Summary of the benchmark study on innovative techniques for sustainable nutrient management in horticulture and a European comparison of nutrient legislation in horticulture

1. Innovative techniques for sustainable nutrient management in horticulture

1.1 Benchmark study on innovative techniques

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. 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, soil bound and soilless). The study mainly focuses on a better water quality through reducing nitrogen (N) and phosphorous (P) losses. 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. The necessary information was gathered by visits to the selected regions between October 2012 and August 2013. The benchmark study was conducted by ILVO, Ghent University, PSKW, PCG, PCS and Inagro, and was financed by the Flemish Land Agency (VLM).

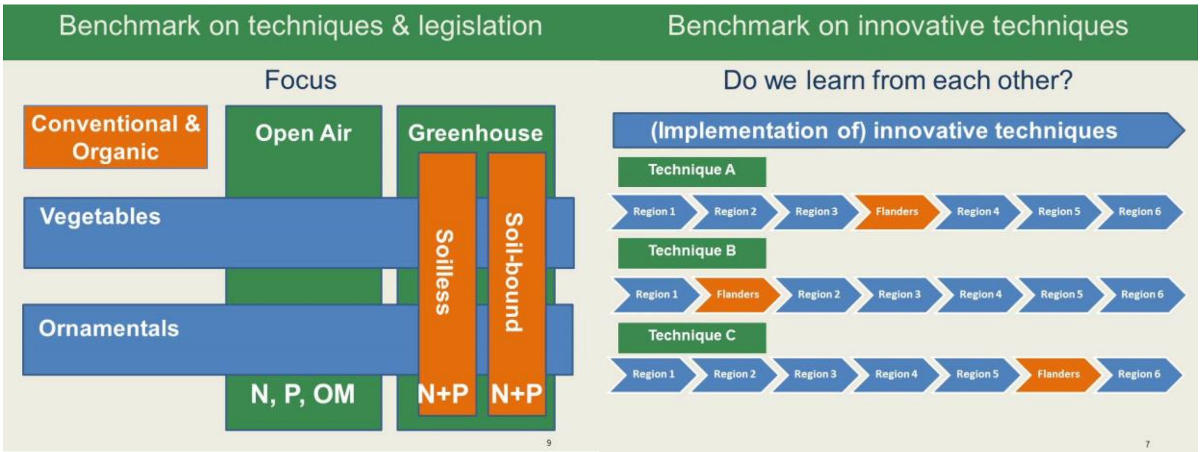


Figure 1 Schematic overview of the focus and approach of the benchmark study on innovative techniques.

Table 1 Overview of the visited countries/regions and institutes.

Land (Regio)	**Instelling**
The Netherlands	PRI Wageningen
	PPO Randwijk
	PPO Vredepeel
	BLGG
	Wageningen UR glastuinbouw, Bleiswijk
	Proeftuin Zwaagdijk
	Grosci 2013
France (Brittany)	CTIFL/SECL (Station d'essais de cultures légumières)
	STEPP Bretagne (Station technique d'expérimentation des plantes en pot)
	CATE (Comité d'action technique et économique) + Chambre d'agriculture du Finistère
Spain (Almeria, Murcia and Valencia)	Coexphal, Universidad de Almería, Research Station Las Palmerillas, IFAPA La Mojonera, Primaflor Groep, IVIA
Belgium (Wallonia)	CEHW
	CRA en Ulg in Gembloux
Germany (Rheinland-Pfalz, Brandenburg and Sleswig-Holstein)	DLR-Rheinpfalz
	YARA Research centre
	IGZ Grosbeeren
	VuB
Switzerland	Agroscope, FiBL, OFAG
Italy	University of Perugia, CRA Metaponto
	NEV2013
Poland	Research Institute of Horticulture, Agricultural Advisory Centre
Denmark	Aarhus University -Dept. of Food Science
Germany (Baden-Württemberg)	State Horticultural College and Research Institute (LVG)

1.2 A study with 4 steps

The project had 4 important steps (Figure 2):

1. Potential techniques and strategies
2. Fact sheets: characteristics of potential innovative techniques
3. Benchmark: degree of implementation, and assessment of potential application in Flanders
4. Research and extension needs

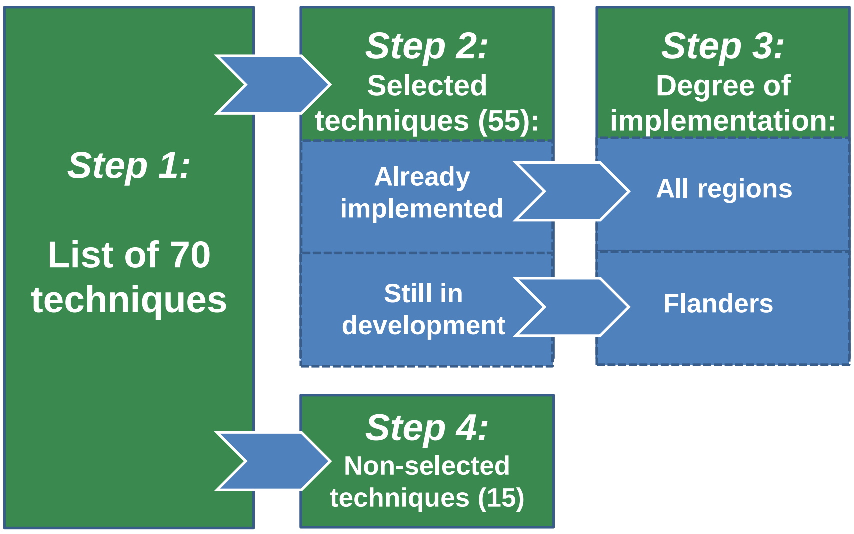


Figure 2 Schematic overview of the four-step approach of the benchmark study.

Step 1: List of potential techniques

A list with potential techniques and strategies within this benchmark study was made based on available reports. The contacted regions were asked to choose relevant techniques from this list for filling the questionnaires. This list was completed with new techniques during the study.

Step 2: Techniques selected by the regions

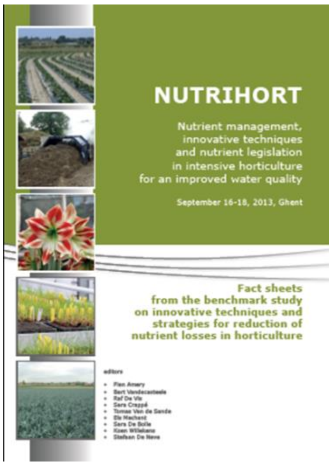
The benchmark is based on standardized questionnaires, i.e. one questionnaire for each technique or strategy for nutrient loss reduction in horticulture.

The benchmark study started from a bottom-up approach.

Contact persons from a visited region indicated which techniques (from the list from Step 1) they found to be relevant or which new techniques they use. Based on this information and after consultation with the contact persons, a selection of techniques was made.

We assembled 55 examples of innovative techniques in Flanders and the visited regions. The fact sheets based on these questionnaires are available as a book:

NUTRIHORT - Nutrient management, innovative techniques and nutrient legislation in intensive horticulture for an improved water quality. September 16-18, 2013, Ghent. Fact sheets from the benchmark study on innovative techniques and strategies for reduction of nutrient losses in horticulture.



Step 3: Implementation in Flanders and the other regions

In total 55 questionnaires were collected. These questionnaires were categorized depending on the degree of implementation. For the questionnaires on innovations already applied in practice for at least some of the regions, we assessed the degree of implementation in the visited regions and in Flanders. 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. Implementation degree is assessed in 4 classes.

For the other techniques, research is still ongoing and implementation by growers has not yet started. For these innovative techniques not yet applied, we evaluated the coverage of these topics by ongoing research and assessed their applicability for Flanders based on a score for technical feasibility and economic feasibility.

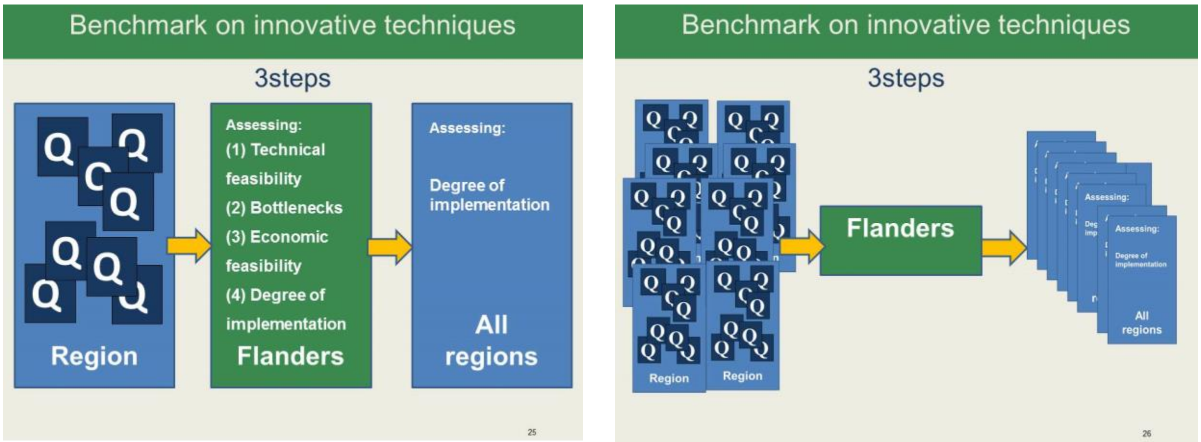


Figure 3 Schematic overview of Step 3 of the four-step approach of the benchmark study on innovative techniques (Q: questionnaire on innovative techniques).

Step 4: Further research needs or blind spots?

In the frame of the benchmark study, first a list of potential techniques was made, after which the visited regions could select techniques for which they prepared fact sheets. Some potential techniques were not selected by any of the regions (Table 2). These techniques are possibly not applicable to horticulture, or are currently not yet investigated or implemented in horticulture. Table 2 could be evaluated regularly, in order to identify research and extension needs. Except for the techniques listed in Table 12, research and extension needs were formulated from the benchmark-exercise (see 1.4 and 1.5).

Table 2 Overview of the non-selected techniques for the benchmark-study

Non-selected techniques for the benchmark study
Postpone the organic manuring until just before sowing/planting
Choose plant species with a relatively low N need
Determine the nitrogen working coefficient (efficient N content) of manure
Add a nitrification inhibitor to the manure
Choose the appropriate organic manure: N/P ratio, manure type and processed products for the crop
Replace slurry manure by farmyard manure
Finetune the equipment when performing row fertilisation and manure application
Use GPS to avoid overlap
Use fixed trails
Visualise the soil per parcel by soil mapping
Determine the need of other nutrients than N and P for the crop
Install a level controlled deep drainage system
Avoid moisture or percolation water coming out of the substrate during crop switching
Reduce water use by means of crop evapotranspiration models
Treat process water with algae
Collect the cleaning water of filters
Dimension the rain water collector to the crop water use
Adapt the water gift by use of continuous drain measurement
Treat recirculation water by use of a rapid sand filter
Use organic material with a high C/N ratio
Treat recirculation water by use of a slow sand filter
Select a crop with deep roots after a crop with superficial roots
Use iron coated sand (in soil, around drain system) for capturing of P
Use organic material with low P content

1.3 Results of the benchmark study

This benchmark study assembled 55 examples of innovative techniques in Flanders and the visited regions. Those examples of innovative techniques were clustered and divided into two categories: 1) 19 cluster techniques already effectively implemented in one or more regions, and 2) 11 cluster techniques still in development or just ready for use in practice. The implementation degree in Flanders was assessed for all these techniques and compared with the other regions. We assessed the applicability for Flanders and the need for additional research on the innovative techniques not yet applied.

The first category of techniques are related to: crops and crop rotations, the use of catch crops, crop residues management, reduced tillage, the use of local varieties, re-use of drain water, planning and application of fertilisation, the use of different types of fertilisers, closed cultivation constructions, measurement of nitrogen demand based on soil analyses, models and crop measurements. These techniques are already applied in Flanders or are a topic of ongoing research.

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.

Most of the innovative techniques are currently applied in practice or still under research in Flanders and other regions. The stringent nutrient legislation in Flanders is an important driving force for implementation of innovative techniques, both for open air and greenhouse horticulture. Research results should be communicated to all stakeholders involved. 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 organized within European collaboration, as issues are relevant for several of the visited regions.

Most techniques focused on reducing N losses. Currently less focus is on reducing P losses from greenhouse or open air horticulture, and maintaining or increasing organic carbon levels in horticultural soil. However, nutrient legislation in Flanders and the Netherlands has shifted the focus from N to P as the limiting element for organic fertilizer application. By reducing the P input by organic fertilizers and manure, we should take care for maintaining optimal organic carbon levels in arable soils.

1.4 Bottlenecks and actions to increase suitability and implementation of innovative techniques

Table 3 gives an overview of the bottlenecks and actions needed to increase the suitability and implementation of the innovative techniques mentioned in Table 1 in Flanders. Furthermore, the technical and economic feasibility are indicated. This table is an example on how the focus group can further explore how to increase the implementation of these techniques, and select the most cost-effective solutions.

Table 3 Overview of possible bottlenecks and actions needed to increase the suitability/implementation of the innovative techniques (Table 1). 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) (Vandecasteele et al., 2014).

	Technique	**Bottlenecks**	**Actions needed to increase suitability/implementation of technique**	**Technical feasibility (assessed for Flanders)**	**Economic feasibility (assessed for Flanders)**
A	Crop rotations	Knowledge-intensive; For specialized horticultural firms, adjusting crop rotation is difficult from an economic point of view; Adjusting crop rotation needs sufficient land area; More attention to planting deep-rooting crops in autumn;	Decrease specialization, use broader rotations (including non-vegetables?) ==> is often difficult; Exchanging land area?	2	0
B	Catch crops	Knowledge-intensive; Some vegetables need N late in the year and are harvested late in the year. Sowing catch crops is not always possible.	Knowledge of matching catch and vegetable crops (effect on vegetable yield?): these should not come from the same familiy of plants; Machine adjustment needed to sow between the rows; More knowledge about the risk for diseases whenleaving crop residues after harvest is needed;	2	2
C	Local varieties	Knowledge-intensive; Insufficient research results; Higher risk for lower production; Variety research does not take N efficiency into account; Crop residue not winter hardy (risk for N leaching)	N efficiency could be included in variety research	1	1
D	Management of crop residues after harvest	Extra costs; Labour intensive; Insufficient research results; Adjusting crop rotation could be a good solution regarding crop residues; Removal of crop residus is very expensive; Not incorporing crop residues could reduce N leaching, but can increase crop diseases and can induce odour nuisance; What can be done with the collected crop residues?		-1	-1
E	Reduced or ploughless tillage	Knowledge intensive; Not incorporating cauliflower (multiple cropping) crop residues can induce rhizoctonia;	Crop rotation should be sufficiently broad in order to not have disease pressure increased. Research needed to investigate wether this is practicable;	-1	1
F	Drain water recirculation	For some vegetable crops, higher risk for lower crop quality and/or higher disease pressure;	Development of new techniques for desinfection and decomtamination of drain water; Sensitization about advantages of recirculation (fertilizer and water savings); Delivering possible solutions to avoid drain water;	2	2
G	Fertilizer planning	In Flanders, fertilizer planning and registering is compulsary, but fertilization is often planned according to own production of animal manure instead of crop need;	Sensitization about reduced fertilizer use (without yield decrease) when applying the KNS-system;	2	2

Table 3 Continued

	Technique	Bottlenecks	Actions needed to increase suitability/implementation of technique	Technical feasibility (assessed for Flanders)	Economic feasibility (assessed for Flanders)
H	Split the N dose for a higher efficiency	Knowledge intensive; Soil sampling for additional fertilizer application needs to occur at the right moment; One has to follow a fertilizer advice system. This system needs to take mineralisation, site properties and history, release from crop residues from early cultivation into account;	More advice is needed to give farmers more insight into the soil sampling (for additional fertilizer application) results; Sensitization about reduced fertilizer use (without yield decrease) when applying the KNS-system;	2	2
I	Fertilizer placement	No specific bottlenecks, except burning of developing roots;	More thourough demonstration of the possibilities; Support for adjustment of planting machines;	2	2
J	Foliar N fertilizers as top dressing	Knowledge intensive; Insufficient research results; Higher risk for lower production or crop quality; Risk for burning of leafs;	Foliar N fertilizers with a very low osmotic pressure, through which larger amounts of fertilizer can be given without a risk for burning; Sensitization should focus on reducing soil N residue, rather than fertilizing optimally towards the end of the season;	1	1
K	Commercial organic fertilizers	Sometimes more expensive;		1	-1
L	Ammonium-stabilized fertilizers	Sometimes more expensive; On the one hand, slower functioning could be limited; on the other hand, N release can take too long;	Sensitization;	2	2
M	Controlled release fertilizers	Too expensive for many growers; N release can take too long for fast growing crops; Climate has a large influence;		1	-1
N	Compost application as fertilizer	Legislation; Competition between compost and animal manure; In Flanders, insufficient amounts of compost are available for widespread application in agriculture; currently the use of compost in horticulture is limited; Working N in compost?; Insufficient research results for P;		2	2
O	Fertigation	Knowledge and maintenance intensive, expensive;	Knowledge needed about uptake of nutrients and water in order to avoid leaching because of fertigation.	1	0
P	Irrigation based on moisture sensors	Expensive, knowledge intensive, insufficient research results;	Development of model driven determination of optimal irrigation/fertigation based on soil moisture content and crop nutrient/water uptake.	1	1
Q	Determine the N need by soil determinations	Knowledge intensive, expensive. Need for a large number of reference plots to monitor soil nutrient residu, in order to capture the large varability in precipitation and soil types;	Despite the use of a N advice system based on soil determinations, more information is needed to implement this technique on a large scale in Flanders. Advice should be site specific, taking into account site properties and history. Ideally, soil sampling linked to a fertilizer advice with sufficient explanation and support should result in more knowledge about the soil. Bringing this knowledge to the farmer is a major challenge. Development and implementation of model driven advice systems;	2	2
R	Determine the N need by crop determinations	Knowledge and labour intensive, expensive, insufficient research results; Calibration is crop specific, and often also cultivar and soil specific; Crop varieties change quick, which asks permanent investments; A good result asks many measurements, and devices are expensive; Crop N shortage could also be due other factors than too little soil N (e.g. drought);	Research to possible combinations of crop and soil measurements, taking into account technical and economic feasability in relation to parcel sizes in Flanders;	-1	0

1.5 Future research needs

The benchmark study and the conference allow for defining the most important future research needs:

- Research should focus on a combined assessment of crop nitrogen (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.
- Removal of crop residues is a valuable option for significant reduction of N leaching. A link with the bio-based economy seems to be 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 fertilisers, manure and compost for combining a reduction of phosphorus losses with a sufficiently high organic carbon level in arable soils.
- There is room for improving the use of water treatment techniques for processing drain water surplus.

The next step was an action plan for horticulture in Flanders related to the application of innovative cultivation and fertilisation 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.

1.6 Future extension needs

In many EU member states (including some visited regions), farmers are not aware of (results of) measurements on ground- and surface water. In Flanders, farmers are informed through different channels about their role regarding water quality.

Farmers should be convinced to use less fertilizer. Those who are in the vanguard could implement reduced fertilizer use in demonstration trials. In this way, they can show that it is feasible to reduce fertilizer use. However, these demonstration trials would always reach the same group of farmers. For this reason it would be necessary to reach other farmers for example through individual assistance. When advising farmers it is important to encourage them and to convince them to change their fertilizer practices.

Which techniques do we need to further elucidate?

- Well-reasoned additional fertilizer application (e.g. KNS);
- To encourage farmers to develop specific knowledge regarding their parcels and farm management in general through the use of analyses of soil, manure, etc.:
    - Through soil sampling knowledge regarding soil mineralization can be increased, and fertilizer application can be adjusted based on this information;
    - Analysis of the animal manure gives information about its nutrient content, and this information can be taken into account when applying organic fertilizer;
    - Use of a ‘nitrogen window’ to adjust additional fertilizer applications;

- Farmers should take the soil samples (they are required to take) to increase knowledge on their parcels, and they should sample the soil on the most relevant moment for fine-tuning of the fertilizer application (instead of taking soil samples because of they are required to do so);
- Fertilizer placement (row, point, etc.) for as many crops as possible:
  - When machines are self-adjusted, one has to make sure that fertilizer application occurs close to the plant, not in the middle of two rows;
  - Role of constructors?
- Well-reasoned use of cover crops, depending on the rotation;
- Tuning fertilizer choice to application moment:
  - Slow-release fertilizers: when planting long-term crops;
  - Fast-release fertilizers: for short-term crops and for additional fertilizer application;
- Many techniques are still being investigated (e.g. management of crop residues), and are not economic feasible. There is a need for practical implementation of these techniques and for sufficient incentives to implement these techniques in practice.

2. European comparison of nutrient legislation in horticulture

The second part of the benchmark study compared the legislation on nutrient management in horticulture in different European regions. It was a difficult task because the legislations are rather complicated. Besides a lot of exceptions are included in most of the legislations. General conclusions are that the area of Nitrate Vulnerable zones and prohibition periods of nutrient applications are quite different between countries. Maximum allowed N application rates are expressed as efficient N in some countries and in others as total N or are set in kg N/ton produced fresh, marketable yield. The N fertilisation standards of several vegetables and ornamental crops show large differences between regions. Phosphorus fertilisation limits are only introduced in a limited number of countries although the phosphorus concentration in surface waters in a lot of regions is too high to prevent eutrophication. 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 potentially 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 proved to be effective in the field.
One of the outcomes of the benchmark study is the proposal for common actions to reduce the nitrogen losses in an equitable way and reduce the often large differences between legislation and its implementation in practice throughout Europe.

3. International conference Nutrihort presents innovative techniques for sustainable nutrient management

On 16, 17 and 18 September 2013, scientists, policy makers and other experts discussed the challenges of sustainable nutrient management in the horticultural sector during Nutrihort in Ghent. The challenge: a viable horticulture and improved water quality.

Horticulture is an important economic sector, but at the same time it has a major impact on soil and water quality, both in Flanders and in other regions within the European Union and beyond. A sustainable balance between crop quality demands and the environment is a major challenge. Therefore, the European Commission had requested Flanders to organise an international conference focusing on nutrient management, legislation and innovative technologies for an improved water quality in vegetable and ornamental production. During Nutrihort 150 scientists, policy makers and other experts from 17 countries have met at the Faculty of Bioscience Engineering of Ghent University.

The range of contributions was impressive. Results for various cultivation systems with a variable degree of complexity and implementation were presented. Besides research results as such, some presenters focused on how to combine research and extension for increasing the implementation of new techniques. One of the key messages is that convincing the farmer to change habits is a bottleneck.

The conference reflected the state of the art in sustainable and innovative techniques of vegetable and ornamental plant production. Similar techniques have been assembled in the benchmark study.

The main question participants have tried to answer is how cultivation and fertilization techniques in conventional and organic vegetable and ornamental production should be adapted to achieve the (European) legal water quality objectives. The conference highlighted the latest research results from different perspectives. The major challenge is to ensure that knowledge is transferred to the growers. Besides this problem of knowledge acquisition, the growers are faced with the market requirements in terms of quality and quantity. These requirements are not always easy to combine with the water quality objectives. Energy, water and pesticide costs are more important for growers than the cost of nutrients. However, a change can be observed: nowadays nutrient management is put high on the agenda in innovative horticulture.

Nutrihort not only focused on open air horticulture, also greenhouse horticulture had a prominent role. This sector constantly seeks new state of the art techniques for recycling nutrients. Water treatment and quality of the used water in combination with fertilisers play a crucial role in obtaining the environmental objectives and marketing a quality product. Nutrient use efficiency is also becoming increasingly important in greenhouse horticulture.

Nutrihort confirmed that there is a need for clear rules and codes of good practices, but they cannot simply be copied from the other agricultural sectors (arable, pasture and forage crops). An innovative horticultural sector needs customisation by growers, but also by policy makers.

When open air horticulture wants to improve water quality, lower nitrogen and phosphorus losses during the cropping period and after harvest are needed. This challenge summarises all previous ones. Nutrihort has managed to identify combinations of different strategies to decrease nitrogen and phosphorus losses in horticulture.

NEV 2013, the benchmark study and the Nutrihort conference have answered some questions, but still more research is needed. Besides the scientific knowledge, this conference has pointed out the importance of the knowledge transfer to the farmers. In this matter, opportunities may also be provided by a 'European Innovation Partnership' (EIP). Common actions should be proposed to reduce the N and P losses in an equitable way and reduce the often large differences between legislation and its implementation in practice throughout Europe.

4. Reports

This project "Benchmark study and European conference on innovative techniques and strategies for reduction of nutrient losses in horticulture" resulted in 4 reports as addendum to the final report:

- NUTRIHORT - Nutrient management, innovative techniques and nutrient legislation in intensive horticulture for an improved water quality. September 16-18, 2013, Ghent. Book of Abstracts
- NUTRIHORT - Nutrient management, innovative techniques and nutrient legislation in intensive horticulture for an improved water quality. September 16-18, 2013, Ghent. Proceedings
- NUTRIHORT - Nutrient management, innovative techniques and nutrient legislation in intensive horticulture for an improved water quality. September 16-18, 2013, Ghent. Fact sheets from the benchmark study on innovative techniques and strategies for reduction of nutrient losses in horticulture
- Internationale benchmark van nutriëntenregelgeving en van innovatieve cultiveringstechnieken voor tuinbouw met betrekking tot waterbescherming. Verslagen van de bezoeken aan de regio's. (In Dutch)

You can find the 4 sub-reports belonging to the final report on
http://www.ilvo.vlaanderen.be/nutrihort/LeftMenu/Reports/tabid/7454/Default.aspx