was also to investigate the effect of different treatments (Table 1) on the hibernation of the thyme plants. Therefore, the dead plants in all plots, the damaged plants in the cluster and the healthy plants were recorded two times, one time in winter and one time in spring (Figure 3). The lowest number of damaged and died plants was obtained in the treatment 'standard fertilisation and covered with fleece' followed by 'no N-fertilisation'. In the treatments 'double density of thyme plants' and additional K fertilisation, was the hibernation influence equivalent. Double amount of nitrogen fertilisation was negatively affecting the hibernation, many plants died during the winter. This negative effect of higher nitrogen supply on the hibernation resistance was also mentioned in other publications (Baranauskiene et al., 2003).

Table 1 Treatments to investigate the effect of N and K fertilisation, plant density and fleece cover on the essential oil yield and hibernation

Treatments	Comments
1. Standard fertilisation[1], no N-fertilisation	Plant spacing 30 x 40 cm
2. Standard fertilisation[1] with additional N-supply	Additional 60 kg N ha^{-1}, Plant spacing 30 x 40 cm
3. Standard fertilisation[1] with additional K-supply	Additional 100 kg K_2O ha^{-1}, Plant spacing 30 x 40 cm
4. Standard fertilisation[1] and fleece cover	Fleece cover (weight 30g m^{-2}) November-March; Plant spacing 30 x 40 cm
5. Standard fertilisation[1] and double plant density	Plant spacing 15 x 40 cm
[1] **Standard fertilisation** 60 kg N ha^{-1}, 17 kg P_2O_5 ha^{-1}, 115 kg K_2O ha^{-1}, 10 kg MgO ha^{-1} and 40 kg CaO ha^{-1}	

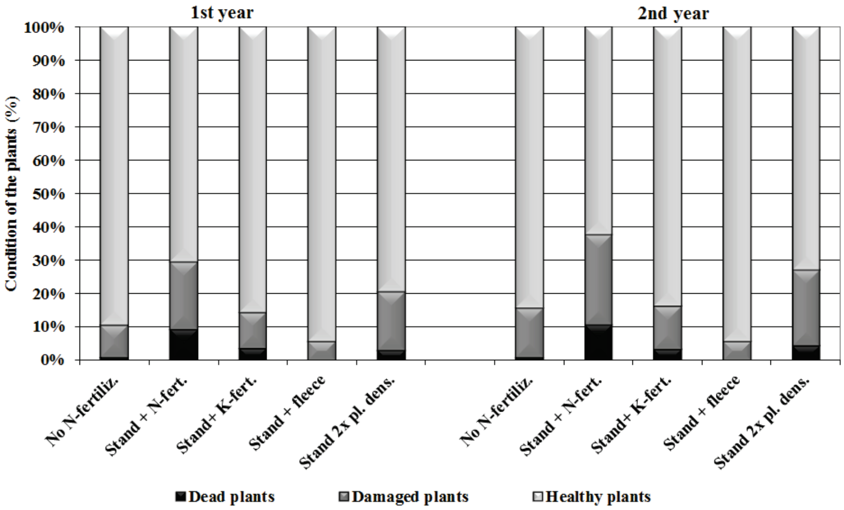


Figure 3 Condition of the thyme plants after 1st and 2nd year of hibernation, cultivated with three different fertilisations, protection with fleece and double plant density.

In order to evaluate the influence of the different treatments on all quantitative and qualitative parameters measured and detected a ranking was conducted (Table 2). In result of this statistically ranking it was proved that the best treatment was 'standard fertilisation and double plant density' and on the second place the treatment 'standard fertilisation and fleece cover' was discovered.

Table 2 Evaluation of ranking the influence of treatments on different parameters obtained in the experiment with thyme (Kruskall-Wallis-Test)

Treatments	Yield of dried leaves	Leaf fraction on the plant	Essential oil content	Thymol-content	Ranking
No N-fertilisation	5.46	15.87	8.50	12.38	3
Standard fert. + N-fertilisation	11.50	12.12	7.04	10.25	4
Standard fert. + K-fertilisation	7.79	9.54	11.16	10.54	5
Standard fert. + fleece cover	14.96	11.50	10.71	8.66	2
Standard fert. + double plant density	16.35	11.75	11.58	11.34	1

Nevertheless, in the treatment 'no N-fertilisation' the highest leaf fraction on the plant could be obtained, whereas in this treatment the produced biomass and essential oil per ha was the lowest.

Comparing the results obtained in the three experimental years, sometimes high differences were observed, but the correlation coefficient between the years and the leaf fraction on the plants was with 0.34% not very high.

Conclusion

It seems that the percentage of leaves per produced biomass cannot be influenced by additional nutrient supply. But because of the very different results for this parameter in the three years of cultivation influences of the climate conditions and frequency of harvesting should considered in further experiments. Also the content of essential oil in the thyme plants seems to be not dependent on the nutrient supply. Other factors as harvesting frequency, average temperature and precipitation are more important. The essential oil yield is depending on the interaction between fertilisation, number and time of harvesting and the weather conditions. While there were no effects of fertilisation on yield the hibernation was clearly affected especially by N-fertilisation. Based on this a reduced N-fertilisation seems to be recommended. In further experiments plant density and covering with fleece should investigated in more detail.

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(59) Optimisation of the SUSON strategy as a method for sustainable fertilisation in glasshouse butterhead lettuce

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Abstract: *The SUSON fertilization strategy (acronym for 'SUstained low SOil mineral N content'), was presented by Bleyaert et al. in 2007. Instead of standard basic dressing at planting up to some disputable and high target level, SUSON tries to maintain soil nitrogen content just above, but very close to a fixed low threshold level, therefore applying fertigation during the cultivation period, based on frequent soil analysis. Frequent experiments in various growing seasons and various soil types showed a threshold level of 60 kg/ha N in winter and of 90 kg/ha N in summer could guarantee the production of heavy lettuce of good quality. Compared to standard fertilization at planting, the SUSON strategy yielded an average reduction of 22.0 % for both fertilizer use and for nitrogen content in the 0-90 cm soil layer. However, the procedure of adjusting soil nitrogen content only at downward trespassing of the threshold level, and adjusting up to a level of 50 % above the threshold level showed some disadvantages: frequent measurement of soil N is necessary, and high fertilizer concentrations needed for overhead fertigation can cause necrotic burns in sunny periods. Therefore, a new working procedure was tested out for spring and summer periods: from planting on, nitrogen fertilizer was continuously added to the irrigation water, at a low concentration of 1.8 dS/m. Experiments in spring period proved this adaptation to yield excellent lettuce heads, on the condition that each fertigation turn of 4 L/m² was preceded and followed by irrigation with respectively 0.5 L/m² and 1.0 L/m² of pure water. Increase of the fertigation concentration to 2.2 dS/m could not increase lettuce head weight. However, postponing fertigation to start only at head formation did cause lower head weights.*

Keywords: *nitrate, leaching, fertigation, vegetables*

Introduction

In order to comply with the European nitrate directive, setting an upper limit of 50 ppm to the nitrate content of groundwater, more efficient fertilization strategies, reducing nitrate emission to the environment while maintaining plant productivity and quality level, should be developed. For vegetable growing, general fertilization practice consists of basic dressings at planting only, adjusting measured soil level to some target level. To minimize risks of fertilizer shortage for nitrogen (N), this target value is based on worst case values of the nitrogen balance components: minimal N input by mineralization, and maximal N output by crop growth, leaching or volatilization (denitrification). In most cases this fertilization strategy leads to excess fertilization (Salomez et al., 1999).

In a first attempt to minimize the excess N fertilization, we tried to apply the balance sheet method, as proposed by Hofman (1983) and Neeteson et al. (1988), which calculates N fertilization as being the deficit between mineral N (N_{min}) available in the rooting zone and mineral N needed for crop growth. As exact prediction of at least some of the N balance components showed to be troublesome (Salomez et al., 2001; Bleyaert & Vergote, 2002; Salomez et al., 2004), SUSON (Sustained low Soil mineral N content) strategy suggests directly to measure resulting soil N content at regular times during the cultivation period, and to apply N fertilization in order to withhold soil N content from dropping under some threshold level. This threshold level is supposed to correspond to the level of the latent N_{min} residue. Bleyaert et al. (2007a) obtained heavy butterhead lettuce of good quality applying the SUSON strategy using a threshold level of 60 kg/ha for winter period (15/08-31/01) and 90 kg/ha for summer period (1/02-14/08). Compared to standard fertilization at planting, the SUSON strategy yielded an average reduction of 22.0 % for both fertilizer use and for nitrogen content in the 0-90 cm soil layer. However, the procedure of adjusting soil N content only at downward trespassing of the N threshold level, and adjusting up to a level of 50 % above the threshold level showed some disadvantages: frequent measurement of soil N is necessary, and high fertilizer concentrations needed for overhead fertigation can cause leaf burns (necrotic spots) in sunny periods. This problem can be solved by applying fertigation by T-tape (Bleyaert et al., 2007b). However, the installation and removal of T-tape, which should be repeated at every growing cycle of lettuce, requires extra work, which makes it unappealing to the growers. Therefore, a new working procedure for application of the SUSON strategy was tested out for spring and summer periods: small basic quantities of N fertilizer are added continuously to the irrigation water anyhow, regardless of soil N measurement. Fertilizer concentration is raised only when soil N measured still tends to fall under the threshold level. Questions to be answered were: (1) what should be the N concentration in irrigation water, in order to postpone as much as possible downward trespassing of the N threshold level, but still being low enough to maintain residual soil N at harvest very close to this threshold level and to avoid the risk of leaf burns, and (2) at which developmental plant stage should basic N-addition to the irrigation water (= fertigation) start?

Materials and Methods

The adapted SUSON strategy was tested out in two experiments with butterhead lettuce (*Lactuca sativa* L. var *capitata*), grown in spring conditions.

In 2009, cv. Sintia (Rijk Zwaan) was sown on March 4, planted out on April 3 and harvested on May 12. Planting distance was 0.27 x 0.27 m. Standard fertilization strategy was compared with three SUSON modifications, adding calciumnitrate (with exception of the last week before harvest: potassiumnitrate) to the irrigation water at a concentration of 1,8 or 2,2 dS/m, and starting at planting or at the onset of head formation, on April 21 (Table 1). The decision to irrigate was based on growers experience, just like in practice, taking into account weather conditions, plant conditions and soil humidity. The water used was rain water, having an electrical conductivity (EC) of 0.05 dS/m only. In order to diminish the risk of leaf burns, each fertigation turn (4.0 L/m²) was preceded by leaf wetting (0.5 L/m²), and followed by rinsing (1.0 L/m²) with pure water (i.e. rain water without fertilizers). For young plants, the water quantity for fertigation was reduced to 2.0 L/m² only (Fig. 1). At any fertigation turn, treatments which not were meant to receive fertilization did receive the same quantity of pure water as the fertilized treatment, i.e. 3.5 L.m² for young plants, and 5.5 L/m² later on. As N soil before fertilization at planting already was 122 kg/ha, all SUSON treatments started with this N level instead of the target level of 90 kg/ha. The quantity of N supplied by fertigation during the growing period was 84.2; 60.9 and 74.4 kg/ha for treatments Sp 1.8; Sh 1.8 and Sh 2.2 resp. Fertilization of other nutrients than N was based on standard advice from the Belgian Soil Service, following soil analysis.

Table 1 Description of the experimental treatments for the 2009 experiment

Fertilization treatment	Abbreviation	Target level for N fertilization at planting (kg/ha)	N supply with irrigation
Control	Control	210	None
SUSON at planting 1.8 dS/m	Sp 1.8	90	1.8 dS/m, starting at planting
SUSON at head formation 1.8 dS/m	Sh 1.8	90	1.8 dS/m, starting at head formation
SUSON at head formation 2.2 dS/m	Sh 2.2	90	2,2 dS/m, starting at head formation

Experimental plot size was 8.00 m x 10.00 m. Large plot sizes were chosen to enable the use of the standard automatic sprinkler installation in the experimental glasshouse, which was considered to be necessary for a realistic estimation of the risk of leaf burns. However, as a consequence no replicates were possible. At harvest, marketable head weight for each plot was measured for 36 plants. On the field, all plots were scored (scale 1-9) on head size, soil covering and leaf burns.

Analysis of soil N was carried out weekly, and was increased to two times a week in the week before harvest. As a method ready for use in practice, a rapid test was used, based on reflectometry with the RQ-flex instrument. The instrument only measures nitrate N, but this is acceptable as the concentration of ammonium in Flemish soils mostly is very low. Wet soil, randomly taken from eight sampling places, was mixed and added to 200 mL of rain water up to a volume increase to 300 mL (1.5 volume method). After shaking for two minutes and filtering, a Reflectoquant strip successively was held in the solution for two seconds, and put in the RQ-flex instrument. Frequent tests before showed a good correlation ($r^2 > 0.90$) of the test result, R, with laboratory analysis when using a conversion factor of 1.539 ($R<50$), 1.421 ($50<R<100$) or 1.302 ($R>100$). Nevertheless, at some occasions soil N level was verified by laboratory analysis. 20 g moist and grinded soil was mixed with 100 mL of a 0.01 N $CaCl_2$ solution. After filtering, the $CaCl_2$ extracts were measured colorimetrically by a Segmented Flow Analysing system (SFA), determining at the same time NO_3^- - and NH_4^+-N concentration. The results are expressed on a dry weight basis (105 °C). For the conversion into kg/ha N a general soil bulk density of 1.1 kg/L was assumed. The soil ammonium N in these experiments was measured to be less than 6 kg/ha, confirming indeed ammonium N to be negligible.

In 2010, after it was clear that fertigation should start at planting already, and that increase of N fertilizer concentration did not yield any better results, the effect of a lower N concentration (1,5 mS) was studied. The experimental treatments are shown in Table 2. The fertigation procedure was exactly the same as in the 2009 experiment, with one exception: for wetting and rinsing of the lettuce leaves, another water source and water circuit was used than for fertilization supply. This assured the use of really pure water, without the presence of any residual fertilizers. In this experiment, eight cultivars were used: Arcadia and Gardia (Rijk Zwaan), Fidel (Nunhems), Hilton (Enza), Motivo, Tonava, LS 8220 and LS 8227 (Syngenta Seeds). Sowing occurred on December 17, 2009, planting on February 18, 2010, and harvesting on April 8, 2010. Planting distance again was 0.27 x 0.27 m, and plot size 8.00 m x 10.00 m, for the same reason as described before, allowing no replicates. As cultivar plots were randomized within each fertilization plot, they could not serve as replicates for fertilization, and so no statistical analysis of treatment effects was possible. Observations and soil analysis were the same as in the 2009 experiment. Soil N level at planting, before fertilization, was 89 kg/ha, allowing the low target level for the SUSON treatments to be reached. The quantity of N supplied by fertigation during the growing period was 52.4 and 63.0 kg/ha for treatments Sp 1.5 and Sp 1.8 respectively.

Table 2 Description of the experimental treatments for the 2010 experiment

Fertilization treatment	Abbreviation	Target level for N fertilization at planting (kg/ha)	N supply with irrigation
Control	Control	210	None
SUSON at planting1.5 dS/m	Sp 1.5	90	1.5 dS/m, starting at planting
SUSON at planting 1.8 dS/m	Sp 1.8	90	1.8 dS/m, starting at planting

Results and Discussion

In the experiment 2009, starting fertigation only at head formation (Sh) resulted in lower head weights (Table 3), no matter what N concentration (or quantity) was supplied. This suggests the N given in the period shortly after planting to have a more important effect on plant growth than N given after head formation, and the latter cannot replace the former. The fact that the higher N supply (84 kg/ha vs. 61 kg/ha) between Sp 1.8 and Sh 1.8 did not result in a higher soil N content (Fig. 1) indeed could indicate that the surplus of N given has been taken up and was converted into plant material. It should be emphasized however, that warm weather conditions occurred in the period before April 21 (start of head formation), which can have caused more rapid plant growth, and thus higher needs for N in that developmental period than normal. While the SUSON treatment started at planting yielded lettuce heads of the same weight and quality as the control treatment – the quantity of applied N being almost equal (88 vs 84 kg/ha), Fig. 1 shows that it was very successful in maintaining, during all the cultivation period, a much lower soil N content than the control. Even at harvest, the soil N in the control treatment surpassed that in the SUSON treatment with more than 50 kg/ha. Validation of RQ flex measurements with laboratory analysis, on April 15 and May 12, showed comparable values for the control treatment, but more elevated values, with some 20 kg/ha, for the SUSON treatments. The contrast between SUSON treatments however was comparable. Table 3 shows that in each of the SUSON treatments leaf burns still were present, which was unexpected. Even though the necrotic spots were small, and occurred on the older leaves only, they removed much of the confidence of growers in SUSON strategy. Small tests revealed that the water used to wet and rinse the lettuce leaves was not as pure as was supposed. Presumably it contained residual N solution of the former fertigation turn that still was present in the long water conducting pipes occurring in the experimental glasshouse facility. To avoid this technical problem, in the 2010 experiment, wetting and rinsing water was taken from another source, being conducted in other water pipes. Maybe, as a result of this, in the 2010 experiment no leaf burns occurred at all. Another reason however could be the milder weather conditions in 2010 than in 2009: temperature inside the glasshouse was more than 20 °C for 75 hours, and more than 25 °C for 3 hours only, while in 2009, the number of respective hours was 197 and 38. But, since it is already common practice for growers sometimes to add fertilizers to irrigation water at concentrations of up to 1.8 dS/m, without rinsing, it is unlikely that the proposed procedure for SUSON application could cause any plant damage. Only for conditions of increased fertilizer concentrations, the plant safety of the procedure should be tested in hot weather conditions.

Table 3 Observations at harvest for the 2009 experiment[1]

Treatment	Marketable head weight (g)	Soil covering	Head size	Leaf burns
Control	547	7.2	7.7	9.0
Sp 1.8	546	7.1	8.0	6.5
Sh 1.8	528	7.0	8.1	6.3
Sh 2.2	519	7.5	8.2	6.3

[1]Scale 1-9 (excepted for head weight). For soil covering and head size, a high score reflects a good result. For head size, 9 means large, more open heads (not tightly compacted). For leaf burns, the lower score reflects less leaf burns (9 = no leaf burn at all).

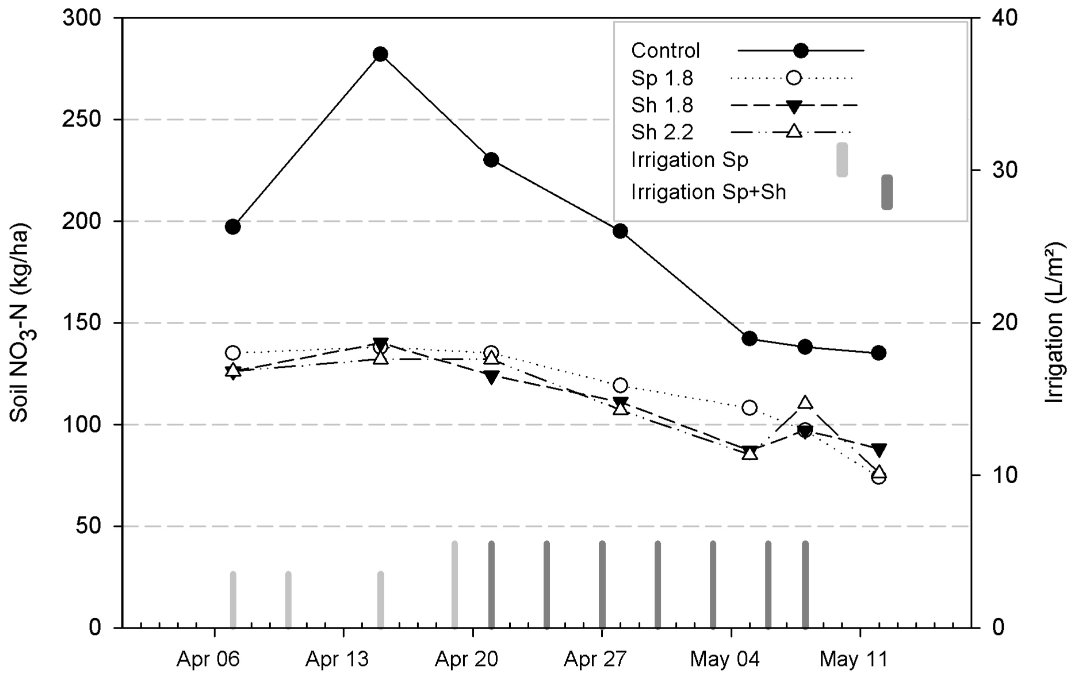

Figure 1 Course of nitrate-N in top soil (0-30 cm) for the four fertilization treatments in experiment 2009, measured by RQ-flex. Vertical bars represent irrigation turns. Onset of head formation visibly was estimated on April 21.

In the 2010 experiment, treatments with the adapted SUSON strategy obtained better head weights and head sizes than the control treatment (Table 4). This was true for all cultivars, with only one exception for the head weight of LS 8220 in Sp 1.5. In this experiment however, the quantity of applied N to the SUSON treatments was 60 to 70 kg/ha lower than the basic N dressing of 121 kg/ha applied to the control. This suggests N applied through irrigation to be more effective than N already present in the soil, but another explanation could be a detrimental effect in the control treatment of irrigation turns with pure rain water, because of the dilutive effect. The lower quantity of N applied in the SUSON treatments clearly resulted in a much lower level of soil N during all the cultivation period (Fig. 2). The use of a fertilizer concentation of 1.5 dS/m (Sp 1.5) regularly corresponded to a lower soil N level than the use of a concentration of 1.8 dS/m (Sp 1.8). This lead to an earlier downward trespassing of the treshold level of 90 kg/ha: some 10 days before harvest already, while in the Sp 1.8 treatment, this was only the case during the last few days. Presumably as a result of this, head weight of almost all cultivars was lower and head size inferior in the treatment Sp 1.5. Verification of the RQ-flex measurements with laboratory analyses for the three latest measurement points showed good fit, excepted for the analysis of Sp 1.5 on March 23, showing 106 k/ha (lab) instead of 131 kg/ha (RQ-flex). This was more in line with the other Sp 1.5 measurements and confirmed the lower soil N level for this treatment.

Table 4 Observations at harvest for the 2010 experiment[1]

Cultivar	Marketable head weight (g)			Soil covering			Head size		
	Control	Sp 1.5	Sp 1.8	Control	Sp 1.5	Sp 1.8	Control	Sp 1.5	Sp 1.8
Arcadia	445	474	487	8.0	7.8	7.5	6.5	7.5	7.0
Fidel	452	478	473	7.5	8.2	7.9	7.5	8.0	8.5
Gardia	454	469	487	7.8	7.8	7.5	7.5	7.5	8.0
Hilton	451	477	482	7.5	7.8	7.0	7.5	7.5	8.0
Motivo	405	424	421	8.0	7.8	7.8	6.5	7.0	7.0
Tonava	388	423	424	7.5	7.5	7.5	7.0	7.5	7.0
LS 8220	400	379	423	7.8	7.5	7.5	7.0	7.5	8.0
Nisava	387	392	427	7.5	7.6	7.8	7.0	7.8	8.0
Mean	423	440	453	7.7	7.8	7.6	7.1	7.5	7.7

[1]Scale 1-9 (excepted for head weight). For soil covering and head size, a high score reflects a good result. For head size, 9 means large, more open heads (not tightly compacted).

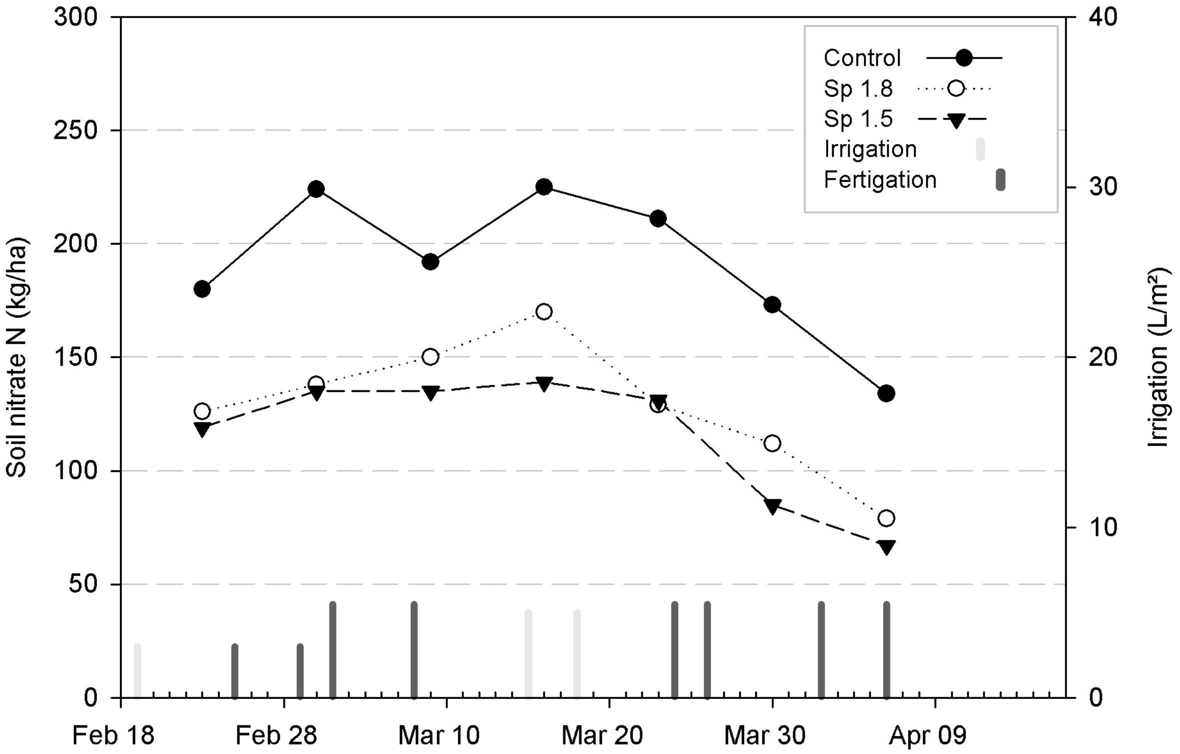

Figure 2 Course of nitrate-N in top soil (0-30 cm) for the three fertilization treatments in experiment 2010, measured by RQ-flex. Vertical bars represent irrigation (water without fertilizer) or fertigation (water + fertilizer) turns. Onset of head formation visibly was estimated on March 23.

In both experiments, the adapted SUSON strategy, starting N fertilizer supply with irrigation immediately at planting, irrespective of soil analysis, allowed to avoid the use of high fertilizer concentrations, and thus the occurrence of leaf burns. In these experiments, the initial fertilizer concentration of 1.5, 1.8 or 2.2 dS/m never was increased during the growing period. Only at the end of the growing period, downward trespassing of the N threshold level was observed, but only for the treatments Sh and Sp 1.5 this tresspassing was substantial, resulting in inferior lettuce production. In these cases, when following the adapted SUSON strategy, the basic fertilizer concentration of the irrigation water should in fact have been increased, but this was forgotten. For Sp 1.8, the experimental results indicate that in the course of the growing period no increase might be necessary, but this should be confirmed with more experiments. In the meantime, it is adviced to base the decision whether or not to increase fertilizer concentration on soil N analysis, some 14 days before harvest. On the other hand, correction of fertigation can be necessary in order to prevent residual N at harvest largely to surpass the N threshold level. In experiment 2010, such correction was carried out by switching off fertilizer addition when soil N was higher than 1.5 times the N treshold level (145 kg/ha for summer periods). Fig. 2 shows that in 2010, such “high” soil N levels occurred at two successive measurements, resulting in the application of two irrigation turns without fertilizer addition. This fertigation stop was applied at once for both Sp treatments. For the Sp 1.8 treatment, it yielded a final soil N level that was quite close to the treshold level (RQ-flex: 79 kg/ha; lab: 77 kg/ha), but for the Sp 1.5 treatment, final soil N level was too low (RQ-flex: 67 kg/ha – lab: 55 kg/ha). For this latter treatment, fertigation stop was not necessary – soil N never surpassed 145 kg/ha, while continuation of it very well could have resulted in a perfect course of soil N: tightly around and just above the N threshold level.

As irrigation mostly is, at least to some extent, proportional to plant growth, and so to N uptake as well, it could be possible that some N concentration for fertigation exists that allows in most cases to fulfil the SUSON goals without the need for corrections. Further experiments, in various growing seasons, should reveal this. In this case, no soil N measurement would be necessary any more, thus making SUSON strategy much more accessible for growers.

Conclusion

The experiments carried out in 2009 and 2010 indicate that SUSON strategy can be applied very well by adding calciumnitrate or potassiumnitrate to the irrigation water up to an EC of 1.5 to 1.8 dS/m, regardless of any soil analysis, and starting from planting on. This modification preserves the initial goals of the SUSON strategy, being restriction of N fertilizer use to the strict minimum, and maintaining low soil N levels during all the cultivation period, while still safeguarding normal lettuce head weights of good quality. In order to diminish the risk of leaf burns, it is adviced to wet lettuce leafs before each fertigation turn with 0.5 L/m² of pure water, and afterwards to rinse them with 1.0 L/m²; again of pure water. To verify whether the fertilizer concentration in irrigation water should be increased or decreased, soil N analysis should be carried out at least twice in each cultivation period: one at onset of head formation, and a second one two weeks before harvest. Increase of fertilizer concentration has to start when soil N approaches the N threshold level of 60 kg/ha during winter and 90 kg/ha during summer period. Decrease is necessary only when soil N surpasses 1.5 x threshold level.

More experiments, in various seasons, should indicate whether not, within the range 1.5 – 1.8 dS/m, one fertilizer concentration for fertigation can be found which can guarantee SUSON goals without the need for corrections. In this case, no soil N measurement would be necessary any more, thus making SUSON strategy much more accessible for growers. If this is not the case, experiments in hot weather conditions should verify if the described fertigation procedure, with wetting and rinsing of the leaves, sufficiently can protect plant leafs against leaf burns when increase of fertilizer concentration is required.

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(60) Fertigation and winter cover crops as complementary tools for the N nutrition of processing tomato

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Abstract: *Fertigation can allow both to match fertiliser application and N crop requirements at any crop growth phase and to improve the fertilisation efficiency by localization close to the roots. Cover crops are a powerful tool for N management and for limiting the risk of N leaching. Within a sound strategy for a conservative horticulture, fertigation and winter cover crops could be suggested as complementary tools in order to guarantee both adequate vegetable crops N nutrition and environmental benefits. A 2-year field experiment was carried out on processing tomato fertilised by different methods: green manuring of winter cover crops (i.e. hairy vetch and barley as pure stands or mixtures), fertigation, green manures+fertigation. Pure vetch cover crop was able to supply a considerable amount of nitrogen to match N requirement of a subsequent crop of processing tomato, without significant differences with fertigation, applied alone or in combination with winter cover crops. Pure vetch green manure showed a low risk of N leaching during tomato crop cycle but it was poorly effective in reducing the N leaching during the fall-winter period. Incorporation of cover crops with high C/N as pure barley and mixture barley-vetch, although supplied very low amount of N for a subsequent tomato crop, contributed to fix N into the soil and it reduced the environmental impact related to the mobility of nitrogen along the soil profile during fall-winter period and crop fertigation.*

Keywords: *green manuring; environmental issue; N leaching; critical N; Lycopersicon esculentum L.*

Introduction

In processing tomato fertigation allows to match fertiliser application and N crop requirements at any crop growth phase and to improve the fertilisation efficiency by localization close to the roots (Battilani, 2003; 2006; Singhandupe et al., 2003; Farneselli et al., 2007; Zotarelli et al., 2009). However, agronomic research should cope with environmental issue by finding sustainable technical solutions at system level rather than at simple technique scale (Agostini et al., 2010). Introducing catch crops and green manures in a horticultural system is a powerful tool for N management and for limiting the risk of N leaching particularly during the winter (Thorup-Kristensen 2003; Benincasa et al., 2004; Macdonald et al., 2005; Benincasa et al., 2008; Tosti et al., 2012). Within a sound strategy for a conservative horticulture, fertigation and winter cover crops could be suggested as complementary tools in order to guarantee both adequate vegetable crops N nutrition (Farneselli et al., 2007; Boldrini et al., 2006; Benincasa et al., 2010) and environmental benefits (Tosti et al., 2012). The aim of the research was to verify the efficacy of fertigation and cover crops as complementary tools for N fertilisation on crop growth, yield and potential N leaching in processing tomato.

Materials and Methods

Field experiments were carried out in two growing seasons (2010-2011 and 2011-2012) at the Experimental Station of the Department of Agricultural and Environmental Sciences of the University of Perugia (Papiano, Central Italy, 43°N, 165 a.s.l.) on processing tomato (*Lycopersicum esculentum* L., cv. Perfectpeel). The soil was clay-loam with 1.3% organic matter and both years the preceding crop was soft winter wheat.

Barley (*Hordeum vulgare* L. cultivar Amillis) and hairy vetch (*Vicia villosa* Roth., cultivar Capello) cover crops were sown on 17.11.2010 and 31.10.2011 as pure crops at the ordinary sowing rates (400 seeds m^{-2} of barley, B100; 200 seeds m^{-2} of vetch; V100) and as a mixture with a 75:25 seed ratio (i.e. barley at 75% of its full sowing rate + vetch at 25% of its full sowing rate, B75V25). Cover crops were sown in rows spaced 0.15 m apart; barley and hairy vetch in the mixtures were sown in the same row. No N fertilisation was supplied to the cover crops while phosphorus and potassium were applied at cover crops planting to all plots at a rate of 100 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}. At killing dates (27.4.2011 and 26.4.2012) the hairy vetch plants were at the beginning of flowering, while barley plants were at ear emergence. Cover crops aboveground biomass was mowed, finely chopped and immediately incorporated into the soil (0.2 m depth) by a rotary cultivator equipped with tines and a back-roller. Two controls were also added to the experiment: barley was grown as in B100 but the aboveground biomass was removed instead of being incorporated into the soil at the killing date (RB) and a bare soil (i.e. without any cover crop) was left during cover crops growing cycle (BS).

Processing tomato was transplanted on 11.05.2011 and 15.05.2012 at a density of 3.2 plants m^{-2} in a twin-row plant arrangement (0.4 +1.2 m). The tomato was fertilised by different methods: only by green manures of hairy vetch and barley (pure stand and in mixture), only fertigation, or a combination of green manure+fertigation. Where the crop was only fertigated (i.e. RB+Fert and BS+Fert) 300 kg N ha^{-1} were applied; where the crop was fertigated in combination with green manuring (i.e. B100+Fert; B75V25+Fert) nitrogen rates were calculated as a difference between 300 kg N ha^{-1} and N content of green manures. A liquid fertilizer containing 7.5% N-NO_3, 7.5% N-NH_4 and 15% urea-N was used. Fertigation N rates during the crop cycle was applied by following N uptake rates in processing tomato found by Tei et al. (2005). Two unfertilised controls were also applied: tomato in BS plots (BS-N0) and RB plots (RB-N0). The experimental design was a completely randomized block with 3 replicates; the plot size was 92 m^2 in both years.

The same irrigation volume was applied in a two-times-per-week irrigation schedule for all treatments, according to FAO method (Allen et al., 1998) and by using K_c determined on the basis of previous researches carried out on the same processing tomato cultivar (Tei et al., 2002).

The aerial biomass and total-N accumulation of green manures were measured at incorporation date. Aboveground biomass of vetch and barley in the mixture was separated by hand. The aerial biomass and N accumulation of tomato was measured by sampling 4 plants per plot at 20, 33, 42, 49, 56, 63, 70, 84, 98 and 104 Days After Transplanting (DAT) in 2011 and at 29, 36, 43, 50, 57, 84, 71, 78, 85, 98 and 105 DAT in 2012. In each plot, the harvested aboveground biomass of cover crops and tomato was weighed, oven dried at 80°C ground to a fine powder and stored for the analysis of N content. For both cover crops and tomato plant samples, an automatic analyser (FlowSys, Systea, Italy) was used to measure reduced-N concentration in Kjeldhal digests prepared according to Isaac and Johnson (1976). In this paper only the data collected at the final harvest (23.08.2011; 28.08.2012) are shown. Fresh weight of tomato marketable yield was also calculated at the final harvest.

The soil solution was extracted by suction lysimeters (Curley et al., 2010) at 0.6 m depth every week during the cover crops and tomato growth cycle the day after any significant rainfall or irrigation/fertigation event. The N-NO_3 concentration of the water samples was measured by an ion-specific electrode meter (Cardy, Spectrum Technologies, Inc., Plainfield, IL).

Results and Discussion

The aboveground biomass of cover crops (Tab. 1) in 2011 was 2.3 t ha^{-1} in B100, 3.8 t ha^{-1} in V100 and 2.6 t ha^{-1} in the mixture B75V25 (15% of vetch). On average the biomass recorded in 2011 was lower than in 2012 (approximately -54% of biomass and -55% of N accumulated) due to dry winter. In 2012 the vetch in the mixture was not really present so B100 and B75V25 produced the same amount of biomass (on average 6.4 t ha^{-1} of barley); the pure vetch cover crop was highly infested by weeds (2.2 t ha^{-1}) that were soil incorporated with the legume biomass (5.9 t ha^{-1} in total).

Table 1 Dry weight accumulation (Mg ha^{-1}) and N accumulation (kg ha^{-1}) of the cover crops aboveground biomass at the date of its incorporation into the soil in 2010-2011 and 2011-2012. Standard errors in brackets

	Aboveground biomass (Mg ha^{-1})						N accumulation (kg ha^{-1})					
	Vetch		Barley		Total		Vetch		Barley		Total	
2010-2011												
B100 (RB)	-		2.3	*(0.16)*	2.3	*(0.16)*	-		22	*(1.8)*	22	*(1.8)*
V100	3.8	*(0.47)*	-		3.8	*(0.47)*	113	*(17.6)*	-		113	*(17.6)*
B75V25	0.4	*(0.09)*	2.2	*(0.22)*	2.6	*(0.17)*	13	*(3.6)*	21	*(2.7)*	34	*(3.8)*
2011-2012												
B100 (RB)	-		6.5	*(0.94)*	6.5	*(0.94)*	-		71	*(13.0)*	71	*(13.0)*
V100	3.7	*(0.53)*	-		5.9*	*(0.62)*	117	*(17.06)*	-		166*	*(11.4)*
B75V25	-		6.3	*(0.77)*	6.3	*(0.77)*	-		68	*(8.6)*	68	*(8.6)*

* Weed biomass included

Green manures in 2011 contained on average the following amount of N: 22 kg N ha^{-1} in B100, 113 kg N ha^{-1} in V100 and 34 kg N ha^{-1} in B75V25 (about 38% from vetch). In 2012 B100 and B75V25 supplied into the soil contained about 70 kg N ha^{-1} while V100 accumulated 117 kg N ha^{-1} plus about 50 kg N ha^{-1} by weed biomass.

The aerial biomass accumulation in processing tomato in the unfertilized controls (i.e. BS and RB) and in B100 and B75V25 was 43% lower (as average over treatments and years) than in fertigated treatments (i.e. only fertigated, BS+Fert and RB+Fert, or where fertigation was applied in combination with cover crops, B100+Fert, B74V25+Fert) (Tab. 2). In both years, no significant difference was detected between fertigated treatments, with or without cover crops (i.e. B100+Fert) and green manure of pure vetch (V100).

Table 2 Dry weight accumulation (Mg ha^{-1}), N accumulation (kg ha^{-1}) and fresh weight fruit yield (Mg ha^{-1}) in processing tomato in 2010-2011 and 2011-2012. Standard errors in brackets.

	Aboveground biomass (Mg ha^{-1})	**N uptake (kg ha^{-1})**	**Fruit yield (Mg ha^{-1})**	**Aboveground biomass (Mg ha^{-1})**	**N uptake (kg ha^{-1})**	**Fruit yield (Mg ha^{-1})**
	2010-2011			**2011-2012**		
B100	5.7 *(1.18)*	103 *(2.4)*	58 *(8.4)*	7.2 *(0.36)*	107 *(4.4)*	65 *(1.7)*
B75V25	7.4 *(0.51)*	143 *(0.8)*	79 *(2.9)*	7.3 *(0.39)*	110 *(11.0)*	63 *(5.1)*
V100	11.2 *(0.04)*	195 *(0.4)*	124 *(7.1)*	11.7 *(0.85)*	180 *(12.4)*	115 *(1.9)*
B100+Fert	11.3 *(1.16)*	304 *(1.9)*	124 *(2.1)*	12.0 *(0.49)*	274 *(15.8)*	132 *(1.2)*
B75V25+Fert	10.8 *(0.34)*	289 *(1.2)*	133 *(3.4)*	13.0 *(0.47)*	266 *(12.3)*	127 *(2.7)*
BS+Fert	12.6 *(0.64)*	348 *(2.1)*	104 *(24.5)*	15.1 *(1.42)*	394 *(34.3)*	117 *(3.4)*
RB+Fert	11.4 *(0.60)*	320 *(2.6)*	135 *(6.7)*	13.6 *(1.03)*	348 *(26.9)*	121 *(3.2)*
RB-N0	6.2 *(0.65)*	123 *(2.3)*	61 *(7.8)*	7.4 *(1.02)*	117 *(12.9)*	96 *(2.3)*
BS-N0	7.0 *(0.49)*	118 *(0.2)*	78 *(5.1)*	9.3 *(1.13)*	184 *(23.1)*	60 *(3.0)*

The accumulation of N in processing tomato dry biomass showed similar trends to the aerial biomass accumulation in both years for all treatments with exception of V100 (Tab. 2). In pure vetch, indeed, the amount of N accumulated in processing tomato biomass was significantly lower than that recorded in all fertigation treatments (on average in both years 187 kg ha^{-1} in V100 compared to 318 kg ha^{-1} as average of all the fertigated treatments). Nevertheless, as already described above, the biomass accumulation in V100 was quite similar to that measured in the fertigation treatments. These results suggest that both in 2010-2011 and 2011-2012 pure vetch allowed an adequate crop growth while fertigation, both alone and in combination with green manure, determined a luxury N consumption.

Results of marketable fruit yield were in line with those of above-ground biomass: tomato after V100 yielded (124 t ha^{-1}) at the same level of fertigated treatments (i.e. average of BS+Fert, RB+Fert, B100+Fert, B74V25+Fert) in 2011 and just 8% lower (115 vs 124 t ha^{-1}) in 2012; green manures with a high component of barley (i.e. B100 and B75V25) yielded about 47% lower (as average over years and treatments) than fertigated and V100 treatments.

The presence of cover crops preceding fertigation (B100+Fert and B75V25+Fert) significantly decreased N-NO_3 concentration both in 2010-2011 and 2011-2012 in suction lysimeters during tomato crop cycle as compared to BS+Fert and RB+Fert (Fig. 1). Results suggest that the incorporation of cover crops with high C/N ratio as B100 and B75V25 (on average 30, data not shown) contributes to fix N into the soil and it reduces the environmental impact related to the mobility of this element along the soil profile both during the fall winter-period (data not shown) and tomato crop cycle (Farneselli at al., 2008). The N-NO_3 concentration of soil solution in tomato that succeeded pure and mixed cover crops (i.e. B100, B75V25 and V100) was very low and similar to the value measured in the unfertilised controls for the whole crop cycle in both years. Also the incorporation of pure vetch, with low C/N ratio (approximately 12, data not shown), determined low N-NO_3 concentration in soil solution. Although pure vetch green manure supplied a considerable amount of NO_3-N for the subsequent tomato crop and contributed to reduce the leaching during the tomato crop cycle, it was poorly effective in reducing the N leaching during the fall-winter period when the risk of N loss I very high (data not shown).

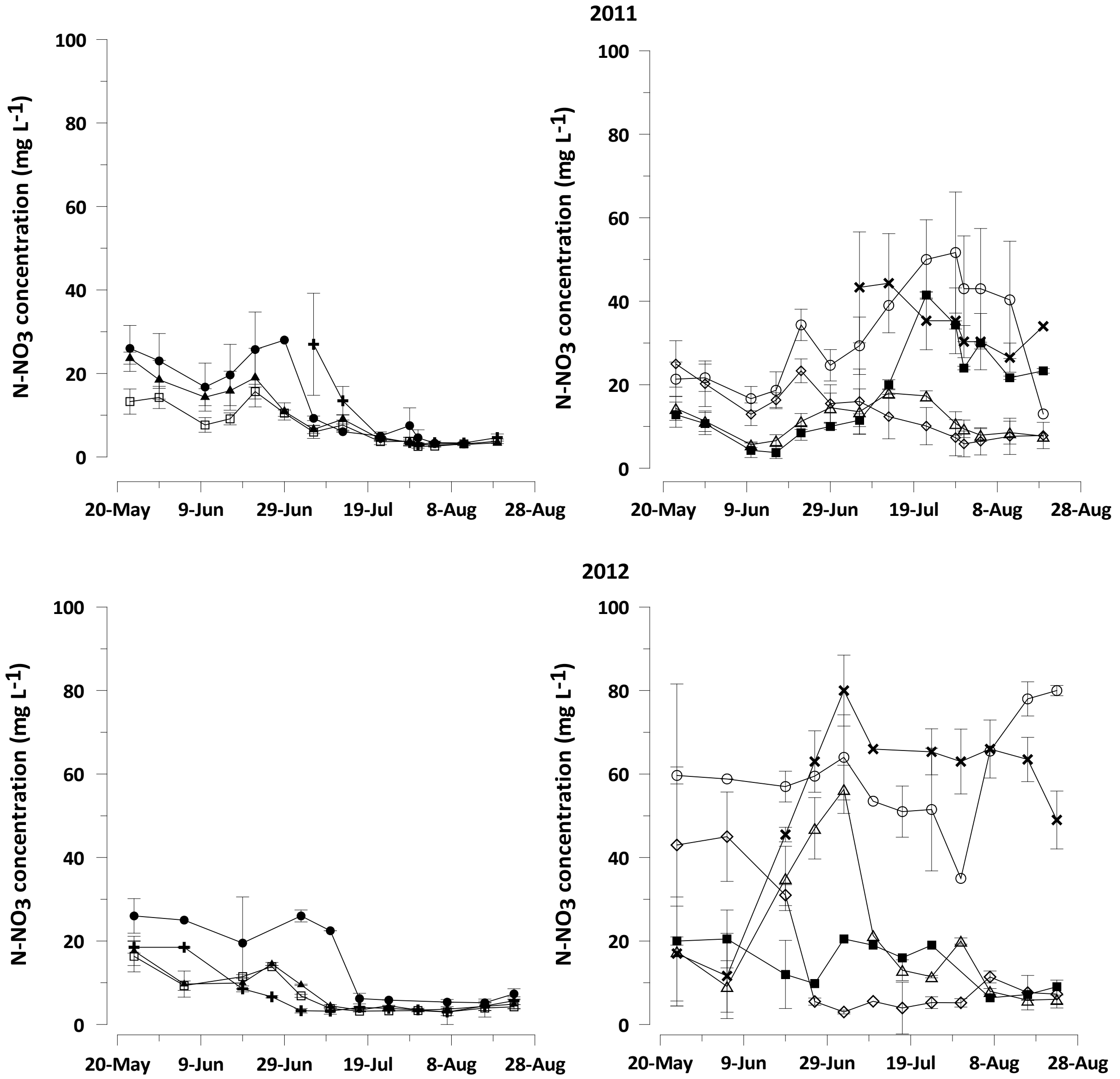

Figure 1 Time course of N-NO_3 concentration in suction lysimeters at 0.6 m depth during processing tomato cycle in 2011 and 2012. Bars indicate ± SEs. Symbols: observed data:

(● V100; ▲ B75V25; □B100; ✚ RB-N0; ○ BS+Fert; △ B75V25+Fert; ■ B100+Fert; ✖ RB+Fert; ◇ BS-N0)

Conclusion

Results suggest:

1) a pure vetch cover crop was able to supply a considerable amount of nitrogen to match N requirement of a subsequent crop of processing tomato, without significant differences with fertigation, applied alone or in combination with winter cover crops;
2) a pure vetch green manure showed a low risk of N leaching during tomato crop cycle but it was poorly effective in reducing the N leaching during the fall-winter period;
3) the incorporation of cover crops with high C/N as pure barley and mixture barley-vetch, although supplied very low amounts of N for a subsequent tomato crop, contributed to fix N into the soil and it reduced the environmental impact related to the mobility of nitrogen along the soil profile during fall-winter period and crop fertigation.

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(61) DEMETER: Sustainable and integrated soil management to reduce environmental effects

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Abstract: *Flemish and Dutch agricultural land management is characterized by a structural surplus of nutrients. At the same time, soil degradation is intensifying and substantial amounts of soil organic matter are lost. The rationale of the project 'DEMETER' is that insights in sustainable nutrient and soil organic matter management can be translated into practical recommendations to farmers by offering them a decision support tool (DST) that simultaneously optimizes soil organic matter and nutrient applications to the soil.*

A DST, which delivers advice on nutrient management (N and P balances) and carbon evolution in the soil (based on the Roth-C model, Coleman and Jenkinson, 1996) has been developed. To enhance a successful implementation of the DST in agricultural practice, the number of input variables is limited and the program works with a user-friendly interface. The DST is being tested and fine-tuned based on the experiences of 80 Flemish and Dutch arable and dairy farms in the period 2013-2015. Soil and manure samples on all farms (1-2 fields per farm) are analysed in order to give tailored recommendations on sustainable soil and nutrient management. The farmers are supported by counsellors through individual farm visits in Flanders and group sessions in the Netherlands. Each year, the application of sustainable soil management will be evaluated through additional measurements. Towards the end of 2014, the definite content of the DST tool will be assessed and the tool will be made available on-line..

Keywords: *decision support tool; nutrient management; soil organic matter management; fertilizer recommendation*

Introduction

Due to the high manure pressure and the intensive nature of agricultural production in Flanders and The Netherlands, special attention is needed to prevent nutrient losses to the environment and to protect the soil from soil degradation, e.g. loss of soil organic matter. A lot of research has been done on sustainable nutrient management including management of soil organic matter and the impact on the environment. Unfortunately this research hardly finds its way to daily farm management, as the gap between research and farmers is too wide.

Three organisations decided to deal with these two issues together in the framework of a LIFE+ project, called DEMETER. The project DEMETER is managed by the Flemish Land Agency (VLM, Belgium), the Nutrient Management Institute (The Netherlands) and Ghent University, Faculty of Bioscience Engineering, Department of Soil Management (Belgium).

The aim of this project is to translate the results of scientific research on the combined management of nutrients and soil organic matter into practical recommendations to farmers, offering them a decision support tool that will simultaneously consider nutrient and soil organic matter management.

The DEMETER project has 4 specific objectives:

· To increase the knowledge of the agricultural sector concerning the principles of sustainable nutrient and soil organic matter management in daily farm practices.

· To provide a practical tool which supports farmers in sustainable soil and nutrient management.

· To enhance the effective implementation of sustainable soil and nutrient management.

· To increase awareness amongst all agricultural stakeholders about the benefits of sustainable soil and nutrient management and the environmental risks caused by decreasing soil organic matter levels.

On a practical level, this project aims to develop an accessible webtool combining a nutrient and an organic matter module. The developed tool will be tested on the field during 3 years in collaboration with 80 Flemish and Dutch farmers.

Materials and Methods

Field monitoring

In Flanders, 50 farms were selected (10 farms in each province) in a way to be representative for particular problems, i.e. in an intensive horticulture region in West Flanders, in an erosion vulnerable region in East Flanders, Flemish Brabant and Limburg and in an intensive livestock farming region in Antwerp. Two fields per farm are monitored during a field survey (2013-2015). Organic matter content and nitrogen mineralization capacity were the most important parameters for the selection of the fields in which a wide range of values for each parameter was pursued. Only fields with arable crops were selected as the DST is not able yet to deal with (permanent) grassland.

In the Netherlands, 30 farms were selected in the sandy region of Southeast Netherlands (Province of North Brabant and Limburg). One field per farm was selected and will be monitored during the project period.

On each field, soil samples were collected at the beginning of the monitoring period to determine basic soil fertility (organic matter, pH, plant-available P, K and Mg). Additionally, each year soil samples will be collected at the beginning and at the end of the growing season to determine mineral N in the soil in different soil layers (0-30 cm, 30-60 cm, 60-90 cm). Organic materials applied on the selected fields (manure, slurry, compost, …) will be analysed for dry matter and total N and P content.

Additional information was collected for each field including crop rotation, fertilisation history, tillage, ….

Development of the Decision Support Tool (DST)

The DST aims to translate insights in sustainable nutrient and soil organic matter management into practical recommendations for farmers. The DST consists of a nutrient module and an organic matter module.

The organic matter module calculates the long term (30 years) evolution of organic carbon in the selected field based on the Roth-C model. The input data for this model are climate data (temperature, rainfall and evapotranspiration), soil characteristics (texture, bulk density, organic matter content), crop rotation and input of organic materials. The organic matter module was validated using data from long term field experiments.

In the nutrient module of the DST, a mineral N balance and a P balance is calculated for the selected field. The mineral N balance consists of 7 input parameters (mineral N in the soil, mineralization of soil organic matter, catch crop, crop residues and organic materials, ploughing of permanent grassland and N deposition) and 2 output parameters (N uptake by crops and leaching). The P balance considers the application of organic materials as P input and P uptake by crops as P output. P balances are calculated over a whole crop rotation period. Both the organic matter dynamics and nutrient balances are calculated on the field scale.

Training of the farmers

In Flanders, the farmers will be advised about sustainable soil management individually. Twice a year the counsellors of the Flemish Land Agency will visit the farmers to discuss the field results and appropriate soil management.

In the Netherlands, farmers are trained in group sessions. Three groups of each 10 farmers will meet at regular basis (at least twice a year) and discuss field results and sustainable soil management.

Demonstration days for the farmers as well as contacts with stakeholders will be organised on a regular basis in Flanders and The Netherlands.

Results and Discussion

Field monitoring

The location of the 50 participating farms in Flanders is shown in Figure 1. Soil characteristics of the selected fields are presented in Figure 2 and 3. Figure 2 shows that most fields have a loam, sandy loam or sand texture (more or less equally divided). The distribution of the soil organic matter content over several classes in Flanders is presented in Figure 3. Especially in the loamy and sandy loam soils, soil organic matter content is low; 63 and 50 % of these soils have an organic matter content lower than 1 % C. Figure 4 shows the crops cultivated on the selected fields in 2013. The most important crops on the fields are maize, winter wheat, sugar beet, vegetables and potatoes.

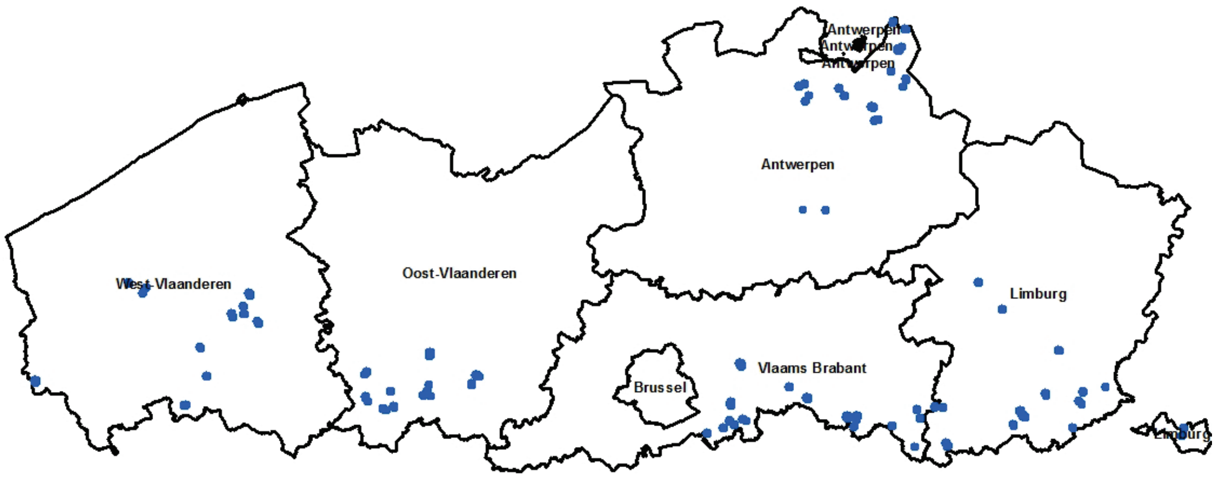

Figure 1 Location of the 50 participating farms in Flanders (Belgium)

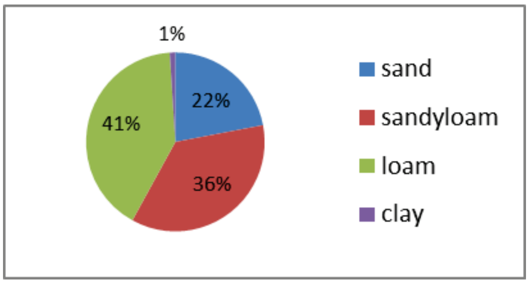

Figure 2 Soil textures of the 100 selected fields in Flanders

(Nomenclature based on the Belgian soil texture classification)

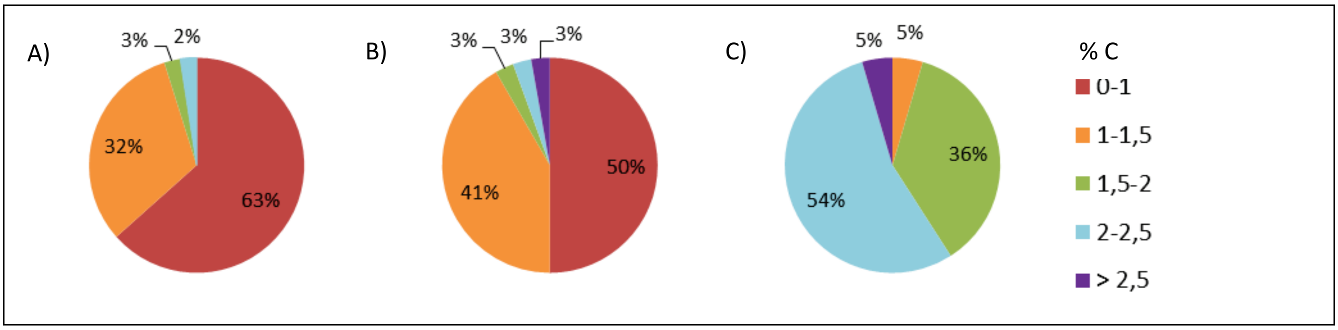

Figure 3 Distribution of the soil organic matter content (% C) of the loamy soils (A), the sandyloam soils (B) and the sandy soils (C) over several classes in Flanders

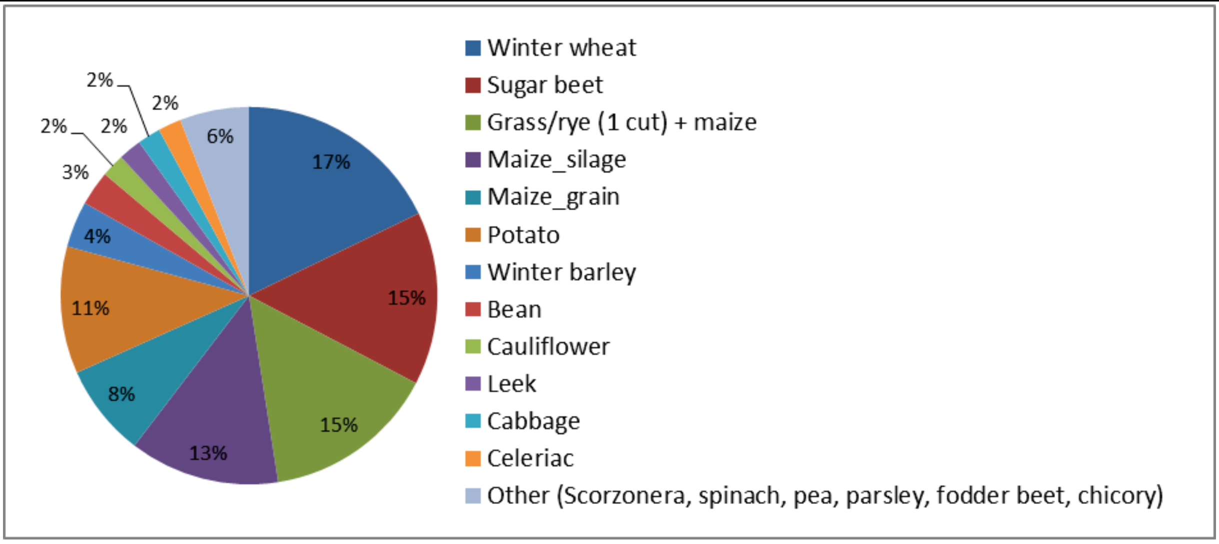

Figure 4 Crops of the selected fields in Flanders in 2013

The location of the 30 participating farms in the Netherlands is shown in Figure 5, with most farms in the southeast area of the province of North Brabant. The most important crops grown in 2013 were maize, grass, winter wheat, ware potatoes, (fruit)trees, ornamental plants, leek and spinach. For part of the selected fields, the distribution of the organic matter contents over organic matter classes is presented in Figure 6. Six percent has an organic matter content below 2% OM and 59% below 3% OM. In the Netherlands, fields with organic matter contents below 3% OM should receive special attention with respect to the organic matter management.

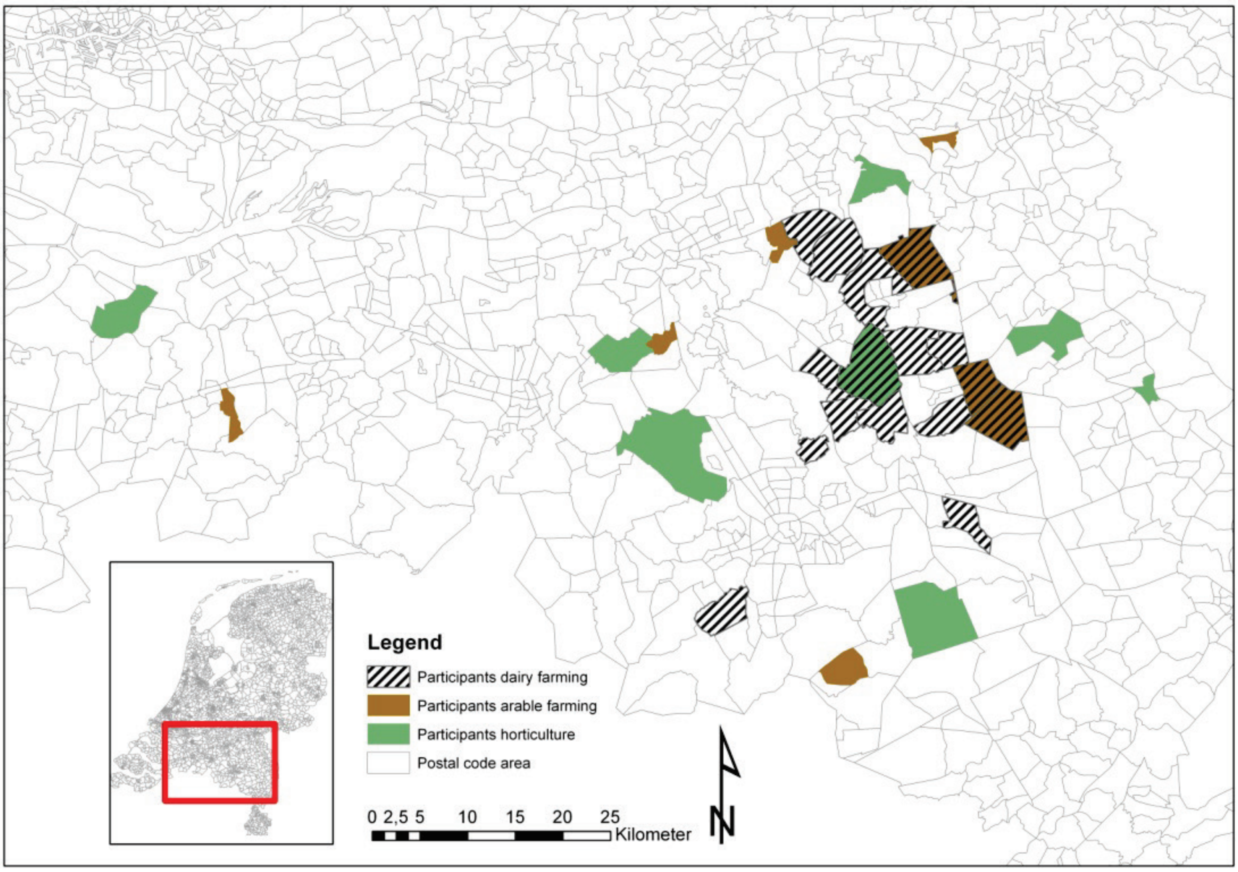

Figure 5 Location of the 30 participating farms in the Netherlands

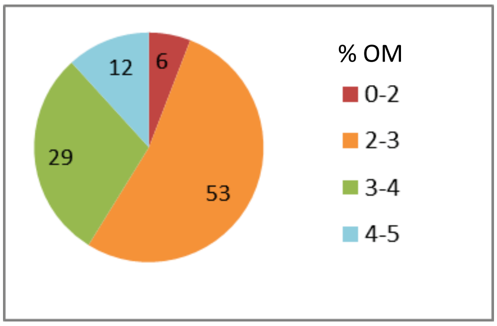

Figure 6 Distribution of soil organic matter contents (% OM) of the selected fields over several classes in the Netherlands

Recommendations generated by the Decision Support Tool (DST)

For each field, a recommendation report concerning sustainable organic matter and nutrient management was generated at the beginning of the growing season. The structure of this report is illustrated for a specific field, called Field A, as an example of a loamy soil which is located in the horticultural region in West Flanders. The first part of the report is the simulation of the organic matter content in the soil (Figure 7) with a specific crop rotation and organic matter management (Table 1). The simulation of the participating fields in Flanders indicated that in many cases additional efforts are needed to achieve optimal soil organic matter contents (data not shown). The second part of the report is the mineral N balance of the field (Table 2) based on the measurement of mineral N in the soil and specific field and crop data. For the participating fields, the N recommendations based on the mineral N balance in the DST were realistic and in line with other N recommendation tools (data not shown). Additionally, the N recommendations are evaluated based on crop yield and residual mineral N in the soil after harvest. The third and last part of the report is the P balance of the field (Table 3). The P balance shows the P input through organic amendments, the P uptake of the crops and the difference between input and output. Many fields in Flanders and the Netherlands contain high amounts of P in the soil due to historical fertilisation. In many cases the P balances show that the P input by organic manure or mineral P fertilisers should be lowered, as the amount of plant available P in the soil is still very high.

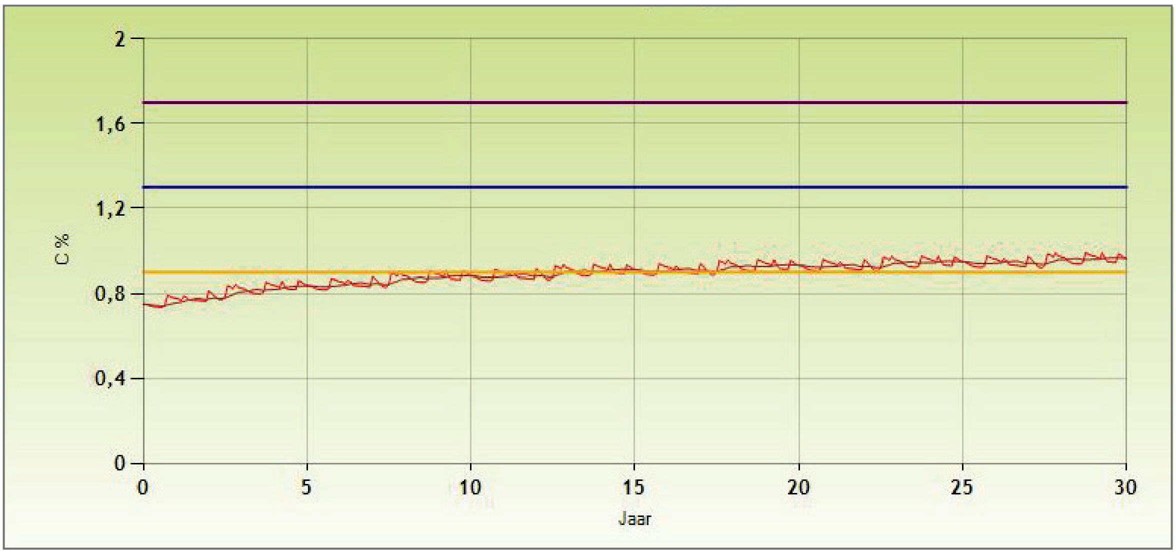

Figure 7 Simulation of organic matter evolution in the soil of Field A, as included in part 1 of the recommendation report (see Table 1 for crop rotation and organic material application)
Red line = organic matter content in the soil, C%
Blue line = lower limit of target zone of soil organic matter in a loamy soil
Purple line = upper limit of target zone of soil organic matter in a loamy soil
Yellow line = minimum value of soil organic matter in a loamy soil, set up by the Flemish government in the framework of the European Mid Term Review (since 2005, all farmers receiving direct payments are subject to compulsory cross-compliance including the requirement of maintaining land in good agricultural condition)

Table 1 Crop rotation and organic material application on Field A, as included in part 1 of the recommendation report

	Crops and catch crops	Application of organic material
Year 1	winter wheat, harvested in August	pig slurry in August
Year 2	phacelia, incorporated in february Brussels sprouts, harvested in November	pig slurry in April
Year 3	pea, harvested in June beans, harvested in September	pig slurry in June
Year 4	winter wheat, harvested in August	pig slurry in August
Year 5	phacelia, incorporated in february potato, harvested in August	pig slurry in March

Field A = field with a loamy soil which is located in the horticultural region in West Flanders

Table 2 Mineral nitrogen balance of Field A, as included in part 2 of the recommendation report

Balance for 'winter wheat'	in kg N/ha
N uptake crop	220
N buffer	30
Total need of N	250
- measurement of mineral N in the soil	26
- mineralization of crop residues (potato)	7
- mineralization of catch crops (no catch crop on Field A)	0
- mineralization of permanent grassland destruction (not for Field A)	0
- mineralization of soil organic matter	24
- mineralization of organic material if already applied	0
- deposition of N	15
- Total supply of mineral N	72
Remaining need of mineral N	**178**

Table 3 Phosphorus balance of Field A, as included in part 3 of the recommendation report

Year of rotation	Year 1		Year 2		Year 3		Year 4		Year 5	
expressed as kg/ha	P_2O_5	P	P_2O_5	P	P_2O_5	P	P_2O_5	P	P_2O_5	P
Input of P with application of organic materials	39	17	59	26	70	31	39	17	59	26
Output of P due to export of crops	89	39	53	23	59	26	81	35	55	24
Saldo	**-50**	**-22**	**6**	**2**	**11**	**5**	**-42**	**-18**	**4**	**2**

Training of the farmers

During springtime, each participating Flemish farm was visited by VLM-counsellors to discuss the soil and manure analyses and the recommendation report. At the end of the growing season, the farmers will be visited again to evaluate the applied fertilisation and the amount of nitrate in the soil after harvest. In the Netherlands, separate group meetings were held for arable and dairy farmers.

Demonstration days for the farmers and stakeholders will be organised later on during the project period.

Conclusion

A decision support system was developed which may help farmers to optimize nutrient and soil organic matter management simultaneously at the level of the field. During the first year of the project, all participating farms and fields were selected, soils were analysed and recommendation reports were generated. First calculations illustrate the potential of the DST as a valuable tool for fertiliser recommendations and management of soil organic matter.

A widespread use of such a tool might increase awareness amongst farmers for more sustainable soil management techniques that will maintain or increase soil organic matter whilst minimizing nutrient loss risks.

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(62) Soil organic matter management within the legal constraints of the fertilization laws – BOPACT field trial

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Abstract: *Almost all soil and crop management practices have implications for soil organic matter (SOM) but the most obvious way for increasing the SOM content is by using organic fertilizers such as animal manures or compost. However, legislative restrictions related to the nitrate directive limit the use of fertilizers and consequently may constrain the built-up of stable SOM. Therefore, in the spring of 2010 a long term field experiment (BOPACT) was established at ILVO to investigate if the SOM can be increased within the legal constraints of the Manure Decree using slurry and the application of good agricultural practices (cover crops, straw incorporation) and, if not, if this goal can be reached with an extra dose of compost without increasing N leaching. The experiment has a strip split plot design with three factors and four replications. The factors are 1) slurry application (cattle vs pig slurry), 2) tillage practices (ploughing vs non-inversion tillage), and 3) compost application (0 vs 2 ton C/ha.year). The trial has a 4-year rotation with maize, potato, summer barley and leek, with cover crops during winter periods. After three years, the change in SOM content (0-30 cm) was significantly (p<0.05) higher for cattle slurry compared to pig slurry and for compost application compared to no compost amendment. Moreover, in 2012 the hot-water extractable carbon was significantly (p<0.01) higher in the compost plots than in the non-amended plots. An extra compost amendment did not increase the postharvest mineral N content in soil which could be leached over winter. As the experiment is still ongoing, we will continue to monitor the SOM evolution and nutrient dynamics.*

Keywords: *long term field experiment; compost; slurry; non-inversion tillage; N leaching*

Introduction

Several large-scale studies have indicated declining soil organic matter (SOM) contents in intensively managed cropland soils in the Flanders region of Belgium during the last few decades (Sleutel et al., 2003; Sleutel et al., 2007). As SOM content is regarded as a major indicator for soil quality and as its management is crucial for agricultural production, improved SOM management is required (Doran and Parkin, 1994; Leroy, 2008; D'Hose et al., 2013). Almost all soil and crop management practices have implications for SOM but the most obvious way for increasing the SOM content is by using organic fertilizers such as animal manures or compost (Leroy, 2008). However, the Manure Decree, to comply with the Nitrate Directive, limits the use of organic fertilizers and consequently may constrain the built-up of stable SOM. Therefore, a long term field experiment (BOPACT) was established at ILVO to investigate if SOM can be either maintained or increased within the legal constraints of the Manure Decree using slurry and the application of good agricultural practices (e.g., cover crops, straw incorporation) and, if not, if this goal can be reached by yearly adding an extra compost dose and without increasing the risk for N leaching.

Materials and Methods

Study site and experimental layout

A long-term field experiment was initiated in 2010 at ILVO in Merelbeke (50° 59' 6.84" N, 3° 46' 24.10" E, 24m above sea level). Climate is fully humid temperate with warm summers (Kottek et al., 2006) with approximately 725mm annual precipitation and a mean annual temperature of 9°C (KMI meteorological station, Melle). The soil is classified as a Bathygleyic Cambisol (IUSS Working Group WRB, 2007; Dondeyne, pers. commun.). The texture of the Ap horizon (0-35 cm) is sandy loam (USDA) with a soil particle size distribution of 57.0, 37.7 and 5.3% for sand, silt and clay, respectively. Initial pH-KCl , total C and total N of the soil (0-30cm) were 5.9, 0.81% and 0.09%, respectively. The experiment has a strip split plot design (plot size: 15 x 15m) with three factors and four replications (Gomez and Gomez, 1984). The factors are 1) slurry application (horizontal factor; cattle vs pig slurry), 2) tillage practices (vertical factor; conventional tillage vs non-inversion tillage), and 3) farm compost application (subplot factor; 0 vs 2 ton C.ha^{-1}.y^{-1}). The trial has a 4-year rotation with forage maize (*Zea mays* L. ssp. *mays)*, potato (*Solanum tuberosum* L.), summer barley (*Hordeum vulgare* L.) and leek (*Allium porrum* L.), with cover crops during winter (winter barley (*Hordeum vulgare* L.)

after the potato harvest in 2011 and white mustard (*Sinapis alba* L.) after the summer barley harvest in 2012). Further, the summer barley straw is incorporated into the soil (0-5cm) by means of a rotary cultivator.

About one week before the sowing/planting of the crops in spring, both the pig (PS) and cattle (CS) slurry were applied at a rate of 170 kg N.ha^{-1} y^{-1} (maximum allowed dose according to the current Manure Decree). The surface application by means of a slurry injector was immediately followed by incorporation with a cultivator (0-10cm). A few days later the soil was tilled to a depth of 25-30cm using a conventional plough for the conventional tilled plots (CT) and a cultivator (Actisol) for the non-inversion tilled plots (NIT). Just before sowing/planting of the crops, mineral N fertilizer (ammoniumnitrate 27% N) was applied on top of the slurry to meet the requirements of maize and potato. Finally, seedbed was prepared using a rolling harrow. Plots received 0 or 2 ton C.ha^{-1} y^{-1} by farm compost (FC) applications, further indicated as FC0 and FC1 plots, after the harvest of the crop in fall, except for 2010 where FC application was postponed to spring 2011 due to practical constraints. FC was incorporated into the soil by means of a rolling harrow (0-5cm). FC, CS and PS were sampled during application (one sample in each of the four replications of the field trial) and analyzed afterwards (methods for compost analysis are described in Steel et al. (2012)). Table 2 represents the application rates of FC and slurry and the contents as well as the corresponding amounts of applied nutrients and organic matter per ha.

Crop yields

Crop yields were determined annually from 2010 on. The forage maize was harvested in October 2010. Two rows of 10m (15m²) in the middle of the individual plots were harvested using a Haldrup M-63 maize harvester. During harvest, a sample was taken and dried for 48 h at 70° C. Potatoes were harvested in September 2011. Two rows of 8m (12m²) in the middle of the plot were harvested manually and weighted. Afterwards, a fixed amount of tubers was randomly selected, washed, cut in pieces and dried for 48 h at 70°C. The summer barley was harvested (August 2012) when the dry matter content of the grain was approximately 85%. Within each plot, two strips of approximately 20m² were harvested using a plot combine harvester. The grain was weighted after which a sample of approximately 1kg was taken and dried for 48h at 70°C.

Yields of the forage maize, potato tubers and the summer barley grain are reported on a dry matter weight basis.

Soil sampling and analysis

Soil samples were collected for chemical properties at the beginning of the experiment (April 2010) and after the harvest of the summer barley (August 2012; just before the application of farm compost and straw incorporation). A bulk sample of 10 cores (0-30 cm) per plot was collected, homogenized and stored at field moisture content at 4°C. Prior to chemical analysis, samples were divided into three sub-samples. One sub-sample was immediately used for pH determination. The pH was measured potentiometrically in a 1:5 soil:KCl (1M) extract according to ISO 10390. The second and third sub-sample were oven dried at 45°C and 70°C, respectively, and prior to analysis of chemical soil properties, the samples were ground in a mortar and passed through a 2mm and 250 µm sieve, respectively. Ammonium lactate extractable P and K (P-AL and K-AL) were assessed on the second sub-sample by extraction of the soil with ammonium lactate (extraction ratio 1:20) in dark polyethylene bottles, shaken for 4 hours and the suspension was filtered in dark polyethylene bottles that were stored cool (4°C) until analysis. P-AL and K-AL were analyzed at 770 nm and 214 nm, respectively, using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES, Varian Vista-Pro) with an axial torch (Egnér et al., 1960). Soil organic carbon (SOC) and total N were measured on the third sub-sample by dry combustion at 1050°C using a Skalar Primacs SLC TOC (Total organic carbon) analyser (ISO 10694) and at 950°C using a Thermo Flash 4000 N-analyser (ISO 13878), respectively. Hot-water extractable carbon (HWC) was extracted following the method of Haynes and Francis (1993). TOC in the extracts was determined on a Skalar Primacs SLC TOC analyser. Soil samples for the determination of the mineral N (NO_3^--N + NH_4^+-N) concentration in soil were taken every year in spring (before the slurry application) and in summer or fall (after crop harvest). Composite soil samples of 8 cores per plot were taken to a depth of 90 cm in 3 layers: 0-30 cm, 30-60 cm and 60-90 cm. The soil samples were stored at -18°C until further analysis. Before analysis, the soil samples were thoroughly mixed in order to homogenize the samples. After, soil mineral N was determined in a 1M KCl extract according to ISO TS14256-1:2003 with a Foss Fiastar 5000 continuous flow autoanalyser.

Table 2: Applied farm compost, pig and cattle slurry: fresh application rates, composition and applied amounts of nutrients and organic matter (OM)

	Farm compost				Pig slurry				Cattle slurry			
	2011*	2011	2012	Avg./**Total**	2010	2011	2012	Avg./**Total**	2010	2011	2012	Avg./**Total**
Fresh application rate ($Mg.ha^{-1}$)	21.6	19.2	23.8	21.5	38.4	53.0	25.0	38.8	47.4	47.5	44.5	46.5
DM (%)	36.5	35.5	36.5	36.1	4.1	1.3	28.2	11.2	8.2	8.2	8.2	8.2
C:N	17.8	18.8	24.7	20.4	3.2	1.5	4.6	3.1	11.1	10.8	10.6	10.8
Nutrients ($g.kg^{-1}$ fresh matter)												
N	5.8	4.9	3.7	4.8	4.3	2.2	6.9	4.5	3.0	3.4	3.5	3.3
P	1.1	1.0	0.7	0.9	1.2	0.2	1.8	1.1	0.9	0.5	0.6	0.7
K	5.9	5.0	3.4	4.7	2.9	1.8	5.2	3.3	5.4	3.2	3.6	4.1
OM	185	166	163	171	26	6	57	30	60	66	67	64
Nutrient application rate ($kg.ha^{-1}$)												
N	125	94	88	**307**	163	119	172	**454**	142	160	157	**459**
P	24	19	17	**60**	45	10	45	**100**	42	25	29	**95**
K	128	95	80	**303**	112	93	129	**334**	258	152	162	**571**
OM	3992	3187	3886	**11065**	990	329	1419	**2737**	2850	3123	2993	**8966**

[a] Farm compost application in fall 2010 was postponed to spring 2011
DM: dry matter; OM: organic matter

Statistical analysis

Crop yields and soil data from 2010 and spring 2011 were analysed with SPSS Statistics 19 using a 2-factor Strip-Plot ANOVA with slurry and tillage as factors. From fall 2011 on, the subplot factor compost was included in the analysis, resulting in a strip-split plot design. The data were analyzed using the given procedures in Gomez and Gomez (1984). When two-way interactions between the factors occurred, data were analyzed with SPSS Statistics 19 using a one-way ANOVA with the specific interaction term (e.g., slurry x tillage) as factor. Significant differences between means were determined by Scheffé's test.

Results and Discussion

Crop yields

In 2010 and 2011, no significant effects of the trial treatments on forage maize and potato DM yield have been observed (data not shown). In 2012, a significant slurry ($p<0.01$), tillage ($p<0.01$) and interaction (slurry x tillage; $p<0.05$) effect on summer barley DM yield has been measured. The application of both PS and CS in combination with NIT resulted in a significantly higher ($p<0.01$) DM yield compared to the PS-CT and CS-CT combinations (Figure 1). From the start of the growing season, the plants grew faster on the NIT plots and were bigger. We assume that the summer barley plants could benefit more from the slurry application in the early growth stages as the slurry remained in the top soil layer in the NIT plots. Our findings are in accordance with Van den Putte et al. (2010). Their meta-regression analysis on European crop yields under conservation tillage revealed an increase in spring cereal yield under continuous reduced tillage systems when spring cereals were grown in a crop rotation with more than just cereals. Further, the significantly lower ($p<0.01$) DM yield in the PS-CT plots can be attributed to the fact that the summer barley was lodged to a considerable extent at the time of harvest in those plots. Similar to in 2010 and 2011, there were no effects of compost application on summer barley DM yields.

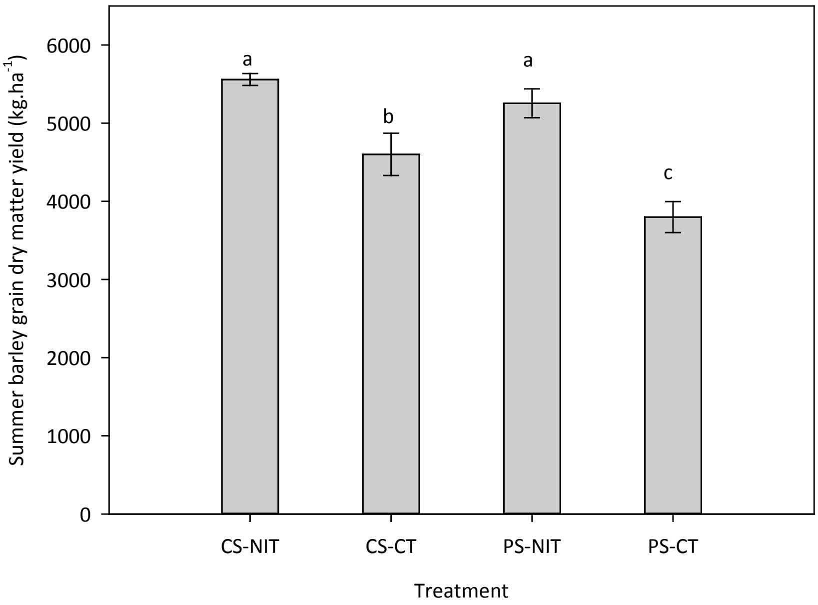

Figure 1: Dry matter yield (kg.ha^{-1}) and standard deviations of summer barley grain harvested on the BOPACT field trial in 2012 (CS: cattle slurry; PS: pig slurry; CT: conventional tillage; NIT: non-inversion tillage). Treatments marked with the same letter do not differ significantly according to Scheffé ($p<0.01$).

Soil chemical properties

After three growing seasons (2010-2012) the change in SOC content (0-30cm) was significantly ($p<0.05$) higher for CS compared to PS and for FC1 compared to FC0 (Table 3). We attribute this to the high C:N ratio of the cattle slurry and the farm compost and consequently the higher amount of applied organic matter to the soil compared to pig slurry and no compost amendment (FC0), respectively (Table 2). These results agree with a considerable number of studies, concerning fertility trials of similar or longer duration, which pointed out that the repeated application of compost and/or cattle slurry increased the SOC content (Nevens and Reheul, 2003; Leroy, 2008; D'Hose et al., 2013). No significant effects among the different tillage treatments, nor interaction effects could be observed.

Farm compost application also significantly ($p<0.01$) increased HWC (Table 3). Although HWC has been suggested as a sensitive indicator of SOC changes (Ghani et al., 2003), the HWC:SOC ratio seems more useful as it could give an indication about the stability of SOC. However, the HWC:SOC ratio was not significantly affected by one of the treatments in our experiment.

Further, a significant farm compost ($p<0.05$) and interaction (slurry x farm compost; $p<0.01$) effect on pH-KCl has been measured (Table 3). The application of CS in combination with FC resulted in a significantly higher ($p<0.05$) pH-KCl compared to the CS plots without compost amendment (CS-FC0) (Figure 2). This can be attributed to the fact that the FC used had a higher pH than soil to which it was applied, but also other mechanism can be involved such as the proton consumption capacity of humic material present in the compost (Mokolobate and Haynes, 2002). However, when FC was applied in combination with PS (PS-FC1), no such effects have been observed (Figure 2).

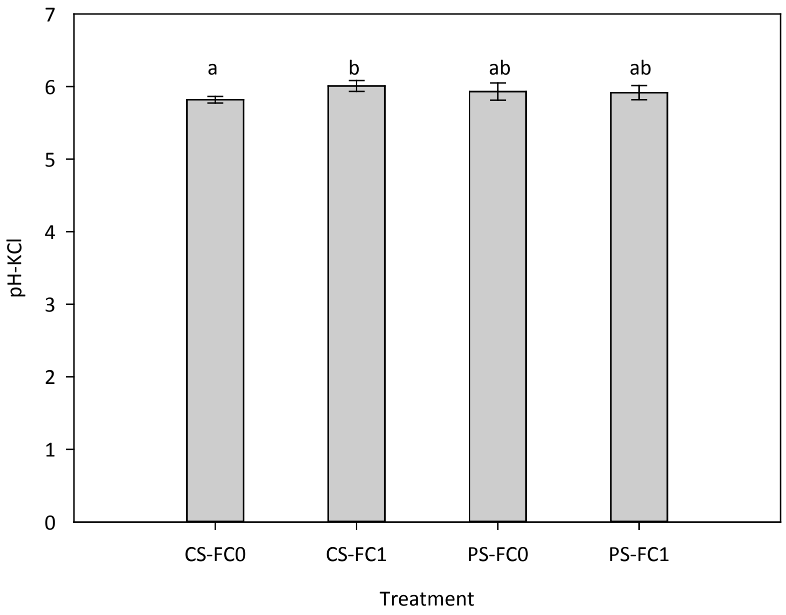

Figure 2: pH-KCl and standard deviations in the 0-30cm soil layer of the BOPACT field trial in August 2012 (CS: cattle slurry; PS: pig slurry; CT: conventional tillage; NIT: non-inversion tillage). Treatments marked with the same letter do not differ significantly according to Scheffé ($p<0.05$).

Both the application of CS and FC significantly ($p<0.01$) increased K-AL compared to the plots receiving PS and no FC (Table 3), which can be directly linked with the high K application rate of both CS and FC (Table 2). The other soil chemical properties (P-AL and total N) showed no significant differences among the treatments.

Residual mineral N concentration in soil

The residual mineral N concentration in soil of all treatments after the 2011 harvest in September, in March 2012 and after the harvest in August 2012 are listed in Table 4. After the harvest of the summer barley in 2012, a significant lower ($p<0.05$) mineral N concentration has been observed in soil under non-inversion tillage compared to ploughed soil. A higher N-uptake of the summer barley resulting from the higher DM yield in the NIT plots (Figure 1) or a lower N-mineralization in those NIT-plots are just a few potential explanations. However, further research is required to confirm these hypotheses.

Our results illustrate that an extra farm compost amendment did not increase residual mineral N concentrations in soil (Table 4). Also Nevens and Reheul (2003) suggested that the use of vegetable, fruit and garden waste compost in combination with cattle slurry in a monoculture silage maize had no influence on the post harvest residual mineral N in soil and hence did not increase the risk of nitrate leaching during winter. For these reasons, they stated that compost and slurry should not be judged along the same lines when the potential environmental (N) threats are considered.

Table 3: Soil chemical properties and standard deviations of all treatments in the BOPACT field trial (0-30cm) as measured in August 2012 or expressed as a difference between the measurements at the start of the experiment (April 2010) and August 2012.

Year	2012						2010-2012
Soil property	HWC ($mg.kg^{-1}$)	HWC/SOC	total N (%)	pH-KCl[a]	P-AL ($mg.kg^{-1}$)	K-AL ($mg.kg^{-1}$)	Δ SOC (%)
Factor							
Slurry							
CS	821 ± 164 *a*[1]	0,096 ± 0,018 *a*	0,072 ± 0,005 *a*	5,91 ± 0,14	23 ± 2 *a*	18 ± 2 *a*	0,05 ± 0,06 *a*
PS	807 ± 125 *a*	0,099 ± 0,017 *a*	0,071 ± 0,004 *a*	5,92 ± 0,13	24 ± 2 *a*	15 ± 2 *b*	0,02 ± 0,05 *b*
Tillage							
NIT	834 ± 154 *a*	0,101 ± 0,019 *a*	0,071 ± 0,004 *a*	5,92 ± 0,13	23 ± 2 *a*	16 ± 2 *a*	0,02 ± 0,06 *a*
CT	794 ± 135 *a*	0,094 ± 0,016 *a*	0,071 ± 0,004 *a*	5,91 ± 0,13	25 ± 2 *a*	17 ± 2 *b*	0,05 ± 0,04 *a*
Farm compost							
FC0	784 ± 155 *a*	0,095 ± 0,018 *a*	0,070 ± 0,004 *a*	5,87 ± 0,12	24 ± 2 *a*	15 ± 2 *a*	0,01 ± 0,06 *a*
FC1	844 ± 129 *b*	0,099 ± 0,017 *a*	0,072 ± 0,005 *a*	5,96 ± 0,13	24 ± 2 *a*	18 ± 2 *b*	0,06 ± 0,04 *b*

[1] Within each factor, treatments marked with the same letter do not differ significantly ($p<0.05$)

[a] For pH-KCl interaction occurred between the factors slurry and farm compost ($p<0.01$)

CS: cattle slurry, PS: pig slurry, CT: conventional tillage, NIT: non-inversion tillage, FC0: no farm compost application, FC1: farm compost application, HWC: hot-water extractable carbon; P-AL, K-AL: ammonium lactate extractable P and K, Δ SOC = SOC 2012 – SOC 2010

Table 4: Residual mineral N concentrations and standard deviations of all treatments in the BOPACT field trial (0-90cm)

		Mineral N ($NO3^{-}$-N + $NH4^{+}$-N) ($kg.ha^{-1}$)		
Sampling date		19/09/2011	19/03/2012	29/08/2012
Factor				
	Slurry			
	CS	113 ± 54 *a*[1]	26 ± 5 *a*	63 ± 10 *a*
	PS	79 ± 20 *a*	22 ± 2 *a*	63 ± 8 *a*
	Tillage			
	NIT	95 ± 55 *a*	23 ± 4 *a*	58 ± 8 *a*
	CT	97 ± 29 *a*	24 ± 5 *a*	68 ± 7 *b*
	Farm compost			
	FC0	99 ± 57 *a*	23 ± 4 *a*	61 ± 8 *a*
	FC1	93 ± 26 *a*	24 ± 5 *a*	65 ± 10 *a*

[1] Within each factor, treatments marked with the same letter do not differ significantly ($p<0.05$)

CS: cattle slurry, PS: pig slurry, CT: conventional tillage, NIT: non-inversion tillage, FC0: no farm compost application, FC1: farm compost application

Conclusion

Overall, our preliminary results show that after three growing seasons (2010-2012) the change in SOC content was significantly higher for cattle slurry compared to pig slurry and for compost application compared to no compost amendment. Further, an extra compost amendment also did increase HWC and K-AL while it did not increase residual mineral N content at harvest which could be leached over winter. The effects of non-inversion tillage and both the application of slurry and farm compost on crop yields are not yet conclusive.

As the experiment is still ongoing, we will continue to monitor the SOM evolution, nutrient dynamics and crop yield responses, as well as physical and biological soil parameters. In addition, the effects of the soil treatments on disease pressure caused by soil-borne fungi and plant–parasitic nematodes are studied as well.

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(63) Recent evolution and trends in the soil fertility of Flemish vegetable fields (1998-2012)

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***Abstract:** The Soil Service of Belgium (SSB, spin-off of the KU Leuven) formulates each year thousands of fertilization recommendations based on soil analyses. Soil samples are taken in the ploughing layer (0-23 cm) in order to determine the overall soil fertility (pH, C, P, K, Mg, Ca, Na). Liming and fertilization recommendations are then calculated by the BEMEX expert system. In the last 15 years (1989 - 2011), SSB determined the soil fertility of more than 65 000 soil samples from fields with typical vegetable rotations. The samples originated from the whole of Flanders, but especially from the sandy-loam and sandy soils in West-Flanders (the major vegetable-growing area in Flanders). Fertilization recommendations were calculated mainly for Brussels sprouts, leek, cauliflower, spinach and carrots. In this contribution, the statistics and trends of the soil fertility are discussed for cauliflower and leek.*

Keywords: *fertilization recommendation; BEMEX; cauliflower; leek*

Introduction

In their cropping practices, farmers aim at optimal yields in combination with a maximal financial return and in respect for the environment. To achieve this, an optimal soil fertility, with a sufficient water and nutrient supply for the crops is essential. Through an adequate fertilization, farmers have to complement any nutrient deficits and avoid excesses or disproportions. Therefore, fertilization recommendations have to be calculated accurately, based on soil fertility, proportions of nutrients in the soil, expected nutrient supply by mineralization, expected nutrient losses through leaching, crop requirements, specific parcel information, etc.

The Soil Service of Belgium (SSB, spin-off of the KULeuven) formulates each year thousands of fertilization recommendations based on soil analyses. Soil samples are taken in the ploughing layer (0-23 cm) in order to determine the overall soil fertility (pH, C, P, K, Mg, Ca). Liming and fertilization recommendations are then calculated by the BEMEX expert system (Geypens *et al.*, 1989; Vandendriessche *et al.*, 1996). In the last 24 years (1989 - 2012), SSB determined the soil fertility of more than 65 000 soil samples from fields with typical vegetable rotations. The samples originated from the whole of Flanders, but especially from the sandy-loam and sandy soils in West-Flanders (the major vegetable-growing area in Flanders). Fertilization recommendations were calculated mainly for Brussels sprouts, leek, cauliflower, spinach and carrots.

In this paper, the soil fertility is discussed for cauliflower and leek in the major vegetable growing areas in Flanders, the sandy and the sandy-loam region. The situation of C-content, pH and nutrient contents (P, K, Mg and Ca) in the period 1989-1991 is compared to the recent situation in 2008-2011. Also an insight is given into the fertilization recommendations for cauliflower and leek, in relation to the parcel specific soil fertility.

Materials and Methods

Soil fertility is determined by the Soil Service of Belgium based on a standard soil analysis of representative soil samples of the upper soil layer (0-23 cm). In a standard soil analysis the parameters that are important for overall soil fertility are determined: soil texture (soil type), pH, C content, content of P, K, Mg and Ca.

Soil texture is determined by palpation. pH is measured in a KCl-solution. C-content is analysed with the modified Walkley & Black method and is expressed in %. The elements P, K, Mg, Ca and Na are extracted in ammonium lactate (A.L.-extract) and then determined by Inductively Coupled Plasma (ICP). They are expressed in mg/100 g dry soil.

In order to interpret the analysis results, SSB relies on soil fertility classes for the different soil fertility variables related to the agricultural standards of optimal plant growth. The agricultural standards provide a clear and interpretable reference. The soil fertility classes are based on extensive field research combined with 65 years of experience in the agricultural and horticultural sectors. The knowledge gathered from long- and short-term field trials is integrated in response and surplus functions, which are at their turn integrated in BEMEX, a fertilizer expert system (Vandendriessche *et al.*, 1996). The soil fertility classes are different for arable crops and for pasture and take account of soil texture and organic matter content. Seven soil fertility classes are distinguished, ranging from “very low” to “very high”. The adjectives “low” and “high” mean that the corresponding class is situated outside the optimal ranges. In the optimal zone (i.e. the middle soil fertility class), most plants will show an optimal growth, provided that rational fertilization and liming is applied. The optimal zone is not only an agronomic optimum (optimal plant growth), but is also an environmental optimum since it corresponds to a minimal amount of nutrient leaching (Elsen *et al.*, 2010). In Table1 the soil fertility evaluation classes and optimal zones are given for arable crops in sandy-loam soils.

Based on the standard soil analysis and the evaluation standards, an overall fertilization and liming recommendation on a particular field can be calculated for the following 3 crops or 3 growing seasons with the BEMEX expert system (Geypens *et al.*, 1989; Vandendriessche *et al.*, 1996; Elsen *et al.*, 2010).

Table 1 Evaluation standards for the different soil fertility parameters for arable crops in sandy loam soils.

Soil fertility class	C %	pH-KCl[1]	P[2] mg/100 g	K[2] mg/100 g	Mg[2] mg/100 g	Ca[2] mg/100 g
very low	< 0,8	< 4,5	< 5	< 6	< 4	< 40
low	0,8 – 0,9	4,5 – 5,5	5 – 8	6 – 10	4 – 5	40 – 69
rather low	1,0 – 1,1	5,6 – 6,1	9 – 11	11 – 13	6 – 8	70 – 99
optimal zone	1,2 – 1,6	6,2 – 6,6	12 – 18	14 – 20	9 – 14	100 – 240
rather high	1,7 – 3,0	6,7 – 6,9	19 – 30	21 – 35	15 – 18	241 – 360
high	3,1 – 7,0	7,0 – 7,4	31 – 50	36 – 60	19 – 30	361 – 450
very high	> 7,0	> 7,4	> 50	> 60	> 30	> 450

[1] Valid for soils with a carbon content within the optimal zone
[2] Valid for soils with a bulk density of 1,3 $g.cm^{-3}$

Results and Discussion

In the next paragraphs the actual situation (2008-2011) of the soil fertility for cauliflower and leek in the Flemish sandy and sandy loam region is discussed and compared to the situation in 1989-1991, based on the parameters pH, C-content and P-, K-, Mg- and Ca-content. The results shown in the tables are based on extensive samples, however it should be noticed that the vegetable acreage has evolved in the course of time and that the comparison of the two periods (1989-1991 and 2008-2011) doesn't necessarily relate to exactly the same parcels.

For each crop, region and period, a summary table is given with the distribution of the soil samples over the different soil fertility classes for each soil fertility parameter, followed by a table giving the corresponding average fertilization recommendations (**Fout! Verwijzingsbron niet gevonden.**Tables 2 to 9).

Table 2 Flemish sandy region - Cauliflower – 1989-1991

Percentage distribution of the soil samples over the soil fertility classes.

Soil fertility class	pH	C %	P mg/100 g	K mg/100 g	Mg mg/100 g	Ca mg/100 g
very low	1,0	3,7	0,2	0,4	1,2	0,2
low	6,6	5,4	0,0	1,9	3,5	6,0
rather low	18,4	11,6	1,0	6,2	12,0	14,9
optimal zone	21,9	42,3	4,2	18,2	37,5	54,7
rather high	24,2	33,1	15,1	43,9	25,5	8,9
high	15,1	3,9	47,6	24,4	17,2	7,2
very high	12,8	0,0	31,9	5,0	3,1	8,1

Average fertilisation recommendations (kg/ha or neutralising value for lime) per soil fertility class.

Soil fertility class	Lime	N[1]	P_2O_5	K_2O	MgO
very low	3.200	266	230	450	128
low	2.932	259	-	398	123
rather low	1.606	249	180	358	115
optimal zone	471	225	135	306	98
rather high	0	189	73	232	58
high	0	148	36	133	15
very high	0	-	0	54	0
average	626	216	36	224	74

[1]The average N fertilisation recommendations are indicative and are based on the crop uptake and the evaluation of the carbon content.

Table 3 Flemish sandy-loam region - Cauliflower – 1989-1991

Percentage distribution of the soil samples over the soil fertility classes.

Soil fertility class	pH	C %	P mg/100 g	K mg/100 g	Mg mg/100 g	Ca mg/100 g
very low	0,9	1,1	0,0	0,2	0,0	0,5
low	23,8	3,3	0,4	4,2	1,1	10,6
rather low	32,5	9,5	1,1	7,3	9,7	31,8
optimal zone	24,0	42,4	7,0	28,8	43,9	53,4
rather high	13,3	38,9	29,1	48,4	24,5	2,7
high	4,4	4,8	46,3	10,2	19,9	0,5
very high	1,1	0,0	16,1	0,9	0,9	0,5

Average fertilisation recommendations (kg/ha or neutralising value for lime) per soil fertility class.

Soil fertility class	Lime	N[1]	P_2O_5	K_2O	MgO
very low	5.480	283	-	440	-
low	3.438	271	205	403	140
rather low	1.859	264	180	360	114
optimal zone	640	242	130	302	84
rather high	0	199	73	230	42
high	0	142	38	122	4
very high	0	-	0	20	0
average	1.625	224	51	255	61

[1]The average N fertilisation recommendations are indicative and are based on the crop uptake and the evaluation of the carbon content.

Table 4 Flemish sandy region - Leek – 1989-1991

Percentage distribution of the soil samples over the soil fertility classes.

Soil fertility class	pH	C %	P mg/100 g	K mg/100 g	Mg mg/100 g	Ca mg/100 g
very low	1,1	5,5	0,2	0,6	0,2	0,0
low	8,3	8,3	0,4	3,6	4,9	6,6
rather low	20,8	15,1	0,6	4,9	13,0	19,3
optimal zone	23,8	45,0	4,6	21,5	38,5	59,7
rather high	28,2	24,2	15,7	46,3	27,0	8,7
high	13,6	1,9	50,5	20,8	14,9	3,6
very high	4,2	0,0	28,0	2,3	1,5	2,1

Average fertilisation recommendations (kg/ha or neutralising value for lime) per soil fertility class.

Soil fertility class	Lime	N[1]	P_2O_5	K_2O	MgO
very low	4.129	253	190	400	130
low	2.952	243	170	363	126
rather low	1.524	238	160	315	120
optimal zone	456	215	118	262	100
rather high	0	175	56	196	57
high	0	137	32	95	4
very high	0	-	0	7	5
average	718	212	33	198	77

[1]The average N fertilisation recommendations are indicative and are based on the crop uptake and the evaluation of the carbon content.

Table 5 Flemish sandy-loam region - Leek – 1989-1991

Percentage distribution of the soil samples over the soil fertility classes.

Soil fertility class	pH	C %	P mg/100 g	K mg/100 g	Mg mg/100 g	Ca mg/100 g
very low	3,1	1,7	0,6	0,0	0,0	0,0
low	20,0	6,5	1,1	6,5	2,5	17,2
rather low	31,8	12,7	2,3	6,5	12,7	30,4
optimal zone	27,3	37,7	9,3	28,7	43,1	46,8
rather high	9,0	39,7	25,6	45,6	27,3	4,2
high	6,8	1,7	44,2	12,1	11,3	0,6
very high	2,0	0,0	16,9	0,6	3,1	0,8

Average fertilisation recommendations (kg/ha or neutralising value for lime) per soil fertility class.

Soil fertility class	Lime	N[1]	P_2O_5	K_2O	MgO
very low	4.339	242	200	-	-
low	2.876	263	173	356	122
rather low	1.785	253	160	318	115
optimal zone	804	229	115	255	89
rather high	3	196	57	197	46
high	0	113	33	80	2
very high	0	-	0	0	0
average	1.498	219	47	217	69

[1]The average N fertilisation recommendations are indicative and are based on the crop uptake and the evaluation of the carbon content.

Table 6 Flemish sandy region - Cauliflower – 2008-2011

Percentage distribution of the soil samples over the soil fertility classes.

Soil fertility class	pH	C %	P mg/100 g	K mg/100 g	Mg mg/100 g	Ca mg/100 g
very low	0,2	6,2	0,0	0,0	0,2	0,3
low	5,7	10,3	0,2	1,5	0,5	6,9
rather low	18,8	17,7	0,6	5,1	5,1	18,6
optimal zone	22,3	44,1	3,1	25,8	26,5	50,4
rather high	20,3	21,4	16,6	51,8	28,3	10,8
high	16,2	0,3	46,3	15,2	34,8	5,8
very high	16,5	0,0	33,2	0,6	4,6	7,2

Average fertilisation recommendations (kg/ha or neutralising value for lime) per soil fertility class.

Soil fertility class	Lime	N[1]	P_2O_5	K_2O	MgO
very low	3.650	233	-	-	130
low	3.160	225	210	401	120
rather low	1.552	216	180	358	112
optimal zone	565	202	129	303	84
rather high	0	177	73	224	41
high	0	123	37	115	1
very high	0	-	0	23	0
average	604	203	35	236	41

[1]The average N fertilisation recommendations are indicative and are based on the crop uptake and the evaluation of the carbon content.

Table 7 Flemish sandy-loam region - Cauliflower – 2008-2011

Percentage distribution of the soil samples over the soil fertility classes.

Soil fertility class	pH	C %	P mg/100 g	K mg/100 g	Mg mg/100 g	Ca mg/100 g
very low	0,3	4,5	0,0	0,1	0,0	0,3
low	7,4	10,4	0,2	1,4	0,0	4,8
rather low	25,7	17,8	0,7	4,1	2,1	22,2
optimal zone	41,8	49,2	4,5	27,0	23,0	67,9
rather high	17,2	17,7	22,9	58,9	29,9	3,6
high	6,7	0,4	48,3	8,4	38,7	0,7
very high	0,9	0,0	23,4	0,1	6,3	0,5

Average fertilisation recommendations (kg/ha or neutralising value for lime) per soil fertility class.

Soil fertility class	Lime	N[1]	P_2O_5	K_2O	MgO
very low	5.485	231	-	470	-
low	2.967	229	203	401	-
rather low	1.594	219	180	359	113
optimal zone	705	209	136	296	78
rather high	0	187	71	226	37
high	0	112	39	107	0
very high	0	-	0	40	0
average	942	210	43	243	32

[1]The average N fertilisation recommendations are indicative and are based on the crop uptake and the evaluation of the carbon content.

Table 8 Flemish sandy region - Leek – 2008-2011

Percentage distribution of the soil samples over the soil fertility classes.

Soil fertility class	pH	C %	P mg/100 g	K mg/100 g	Mg mg/100 g	Ca mg/100 g
very low	0,2	10,8	0,0	0,0	0,3	1,0
low	6,5	17,7	0,1	2,3	1,5	9,8
rather low	22,4	23,3	0,3	5,7	6,9	26,3
optimal zone	33,5	39,7	2,4	27,7	33,4	53,2
rather high	24,0	8,4	14,6	53,0	25,2	6,1
high	10,7	0,1	49,5	10,4	29,9	2,9
very high	2,7	0,0	33,1	0,9	2,8	0,7

Average fertilisation recommendations (kg/ha or neutralising value for lime) per soil fertility class.

Soil fertility class	Lime	N[1]	P_2O_5	K_2O	MgO
very low	1.738	231	-	-	130
low	2.855	224	170	363	124
rather low	1.579	217	160	318	114
optimal zone	541	204	118	264	86
rather high	0	185	55	196	41
high	0	135	32	90	1
very high	0	-	0	0	0
average	725	212	28	213	49

[1]The average N fertilisation recommendations are indicative and are based on the crop uptake and the evaluation of the carbon content.

Table 9 Flemish sandy-loam region - Leek – 2008-2011

Percentage distribution of the soil samples over the soil fertility classes.

Soil fertility class	pH	C %	P mg/100 g	K mg/100 g	Mg mg/100 g	Ca mg/100 g
very low	0,2	5,8	0,0	0,0	0,2	0,4
low	7,5	14,9	0,3	1,5	0,6	7,2
rather low	26,6	24,1	0,3	4,1	2,5	24,4
optimal zone	39,2	43,8	2,5	27,7	25,4	63,0
rather high	17,4	11,2	17,6	58,8	28,4	3,7
high	7,6	0,2	53,5	7,8	39,1	0,6
very high	1,5	0,0	25,8	0,1	3,8	0,7

Average fertilisation recommendations (kg/ha or neutralising value for lime) per soil fertility class.

Soil fertility class	Lime	N[1]	P_2O_5	K_2O	MgO
very low	4.217	231	-	-	130
low	2.832	227	174	360	130
rather low	1.674	218	160	318	112
optimal zone	694	208	108	260	80
rather high	0	188	55	198	38
high	0	142	32	68	0
very high	0	-	0	0	0
average	938	212	31	212	35

[1]The average N fertilisation recommendations are indicative and are based on the crop uptake and the evaluation of the carbon content.

Soil acidity and liming recommendations

For cauliflower in the sandy region, approximately 22% of the parcels had an optimal pH in the period 1989-1991 and 26% of the parcels had a pH lower than the optimal range. In the sandy-loam region, the percentage of parcels with optimal pH was 24%, but a higher percentage of parcels (57%) had a pH below optimum. In the period 2008-2011, the situation was improved considerably in the sandy-loam region: the percentage of parcels with pH below optimum decreased to 33%.

For leek, similar observations are made. The percentage of parcels with pH below optimum in the sandy region decreased hardly between 1989-1991 and 2008-2011 from 30% to 29%, but in the sandy-loam region it decreased significantly from 55% to 34%.

The acidity or pH of the soil determines strongly the availability and plant absorption of nutrients in the soil. The optimal pH depends on the crop, the soil texture and its carbon content (organic matter content). If the pH is lower than the optimal range, a catch up lime application is recommended in order to redress the pH. If the pH lies within the optimal range, a maintenance lime application is recommended in order to maintain the pH within this range during cultivation of the next 3 crops. This lime application has to compensate for the natural acidification of the soil. If the pH is higher than the optimal range, no lime should be applied at all. When the pH is too high, nutrients are immobilized in the soil causing deficiency symptoms on crops.

Due to the observed improvement of the pH especially in the sandy-loam region, the average liming recommendations in this region decreased between 1989-1991 and 2008-2011 respectively from 1.625 nv/ha to 942 nv/ha for cauliflower and from 1.498 nv/ha to 938 nv/ha for leek.

Carbon content and indicative N fertilization recommendations

The C content of the soil is analyzed as a measure for the soil organic matter content. Soil organic matter has a direct influence on the physical and chemical characteristics of the soil and on the microbial activity in the soil. It improves soil structure and water management. It functions as an important crop nutrient source and provides nitrogen, phosphorus, sodium and trace elements. Finally it plays an important role in the buffering of the soil pH and the adsorption of nutrients (cation exchange capacity).

Both for cauliflower and leek, in both regions, the C content of the soil decreased between 1989-1991 and 2008-2011. The percentage of parcels with a C content below the optimum range increased considerably between the two periods, from 14-21 to 33-34% in cauliflower and from 21-29 to 45-52% in leek parcels.

Based on the soil C content as well as the soil texture, the parcel history and the crop requirements, the BEMEX system calculates indicative N fertilization recommendations. However, the N index analyses and recommendations (Geypens *et al.*, 1994) provide a more accurate evaluation of the N situation and fertilization recommendation.

Phosphorus content and fertilization recommendations

Since 1989-1991, all the cauliflower and leek parcels in both regions are very well supplied with phosphorus. Most of the parcels show a P content higher than the optimum range in 1989-1991, and this situation has not changed in 2008-2011, although it should be noticed that the historical enrichment of P in the soil has been stopped.

In parcels with a low P content, the P fertilization recommendations are higher than the crop uptake, in order to redress the P status of the soil and to guarantee a sufficient P supply for the crops. However, the soil analysis results show that the P content in most of the agricultural parcels in Flanders is high. Therefore, the P recommendations are in general lower than the crop uptake and often zero applications are recommended.

Potassium and magnesium content and fertilization recommendations

Analogue to P, most of the parcels with cauliflower and leek are very well supplied with K and Mg, in the period 1989-1991 and even more in the period 2008-2011.

For K fertilization recommendations the sampling period is taken into account, depending on the crop type. Indeed, especially in sandy soils with low organic matter content, K easily leaches during winter. K requirements also depend strongly on the crop type. In the calculation of the fertilization recommendations, the ratio between the cations K/Mg/Ca/Na is taken into account, because these elements compete for uptake by the plants (antagonism).

The crop requirements for Mg are relatively low. With low Mg contents in the soil, Mg fertilization is recommended in order to avoid deficiency symptoms. When K and Ca contents of the soil are high, Mg uptake by the crop is lower because of the antagonism between the cations. The fertilization recommendations are calculated in such a way that disproportions between these cations are adjusted as soon as possible.

Conclusion

Results of standard soil analyses in vegetable fields, performed by the Soil Service of Belgium in the last 24 years (1989 - 2012), indicate an improving soil acidity (pH) for cauliflower and leek parcels in the main vegetable growing areas in Flanders (sandy and sandy-loam region). However, work still has to be done because approximately 25 to 33% of the parcels still show a pH below the optimal range.

As for the soil organic matter content, the analysis results show an unfavorable evolution between 1989 and 2012, with a significant increase of the percentage of parcels below the optimal zone of C-content. Especially in the vegetable growing region in Flanders, this evolution can be attributed to the frequent application of slurry, providing relatively high amounts of nutrients in combination with a low organic matter supply. To improve the situation, applications of organic fertilizers containing relatively more effective organic matter, such as litter manure or compost, should be recommended.

Finally, particular attention should be paid in the vegetable fields to the amounts and proportions of the different nutrient cations, in order to obtain an optimal plant nutrition. Accurate soil analyses are necessary in order to provide adequate fertilization recommendations and to fine-tune the overall fertilization.

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(76) Pelletized legume plants as fertilizer for vegetables in organic farming

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Abstract: *Effect of pelletized organic fertilizer Ekofert K produced from biomass of red clover has been studied in organic cultivation of celeriac. Fertilizer was preplant applied in doses equivalent to 120, 180 and 240 kg N/ha. The effectiveness of organic fertilizer were compared with mineral fertilization of 100 kg N/ha and control treatment. Nutrients content was measured in soil horizons of 0-30 cm, 30-60 cm and 60-90 cm. Organic fertilizer (Ekofert K) in all applied doses significantly increased plant biomass (19.6-35.5%) and marketable yield (21.5-33.9%) compared to the control treatment, but in relation to mineral N fertilization only the rates of 180 and 240 kg N/ha resulted in significant yield increase (16.3-19.0%). Effectiveness of organic fertilizer applied at 120 kg N/ha was comparable to mineral fertilization.*

The highest N-NO_3 content was recorded in topsoil horizon at 5 weeks after fertilizer incorporation to soil. For organic fertilizer and mineral treatments it was 53.6 to 76.3 and for control 38.3 mg N-NO_3/dm^3. The nitrogen uptake in following growing period gradually diminished to 20.6-31.0 mg N-NO_3/ha in topsoil horizon. Compared to the control, however, the highest difference of N-content in soil (10 mg N-NO_3/ha) showed in the treatments with highest rate of organic fertilizer (240 kg N/ha). In subsoil horizon (30-60 cm) the highest N-content was recorded after 8 weeks of celeriac growth and then decreased to a slightly lower level than in the first weeks of plant growth. The only exception was organic fertilizer applied at 240 kg N/ha, where N-content in soil increased to 24.3 mg N-NO_3/dm^3. The amount of nitrogen leached from the highest rate of organic fertilizer application to the soil horizon of 90 cm was only 6 mg N-NO_3/dm^3 higher than this from the control object.

Keywords: *organic fertilizer, celeriac, nitrogen, N-uptake, N-leaching*

Introduction

According to current rules, organic agriculture is based on natural and organic fertilizers mainly. The use of animal based nutrient sources in organic plant production has always been considered far from ideal and there are now intentions within the EU to ban all animal by-products in organic plant raising (Unspecified, 2003). Almost all organic fertilizers are favourable to soil and plant growth, only some of them produced from seeds of lupin, pea or field pea cannot be applied to direct sown vegetables because they inhibit germination (Laber, 2009). Also fertilizer produced from ricinus seeds inhibits crop seeds germination (Braun et al., 2000). Since soil organic matter and organic fertilizers are the major sources of nitrogen for crops, it is impossible to adequately predict fertilizer requirements as affected by mineralization rate of that matter (Shepherd et al., 1996). Organic fertilizers are applied as a basic nutrient source (preplant use) but also as a supplementary feeding to provide ready available nutrients, especially nitrogen. Legume plants are traditionally rich in N, but also the use nettles could be worthwhile (Peterson and Jensén, 1985). Finally, sheep wool is also recommended in organic farming as a fertilizer rich in nitrogen (Böme et al. 2012).

The objective of this study was to assess the influence of organic fertilizer produced from dry biomass of red clover on the yield and quality of celeriac, as well as to determine the availability of nutrients released from fertilizer pellets and the risk of nutrient migration in the soil profile during plant growth.

Materials and Methods

Field experiments were conducted in 2012 in Skierniewice, central Poland, on a sandy-loam soil (pH 6.5 and organic matter content 1.6%). Celeriac cv. Diamant was grown from module raised transplants planted in the field in half of May, at a density of 80 000 plants per hectare. Before planting, the experimental field was fertilized with plant compost at 25 tons per hectare. Plants were supplementary irrigated in draught periods.

Experimental factor was pelletized organic fertilizer produced from red clover meal (Ekofert K; nutrient content of NPK in % of DM: 3.1-0.2-3.0) was applied in celeriac cultivation in doses equivalent to 120, 180 and 240 kg of nitrogen per hectare. The efficacy of organic fertilizer was compared with conventional mineral fertilizer at dose of 100 kg N per hectare - split in two rates, each of 50 kg N per hectare, applied as preplant and sidedress - and control treatment without any additional fertilization (except the compost incorporated on the whole field before planting). Thus, following five experimental treatments were assessed in the research:

1. Control treatment
2. Mineral fertilization of 100 kg N/hectare
3. Organic fertilizer (Ekofert K) – 120 kg N/hectare
4. Organic fertilizer (Ekofert K) – 180 kg N/hectare

5. Organic fertilizer (Ekofert K) – 240 kg N/hectare

This single factorial experiment was laid out in a randomised block design. There were three replications of each treatment and treatments were randomized within blocks.

The single harvest of celeriac was applied and plant weight, total and marketable yield and quality of tubers (internal cavity) were determined.

Soil analysis of macronutrients content (N,P,K) in two soil horizons (topsoil: 0-30 cm and subsoil: 30-60 cm) were performed 3 times during the growing period at 4 weeks intervals, starting one months after planting. After harvest the content of these nutrients was also detected in deep horizon (60-90 cm). The content of nitrogen, phosphorus and potassium in the soil was determined according to soil analysis after the modified Spruway method (Nowosielski, 1988).

The results of the experiment were subjected to one-way analysis of variance with the significance of the means tested with Newman-Keul's test at P=0.05.

Results and Discussion

Organic fertilizer (Ekofert K) in all applied doses significantly increased plant biomass and marketable yield of organic celeriac with 21.5 to 33.9 % compared to unfertilized control treatment. In relation to conventional mineral N fertilization, however, significant differences in plant biomass and marketable yield were detected for Ekofert K applied at 180 and 240 kg N per hectare and yield increased 16 and 19 % respectively. Organic fertilizer Ekofert K applied at 120 kg N per hectare had the same influence on plant biomass and marketable yield of celeriac as mineral fertilization at 100 kg N per hectare, though the amount of available nitrogen in organic fertilizer was much lower than that in mineral fertilizer (Fig. 1). In Swiss research, slightly higher yields were obtained with applying purely organic fertilizer than with pure mineral or organic-mineral fertilizers (Spiess et al., 2011).

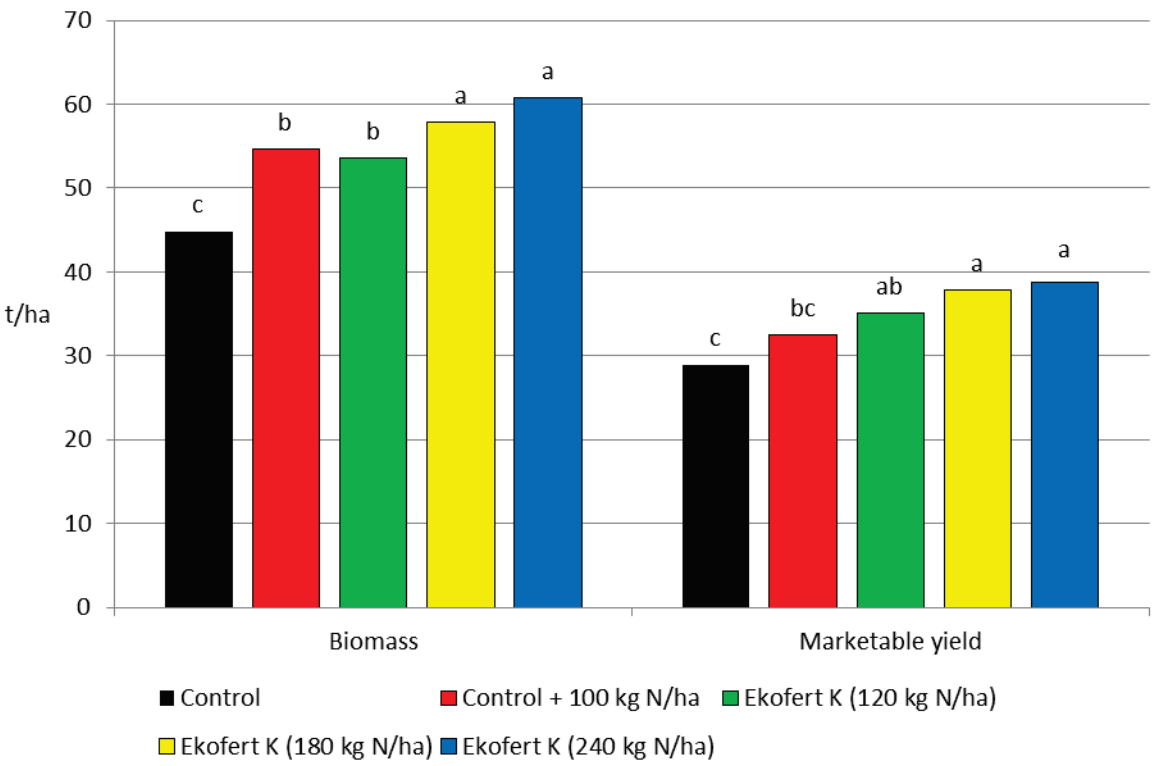

Figure 1 Biomass value and marketable yield of celeriac as an effect of applying new plant fertilizer Ekofert K (significant differences marked with different letter)

Lower growth of Japanese leafy vegetables (Brassicaceae family) in different organic fertilizer treatments (combined fertilizer with rice bran, oil-seed sludge, fish meal-multi component) compared to mineral fertilization was reported by Xu et al. (2003) for plants in early stage and explained by the lower available nutrients in organic fertilizers. However, at later stages plants grew better in organic fertilization treatments resulting in a final higher total yield than in mineral fertilization treatment, which was attributed to the high nutrient sustainability of organic fertilizer and the improved biological properties of the soil. Organic fertilizer produced as pellets from sheep wool and applied in iceberg lettuce field cultivation secured the best quantitative and qualitative yield parameters compared to mineral and plant derived fertilizers like lupine and ricinus wholemeal. Based on analysis of nutrient content in plants it seems that sheep wool pellets can, for some crops, substitute mineral fertilizers (Böme et al., 2010).

Soil analysis showed changes in nutrient availability during plant growth depending on fertilization treatment. At the beginning of plant growth, 5 weeks after organic fertilizer incorporation into the soil, the nitrate N-content in topsoil horizon (0-30 cm) was the highest in all fertilized objects compared to the unfertilized controls. For Ekofert K applied at 180 and 240 kg N per hectare N-content was 64.6 and 76.3 mg N-NO_3/dm^3 respectively, but for Ekofert K applied at 120 kg N per hectare 53.7 mg N-NO_3/dm^3 was recorded which was nearly equal to mineral fertilization. The lowest N-content was detected in the unfertilized control (38.3 mg N-NO_3/dm^3). Due to N-uptake by celeriac plants in the following 12 weeks, N-content gradually diminished in the topsoil horizon of control object and objects fertilized with Ekofert K. The only exception was the object with mineral fertilization, where N-content slightly increased 4 weeks after the topdressing but then also decreased in the following 8 weeks of growing. After harvest, nitrate N-content was diminished in all experimental treatments to 20.6 - 31 mg N-NO_3/dm^3. In subsoil horizon (30-60 cm), the highest content of nitrogen was detected after 8 weeks of celeriac growing and then decreased to a slightly lower level than this of the first weeks of plant growth (8.6 – 11.3 mg N-NO_3/ha). The only exception was Ekofert K applied in the highest rate of 240 kg N/ha, where microbial processes after harvest increased N-content in soil to 24.3 mg/dm^3. In the deepest soil horizon (60-90 cm), N-content was low and varied from 7.7 mg/dm^3 for both control treatments to 14.3 mg/dm^3 for Ekofert K application at 240 kg N per hectare. This means that nutrients released from organic fertilizer were available and easy taken by roots spreading in soil layers during plant development and, consequently, risk of soil pollution with nitrates was reduced (Fig. 2, 3 and 4).

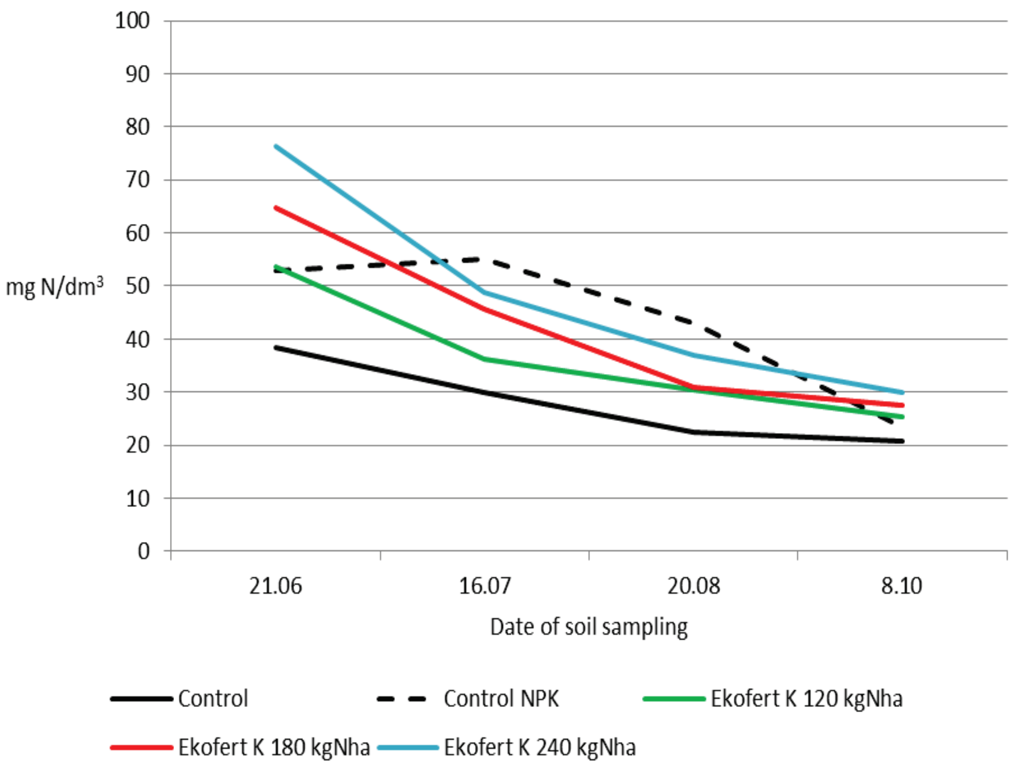

Figure 2 Nitrogen-content (N-NO_3) in the topsoil horizon (0-30 cm) during celeriac growth

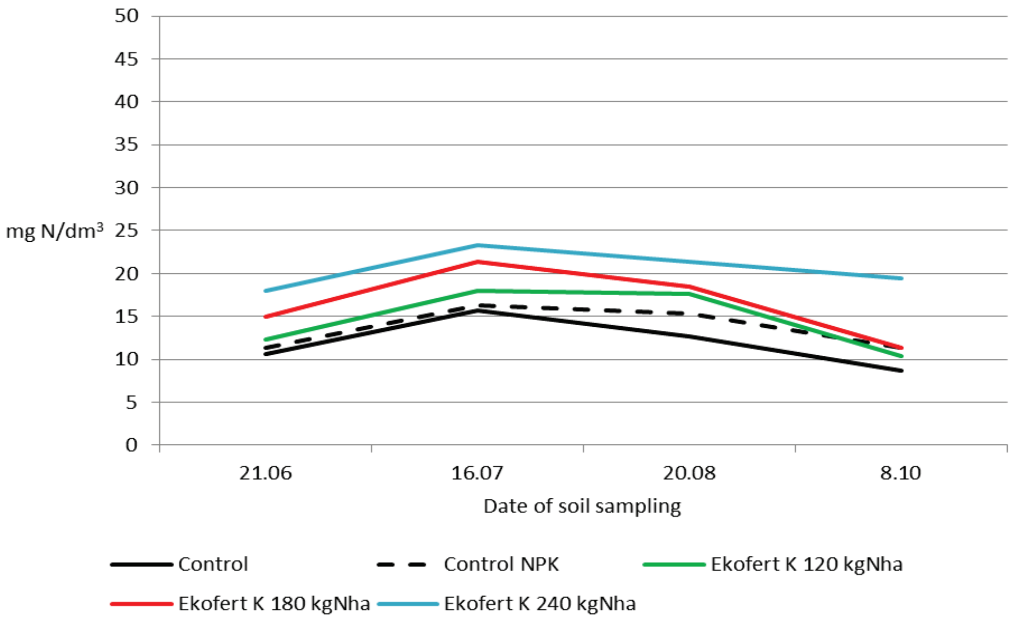

Figure 3 Nitrogen-content (N-NO_3) in the subsoil horizon (30-60 cm) during celeriac growth

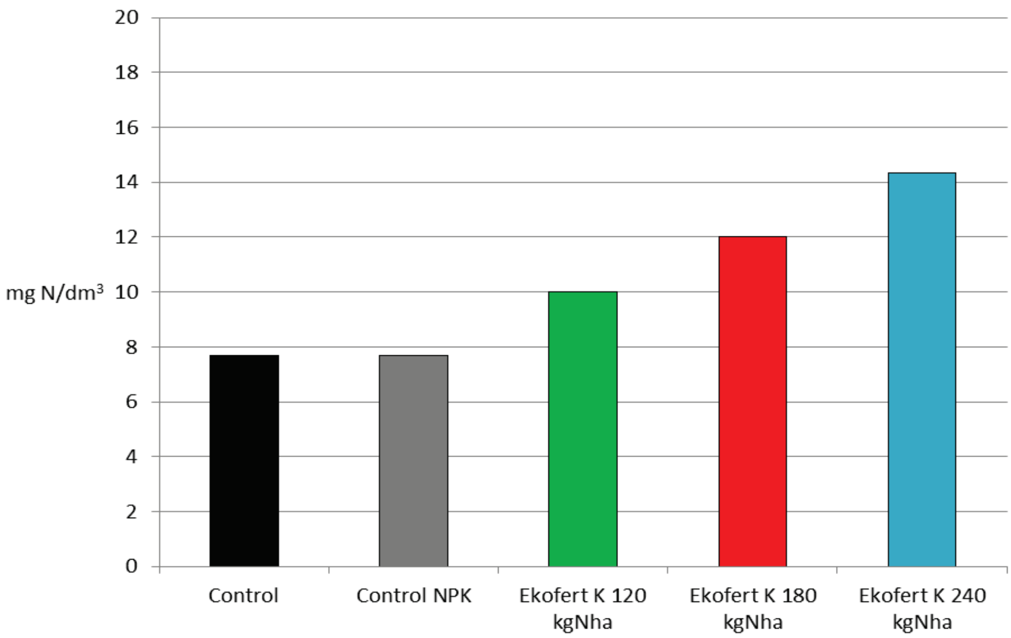

Figure 4 Nitrogen-content (N-NO_3) in the deep horizon (60-90 cm) after harvest (8 Oct. 2012)

Investigation on suitability of grain legumes (milled seeds of pea, yellow lupine and faba bean) and industrially processed plant and microbial residues for replacement of mineral fertilizers showed that N release from organic fertilizer was significantly related to the N-content of fertilizer, but soils modified this relationship. Highest N mineralization was recorded for ricinus seeds and relatively lower for pea. It is concluded that N-content of organic fertilizers indicates, but not predicts, their N-release (Stadler et al., 2006).

A tendency for decreasing potassium content in the soil during the growing period was noticed for the topsoil horizon (0-30 cm). In contrast, potassium content in the subsoil horizon (30-60 cm) decreased untill the last 4 weeks before harvest and then increased again to a similar or slightly higher level than this noticed in the first weeks of plant growth in the field (Fig. 5, 6 and 7). After celeriac harvest, potassium content in deepest topsoil layer (60-90 cm) for all fertilization treatments was not higher than this for the unfertilized control treatment.

No differences of phosphorus content in the soil profile of experimental treatments were recorded due to type and doses of applied fertilizers.

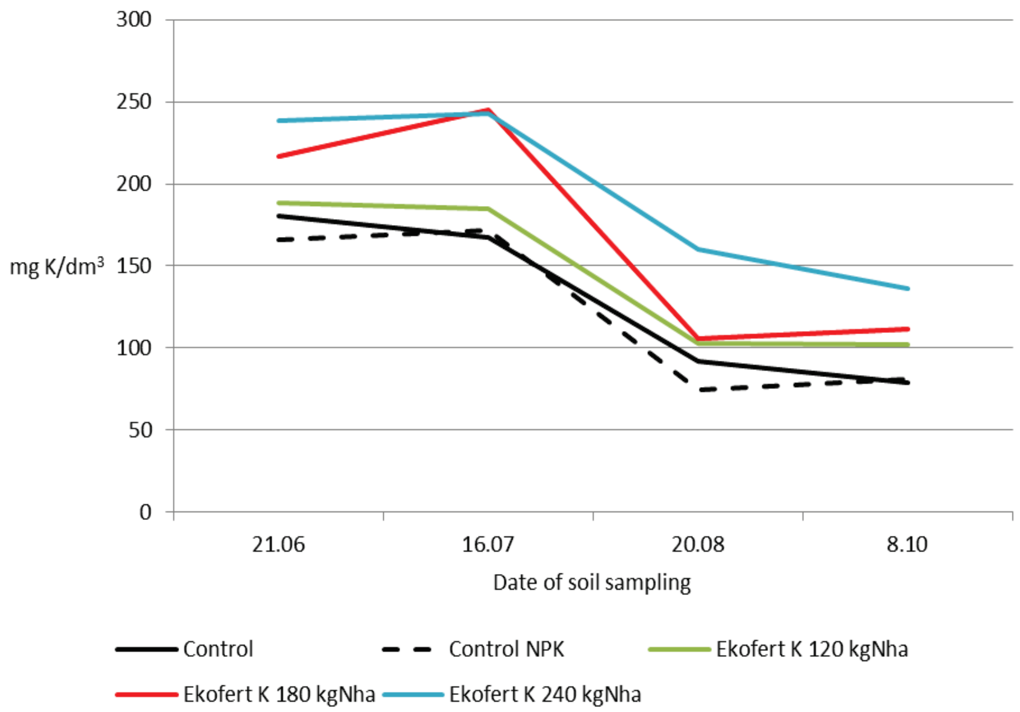

Figure 5 Potassium content (K) in the topsoil horizon (0-30 cm) during celeriac growth

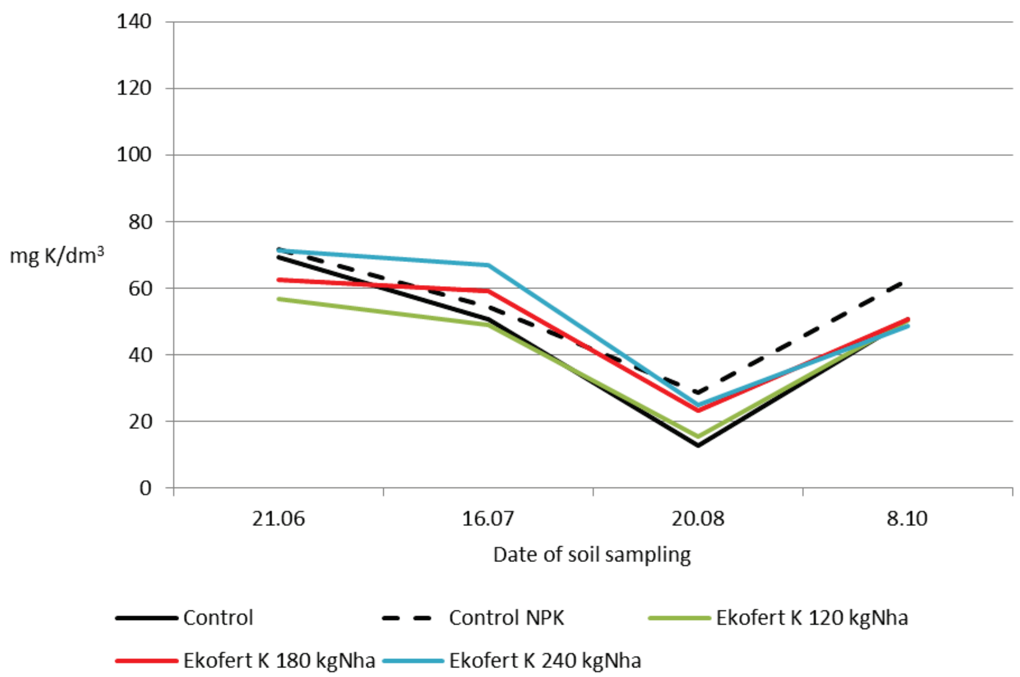

Figure 6 Potassium content (K) in the subsoil horizon (30-60 cm) during celeriac growth

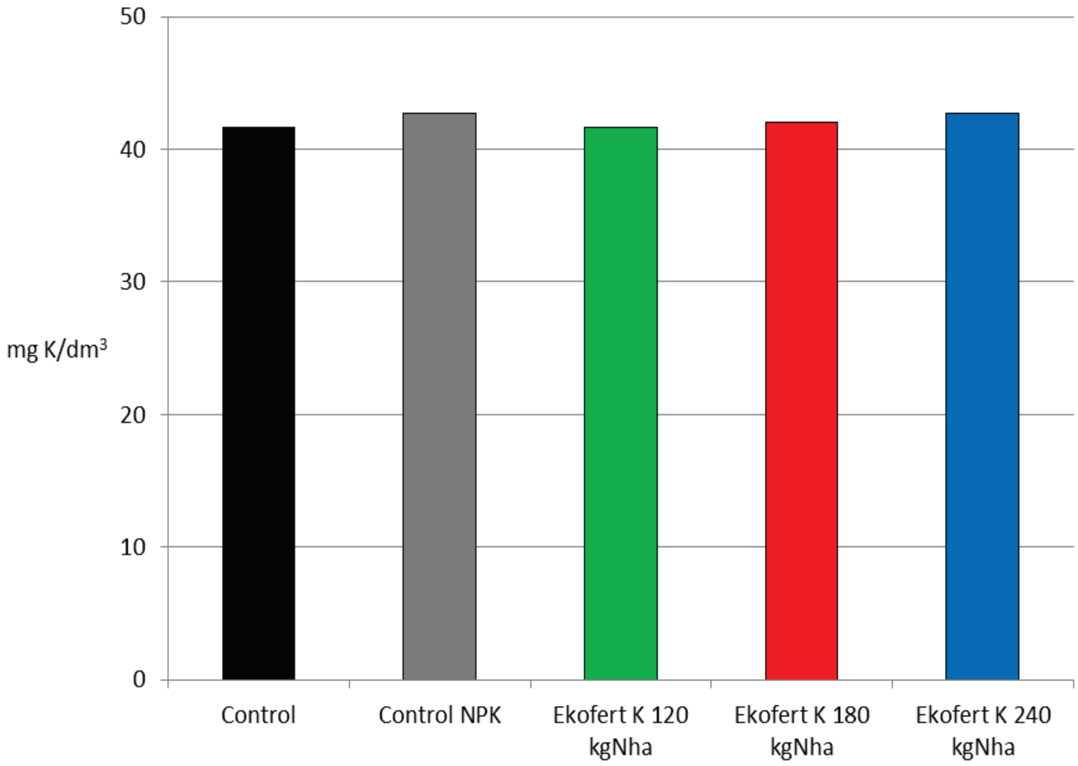

Figure 7 Potassium content (K) in the deep soil horizon (60-90 cm) after harvest (8 Oct. 2012)

Figure 8 Pre-plant application of Ekofert K at 120 kg N/ha

Conclusion

Pelletized organic fertilizer Ekofert K, produced from dried biomass of red clover and rich in nitrogen, had positive influence on celeriac yield.

The efficacy of organic fertilizer was equivalent to mineral fertilization of 100 kg N per hectare when applied at lowest rate of 120 kg N per hectare and was significantly higher (yield increase up to 19 %) when applied at 180 and 240 kg N per hectare.

Ekofert K applied in preplant basic treatment was a good source of available nutrients released gradually during plant growth.

Gradual decomposition of the organic plant fertilizer had no considerable impact on the nutrient content in the soil profile, even at highest dose of 240 kg N/ha, and did not cause threat for the soil environment.

The development of celeriac root system secured a good uptake of nutrients released from the fertilizer's organic matter during the vegetation season.

Acknowledgements

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(77) Alternative substrates for overcoming transplanted stress of ornamental plants

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Abstract: *Ornamental plants are subjected to environmental stress when transplanted due to the different chemical and physical characteristics of soil and pot substrates. The main object of this work was to assess the effect of different pot substrates on plant response after transplant, with the final aim of improving plant adaptation to the new root environment and cultivation sustainability. A two-year-long experiment (2011-2012) was carried out in open field. Treatments were: i] a typical mixed cultivation substrate (peat 50% V:V, coconut fiber 20% V:V, pumice 30% V:V) commonly used by growers in the area of Pistoia (Tuscany, Italy) as a control; ii] control substrate blended with 2 g/L of Luquasorb®, a superabsorbent polymer of potassium polyacrylate used for improving water retention in the substrate ; and iii] control substrate in which 20% V:V peat fraction was substituted with urban compost. Treatments were applied to different species, Rosa spp. (cv. 'The Fairy') and Abelia x grandiflora, in a typical two-factor randomized block design. Plant destructive analyses were conducted to assess the main biometric parameters at the end of the nursery period while non-destructive analyses were conducted after transplant. The Luquasorb®-substrate showed the best results in terms of plant growth and development as assessed just before transplant. No significant differences were observed during the successive period after transplant among the different treatments. The use of Luquasorb® can be a valuable strategy to improve the ability of nursery plants to overcome transplant stress but further research is required.*

Keywords: *ornamental plants, transplant stress, substrates, compost, superabsorbent polymer*

Introduction

In horticulture, soilless substrates are used for growing seedlings, plant propagation and ornamental plant production. Market value of potted plants is greatly influenced by production technique and management as substrate quality, drainage, irrigation, water quality and fertilization (Chavez et al., 2008). In addition, good quality of soilless plants require growing media with adequate water retention and aeration (Erstad and Gislerod, 1994) and a fertilization management that ensures a continuous nutrient supply (Macz et al., 2001). When transplanted, ornamental plants are subjected to environmental stress due to the different chemical and physical characteristics of soil and pot substrates. Consequently, a good root quality and an adequate physiological status are fundamental to overcome transplant stress, a typical abiotic stress attributable to drought stress. In fact, the ability to overcome transplant stress is affected by the root system including size and distribution (Grossnickle, 2005). Root quality is strictly linked to water management and substrate quality, in particular its water retention and aeration properties.

Transplant stress occurs especially in unfavourable conditions like poor quality of soil and water, adverse environment and difficult management conditions, which are typical scenarios of urban areas. The transplantation of plants in urban areas is affected by drought stress and the physiological status of young plants plays a crucial role in overcoming this problem. Some products able to overcome problems related to transplant stress have been tested in previous research: substrate amendments with phosphate based hydrophilic polymers (Meena, 2009) and substances capable to absorb several times its weight of water, retain this water and supply it to the plant roots during water stress, thereby enhancing plant survival and growth (Callaghan et al., 1998; Akhter et al., 2004). The addition of hydrogel to soils can improve not only its water holding capacity, but also the supply of plant available water (Al-Darby, 1996; Al-Sheikh et al., 1996).

Urban or green compost can be added to substrates to improve their quality (Rea et al., 2009). The quality of compost – determined based on maturity, particle size, porosity, water-holding capacity, air capacity, low electrical conductivity (EC) and low pH (Gouin, 1998) – are fundamental for its use in agriculture. Compost usually shows a high porosity and air capacity, while water-holding capacity is low (Abad et al., 2001). It also has a high salt and nutrient content (Lopez-Real et al., 1989). EC has been shown to be an important factor when compost is used as a substrate for horticultural plants and seedlings (Sanchez-Monedero et al., 1997; Eklind et al., 1998).

The aim of this research was to obtain high quality plants, capable to overcome problems related to transplant stress, through innovative management techniques concerning the addition of different substances in a typical substrate used by nursery plant growers.

Materials and methods

Plant materials and Experimental design

The research was conducted on *Rosa* 'The Fairy' and glossy abelia (*Abelia x grandiflora*), two ornamental plants used in urban landscaping. Rooted cuts were grown in an open field trial at CRA-VIV, in central Italy (latitude 43.54°N, longitude 10.42°E, altitude 62 m) from June 2011 to April 2012.

Treatments was represented by three different substrates: i] control, a mixture used by plant growers in Pistoia (peat 50% V:V, coconut fiber 20% V:V, pumice 30 % V:V); ii] control substrate amended with 2 g/L of Luquasorb®, a superabsorbent polymer of potassium polyacrylate used for maintaining water reserve in pots, produced by BASF Group; iii] control substrate in which 20% V:V peat fraction was substituted with urban compost. Urban compost used in this experiment was produced by urban residuals. Its analysis showed a low EC (about 1000 µS/cm), although Cl^- and other ions were present in high concentrations (data not showed).

After a brief period in greenhouse, plants were transplanted in bigger Ø 18 cm pots, using the same substrates, and collocated in open field. Fertilization was provided by two slow release FICOTE® types fertilizers (19-9-11; 8-9 months; 2.5 kg/m^3 and 17-9-10; 12-14 months; 2.5 kg/m^3) and an organic fertilizer, CO-ACTYL (3.5 kg/m^3). Irrigation was provided by a micro irrigation system and was managed according the needs of the control substrate. The three treatments were disposed in three randomized blocks with 12 plants/experimental unit resulting in 108 plants. A pruning was conducted in January and a second fertilization was provided in March with a controlled release fertilizer, OSMOCOTE® type (19-6-11; 5-6 months; 7.5 kg/m³). At the beginning (June 2011) and at the end (April 2012) of the nursery cycle, plants were analyzed. Destructive analyses were conducted to evaluate plant growth, while *in vivo* analyses were conducted to evaluate the plants response to transplant. At the end of the nursery cycle, plants were transplanted in open field on 21 June 2012.

Plant growth in nursery cycle analysis

Both destructive and *in vivo* evaluations of plant height, chlorophyll content, biomass accumulation as fresh and dry weight of shoots and roots, and total leaf area were carried out. Shoots were divided in leaves and branches. Dry weight was obtained by drying samples at 75°C.for 5 days Total leaf area was measured using WinDIAS Image Analysis System (Delta-T Devices, U.K.).

Plant growth post transplant analysis

To evaluate plants capability to overcome transplant stress, irrigation was carried out during the first two days only and then it was suspended until the eleventh day for glossy abelia and the fifteenth day for *Rosa*. Parameters evaluated were plant height, plant cover index and survival.

Statistical analysis

One-way analysis of variance (ANOVA) was performed to assess the effect of treatments on the evaluated parameters. Treatments were compared by LSD test.

Results

At the beginning of the experiment, plant materials were evaluated and no significant differences were observed for plant weight (fresh and dry), plant height, chlorophyll content and total leaf area (data not shown).

Nursery plants

In *Rosa* "The Fairy", treatments have not induced significant differences on leaf and shoot development (Fig. 1). In contrast, significant differences were observed on root weight (Fig. 3.I and 3.II) for each treatment: the Luquasorb®-substrate had significant higher root weight. No significant differences were observed in total leaf area (Fig. 4.I) and plant height (data not shown).

In *Abelia x grandiflora*, leaf biomass production (Fig. 2.I and 2.II) and total leaf area (Fig. 4.II) showed significant differences, but no differences were recorded in shoot weight (Fig. 2.III and 2.IV) and plant height (data not shown).

Also in glossy abelia, significant differences were observed on root weight (Fig. 3.III and 3.IV) for each treatment: the Luquasorb®-substrate had significant higher root weight.

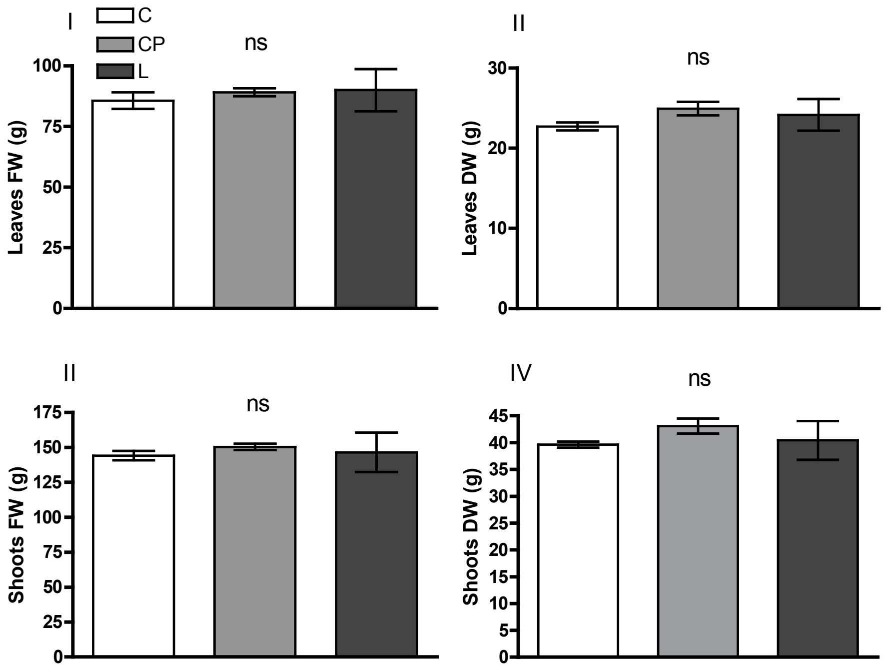

Figure 1 Leaf and shoot fresh (FW) and dry (DW) matter *Rosa* "The Fairy" grown on Control (C), Compost (CP) and Luquasorb® (L) substrates. Data were subjected to one-way ANOVA (n=6).

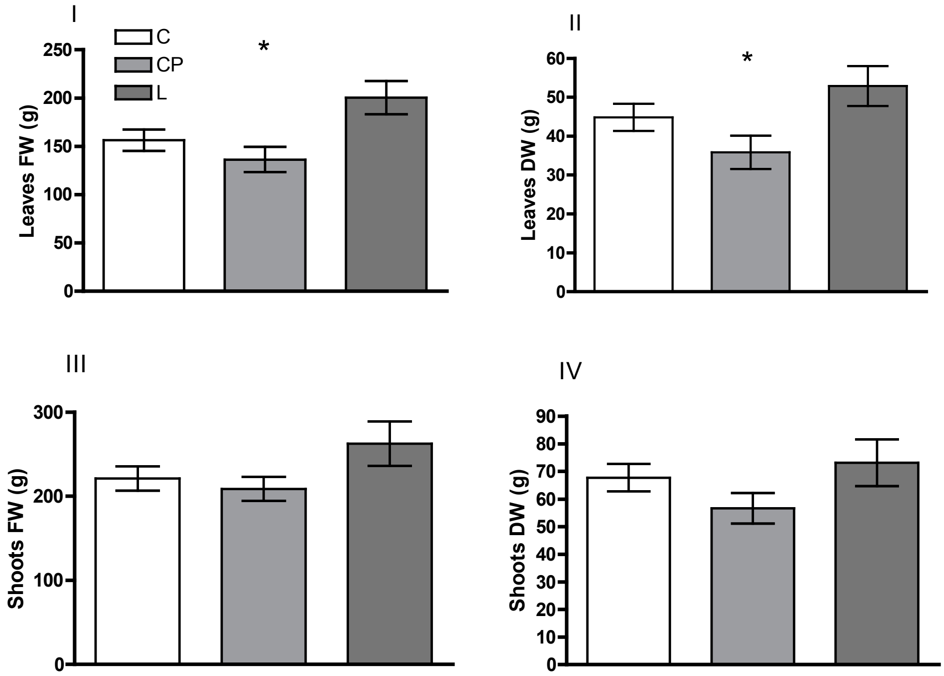

Figure 2 Leaf and shoot fresh (FW) and dry (DW) matter *Abelia x grandiflora* grown on Control (C), Compost (CP) and Luquasorb® (L) substrates. Data were subjected to one-way ANOVA (n=6). (*P<0.05)

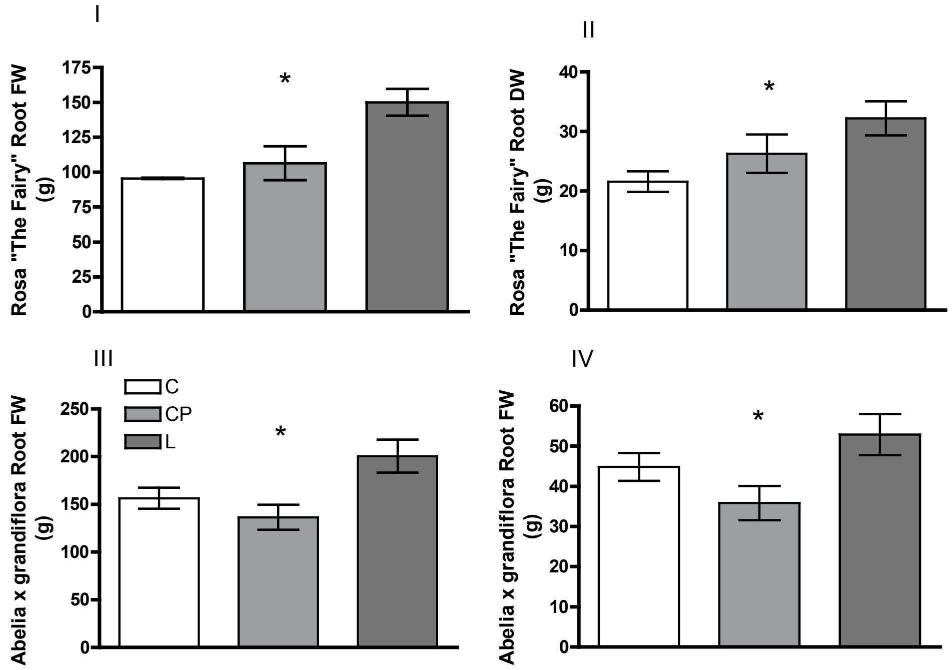

Figure 3 Root fresh (FW) and dry (DW) matter in *Rosa* "The Fairy" (I and II) and glossy abelia (III and IV) grown on Control (C), Compost (CP) and Luquasorb® (L) substrates. Data were subjected to one-way ANOVA (n=6). (*P<0.05).

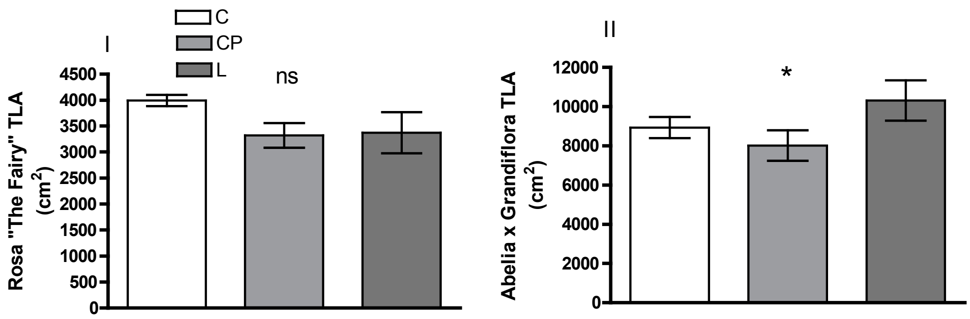

Figure 4 Total leaf area (TOTAL LEAF AREA) in *Rosa* "The Fairy" (I) and glossy abelia (II) grown on Control (C), Compost (CP) and Luquasorb® (L) substrates. Data were subjected to one-way ANOVA (n=6). (*P<0.05).

Transplanted plants

All *Rosa* plants have overcome transplant stress. *Rosa* plants, after transplant (July) and 3 months later (September), showed statistic differences in cover index (Fig. 5) but did not show significant difference in plant height following each treatment (data not shown). Plants grown in the Luquasorb®-substrate showed a better aesthetic performance in June and in the following months. Plants grown in the control showed an improvement in the months following transplant, unlike plants grown in the compost-substrate, which showed the worst aesthetic performance after transplant.

Many glossy abelia plants did not overcome transplant stress, because these plants were more sensitive to drought stress. Fifteen days after transplant, plant mortality exceeded 50%, 38.5% and 65% for plants grown in the control-, Luquasorb®-, and compost-substrate respectively. Moreover, surviving plants showed significant damage, invalidating their aesthetic and ornamental value (data no shown).

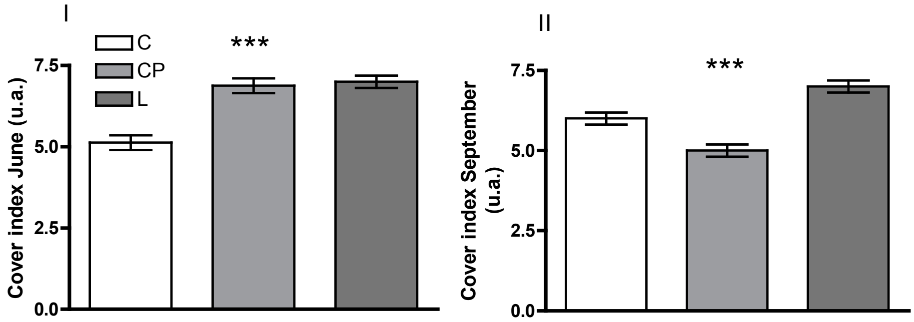

Figure 5 Cover index in *Rosa* “The Fairy” at the transplant in June (I) and after 3 month in September (II) grown on Control (C), Compost (CP) and Luquasorb® (L) substrates and transplanted in open field. Data were subjected to two-way ANOVA (n=8). (***P<0.001).

Discussion

Our research showed different treatment responses by the two plant species. In *Rosa* “The Fairy”, leaf and shoot development was not influenced by treatment. In contrast,, for glossy abelia significant differences were recorded for leaf weight and total leaf area. Glossy abelia plants grown in Luquasorb®-substrate showed higher values of biomass production and a higher aesthetic quality, confirming previous results (Al-Harbi et al., 1996; Meena, 2009, Pacifici et al., 2013). Differently, treatments influenced root development in both species. Roots grown in Luquasorb®-substrate showed higher fresh and dry weight than the control and the compost-substrate. The higher root dry weight observed in the Luquasorb®-substrate confirmed the results of Zhang et al. (2005) and Meena (2009). Glossy abelia development was compromised by the compost-substrate as it showed lower values on root, leaf and shoot development. In contrast, *Rosa* “The fairy” , grown in the control-substrate showed lower values. In previous works, plant growth was found positively influenced by the use of compost (Herrera et al.,2008). Roots of plants grown on the Luquasorb®-substrate showed better development suggesting a higher ability to explore the soil after transplant. Parameters evaluated after transplanting showed a good capacity to overcome transplant stress for *Rosa* “The Fairy”. Response of glossy abelia to the compost-substrate suggests an intolerance to high EC values: this problem was suggested by many authors (Lopez-Real et al., 1989; Sanchez-Monedero et al., 1997; Eklind et al., 1998). It is important to underline that the responses of the two species was different because each species shows different sensitivity to soil and substrate salinity. In this perspective, it is also difficult to design a standard substrate for all plant species and results should not be extrapolated to other species than those examined.

Conclusion

In general, nursery plants grown in the Luquasorb®-substrate showed the best results in relation to biometrical parameters among the three tested substrates. After transplant in open field, the plants showed improved performances and the differences among treatments were no longer visible. For the nursery plants market, bigger and compact plants have a greater value. From this point of view, *Rosa* “The Fairy” plants grown in Luquasorb®-substrate showed a higher commercial value, although transplant stress was homogeneously overcome by all treatments. Plant roots grown in Luquasorb®-substrate showed higher development, suggesting a higher exploration of soil. In conclusion, the use of Luquasorb® can be a valuable strategy to improve the ability of nursery plants to overcome transplant stress, but further research is required.

Acknowledgements

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(78) New biodegradable agro-fleece for soil mulching in organic vegetable production

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Abstract: *In field experiments the usefulness of a new organic biodegradable agro-fleece Covelana K was studied in celeriac (Apium graveolens L. rapaceum) cultivation. The influence of organic agro-fleece on yield, nutrient availability and weeds compensation was compared with 3 types of control objects: non-covered, non-covered but mineral fertilized (100 kg N per ha) and mulched with fresh red clover biomass. Organic agro-fleece had a positive impact on plant development and celeriac yield. Compare to the non-covered object organic agro-fleece significantly increased yield (23%) and share of large roots in marketable yield. The greatest impact on plant development and celeriac yield was obtained by soil mulching with fresh red clover biomass. In relation to organic agro-fleece cover yield increase was higher by 28%. Soil mulching with biodegradable agro-fleece Covelana K eliminated weed problems during the entire growing period. During the first weeks of the celeriac growing period soil mulching with organic agro-fleece depleted nitrate nitrogen in the topsoil horizon (0-30 cm) by 42%, partly due to nitrogen immobilization by soil microorganisms. But in the following weeks of the growing period the rate of nutrients release from organic matter of agro-fleece was higher than plant uptake, so some increase of nitrogen content in the soil was recorded. In objects mulched with red clover decomposition of fresh biomass released a considerable amount of nitrogen and decrease of soil nitrogen content was only 7%.*

Keywords: *biodegradable, mulching, organic fleece, nutrients release, celeriac*

Introduction

For years some plants were grown not solely to harvest but for many other purposes such as: improving soil quality, erosion control, nitrogen management, weed suppression. The main reason of such crops cultivation was to keep the soil surface covered as long as possible. Notably in organic farming are cover crops used to reduce the weed population and as a source of organic matter and nutrients (Laber, 2009). General tendency to lower production costs triggered off a lot of changes in commercial farming practices including mulching. In the field vegetable production soil mulching is consider as a favourable treatment which practically eliminate necessity of expensive weed control, enhance plant yielding, improve soil water condition and reduce soil erosion. As soil cover the polypropylene fleece is very often used, a white fleece mostly to rise the soil temperatures and obtain a better yield (Hamouz et al., 2005) and a black one to prevent weeds (Kaniszewski et al., 2011). The problem with artificial fleeces is that all those materials are non-biodegradable and have to be removed by hand from the field at the end of growing season and that plastic currently goes into landfills at a cost. In sustainable agriculture the use of biodegradable coverings is highly expected but only some companies offer biodegradable plastic mulch (Johnson, 2012). But use of an organic biodegradable mulch may be more favorable for the natural environment and provide advantages such as reduction of water losses, limitation of soil erosion, maintain uniform soil temperature, prevent weed germination and other biological and chemical effects (Williams, 1997).

The objective of this study was to assess the influence of organic biodegradable agro-fleece on yield and quality of celeriac, weeds control as well as nutrients availability and their migration in soil profile.

Materials and Methods

Field experiment was conducted in 2012 in Skierniewice (Poland) on a sandy-loam soil (pH 6,5 and organic matter content 1,6%). Celeriac *cv. Diamant* was grown from module raised transplants planted in the field in half of May, at density of 80 000 plants per hectare. The basic pre-plant fertilization was plant compost applied in rate of 25 tons per hectare. Plants were supplementary irrigated in draught periods.

Experimental factor was biodegradable organic fleece (Covelana K) made from a by-product of the textile industry and enriched with dried and ground red clover biomass (100 g per 1 m^2 of fleece). The efficiency of agro-fleece application for crop yield, weeds control, nutrients content in the soil and their availability was determined and compared with 3 types of control objects: non-covered, non-covered but mineral fertilized (100 kg N per ha) and mulched with fresh cut red clover (30 t/ha directly after planting and then supplemented with another 10 t/ha at 4 weeks later). The following four experimental treatments were assessed:

1. Non-covered control treatment
2. Non-covered but mineral fertilized of 100 kg of nitrogen per hectare
3. Red clover (fresh biomass) mulch
4. Organic agro-fleece mulch (Covelana K)

Single factorial experiment was laid out in randomised block design. There were three replicates of each treatment randomized within blocks.

Celeriac was harvested once and plant weight, total and marketable yield and quality of tubers (internal cavity) were determined.

Soil analysis of macronutrients content (N, P, K) in two soil horizons (0-30 cm and subsoil 30-60cm) were performed 3 times in growing period at 4 weeks intervals, starting one months after planting. After harvest the content of these nutrients was also detected in deep horizon (60-90 cm). The contents of N, P and K in the soil were determined according to soil analysis after the modified Spruway method (Nowosielski, 1988).

The results of the experiment were subjected to one-way analysis of variance and significant differences of the means were compared with Student's t-test at p=0,05.

Results and Discussion

The results of the field experiments showed that the use of biodegradable fleece enriched with dry red clover (Covelana K) for soil mulching had a favorable impact on celeriac plant development and yield. Organic agro-fleece (Covelana K) mulching significantly increased plant biomass and marketable yield compare to non-covered control treatment (24 and 23% respectively) and was nearly equal effective as the mineral fertilized control (Fig. 1). Organic agro-fleece (Covelana K) mulching also increased average root weight of celeriac by 11% and share of large roots in marketable yield compare to mineral fertilized control (data not presented). The most effective for plant development and yield, among all experimental treatments, was soil mulching with fresh red clover biomass. The obtained yield of 48 tons per hectare was significantly higher compare to non-covered control by 65%, mineral fertilized control by 41% and to organic agro-fleece (Covelana K) by 28% (Fig. 1). Considerable increase of average tuber weight and share of large tubers in marketable yield was also recorded when mulched with red clover. In previous experiments the highest increase of celeriac yield was also obtained with red clover mulch and better crop yielding was achieved when organic agro-fleece (Covelana K) enriched with dry red clover was applied in comparison to organic ago-fleece non supplemented with red clover (Kaniszewski et al, 2011). A similar effect was obtained by Riley and Dragland (2002) for red clover single surface mulch application in red beet and cabbage where yield increase was up to 55% and 41% respectively, but with double application a greater response were achieved in cabbage than in red beet.

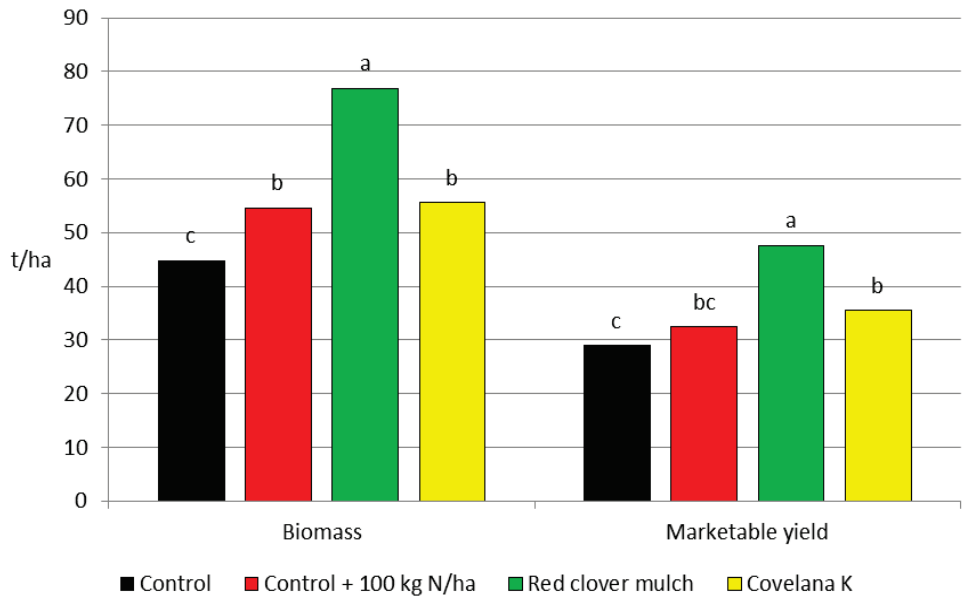

Figure 1 Marketable yield of celeriac mulched with fresh red clover and biodegradable fleece (Covelana K) (significant means marked with different letter)

Organic fleece mulching practically overcomes weed problems in celeriac growing and maintained the soil surface free of weeds during the cultivation period. The only weeds were found in holes made in the fleece when transplants were planted. Red clover mulch considerably limited weeds problem, particularly during the first weeks after planting, but didn't eliminate the necessity of crop weeding during later weeks of plant growth (Fig. 2). Red clover chopped mulch was effective in weed control in red beet and cabbage culture and this latter also showed some effect in pest control (Riley and Dragland, 2002). A red clover layer of 3 cm used for soil mulching in red beet and cabbage gave good control of annual weeds but not perennials. That practice was, however, consider as labour-intensive and required an area of two to three times that of the vegetable plots (Riley and Brandsaeter, 2001).

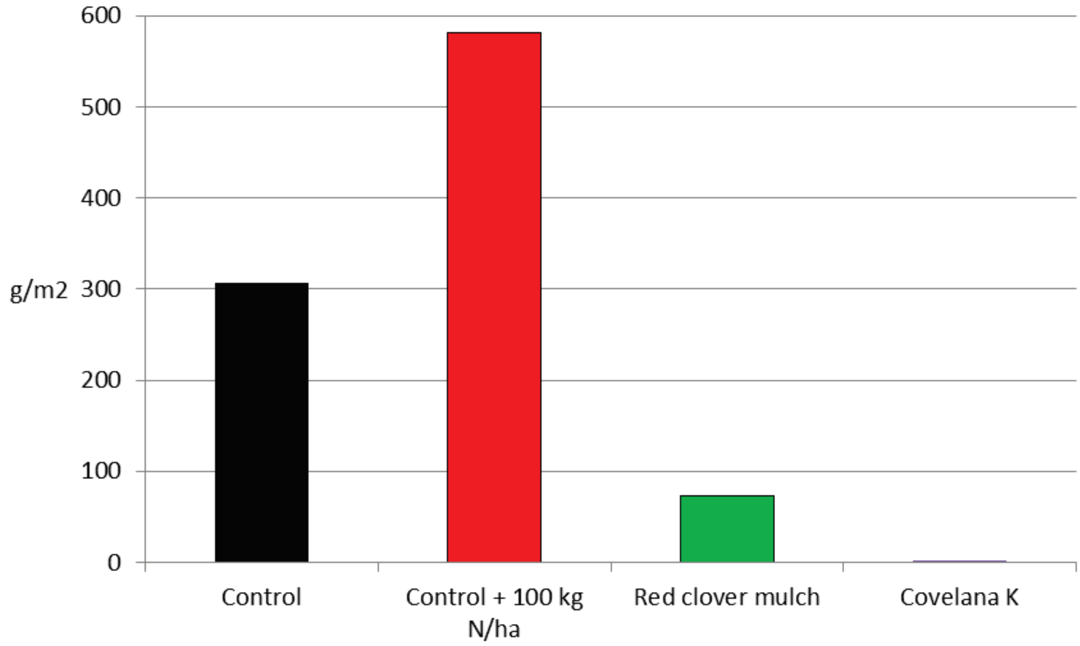

Figure 2 The efficacy of soil mulching on weed control in celeriac cultivation

Soil analysis performed 5 weeks after planting revealed differences in nitrogen content of the topsoil horizon (0 - 30 cm) of the experimental objects. Soil nitrate content was respectively 36 and 38 mg $N\text{-}NO_3/dm^3$ in the soil mulched with organic fleece (Covelana K) and in the non-covered control, but it was considerably higher in the mineral fertilized control and soil mulched with red clover (53 and 55 $N\text{-}NO_3/dm^3$ respectively). As celeriac development and nutrient uptake enhanced during the vegetation season, the amount of available nutrients in soil gradually diminished in all experimental objects. The only exception was mineral fertilized control, where top dressing with 50 kg N/ha increased $N\text{-}NO_3$ content within 8 weeks after transplanting. Due to decomposition of fresh red clover biomass during the first 8 weeks following transplanting considerable amounts of nutrients were released and decrease of the nutrient content of the topsoil was limited to 7% but increased considerably thereafter. In last weeks of celeriac growth limited nutrient uptake and simultaneous intensive decomposition of red clover mulch biomass increased $N\text{-}NO_3$ content in soil up to 44 mg/dm^3. In topsoil horizon of objects mulched with organic fleece (Covelana K) $N\text{-}NO_3$ content considerable decreased in first 8 weeks of growing (up to 42%) as a result of partial nitrogen immobilization by soil microorganisms. In further part of the season mineralization rate of agro-fleece organic matter was slightly higher than crop nutrient uptake and resulted in a little increase of nitrogen content in topsoil horizon till harvest (Fig. 3).

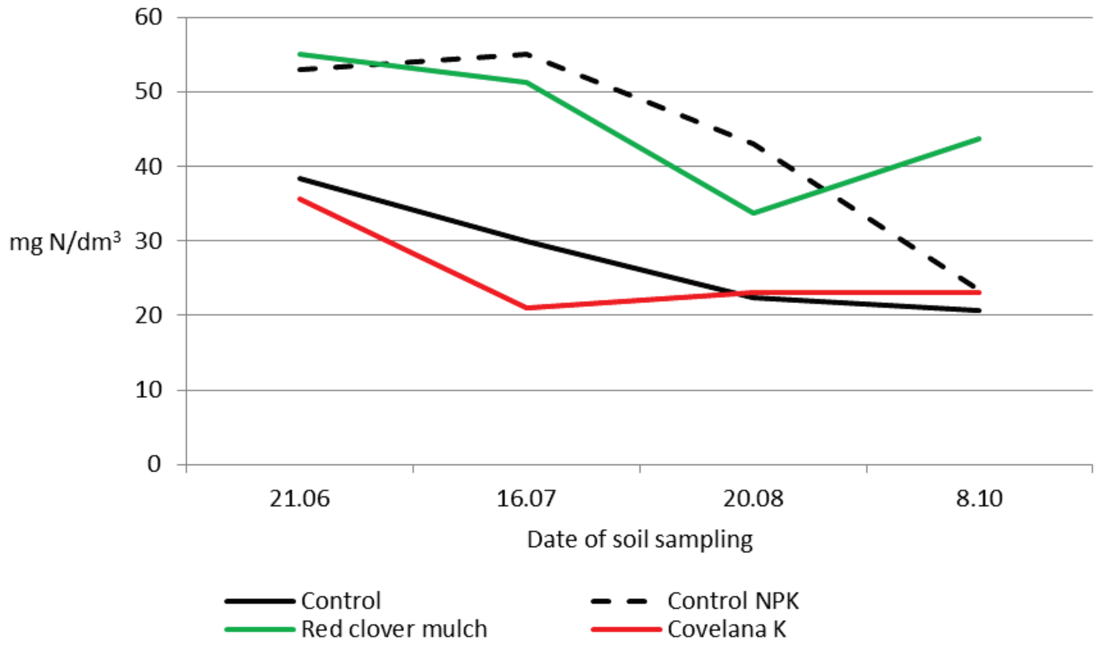

Figure 3 Nitrogen content ($N\text{-}NO_3$) in topsoil horizon (0- 30 cm) during celeriac growth.

In the subsoil horizon (30-60 cm) increase of $N\text{-}NO_3$ content was recorded in both control objects and mulched with red clover from 8 till 12 weeks of celeriac growing and then decreased to a level slightly lower than the nitrate nitrogen content in the first weeks of plant growth (6,3 – 16,03 mg $N\text{-}NO_3$/ha). It may indicate insignificant nitrogen migration in soil profile as a result of yet insufficient roots development of young plants in this soil layer. In soil mulched with organic agro-fleece (Covelana K) gradual decrease of nitrogen content in subsoil horizon was recorded (Fig. 4). No increase and migration of nutrients to the deepest soil horizon (60 – 90cm) was observed in the non-covered control objects and objects mulched with agro fleece (Covelana K) after. Only in objects mulched with red clover limited migration of $N\text{-}NO_3$ released from biomass was observed (Fig. 5). Experiments performed by Riley and Draglan (2002) s showed that surface mulching with red clover in a red beet and cabbage crop led to significantly higher levels of mineral nitrogen after harvest. Much higher soil mineral nitrogen levels were observed following the red beet crop compared to the cabbage crop (47 and 14 kg N/ha respectively) due to the longer growing period of cabbage.

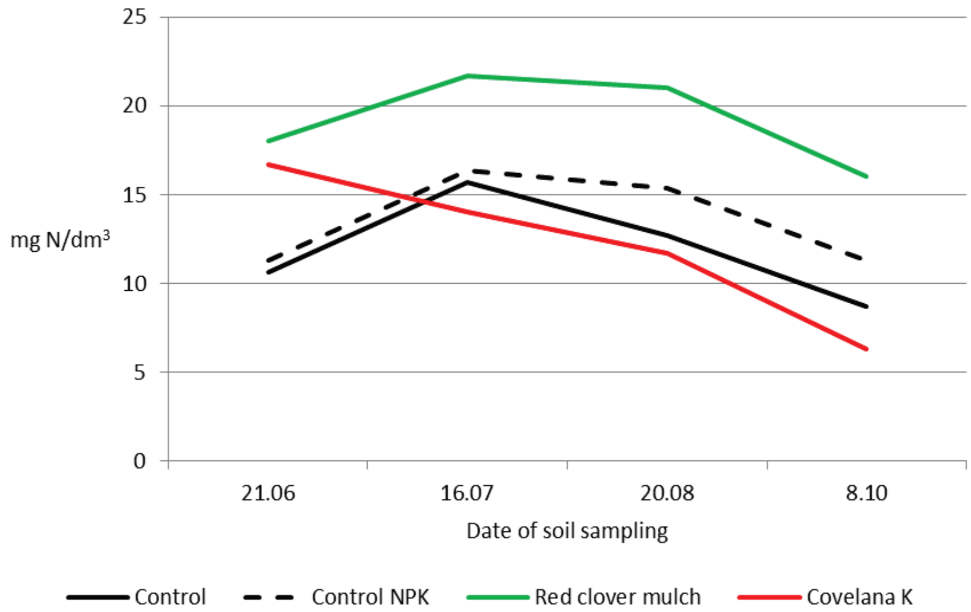

Figure 4 Nitrogen content ($N\text{-}NO_3$) in subsoil horizon (30- 60 cm) during celeriac growth.

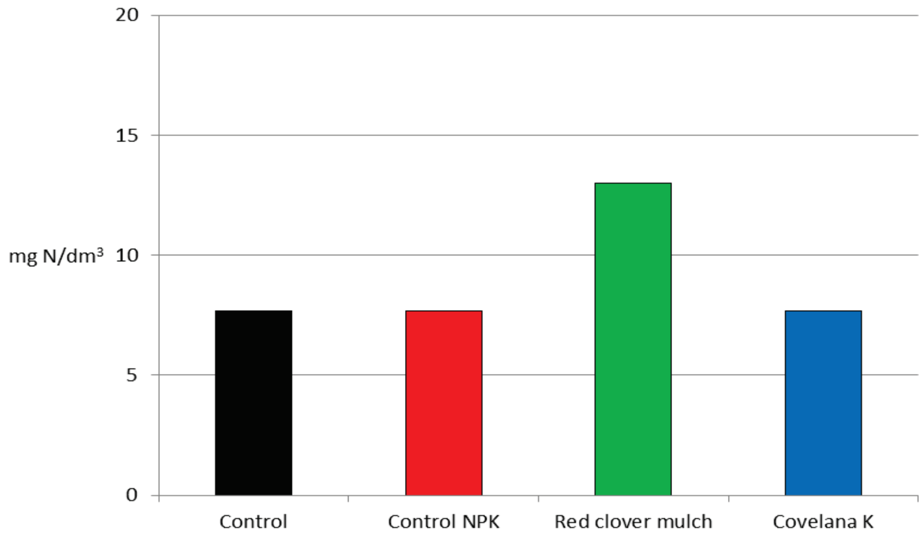

Figure 5 Nitrogen content (N-NO_3) in deep soil horizon (60- 90 cm) after harvest (8 Oct. 2012).

K content in topsoil horizon was similar for both control, non-covered objects and mulched with agro-fleece (Covelana K) and gradually decreased within celeriac vegetation. At 5 weeks after planting K-content varied from 161 to 224 mg K/dm^3 and dropped to 79 – 87 mg K/dm^3 at harvest time . Much higher K content was recorded for red clover mulch. At 5 weeks after planting it was 275 mg K/dm^3 but within next 4 weeks increased up to 343 mg K/dm^3 as a result of a higher K release from mulch biomass than K uptake by young celeriac plants. In the following weeks of intensive plant growth K uptake surpasses the K release from organic matter and soil K content dropped by 43% and again increased at harvest time due to a smaller plant growth rate and reduced nutrients needs. After celeriac harvest potassium content in topsoil horizon was high (232 mg K/dm^3) and risky in aspect of soil pollution (Fig. 6). Similar tendency was recorded for the subsoil horizon (30 – 60 cm) but potassium content was 2- 3 times lower than in topsoil horizon and in most intensive plant growth (12-13 weeks after planting) varied from 13 – 29 mg K/dm^3. Limited plant needs at harvest time caused migration of K in soil profile and increased its content in soil up to 50-75 mg K/dm^3, but differences between experimental objects were not large, though slightly higher for red clover mulch (Fig. 7). In the deepest horizon (60-90 cm) potassium content was lower by 20-50% compared to upper soil horizons and did not vary between experimental objects (Fig. 8).

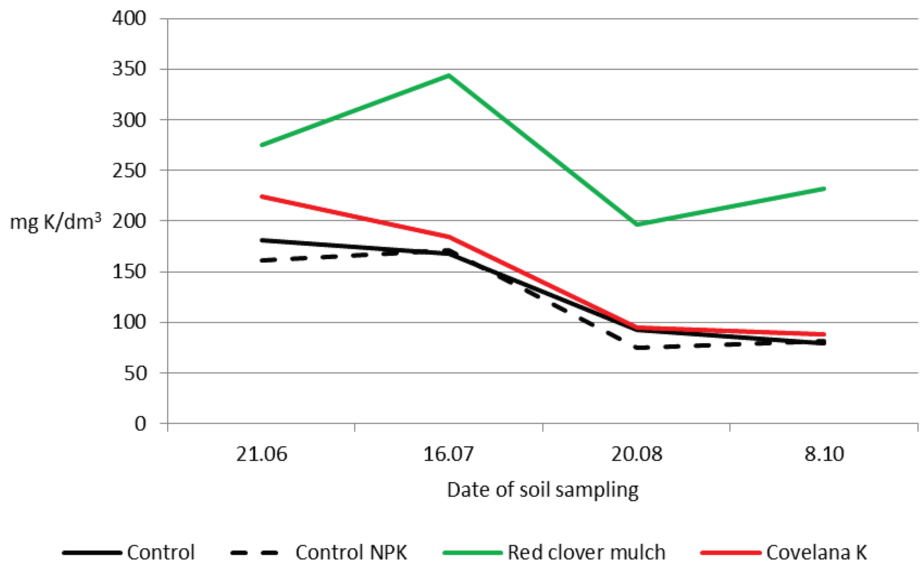

Figure 6 Potassium content (K) in topsoil horizon (0- 30 cm) during celeriac growth.

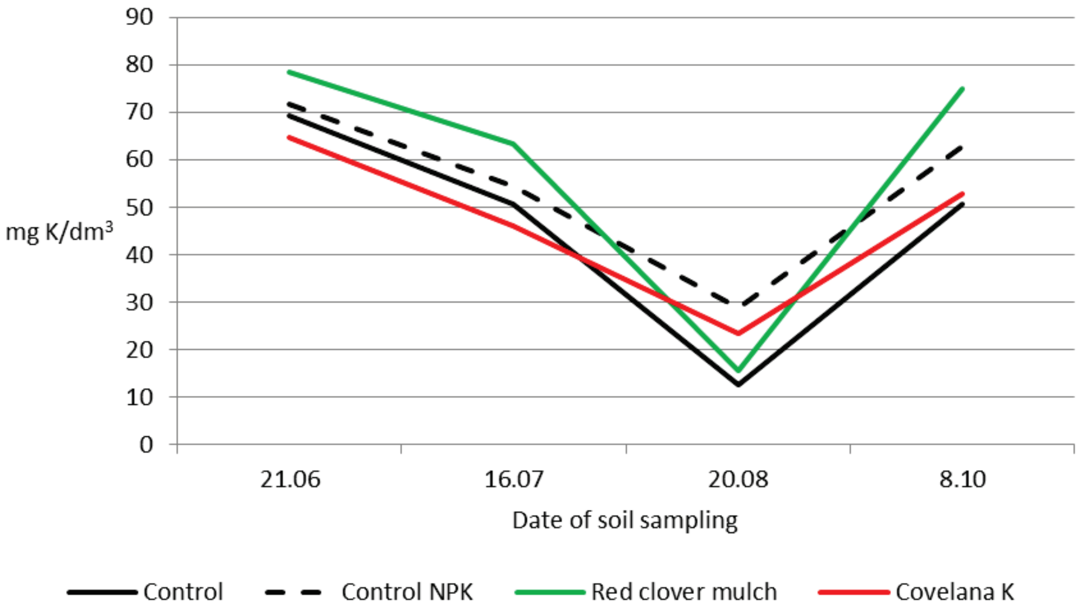

Figure 7 Potassium content (K) in subsoil horizon (30- 60 cm) during celeriac growth.

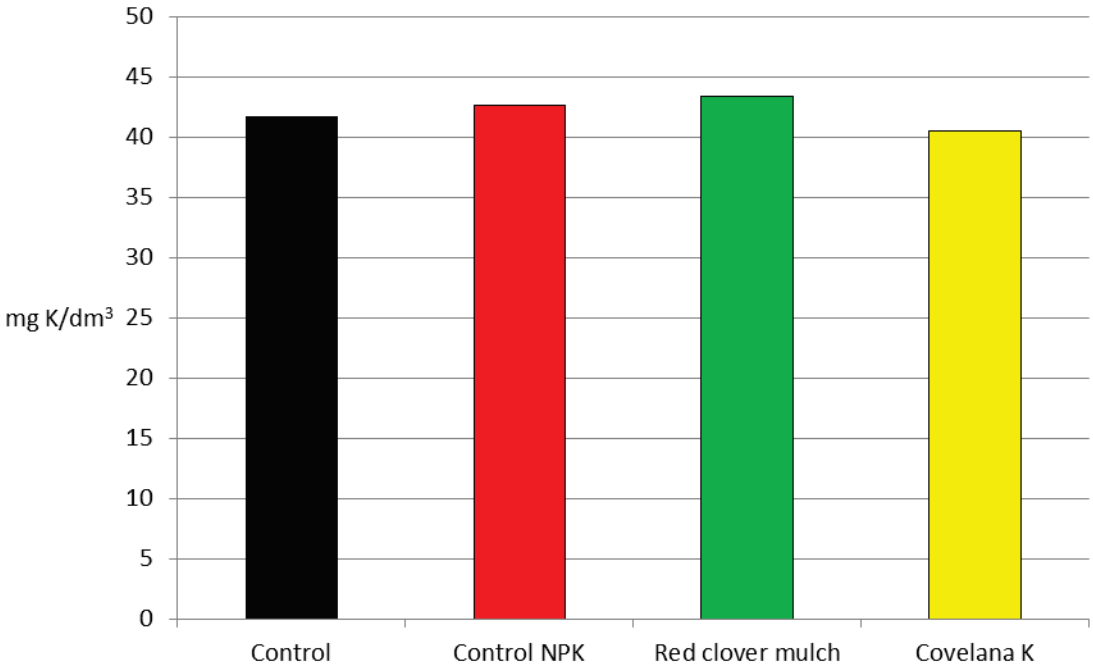

Figure 8 Potassium content (K) in deep soil horizon (60- 90 cm) after harvest (8 Oct. 2012).

Conclusion

Soil mulching with biodegradable organic fleece had a favourable effect on weed control during the growing period of celeriac.

Biodegradable organic fleece enriched by dried biomass of red clover considerably increased crop yield of celeriac to the crop yield obtained with mineral fertilization at dose of 100kg N/ha as well as average tuber weight.

Gradual decomposition of organic fleece released considerable amount of easy available nutrients, secured good plant uptake and did not cause any threat of nutrients excess in soil environment after celeriac growing.

Red clover fresh biomass used for soil mulching was most effective for yield enhancing, but less for weed control and hand weeding was required later in the season.

Decomposition of red clover mulch biomass gradually released high amounts of available nutrients within vegetation season which could be a potential threat of soil pollution if not exploited by the crop.

Acknowledgements

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(79) Effect of different rates of nitrogen fertilization on vegetative development and productivity of cape gooseberry (*Physalis peruviana* L)

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Abstract: *The main goal of the present study was to establish the influence of different level of nitrogen fertilizer on the morphological and physiological behavior of cape gooseberry plants and on the quantity and quality of the obtained fruits. Experiments were carried out with two varieties. Five rate of ammonium nitrate fertilizer (34, 27% N) – 0, 70, 140, 210 and 280 N kg.ha^{-1} were applied in three times – ⅓ before planting soil preparing and the remainder was divided into two and used in two stages of development - beginning of flowering and twenty days later. Plants from different variants were grown on the same level of 160 kg.ha^{-1} P_2O_5 and 120 kg.ha^{-1} K_2O applied in autumn plowing. The morphological behavior in dynamic in three phases of mass flowering, beginning and mass fruiting were measured. Parameters of leaf-gas exchange were analyzed. Uptake of nitrogen, phosphorus and potassium from vegetative part and with fruits, necessary to forming 1000 kg fruits were calculated. The rate of 210 kg.ha^{-1} N causes most highly vegetative development of stem and leaves and also of total vegetative weight. Lower doses of 70 and 140 kg.ha^{-1} N influenced on formation of the highest yield. Regression interaction between nitrogen rate and productivity was established. Content of vitamin C, total sugar, pectin and acid were changed in limited extent.*

Keywords: *ammonium nitrate; leaf-gaze exchange; vitamin C; pectin; sugar*

Introduction

Cape gooseberry is a comparatively new vegetable crop for Bulgaria and for Europe, but with very good perspectives for production, due to an appropriate climate condition, as well as very good sales of products on domestic and international market. Fertilization researche in vegetable crops is of particular importance, as confirmed by studies conducted by many scientists as Choleva et al. (2007), Todorova et al. (2009), Haytova and Bileva (2011), Kostadinova (2011), and Haytova (2012). In cape gooseberry growing one must pay particular attention to appropriate fertilization with N (Chernok, 1997; Kendall, 2008; Christov, 2010). According to them in the most cases, a high yield is obtained at lower level of N fertilization. Similar opinion were expressed by McCain (1993): he noted that although the plants do not require a large amounts of fertilizer, the production increases significantly when performing balanced fertilization, and the most appropriate is using $N_{12}P_5K_{10}$. Higher quantities of N approximately with 50kg N/ha caused much more luxuriant vegetative growth, in which case the setting of flowers and fruits greatly was reduced (Crawford, 2004). Paksi et al. (2007) also stresses the need to apply limited N fertilization, because in higher quantities of this fertilizer the vegetative growth of the plants is excessively strong. Ramos-Lara et al. (2002) emphasized that the efficient use of N from cape gooseberry achieved by applying 160 kg N.ha^{-1}. Contrary view of the need for N at this vegetable crop express El-Tohamy et al. (2009) and Castro-Brindis et al. (2004), and comes to the position that the highest yield was obtained at a high concentration of N. Stock and Evans (2006) concluded that adding extra N in cape gooseberry is mostly associated with increasing the content of $_{15}$N and the changes in its distribution in the leaves.

The main goal of the present study was to establish the optimal level of N fertilization of cape gooseberry in Bulgarian climate conditions and its impact on the morphological and physiological events as well as on its productivity.

Materials and methods

The experiments were carried out during 2008-2010 years in Agricultural University, Plovdiv, with two genotypes – one was the first Bulgarian variety Plovdiv and the other was Obrazec 1. During autumn plowing 160 kg.ha^{-1} P_2O_5 and 120 kg.ha^{-1} K_2O as triple superphosphate and potassium sulphate, respectively were applied. Seeds were sown in plastic green house in middle of the March at 1.5 g/m^2. On 20 of May the seedlings were planting by scheme 70 × 50 cm on the experimental plots of 10 m^2, in four replications. The soil classified as Molic-Fluvisols, is loamy, with 30% clay. Five rate of N as an ammonium nitrate fertilizer (34, 27% N) – 0 (control), 70, 140, 210 and 280 N $kg.ha^{-1}$ were applied in three times – ⅓ before planting soil preparation and the remainder was divided into two doses and used in two stages of development - beginning of flowering and twenty days later. Through the vegetation periods all agricultural practices were performed. The studies were done in three stages of plant development - mass of flowering (m. flowering), beginning of fruiting (b. fruiting) and mass of fruiting (m. fruiting). Total vegetative weight, height of plants, number of branches, number of leaves, leaf area and weight of leaves were measured on 15 plants in the above mentioned phases. Intensity of photosynthesis, intensity of transpiration and stomatal conductivity in the same phases were established with LCA-4 (UK) systems on the normal developed leaves from middle layer of plant on the five intact plants from each replication. The necessary amounts of basic nutritional macroelements - N, phosphorus and potassium, about formation and obtaining of 1000 kg fruits has been calculated. This was done on the base of uptake from soil through stems, leaves and fruits of the quantity of N (by methods of Kjeldahl), phosphorus (by calorimetric methods) and potassium (on flame photometer) after wet digestion. These analyses were performed in stage of botanical maturity in four replicates on average samples taken from each replication in which the plants were grown. All these methods are described in Thomov et al. (1999). Content of dry matter (by drying in oven in 105^0C), vitamin C (by methods of Murry), total sugar (Hagedorn-Yensen method), total acids, were investigated in full maturated fruits in stage of mass fruiting. The methods of these analyses are described in details in Stambolova et al. (1978). Content of pectin in the mentioned stage was determined according to the methods of Institute of Medicine (2004). Chemical content was established in four replicates in average samples taken randomly from each replications in which the plants were grown. Total yield was established by two harvests in full maturity. Data of the study were subjected to analysis of variance, and least significant differences between means were calculated by the Fisher test at p = 0.05. Methods for ANOVA and regression analysis are described in Fowel and Cohen (1992). The presented data are mean values from the three years of the investigation periods, because the trends were similar.

Results and discussion

Applying different levels of N fertilization affects the morphological development of cape gooseberry plants. Total vegetative weight (Figure 1) increased in each investigated stage of development and in mass fruiting in variant $N_{280}P_{160}K_{120}$ in Plovdiv reached to 1426.72 g as about the control it was 546.94 g, while for Obrazec 1 was from 526.44 g (control) to 895.67 g, but already in variant $N_{210}P_{160}K_{120}$. Application of ammonium nitrate strongly increased the total vegetative weight. Genotype responses between both varieties were observed. In Plovdiv, which inherently has a strong vegetative growth the effect of fertilization was more expresed and with increasing fertilizer quantities the weight increased in all phases and variants. In Obrazec 1 however at the highest fertilizer rate in stage of mass fruiting suppressive effect was established towards to previous one (N_{210}) as the values of this index are lower, but significantly higher than those of the control. In both varieties the highest increase was observed between beginning and mass fruiting. This is probably, on one hand is connected with a long period between the two phases, and on the other with the time required to observe the effect of N fertilization. Rajnish et al. (2006) when studying the effect of N on cape gooseberry, also found that in the initial phases, there was no differentiation between tested variants, but during their development the differences between the plants under the influence of different amount of N fertilizer became clear.

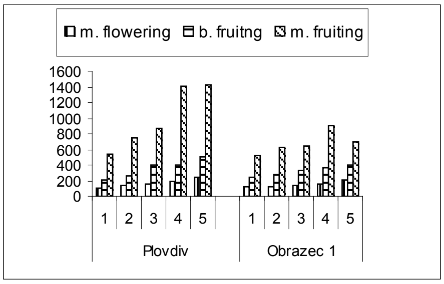
Height of the plant (Fig. 2) and number of branches (Figure 3) are essential morphological behaviors of cape gooseberry, on which depends largely the overall development of plant and its potential and productivity. The significance of this indices are emphasized from Skvorcova (1997), and she pointed out that the branching of cape gooseberry is sympodial type and purposeful breeding activities involves making assessment and in this field. The effect of N fertilization on plant height, as above indicated for total vegetative mass in the initial phase of measuring - mass flowering was weak. The differences between the variants are 4.72 cm to 17.92 cm for the N_{70} to N_{280} for Plovdiv, and for Obrazec 1 from 3.05 cm to 5.5 cm for the same variants. The last variety is characterized by formation of lower plants. Highest rate of increase was established between phases beginning and mass fruiting. Suppression in the increase in the application of the biggest fertilizer norm of N_{28} than the lower level of the N_{21} in both varieties was observed yet in beginning of fruiting, but the values are higher than non fertilization plants. The plant reached maximum height of 144.0 cm and 121.28 cm, for Plovdiv and for Obrazec 1, respectively, in implementing the N_{210} in mass fruiting.

In direct relation to the height of plants is the number of branches set, as it is determining the productivity of the plant. Typical for this feature is that in the last phase of counting the number of branches set in most variants is lower, compared to the previous phase. This may be due to the fact that not all of the previously set branches have developed to the phase of mass fruiting. The differences were in relatively narrow range between the phases of counting and between different variants. It can be noted that the plants of the Plovdiv have formed and developed a large number of branches, but in this variety suppressed effect of the highest rates of fertilization N_{280} was better shown. The largest number of branches in the beginning of fruiting is recorded in $N_{210}P_{160}K_{120}$ in Plovdiv. It was also observed in phase of mass fruiting in $N_{140}P_{160}K_{120}$ for Obrazec 1. According to other studies, conducted in India by Prasad (1979), Rajnish Kr. et al. (2006) and by Sahoo et al. (2002), however, the ability of cape gooseberry to branching is highest at lower fertilization rate of 90 kg N.ha^{-1}. McCain (1993) and Sarkar and Chattopadhyay (1993) also highlighted that the studies for number of branches are extremely important because they are related to plant productivity. According to Christov (2010) it is necessary to specify N fertilizer application rate in respect with the increased formation of branches which, in turn, make it difficult to conduct picking.

Development of the leaf is the clearest response of plants to N fertilization. Greater vegetative development after application of different fertilization rates were observed in the number of leaves (Figure 4). In dynamic and under the action of the N fertilizer the formation of more leaves was recorded. As a result of the increase of fertilizer over N_{210} negative reaction in plants was induced. Formation and development of leaves were suppressed, and in level N_{280} still in phase of mass flowering, lower number of leaves were recorded in the lower N levels and decrease was the greatest in mass fruiting in Obrazec 1 - with 28.01%. The values are higher than those of non fertilizing plants. Highest number of leaves was recorded in phase of mass fruiting at fertilization $N_{210}P_{160}K_{120}$, as Plovdiv was 1136.67 and for Obrazec 1 - 703.11.

The weight of leaves (Figure 5) also varied according to the N fertilization. Differences between fertilization rates for mass flowering were relatively small except between the control and the first tested level of N_{70}, where the increase was approximately 30%. More substantial differentiation occurs at the beginning and mass fruiting. In mass fruiting in the variant with the highest number of leaves $N_{210}P_{160}K_{120}$, the highest weight - 915.78 g and 512 g for Plovdiv and for Obrazec 1 was measured, respectively. After this dose in that phase as well as other morphological characteristics depressive effect was established and decrease was with 15.2% in Plovdiv and 20.21% for Obrazec 1. In the formation of total vegetative leaf-stem weight the proportion of leaves prevails and it was 56.80% in the full flowering in variant N_{210} to 68.91% at the beginning of fruiting for N_{280} in cultivar Plovdiv and from 55.93% in mass fruiting of N_{140} to 71.78% in mass flowering of N_{70} in the other variety.

A significant indication of the morphological development of the plants under the action of the N is the leaf area (Figure 6). In this feature, similar of the remaining two properties of the leaves number and weight, with advancing development and as a result of N fertilization its values increased. Greater differences were founded in mass fruiting as leaf area in variant $N_{210}P_{160}K_{120}$ reached the highest value of 21457.03 cm^2 for Plovidiv and 14961.11 cm^2 for Obrazec 1. This once again confirms that variety Plovdiv is characterized by stronger growth. Differences in the effect of N levels between N_{70} and N_{140} on this indicator in both varieties were weaker. Suppression of leaf area in N_{280} was only at mass fruiting. In the previous two phases stimulating effect remains, which may be determined the higher weight that was recorded in a mass flowering and beginning of fruiting of this variant even at a small number of set leaves.



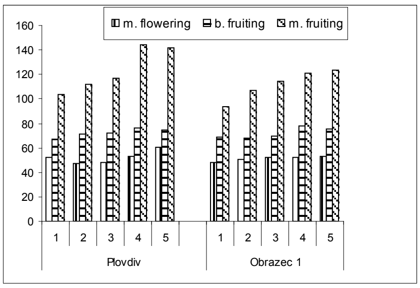
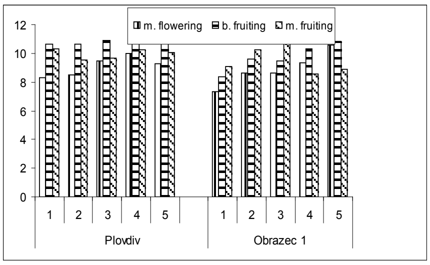


Figure 1 Total vegetative weight (g)

Figure 2 Height of plant (cm)



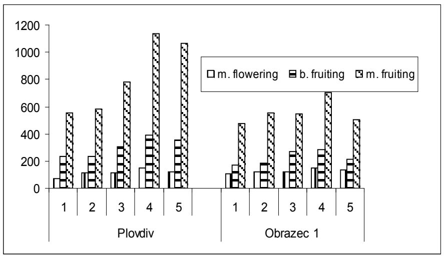
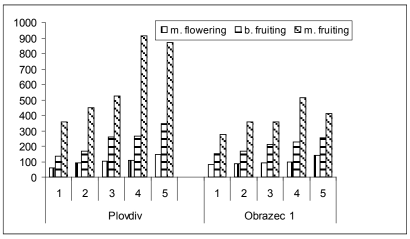


Figure 3 Number of branches

Figure 4 Number of leaves

1-$N_0P_{160}K_{120}$; 2- $N_{70}P_{160}K_{120}$; 3- $N_{140}P_{160}K_{120;}$ 4- $N_{210}P_{160}K_{120}$; 5- $N_{280}P_{160}K_{120}$

Physiological development of cape gooseberry due to the implementation of various norms of N also changes substantially. The intensity of photosynthesis (Figure 7) is characterized by non unidirectional course. In all variants with increasing development of the plants the values were reduced, except for the control of Obrazec 1. This eventually could be related on the one hand with the advanced development of plants or other with aging of leaves (Berova and Karanatsidis, 2008). The effect of N levels N_{70} and N_{140} was associated with increases in photosynthetic activity in different phases, to those of the previous version. Most intense photosynthesis for both varieties was recorded in plants from variant $N_{140}P_{160}K_{120}$ in mass flowering and in beginning of fruiting. After increasing the nitrogen fertilization to N_{210} and N_{280} intensity reduced, but it was still higher than the control. Inhibition was observed at the highest fertilizer rate in phases of mass flowering and beginning of fruiting of Plovdiv and mass flowering in Obrazec 1, where the data for photosynthesis are lower than those of not fertilized plants. Transpiration almost follows the same course as well as photosynthesis. Also after phase mass flowering intensity was lower with exception in the beginning for fruiting in variant N_{280} for Plovdiv and in beginning of fruiting in control and in variant N_{70} for Obrazec 1. In contrast to the photosynthesis, transpiration in both varieties exhibits some differentiation. In Plovdiv course of transpiration almost coincides with that of photosynthesis. The intensity level was raised to N_{140} and then decreased, but was relatively higher than that of the control. In plants of the Obrazec 1, however, transpiration was with greater intensity at all tested levels of fertilization with exception of phase mass flowering in the highest fertilization rates, where there was a small inhibition than the measurement of the same phase in the previous variant. It can be assumed that plants with higher transpiration are with better physiological potential and water status, particularly if it is combined with a high stomatal conductivity (Stoeva and Kaymakanova, 2008). As with the other two indicators of leaf gas exchange, and in regards to stomatal conductivity the tendencies of higher values in mass flowering maintained and then declined. Small variations were found in Obrazec 1 at the beginning of fruiting for the control and for fertilization with N_{70}. Some increase in the application of nitrogen fertilization occured in mass fruiting in almost all variants the highest stomatal conductivity measured in this phase of N_{280} in plants of Plovdiv, as this variety was characterized by higher conductivity in almost all measurements. Strictly expressed regularity regarding to stomatal conductivity was not detectable. Stock and Evans (2006) emphasized that in cape gooseberry the stomatal conductivity and transpiration does not always influence the absorption of N fertilizer at different rates.



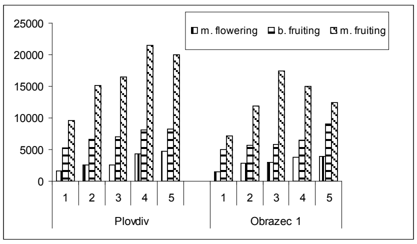


Figure 5 Weight of leaves (g) **Figure 6** Leafs area (cm^2)

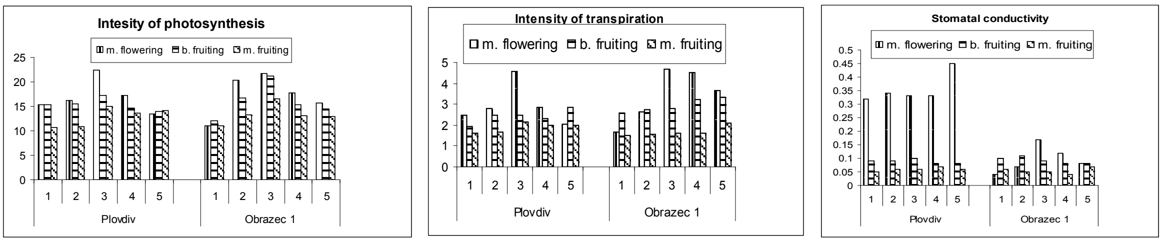


Figure 7 Intensity of photosynthesis ($\mu molCO_2m^{-2}s^{-1}$), intensity of transpiration ($\mu molH_2Om^{-2}s^{-1}$) and stomatal conductivity ($\mu molCO_2m^{-2}s^{-1}$)

1-$N_0P_{160}K_{120}$; 2- $N_{70}P_{160}K_{120}$; 3- $N_{140}P_{160}K_{120}$; 4- $N_{210}P_{160}K_{120}$; 5- $N_{280}P_{160}K_{120}$

In Table 1 the results are presents for the necessary basic macroelements - N, phosphorus and potassium for the formation of 1000 kg fruits. The different N rates caused a significant effect on the absorption and on the amount of nutrients, used by plants for their growth, biomass accumulation and formation of productivity. In all variants the amount of assimilated macroelements for forming a unit of production increased with increase of the amount of N fertilizer. It is assumed that on the one hand, this is associated with higher leaf-stem weight, on the other with a higher yield compared with non-fertilized plants. An exception was observed for $N_{280}P_{160}K_{120}$, where there was a small decrease compared to N_{210} and the yield was lower than the previous variant. The amount of N in variety Plovdiv necessary for the formation of 1000 kg fruit of cape gooseberry ranged from 39.65 kg.1000 kg^{-1} to 103.14 kg.1000 kg^{-1}. The quantity was lower for Obrazec 1 – 39.22 kg/1000kg to 79.83 kg/1000kg. Phosphorus used by this crop varied from 30.29 kg.1000 kg^{-1} to 54.91 kg.1000 kg^{-1} of Plovdiv and from 28.72 kg.1000 kg^{-1} to 46.09 kg.1000 kg^{-1} for the other variety. Potassium is most needed for the formation of 1000 kg of fruits cape gooseberry, which is proven by the uptake of this element – 72.03 kg.1000 kg^{-1} to 138.74 kg.1000 kg^{-1} and 80.35 kg.1000 kg^{-1} to 121.79 kg.1000 kg^{-1}, for Plovdiv and Obrazec 1 respectively. However in comparison with the obtained highest yield the necessary quantities for N to produce 1000 kg fruits of cape gooseberry are 49.40 to 61.99 kg, for phosphorus from 32.95 to 37.88 kg and for potassium from 96.63 to 104.99 kg or averaged for 1000 kg of fruits are needed 55.69 kg N, 53.41 kg P_2O_5 and 100.81 kg K_2O.

Improving the yield of plants is a major objective of any agrotechnological practices. Fertilization with N greatly affected yield of cape gooseberry. Data are presented in Table 2. Results over the three years of study in both varieties are approximately similar. All tested fertilization rates of N caused increased yield compared to non fertilized plants. Genotypic response regarding to productivity was depending on N fertilization. The highest yield of Plovdiv – 4194.3 kg.ha^{-1} was obtained by fertilization with $N_{70}P_{160}K_{120}$. In this variant in 2008 and 2009 was founded the highest productivity. On the next place of fruiting in this variety was the variant $N_{140}P_{160}K_{120}$, with 54.41% over the control. Increasing the quantities of N contributed to obtaining of lower yields than smaller levels of fertilizer, but also higher than non fertilized plants. Decrease in N_{210} in comparison with N_{70} was with 19%, and in N_{280} was almost close to the control, even in 2010 there was inhibition and the productivity was lower than that of N_0. It can be assumed that these results are in relation with the significantly higher vegetative growth above mentioned in these variants, which eventually impedes setting and formation of fruits. Similar conclusions were reached by other researchers as (Crawford, 2004 and McCain, 1993) who reported strong vegetative growth when using larger quantities of N in cape gooseberry with greatly reduced setting of flowers or fruits respectively. In Obrazec 1 and in the three years of study the high productivity showed the plants fertilized with N_{140}, with 30.54% over the control and second was the next tested level of N_{210}, where the increase was 26.92%. Throughout the whole period the highest level of N_{280} caused inhibition and reduction to the control with 29.15%. The obtained data are significantly different except for N_{70} in Obrazec 1 for 2008 and 2009. McCain (1993) also found that the most appropriate is to apply low quantity of N and best fertilizer rate according him is N_{120}. The importance of N for the yield formation of cape gooseberry highlighted by Sarkar and Chattopadhyay (1993). According to them, the content of N and potassium in the leaves have a strong influence on the formation of the fruit. The relationship between the amount of these two macronutrients and quantity of fruit set, and hence on the yield is generally very strong. Established correlation between these indicators was high and positive.

Regression relationship between rate of N fertilization and the yield is shown in Figure 8. Regression in both varieties is a polynomial type. Coefficient of determination is very high R_2 = 0.79 for Plovdiv and R_2 = 0.81 for Obrazec 1. This indicates that approximately in 80% of the cases with tested N fertilization rates the productivity of cape goosberry will follow the discussed trend and changes will be with the above mentioned character.

Table 1 Necessary nutrient elements (kg) for development of 1000 kg cape gooseberry fruits

Variants	Plovdiv			Obrazec 1		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
$N_0P_{160}K_{120}$	39.65	30.29	72.03	39.22	28.72	80.35
$N_7P_{16}K_{12}$	49.40	32.95	96.63	55.64	36.67	112.46
$N_{14}P_{16}K_{12}$	53.33	36.63	113.86	61.99	37.88	104.99
$N_{210}P_{160}K_{120}$	103.14	60.01	156.11	79.74	41.89	110.17
$N_{280}P_{160}K_{120}$	101.17	54.91	138.74	79.83	46.09	121.79

The cape gooseberry fruits are of high nutritional value, which according Skvorcova (1997) is due to its chemical composition, organic acid and sugars they contain a significant amount of pectin. They are also very rich in vitamins B and C, carotene, polyphenols and esters of cinamon acid, carbohydrates, pectin, protein, fat, fiber, β-carotene (Mazumdar and Basu 1979; McCain 1993; Sarkar and Chattopadhyay 1993; Fischer et al. 2000; Ramadan and Morsel 2005). The chemical composition of the fruits is shown in Table 3. Dry weight in both varieties varies depending on the applied quantities of N fertilizer. Less this concern to Obrazec 1, where the increase and variation between values was in a narrow range. The highest increase of 51.72% was recorded for Plovdiv in $N_{140}P_{160}K_{120}$. The next variant it reduced and in N_{280} was lower compared to the control.

Strict trend on the vitamin C content is not observed. A slight increase was observed at N_{70} and N_{140}, and a further increase in N the values decreased, and in Plovdiv even below those of non fertilized plants. The amount of sugar increased slightly, for Plovdiv only in N_{70}, and for Obrazec 1 except for this variant also for N_{140}. The differences between both varieties were established in relation to the content of acids. In Obrazec 1 it was lower in all tested levels, while in Plovdiv slightly higher levels were measured with the highest values for N_{140}.

Skvortsova (1997), Sarkar and Chattopahyay (1993) and Kendall (2008) reported that as the content of pectin is greater the economic and biological value of cape gooseberry is higher, and thus the fruit are with improved quality. From the conducted studies was established that the fruit of this crop contained significant amounts of pectin. N fertilization slightly influenced the synthesis of pectin and level of N_{140} in cultivar Plovdiv increased it quantity with 7.4%. In Obrazec 1 its values was the highest in fertilization with N_{280} - with 10.37% while in N_{70} and N_{210} was with 9.43% more than non fertilized plants.

Table 2 Productivity of cape gooseberry under different level of N fertilization kg.ha^{-1}

Variants	Plovdiv				Obrazec 1			
	2008	2009	2010	average	2008	2009	2010	average
$N_0P_{160}K_{120}$	1769.4	1627.8	3805.8	2401.0	2434.2	2239.5	2975.3	2549.7
$N_{70}P_{160}K_{120}$	4466.4	4108.0	4008.4	4194.3	2454.2	2257.9	3603.9	2772.0
$N_{140}P_{160}K_{120}$	3693.2	3397.8	4031.9	3707.6	3309.8	3045.0	3630.6	3328.5
$N_{210}P_{160}K_{120}$	3374.6	3244.7	3576.2	3398.5	3292.2	3028.8	3387.8	3236.3
$N_{280}P_{160}K_{120}$	2471.3	2273.6	3087.9	2610.9	1674.2	1540.3	2205.3	1806.6
LSD	320.4	526.8	435.2	197.1	197.6	344.3	292.2	202.3

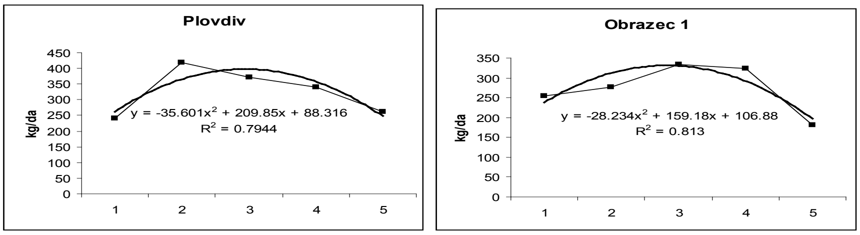


Figure 8 Regression dependences between level of N fertilization and yield in cape gooseberry;

1-$N_0P_{160}K_{120}$; 2- $N_{70}P_{160}K_{120}$; 3- $N_{140}P_{160}K_{120}$; 4- $N_{210}P_{160}K_{120}$; 5- $N_{280}P_{160}K_{120}$

Table 3 Chemical components in cape gooseberry fruits

Variants	Plovdiv					Obrazec 1				
	Dry weight (%)	Vitamin C (mg%)	Total sugar (%)	Total acid (%)	Pectin (%)	Dry weight (%)	Vitamin C (mg%)	Total sugar (%)	Total acid (%)	Pectin (%)
$N_0P_{160}K_{120}$	16.26	34.16	9.31	0.89	1.08	15.34	31.88	9.19	1.25	1.06
$N_{70}P_{160}K_{120}$	18.24	35.61	10.20	0.92	1.05	16.02	32.82	9.70	0.92	1.16
$N_{140}P_{160}K_{120}$	24.67	36.18	8.82	1.16	1.16	16.47	39.51	9.37	0.99	1.04
$N_{210}P_{160}K_{120}$	17.57	32.13	8.88	0.89	1.09	16.85	37.53	8.85	0.91	1.16
$N_{280}P_{160}K_{120}$	15.81	33.22	8.22	0.91	1.04	16.69	35.60	8.25	0.89	1.17

Conclusions

Application of different N rates caused a significant increase in vegetative growth of plants of *Physalis peruviana* L. as the highest was in the level N_{210}. At a rate of N_{280} there was suppressive effect on the development towards to previous quantity, but higher than in non fertilized plants. This is especially well seen in the number and weight of set and formed leaves, and in the later stages also on the height of the stem.

The intensity of the photosynthesis and transpiration with advancing of development of the plants in separate stages, reduced, but under the action of N increased, and the highest level was at N_{14}, then decreased, but remained at higher values than those of the control.

The optimal amounts, with the highest effectiveness of use of nutrients, needed for forming and development of 1000 kg fruits, ensuring the highest yield were 55.69 kg N, 53.41 kg P_2O_5 and 100.81 kg K_2O.

The varietal responses regarding productivity of cape gooseberry to N fertilization were established. The yield of variety Plovdiv was the highest in applying the level N_{70} and for Obrazec 1 in N_{140}, 4194.3 kg.ha^{-1} and 3328.5 kg.ha^{-1} respectively.

Under the effect of N fertilizer the chemical composition of fruits was less influenced. The content of dry matter, ascorbic acid, sugar and total acid increased depending on the variety to levels N_{70} and N_{210}. The amount of pectin in most variants also increased.

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(80) Effects of some organic fertilizers on growth of grapevines infested with *Xiphinema index*

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Abstract: *Effects of some organic fertilizers on growth of grapevines are reviewed, focusing on its potential for managing the nematode vector of GFLV - Xiphinema index. Pot experiments were carried out at the Agricultural University of Plovdiv, Bulgaria in 2004, 2007 and 2010 with - Vitis vinifera L. cv. "Cabernet Sauvignon" grafted on rootstock SO4, ungrafted "Palieri" and Vitis vinifera L. cv. "Rubin" grafted on rootstock SO4 respectively. Dry extract of green algae Chlorella vulgaris, humic fertilizer "Humustim" and highly concentrated liquid fertilizer "Humusil" were tested. Plant height, root length, fresh and dry weight of the plants, average based on repetitions and variations were determined at the end of the experiment.*

The results show that in comparative aspect Chlorella vulgaris and "Humusil" significantly have the best effects on both plant growth and suppression of ectoparasitic nematode X. index while "Humustim" has a moderate effect. The beneficial effect of microalgae Chlorella vulgaris and liquid fertilizer "Humusil" is due to increased plant immunity and improves soil health.

Key words: *plant-parasitic nematodes; grapevine; Chlorella vulgaris; Humustim; Humusil;*

Introduction

Extoparasitic nematodes of family Longidoridae, among which virus vectors are proven, are widespread on a variety of crops in Europe including Bulgaria (Alphey and Taylor, 1986; Choleva, 1994). The most economically important nematode transmitted virus of *Vitis* vinifera is *Grapevine fanleaf nepovirus* (GFLV). It reduces crop yield up to 80% and affects fruit quality (Andret-Link, 2004; Kovachevski et al., 1995). Dagger nematode *Xiphinema index,* the natural vector of GFLV is commonly found in Bulgarian vineyards (Choleva, 1994; Bileva and Arnaudova, 2011; Bileva et al., 2009; Bileva, 2012). Besides being a virus vector *Xiphinema index* causes direct damage by feeding on grapevine root tips. Common symptoms of *X. index* feeding are plant stunting, chlorosis, galls and root necrosis (Van Zyl et al., 2012). Combination of nematode feeding and its association with GFLV may lead to grapevine death. During the last years, in organic and sustainable agriculture priority is given to the application of non-synthetic chemical and bio-products to control pathogens and to increase soil fertility. In Bulgaria and Macedonia, there are examples of novel methods being investigated concerning the effect of the organic fertilizers (Lumbricompost, Humustim, Humusil, *Chlorella vulgaris, etc.*) used to improve growth and productivity of different crops and to manage soil health (Panayotov et al., 2004; Bileva and Babrikov, 2007; Bileva et al., 2007, 2009; Bileva, 2013; Choleva et al., 2007; Petkova and Poryazov, 2007; Haytova, 2009, 2012, 2013.; Dincheva et al., 2009; Stojanova et al., 2011).

The aim of the study was to establish the effect of organic fertilizers - Humustim, Humusil and green alga *Chlorella vulgaris* - on the growth of test grapevine plants and their influence on the root ectoparasite *Xiphinema index*.

Materials and methods

The study was conducted during 2004, 2007 and 2010 in the Laboratory of Zoology, Department of Ecology & Environmental protection at Agricultural University of Plovdiv, Bulgaria.

Pot experiment with seedlings of *Vitis vinifera* L. *cv.* "*Cabernet Sauvignon*" grafted on rootstock SO4 cultivated in posts with 1 000 cm^3 sterilized soil (a plant per pot in three repetitions) was carried out during 4 months (2004). The grapevine seedlings were pre-soaked under scheme by the producer in a solution of Humustim (on the base of potassium humates-3%N, 1.14%P_2O_5, 7.83%K_2O, 3.92%Ca, 1.1%Mg, Cu, Zn, Mo, Mn Co, B, S; Agrospeis Ltd., Bulgaria). After planting, test plants were artificially infested with *Xiphinema index* and treated with *Chlorella vulgaris* (dry extract of monocellular green alga *Chlorella vulgaris*, "The Golden apple"- Plamen Barakov, Bulgaria). The nematodes were taken from the rhizosphere of naturally *Xiphinema index* infested grapevines in the region of Pomorie town – South-East Bulgaria (42.55 ^{o} N 27.65 ^{o} E). They are placed in a pot with *Ficus carica* for artificial multiplication. The nematodes were extracted from 200 cm^3 of soil samples by Cobb's sieving and gravity method (Cobb, 1918) in combination with Baermann funnel method. Soil sieving (2 mm, 150 µm и 63 µm) was used and a 48 h decanting period through a

Baermann funnel. Counting of nematodes was carried out with stereoscopic microscope. Numbers of *X. index* in the infested variants are calculated on the base of six specimens /100 cm ^{3}soil – this is the minimum number of nematodes for Bulgarian population of *X. index* that cause damage to the roots of vine found by Choleva (2000). The trials with *Ch. vulgaris* included the application of 0.5 g, 1.0 g and 2.0 g algae per plant/pot dissolved in 100 ml water. The plants were watered once with solution. The variants are: V_1 (infested + 0.5 g *Ch. vulgaris*), V_2 (infested + 1 g *Ch. vulgaris*), V_3 (infested and + 2 g *Ch. vulgaris*), V_4 (infested and non treated plants), V_5 (uninfested and non treated plants), V_6 (uninfested + 0.5 g *Ch. vulgaris*), V_7 (uninfested + 1 g *Ch. vulgaris*), V_8 (uninfested + 2 g *Ch. vulgaris*), V $_9$ (uninfested + Humustim), V $_{10}$ (infested + Humustim).

An eight-variance experiment with ungrafted grapevine seedlings *cv*. "*Palieri*"(a plant per pot with 1 000 cm ^{3} sterilized soil in three repetitions) and *X. index* was carried out for 6 months in 2007. In this assay, the population of *X. index* and green algae was identical to that described in the previous test. Numbers of nematodes in the infested variants are calculated as in previous experiment. The trials with *Ch. vulgaris* included applying of 0.5 g, 1.0 g and 2.0 g algae per plant/pot dissolved in 100 ml water. The plants were watered once with solution. The variants are V_1 to V_8, as described above.

A third pot experiment with seedlings *Vitis vinifera* L. *cv.* "*Rubin*" grafted on rootstock SO4 was carried out during May-October in 2010. The following variants were conducted: V_1 (infested + 1 g *Ch. vulgaris*), V_2 (infested + 2 g *Ch. vulgaris*), V_3 (1 g *Ch. vulgaris*), V_4 (2 g *Ch. vulgaris),* V_5 (uninfested and non treated plants), V_6 (infested and non treated), V_7 (infested + Humusil), V_8 (Humusil).Test plants were cultivated in pots with 1 000 cm ^{3} naturally *X. index* infested soil and 150 ml coconut (a plant per pot in five repetitions). The soil was taken from rhizosphere of naturally *X. index* infested vines from the Experimental station of Department of Viticulture, Agricultural University of Plovdiv. Sterilized soil is used as *X. index* free control. The nematodes were extracted from 200 cm^3 of soil samples by Cobb's method (Cobb, 1918) in combination with Baermann funnel method. Counting of nematodes was carried out with stereoscopic microscope. In the infested variants initial population (IP) of ectoparasite *X. index* was IP=84/sp./100 cm ^{3} soil. The test plants were treated with l**iquid fertilizer Humusil** [on the basis of **Lumbricompost –** N, P2O5, K2O, CaO, MgO, live bacteria – *Bacillus cereus, B.aglomeratus;* BulBioEco Ltd., Bulgaria] and green alga *Chlorella vulgaris* (described above). In the variants with Humusil, the grape seedlings were pre-soaked for 24 hours in diluted Humusil before planting, watered with 2 % solution at seventh day and applied as foliar fertilizer every two weeks till the mid of August (according to recommendations of manufacturer).

After completion of the experiment, the soil of infested variants was mixed well to be homogenized. Nematodes were extracted from soil by sieving and gravity method (Cobb, 1918) in combination with Baermann funnel method from 100 cm^3 soil of each repetition. Nematode suspensions were fixed in T.A.F (Formalin (= 37% formaldehyde) 7.6 ml; Tri-ethylamine 2 ml; Distilled water 90.4 ml) and then were transferred to glycerine with the glycerine-ethanol method (Seinhorst 1959) for analyses of nematode communities.

Morphological data - plant height, root length, fresh and dry weight - were analyzed. At the end of experiments, the Final nematode Population (FP) was recorded. Data were analyzed using the single factor analysis for field experiments by BIOSTAT programme (ANOVA) (Dimova & Marinkov, 1999).

Results and Discussion

In pot experiments with grapevine seedlings *cv. "Cabernet Sauvignon"* very good results have been obtained in trials with *Ch. vulgaris*. Strong stimulating effects of 1 g *Ch. vulgaris* on plant growth and development were observed in grape seedlings infested by *X. index* (Table 1, Fig. 1). A strong suppressing effect on obligate ectoparasite *X. index* (FP = 14 sp./pot) in comparison with initial density was observed in infested and treated with 1 g *Ch. vulgaris* plants. Nearly four times higher than the initial populatin of *X. index* has been reported in variants with infested and non-treated plants (FP = 227 sp./pot). In infested control, the grape seedlings have greatly reduced roots, with coral-like malformation and typical initial necrosis caused by ectoparasite *X. index.*

The biometrics of Humustim plants are close to those of control variant (untreated and uninfested grape seedlings). Proven suppression of root ectoparasite *X. index* was observed in trials with Humustim in comparison with the infested control soil.

The effect of *Ch. vulgaris* on grape seedlings cv. *Palieri* showed promising results, confirmed by plant growth. The results showed that the infested and non treated test plants were with a poorly developed vegetative part, in comparison with uninfested and non treated plants (Table 2, Fig. 2). Application of 1 g *Ch. vulgaris* significantly improved plant development and decreased final nematode population in variants of infested and treated plants FP = 21 sp./pot, in comparison with IP = 65 sp./pot. Compared to the initial population, a triple number of dagger nematodes was recorded in infested control (V_4) FP = 214 sp./pot and plants showed clear nematode damage. There is a weak suppression of *X. index* FP = 43 sp./pot in application of 0.5 g Chlorella (V_1). A phytotoxic effect in the variant with 2 g Chlorella (V_8) was observed (Table 2, Fig. 2). The plants are not fully grown, with least developed vegetative part and roots, and with morphometric parameters close to the control variant.

Table 1. Morphological characteristics of grape seedlings *cv. Cabernet Saugvinon* in pot experiment

Variants	Plant height/cm	Fresh weight/g	Dry weight/ %
Control (untreated and uninfested grape seedlings) V_5	103	40	27
V_1 (*X. index* + 0.5 g Chlorella)	105	43	25
V_2 (*X. index* + 1 g Chlorella)	110	56	34
V_3 (*X. index* + 2 g Chlorella)	98	37	20
V_4 (*X. index*)	56	55	14
V_6 (0.5 g Chlorella)	107	59	38
V_7 (1 g Chlorella)	168	62	25
V_8 (2 g Chlorella)	99	51	21
V_9 (Humustim)	97	42	15
V_{10} (*X.index +* Humustim*)*	90	39	24
GD 5 %	4.10	2.91	
1%	5.52	3.93	
0.1 %	7.34	5.21	

Table 2. Plants biometric data from a pot experiment with c*v. Palieri.*

Variants	Plant height/cm	Root length/cm	Fresh weight /g		Dry weight/g	
			Leaves	Roots	Leaves	Roots
Control (uninfested and non treated plants) $\mathbf{V_5}$	47	17	10.929	3.066	2.562	1.084
$\mathbf{V_1}$ (*X. index* + 0.5g Chlorella)	31	16	5.947	1.847	1.297	0.811
$\mathbf{V_2}$ (*X. index* + 1g Chlorella)	45	20	11.757	6.190	3.179	2.699
$\mathbf{V_3}$(*X. index* + 2g Chlorella)	38	18	8.153	2.334	2.275	0.758
$\mathbf{V_4}$ (*X. index* and non treated plants)	29	10	4.435	1.277	0.896	0.677
$\mathbf{V_6}$ (uninfested +0.5g Chlorella)	42	13	5.261	2.864	2.001	1.656
$\mathbf{V_7}$ (uninfested + 1g Chlorella)	53	23	12.298	4.249	4.348	2.253
$\mathbf{V_8}$ (uninfested + 2g Chlorella)	40	19	7.722	2.308	1.561	0.689
GD 5 %	3.600	2.632	2.361	1.753	0.789	0.897
1%	4.884	3.571	3.204	2.378	1.071	1.218
0.1 %	6.555	4.793	4.300	3.190	1.438	1.634

After 180 days a positive impact of *Chlorella vulgaris* and liquid fertilizer Humusil on *X. index* infested grapevines cv. Rubin was established (Table 3, Fig. 3). Application of *Chlorella vulgaris* at 1 g (V_1 and V_3) significantly improved plant development (Fig.3). Data showed increased plant growth and triple reduction of the community of plant-parasitic nematode densities in treatment V_7 (*X. index* + Humusil) and double reduction in V_1 (*X. index* +1 g *Ch. vulgaris*). A stimulation effect on predators and high increase in omnivorous nematodes in infested and treated 1 g Chlorella variant was observed (Fig. 4). The increase of the numbers of bacterial feeders in trial with infested and Humusil treated grape seedlings cv. Rubin was recorded, which is a result of influence of organic fertilizer on the soil biotic balance.

In this assay with grape seedlings *cv. Rubin*, poorly developed test plants with yellow leaf colouring in variants V_2 (infested and treated with 2 g *Ch. vulgaris*) and V_4 (uninfested and treated 2g *Ch. vulgaris*) were also observed (Table 3). We may conclude that applying 2 g dry extract of *Ch. vulgaris* per pot/plant has a phytotoxic effect on grapevines.

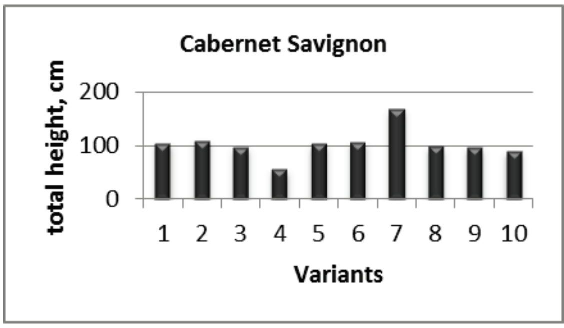
The best results obtained in this study were in trials with 1 g *Ch. vulgaris*. They are in accordance with the results established by Choleva et al., 2005, 2007; Yancheva and Bileva, 2006. *Chlorella vulgaris* in this concentration (1 g dry extract/plant) has a suppressing effect on root extoparasite *X. index*.

Other benefits of organic fertilizers are better and stronger root system, better developed vegetative part of grapevine and growth boost. The liquid fertilizer Humusil prevents the appearance and growth of pathogenic micro flora and increases the number of free-living and predator nematodes which are very important components in soil management.

In comparative aspect, the results show that *Ch. vulgaris* and Humusil significantly have the best effects on both plant growth and suppressing of ectoparasitic nematode *X. index* while Humustim has a moderate effect.

Table 3. Phenological data from a pot assay with grape seedlings *cv. Rubin.*

Variants	Plant height/cm	Root length/cm	Fresh weight/g		Dry weight/g	
			Leaves	Roots	Leaves	Roots
Control (untreated and uninfested grape seedlings) V_5	58.75	20	12.5	7.25	6.75	5.0
V_1 (*X. index* + 1g Chlorella)	67.5	18.75	9.75	7.0	6.0	4.75
V_2 (*X. index* + 2g Chlorella)	61.25	17.5	6.75	4.75	4.25	3.25
V_3 (1g Chlorella)	71.5	23.25	14.25	9.75	7.0	5.50
V_4 (2g Chlorella)	60.5	21.0	7.25	5.5	4.0	3.0
V_6 (*X. index*)	43.5	16.0	3.25	1.75	1.25	0.5
V_7 (*X. index* + Humusil)	63.75	17.25	8.5	5.25	5.25	3.75
V_8 (Humusil)	92.5	25.0	15.25	8.25	7.5	5.75
GD 5 %	8.03	2.67	3.33	1.72	1.36	0.94
1%	10.84	3.61	4.49	2.32	1.83	1.27
0.1 %	14.24	4.80	5.97	3.09	2.43	1.69



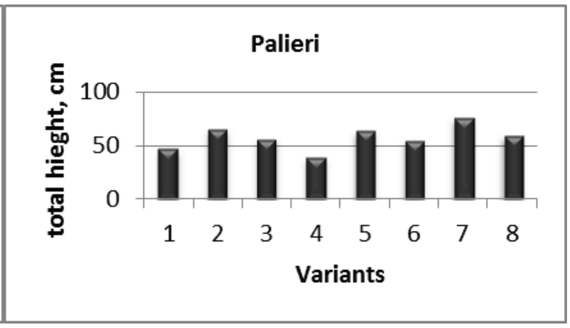


Figure 1. Influence of Chlorella vulgaris and Humustim on height of grape seedlings infested by Xiphinema index

Figure 2. Effect of Chlorella vulgaris on vegetative part of grape seedlings cv. Palieri infested by Xiphinema index

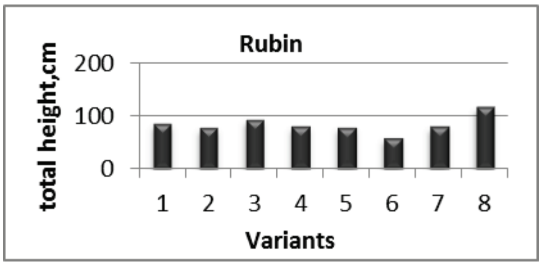


Figure 3. Influence of Chlorella vulgaris and Humusil on height of grape seedlings infested by Xiphinema index

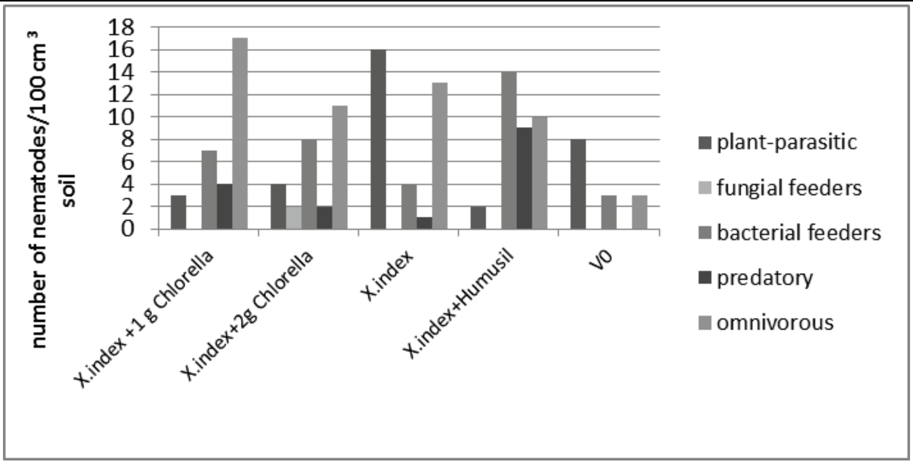


Figure 4. Proportion of nematode communities in the infested and treated variants (V_1, V_2, V_6, and V_7) and initial populations (V_0) in pot experiment with grape seedlings variety Rubin.

Conclusions

The preventive actions for nematode control before planting of grapevines, including the use of certified virus-free material and resistant rootstocks, is always preferable.

In agricultural condition when no further preventive technologies are available, data has shown that the application of some organic products such as green algae and liquid fertilizer Humusil increase plant growth and lower nematode densities. These bio-products may help farmers reduce the problem of nematode damages whilst avoiding environmental contamination due to pesticides.

The beneficial effect of microalgae *Chlorella vulgaris* and humic fertilizer Humusil is due to increased plant immunity and improve the soil health. The grapevines that are treated with Humusil have a strong immune system which makes them resistant to ectoparasite *X. index.*

We may recommend to farmers to include dry extract of *Chlorella vulgaris* and organic fertilizer Humusil when replanting a vineyard, especially in areas threatened by the presence of dangerous pathogen *Xiphinema index* vector of GFLV.

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(81) Effect of nitrogen source on soil nitrate concentration and yield, and quality of intermediate-day onions

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Abstract: The effect of nitrogen source application, broadcast onto the planting bed during the growing phase, on soil nitrate concentration, soil pH, yield, and quality of intermediate-day onions was evaluated in a field experiment in southern Portugal. In addition, the soil potential for providing nitrate-N to the crop along the growing season was also monitored. The field trial consisted of six treatments of different combinations of ammonium nitrate (17% NH_4-N + 17% NO_3-N) (AN) and ammonium sulphate (20.5 % NH_4-N and 60% SO_3) (AS) as fertilizers. Soil NO_3-N and soil pH were measured at 0, 47, 76, 95, and 124 days after transplanting (DAT). Nitrogen source did not significantly affect the soil nitrate concentration, commercial yield, bulb dry weight, soluble solids or pH. AS-AS application as compared with AN-AN led to a significantly decrease in soil pH. The nitrate release through the mineralization of organic matter began in the first 47 DAT and occurred throughout the growing season. At 0 to 10 cm soil depth from 0 to 47 DAT, nitrate concentration increased by 14.8 mg kg^{-1}. A significant amount of N uptake was provided by the soil, achieving a high commercial yield of 7.52 kg m^{-2} in the treatment without nitrogen application and 9.05 kg m^{-2} where N (45kg N/ha) was applied.

Keywords: *Allium cepa L.; ammonium sulphate; ammonium nitrate; intermediate-day onions; nitrate; organic matter mineralisation*

Introduction

In onions, the potential for nitrogen (fertilizer) loss by leaching, applied during the vegetative growth phase, is high because the root system of onion grows slowly (Thorup-Kristensen, 2001), not exceeding a 10 cm depth up to 32 days after transplantation (DAT) (Machado et al., 2009) and nitrogen needs during the vegetative growth phase (40 to 55% of the crop-cycle length) are very low: less than 5 % to 8 % of total N uptake (Brown, 2000; Halvorson et al., 2002; Machado et al., 2012; Pire et al., 2001). For intermediate-day onions that are planted at the end of the winter, in the Mediterranean climate, when soil temperature is more favourable for organic matter mineralisation, it is not advisable to apply pre-plant N in most soils (Machado et al., 2012). In order to increase use efficiency of nitrogen, it should be broadcast onto the bed during the vegetative growth phase in the form of ammonium. AN is often recommended for broadcasting applications during the vegetative growing phase of the onion crop (Odet et al., 1989). AS, besides supplying all nitrogen in the form of ammonium, also provides sulphur, which onion requires to a relatively high degree (Odet et al., 1989, Pôrto et al., 2006) and is an essential element for achieving optimum onion crop development (Hamasaki et al., 1991). However, AS fertilizer has the highest acidification rate among N sources (Chien et al., 2008). The objective of the present study is to evaluate the influence of the application of two fertilizers – AN and AS – broadcast onto the planting bed during the growing phase, on soil nitrate concentration, soil pH, yield, and quality of intermediate-day onions. In addition, the aim was also to monitor the soil potential for providing nitrate-N to the crop along the growing season.

Material and methods

A field experiment was set up on 3 March 2012 on a luvisol sandy loam soil at the Mitra Research Farm in Évora, Portugal (38º57' N. 8º32´ W; elev. 200 m). Soil characteristics are summarised in Table 1. The field trial consisted of six treatments of different combinations of ammonium nitrate (17% NH_4-N + 17% NO_3-N) (AN) and ammonium sulphate (20.5 % NH_4-N and 60% SO_3) (AS) as fertilizers: 0 kg N ha^{-1} (0N); 15 and 30 kg N ha^{-1} applied at 14 and 49 DAT using ammonium sulphate) (AS-AS); 15 and 30 kg ha^{-1} applied at 14 and 49 DAT using ammonium nitrate (AN-AN); 15 and 30 kg ha^{-1} applied at 14 and 49 DAT, respectively, through ammonium sulphate and ammonium nitrate) (AS-AN); 15 and 30 kg ha^{-1} applied at 14 and 49 DAT respectively by ammonium nitrate and ammonium sulphate AN-AS; and a treatment without crop and N application (0N-WC). The experiment was set up in a randomised block design with four replications per treatment. Onion seedlings (var. Guimar, Sakata) were transplanted at 45 days after emergence into raised beds (0.1m high and 0.6m wide) containing three rows, in which plants were spaced at intervals of 0.1m within rows x 0.2 between rows (30 plants m^{-2}). Each plot was 5 m long and 3 m wide and consisted of three raised beds. Because soil P and K levels were high, therefore no pre-or post–plant applications of P and K were applied. In terms of irrigation, a sprinkler system was installed in which the distance between the adjacent sprinklers and branch lines was

10 m. Irrigation management was based on soil water tension as measured by the granular matrix sensors (Watermarks soil water sensors, Irrometer Co., Riverside. CA) and in accordance with the reference evapotranspiration (ET_0) of the two days prior to irrigation. In each plot, two watermarks were installed at 0.15 m below the soil surface. Watermark sensors were read daily, when the average soil water tension (from 09:00 to 10:00 hours in the morning) of ≥ 25 kPa was applied an irrigation. The volume of water to be applied in each irrigation was always less than the sum of the ET_0 from the previous two days. Catch-cans for measuring the applied irrigation water were installed above the crop canopy in the centre of each plot. Soil NO_3-N and pH were measured at 0, 47, 76, 95 and 124 DAT. Soil nitrate was determined by collecting three randomised soil cores from each plot, between plant rows. Each core (diameter 3 cm) was 0.3 m deep, divided into 0.1 m increments. Nitrate was measured with a specific nitrate electrode (Crison, 2002) and pH (1:2.5) was measured with micro pH 2000 (Crison, 2000). The onions were harvested on June 3th, when ± 80% of the plants had their leaves flattened. For yield and quality evaluation, all the bulbs from plants grown in a 5 m^2 area were hand harvested. One hundred plants were harvested from each plot, and equatorial and neck diameters were measured. Six plants were separated into leaf and bulb components and oven-dried at 70 º C for 2-3 days and then weighed. Soluble solids (ºbrix) and pH were measured in homogenised onion juice from the six bulbs. The data were analysed by using variance analysis, using SPSS software (Chicago. Illinois. USA) and the means were separated at the 5% level using Fisher's least significant difference (LSD) test.

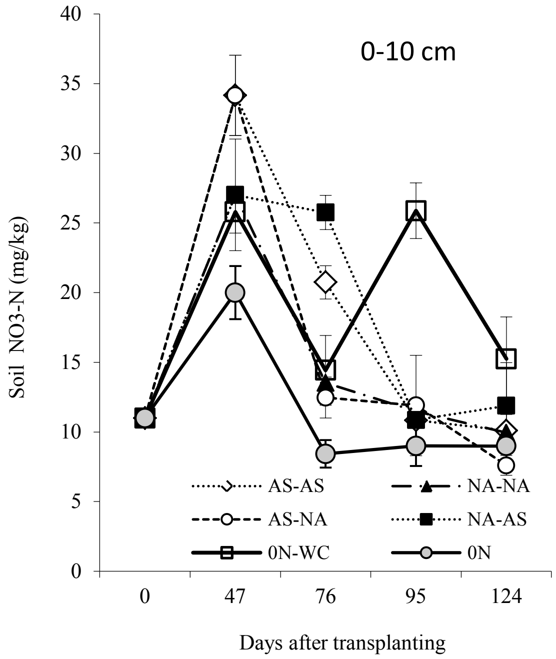
Table 1 Physical and chemical characteristics of the soil (†)

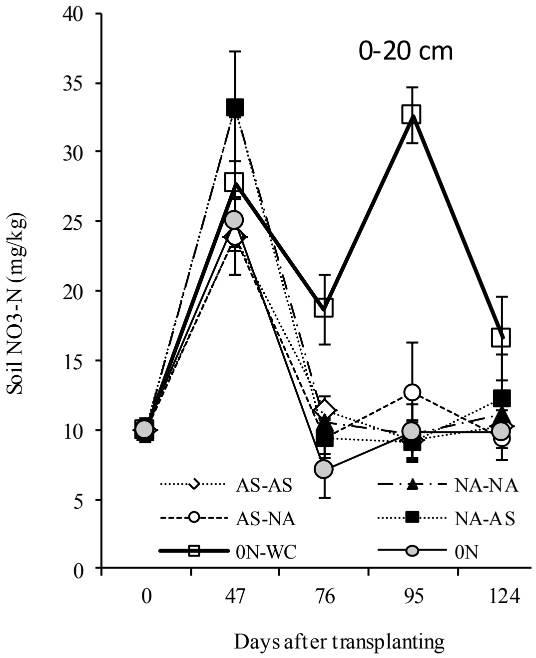
Bulk density ($g \cdot cm^{-3}$)	1.48
Organic matter (%)	2.9
pH (H_2O)	7.2
NO_3- (mg kg^{-1})	11
P_2O_5 (mg kg^{-1})	>250
K_2O (mg kg^{-1})	>250
Ca^{2+} (meq/100g)	7.57
Mg^{2+} (meq/100g)	1.67

(†) – Soil was collected from the top 40 cm of the soil profile

Results and Discussion

The soil nitrate-nitrogen concentration at the different sampling dates and soil depths in treatments where nitrogen was applied was not significantly affected by nitrogen source (p> 0.05). Soil nitrate concentration at 47 DAT in treatments where AS was applied at 14 DAT (AS-NA and AS-AS) presented the highest values and these were significantly higher than in 0N treatment (P<0.01) (Figure 1). This indicates that ammonium nitrification occurred between the first application (14 DAT) of ammonium sulphate and that at 47 DAT. Soil nitrate concentration at a depth of 10 to 30 cm of the 0N was similar to the treatments where nitrogen was applied (p > 0.05). In the treatment without plants (0N-WC), soil NO_3-N concentration, at the different depths, presented fluctuations between different sampling dates but was always greater than at 0 DAT (Figure 1). This indicates that nitrate release through organic matter mineralisation occurred along the onion cycle starting during the first 47 DAT. In this period, at a depth of 0 to 10 cm, even though the air temperature was relatively low (7.8 to 16.4 ° C), NO_3-N concentration increased by 14.8 mg kg^{-1} (Figure 1). When soil temperature rises above 10 ° C, nitrification occurs rapidly, starting 2 to 3 days after (http://extension.psu.edu/). This indicates that soil contribution nitrogen uptake started early in the growing season. Soil nitrate-N concentration in 0N-WC at a depth of 0-10 cm was significantly higher than in 0N on all sampling dates (Figure 1), even though higher nitrate loss by leaching was expected. In the 0N-WC treatment at a depth of 0 to 10 cm at 95 and 124 DAT and at depths of 10 to 30 cm at 76, 95 and 124 DAT, soil nitrate concentration was significantly higher than that in 0N and in treatments where nitrogen was applied, indicating that a significant proportion of the nitrogen uptake during the bulb growth stage was supplied by the nitrate released from organic matter. In the 0N-WC treatment at depths of 10-20 cm, NO_3-N concentration at 95 DAT increased by 22.13 mg kg^{-1} in comparison with other treatments (Figure 1). Soil pH was significantly affected by nitrogen source (p <0.001) and depth (p <0.001) (Figure 2). Ammonium sulphate application on two dates, or alternately, decreased soil pH at 0-20 cm depth, as compared with other treatments (AN-AN and 0N). This is due to the high degree of acidification effect of ammonium sulphate (Chien et al., 2008). The decrease in soil pH was higher at the soil surface (0-10 cm) and was observed after the first application (Figure 2). This also shows that ammonium nitrification started soon (between the 14 and 47 DAT). Despite the decrease in pH, values were always greater than 6.20 (Figure 2), within the range of values recommended for onions (6 to 7) (Brewster, 1994; Odet et al., 1989). Nitrogen application increased significantly commercial yield and bulb fresh weight ($p<0.01$) (Table 2). The nitrogen source applied either on two application dates or alternately did not significantly affect commercial yield, bulb dry matter, bulb fresh weight, pH or Brix ($p> 0.05$) (Table 2). This behaviour also shows that sulphur application (52 kg S ha^{-1} in AS-AS treatment) through ammonium sulphate did not affect yield, º Brix or pH. Even though the amount of N applied was relatively low – 18. 1 kg N ha^{-1} in 0N treatment (through the N in irrigation water) and 63.1 kg N ha^{-1} in treatments where nitrogen was applied (18.1 kg N ha^{-1} through the N in irrigation water plus 45 by fertilization) – commercial yield was high, 7.62 kg m^{-2} in 0N and 9.05 kg m^{-2} in the treatments where nitrogen was applied. This Indicates that soil nitrogen released from organic matter provided a significant contribution to crop nitrogen uptake. Nitrogen uptake by the crop can reach values of between 80 and 160 kg ha^{-1}, varying according to the cultivar, climate, density and productivity levels (Odet et al., 1989; Brown, 2000; Sullivan et al., 2001; Pire et al., 2001).





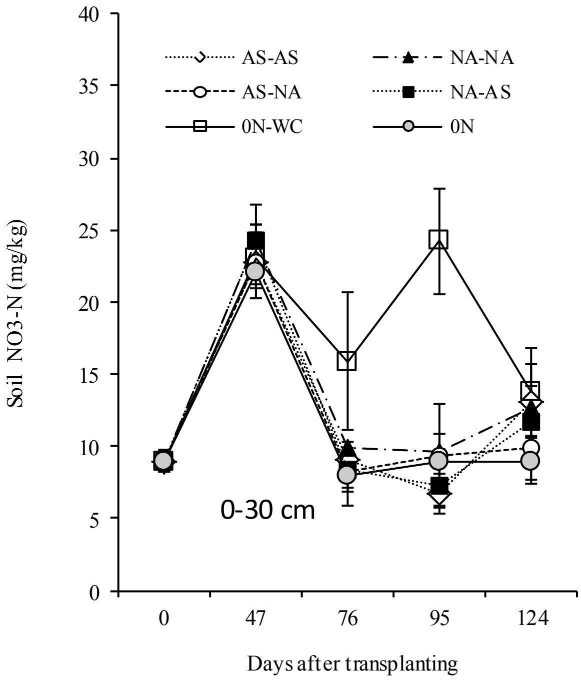
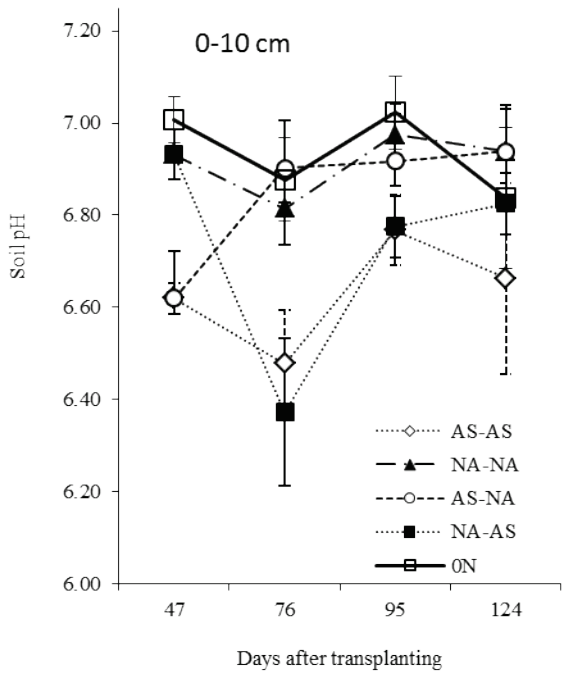
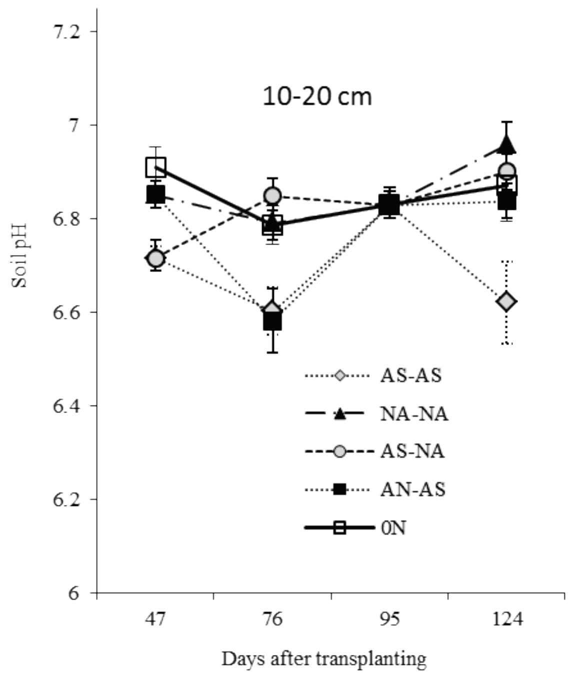


Figure 1

Soil nitrate-N concentration at depths of 0-10 cm, 10-20 cm and 20 to 30 cm at 0, 47, 76, 95 and 124 days after transplanting in 0N (0 kg N/ha) , 0N-WC (soil without plants and 0 kg N/ha), AN-AN, AS-AS, AN-AS and AS-AN treatments. The vertical bars are the SE of the means.





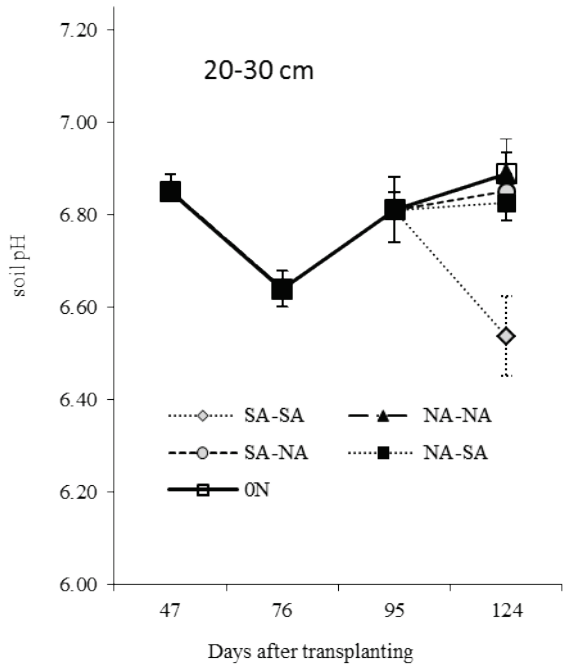


Figure 2

Soil pH at depths of 0-10 cm, 10-20 cm and 20 to 30 cm at 47, 76, 95 and 124 days after transplanting in 0N, AN-AN, AS-AS, AN-AS and AS-AN treatments. The vertical bars are the SE of the means.

Table 2 Effect of treatments on commercial yield, bulb dry weight, ºbrix and pH

Treat.	Commercial yield	Bulb dry weight		Bulb		º brix	pH
	(kg m^{-2})	(kg m^{-2})	(%)	Fresh weight (g)	Diameter (cm) (†)	(%)	
0 N	7.52 b	0.82	9.45	247.1b	8.24	9.21	5.49
AS-AS	9.27 a	1.06	10.10	254.3 a	8.33	10.10	5.59
AN-AN	9.39 a	1.01	9.38	260.6 a	8.29	9.38	5.54
AS-NA	9.27 a	1.16	9.56	263.9 a	8.39	9.56	5.64
AN-AS	8.30 a	0.93	9.23	270.0 a	8.39	9.23	5.64

§ - Within each column, means with different letters are significantly different ($P < 0.05$) (LSD). † - Equatorial diameter

Conclusions

N source broadcast onto beds during the vegetative growth phase did not significantly affect soil nitrate concentration, commercial yield, bulb dry weight, ºBrix or pH. Ammonium nitrification of AS started soon after its application. Ammonium sulphate application on two dates, or alternately, decreased soil pH at 0-20 cm depth, as compared with other treatments (AN-AN and 0N). Nitrate release through the mineralisation of organic matter began during the first 47 DAT and occurred throughout the growing season. This led to a significant amount of N being released by organic matter, enabling a high commercial yield, 7.52 kg m^{-2}, to be achieved in the treatment without N application, and 9.05 kg m^{-2} to be obtained where N was applied.

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(82) Influence of foliar fertilization on the nutrient uptake of zucchini squash (*Cucurbita pepo* L. var. *giromontia*)

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Abstract: *Fertilization has an important role in the absorption of macronutrients, their content in different plant parts and formation of the yield. Zucchini squash are vegetable crops "responsive" of fertilization due to rapid accumulation of vegetative mass and realizing significant yield in a relatively short period of harvest. The maximum production of vegetative mass is related to the maximum biological nutrient uptake.*

The main aim of this study was to investigate the influence of various complex foliar fertilizers on the nutrient uptake of zucchini squash. The experiments were carried out during the period 2007-2009, on Experimental Field of Department of Horticulture at the Agricultural University of Plovdiv, Bulgaria. Variety Izobilna F1 was used for the experiments. The field experiments were done by randomized block design with four replications. Complex foliar fertilizers Fitona 3, Hortigrow and Humustimin in three concentrations, separately and in background on soil fertilization $N_{16}P_{16}K_{16}$ *were used. The content of N,* P_2O_5 *and* K_2O *in stem, leaf, and fruits were determined. Linear relationship between the amount of vegetative mass and nutrient uptake and between yield and nutrient uptake determined high values of correlation coefficients.*

The results of this experiment indicate that foliar fertilization with complex foliar fertilizers Fitona 3, Hortigrow and Humustim influence the mineral composition of the formed biomass, which affects the biological nutrient uptake. Formed total biomass and nutrient uptake was greatest after fertilization $N_{16}R_{16}K_{16}$ *+ Humustim followed by* $N_{16}R_{16}K_{16}$ *+ Hortigrow* $N_{16}R_{16}K_{16}$ *and Fitona. Plants absorb most potassium and nitrogen and less phosphorus. A similar trend was found in export nutrients through fruits.*

Keywords: *plant nutrition, nutrient export, mineral content, fertilization, cucurbita pepo*

Introduction

Fertilization has an important role in the absorption of macronutrients, their content in different plant parts and formation of the yield. Zucchini squash are vegetable crops "responsive" of fertilization due to rapid accumulation of vegetative mass and realizing significant yield in a relatively short period of harvest (Martinetti and Paganini, 2006). In this regard is the research of Doikova et al. (1996) in order to establish the biological export of N, P_2O_5 and K_2O in zucchinis after soil fertilization. The authors indicate that nitrogen fertilization - separately or in combination with increasing doses of phosphorus and potassium - increase yield and vegetative mass, as result of increased export of nutrients in the total biomass. This relationship is strong individual and depends on the variety, soil type, the level of fertilization and the quantity of fertilizers used.

Although it has been shown that foliar application is an appropriate agro-technical event in the technology of cultivation of vegetable crops (Panayotov, 2004; Panayotov, 2005; Panayotov and Stoeva, 2005; Bileva and Babrikov, 2007; Al-Humrani, 2009; Fernandez and Eichert, 2009), the determination of the total nutrient uptake of macronutrients of zucchinis will help to explain in greater detail the effect of foliar application on growth and productivity of plants. Scientific information on the biological removal of nutrients in vegetative mass and uptake after using of foliar fertilizers on zucchinis is limited.

The main aim of this study was to investigate the influence of various complex foliar fertilizers on the nutrient uptake and biological removal by zucchini squash.

Materials and Methods

The investigations were conducted in the period 2007–2009 under open field conditions with zucchini (*Cucurbita pepo* L. *var. giromontia*), cultivar Izobilna F_1 on the experimental field of the Agricultural University of Plovdiv, Bulgaria. The soil of the field is classified as Molic Fluvisols (Popova and Sevov, 2010). The depth of the humus horizon is 28 - 30 cm. The soil is loamy (clay content from 30% to 41%). Chemically, the soil is characterized by a low content in organic matter (1.46 %), pH neutral to slightly alkaline (7.17 - 7.37) and by the presence of large amounts of $CaCO_3$, which gives more favorable physical-chemical water and soil properties, despite the heavy physical composition. Nitrogen content was low (32-46 mg.kg^{-1}), while there was a good stock of soluble phosphorus (P_2O_5 - 16.7-18 mg.kg^{-1}) and potassium (K_2O - 67-96 mg.kg^{-1}). For the purpose of the experiment three different complete foliar fertilizers were used: Fitona (7.20% N, 5.20% K_2O, 1.5% Ca, 0.9% Mg, 0.1% Fe, 0.1% B, Cu, Zn, Mn, Mo. Fitotech Ltd., Bulgaria), Hortigrow® (20% N, 20% P_2O_5, 20% K_2O, 0.06% Fe, 0.02% Zn, 0.01% Mn, 0.01% Cu, 0.02% B, 0.001% Mo and 1% amino acids, Hortiland Ltd,. The Netherlands), Humustim (on base of potassium humates-3% N, 1.14% P_2O_5, 7.83% K_2O, 3.92% Ca, 1.1% Mg, Cu, Zn, Mo, Mn Co, B, S. Agrospeis Ltd., Bulgaria). Soil fertilization was carried out with NPK using a ratio $N_{16}P_{16}K_{16}$. Phosphorus ($Ca(H_2PO_4)_2$ - 46% P_2O_5); and potassium (K_2SO_4 - 50% K_2O) fertilizers were applied with last tillage of soil before planting. Nitrogen fertilizer, introduced as NH_4NO_3 (34% N), was applied twice during the growing season. First application was after formation of new leaves of plants after planting, and the second - 20 days after the first.

Water solution of foliar fertilizers was prepared. Foliar fertilizers were applied in the given concentrations three times in the following phases: beginning of flowering, beginning of fruit production and beginning of mass fruit production. Solution with the needed concentration was prepared for the different treatments. Control plants were treated with pure water. The consumption of working solution in the first spraying was 600 l.ha-1, and in the second and third 800 $l.ha^{-1}$.

Plants were cultivated according to the conventional technology for early field production of marrows, using previously produced seedlings (Cholakov, 2009). The seedlings were planted after thirty days of cultivation in non-heated polythene tunnel. Plants were planted on bed-furrow surface, according to scheme 100+60/50 cm and density of plantation 25000 $plants.ha^{-1}$ in beginning of May. Growth period was 45 days after planting.

Treatments of the experiment: 1. Control - non fertilized; 2. Foliar fertilization with 0.2% Fitona; 3. Foliar fertilization with 0.3% Fitona; 4. Foliar fertilization with 0.4% Fitona; 5. Foliar fertilization with 0.1% Hortigrow; 6. Foliar fertilization with 0.2% Hortigrow; 7. Foliar fertilization with 0.3% Hortigrow; 8. Foliar fertilization with 0.2% Humustim; 9. Foliar fertilization with 0.3% Humustim; 10. Foliar fertilization with 0.4% Humustim; 11. Soil fertilization with $N_{16}P_{16}K_{16}$; 12. Soil fertilization with $N_{16}P_{16}K_{16}$ + 0.2% Fitona; 13. Soil fertilization with $N_{16}P_{16}K_{16}$ + 0.3% Fitona; 14. Soil fertilization with $N_{16}P_{16}K_{16}$ + 0.4% Fitona; 15. Soil fertilization with $N_{16}P_{16}K_{16}$ + 0.1% Hortigrow; 16. Soil fertilization with $N_{16}P_{16}K_{16}$ + 0.2% Hortigrow; 17. Soil fertilization with $N_{16}P_{16}K_{16}$ + 0.3% Hortigrow; 18. Soil fertilization with $N_{16}P_{16}K_{16}$ + 0.2% Humustim; 19. Soil fertilization with $N_{16}P_{16}K_{16}$ + 0.3% Humustim; 20. Soil fertilization with $N_{16}P_{16}K_{16}$ + 0.4% Humustim.

Total vegetative mass as the sum of the mass of stems and leaves of the plant was determinate.

Total yield as result by all harvests during the growing season was determinate. The collection of the total fruits in consumptive maturity was made.

The content of nitrogen, phosphorus and potassium in stems, leaves and fruits were determinate after wet digestion of vegetative material – nitrogen by methods of Kjeldahl, phosphorus by calorimetric methods and potassium on flame photometer. All these methods are described in Tomov et al. (1999). Materials were collected at the end of the growth period. Analyses were performed in four replications on average samples taken in which of variants.

Biological removal of N, P_2O_5, K_2O with total biomass of plants was calculated by methods described in Gorbanov et al. (1990). The necessary amounts of basic macro elements nitrogen, phosphorus and potassium to produce 1000 kg yield of fruits was calculated based on the quantitative uptake of nitrogen, phosphorus and potassium.

Statistical analysis: the results were elaborated using the dispersion analysis method for one factor field trial and regression analysis (Dimova and Marinkov, 1999), using the program BIOSTAT (ANOVA). The presented data are mean values from the three years of investigation, because the trends were similar.

Results and Discussion

Nutrient uptake of N, P_2O_5, K_2O with vegetative mass and fruits, average for the period 2007-2009, is different and depend on the applied fertilization (Figure 1.). This is due to changes in the mineral content of plants and crop yields, depending on the amount of biomass and obtained yield. The least quantity of N, P_2O_5 and K_2O was established in the stems, leaves and fruits of the control. With foliar application of fertilizers, the content of N increases with increasing of the vegetative mass and yield. Bigger amount of N was uptake with the stems, leaves and fruits of the plants fertilized with $N_{16}R_{16}K_{16}$ + studied foliar fertilizers. Absorbed nitrogen is most at $N_{16}R_{16}K_{16}$ + Humustim followed by $N_{16}R_{16}K_{16}$ + Hortigrow and $N_{16}R_{16}K_{16}$ + Fitona, with small differences between the variants. A similar trend is seen in the uptake of P_2O_5 and K_2O. With an increase in the vegetative mass of the plants, uptake of these elements is increased. The less absorption is in variants with foliar fertilization without soil fertilization of NPK, compared with mixed fertilization (soil and foliar application).

Increased uptake of nutrients after foliar application of products based on potassium humates may be due to the growth promotion of plants, resulting in the improvement of photosynthetic activity, chlorophyll content and the enhanced absorption capacity of the root system. Following Chen and Aviad (1990), humic acids can give direct effects as a source of nutrients as well as substances having physiological activity of phytohormones. Another often cited mechanism of action of the humic acids is increased absorption of nutrients and increased cellular permeability (Chen et al., 2001).

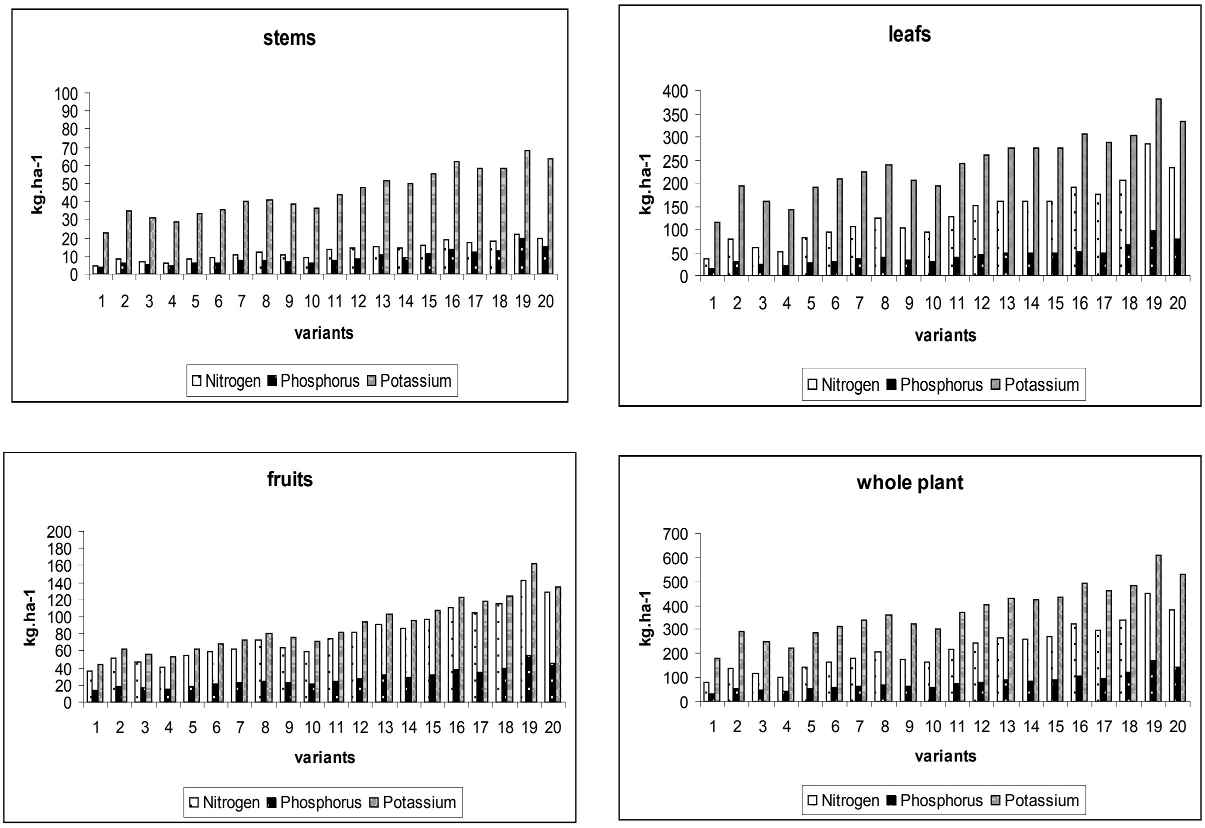

Figure 1. Biological removal of nitrogen, phosphorus and potassium, average for the period 2007-2009

1. Control	6. Hortigrow – 0.2%	11. $N_{16}P_{16}K_{16}$	16. $N_{16}P_{16}K_{16}$ + Hortigrow – 0.2%
2. Fitona – 0.2%	7. Hortigrow – 0.3%	12. $N_{16}P_{16}K_{16}$ + Fitona – 0.2%	17. $N_{16}P_{16}K_{16}$ + Hortigrow – 0.3%
3. Fitona – 0.3%	8. Humustim – 0.2%;	13. $N_{16}P_{16}K_{16}$ + Fitona – 0.3%	18. $N_{16}P_{16}K_{16}$ + Humustim – 0.2%
4. Fitona – 0.4%	9. Humustim – 0.3%;	14. $N_{16}P_{16}K_{16}$ + Fitona a – 0.4%	19. $N_{16}P_{16}K_{16}$ + Humustim – 0.3%
5. Hortigrow – 0.1%	10. Humustim – 0.4%;	15. $N_{16}P_{16}K_{16}$ + Hortigrow – 0.1%	20. $N_{16}P_{16}K_{16}$ + Humustim – 0.4%

In other studies it was found that better absorption of nutrients, correcting nutritional deficiencies and enhanced productivity of plants were obtained by the application of complexes of cations of amino acids in foliar fertilizers (Taiz and Zeiger, 1998). The content of elements such as Mg, Zn and Cu in the formulation of fertilizers also influences the activity of absorption, transportation and accumulation of macronutrients (Fageria et al., 2009).

Under the influence of different fertilization - foliar spraying separately or combination of soil fertilization and foliar application - plants uptake bigger quantity of potassium. The quantity of phosphorus is less. In the group variants $N_{16}R_{16}K_{16}$ + studied foliar fertilizers, the part of potassium is reduced, due to the increase of the part of nitrogen. Of total exports of NPK, the amount of absorbed P_2O_5 remains the most relatively constant.

The maximum production of vegetative mass is related to the maximum biological nutrient uptake. The linear relationship between the amount of total vegetative mass and uptake of NPK with R^2 = 0.857 was established. It means that approximately 80% of the applied fertilizer will cause the respective absorption of nutrients (Figure 2.).

Our results are in direct relation to investigations of Huett and Dettmann (1991) and Huett and Dettmann (1992) who found similar trends in the absorption of N, P_2O_5 and K_2O in plants of zucchinis. The largest uptake of N and K_2O have reported with vegetative mass (stems + leaves), in preference to the leaves. Authors concluded that plants priority absorbed N and K_2O, indicating the direct correlation between the amount of vegetative mass formed per unit area, the level of yields and biological removal of NPK.

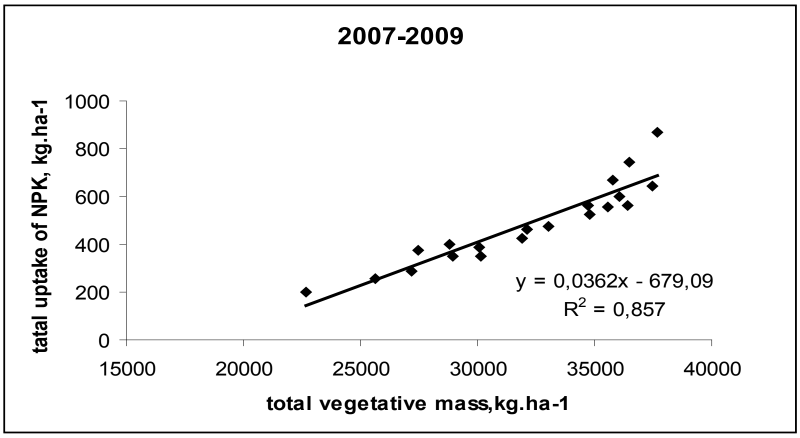

Figure 2. Relationship between the amount of total vegetative mass and uptake of NPK

The results of our experiment indicate that foliar fertilization with complex foliar fertilizers Fitona, Hortigrow and Humustim increase the productivity of zucchini. The biological effect of foliar fertilization was demonstrated most clearly with results of the variant of soil fertilization $N_{16}P_{16}K_{16}$ and foliar application with 0.3% Humustim. There variant gave the highest total yield. The increase of total yield in this variant was in comparison with control was 73% (Figure 3.) and in comparison with soil fertilization without any foliar application 31%. Following in rank were $N_{16}P_{16}K_{16}$ + 0.4% Humustim, $N_{16}P_{16}K_{16}$ + 0.2% Hortigrow and $N_{16}P_{16}K_{16}$ + 0.3% Fitona. In comparison with control their yield were higher by 63%, 62% and 55%, respectively and in comparison with soil fertilization $N_{16}P_{16}K_{16}$ without any foliar applicationyield was increased with 31%, 23%, and 23% respectively.

Direct relationship between yield and uptake of N, P_2O_5 and K_2O is described by regression equations (Figure 4.). Strong linear relationship between the yield and absorptions of total quantity of macronutrients was established. Higher values of the coefficient of determination show that this impact will be established by 92% to 96% of cases.

Several researchers in their studies pointed out that there is a positive correlation between biological removal of nutrients and total yield (Abou El - Nasr (2001), Abou El - Yazeid et al. (2007), Faten et al. (2010), Hoda Mohamed et al. (2010). Huett and Dettnann (1992) reported that with fruits zucchini absorbed greatest quantity of nitrogen and potassium and the ratio between both elements has a very slight prevalence of potassium. Their results correspond with our findings in figure 1.

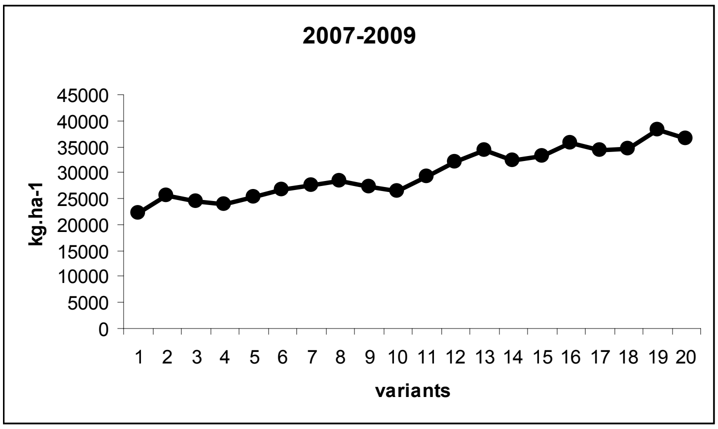

Figure 3. Total yield of fruits of zucchini, average for the period 2007-2009

1. Control	6. Hortigrow – 0.2%	11. $N_{16}P_{16}K_{16}$	16. $N_{16}P_{16}K_{16}$ + Hortigrow – 0.2%
2. Fitona – 0.2%	7. Hortigrow – 0.3%	12. $N_{16}P_{16}K_{16}$ + Fitona – 0.2%	17. $N_{16}P_{16}K_{16}$ + Hortigrow – 0.3%
3. Fitona – 0.3%	8. Humustim – 0.2%;	13. $N_{16}P_{16}K_{16}$ + Fitona – 0.3%	18. $N_{16}P_{16}K_{16}$ + Humustim – 0.2%
4. Fitona – 0.4%	9. Humustim – 0.3%;	14. $N_{16}P_{16}K_{16}$ + Fitona a – 0.4%	19. $N_{16}P_{16}K_{16}$ + Humustim – 0.3%
5. Hortigrow – 0.1%	10. Humustim – 0.4%;	15. $N_{16}P_{16}K_{16}$ + Hortigrow – 0.1%	20. $N_{16}P_{16}K_{16}$ + Humustim – 0.4%

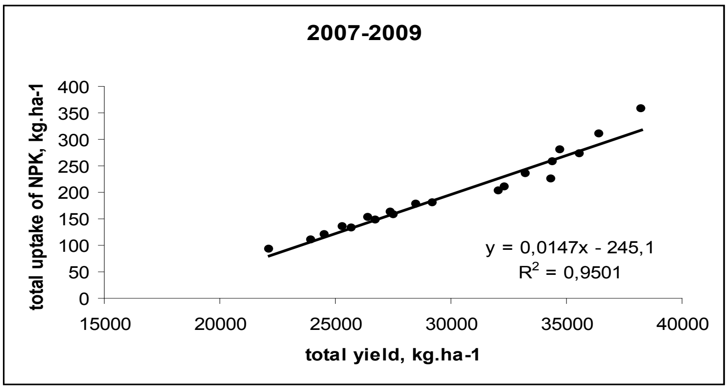

Figure.4. Relationship between the of total yield and uptake of NPK

In fact, it was determined that foliar fertilization does not replace soil-applied fertilizer completely but it does increase the uptake and hence the efficiency of the nutrients applied to the soil (Tejada and Gonzalez, 2004). One of the benefits of foliar fertilization is the increased uptake of nutrients from the soil. This notion is based on the belief that the foliar fertilization causes the plant to release more sugars and other exudates from its roots into the rhizosphere. Beneficial microbial populations in the root zone are stimulated by the increased availability of these exudates. In turn, this enhanced biological activity increases the availability of nutrients, disease-suppressive biochemicals, vitamins, and other factors beneficial to the plant (Tejada and Gonzalez, 2004). Fritz (1978) pointed out that a repeated application of small units of foliar fertilizers stimulates plant metabolism and an increased nutrient uptake by the roots can be observed. Our results support the previous reports.

Application of foliar fertilizers - separately or in combination with $N_{16}P_{16}K_{16}$ - influenced the quantity of macronutrients necessary for the formation of 1000 kg yield of fruits. These augmentations are higher for nitrogen and potassium, and less for phosphorus (Figure 5.).

The average results for the period of study shows that in realizing the average yield of 22137.44 $kg.ha^{-1}$ to 38566.05 $kg.ha^{-1}$, necessary amount of nitrogen for 1000 kg yield is from 1.644 kg for control to 3.738 kg for $N_{16}P_{16}K_{16}$ + 0.3 % Humustim, necessary amount of P_2O_5 from 0.589 kg to 1.414 kg and necessary amount of K_2O from 1.975 kg to 4.217 kg (Figure 5.).

Tendency to increase the amount of nitrogen, phosphorus and potassium spent on construction of 1000 kg production was established. It is better expressed in variants of fertilization with $N_{16}R_{16}K_{16}$ + foliar fertilizer.

The maximum of the necessary nutrients for the formation of the 1000 kg of yield is in $N_{16}P_{16}K_{16}$ + 0.3% Humustim.

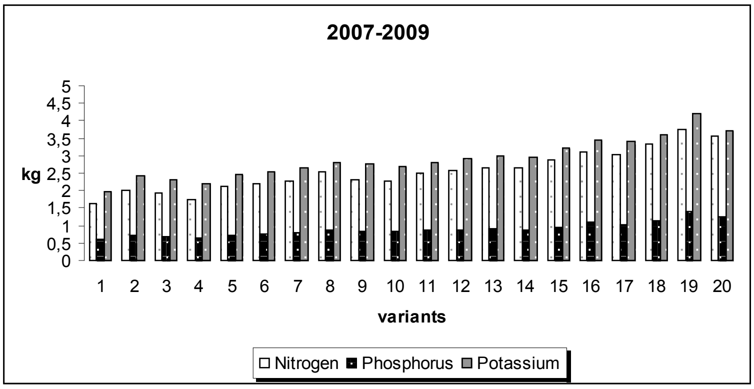

Figure 5. Necessary amounts of nitrogen, phosphorus and potassium for 1000 kg yield of zucchini fruits

1. Control	6. Hortigrow – 0.2%	11. $N_{16}P_{16}K_{16}$	16. $N_{16}P_{16}K_{16}$ + Hortigrow – 0.2%
2. Fitona – 0.2%	7. Hortigrow – 0.3%	12. $N_{16}P_{16}K_{16}$ + Fitona – 0.2%	17. $N_{16}P_{16}K_{16}$ + Hortigrow – 0.3%
3. Fitona – 0.3%	8. Humustim – 0.2%;	13. $N_{16}P_{16}K_{16}$ + Fitona – 0.3%	18. $N_{16}P_{16}K_{16}$ + Humustim – 0.2%
4. Fitona – 0.4%	9. Humustim – 0.3%;	14. $N_{16}P_{16}K_{16}$ + Fitona a – 0.4%	19. $N_{16}P_{16}K_{16}$ + Humustim – 0.3%
5. Hortigrow – 0.1%	10. Humustim – 0.4%;	15. $N_{16}P_{16}K_{16}$ + Hortigrow – 0.1%	20. $N_{16}P_{16}K_{16}$ + Humustim – 0.4%

Of the total NPK, the largest proportion comes from K2O with 44.61 to 48.17%, followed by nitrogen with 37.70 to 41.68% and finally phosphorus with 13.45% to 15.09%. These results are in line with findings of Rankov (2006).

Conclusions

Under the influence of foliar fertilization applied separately or after NPK soil fertilization, there are changes in the mineral composition of the formed biomass, which affects the biological removal of nutrients. Uptake of nutrients with the total biomass is highest after fertilization with $N_{16}P_{16}K_{16}$ + Humustim, followed by $N_{16}P_{16}K_{16}$ + Hortigrow and $N_{16}P_{16}K_{16}$ + Fitona. Plants absorb potassium and nitrogen and less phosphorus. After the combination of soil and foliar application decreased proportion of potassium and increased proportion of nitrogen were observed.

The application of foliar fertilizers - separately or in combination with soil fertilization - increases the amount of nutrients necessary for the formation of 1000 kg yield of zucchini. The impact is greater when $N_{16}P_{16}K_{16}$ fertilizers were incorporated in soil prior. To obtain 1000 kg of yield 1.644 kg to 3.738 kg of nitrogen, 0.589 to 1.414 kg phosphorus and 1.975 kg to 4.217 kg potassium are required. Fertilization with $N_{16}P_{16}K_{16}$ + 3% Humustim established the greatest amounts of NPK necessary for 1000 kg yield of zucchinis.

Acknowledgements

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(83) Survey activities in the area of Sestu (southern Sardinia) aimed at defining the agronomic techniques to reduce the nitrate pollution

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Abstract: *The horticultural reality in the Sestu district is characterized by a high intensity of growing cycles. The rapid succession of growing cycles and the single-crop regime applied by most farms has over the years led to the worsening of soil fertility and the quality of ground water, thus underscoring the need to adopt sustainable farming practices. Three cultivation cycles of lettuce were performed, in each cycle three different fertilization regimes were compared to determine their effect on production and the release of nitrates. The control fertilization provided manure management following normal usage in the district, distributing in the first cycle a 12-12-17 granular ternary compound at the time of the transplant and in the second cycle the same compound followed by fertilization with a 20-20-20 soluble fertilizer. The second fertilizer regime provided a split distribution of a 15-10-30 soluble compound, in accordance with crop absorption rhythms (Bianco and Pimpini 1990), The third fertilizer regime provided use of slow-release fertilizers based on leonardite and gluconic acid (FertireV), in liquid form: basic Glucohumate at the time of transplant and Glucohumate nitrogen during the cycle. The fertilization technique normally adopted by farms in the Sestu horticultural district determine the higher amount of nitrate leaching compared to thesis 2 and 3. The nitrogen split distribution in accordance with crop absorption rhythms led to equal results in production with respect to the control thesis and reduced losses of nitrates by leaching. The use of slow-release fertilizers led to minor losses of nitrates by leaching compared to the control and produced significantly better crops than the other theses only in the summer cycle.*

Keywords: *nitrate, leaching, fertilization, lettuce*

Introduction

The horticultural reality in the Sestu district is characterized by a quite limited average size of farms and a high intensity of growing cycles. The rapid succession of growing cycles and the single-crop regime applied by most farms has over the years led to the worsening of soil fertility and the quality of ground water.

In this project the fertilization technique ordinarily used by horticultural farmers is the subject of investigation. The adoption of a rational fertilization technique is fundamental in guaranteeing a good level of production, in reducing environmental risks caused by the leaching of nitrates and in limiting the costs of production by avoiding excesses in the distribution of fertilizers (Benedetti and Sequi 1999). The technicians of the two horticultural cooperatives in the district reported that the following fertilization technique is applied: at the time of transplant granular ternary compounds are used, with doses from 500 to 1000 kg ha^{-1} and a dose of N from 60 to 120 kg ha^{-1}; in the stage of maximum growth one or two fertigations using soluble ternary compounds, at a dosage of 70 kg ha^{-1} for each irrigation, with a dose of N of 14 kg ha^{-1}. In the case of horticultural crops that conclude their productive cycle in two to three months, slow-release fertilizers are not advisable (Triberti 2004).

Materials and Methods

Experimental activity was carried out in four fields of the Sestu horticultural district representative of two different soil types: clay loam and sandy clay loam, identified by adopting an experimental plan of one factor with four replications. Tests were carried out on homogeneous plots of 1000 m^2; the area of each plot was 80 m^2. Three cultivation cycles of lettuce were performed (spring, summer and autumn 2007); for every cycle the most cultivated variety of lettuce in the district of Sestu was used with a density of 10 plants per square metre (Cv Nogal, Passepartout, Rubette, Eitude). In each cycle three different fertilization regimes were compared to determine their effect on production and the release of nitrates.

It was impossible to carry out the three cultivation cycles on the same farm due to unwillingness to host the tests; thus in the second and third cycles Farm 2 was replaced by Farm 3 and in the third cycle Farm 1 was replaced by Farm 4.

Scenarios in the first cycle (farm 1 - 2) and second cycle (farm 1):

- Control - Manure management following normal usage in the district.

  First cycle: granular ternary compound (12-12-17) at the time of the transplant (N = 9.6 g m^{-2}).

  Second cycle: the same compound (12-12-17) at the time of the transplant (N = 4.8 g m^{-2}) followed by fertilization with a 20-20-20 soluble fertilizer (N = 2.4 g m^{-2}).

- A split distribution of a 15-10-30 soluble compound, in accordance with crop absorption rhythms (Bianco and Pimpini 1990).

  First cycle N = 9.5 g m^{-2}. Second cycle N =7.2 g m^{-2}.

- Use of slow-release fertilizers based on leonardite and gluconic acid (FertireV), in liquid form: basic Glucohumate at the time of transplant and Glucohumate nitrogen during the cycle.

  First cycle N= 4.3 g m^{-2}. Second cycle N = 6.5 g m^{-2}.

Scenarios in the second cycle on farm 3 which replaced farm 2, were adapted to the fertilization ordinarily carried out by the farmer. In all three conditions, fertilization prior to transplant was with an organic compound in pellet form (Stalfer) (N = 4 g m^{-2})

- Control: granular ternary compound (12-12-17) at the time of the transplant (N = 2.4 g m^{-2}).
- A split distribution of urea phosphate, ammonium and calcium nitrate (N = 2.4 g m^{-2}).
- Use of slow-release fertilizers based on leonardite and gluconic acid (FertireV) (N = 2.4 g m^{-2}).

Scenarios in the third cycle farm 3:

- Control: granular ternary compound (12-12-17) at the time of the transplant and twenty days after the transplant and two fertilizations with ammonium nitrate (N = 2.5 g m^{-2}).
- A split distribution of urea phosphate, ammonium and calcium nitrate (N = 2.5 g m^{-2}).
- Distribution of 12-12-17 granular fertilizers at the time of transplant, nitrogen glucohumate (FertireV) and ammonium nitrate alternating during the cultivation cycle (N = 1.8 g m^{-2}).

In all scenarios, fertilization prior to transplant was with bovine manure (N = 7.5 g m^{-2})

Scenarios in the third cycle farm 4:

- Control: granular ternary compound (12-12-17) at the time of the transplant and twenty days after the transplant and two fertigations with ammonium nitrate (N = 7.9 g m^{-2}).
- A split distribution different ternary fertilizers: (14-25-5), (35-5-8), (20-20-20), 8-5-44 and organic fertilizers: Azomin and Supernat 93 (N = 7.9 g m^{-2}).
- Distribution of 12-12-17 granular fertilizers at the time of transplant, nitrogen glucohumate (FertireV) and ammonium nitrate alternating during the cultivation cycle (N = 6.4 g m^{-2}).

In all scenarios fertilization prior to transplant was with nitrated calcium cyanamide (N = 10 g m^{-2}).

On the farms, soils were prepared in the usual way. Following this, suction lysimeters (soil moisture sampling) were inserted at depths varying from 60 to 70 cm, one for each experimental unit, to allow the taking of solutions circulating in the soil and the weekly monitoring of leaching of nitric nitrogen in the different theses. Chemical analyses were carried out on a soil sample taken at the beginning and end of the productive cycle: pH, conductivity, total-N, N-NO3, N-NH4 . Samples of the solutions from the lysimeters were taken weekly for the analytical determination of the nitrate concentration in the leach. Every week, colorimetric analyses of the chlorophyll content of the lettuce leaves were performed (Spad Meter Minolta). At the time of harvesting, analyses were performed to ascertain the productive and qualitative characteristics of the lettuces and soil samples for each thesis were taken for analysis.

All the analytical determinations in soils are developed according to the official methods of chemical analysis of the soils published in the ordinary Supplement to the Official Gazette n° 131 of May 25 th 1992 and in the G.U. of May 12 th 1994.

The determination of the content in Nitrates in vegetables are developed according to the norm UNI EN 12014-2 (method for HPLC/IC) or in alternative according to the norm UNI EN 12014-7 (method of the continuous flow - reduction with cadmium).

The determination of the content in nitrates in the leach are developed according to the method of the continuous flow (QuAAtro microflow system AX FLU) that foresees the reduction with cadmium.

All data were statistically processed by means of the variance analysis and Duncan's test for separation of means was performed.

Results and Discussion

On Farm 1 the distribution of all nitrogen at transplant (control) caused in both cycles a greater release of nitrates in the drainage, in the second cycle the minor amount of nitrogen distributed led to containment of the release of nitrates (Fig. 1). In the first cultivation cycle the fertilization plan was designed providing for a 60 day cycle; in reality, the lettuces completed the cycle in 50 days. The distribution of nitrogen did not satisfy the real requirements of the plants in the scenarios with split distribution and slow release, this resulted into a production that was significantly lower than the control thesis, in which all the nitrogen had been distributed at the time of the transplant (Fig. 2). In the second cycle the differences in production were not statistically significant. The nitrates in the lettuces did not exceed the maximum statutory levels in either of the cycles. The chemical analyses carried out on soil samples at the end of the second cycle showed a decrease in nitrate content in the scenario with split distribution and an increase in the ammonium concentration in all theses (Tab.1)

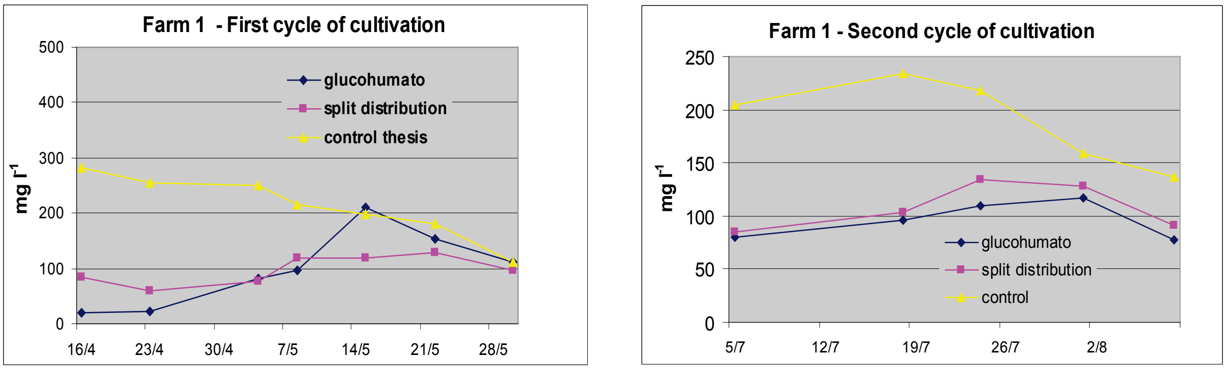


Figure 1 Concentration of nitrates in the solution collected at 60 cm depth in Farm 1

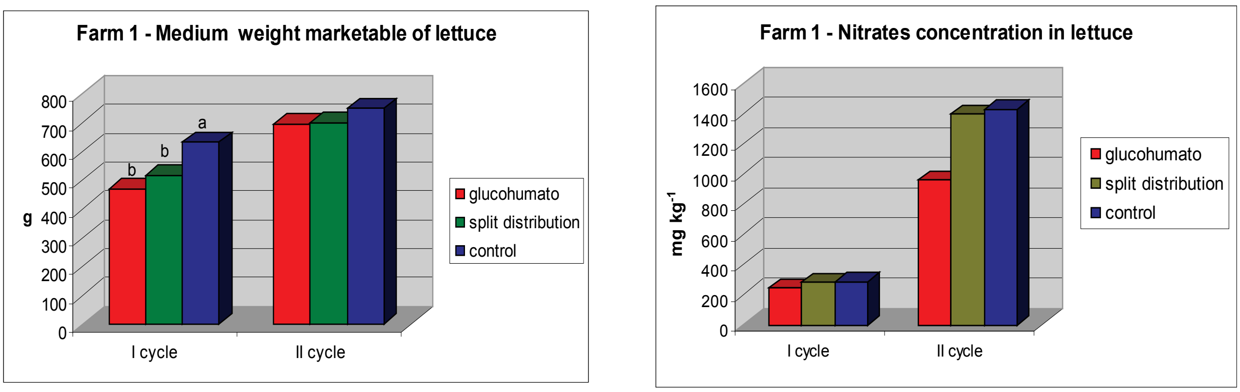


Figure 2 Production and concentration of nitrates in lettuce in Farm 1 - Different letters indicate significant differences at p<0,05 (Duncan test)

Table 1 Analyses performed on soil samples at the beginning and end of the cycle on Farm 1 and Farm 2

		Farm 1			Farm 2		
		Total-N g kg^{-1}	N-NO3 mg kg^{-1}	N-NH4 mg kg^{-1}	Total-N g kg^{-1}	N-NO3 mg kg^{-1}	N-NH4 mg kg^{-1}
beginning of the cultivation		1.5	20.4	0.17	1.2	34.80	0.15
end of 1st cycle	Control	1.0	5.71	1.80	1.0	7.37	<0.1
	Split distribution	1.2	5.84	0.90	1.0	5.95	<0.1
	Glucohumate	1.4	5.54	<0,1	1.0	4.25	<0.1
end of 2nd cycle	Control	1.5	4.41	24.30			
	Split distribution	1.3	1.72	7.47			
	Glucohumate	1.1	4.68	9.57			

On Farm 2 only the first production cycle was implemented; here too the concentration of nitrates in the drainage solution was higher in the control thesis than in the other two scenarios (Fig. 3). In this test the harvest was delayed by 10 days compared to the previous one; the longer duration of the cultivation cycle made it possible for the theses to reach the production levels of the control thesis with split distribution and glucohumate. The production differences were not statistically significant (Fig. 4) and the nitrate content, determined on the harvested leaves, did not exceed the maximum statutory levels. At the end of the 1st cycle the chemical analyses carried out on soil samples showed a reduction in the nitrate and ammonium content in all scenarios (Tab.1).

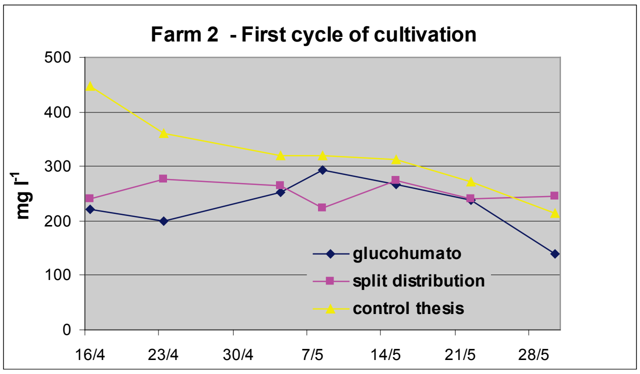


Figure 3 Concentration of nitrates in the solution collected at 70 cm depth on Farm 2

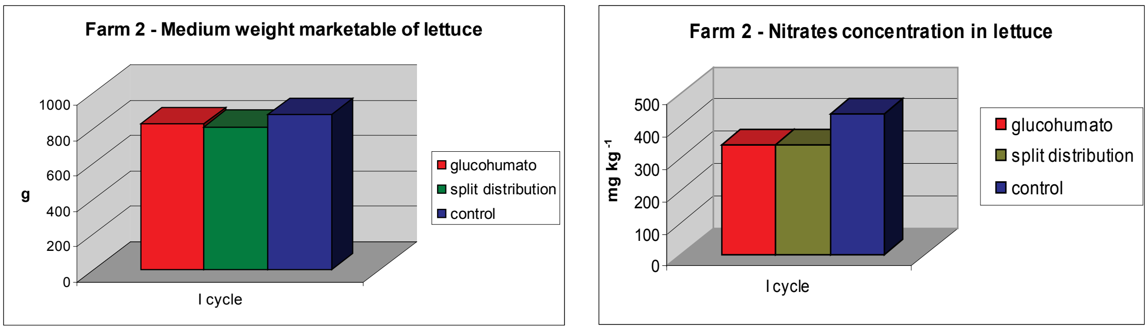
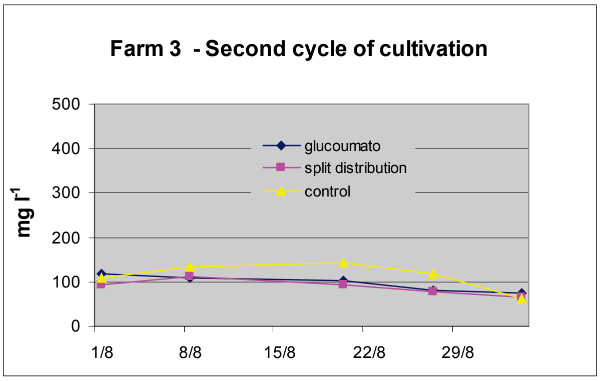


Figure 4 Production and concentration of nitrates in lettuce in Farm 2

On Farm 3, where one summer and one winter cycle were implemented, the usual practice is to use organic fertilizers buried while preparing the soil, thus the use of covering nitrogen fertilizers is quite limited. In the summer cycle, the nitrate concentration in the drainage solution collected during soil moisture sampling was quite low and the differences were not statistically significant. In the winter cycle, the test was conducted on a plot of land different from that of the previous cycle; the samples taken in the first stages of the cycle showed a very high nitrate concentration in the drainage solution in all plots, with statistically significant differences between the values of the control and those in the scenarios treated with glucohumate, in which the lowest concentration was found. The distribution of granular ternary fertilizer at the time of the transplant, even when divided into two applications 20 days apart, determined a greater loss of nitric nitrogen by leaching. At the end of the cycle the nitrate concentration in the split distribution thesis was significantly lower than that of the control; the differences found between the glucohumate thesis and the other two were instead not significant. The nitrate concentration in the drainage solution was quite high in the winter cycle compared to the summer cycle (Fig. 5); the explanation of this phenomenon is to be found in the amount of water that caused leaching. In the summer cycle large amounts of water were supplied by irrigation (3000 m^3ha^{-1}) while in the winter cycle rainfall was quite limited (960 m^3ha^{-1}), thus determining a reduction in the amounts of water collected by the samplers compared to the summer cycle, with a consequent greater concentration of nitrates in the solution. In the summer cycle, characterized by very high maximum temperatures (some days above 40°C**)** which conditioned the development of the plants, the production was better in the thesis with slow-release fertilizers, while in the winter cycle the differences were not statistically significant (Fig. 6). In the summer cycle the level of nitrogen in the lettuces was quite low, the nitrates did not exceed the maximum statutory levels in the winter cycle. The chemical analyses carried out on soil samples at the end of the second cycle showed an increase in nitric nitrogen content in the control thesis and an increase in ammonium concentration in all theses. At the end of the 3rd cycle the chemical analyses showed an increase in nitric nitrogen content and a reduction in ammonium content in all scenarios (Tab.2).



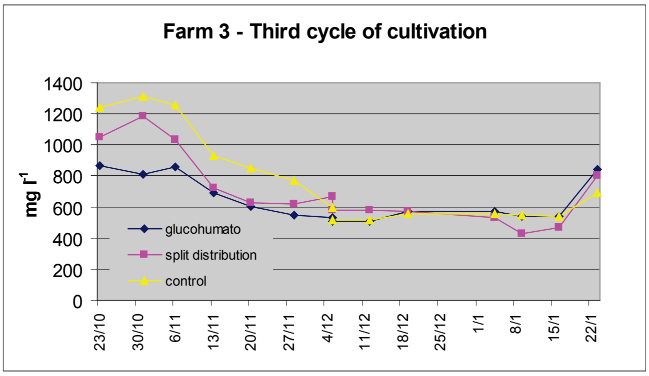
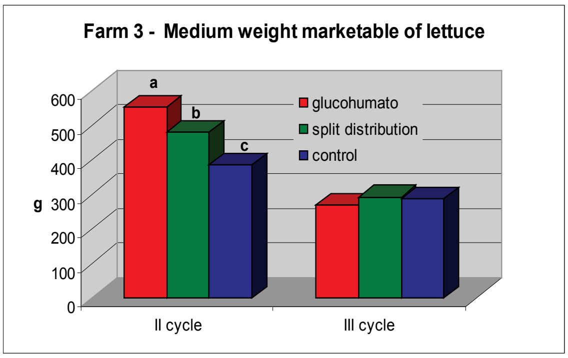


Figure 5 Concentration of nitric nitrogen in the solution collected at 60 cm depth on Farm 3



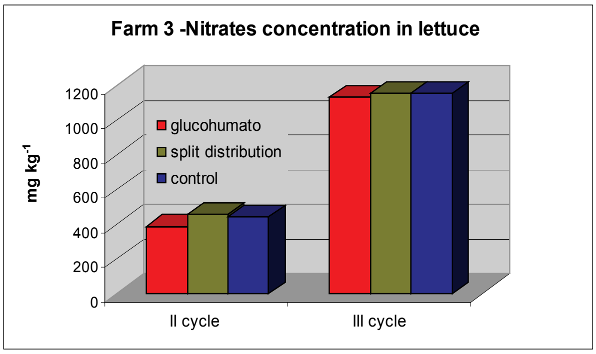


Figure 6 Production and concentration of nitric nitrogen in lettuce in Farm 3 -Different letters indicate significant differences at p<0,05 (Duncan test)

Table 2 Analyses performed on soil samples at the beginning and end of the cycle on Farm 3 and Farm 4

		Farm 3			Farm 4		
		Total-N g kg^{-1}	N-NO3 mg kg^{-1}	N-NH4 mg kg^{-1}	Total-N g kg^{-1}	N-NO3 mg kg^{-1}	N-NH4 mg kg^{-1}
beginning of the cultivation		0.9	4.0	1.17			
end of 2nd cycle	Control	1.2	17.40	8.52			
	Split distribution	1.0	3.33	6.42			
	Glucohumate	0.8	3.50	4.32			
beginning of the cultivation		1.4	21.50	28.00	0.9	23.4	21.7
end of 3rd cycle	Control	0.9	36.40	2.63	1.6	38.0	19.2
	Split distribution	1.4	65.00	5.25	1.4	26.3	59.5
	Glucohumate	1.5	75.40	2.63	1.4	15.6	15.4

Farm 4 also showed a significantly higher concentration of nitrates in the solution collected during soil moisture sampling in the control (Fig. 7). In this test the differences were far more significant compared to those on Farm 3. However, such differences cannot be attributed exclusively to the different treatments; in fact, from the first samples taken on 13 November, before fertilization was differentiated in the different theses, it can be seen that the nitrate concentration in the samples taken from the control plots was much higher. The explanation of this fact is to be found in the non-homogeneous distribution of nitrate calcium cyanamide performed by the farm owner prior to the preparation of the soil. The production differences were not statistically significant (Fig. 8) and the nitrate content, determined on the harvested leaves, was below the maximum statutory limits. The chemical analyses performed on soil samples at the end of the 3rd cycle showed an increase in Total N content in all scenarios, but an increase in nitric nitrogen content only in the control and an increase in ammonium concentration only in the split distribution scenario (Tab.2).

In all tests the colorimetric determination of leaf chlorophyll content performed with the Minolta SPAD did not show statistically significant differences between the theses.

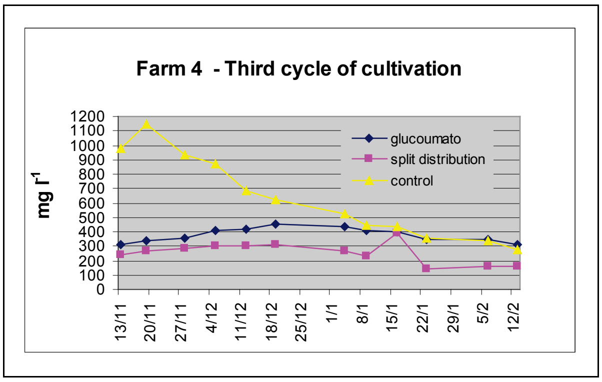
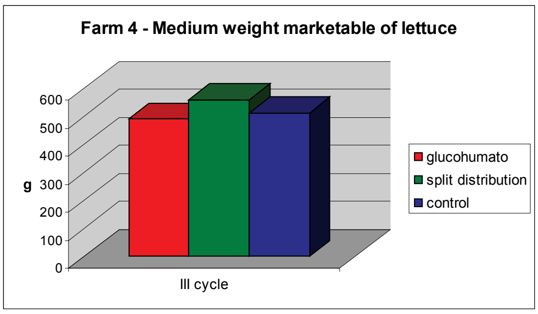


Figure 7 Concentration of nitric nitrogen in the solution collected at 50 cm depth on Farm 4



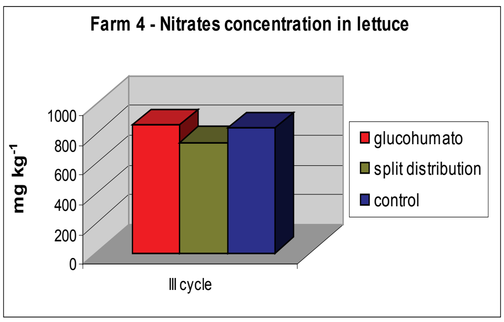


Figure 8 Production and concentration of nitric nitrogen in lettuce in Farm 4

Conclusion

The results obtained in the three cycles of lettuce cultivations show that the fertilization technique normally adopted by farmers in Sestu horticultural district determine the higher amount of nitrate leaching. Even reducing the amount of the granular ternary compound (12-12-17) and splitting in two with a 20-day interval the distribution significantly higher concentrations of nitrate were found in the samples compared to the use split distribution of soluble compound and slow-release fertilizers, in accordance with crop absorption rhythms.

In normal conditions the differences in production were not statistically significant, in two exceptional condition the differences were significant: in the 1st cycle on Farm 1 the harvest was 10 days earlier than the planned and the production was better in the control, in which all the nitrogen had been distributed at the time of the transplant; in the 2nd cycle on Farm 3 climatic conditions was characterized by very high maximum temperatures (some days above 40°C**)** which conditioned the development of the plants, the production was better in the thesis with slow-release fertilizers. These circumstances made it possible to verify the positive influence of glucohumate nitrogen on plant nutrition in critical environmental conditions.

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(88) Dynamics of integrated organic and mineral nitrogen applications and their impact on crop performance

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Field experiments were conducted to evaluate the effects of integrated organic and mineral fertilization through drip irrigation (fertigation) on nitrogen and water use efficiencies by maize and bean grown on a sandy soil. Fertilization treatments were: (a) 120 kg N/fed (fed= 4200 m²) and 20kg N/fed for maize and bean, respectively, were applied to the soil through fertigation either in mineral form (ammonium nitrate), organic form (chicken manure extract) or mixtures of organic and mineral fertilizers by the proportions: 75 % organic + 25 % mineral; 50 % organic + 50 % mineral and 25 % organic + 75 % mineral, and (b) the same fertilization treatments as in (a) plus a supplement addition of 50 L/fed of humic substances (Hu).

Increasing the mineral content in fertilizer mixtures had a positive effect on the yield of both maize and bean. The highest yield was realized with the plants that received the fertilizer mixture 75 % mineral + 25 % organic. Addition of Hu with the 100 % mineral fertilization further increased the yield of the two crops. Applying mixtures of mineral-organic fertilizers increased nutrient content in plants more than the sole application of either. In most cases mixing humic substances with fertilizers had positive effects on nutrient content compared to treatments without humic substances.

Nitrogen use efficiency (NUE expressed as kg yield/kg N) increased with increasing the mineral content in the fertilizer mixtures. Highest values were realized with the plants that received the fertilizer mixture 75 % mineral + 25 % organic.

Increasing the mineral content in fertilizers mixtures had a positive effect on values of irrigation water use efficiency (WUE expressed as kg yield/m^3 water) recording 0.76 kg m^{-3} and 0.79 kg m^{-3} for maize grain and bean seeds respectively; both were realized with the plants that received the fertilizer mixture 75 % mineral + 25 % organic.

Introduction

Due to the limitation of further expansion of irrigated land in most countries, a large part of the future food requirements will need to be covered by a more efficient use of irrigation water and fertilizers. One of the most important challenges facing sustainable agriculture is to provide crops with an optimal quantity of water and nutrients throughout the growing season in the most efficient manner possible. Fertigation is considered the best answer to this challenge, whereby both water and fertilizers are delivered to crops simultaneously through the irrigation system. Scheduling fertilizer applications on the basis of needs reduces nutrient losses compared to conventional application methods that depend on the soil as a reservoir for nutrients. The method of fertilizer application also improves the use efficiency of nutrients. Well-balanced fertigation program will satisfy the exact needs of the plant as they change along the season, increase efficient use of water and fertilizers, increase yield, protect the environment and sustain irrigated agriculture**.**

The fertigation technique is used mainly with N, P and K mineral fertilizers, whereas, little data have been reported concerning the fertigation using organic fertilizers.

Therefore, the present investigation was conducted to study the effect of fertigation involving mineral and organic fertilizers applied through drip irrigation on growth, yield and yield quality of maize and bean plants cultivated in a sandy soil.

Materials and Methods

The experimental part of this work aimed principally at evaluating the effects of integrated organic and mineral fertilization through irrigation (fertigation) on different crops cultivated in a virgin sandy soil.

Grains of maize and seeds of faba bean were obtained from the Field Crops Research Institute, A.R.C, Ministry of Agriculture, Giza, Egypt; seeds of faba bean were inoculated with the proper rhizobia before sowing. Drip irrigation system with fertilizer distribution equipments was used. Emitter discharge was 1.6 Lh^{-1} at 1.0 bar operating pressure and 30 cm spacing between emitters. Calculated irrigation water requirements were 2860 m^3 fed^{-1} for maize and 1425 m^3 fed^{-1} for faba bean (fed = 4200 m^2).

Fertilization:

1) Control treatment: soil without any fertilizer added to the soil through fertigation.

2) Fertilizers added to the soil through fertigation:

a) Mineral fertilizer (120 kg N/fed) for maize (250 kg/fed 20 : 20 : 20 fertilizer + 210 kg/ fed ammonium nitrate 33.5% N) and 20kg N/fed for faba bean (100 kg fed^{-1} 20 :20 :20 fertilizer).

b) Organic fertilizer - chicken manure extract (100% ChM) at the rate of 120 kg N/ fed^{-1} for maize and 20 kg N fed^{-1} for faba bean.

c) Mixtures of chicken manure extract and the mineral fertilizers by the following ratios:

75% ChM + 25 % NPK ; 50% ChM + 50 % NPK; 25 % ChM + 75 % NPK

d) The same fertilization treatments in (c) + 50 L fed^{-1} of humic substances.

Results and Discussion

Integrated fertilizer application through irrigation affected positively the vegetative characteristics of both maize and bean plants. Fertigation with different combinations of NPK+ChM mixtures plus holmic substances produced more vigorous shoots compared to the corresponding combinations without holmic substances. These results are in accordance with those of Medina et al. (2004); Singer et al. (2004). Abd-El Mageed et al. (2006) and Roy et al. (2006).

Yield and yield attributes

Integrated mineral/organic fertigation positively affected the yield of maize and bean with different magnitude. Increasing the mineral content in fertilizer mixtures had a positive effect on the yield of both maize and bean, where the higher yield was realized with the plants that received the fertilizer mixture 3/4 mineral + 1/4 organic. Addition of Hu with the fertilization treatment NPK 100% in mineral form further increased the yield of the two crops. Combinations of mineral/organic fetigation had positive effects on maize straw and grains and also on bean straw and seeds. Increasing the mineral content in fertilizer mixtures had a positive effect on the grain yield of maize, where the higher yield was realized with the plants that received the fertilizer mixture 3/4 NPK + 1/4 ChM. The effect of addition of Hu was less evident. However, with increasing the proportion of the mineral content in the fertilization dose, a positive but not significant effect was noticed due to the addition of Hu with the mixture. Ertan (2007) studied the effect of foliar and soil fertilization with humic acid on tomato and found that both foliar and soil HA treatments positively affected fruit characteristics including fruit diameter, fruit height, mean fruit weight and fruit number per plant. According to Selim *et al.* (2009), application of humic substances through drip irrigation enhanced potato tubers yield, starch content and total soluble solids. Taha *et al.* (2006) concluded that humic substances gave the highest values of available nutrients, yield and nutrient uptake by wheat plant grown on different Egyptian sandy soils.

Humic substances have been shown to increase the uptake of nitrogen by plants, and to increase soil nitrogen utilization efficiency (Yusuf et al. 2009). It can also enhance the uptake of potassium, calcium, magnesium and phosphorus (Arancon *et al.* 2006).

Water and nitrogen use efficiency

Increasing the mineral content in fertilizer mixtures had a positive effect on the value of water use efficiency (WUE). The highest values were realized with the plants that received the fertilizer mixture 3/4 NPK + 1/4 ChM. Addition of Hu with the fertilization treatment NPK 100% in mineral form had insignificant effect on values of water use efficiency of both maize and bean plants. El-Gindy and Abdel Aziz (2003) reported that the highest value of WUE was (1.3 kg/m^3) for corn crop under drip irrigation system. The drip irrigation saved about 20.3% from water requirement compared to sprinkler irrigation system. Zotarelli et al. (2009) evaluated the interaction between N-fertilizer rates and irrigation scheduling on yield and irrigation water use efficiency (iWUE). The surface drip irrigation treatment required 15-51% less water when compared to conventional treatments.

Also, increasing the mineral content in fertilizer mixtures had a positive effect on the values of nitrogen use efficiency (NUE). The highest value for maize grain yield (17.9 kg kg^{-1}N), and for bean seed yield (53.4 kg kg^{-1}N) was realized with the plants that received the fertilizer mixture 3/4 NPK + 1/4 ChM. Addition of Hu with the fertilization treatment NPK 100% in mineral form had insignificant effect on values of water use efficiency of both maize and bean plants. Neilsen et al., (2002) and Neilsen and Neilsen (2006) showed that scheduling of irrigation with fertigation in high density apple orchards improved the efficiency of fertilizer used by 10 to 38 percent. In this respect, Thomas et al. (2003), with cauliflower and broccoli grown on sandy loam or finer soils and fertigated through subsurface drip irrigation concluded that yield and quality, N uptake in the above ground biomass and N use efficiency were significantly affected. The nutrient-uptake efficiency with mineral-nutrient applications through the irrigation stream, according to (Mustafa et al., 2006 , Akimasa and Uehara 2007) ,was increased substantially.

Table 1 Water use efficiency (Kg/m^3) by maize and bean

Treatments	Maize			Bean		
	Biomass	Straw	grains	Biomass	Straw	grains
NPK	2.165	1.399	0.766	1.576	1.282	0.294
3/4NPK + 1/4ChM	3.325	2.662	0.663	2.675	2.062	0.613
1/2NPK + 1/2ChM	3.665	2.956	0.709	3.283	2.527	0.756
1/4NPK + 3/4ChM	3.324	2.679	0.645	2.714	2.114	0.600
ChM	3.240	2.641	0.599	2.817	2.204	0.613
NPK + Hu	2.815	2.259	0.556	2.419	1.807	0.612
3/4NPK + 1/4ChM + Hu	3.394	2.728	0.666	2.878	2.090	0.788
1/2NPK + 1/2ChM + Hu	3.846	3.088	0.758	2. 860	2.204	0.656
1/4NPK + 3/4ChM + Hu	3.410	2.784	0.626	2.705	2.175	0.530
ChM + Hu	3.281	2.643	0.638	2.454	1.900	0.554

Table 2 Nitrogen use efficiency (Kg kg^{-1}N) by maize and bean

Treatments	Maize			Bean		
	Biomass	Straw	grains	Biomass	Straw	grains
NPK	79.233	63.433	15.800	190.700	147.00	43.700
3/4NPK + 1/4ChM	87.350	70.458	16.892	230.350	180.200	50.150
1/2NPK + 1/2ChM	79.217	63.842	15.375	204.650	150.750	53.900
1/4NPK + 3/4ChM	77.192	62.925	14.267	199.900	157.150	42.750
ChM	67.108	53.850	13.258	170.850	128.850	42.000
NPK + Hu	80.185	64.447	15.738	183.081	141.601	41.480
3/4NPK + 1/4ChM + Hu	90.876	72.965	17.911	202.707	149.347	53.360
1/2NPK + 1/2ChM + Hu	80.565	65.785	14.780	191.828	147.398	44.430
1/4NPK + 3/4ChM + Hu	77.527	62.456	15.071	171.344	135.424	35.920
ChM + Hu	76.195	62.415	13.780	167.927	130.387	37.540

Conclusion

It has been established that integrated mineral and organic fertilization through irrigation (fertigation) increased the measured vegetative growth parameters, yield, nutritional status and both water and nitrogen use efficiency by maize and faba bean plants compared to sole application. Positive effects were recorded using mixtures of different organic and mineral proportions. Therefore, it is recommended to apply the fertilizer as mixture of the two forms taking into consideration the soil type, the irrigation system under use and also the economical factor.

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