EIP-AGRI Focus Group

Fertiliser efficiency - horticulture in open field

Final report

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Abbreviations

CRF	controlled release fertilisers
EIP	European Innovation Partnership
EIP-AGRI	European Innovation Partnership for Agricultural Productivity and Sustainability
FG	Focus Group
KISS	keep it short and simple
K_2O	potassium oxide
N	nitrogen
NH_3	ammonia
NO_3^-	nitrate
N_2O	nitrous oxide
NUE	nitrogen use efficiency
P	phosphorus
P_2O_5	phosphate
SOM	soil organic matter

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1 Summary

The Focus Group on 'Fertiliser efficiency – focus on horticulture in open field' was launched as part of the activities carried out under the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI). The Focus Group brought together 20 experts, from throughout Europe. During the two Focus Group meetings, the experts worked on the following question: 'How to use innovative fertilisation and nutrient recycling to solve the conflict between the need for crop fertilisation and legislative requirements regarding water quality?'.

To facilitate the discussion during the first Focus Group meeting, a starting paper on **innovative techniques** in vegetable soil-grown open field systems was prepared. The starting paper includes innovative techniques for soil-grown horticulture that are already implemented in some regions or are ready to be used. The experts indicated that costs, knowledge gaps in research and knowledge gaps for growers are the three main **bottlenecks** impeding the adoption of innovative techniques. The experts also evaluated the rate of implementation of these innovative techniques on farms in their region. In more than 40% of the evaluated regions, crop rotation, fertigation, soil sampling to determine nitrogen need, fertilisation planning, splitting nitrogen doses and fertiliser placement are techniques which have a high implementation rate, that is to say more than 20% of the farms are implementing them. When the implementation rate and the bottlenecks were considered together, it was clear that various bottlenecks inhibited the implementation of some, but not all, innovative techniques. Costs were not frequently mentioned as a bottleneck for the techniques with a high implementation rate, with the exception of fertigation.

During the first Focus Group meeting, each expert was asked to prioritise the innovative techniques which: (I) 'save/optimise fertiliser use', (II) 'reduce nitrogen and phosphorus leaching' and (III) 'have the most rapid environmental impact while maintaining yield and quality'. In all 3 exercises, fertilisation planning, soil sampling to determine the nitrogen need, and irrigation based on a moisture sensor were defined as priorities by the experts, but these techniques have a different implementation rate and number of bottlenecks. Fertilisation planning is implemented at a high rate (more than 20% of the farms) in 14 of the 16 expert regions and experts found it had very few bottlenecks. Soil sampling to determine the N need is implemented at medium rate (2-20% of the farms) and at a high rate in 6 and 7 of the 16 regions respectively. Knowledge intensiveness for farmers (accessing and dealing with large quantities of varied knowledge) is the major bottleneck restricting the use of this technique. The estimation of the mineralisation rate of fields was also considered as a particular difficulty. Irrigation based on moisture sensors has a low implementation rate (<2% of the farms) in 12 of the 16 regions although experts indicated few bottlenecks for this technique. This may be because the low cost of water reduces the incentive to optimise water use. As most innovative techniques are difficult to implement without making additional management changes and can depend on region and crop, the Focus Group did not make a list of the 'most promising' techniques. The prioritisation of innovative techniques was used as a starting point to select the topics for a series of mini-papers which were written on recommended innovative methods to optimise fertiliser use and nutrient recycling. The mini-papers were produced by one or more Focus Group experts and they included a description of the topics, identified bottlenecks, lessons learned and necessary actions.

During the second Focus Group meeting, the experts discussed the mini-papers and summarised necessary actions to decrease nutrient losses. They found that communication with growers is beneficial from the very start of idea development through to initial implementation. Through a multi-actor approach, the growers' requirements and problems can be determined. During the development of innovative techniques, a bottom-up identification of the innovation needs of different stakeholders is essential. The user-friendliness of practical techniques has to be assessed and the economic profitability

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and feasibility at farm level have to be taken into account. Field trials on growers' fields allow demonstration under local and relevant weather and soil conditions. Applications for smartphones can assist growers by giving interesting information and increasing the user-friendliness of the innovative techniques. The collection of proposals for action also include proposals for topics of Operational Groups:

- Fertilisation advice and planning
- Precision application of fertilisation
- Fertigation
- New organic fertilisers
- Crop rotation
- Incentives to improve soil quality
- Managing crop residues
- Simulation models

Other Operational Groups to test solutions and opportunities might focus on system approaches or on organisation of targeted knowledge exchanges.

Also several common themes that would improve the adoption of innovative techniques were identified. These were:

- Need for the integration of different techniques,
- Need for detailed information on nutrient dynamics and water uptake,
- User-friendliness of the innovative techniques.

The state of play, innovation process and fail factors of these common themes were discussed and some recommendations were given. The main recommendations are:

- Involve growers and advisers from the start in the development of a technique,
- Develop innovative techniques using sound science, considering practical application issues and exploiting ideas from growers,
- Implement the KISS (keep it short and simple) strategy,
- Organise feedback loops and continuous communication with growers and advisers after initial implementation of a newly developed technique
- Formulate clear messages in growers' language and explaining the underlying principles of the innovative techniques in order to support their correct use.
- Collect and share available data between regions, research groups and extension services on nitrogen and phosphate uptake and offtake and of crop water requirements,
- Construct integrated solutions (for instance using teams of advisers with different expertise) to assist in the implementation of a system approach.

This report presents the context and the results from this Focus Group. It includes its outcomes, with the goal to support the implementation of the EIP-AGRI.

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2 Introduction

The Focus Group (FG) on 'Fertiliser efficiency – focus on horticulture in open field' was launched by the European Commission in 2014 as part of the activities carried out under the European Innovation partnership for Agricultural Productivity and Sustainability (EIP-AGRI).

Intensive production systems use a high level of external resource inputs per area and time of the growers. Vegetable production systems are at the upper limit of production intensity, relying on the high economic value of the product (Nicola *et al.*, 2013). Considerable NO_3 leaching is a common occurrence in vegetable production in the open field where low nitrogen use efficiencies (NUE) are often combined with excessive irrigation, short growing cycles and shallow rooting crops. Within the European Union, there is an increasing need to reduce NO_3^- leaching losses which are associated with NO_3^- contamination of ground- and surface water. Additionally, there is a need to reduce other nitrogen (N) losses such as nitrous oxide (N_2O) emission, ammonia (NH_3) volatilisation and erosion. Consequently, there is a strong requirement to significantly improve NUE in intensive vegetable production (Thompson *et al.*, 2013).

Phosphorus (P) is a non-renewable resource and an essential nutrient for plants. It is a pollutant for continental aquatic ecosystems, as it triggers eutrophication. Horticultural systems are often characterised by P surpluses and P accumulation in soils because of high P fertilisation rates and low P offtakes from the crops. More sustainable use of P in horticultural systems is needed, including more efficient use, recycling and reducing losses (Pellerin & Nesme, 2013).

3 Brief description of the process

3.1 Objectives and main tasks of the Focus Group

The Focus Group on 'Fertiliser efficiency – focus on horticulture in open field' brought together 20 experts (see Annex 7.1) with the purpose to explore practical, innovative solutions and best practices to problems or opportunities and give recommendations for interactive innovation projects that can be carried out by Operational Groups or other formats. The objectives of this EIP-AGRI Focus Group are visualised in Figure 1.

The main question of the Focus Group on 'Fertiliser efficiency – focus on horticulture in open field' is: How to use innovative fertilisation and nutrient recycling to solve the conflict between the need for crop fertilisation and legislative requirements regarding water quality?

The main tasks of the Focus Group were:

- Identify how crop quality and yield is influenced by legal requirements (from the Nitrates Directive and the Water Framework Directive) and by which elements in particular (application standards, closed periods, organic matter calculation);
- Identify and compare systems to reduce fertiliser use without affecting yield and quality while taking into account cost-effectiveness and other factors like temperature, humidity, soil etc.;
- Identify and compare innovative systems that can help to solve the conflict between crop quality and quantity demands and the legislative requirements, e.g. innovative fertilisation techniques, crop residue management, irrigation management, crop rotation, organic carbon and by-

products management, N and P dynamics in relation with soil quality, the use of slow release fertilisers and catch crops, nutrient spreading or placement, tillage, other;

- Identify fail factors that limit the use of the identified techniques/systems by farmers and summarise how to address these factors.

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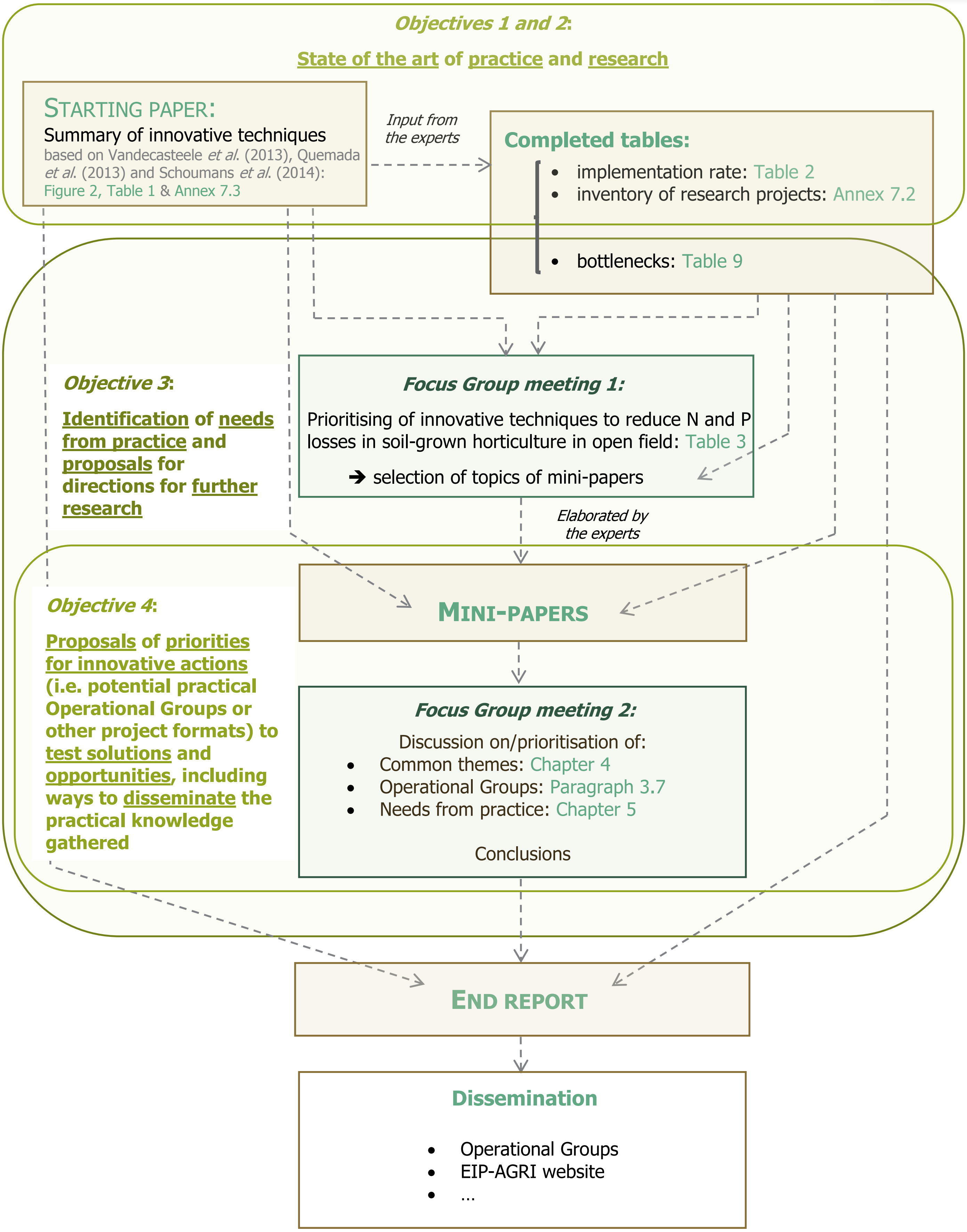

Figure 1 Process of the Focus Group on 'Fertiliser efficiency – focus on horticulture in open field'

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3.2 Starting paper and Focus Group meetings

The process of the Focus Group on 'Fertiliser efficiency – focus on horticulture in open field' is illustrated in Figure 1. To facilitate the discussion during the first Focus Group meeting on 4-5 June 2014 in Alicante (Spain), a starting paper on innovative techniques on farm and field scale in vegetable soil-grown open field systems was prepared. The starting paper includes **innovative techniques** that are already implemented in some regions or are ready for use in **soil-grown horticulture** (paragraph 3.3). Before the first Focus Group meeting the experts were asked to indicate the implementation rate in their regions (paragraph 3.4) and the **bottlenecks** related to these innovative techniques (paragraph 3.5).

During the first Focus Group meeting each expert was asked to prioritise the recommended techniques which: (I) 'save/optimise fertiliser use', (II) 'reduce N and P leaching' and (III) 'have the best possibilities to work on to improve further implementation in practice with respect to yield and quality' (paragraph 3.5). Mini-papers were written to complete the state of the art of the most promising innovative techniques (paragraph 3.6). These are short papers written by one or small groups of Focus Group experts on a specific topic.

During the second Focus Group meeting on 21-22 October 2014 in Almeria (Spain) the experts discussed the mini-papers and summarised the needed actions to decrease the nutrient losses and the lessons learned from the discussions. The experts also assessed the needs from practice (paragraph 5). The collected proposals for action include proposals for topics of Operational Groups (paragraph 3.7). This report presents the context and the results from this Focus Group. It includes its outcomes, with the goal to support the implementation of the EIP-AGRI at different levels. The common themes that permeated the discussion are described in more details in chapter 4.

3.3 Inventory of innovative techniques in vegetable soil-grown open field systems

Three inventory studies were used to determine innovative techniques to reduce nutrient losses and the bottlenecks to be solved in order to increase their implementation (Table 1):

1) 'Benchmark study on innovative techniques for nutrient management in horticulture' (Amery *et al.*, 2013; Vandecasteele *et al.*, 2013): record of techniques currently implemented in practice in Belgium, the Netherlands, France, Spain, Italy, Germany, Denmark, Switzerland and Poland (techniques A to R in Table 1) and ready for implementation (techniques S to Y),
2) 'Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yields' (Quemada *et al.*, 2013): additional technique AA in Table 1,
3) The COST action 869 'Mitigation options for nutrient reduction in surface water and groundwaters' (Schoumans *et al.*, 2014): techniques AB to AD in Table 1.

The impact on water use and long-term effect on soil quality (i.e. organic matter content) of the innovative techniques was also evaluated (see **starting paper**). The innovative techniques can be applied during planting/sowing or during the growing period, but some techniques also have a longer term positive effect on the reduction of nutrient losses and often improve soil quality (Figure 2). A description and a link to fact sheets of the innovative techniques in Table 1 can be found in **Annex 7.3** (Table 8). Tables 6 and 7 in **Annex 7.2** give an overview of finished or ongoing European and national projects on nutrient management and the link with the above mentioned innovative techniques.

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Table 1 Inventory of the innovative techniques at farm and field scale in soil-grown open field horticulture (Source: EIP-AGRI Focus Group starting paper)

Category	Code†	Technique
Crops and crop rotations	A	Crop rotation
	B	Catch crops/cover crops/green manures
	C	Local varieties/varieties with higher nutrient use efficiency
	D	Management of crop residues after harvest
	E	Reduced or ploughless tillage
	S	Mulching
Drain water recirculation	F	Drain water recirculation
Fertiliser application	G	Fertilisation planning
	H	Split the nitrogen (N) dose for a higher efficiency
	I	Fertiliser placement
Fertiliser type	J	Foliar N fertilisers as top dressing
	K	Commercial organic fertilisers
	L	Nitrification inhibitor treated fertilisers
	M	Controlled release fertilisers (CRF)
	N	Compost application as fertiliser
	O	Fertigation
	AB	Manure treatment products
Irrigation	P	Irrigation based on moisture sensor
	V	Determine the N and water need based on a model
	AA	Other techniques for improving water management
Determine the N need	Q	Determine the N need by soil determinations
	R/T	Determine the N need by crop determinations
	U	Determine the N need based on a model
Other techniques	X	Soil amelioration with compost as a soil improver
	Y	Determine the phosphorus (P) need by soil determinations
	AC	Erosion control measures
	AD	Measures for soils with a high P load

†: the different techniques received a code:

* A to R: techniques currently used by farmers recorded by Amery *et al.* (2013) and Vandecasteele *et al.* (2013)
* S to Y: techniques ready for use listed by Amery *et al.* (2013) and Vandecasteele *et al.* (2013)
* AA: additional technique from Quemada *et al.* (2013)
* AB to AD: additional technique recorded by Schoumans *et al.* (2014)

Before/at start growing season

- Reduced/ploughless tillage
- Local varieties
- **Fertilisation planning**
- Split nitrogen dose
- Determine nitrogen need by soil determinations
- Fertiliser placement
- Fertiliser type (e.g. foliar, Controlled release fertilisers (CRF))
- **Manure treatment products**

During growing season

- Split nitrogen dose
- Determine nitrogen need by crop determinations
- Determine nitrogen need by soil determinations
- Fertiliser placement
- Fertiliser type (e.g. foliar, CRF)
- **Manure treatment products**
- **Irrigation based on moisture sensor**
- Other techniques for improving water management

End of growing season

- **Catch crops/cover crops/green manures**
- Management of crop residues after harvest

Long-term

- Crop rotation
- Fertiliser type (e.g. use of compost)
- Reduced/ploughless tillage
- Erosion control measures
- Measures for soils with high phosphorus load

Figure 2 Implemented innovative techniques for reduction of nutrient losses in soil-grown open field horticulture, applied within one growing season or in the long-term
(a mini-paper was written on the innovative techniques in bold)

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3.4 Implementation rate of innovative techniques

The Focus Group experts felt it was important to find out if the implementation rate for certain innovative techniques which are already in use could be increased. As well as identifying the bottlenecks restricting implementation (see 3.5), looking into the reasons for high implementation rate in a pioneer region might also give valuable information on the applicability of the innovative technique. Therefore, the implementation rate of the currently used techniques from the benchmark study (Amery *et al.*, 2013; Vandecasteele *et al.*, 2013) was evaluated for the different regions (Table 2). The table shows that there is a very wide spread of techniques as at least one or more techniques from each of the categories of techniques are applied at a high rate (i.e. implemented at >20% of the farms) in at least 7 regions, with the exception of irrigation.

There are a number of techniques which show a high implementation rate in 40% of the evaluated regions, these are: crop rotation, fertigation, soil sampling to determine the N need and all three example techniques of fertilisation application i.e. fertilisation planning, splitting N doses and fertiliser placement.

3.5 Evaluation of innovative techniques

Experts were invited to identify bottlenecks inhibiting a higher implementation rate and cost-effective factors to increase the implementation of the examples of innovative techniques (Table 9 in annex 7.4). The bottlenecks can be used to further explore how to increase the implementation of these techniques, and to select the most cost-effective solutions.

Many bottlenecks were identified for each technique. The 3 most common bottlenecks were:

- Costs
- Knowledge gaps in research
- Knowledge gaps of growers

Increased risk of crop quality reduction had the lowest reported bottlenecks.

Considering both the implementation rate (Table 2) and the bottlenecks (Table 9 in annex 7.4), these data show that a high implementation rate is not necessarily linked to a low amount of reported bottlenecks (Table 3). Six techniques are implemented at a high number of farms in at least 7 regions:

- Crop rotation
- Fertigation
- Split the N dose for a higher efficiency
- Fertiliser placement
- Determine the N need by soil determinations
- Fertilisation planning

They vary significantly in terms of the number of bottlenecks, for example experts identified over 14 bottlenecks for crop rotation and fertigation, and only 5 bottlenecks for fertilisation planning.

Costs were not frequently mentioned as a bottleneck for these 6 techniques with a high implementation rate, except for fertigation.

However, looking at the techniques in terms of number of bottlenecks, 3 out of the 5 techniques with the most bottlenecks are implemented at a low rate:

- Crop residue removal after harvest (technique D – 15 bottlenecks),
- Foliar N fertilisers as top dressing (technique J – 17 bottlenecks),
- Commercial organic fertilisers (technique K – 17 bottlenecks).

This suggests that bottlenecks for some techniques might inhibit the implementation. The major bottleneck of techniques D and J was costs, while for technique K knowledge gaps in research was mentioned most frequently.

Furthermore, the technique irrigation based on moisture sensor (technique P) has a low amount of marked bottlenecks, but is not implemented at high rate.

When the implementation rate and the bottlenecks were considered together, it was clear that various bottlenecks inhibited the implementation of some, but not all, innovative techniques.

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Table 2 Implementation rate of innovative techniques implemented in open-field vegetable systems in the Pfalz region in Germany (DE), Denmark (DK), Spain and specifically in the regions of Almeria, Huelva and Murcia in Spain (ES, ES_A, ES_H & ES_M), Flanders (FL), the Brittany region in France (FR), Hungary (HU), Ireland (IE), Italy (IT), The Netherlands (NL), Poland (PL), Portugal (PT), Switzerland (SW), United Kingdom (UK) and Wallonia (WA)

Category		Technique	Not implemented	Low (Implemented at <2% of the farms)	Medium (Implemented at 2-20% of the farms)	High (Implemented at >20% of the farms)
Crops and crop rotations	A	Crop rotation		ES_A, ES_H, FL,UK	DE, ES_M	DK, ES, FR, HU, IE, IT, NL,PL, PT, SW, WA
	B	Catch crops/cover crops/green manures	ES, ES_A, ES_H, ES_M,WA	IT	HU, IE, PT, SW, UK	DE, DK, FL, FR, NL, PL
	C	Local varieties	DE, DK, ES_A, ES_H, ES_M, FL, IE, WA	ES, IT, NL, SW	HU	
	D	Management of crop residues after harvest	DE, DK, ES_A, FL, NL, SW, WA	ES, ES_H, ES_M, IT	HU, PL, UK	IE
	E	Reduced or ploughless tillage	DE, ES_A, ES_M, WA	DK, ES, ES_H, FL, IE, NL, PT, SW	HU, IT, UK	
Fertiliser application	G	Fertilisation planning			ES_A, WA	DE, DK, ES, ES_H, ES_M, HU, FL, IE, IT, NL, PL, PT, SW, UK
	H	Split the N dose for a higher efficiency	PL	WA		DE, DK, ES, ES_A, ES_H, ES_M, FL, HU, IE, IT, NL, PT, SW, UK
	I	Fertiliser placement	WA	DE, PL	HU, IE, NL, PT, SW, UK (Brassica)	DK, ES, ES_A, ES_H, ES_M, FL, IT, UK (Onions)
Fertiliser type	J	Foliar N fertilisers as top dressing	WA	ES, ES_M, IT, NL, PL, PT	DK, ES_A, FL, SW, UK	DE, ES_H, HU, IE
	K	Commercial organic fertilisers	WA	ES, IE, IT, NL, UK,	DE, DK, ES_A, ES_M, FL, PT, SW	ES_H, HU, PL
	L	Nitrification-inhibitor treated fertilisers	IE, PL, PT	ES_M, UK, WA	DK, ES,, ES_A, ES_H, HU, SW	DE, FL, IT, NL
	M	Controlled release fertilisers (CRF)	IE, PL, PT, UK, WA	DE, DK, ES, ES_H, ES_M, FL, IT,	ES_A, HU, NL, SW	
	N	Compost application as fertiliser	ES_M, WA	DK, ES_A, ES, DE, IE, IT, UK	ES_H, FL, FR, HU, PT, SW	PL, NL
	O	Fertigation	IE, PL	DK, FL, NL, UK, WA	PT, SW	DE, ES, ES_A, ES_H, ES_M, HU, IT
Irrigation	P	Irrigation based on moisture sensor	DK, FL, IE, PL, WA	DE, ES, ES_M, IT, NL, PT, SW	ES_A, ES_H, HU, UK	
Determine the N need	Q	Determine the N need by soil determinations	IE	ES_A, ES_H, ES_M	DK, ES, IT, SW, UK, WA	DE, FL, FR, HU, NL, PL, PT
	R	Determine the N need by crop determinations	DE, ES_H, FL, FR, PL	DK, ES, ES_A, ES_M, IT, NL, WA	PT, SW, UK	

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Table 3 Prioritisation of the recommended innovative techniques, the link with the bottlenecks (based on Table 9), implementation rate in regions of experts (based on Table 2) and with the mini-papers

Category		Technique	Criteria *			# Bottlenecks	Implementation rate				Mini-paper
			I	II	III		not	<2%	2-20%	>20%	
Crops and crop rotations	A	Crop rotation	5	10	3	16	0	4	2	11	3
	B	Catch crops/cover crops/green manures	13	1	3	7.2	5	1	5	6	3
	C	Local varieties/varieties with higher nutrient use efficiency	0	0	1	12	8	4	1	0	
	D	Management of crop residues after harvest	1	0	0	15	7	4	3	1	
	E	Reduced or ploughless tillage	0	0	0	9	4	8	3	0	
	S	Mulching	0	0	0	9	/	/	/	/	
Drain water recirculation	F	Drain water recirculation	1	1	0	6.5	/	/	/	/	
Fertiliser application	G	Fertilisation planning	1	6	10	5	0	0	2	14	4
	H	Split the nitrogen (N) dose for a higher efficiency	1	1	6	8	1	1	0	14	4
	I	Fertiliser placement	2	4	3	7	1	2	6	8	4
Fertiliser type	J	Foliar N fertilisers as top dressing	0	0	0	17	1	6	5	4	
	K	Commercial organic fertilisers	2	0	1	17	1	5	7	3	5
	L	Nitrification inhibitor treated fertilisers	0	0	0	10	3	3	6	4	
	M	Controlled release fertilisers (CRF)	0	0	0	13	5	7	4	0	
	N	Compost application as fertiliser	0	0	3	11.7	2	7	6	2	5
	O	Fertigation	1	2	3	14	2	5	2	7	7
	AB	Manure treatment products	0	0	1	8	/	/	/	/	5
Irrigation	P	Irrigation based on moisture sensor	6	0	8	3.5	5	7	4	0	6
	V	Determine the N and water need based on a model	0	2	0	9	/	/	/	/	7
	AA	Other techniques for improving water management	0	0	2	14	/	/	/	/	
Determine the N need	Q	Determine the N need by soil determinations	2	5	8	6.7	1	3	6	7	4
	R/T	Determine the N need by crop determinations	0	2	2	8.3	5	7	3	0	4
	U	Determine the N need based on a model	0	2	3	11	/	/	/	/	7
Other techniques	X	Soil amelioration with compost as a soil improver	0	0	0	5	/	/	/	/	
	Y	Determine the phosphorus (P) need by soil determinations	0	0	0	7	/	/	/	/	
	AC	Erosion control measures	0	0	0	4.2	/	/	/	/	
	AD	Measures for soils with a high P load	0	0	0	3.5	/	/	/	/	

*: criteria I: reduction of N and P input; criteria II: reduction of N and P losses & criteria III: techniques with high potential for fast implementation.

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During the first Focus Group meeting each expert (Figure 1) was asked to prioritise the 2 most efficient techniques i.e. the recommended techniques to (I) 'save/optimise fertiliser use or reduce nutrient application', and (II) 'reduce N and P leaching' (Table 3 – criteria I and II). The recommended technique to reduce nutrient application (marked 13 times) is the introduction of N fixating catch crops/cover crops/green manures. Crop rotation (marked 10 times) was prioritised as optimum technique to reduce nutrient losses, followed by fertilisation planning (marked 6 times) and determining the N need by soil determinations (marked 5 times). The prioritising exercise showed that not only fertiliser application (techniques G and I) is a primary management strategy but also smart crop rotations (techniques A and B), soil sampling to determine the N need (technique Q) and optimal irrigation (technique P).

In a second exercise each expert was asked to prioritise techniques with the most rapid environmental impact while maintaining yield and quality (Table 3 – criteria III). The prioritised innovative techniques are fertilisation planning (technique G), irrigation based on moisture sensor (technique P) and soil sampling to determine the N need (technique Q).

The 3 techniques that were defined as priorities by the experts in both exercises have different implementation rates. Fertilisation planning (technique G) is implemented >20% in 14 of the 16 expert regions. Soil sampling to determine the N need (technique Q) is implemented 2-20% and >20% in 6 and 7 of the 16 regions, respectively. Knowledge intensiveness for farmers is the major bottleneck for this technique. The estimation of the mineralisation rate of fields was considered as a particular difficulty. The promising technique P (irrigation based on moisture sensor) has a low implementation rate (Table 2) although only a few experts indicated bottlenecks for this technique (Table 9). This may be because the low cost of water reduces the incentive to optimise water use.

However, as most innovative techniques are difficult to implement without making additional management changes (see **mini-paper 8** and chapter 4) and can depend on region and crop, the Focus Group did not make a list of the 'most promising' techniques.

3.6 Mini-papers

The experts have written specific mini-papers on recommended innovative methods to optimise fertiliser use and nutrient recycling to solve the conflict between the need for crop fertilisation and legislative requirements regarding water quality in soil-grown horticulture in the open field. The topics of the mini-papers were selected during the first Focus Group meeting (Figure 1). As the main bottleneck identified was the cost of the techniques, a **mini-paper on costs and benefits** was written. Given that knowledge intensity for the grower was the second most frequently mentioned bottleneck, a **mini-paper was written on knowledge exchange** between growers, advisers, scientists and other stakeholders. The topics of 5 mini-papers are linked to innovative techniques which were prioritised as the most effective for optimising fertiliser use and nutrient recycling. The **need for a system approach to increase NUE in horticulture is discussed in the last mini-paper** (Figure 2, Table 3). During the subsequent discussions the topic of the mini-papers were further specified.

In the mini-papers the methods are described, the main bottlenecks identified and the lessons learned and needed actions are summarised. In the text the mini-papers will be denoted with their number as listed below:

1. **Costs and benefits of technologies for increasing N efficiency in vegetable production**,
2. **Knowledge transfer approaches to support sustainable intensification of vegetable production in the open field**,

3. **Agro-ecological Service Crops to mitigate the risk of nitrate leaching from vegetable cropping systems**,
4. **Fertiliser planning and simple recommendation systems**,
5. **Opportunities and bottlenecks in the utilisation of new kinds of organic fertilisers**,
6. **Irrigation management using soil moisture sensors**,
7. **Nitrogen and water need based on a model**.
8. **Need for system approach to increase nutrient use efficiency in horticulture**.

3.7 List of relevant topics for Operational Groups

During the second Focus Group meeting possible topics for Operational Groups were collected (Figure 1 and Table 4).

Table 4 List of suggested topics of Operational Groups

	Topic of Operational Group	Code[†]
Technical focus	Fertilisation advice and planning - (Inter)national data sharing for fertiliser planning and advice - Making fertiliser advice more farmer friendly - Making fertiliser advice more sustainable - Developing a business model for fertiliser advice system	G, H 4
	Precision application of fertilisation - Developing the use of GPS, variable rate, …	I
	Fertigation - Optimising irrigation and fertilisation approaches in regions where fertigation is in practice a.o. cost-benefit analysis and testing of N fertigation models - Researching of added value and risks and developing fertigation in regions where irrigation is irregularly used	O 6, 7
	New organic fertiliser - Closing the nutrient loop (recover, recycle, reuse) to produce new fertilisers - Optimising on farm composting: cooperatives for sharing infrastructure and machinery - Advancing organic fertilisers (coating, physical treatment) - Optimising the use of innovative organic sourced fertiliser use	K, N, AB 5
System focus	Crop rotation - Increasing nutrient efficiency with cover crops and optimal use of organic manures - Designing new smart rotations with catch crops or economically profitable (inter)cropping to reduce leaching and increase soil organic matter (SOM)	A, B 3
	Incentives to improve soil quality - Land sharing cooperatives to create long-term incentives for soil management	E, X, AC
	Managing crop residues e.g. in cauliflower and broccoli	D
	Simulation models - Developing decision support systems (DDS) based on simulation models	U, V
	System approach - Developing an advice based on a system approach avoiding opposite advices - Developing soilless cultivation and recirculation systems inside or outside greenhouses - Implementing an agro-ecological approach - Analysing of risks and risk perception	8
Knowledge exchange focus	Knowledge exchange - Improving knowledge exchange by including different experts e.g. social sciences - Improving the feasibility of modern technology by bringing together developers and users - Developing models how to reach hard-to-reach growers	2

[†]: the techniques received a code (see Table 1) and the mini-papers were numbered (see paragraph 3.6)

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The topics for Operational Groups were clustered into 10 areas and they were linked with the innovative techniques and mini-papers. Four topics of Operational Groups have a technical focus and relate to the cropping period, while 5 topics have a system focus and effect long-term nutrient efficiency. As knowledge transfer was considered a key element to support sustainable intensification of vegetable production in the open field and to promote best practice to growers, Focus Groups with a knowledge exchange focus were also suggested.

4 Common themes

4.1 Introduction

The main common themes that came up in the discussion which are necessary to improve fertilisation efficiency were:

- Need for integration of techniques,
- Need for detailed information on nutrient dynamics and water uptake,
- User-friendliness of innovative techniques.

In the following paragraphs, the state of play, innovation process and constraints and challenges are described. For each common theme some recommendations are given.

4.2 Need for integration of innovative techniques

4.2.1 State of play

Nutrient losses from fertilisation have environmental consequences at local and larger scales. Managing this pollution is challenging because of the complex relationships between aquatic and atmospheric emissions e.g. reduction of ammonia (NH_3) volatilisation by injection of animal slurry may increase nitrous oxide (N_2O) losses and NO_3^- leaching.

However, there is also an important trade-off between reducing emissions and agricultural revenue. Innovative techniques effective in reducing aquatic and atmospheric pollution indeed often cost a lot of money, extra workload and/or time to learn new skills. Growers are not triggered to reduce their N fertiliser use because there is a risk of yield reduction. For this reason, adequate management efforts (e.g. fractionation of N fertilisation) are necessary so that significant N fertiliser savings are economically feasible. Most innovative techniques are difficult to implement stand-alone without making additional management changes.

Advisers often focus on improving short-term production without paying sufficient attention to a possible negative impact on long-term production or soil quality. Furthermore efficient long-term soil management is hampered by short-term agricultural land rental.

4.2.2 Innovation process

In an integrated system approach, potential trade-offs are minimised and synergies are maximised. Trade-off analysis becomes an increasingly important approach for evaluating system level outcomes of agricultural production. In an integrated system approach different parameters are evaluated simultaneously:

- Product (yield and quality)
- Nutrient efficiency/losses (N and P)

- Soil quality (not only soil organic carbon and chemical soil quality in general, but also physical and biological soil quality)
- Environment (air and water quality and agro biodiversity)
- Costs and benefits (for farmer and society)

However, agricultural innovation is not just about adopting new technologies, but it can also be about an alternative way of plant production. Next to the agro-ecological approach where soil management and crop rotation is essential, an alternative production method with low nutrient losses is soil-less cultivation in recirculating cropping systems (**mini-paper 8**).

Growers are confronted with trade-offs between maximising short-term production and ensuring sustainable long-term production. For example, removal of N rich crop residues after harvest (technique D) is a valuable option for significant reduction of NO_3 leaching during the following winter period, however, crop residue removal can also have (long-term) negative effects on soil structure when applied under bad weather and soil conditions, or by the reduced application of effective organic matter resulting in lower soil organic matter (SOM) content. Moreover, removing crop residues is labour intensive, increases fuel use and often requires the adaptation of harvest equipment. A link with the bio-based economy is essential to have a promising application to re-use the collected residues as bio-resource. If crop residues are left on the field, their N supply should be taken into account in the fertilisation application rate the following year.

As Figure 2 indicates, nutrient and water management has to be optimised during the entire growing period. Management at crop rotation level (techniques A & B) instead of crop level has an added value as crop rotation can help to maximise crop yield potential, reduce harmful insects, diseases and weeds, help to increase SOM and improve soil physical properties (**mini-paper 3**). By designing smart crop rotations, different relevant aspects can be taken into consideration, i.e., management of crop residues, alteration of crops with deep/shallow roots, use of local varieties and/or varieties with a higher NUE, … Next to N and P_2O_5 fertilisation and water gift, also measures which have an indirect effect on nutrient losses can be applied in open field horticulture, i.e. ploughless tillage (technique E), erosion control measures (technique AC), ...

Based on the analysis of trade-offs and synergies, the most adapted technique can be selected. Trade-offs of innovative techniques are quantified through the analysis of system level inputs and outputs and environmental impacts, but also economics e.g. investments, needed time, … have to be included. However, it is often also beneficial to link different innovative techniques:

- Soil moisture measurements (technique P – **mini-paper 6**) and a model simulating N uptake and water need (technique V - mini-papers **4** & **7**) can be combined in order to optimally fractionate N fertilisation (technique H) and water supply. By taking into account the previous weather and growth conditions and actual N-content of the soil, dynamic fertilisation advice can be obtained during the growing season. For example, potential yield can be overestimated at time of fertilisation, while actual yield is the result of diseases, weather conditions, market situation, … The risk of N losses can be reduced even further if placement of fertiliser is also considered (technique I),
- A sufficient SOM level in arable soils without an increased risk of P losses can often only be obtained by combining catch crops (technique B) and a combined application of N and organic matter (i.e. soil improvers and organic fertilisers, manure and compost) (techniques K, N & AB),
- An optimal combination of mineral and organic fertilisers (after processing) can better meet the N and P demand of crop by adjusting N and P supply (**mini-paper 5**).

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Constraints and challenges for a system approach in horticulture are:

- The knowledge intensiveness related to the analysis of constraints, challenges and opportunities at farm level leads to a need for guidelines/questionnaires/methods to apply the system approach at farm level,
- Economics: it is not practical to change crop rotation in a market driven industry,
- Vegetables are frequently harvested too late to sow a catch crop. The harvest date is mainly determined by the economics/industry,
- Lack of (correct) knowledge of trade-offs by researchers and growers. Trade-off analyses without substantial stakeholder engagement often have limited practical utility for informing practical decision-making,
- Lack of data on nutrient content and efficiencies of new organic products,
- Lack of application methods (lack of adapted machinery or higher costs such as for green manure seeds),
- Legislation complicates trade/use of products or organic fertilisers,
- Legislation and renting of land benefits crop rotation but hampers long-term soil management.

4.2.3 Recommendations

Recommendations for increasing the system approach are:

- Drafting guidelines/questionnaires/methods to apply system approach at farm level,
- Trade-off analysis with stakeholders in regions with high nutrient pressure e.g. by an Operational Group. Growers should be involved in the discussion as well as fertiliser companies, manufacturers of machinery, … in order to assess the technical implication of innovative techniques (i.e. planting of vegetables in green manure crop without ploughing). Also, administrations should be invited to the discussions as legislation often affects the introduction of innovative techniques,
- Need for integrated advice where fertilisation rate is not the only focus, but where other elements are also important such as application technique, soil quality aspects, possible effect on diseases, … are taken into account. A support team with advisers with different expertise can assist in the system approach,
- Commercial organic products need to improve parameterisation and standardisation in order to gain accuracy,
- Dissemination of the identified trade-offs.

4.3 Need for detailed information on nutrient dynamics and water uptake

4.3.1 State of play

Thompson *et al*. (2013) recommended a general management system for optimal N management of intensive vegetable production systems. Tools are included that provide quantitative information on (i) the expected crop N demand, (ii) the expected N supply, and (iii) whether the N supply matches the N demand. However, this implies that the crop N demand and expected N supply during the cropping season are correctly known:

- The total N uptake by vegetables is known but not the N uptake during the cropping period of vegetables grown at small scale. This knowledge is important for the timing of the N advice, development of models, ... (**mini-paper 8**). Tables with N uptake during the growing season for different crops/varieties have to be drafted. Furthermore tables of water need during the cropping period depending on crop, soil texture, planting/sowing date, … are needed.
- The N supply from the soil includes the N in the soil at sowing or planting and the N supply during the cropping period through mineralisation. The N mineralisation rate from SOM, catch crops, … are difficult to predict. In some regions the N content in the soil is measured at sowing or planting and/or during the cropping period. Measuring the N content in the soil or the plant during the growing season of vegetables with a long growing period allows to adapt the N fertilisation rate of the second fraction considering the previous weather circumstances. However, in some regions farmers and advisers do not recognise the added value of paying for soil or plant sampling at the start or during the cropping season.

As many regions cope with P concentrations in surface waters which are too high to prevent eutrophication, P_2O_5 fertilisers should be applied based on a scientific sound P fertilisation recommendation, in which both the P_2O_5 offtake by the crop as the P in the soil is taken into account (technique Y). Information on the P_2O_5 uptake and offtake by vegetables is lacking.

4.3.2 Innovation process

The availability of tables with water and N uptake under different (weather) circumstances during the cropping period for different crops/varieties will enable growers to optimise their fertilisation rate (techniques G, H, U & V).

Challenges for the preparation of tables with N and water uptake and P_2O_5 offtake are:

- The need for integrating several resources in which research conditions are sometimes not reported, which makes it difficult to evaluate the usability of the data,
- Data is often unavailable so that tables have to be drawn based on expert knowledge or judgement and new research results.

4.3.3 Recommendations

Recommendations for increasing knowledge on nutrient and water uptake and on N fertilisation rate during the cropping season:

- Collection and sharing of all available data on N, P_2O_5 and potassium oxide (K_2O) uptake, N, P_2O_5 and K_2O offtake and water need in order to make up tables (by Operational Groups, European multi-actor project or thematic networks),
- Assessment of knowledge gaps to define research needs,
- Multi-actor approach i.e. cooperation of different stakeholders to fill in experimental gaps based on expertise as it is impossible to do experiments that cover all possible circumstances.

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4.4 User-friendliness of innovative techniques

4.4.1 State of play

The driver to develop innovative techniques is often to reduce nutrient losses in order to reduce ecological impact to comply with strict legislation. Although the potential of innovative techniques to increase nutrient efficiency compared to actual farming is illustrated by the research, the application by growers is hard. As well as costs (**mini-paper 1**) e.g. investment for necessary drip irrigation for fertigation, knowledge intensiveness for growers (Table 9) is often mentioned as a bottleneck. Non or low user-friendliness of innovation is due to:

- The complexity of the innovative technique which leads to a long learning period and extra workload. The transparency of the innovative techniques is often not sufficient as researchers do not speak often the same language as growers,
- High data demand i.e. models which might be linked with expensive sampling and measurements in the lab. It is essential to prove the potential added value of calibration and collecting extra data,
- The need for a quick answer on the fertilisation rate needed.

It also sometimes becomes clear that non or low user-friendliness was an incorrect interpretation based on shortage of knowledge. Due to limited communication and actions to transfer the knowledge on the innovative techniques to the growers, the advantages of the innovative techniques or the consequence of the problem are sometimes unknown by the growers.

4.4.2 Innovation process

Innovative techniques are often developed through a top-down knowledge transfer approach. Researchers develop the innovation, and growers either adopt or reject it. In contrast, a multi-stakeholder approach seeks to improve economic and environmental factors and determines the technical knowledge necessary for the use and adoption of an innovative technique. Adoption of innovative techniques to reduce nutrient losses will be improved if growers also participate in the research, development and introduction of them. In 'feedback loops' researchers, advisers and growers can share their perceptions and gain new insight into the development and subsequent use of an innovative technique. Moreover, it means that the observations of the growers (i.e. need for new data, impact on workload or investments, …) can be taken into account when developing an innovative technique. This interactive communication also increases the users' awareness, and can incite them to tackle less familiar topics.

Innovation processes may also include:

- Simplification of complex problems/solutions e.g. a simpler model with a lower data demand to optimise fertilisation rate. The KISS (Keep it short and simple) principle states that most systems work best if they are kept simple; therefore simplicity is a key goal and unnecessary complexity should be avoided,
- Applications that can be used in the field for a quick answer e.g. apps for smartphones.

Also after the introduction of an innovative technique, support from research remains important. This is not only needed to help the growers and their advisers (i.e. train the trainers), but also the feedback loop corrects errors and fills in gaps.

Sharing between growers also helps the introduction of innovative techniques as the opinion of peers is an important incentive to adapt management. Personal contact with growers who have successfully adopted the innovative technique themselves, can give credible reassurances that their attempts to change will not result in financial loss or wasted time. Growers indeed adopt new techniques at different times. In the first years, a few growers adopt them (i.e. "innovators"). Then soon after, a large number try it (i.e. "early adopters"); and finally the remainder accept. Growers particularly learn from early adopters and those who lend their farms to showcase the innovative practices.

Constraints and challenges of increasing user-friendliness of innovative techniques are:

- A multi-stakeholder approach also demands time from growers, advisers and researchers. A contradictory opinion is that fertilisation is too complex for the growers. This means that specialised firms should give the recommendations that growers can implement without reflection by the growers about weather circumstances, previous crop, field condition, …
- Researchers need new expertise to develop innovative techniques e.g. skills to exchange with farmers, advisers and other stakeholders; programming of app, …
- Investment costs for growers e.g. computer programmes, apps for smartphones, …

4.4.3 Recommendations

Recommendations for increasing the user-friendliness of innovative techniques are:

- Development of innovative techniques based on a scientific background, but considering the bottlenecks mentioned by the growers and applying the KISS strategy,
- Involving growers and advisers from the start when developing a the technique and continuing the communication after the first implementation, i.e. feedback loops,
- Formulating clear messages and explaining the underlying principles of each of the innovative techniques e.g. models, measurements of soil moisture content, … These need to be understood by the growers in order to ensure the correct use of the innovative technique,
- Visualisation is a good method to get an overview of the big picture and to filter the most important information which facilitates learning. Different steps, tasks and/or scenarios can be visualised in e.g. decision tree, overview tables, ...

5 Epilogue from the group

5.1 Needs from practice

During the second Focus Group meeting three types of needs from practice were detected:

- Needs during the development of an innovative technique:

  During the development of innovative techniques, a bottom-up identification of the innovation needs of different stakeholders is essential. Through a multi-actor approach the growers' requirements and their problems can be determined. This approach also means that specific local problems and identifying potential and/or main bottlenecks can be addressed. Priority can be given to actions beneficial for different horticultural crops rather than for specific ones.

  An international network can simplify the introduction of innovative techniques which have already been successfully integrated in other regions. However, an adjustment of the technique according to the local weather and soil conditions before the implementation of innovative

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techniques is needed. Lessons learned during the development and first implementation in pioneer regions can be taken into account. Also identified problems and viewpoints from other techniques can facilitate the research and implementation of innovative techniques. Furthermore, reference databases can increase the development efficiency of innovative techniques. These reference databases can contain information on crops (yield, nutrient content and water need based on soil texture, planting/sowing date, …), potential for fractionated fertilisation, …

As well as user-friendly and practical techniques, the economic profitability and feasibility at farm level have to be taken into account. The development of robust systems for measuring soil moisture is needed in order to avoid problems related to re-installation, re-calibration and thereby increasing feasibility of the technique.

- Needs during first implementation:

  Field trials on growers' fields allow demonstration under local and relevant weather and soil conditions. Carrying out practical research on farms improves contact between researchers and growers and allows the identification of growers' practical problems i.e. time need, lack of needed machinery. Sharing between growers facilitates the introduction of innovative techniques as the opinion of peers is an important incentive to adapt management. Growers particularly pick up new practices from early adopters and those whose fields are available for demonstrations of innovative techniques.

- Needs for communication:

  Communication with growers is beneficial from the initial idea development right through to first implementation. Receiving funding for basic extension services such as going to talk to growers, having a cup of coffee with them to gain their trust, is hard to obtain because it is not innovative. Listening to growers' needs is however necessary for an optimal promotion and development of new solutions and tools. Dissemination of the solutions is best done with demonstrations. This is a good way to translate strategic and applied research outputs into practical advice for growers.

  Another effective method to reach a large number of growers is visiting farm discussion and producer groups. Informal contacts are also interesting to exchange knowledge. It is often more difficult to reach smaller growers. It appears that some regular communication methods do not reach all of the growers. These hard-to-reach growers possibly receive more easily information from adviser services. A short information transfer chain can reduce the loss of information between researchers and growers, and makes it also possible for researchers to obtain information from the growers, and lead to the improvement of the innovative techniques.

  Discussions on alternative techniques make the decisions for the grower easier. An overview of options to improve fertiliser efficiency including cost/benefits and applicability in a toolbox of techniques can help to start the discussions.

  Smartphone applications can assist the growers by giving interesting information and increasing the user-friendliness of innovative techniques.

5.2 How to go to practice?

During the Focus Group, the experts were invited to reflect how practices can be approached and what the Focus Group could offer. The following topics were identified:

- The KISS (Keep it short and simple) principle states that most systems work best if they are kept simple. Also communication should take this into account by putting the message into growers' language.
- The main types of knowledge transfer to promote best practice to growers as found by the Focus Group can be ranked as given in Table 5.

Table 5 Ranking of main types of knowledge transfer to promote best practice to growers (Source: mini-paper 2)

1.	One to one advice
2.	Discussion groups and data sharing
3.	Structured workshop/themed event
4.	Web site / summarised information
5.	Expert factsheets
6.	Trade press articles
7.	Sector-specific conferences with a blend of business and research and development insights related to practice
8.	Research and development scientific reports

- Peer group participation can be used to change grower behaviour in a constructive and interactive way. Successful approaches for this are multi-activity and disciplinary and include practical implementation measures for immediate uptake by growers. A key message from these activities is that the most effective workshops are held at grower holdings because peer group pressure is an important part of the need and acceptance to change practice.
- Demonstration activities should involve the final users by asking their needs. Integration of growers and technicians in development and demonstration activities improves knowledge exchange. Involvement of producer organisations and private producers/suppliers can increase the support and investment in improving fertiliser strategies.
- Independent and cheap or free advice, e.g. supported by governments can be more effective in the introduction of innovative techniques. Specific attention should be given to solve specific problems by discussing them with the grower. A bottleneck which is often mentioned is the administration load and costs for legal requirements (registration processes) need to be reduced.

As some innovative techniques need to be applied over a longer period, cost-benefits during medium or long-term periods also need to be determined and communicated.

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7 Annexes

7.1 List of members of the Focus Group

Experts	Expertise
• Canali, Stefano (Italy)	Farm advisor; Expert from agriculture organisation, industry or manufacturing; Scientist
• Carranca, Corina (Portugal)	Scientist
• Coopman, Franky (Belgium)	Farmer; Farm advisor; Expert from agriculture organisation, industry or manufacturing; Scientist
• de Haan, Janjo (the Netherlands)	Scientist
• De Neve, Stefaan (Belgium)	Scientist
• Garming, Hildegard (Germany)	Scientist
• Hajdu, Zoltán (Hungary)	Farm advisor; Other type of advisor
• Javier, Brañas (Spain)	Expert from agriculture organisation, industry or manufacturing
• Malusa, Eligio (Italy)	Scientist
• Martínez Gaitán, Carolina Clara (Spain)	Expert from agriculture organisation, industry or manufacturing
• Mulholland, Barry (United Kingdom)	Expert from agriculture organisation, industry or manufacturing; Scientist
• Nicola, Silvana (Italy)	Scientist
• Plunkett, Mark (Ireland)	Other type of advisor (Specialist advisor)
• Rahn, Clive (United Kingdom)	Other type of advisor; Scientist
• Shaban, Nidal (Bulgaria)	Scientist
• Svensson, Ingvar (Sweden)	Farmer; Farm advisor
• Thompson, Rodney (Non-European country)	Scientist
• Toresano-Sanchez, Fernando Andres (Spain)	Expert from agriculture organisation, industry or manufacturing
• Verhaeghe, Micheline (Belgium)	Farm advisor; Scientist
• Voogt, Wim (the Netherlands)	Scientist
Coordinating expert	
Vandecasteele, Bart (Belgium)	Scientist

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7.2 List of relevant research projects

Tables 6 and 7 give an overview of finished or ongoing European and national projects on nutrient management. The innovative techniques under research are indicated in the last column.

Table 6 Finished/Ongoing European projects on nutrient management

Title	Project reference	Duration	Project location[1]	Objectives	Innovative technique Table 1
VEGINECO: Integrated and ecological vegetable production, development of sustainable farming systems focusing on high quality production and minimum environmental impact	FAIR 3CT 96-2056	01/01/1997 – 31/03/2001	NL, IT, ES, CH	Research into farming systems to develop, test, evaluate and compare prototypes of integrated and ecological vegetable farming systems in four important vegetable-producing regions in Europe, selected to represent different socio-economic, soil and climatic conditions.	
EU-Rotate-N - Development of a model based decision support system to optimise nitrogen use in horticultural crop rotations across Europe	QLK5-CT-2002-01100 (FP5-LIFE QUALITY)	01/01/2003 – 31/12/2006	UK, DE, ES, NO, DK, IT	To provide growers and policy makers with a decision support system for nitrogen (N) management and rotational planning to optimise N use efficiency and economic sustainability in both conventional and organic systems of vegetable production across Europe.	U
FERTORGANIC: Improved organic fertiliser management for high nitrogen and water use efficiency and reduced pollution in crop systems	QLK5-CT-2002-01799 (FP5-LIFE QUALITY)	01/01/2003 – 30/09/2006	DK, PT, IT, PL, SK, CZ	To enhance the use of various organic fertiliser in farming systems and develop new management strategies and decision support system (DSS) components to improve the water and nitrogen use efficiency and hence to reduce the environmental pollution. The study focused on the potato crop because the environmental problems in this high value cropping system are particularly high.	V
OptiMa-N: Optimisation of nitrogen management for groundwater quality improvement and conservation	LIFE04 ENV/IT/000454	01/10/2004 – 30/09/2007	IT	To foster environmentally and economically sustainable practices that enabled farmers to balance production and environmental goals, via crop rotation techniques, use of cover crops and improved quantities of fertiliser inputs.	A, B, Q
AGRI-PERON - Development and implementation of codes of good agricultural practices to reduce point source and diffuse pollutions in the Peron catchments area	LIFE04 ENV/FR/000319	01/09/2004 – 31/10/2007	FR	To improve the farmers' approach to the use of crop-protection products throughout the Peron river basin; in particular to reduce nitrate contamination of the environment and improve the water quality in the river's catchment area.	Various
WAgriCo - Water Resources Management in Cooperation with Agriculture. Compilation and Implementation of Integrative Programmes of Measures According to the WFD to Reduce Diffuse Pollution from Agriculture.	LIFE05 ENV/D/000182	01/10/2005 – 30/09/2008	DE, UK	To set up new participation methods and technologies to reduce diffuse pollution from agriculture and to promote sustainable water resource management.	Various
WATNITMED: Management improvements of WUE and NUE of Mediterranean strategic crops (Wheat and Barley)	509107 (FP6-INCO)	01/01/2005 - 31/08/2009	ES, TN, FI, LB, UK, IT, NL, JO, MA	The general objective of this proposal is to identify and transfer improvements in management of wheat and barley through increasing the capture and/or the use efficiency of water and N (WUE and NUE).	Various
AGWAPLAN - Integrated Protection of Surface and Groundwater in Agricultural Regions	LIFE05 ENV/DK/000155	01/11/2005 – 01/03/2009	DK	To develop and test an integrated advisory approach for the implementation of good agricultural practice (GAP). It demonstrated and quantified the impact of GAP on N and phosphorous (P) in surface and groundwater in 3 pilot areas in mid-eastern Jutland.	

[1]AT: Austria, BE: Belgium, BG: Bulgaria, BR: Brazil, CH: Switzerland, CN: China, CZ: Czech Republic, DE: Germany, DK: Denmark, DZ: Algeria, EE: Estonia, ES: Spain, FR: France, HU: Hungary, IL: Israel, IT: Italy, JO: Jordan, FI: Finland, LB: Lebanon, LU: Luxembourg, LV: Latvia, MA: Morocco, NL: The Netherlands, NO: Norway, PL: Poland, PT: Portugal, SE: Sweden, SI: Slovenia, SK: Slovakia, SW: Switzerland, TN: Tunisia, TR: Turkey, UK: United Kingdom & US: United States

Table 6 Finished/Ongoing European projects on nutrient management (Continued)

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Title	Project reference	Duration	Project location 1	Objectives	Innovative technique Table 1
QUALIWATER - Diagnosis and Control of Salinity and Nitrate Pollution in Mediterranean Irrigated Agriculture	15031 (FP6-INCO)	01/01/2006 – 31/10/2010	ES, TN, UK, MA, DZ, TR	To provide scientific , technical and socio-economic information on salt and Nitrogen contamination, and on pollution control measures in Medit. irrigated agriculture.	P, V
SOLIBAM: Strategies for Organic and Low-input Integrated Breeding and Management	245058 (FP7-KBBE)	01/03/2007 – 31/08/2013	FR, IT	To develop specific and novel breeding approaches integrated with management practices to improve the performance, quality, sustainability and stability of crops adapted to organic and low input systems.	C
EUPHOROS: Efficient use of input in protected horticulture	211457 (FP7-KBBE)	01/03/2008 – 31/08/2012	NL, IT, ES, CH, LV, HU, UK	To develop a sustainable greenhouse system that: does not need any fossil energy & minimises carbon footprint of equipment; with no waste of water nor emission of fertilisers and full recycling of the substrate; with minimal need of plant protective chemicals yet with high productivity and resource use efficiency.	Various
N-toolbox - Toolbox of cost-effective strategies for on-farm reductions in N losses to water	227156 (FP7-KBBE)	01/03/2009 – 30/09/2012	UK, DK, NL, ES	To develop a toolbox of cost-effective technologies to be implemented at the farm level to protect water from nitrate pollution. The project will bring together four partners with expertise in farm level N management in their regions.	Various
NUE-CROPS: Improving nutrient efficiency in major European food, feed and biofuel crops to reduce the negative environmental impact of crop production	222645 (FP7-KBBE)	01/05/2009 – 30/04/2014	UK, DE, CN, BG, DK, US, NL, TR, CH	To develop knowledge, models and tools required to (a) breed/select nutrient use efficient crops and (b) integrate nitrogen use efficiency crops with agronomic innovations to significantly reduce fertiliser use and associated negative environmental impacts of crop production, while maintaining or improving crop yield and quality.	C
AGRICARBON: Sustainable agriculture in Carbon arithmetics	LIFE08 ENV/E/000129	01/01/2010 – 31/12/2014	ES	To encourage the progressive establishment of sustainable agricultural techniques (conservation and precision agriculture) contributing to greenhouse gas (GHG) emission decreases and the adaptation of farming techniques and to new climatic conditions resulting from global warming. Also, the project aims to provide European and national authorities with the necessary information of these techniques to encourage the adoption of environment policies in this area.	
FERTIPLUS: Reducing mineral fertilisers and agro-chemical by recycling treated organic waste as compost and bio-char	289853 (FP7-KBBE)	01/11/2011 – 31/10/2015	NL, DE, BE, UK, ES, IT	To take up the challenge to identify innovative processing technologies and strategies to convert urban and farm organic waste to valuable and safe products for agriculture and allow industries to develop projects and provide adequate information on use and quality of the products.	N, X
TILMAN-ORG: Reduced tillage and green manures for sustainable organic cropping systems	(CORE Organic II)	2011-2014	AT, BE, EE, FR, DE, IT, LU, ES, CH, NL, UK	To design improved organic cropping systems with: • enhanced productivity and nutrient use efficiency, • more efficient weed management and • increased biodiversity, but • lower carbon footprints.	B, E
INTERVEG: Enhancing multifunctional benefits of cover crops – vegetables intercropping	(CORE Organic II)	05/09/2011 – 28/02/2015	IT, DE, DK, SI	Organic vegetables may benefit from intercropping with living mulches, and in this project, scientists assess and evaluate the effects of the technique on the product and on the environment.	S
Catch-C: Compatibility of Agricultural Management Practices and Types of Farming in the EU to enhance Climate Change Mitigation and Soil Health	289782 (FP7-KBBE)	01/01/2012 – 31/12/2014	NL, AT, FR, ES, BE	To assess the farm-compatibility of 'Best Management Practices' (BMPs) that aim to promote productivity, climate change mitigation, and soil quality.	E, X

Table 6 Finished/Ongoing European projects on nutrient management (Continued)

Title	Project reference	Duration	Project location 1	Objectives	Innovative technique Table 1
DEMETER: Sustainable and integrated soil management to reduce environmental effects	LIFE10 ENV/BE/000699	01/01/2012 – 30/03/2016	BE, NL	To foster sustainable soil and nutrient management. This includes guiding and informing farmers on management practices that consider both nutrient and soil organic carbon management simultaneously. The project is centred on the principle that sustainable nutrient and soil organic carbon management not only concern fertilisation practices, but the whole farm management, including tillage practices, crop rotation etc.	U
OSCAR: optimising subsidiary crop application in rotations	289277 (FP7-KBBE)	01/04/2012 – 31/03/2016	DE, UK, CH, NO, MA, PL, SE, DK, IT, NL, BR	To develop improved conservation tillage systems, based on as cover crops (living and dead mulch), that • increase the duration of soil coverage; • minimise soil tillage (intensity); • increase the species diversity; • reduce the need for fertilisers and pesticides; • in dry climates, conserve water and reduce irrigation need.	B, S
IMPROVE-P : IMproved Phosphorus Resource efficiency in Organic agriculture Via recycling and Enhanced biological mobilization	(CORE Organic II)	01/06/2013 – 31/05/2015	UK, CH, DK, NO, AT	To design improved P recycling systems for organic farming. This includes: • enhanced P recycling using secondary P fertilisers as alternative P fertilisers, • higher plant P use efficiency due to enhanced agronomic measures (e.g. adapted cultivars, application techniques, P mobilisation by cover cropping), and • improved P availability to plants by application of Plant Growth Promoting Rhizobacteria (PGPR).	Various
HelpSoil: Helping enhanced soil functions and adaptation to climate change by sustainable conservation agriculture techniques	LIFE12 ENV/IT/000578	01/07/2013 – 30/06/2017	IT	To test and demonstrate innovative solutions and soil management practices to improve soil quality, and to make agricultural systems more resilient against climate change. The project will cover the whole Po plain (an area of some 46000 km^2) and the Alpine and Apennine foot-hills.	
WHEALBI: Wheat and barley Legacy for Breeding Improvement	613556 (FP7-KBBE)	01/01/2014 – 01/01/2019	FR, UK, DE, NL, HU, IT, IL, BE	To strengthen bread wheat and barley production in Europe by enabling the development of new, productive varieties adapted to cropping systems that require lower inputs and which are health and environment friendly.	C
IMBALANCE-P: Effects of phosphorous limitations on Life, Earth system and Society	2013-610028 (ERC Synergy Grants)	01/05/2014 – 30/04/2020		To study the current changes in the carbon (C), P and N balances in the different ecosystems of the planet and assess the impact of the imbalances between these three elements for life on Earth.	
SoilVeg: Improving soil conservation and resource use in organic cropping systems for vegetable production through introduction and management of Agro-ecological Service Crops	(CORE Organic II)	02/03/2015 – 01/03/2018	IT, SI, DK, ES, EE, BE, FR, LV	ASCs are non-marketable intercrops introduced in the agro-ecosystems to provide or enhance ecological services. This project focuses on roller-crimper machinery, used to crush the ASC in the generative stage (just before flowering) just prior to sowing or planting the main horticultural crop on top of the plant residues.	

[1]AT: Austria, BE: Belgium, BG: Bulgaria, BR: Brazil, CH: Switzerland, CN: China, CZ: Czech Republic, DE: Germany, DK: Denmark, DZ: Algeria, EE: Estonia, ES: Spain, FR: France, HU: Hungary, IL: Israel, IT: Italy, JO: Jordan, FI: Finland, LB: Lebanon, LU: Luxembourg, LV: Latvia, MA: Morocco, NL: The Netherlands, NO: Norway, PL: Poland, PT: Portugal, SE: Sweden, SI: Slovenia, SK: Slovakia, SW: Switzerland, TN: Tunisia, TR: Turkey, UK: United Kingdom & US: United States

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Table 7 Finished/Ongoing national projects on nutrient management from Spain, Flanders (Belgium) and the Netherlands

Title	Duration	Project location[1]	Objectives	Innovative technique Table 1
Telen met toekomst (Farming with a future)	2001-2008	NL	Disseminating fertilization measures to reduce nitrate leaching and phosphate losses.	Various
Best practices fertilisation	2005	NL	Inventory of fertilisation measures	Various
Reducing nitrate contamination of underlying aquifers from the greenhouse vegetable production industry at the Spanish Mediterranean coast	01/01/2005 - 31/12/2007	ES	This work evaluated the use of combined prescriptive and corrective management of both irrigation and N as a means to improve the efficiency of the use of N fertiliser, applied by fertigation, and to reduce nitrate leaching loss from greenhouse vegetable production. For prescriptive management, modelling approaches were used to prepare a plan, and for corrective management, monitoring was used to make adjustments to the plan.	Q, U
Drainage and nitrate leaching from intensive vegetable farming systems to underlying aquifers: extrapolation from plot to regional level	04/04/2007 - 31/12/2010	ES	This project had three components: 1. measurements of nitrate leaching from commercial farms (greenhouses), 2. the use of ^{15}N and ^{18}O to determine the sources of nitrate entering the underlying aquifer, and 3. a regional estimation of irrigation, drainage and nitrate leaching for the Campo de Dalias where 80% of the greenhouses close to Almeria are located.	
Fertigation and plant densities in leek	2008-2010	NL	Test fertigation on plant production and reduction in nitrate losses at various planting densities	O
Ecofert I &II: Development of an on-line monitoring and model-based advice system for 'Just-on-time' N fertiliser application in horticulture	01/09/2008 - 31/08/2012 01/10/2012 - 30/09/2014	FL	To study sustainable and efficient use of N and water in horticulture using a model-based advice system for 'Just-on-time' fertiliser application. The main goal is reducing environmental impact without reducing crop production and quality. To develop and test a web-based decision support system for optimal fertiliser advice in horticulture.	V
Use of a combined modelling and monitoring approach to optimise management of fertiliser N for vegetable production in greenhouses	01/01/2009 - 30/06/2012	ES	The VEGSYST simulation model was developed and incorporated into a prototype decision support system (DSS) known as VEGSYST-DSS. The VEGSYST-DSS enables growers to develop combined N and irrigation plans taking into account soil mineral N present in the root zone at planting and also N made available during the cropping period from previous manure applications and from soil organic matter.	Q, U
Teelt uit de grond (soilless cropping)	2009-2017	NL	Develop cost effective closed cultivation systems for outdoor horticulture that comply with European regulations for water quality. The new cultivation system allows growers to produce in a cost effective way with minimal emission from fertilisers and pesticides.	F
Strengthening of tomato flavour and reduction of the excess of nutrients discharged to the environment	01/09/2009 - 01/03/2015	ES	Objectives: (1) Demonstration of the effects produced by the adoption of new techniques to reduce the amount of nutrients discharged to the environment in commercial farms of tomato under greenhouse in the coastal area of Spain and, (2) evaluation of its influence in postharvest quality parameters of fruits.	
Bodemkwaliteit op zandgrond (soil quality on sandy soils)	2011-2016	NL	Development of arable/vegetable cropping systems and strategies with low nitrate leaching and high production	Various
Benchmark study and European conference on innovative techniques and strategies for reduction of nutrient losses in horticulture	01/07/2012 - 31/12/2013	FL	To perform a benchmark study to evaluate the nutrient legislation and innovative techniques for nutrient management in horticulture in Flanders and other European regions.	Various

[1]ES: Spain, FL: Belgium – Flanders, NL: Netherlands

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Table 7 Finished/Ongoing national projects on nutrient management from Spain, Flanders (Belgium) and the Netherlands (Continued)

Title	Duration	Project location1	Objectives	Innovative technique Table 1
Assessment of open field vegetable crop residue management options and potential of catch crops and crop rotations in view of the water quality objectives set by the Manure Action Programme 2011-2014	01/09/2012 - 30/06/2014	FL	To study the best available technique for crop residue management. Two strategies are distinguished: crop residue removal followed by useful utilisation and leaving crop residues on the field. For both strategies, practical and economic considerations are made.	D
Use of optical sensors and simulation models to optimise the management of nitrogen in vegetable crops	01/01/2013 - 31/12/2015	ES	To evaluate the effectiveness of various proximal optical sensors to assess crop N status of cucumber.	R/T
Remote control in greenhouse horticulture and integration with demand and marketing system forecasts	01/07/2013 - 31/12/2014	ES	Objectives: (1) Development of a WSN platform (Wireless Sensor Network) as a decision support system to improve the irrigation and the fertilisation management practices of the tomato crop produced in the region of Almeria in order to reduce the use of inputs and to maintain the yield demanded by a local trading company and, (2) development of demonstrative and training activities in commercial farms to promote the use of this platform by technical advisors of a local trading company.	
REDUNG: Reduction of nitrate leaching in greenhouse soil bound horticulture through well-reasoned water and fertiliser application	01/10/2013 - 31/09/2017	FL	To develop a strategy for irrigation and fertilisation in greenhouse soil bound horticulture. This method will be available for farmers by means of a computer application.	P
Documentation and environmental optimisation of KNS and other fertiliser recommendations systems in horticulture	01/03/2013 - 30/09/2014	FL	This project aims the optimisation of the Flemish fertiliser recommendation systems for vegetables.	Q
Active phosphorus management and mining for an optimal phosphorus efficiency and reduction of phosphorus losses at parcel level (A_Propeau)	01/09/2014 - 31/08/2018	FL	The main objectives of this project are • to improve the efficiency of the applied phosphorus (P), • minimising the impact of P restrictions on crop yield and soil quality, and • providing solutions for reducing P losses to surface water under (intensive) agriculture and horticulture, for the purpose of improving the water quality.	Various

[1]ES: Spain, FL: Belgium – Flanders, NL: Netherlands

7.3 List of documented best practices

Table 8 Description of the innovative techniques mentioned in Table 1 (Quemada *et al.*, 2013; Schoumans *et al.*, 2014; Vandecasteele *et al.*, 2013) and the related fact sheets

Category		Technique	Fact sheet[1]	Example technique (fact sheets)	Description of example techniques
Crops and crop rotations	A	Crop rotation	BR01	Designing smart crop rotations	Designing smart crop rotations with proper crop sequences (main crop - main crop; main crop - cover crop) for an optimal crop performance and a sustainable agricultural practice.
	B	Catch crops/ cover crops/ green manures	BR02	Smart use of N fixing green manure	1. White clover sown in March under a cereal persists after cereal harvest and supplies N to a winter cauliflower crop in the next growing season (July-February); 2. Mixture of faba beans and peas sown in November-December after corn is incorporated in April and supplies N for an autumn cauliflower crop planted in June and 3. Sowing mixtures of cereals and legumes in autumn as a green manure, e.g. before spring broccoli crop (March-June).
			CH02	Winter legumes as green manure crop	Winter legume (e.g. forage pea) green manure crops might deliver 50-100 kg N/ha to the following crop.
			IT02	Mixture of legumes and non-legumes as cover crop	This technique combines the use of legumes as cover crop with non-legumes.
			WA02	Management of intercropping period after vegetables crops to reduce N losses through leaching	Catch crops (rye and rye-grass) are sown following vegetable crops (spinach-bean; spinach-spinach succession) that are harvested late autumn. Rye and rye-grass are sown up to 15th of October and ploughed next year in January-February. This technique leads to considerable N reduction in the 1.5 m soil profile (up to 80 kg N/ha) due to rye cover compared to bare soil in march of following year. The planting date is decisive for mineral N recovery of catch crops.
			NL09	Catch crop	Planning of catch crops after the main crop
	C	Local varieties/ varieties with higher nutrient use efficiency (NUE)	IT03	Local varieties	Using local varieties of legumes, sometimes ancient varieties
	D	Management of crop residues after harvest	NL04	Removal of N rich crop residues after harvest in early autumn	Crop residues are removed at or after crop harvest in early autumn.
	E	Reduced or ploughless tillage	WA06	Ploughless tillage	Ploughless tillage to reduce compaction. Tests were done to compare ploughing - spading machine – decompactor
	S	Mulching	IT01	Mulching and organic fertilisation	The technique is a combination of the mulching of a leguminous crop with the application of organic fertiliser based on composting of waste materials.
Drain water recirculation	F	Drain water recirculation	BR07	Re-use of drain water (recirculation)	Ferti-irrigation of potted plants on tablets by a closed flooding system. By capillary force the substrate absorbs the fertiliser solution in a certain time period (defined by the grower) and the remaining solution is drained from the tablets in a recycling system for re-use in the next watering period. With conductivity measurements extra fertilisation can be added in the re-used solution.
			CH06	Drain water re-use	In Switzerland drain water must be (re)used in agriculture or horticulture according to the state of the art and to the compliance with environmental requirements. For example, drain water of gerbera may be re-used on rose. Or drain water of tomato, is re-used in soil tomato production. This technique is still in practice.
Fertiliser application	G	Fertilisation planning	NL10	Fertilisation planning	Planning of fertilisation, mainly focused on N and P
	H	Split the N dose for a higher efficiency	WA03	Split the N dose for a higher efficiency	N splitting for four crops : carrot (*Daucus carota*), endive (*Cichorium endivia* var. *latifolia*), Welsh onion (*Allium fistulosum*) and curled-leave endive (*Cichorium endivia* var. *crispa*) experimented in Wallonia. The application of split N doses correspond to periods of highest N uptake expressed in days after sowing or transplanting.
	I	Fertiliser placement	DE03	Row or point fertilisation	The fertiliser is applied in a row near the crop or it is placed point-like at the plants.
			NL06	Placement of starter P fertiliser in the row or near individual plants	Placement of mineral P fertiliser in the neighbourhood of seeds or young crops.
			NL11	Placement of starter N fertiliser in the row or near individual plants	Placement of mineral N fertiliser in the neighbourhood of newly planted vegetables.

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Table 8 Description of the innovative techniques mentioned in Table 1 (Quemada et al., 2013; Schoumans et al., 2014; Vandecasteele et al., 2013) and the related fact sheets (Continued)

Category		Technique	Fact sheet[1]	Example technique (fact sheets)	Description of example techniques
Fertiliser type	J	Foliar N fertilisers as top dressing	BR06	Use foliar N fertilisers as top dressing	Certain fertilisers can be absorbed effectively by the vegetation. This technique is used to respond rapidly after discovering nutrient shortages in crops. The fertiliser solution can be applied with a pesticide sprayer.
	K	Commercial organic fertilisers	CH03	Commercial organic fertilisers	Commercial organic nitrogen fertilisers (e.g. feather powder) release the nitrogen relatively slow
	L	Nitrification-inhibitor treated fertilisers	DE01	Use of nitrification inhibitors	Ammonium-stabilised fertilisers can be used earlier in spring than normal NPK fertilisers, because the danger of N loss is lower. The ammonium is protected for 4-6 weeks from being transformed into Nitrate.
	M	Controlled release fertilisers (CRF)	DE02	Use of controlled release fertilisers (CRF)	Controlled release fertilisers for the open field are partly coated. The total amount of nitrogen, that is necessary for a crop, is given in spring.
	N	Compost application as fertiliser	BR09	Use of compost/mycorrhiza in association with reduced fertilisation	The combined use of compost and mycorrhiza has a positive effect on plant growth and development of some ornamental crops. Especially woody plants showed better root development at lower fertilisation rates.
			CH01	Phosphorus fertilisation with green waste compost	Phosphorus fertilisation with limited amounts of compost from green manure.
	O	Fertigation	NL01	Fertigation	Fertigation is the combination of fertilisation (in solution) and irrigation.
	AB	Manure treatment products	{59}, {63}		Usage of separated manure fractions and fertilisers with N/P ratios in line with the N/P ratio required by crop.
Irrigation	P	Irrigation based on moisture sensor	NL05	Irrigation based on moisture sensor	Rational irrigation based on the measurements of a moisture sensor instead of based on intuition.
			SP01	EnviroSCAN (+TriSCAN)	EnviroSCAN is a soil moisture sensor, based on frequency readings in the soil. Using a default calibration equation it gives data in volumetric water content (mm of water per 100 mm of soil measured). It needs in situ calibration. The TriSCAN sensor provides measurements of both soil water and salinity.
			CH04	Irrigation (and fertilisation) management according to soil moisture in strawberry cultivated in soil	This technique makes automatic irrigation, based on the use of a sensor which measures soil moisture, possible. This technique is tested and compared with the use of a tensiometer, which measures water retention, for automatic irrigation.
			CH05	Irrigation (and also fertilisation) management according to substrate moisture or drain volume in soilless raspberry	The aim is to reduce drain water in soilless raspberry. Growers would like to obtain only 5% of drain water. Different drain water volumes are tested: 5%, 10-15% and 15-20%
	V	Determine the N and water need based on a model	SP05	Simulation model of daily crop growth, nutrient uptake and evapotranspiration	Vegsyst is a simulation model of daily crop growth, nutrient uptake and evapotranspiration to be used by on-farm decision making support system. This model requires the input of daily climatic data. It was developed for greenhouse-grown vegetable crops; is being adapted to open field crops.
	AA	Other techniques for improving water management		Deficit irrigation	
				Improved irrigation technologies	
Determine the N need	Q	Determine the N need by soil determinations	BR03	Equiterre: advice according to precipitation, pre-crop and crop earliness	Advice according to precipitation (leaching), pre-crop field history (rich, medium or poor) and crop earliness. The system is based on mineral N analyses on demand (2-3 horizons, labo and nitrachek). N is applied 2-3 times before harvest in case of minor N availability.
			BR05	Determining N mineralisation	N fertilisation based on crop requirement and amount of N released from soil organic matter or crop residues.
			DE04	N-Expert / KNS-system	Intensive use of mineral N soil analyses, crop specific N target values before planting and during growth if necessary and taking N mineralisation (soil humus, crop residues) into account; intensifying crop rotation with special catch crops (high C/N ratio).
			WA01	Use of a recommendation program for the fertilisation planning	Establishment of a N fertilisation recommendation based on a provisional N balance sheet method at field scale. It assumes a balance between crop N needs and N supply from soil and fertilisers. It requires acquisition of a set of specific data from each field, related to the features of the soil (soil texture, carbon rate, mineral N rate of the profile in layer of 0 to 60 cm at the set up of the crop) and to the husbandry history of the field (previous crop, organic amendments, establishment of a green manure, fate of crop residues, ...) which are considered to estimate soil mineral N supply during the growing season). The methods is applicable for several crop, but was validated specifically for in Wallonia for carrots (*Daucus carota*), endive (*Cichorium endivia* var. *latifolia*), Welsh onion (*Allium fistulosum*) and curled-leaved endive (*Cichorium endivia* var. *crispa*).
			NL03	Determine the N need for the crop and farm	Determine the N requirements for the crop and farm based on fertiliser recommendations (guidelines for N fertilisation per crop and differentiated to soil type).
			NL02	Measuring or estimating the mineral N supply from the soil	The mineral N supply can be determined by soil analysis. When the analysis results are always similar or can be related to the previous crop and/or weather conditions, it can also be estimated.

Table 8 Description of the innovative techniques mentioned in Table 1 (Quemada et al., 2013; Schoumans et al., 2014; Vandecasteele et al., 2013) and the related fact sheets (Continued)

Category		Technique	Fact sheet[1]	Example technique (fact sheets)	Description of example techniques
Determine the N need (continued)	R	Determine the N need by crop determinations http://www.youtube.com/watch?v=7BDncg6mZsY http://www.youtube.com/watch?v=nrixH9tFxoA	BR04	Measuring nitrogen in plant juice	Plant N availability is assessed by measurement of nitrate in sap of plant leaf or stem tissue. This technique can be applied either with a field device or a laboratory equipment.
			WA04	Determine the level of the additional mineral dressing by use of crop determinations	Following up the crop N status (CNS) and decidinq on the need to apply complementary N. For Welsh onion, the CNS is assessed through leaf nitrate content measurements (using test strips and Nitrachek reflectometer). Threshold value of 2200 ppm (+/- 5%) has been proposed for the period ranging from 40 to 52 days after sowing. For curled-leaved endive, the CNS can be estimated either through leaf nitrate content measurements or through a chlorophyll meter (Hydro N-tester, Yara, Norway). For the nitrate test, threshold values of 2150 ppm (+/- 5%) and 2270 ppm (+/- 5%) have been proposed respectively for the periods ranging from 24 to 31 days after planting and from 33 to 40 days after planting. Similar threshold values for the chlorophyll meter are respectively for both periods 453 and 478.
	T		DE05	N-Tester: small portable chlorophyll meter	Small portable chlorophyll meter (based on SPAD 502). Used for measuring chlorophyll concentration in the culture (usually on the youngest fully developed leaf). 30 measurements are necessary for determining the nutritional status of the crop and the formation of a fertilisation advice. Requires calibration in field trials.
			DE06	N-sensor: detection of chlorophyll amount of crops	Detection of a crop's green biomass (chlorophyll amount) by measuring the light reflection of the crop. Measurement of either 'passive' (N-Sensor, using daylight) or 'active' (N-Sensor ALS with artificial light source). Measurement of spatial differences in crop condition allows spatially differentiated application of N fertilisers (and other inputs). On-field calibration for cereals with the N-Tester.
			DE07	ImageIT: digital images to calculate the ground coverage	Smartphone app combining input about the culture and field (expected yield, potential mineralisation ...) with photographs of the crop in order to formulate a fertilisation advice.
	U	Determine N need based on a model	NL14	Scientific base for N fertilisation recommendation	Estimation of the N delivery capacity of the soil, based on a model including organic matter quantity and quality and weather influences.
Other techniques	X	Soil amelioration with compost as a soil improver	WA05	Composting rejected trees for soil amelioration	Composting rejected trees to make a microbiologically controlled compost. By adding farmyard manure, straw, green material and soil a C/N ratio of 30 is aimed.
	Y	Determine the P need by soil determinations	NL15	Scientific base for P fertilisation recommendation	Determination of the P intensity, P quantity and P buffering capacity of a soil in order to give rational, scientific based P fertilisation recommendation.
	AC	Erosion control measures	{65}		Contour ploughing
			{74}		Switching from autumn tillage to spring tillage
			{68}, {72}, {75}, {66}, {67}		Reducing soil compaction and improving soil structure
			{21}		Set aside for several years
			{78}		Tillage to avoid tramlines
	AD	Measures for soils with a high/low P load	{6}, {28}, {30}, {36}, {48}, {49}		Using available P in soils to avoid high risk hot spots
			{82}, {28}, {30}, {34}, {35}, {45}, {4}		No application of manure and P fertiliser at high risk hot spots
			{4}		Crop production without fertilisation (P mining)

[1]Fact sheet: Fact sheets from the benchmark study on innovative techniques and strategies for reduction of nutrient losses in horticulture (http://www.ilvo.vlaanderen.be/Portals/69/Documents/Book_fact_sheets_NUTRIHORT.pdf). Fact sheets indicated as '{}' refer to fact sheet numbering by Schoumans *et al.* (2014), available at http://www.cost869.alterra.nl/Fs/List_of_options.htm.

7.4 Overview of bottlenecks for each of the innovative techniques

Table 9 Overview of bottlenecks for each of the innovative techniques

Category		Technique	Fact sheet[1]	Examples technique	Bottlenecks: Costs	Labour intensive	Knowledge intensive for farmer	Knowledge gaps in research	Increased risk of crop yield reduction	Increased risk of crop quality reduction	Legislation	Other	*Details on bottlenecks provided by Focus Group members*
Crops and crop rotations	A	Crop rotation	BR01	Designing smart crop rotations	xxx	x	xxxx	x	xx	x	xx	xx	Farm specialisation: It is not practical to change crop rotation in a market driven industry. Breaking up vegetable crop rotations with cereals leads to foregone profit from high value vegetable crops and affects particularly small farms. Small farms are less flexible because they need to maintain supply to buyers of vegetables. There is no innovative commercial plan for (new) alternative crops. In crop rotation, there are normally crops involved with lower financial return, but they are mainly crops that let the soil rest. Other equipment is required for other crops in a rotation. Fields often rented and farmers question who is responsible for maintaining the pH, %C, structure, … Legislation inhibits easy exchange of land. Dissemination on proper rotations depending of the region and the cropping systems is needed.
	B	Catch crops/cover crops/green manures	BR02	Smart use of N fixing green manure	xxx	x	x	xxx	xx	x	x	xx	There is need for a total approach of catch crops at farm level. Right now, there is a lack of information about disease pressure, nematodes, … Catch crops are grown more often on light soils, on medium and heavy soils they interfere with practical husbandry. Traditional crop system is an obstacle to the incorporation of crop residues. Effectiveness of catch crops for reducing N losses is highly dependent on climate. The weather conditions are difficult to predict which effects the establishment and growth of the catch crop. Green bean crops have high labour cost Vegetables leave frequently the land too late so it isn't possible to sow a catch crop. The harvest date is mainly determined by the factory/industry. Seed legislation should be revised in order to reduce the costs of these seeds.
			CH02	Winter legumes as green manure crop	xx	x	x	xx			x		No established benefit. Seasonality/weather conditions don't allow the cultivation of catch crops.
			IT02	Mixture of legumes and non-legumes as cover crop	xxx		xx	xxx			x	x	Seed legislation should be revised in order to reduce the costs of these seeds.
			WA02	Management of intercropping period after vegetables crops to reduce N losses through leaching	x							x	
			NL09	Catch crop	xx							x	
	C	Local varieties/ Varieties with higher nitrogen use efficiency (NUE)	IT03	Local varieties	xx			xxx	xxx	x	x	xx	Variety choice is determined by market requirements. There is still too less research for local varieties, because it isn't profitable for the big companies who develop new varieties. A breeding programme required. Lack of sufficient seeds/seedling production. Local varieties should be promoted, in particular with inoculation with is efficient mycorrhiza.
	D	Management of crop residues after harvest	NL04	Removal of N rich crop residues after harvest in early autumn	xxxxx x	xxxxx		xxx				xx	Removing harvest residues faces a lot of bottlenecks. We might look in the direction of stabilising the residues at the field as an alternative to reduce N leaching during the winter. Removing residues has been tried but what can you do with them? Use of crop residues in biogas plants is difficult due to the high water content and contamination with soil particles. Harvesting crop residues requires special equipment or adaptation of harvester can be a solution for some crop. Removing crop residues is labour and cost intensive. Removal of crop residues can cause soil compaction (if the soil and weather conditions are not good). If residue are not incorporated ASAP the disease risk increases.

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Table 9 Overview of bottlenecks for each of the innovative techniques (Continued)

Category		Technique	Fact sheet[1]	Examples technique	Bottlenecks: Costs	Labour intensive	Knowledge intensive for farmer	Knowledge gaps in research	Increased risk of crop yield reduction	Increased risk of crop quality reduction	Legislation	Other	Details on bottlenecks provided by Focus Group members
Crops and crop rotations	E	Reduced or ploughless tillage	WA06	Ploughless tillage			xx	xxxx	x	xx			There is too less research regarding reduced tillage and the risk for diseases on the crops. Disease risks if you don't properly incorporate crop residues. Sandy soils require minimum tillage to be successful. Crop rotation is recommended in Portugal, including in particular legumes.
	S	Mulching	IT01	Mulching and organic fertilisation	xx	x	x	xx	xx	x			High rainfall can result in a risk of high N losses. The risk of diseases increases. Mulching is recommended between rows and in spring crops in Portugal.
Drain water recirculation	F	Drain water recirculation	BR07	Re-use of drain water (recirculation)	xxx		xxxx	x		x	x	x	Risk of diseases. Risk of salinisation of the irrigation solution. More knowledge of the system management is required from farmers, technicians and consultants. Construction are needed in the field to collect the drainage water. Farmers need to re-adjust the nutrient solution regularly.
			CH06	Drain water re-use	x		x						Technical feasibility for field crops: equipment is needed to collect and re-use the drain water and to disinfect this rain water.
Fertiliser application	G	Fertilisation planning	NL10	Fertilisation planning			xx				xx	x	Practical knowledge gaps: farmers need support to make the fertilisation planning. Fertiliser planning programme is required. In most cases, the fertilisation planning is only based on local accumulated experience. In Portugal, farmers plan N fertilisation. In general, they have advisers (either official or particular), but modelling is lacking.
	H	Split the N dose for a higher efficiency	WA03	Split the N dose for a higher efficiency	xx	xxx		x			x	x	Farmers need support about the right timing to split the dose and to take a soil sample. Most growers do this where necessary, on retentive soils it is not necessary. Timing of N depends on the N type. More use of the fertiliser spreader and tractor is needed, with a higher cost mainly due to the oil consumption and workdays. More irrigation events are required, which requires more energy consumption.
	I	Fertiliser placement	DE03	Row or point fertilisation	xxx	x	x	x					Adaptation of machinery to specific fertilisation method is needed
			NL06	Placement of starter P fertiliser in the row or near individual plants	xxx	x	x	x			x	xx	Start P fertilisation shows nice results. Demonstration at proper farms is the best way to convince the farmer to use start P. Placement of fertiliser near plants versus broadcast application of fertiliser requires special machines. Many large farm use fertilisation equipment from agricultural production (cereals) due to unavailability of appropriate specialised technology. Fertiliser placement also takes more time. In general, P is broadcast at basal dressing.
			NL11	Placement of starter N fertiliser in the row or near individual plants	xxx	x		x				x	
Fertiliser type	J	Foliar N fertilisers as top dressing	BR06	Use foliar N fertilisers as top dressing	xxxxx	xxx		xx	x	xx	x	xxx	Increasing interest of farmers. Bottleneck is independent non-commercial information about the products. More information on foliar feeds is required. A special machinery is needed to spread the fertiliser, i.e. sprinkler irrigation system with fertiliser injection, spraying equipment, … Foliar applications are more expensive than soil fertilisation. Problems can appear with some mixtures of pesticides. The dose you can apply is very low, but you can't cultivate a crop with frequently very small amounts of nitrogen Increased risk of crop quality reduction due to the spreading of fungi diseases after a foliar treatment under relative high moisture conditions in the air. Foliar N dressing has (rarely) been applied in fruit trees as it is efficient on crop NUE, but it is expensive.
	K	Commercial organic fertilisers	CH03	Commercial organic fertilisers	xxxx	x	x	xxxxx	x		xxx	xx	Most used in organic farming. In conventional farming, common practise is to use manure in combination with cheap mineral fertilisers. Organic matter is very complex. Not enough information about the composition of some commercial organic fertilisers It might be needed to improve the standardisation of available organic fertilisers. Actually each country has its own rules. A new European Council Directive about organic fertilisers could be good. The legislation is very strict for new product, so the products that exist are quite expensive.

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Fertiliser type	L	Nitrification inhibitor treated fertilisers	DE01	Use of ammonium stabilised fertilisers	xxxxx			xxx	x	x			Rate of release is often problematic, not worth the risk. These fertilisers are not effective in all the climate conditions and crop management systems. It should be established in which conditions these fertilisers are effective to prevent N leaching. In fertigation systems, most of nutrients are supplied with fertilisers than contain nitrates.
	M	Controlled release fertilisers (CRF)	DE02	Use of controlled release fertilisers (CRF)	xxxxx x		x	xxx	x			xx	Too expensive and no chance to adjust during the growth. Farmer has no control. The release of the fertilisers must be at the right time during the cropping period. This is not yet optimised. Top dressing required as well. Probably the use of CRF should be combined with high available N fertilisers at high N crop demand. Not suitable with fertigation
	N	Compost application as fertiliser	BR09	Use of compost/mycorrhiza in association with reduced fertilisation	xx	x	x	xxxxx			xxxx	xx	Not allowed if the compost is not of a very high standard. Availability of applied N and P application unknown Despite being one of the oldest fertiliser, farmers do not know how to use it. When compost is not taken into account for nutrient legislation, there is not enough product available to apply, main bottleneck is nutrient legislation pH and temperature changes in the soil can affect the efficacy of mycorrhiza
			CH01	Phosphorus fertilisation with green waste compost	x	x		x	x		xx	x	Compost quality can be different according to the input sources. More knowledge transfer is required to convince growers of benefits The availability for plants of the P applied should be studied. There is a risk that it takes a long time to mineralise the organic P.
	X	Soil amelioration with compost	NL01	Composting rejected trees for soil amelioration	x			x			xx	x	Compost origin and quality. Commercial products need to improve its parameterisation, standardisation and regulation in order to gain accuracy. Legislation about quality standards for composts Actually, by the ecosystem service of carbon sequestration, the addition of composts and crop residues into soil have been encouraged. This technique has also been recommended for poor soils in organic matter in order to improve soil quality.
	O	Fertigation	{59}, {63}	Fertigation	xxxxx x	xx	xx		x			xxxx	Only possible at fields close to the farm. Has been researched but needs careful management to reduce pollution! High investment costs for necessary technology (drip irrigation) in open field horticulture. No incentives in regions where water is not scarce (cheap). Higher cost for installation to apply fertigation Awareness by farmers
	AB	Manure treatment products	NL05	Use separated manure fractions and fertilisers with N/P ratios in line with the N/P ratio required by crop	x		x	xxx	x	x	x		List of organic products and their quality; Lack of knowledge Not allowed on Conventional Production. Analysis and specialised equipment are required Only mixed farms easy access to manure It is not a bottleneck for mineral fertilisers. It is easy to formulate different compositions of the fertiliser or the irrigation solution. Cheap technologies to apply on the farm with low legislation for restrictions so there is a big acceptability.
Irrigation	P	Irrigation based on moisture sensor	SP01	Irrigation based on moisture sensor	x		xx					x	Combination with climatic models (e.g. Geisenheimer Method) Needs calibration, lack of integration in farm management software
			CH04	Enviroscan (+Triscan)	x		x						Availability of water
			CH05	Irrigation (and also fertilisation) management according to soil moisture in strawberry cultivated in soil	xxx		xx					x	Most farmers who irrigate high value vegetable crops already use sensors. Irrigation techniques based on electrical/electronic technology are difficult to implement due to the cost and the farm security. The (poor) water quality should be taken into account. More research is recommended.
			SP05	Irrigation (and also fertilisation) management according to substrate moisture or drain volume in soilless raspberry	x		x						

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Irrigation	AA	Other techniques for improving water management		Deficit irrigation	xx		xxxx	xxx	xxx	xx			Many intensive farmers have moisture sensors but do not always know how to use them. More research is needed to avoid high hydride stress. The development of management systems and sensoring devices is necessary to help taking decisions in field Availability and storage of water.
Determine the N/P need	Q	Determine the N need by soil determinations	BR03	Equiterre: Advice according to precipitation, pre-crop and crop earliness		x	x	xx				x	How to estimate the N mineralisation on a new field (rented per year): % C does not give enough information. There are economic devices that can help us to determine N in the soil but may be expensive for the farmers.
			BR05	Determining N mineralisation	x	x	xx	x				xx	The soil samples must be taken at the right time. Farmers need support for this. Adds tasks to management, high coordination cost in farms with many crops. More research is needed: no reliable test, the mineralisation rate is not known in every cropping season. This is relevant for annual crops; for perennial crops, foliar analysis is more recommended.
			DE04	N-Expert / KNS-system	xxx	xx	xxx	x				xx	Farmers need support to interpret the results of the soil analysis. In UK many farmers take mineral N samples but mainly for crop protocols. Needs to be integrated in farm management software for automatisation
			WA01	Use of a recommendation program for the fertilisation planning		x	x	xx			x	x	Lack of data about N uptake. Some problems are related to sampling and interpretation but recent research projects provide support. N based on historical cropping history and done more based on crop observation and walking in the field Traditional recommendation programs are based on accumulated local experience, not taking into account another sources of fertilisers
			NL03	Determine the N need for the crop and farm		x	x					x	The fertilisation demand can change during the cropping season with changes depending on weather conditions.
			NL02	Measuring or estimating the mineral N supply from the soil	x	xx	xx	xx				x	No reliable soil N test Variability of soil conditions in the same plot. Several samples have to be collected.
	R	Determine the N need by crop determinations	BR04	Measuring nitrogen in plant juice	x	x	x	xxxx				x	Knowledge gaps in practice. A big gap of missing information of N concentration for vegetables, typically for the region Calibration is necessary: what plant parts? How to interpret the result of the analysis? Farmers probably need external help, but this results in a delay for the decision. Farmers probably need to buy expensive equipment. It is difficult to obtain sap of some crops. Properly management of plant samples is needed before extracting the sap sample.
			WA04	Determine the level of the additional mineral dressing by use of crop determinations	xx	xx	xxxx	xxx					If you get a result what does it mean? This is recommended for perennial crops, but it is more expensive than soil analysis. Foliar analysis is the most usual for fruit trees and vineyard, for correcting deficiencies during the season.
Determine the N/P need	T	Determine the N need based on plant determinations	DE05	N-Tester: Small portable chlorophyll meter	x	x	xx	xxx					Lack of data about N uptake Lack of reliable recommendations on fertilisation needs for many crops Healthy leaves must be selected for this measurement.
			DE06	N-sensor: detection of chlorophyll amount of crops	xxx	x	xxx	xxxxx				x	Farmer probably need external help or to buy expensive equipment. When you use external services, decisions are delayed. Need to determine responsive curve to the registered measurements.
			DE07	ImageIT: Digital images to calculate the ground coverage	x	x	xx	x					Knowledge gaps in practice Expensive for the farmer because very few systems are available and surface of arable land is low Foliar determinations are usual for perennial crops; SPAD measurements and modelling should be encouraged.
	U	Determine the N need based on a model	NL14	Scientific base for N fertilisation recommendation	x		xxx	xxx	x	x		xx	Most models are too detailed and not relevant for application in outdoor production systems. Some models are too complex to be used by farmers. Too much inputs are needed. In situ advice / small fields is uneconomic The use of models require a computer and implemented software for this model.

Table 9 Overview of bottlenecks for each of the innovative techniques (Continued)

Category		Technique	Fact sheet[1]	Examples technique	Bottlenecks: Costs	Labour intensive	Knowledge intensive for farmer	Knowledge gaps in research	Increased risk of crop yield reduction	Increased risk of crop quality reduction	Legislation	Other	Details on bottlenecks provided by Focus Group members
Determine the N/P need	V	Determine the N and water need based on a model	WA05	Simulation model of daily crop growth, nutrient uptake and evapotranspiration	x		xx	xxx	x	x		x	Most models are too detailed and not relevant for application in outdoor production systems. Calibration for additional vegetable crops is needed. Software must be developed. Crop water requirements have been estimated by modelling, but the simultaneous recommendation for water and N supply has not been used. Research is recommended for such purpose.
Determine the N/P need	Y	Determine the P need by soil determinations	NL15	Scientific base for P fertilisation recommendation	x			xxxx	x		x		Which analysis is most appropriate? P-AL or P-PAE? New research about the P dynamics in soil should be done to increase the P use/uptake efficiency of plants It is an expensive element to determination in the farm. Proper analytical method, according to soil pH, should be encouraged. Method used in routine is not adequate for each soil type.
Erosion control measures	AC		{65}	Contour ploughing				x					Lack of knowledge of the technique.
			{74}	Switch from autumn tillage to spring tillage					x	x		x	Land ownership Not possible in heavy soils (clay). Fertilisation in autumn with lower risk of structure damage in spring due to organic fertiliser application.
			{68}, {72}, {75}, {66}, {67}	Reduce soil compaction and improve soil structure	xxx	xxx	x	x					Cost and knowledge Land availability i.e. short-term renting It takes a long time to improve the quality of a soil. Increasing organic matter content with organic soil amendments and/or reduced tillage could be necessary. Compaction caused by heavy machinery of the farmer or agricultural contractor.
			{21}	Set aside for several years	xxx								No financial return of the land? Other types of crops as an alternative or subsidy?
			{78}	Tillage to avoid tramlines	x		xx	x	x	x			
Measures for soils with a high/low P load	AD		{6}, {28}, {30}, {36}, {48}, {49}	Make use of available P in soils to avoid high risk hot spots	x			xx	xx	x			
			{82}, {28}, {30}, {34}, {35}, {45}, {4}	Don't apply manure and P fertiliser at high risk hot spots				x			xx		High risk areas identified through legislation Reduction of soil organic carbon content due to a reduced manure application rate.
			{4}	Crop production without fertilisation (P mining)				xx	xx	x			It is not easy to grow crops, especially in alkaline soils due to P fixation. Negative effect on yield in absence of fertilisers. There is a risk of soil fertility decline

[1]Fact sheet: Fact sheets from the benchmark study on innovative techniques and strategies for reduction of nutrient losses in horticulture (http://www.ilvo.vlaanderen.be/Portals/69/Documents/Book_fact_sheets_NUTRIHORT.pdf).

eip-agri
AGRICULTURE & INNOVATION

The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

1) the EU Research and Innovation framework, Horizon 2020,

2) the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

1. to take stock of the state of art of practice and research in its field, listing problems and opportunities;
2. to identify needs from practice and propose directions for further research;
3. to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter on:
http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf

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