EIP-AGRI Focus Group

Fertilisation horticulture

STARTING PAPER

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1 Introduction

The Focus Group 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). The Focus Group brought together 20 experts in two focus group meetings with the purpose to answer the main 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?'.

This starting paper first explains the challenge, and collates the available information at the start of the Focus Group. It then details the preparatory work done by the experts before the first meeting of the group and the themes to be discussed.

2 The challenge

Intensive production systems are by definition using a high level of external resource inputs per area and time. Vegetable production systems are at the upper limit of production intensity, relying on the high economic value of the produce (Nicola et al., 2013). Appreciable nitrate leaching is a common occurrence in vegetable production where low nitrogen use efficiencies (NUE) are often combined with excessive irrigation, short growing cycles and shallow rooting plants. Within the European Union, there is increasing pressure on the agricultural sector to appreciably reduce nitrate leaching losses which are associated with nitrate contamination of ground- and surface water. Additionally, there is pressure to reduce other nitrogen (N) losses, which have undesirable environmental consequences, such as nitrous oxide emission, ammonia volatilisation and erosion. Consequently, there is a strong requirement to appreciably improve nitrogen use efficiency in intensive vegetable production (Thompson et al., 2013).

Phosphorus (P) is a non-renewable resource, an essential nutrient for plants and 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 exports. More sustainable use of P in agricultural and horticultural systems is needed, including more efficient use, reducing losses and recycling (Pellerin & Nesme, 2013).

3 Focus group

The EIP-AGRI Focus Group charter contains more information about objectives, deliverables and membership of a focus group (http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf).

The objectives of an EIP-AGRI Focus Group are:

1. To take stock of the state of the art of practice in the field of the EIP-AGRI Focus Group activity, listing problems and opportunities.

2. To take stock of the state of the art of research in this field, summarising possible solutions to the problems listed.

3. To identify needs from practice and propose directions for further research.

4. To propose priorities for innovative actions by suggesting potential practical operational groups or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

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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? This Focus Group is expected to carry out the following main tasks:

- 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 carbon 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, soil 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.

4 Innovative techniques

This Focus Group focuses on ***farm and field scale*** techniques in vegetable ***soil-grown*** open air systems. As a starting point to identify (i) innovative techniques to reduce nutrient losses and (ii) bottlenecks to be solved in order to increase implementation of innovative techniques, three studies were used:

1) Benchmark study on innovative techniques for nutrient management in horticulture (Appendix 1);
2) Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yields (Quemada et al., 2013);
3) Mitigation options to reduce phosphorus losses from the agricultural sector and improve surface water quality: A review (Schoumans et al., 2014).

The Benchmark study focused on horticulture, while the techniques discussed by Quemada et al. (2013) and Schoumans et al. (2014) relate to agriculture in general.

4.1 Benchmark study

A consortium of research institutes in Flanders (ILVO, UGent, Inagro, PCS, PCG and PSKW) recently performed a benchmark study to evaluate innovative techniques for nutrient management in horticulture (Vandecasteele et al., 2013; more information in Appendix 1). Innovative techniques and strategies for reduction of the nutrient losses in horticulture were collected and evaluated for different regions in Belgium, The Netherlands, France, Spain, Italy, Germany, Denmark, Switzerland and Poland.

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These techniques are related to six groups:

- Crops and crop rotations
- Drain water recirculation
- Fertiliser application
- Fertiliser type
- Irrigation
- Determine the N need

Table 1 gives an overview of the innovations already implemented in practice for horticulture open air (Vandecasteele et al., 2013). Fact sheets were provided to document these techniques.

The implementation rate of the techniques mentioned in Table 1 has been evaluated for the different regions. This information was used to identify bottlenecks inhibiting a higher implementation rate (Vandecasteele et al., 2013).

In addition, an overview was made of the innovative techniques which are currently investigated or ready for implementation but not yet applied in the evaluated regions (Vandecasteele et al., 2013). Fact sheets were provided to document these techniques. As an example for Flanders, the applicability of these techniques was assessed based on technical and economic feasibility (Table 2).

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Table 1 *Implemented innovative techniques* in horticulture, according to the Benchmark study on innovative techniques and strategies for reduction of nutrient losses in open air horticulture (Vandecasteele et al., 2013). A description of each example technique can be found in Appendix 2. Links with phosphorus (P), soil organic carbon (SOC), and water use (WU), as presented in the fact sheets[1], are indicated ('+' = positive effect on SOC or WU, '-' = negative effect).

Category		Technique	Fact sheet[1]	Example technique (fact sheets)	Presentation at NutriHort[2]	Presentation at NEV[3]	Link with P	Link with SOC[4]	Link with WU[4]
Crops and crop rotations	A	Crop rotation	BR01	Designing smart crop rotations	(26), (44), (64)	[43], [53], [61]			-
	B	Catch crops/ cover crops/ green manures	BR02	Smart use of N fixing green manure	(14), (15), (16), (17), (18), (24), (38), (40), (60), (65), (71)				-
			CH02	Winter legumes as green manure crop					
			IT02	Mixture of legumes and non-legumes as cover crop				+	+
			WA02	Management of intercropping period after vegetables crops to reduce N losses through leaching				+	-
			NL09	Catch crop				+	
	C	Local varieties/ Varieties with higher NUE[4]	IT03	Local varieties		[9], [26], [54]			+
	D	Management of crop residues after harvest	NL04	Removal of N rich crop residues after harvest in early autumn	(25), (26), (70), (73), (74)	[10], [22], [43], [53]		-	
	E	Reduced or ploughless tillage	WA06	Ploughless tillage	(8), (28), (62)		x	+	+
Drain water recirculation	F	Drain water recirculation	BR07	Re-use of drain water (recirculation)	(10), (11), (51)	[29]	x		+
			CH06	Drain water re-use			x		
Fertiliser application	G	Fertilisation planning	NL10	Fertilisation planning	(37), (38), (46), (79), (89)	[11], [13], [27]	x	+	
	H	Split the N dose for a higher efficiency	WA03	Split the N dose for a higher efficiency	(6), (46), (83), (87)				
	I	Fertiliser placement	DE03	Row or point fertilisation	(7), (20), (46), (87)		x		
			NL06	Placement of starter P fertiliser in the row or near individual plants			x		
			NL11	Placement of starter N fertiliser in the row or near individual plants					
Fertiliser type	J	Foliar N fertilisers as top dressing	BR06	Use foliar N fertilisers as top dressing	(14), (82)		x		
	K	Commercial organic fertilisers	CH03	Commercial organic fertilisers	(76)	[6], [28]			
	L	Nitrification inhibitor treated fertilisers	DE01	Use of nitrification inhibitors	(46)	[18], [22]			
	M	Controlled release fertilisers (CRF)	DE02	Use of controlled release fertilisers (CRF)	(39), (46), (83)	[5]	x		

Table 1 Continued

Category		Technique	Fact sheet[1]	Example technique (fact sheets)	Presentation at NutriHort[2]	Presentation at NEV[3]	Link with P	Link with SOC[4]	Link with WU[4]
Fertiliser type (continued)	N	Compost application as fertiliser	BR09	Use of compost/mycorrhiza in association with reduced fertilisation	(22), (28), (62), (67), (72)	[17], [24], [37], [38], [39], [59]	x		+
			CH01	Phosphorus fertilisation with green waste compost			x	+	
	O	Fertigation	NL01	Fertigation	(12), (14), (15), (49), (55), (60), (88)	[2], [32], [34], [35], [36], [57]			+
Irrigation	P	Irrigation based on moisture sensor	NL05	Irrigation based on moisture sensor	(5), (10), (12)				+
			SP01	EnviroSCAN (+TriSCAN)			x		+
			CH04	Irrigation (and also fertilisation) management according to soil moisture in strawberry cultivated in soil			x		+
			CH05	Irrigation (and also fertilisation) management according to substrate moisture or drain volume in soilless raspberry			x		+
Determine the N need	Q	Determine the N need by soil determinations	BR03	Equiterre: Advice according to precipitation, pre-crop and crop earliness	(4), (6), (26), (27), (31), (44), (59), (66), (84), (85)	[24], [32], [33], [34], [43], [47], [48], [53], [61]			
			BR05	Determining N mineralisation					
			DE04	N-Expert / KNS-system					
			WA01	Use of a recommendation program for the fertilisation planning					
			NL03	Determine the N need for the crop and farm					
			NL02	Measuring or estimating the mineral N supply from the soil					
	R	Determine the N need by crop determinations	BR04	Measuring N in plant juice	(4), (6), (26), (42), (47), (48), (86)	[3], [43], [47], [53]			
			WA04	Determine the level of the additional mineral dressing by use of crop determinations					

[1]Fact sheet: During the benchmark study 55 examples of innovative techniques in Flanders and the visited regions were assembled. Fact sheets for these examples are published: NutriHort - Nutrient management, innovative techniques and nutrient legislation in intensive horticulture for an improved water quality. September 16-18, 2013, Ghent. Fact sheets from the benchmark study on innovative techniques and strategies for reduction of nutrient losses in horticulture (http://www.ilvo.vlaanderen.be/Portals/69/Documents/Book_fact_sheets_NUTRIHORT.pdf).

[2]'()' refer to presentation numbering at the NutriHort conference (http://www.ilvo.vlaanderen.be/Portals/69/Documents/Programme_Nutrihort.pdf).

[3]NEV: Nitrogen, Environment and Vegetables conference, organised in April 2013 (Torino, Italy); See Appendix 3 for presentation numbering ('[]') at NEV.

[4]SOC: Soil organic carbon, WU: Water use, NUE: Nutrient use efficiency.

Table 2 Assessment of applicability in Flanders of *innovative techniques ready for implementation* in open air horticulture. A description of each example technique can be found in Appendix 2. Technical feasibility: -2: at least 3 major bottlenecks, -1: less than 3 major bottlenecks but more than 1 major or two small bottlenecks, 0: at maximum 1 major or two small bottlenecks, 1: only one small bottleneck, 2: no bottlenecks. Economic feasibility: -2: Yearly costs >5% of turnover, -1: yearly costs are between 2 and 5% of turnover, 0: yearly costs are between 0.5 and 2% of turnover, 1: yearly costs are between 0.1 and 0.5% of turnover, 2: yearly costs <0.1% of turnover) (Vandecasteele et al., 2013). Links with phosphorus (P), soil organic carbon (SOC), and water use (WU), as presented in the fact sheets[1], are indicated ('+' = positive effect on SOC or WU, '-' = negative effect).

	Technique	Fact sheet[1]	Technique/strategy name	Presentation at NutriHort[2]	Presentation at NEV[3]	Technical feasibility (assessed for Flanders)	Economic feasibility (assessed for Flanders)	Link with P	Link with SOC[4]	Link with WU[4]
S	Crops and crop rotations: mulching	IT01	Mulching and organic fertilisation	(40)		1	1		+	+
T	Determine the N need based on crop determinations	DE05	N-Tester: small portable chlorophyll meter	(4)	[3], [20]	0	1			
		DE06	N-sensor: detection of chlorophyll amount of crops			0	0			
		DE07	ImageIT: digital images to calculate the ground coverage			0	1			
U	Determine the N need based on a model	NL14	Scientific base for N fertilisation recommendation	(4), (30)	[19], [30], [45]	-1	1			
V	Determine the N and water need based on a model	SP05	Simulation model of daily crop growth, nutrient uptake and evapotranspiration	(52)	[4], [8], [21], [50], [51], [56]	-1	1			+
X	Soil amelioration with compost as a soil improver	WA05	Composting rejected trees for soil amelioration	(28), (62), (67)		0	0	x	+	
Y	Determine the P need by soil determinations	NL15	Scientific base for P fertilisation recommendation	(23)		2	1	x	-	

[1]Fact sheet: During the benchmark study 55 examples of innovative techniques in Flanders and the visited regions were assembled. Fact sheets for these examples are published: NutriHort - Nutrient management, innovative techniques and nutrient legislation in intensive horticulture for an improved water quality. September 16-18, 2013, Ghent. Fact sheets from the benchmark study on innovative techniques and strategies for reduction of nutrient losses in horticulture (http://www.ilvo.vlaanderen.be/Portals/69/Documents/Book_fact_sheets_NUTRIHORT.pdf).

[2]'()' refer to presentation numbering at the NutriHort conference (http://www.ilvo.vlaanderen.be/Portals/69/Documents/Programme_Nutrihort.pdf).

[3]NEV: Nitrogen, Environment and Vegetables conference, organised in April 2013 (Torino, Italy); See Appendix 2 for presentation numbering ('[]') at NEV.

[4]SOC: Soil organic carbon, WU: Water use, NUE: Nutrient use efficiency.

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Except for the identification of innovative techniques for nutrient management in horticulture, the Benchmark study furthermore allowed to define the most important future research needs (Vandecasteele et al., 2013):

- Research may focus on a **combined assessment of crop N demand, based on soil sampling, crop determinations and models.** The issue of crop determinations is valuable if these techniques are able to detect N shortages early enough. Thompson et al. (2013) recommended a general management system for optimal N management of intensive vegetable production systems, in which 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. The main categories of available tools recommended were (i) soil testing approaches (e.g. soil mineral N in the root zone at planting), (ii) N balance calculations (N inputs and outputs), (iii) modelling approaches, and (iv) crop/plant testing approaches (monitoring crop N status through sap analysis and optical sensors).
- The use of **local varieties and/or varieties with a higher nutrient use efficiency** is a research need. Rooting depths and nutrient use efficiency may be used as criteria in variety choice.
- For removal of **crop residues**, being a valuable option for significant reduction of N leaching, a link with the bio-based economy is essential to have a promising application for growers: collected residues can be re-used as bio-resource. However, more research is needed as also negative effects of crop residue removal on soil structure or applicability under bad weather conditions are to be evaluated. There is a need for developing special harvest equipment as well.
- **Optimal use of catch crops**, **soil improvers and organic fertilisers, manure and compost** for combining a reduction of P losses with a sufficiently high organic carbon level in arable soils.

From the 'Nitrogen, Environment and Vegetables'-workshop (Turin, April 2013) and the Benchmark study, it was concluded that the main management practices (or combinations of these practices) that can reduce risks of water pollution in horticultural areas are (Vandecasteele et al., 2013):

- Accurate prediction of fertiliser demand (combining foliar and soil water tests with models);
- Precision techniques, in view of calibrating timing and doses of fertiliser applications;
- Crop residues management (removal from the field or other variants);
- Optimisation of crop rotations (deep/shallow roots) and use of local varieties and/or varieties with a higher nutrient use efficiency;
- Use of catch crops in certain situations.

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4.2 Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yields (Quemada et al., 2013)

Quemada et al. (2013) conducted a meta-analysis of published experimental results (published from 1981 to 2012; mainly vegetables and cereals; most data came from the European Mediterranean basin (35%) and from the Midwest of the United States (30%)) from agricultural *irrigated systems*, in order to identify those strategies that have proven effective at reducing nitrate leaching and to quantify the scale for reduction that can be achieved. They identified four strategies; each strategy included several treatments (Table 3). The authors concluded that improving water management practices offers the greatest potential for reductions in nitrate leaching to groundwater, and matching irrigation supply to crop needs should be the primary water management technique implemented. Further reductions in nitrate leaching can be achieved if scheduling is improved, with a concurrent slight increase in crop yields. Improved fertiliser management reduced nitrate leaching by a mean of 40% relative to management where fertiliser use was not optimised, indicating that this is also a priority when designing policies to mitigate nitrate leaching. The results suggest that a combination of optimal water management and applying recommended fertiliser rates is also the most profitable choice for the farmer: crop yields for both approaches are reduced by less than 5% relative to the controls. Therefore, optimising water and fertiliser management practices appear to be "win-win" choices for reducing nitrate leaching. Other strategies, while providing some benefits in reducing N losses, may only be recommended once the primary approaches of improving water and fertiliser management are implemented (Quemada et al., 2013). Improved fertiliser management, the use of cover crops and the use of improved fertiliser technologies could also be used to improve nutrient use efficiency in rainfed systems, and were also included in the Benchmark study (Table 1). The combined optimisation of water and fertiliser management practices is highly relevant for open air crops in Mediterranean (Southern Italy, Spain, Southern France, Greece, …) and continental (parts of Denmark, Germany, …) parts of Europe, and for greenhouse crops as well.

Table 3 Categories (strategies and treatments) to control nitrate leaching in irrigated land defined from the systematic analysis of selected peer reviewed articles (Quemada et al., 2013). New techniques compared to Table 1 are indicated in *italics*, and are included in Table 5 (which contains the results of the inventory of innovative techniques) as technique AA: 'Other techniques for improving water management'.

Strategies	Treatments	Corresponding techniques Table 1
Improved water management (IWM)	Adjust water application to crop needs	V
	Deficit irrigation	
	Improved irrigation schedule	P
	Improved irrigation technologies	
	Mulched soil	(S)
Improved fertiliser management (IFM)	Use recommended fertiliser rates	G
	Reduction in the recommended fertiliser rate	G
	Optimised timing of fertiliser application	G, H
	Fertigation	O
Use of cover crops (CC)	Replacing winter fallow by a non-legume CC	B
	Replacing winter fallow by a legume CC	B
Improved fertiliser technologies	Controlled release fertiliser	M
	Nitrification inhibitor	L

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4.3 Mitigation options to reduce phosphorus losses from the agricultural sector and improve surface water quality: A review (Schoumans et al., 2014)

Most techniques identified in the Benchmark study (Vandecasteele et al., 2013) and by Quemada et al. (2013) focus on reducing N losses at field scale. Much less attention goes to reducing phosphorus (P) losses. In the frame of the COST action 869, Schoumans et al. (2014) made an overview of mitigation practices for reducing P losses that have been tested (in Europe) to varying degrees (Table 4). This overview includes various categories of mitigation options (at various scales) in relation to P. Fact sheets were provided to document these techniques.

Table 4 Mitigation strategies for nutrient management at farm scale, at field scale, at catchment scale and in aquatic ecosystems (Schoumans et al., 2014). New techniques compared to Tables 1 and 3 are indicated in *italics*; some of these techniques (AB, AC and AD; indicated in the last column) are included in Table 5, which contains the results of the inventory of innovative techniques. AB = Manure treatment products; AC = Erosion control measures; AD = Measures for soils with a high P load. We marked interesting techniques in green, possible interesting techniques in orange, and techniques not of interest for crop production in red. Furthermore, we estimated links with nitrogen (N), soil organic carbon (SOC), and water use (WU) ('+' = positive effect on SOC or WU, '-' = negative effect).

	Strategy	Aim	Factsheets[1]	Measure	Corresponding techniques Table 1	Link with N	Link with SOC[2]	Link with WU[2]	
Mitigation strategies for nutrient management at farm scale	Environmentally sound fertiliser application & nutrient handling	Incorporate soil P into management strategy to achieve moderate soil P levels	{6}, {28}, {30}, {36}, {48}, {49}	*Use of available P in soils to avoid high risk hot-spots*					*AD*
		Reduce P content of the soil at high risk hot spots	{82}, {28}, {30}, {34}, {35}, {45}, {4}	*No application of manure and P fertiliser at high risk hot spots*		x			*AD*
		Increase P efficiency of crop uptake via appropriate placement and time of application	{59}, {63}	*Use of separated manure fractions and fertilisers with N/P ratios in line with the N/P ratio required by crop*		x			*AB*
			{8}	Application of P near the roots instead of broadcast	I	x			
			{81}	Avoidance of applying manure and P fertilisers before heavy rainfall or prolonged rainfall	G	x			
			{24}, {25}	Phasing of nutrient fertilisation application over the year	H	x			
			{83}	*Creation of sufficient storage capacity*					
	Change P input	Avoid high P content in fodder by increasing digestible P and lowering total P content in feed	{1}, {80}	*Feeding livestock with refined fodder, taking account of their requirements given their growth phase*		x			
			{1}, {80}	*Use of feed with a lower content of phytate-P or addition of phytase to feed to increase digestibility of phytate-P*					
	Change P output	Exploit the commercial value of the manure surplus	{46[3]}	*Making products for export or for arable farms*					
			{46}	*Producing secondary P resources for industries by incineration to P ash*					

[1]'{}' refer to fact sheet numbering by Schoumans et al. (2014), available at http://www.cost869.alterra.nl/Fs/List_of_options.htm

[2]SOC = Soil organic carbon, WU = Water use

[3]Schoumans et al. (2010), [4]Ulén et al. (2010, 2012a, 2012b), [5]Gascuel-Odoux et al. (2011)

Table 4 Continued

	Strategy	Aim	Factsheets[1]	Measure	Corresponding techniques Table 1	Link with N	SOC[2]	WU[2]	
Mitigation strategies at field scale.	Change soil management	Avoid transport of particles or particulate P	{3}, {69}	No tillage/direct drilling: leaving more than 30% of the soil covered with plant residues or undisturbed stubble	E	x	+		
			{73}, {76}, {71}	Shallow cultivation: Soil tillage to <10 cm depth, no inversion	E	x	+		
			{65}	*Contour ploughing*					*AC*
			{74}	*Switching from autumn tillage to spring tillage*		x			*AC*
			{68}, {72}, {75}, {66}, {67}	*Reducing soil compaction and improving soil structure*		x	+		*AC*
		Avoid leaching of dissolved P concentrations in soils	[4]	*Conventional ploughing or interspersing periods of ploughless tillage with conventional ploughing*					
			{5}, {79}	*Addition of chemical compounds to the soil to bind soluble P*					
		Reduce nutrient budgets and increase soil storage capacity by extensification and agro-forestry	{21}	Introduction of crop rotation and inclusion of more years of grass or develop mixed (perennial and annual) cropping systems	A	x			
			{21}	*Set-aside for several years*					*AC*
		Avoid transport of particulate P in tramlines	{78}	*Tillage to avoid tramlines*					*AC*
	Change crop management	Avoid erosion and reduce surface runoff	{52}	Grassland instead of arable crops or grow deep-rooting crops	A	x			
		Change cropping system	{21}, {33}	Introduction of crop rotation and inclusion of more years of grass or development of mixed (perennial and annual) cropping systems	A	x			
		Avoid leaching	{51}	Application of catch crops (and harvest the products)	B	x			
			{4}	*Crop production without fertilisation (P mining)*					*AD*
Mitigation strategies at catchment scale.	Water management	Change runoff flow by blocking or reducing overland flow	{53}	*Creation of ponding systems*					
			{52}	*Construction of grassed waterways*					
			{56}	*Creation of sediment boxes*					
			{9}	*Improved surface irrigation*		x		+	
		Avoid subsurface losses through leaching	{58}	*Removal of trenches and ditches or allowance to deteriorate*					
			{10}, {55}, {6}	*Installation of drains*					
			{7}, {54}	*Controlled drainage systems*					
			{57}	*Irrigation of meadows with drainage water*					
	Land use management	Improve location of sinks and sources by changing agricultural use patterns	[5]	*Alternation of grassland and arable land. Avoidance of certain crops in hilly areas*					
			{21}	*Locating crops with high nutrient uptake on bottom lands*		x			
		Protect very vulnerable areas by nature development	[5]	*Afforestation or setting aside agricultural land*					
	Landscape management	Reduce direct losses from farm yards	{47}, {44}, {27}	*Minimising the volume of dirty water produced and collect farm yard runoff*					
		Reduce direct losses from livestock	{11}, {19}	*Prevention of contact with surface water: fences, bridges*					
		Reduce surface runoff and erosion from field to field within the catchment	{12}, {19}, {20}	*Re-site gateways and paths: trails, roads, controlled access for livestock and machinery*					
		Intercept nutrients from runoff, erosion and subsurface losses to waters	{17}, {22}	*Vegetated buffer strips*					
Mitigation strategies in aquatic ecosystems.	River maintenance and river restoration	Increase nutrient retention capacity	{37}	*Limiting of cutting of vegetation and reducing regular removal of gravel and impediments to flow*					
			{39}, {41}	*Re-meandering, restoring flood plains and reconnecting inundation areas*					
	Lake rehabilitation and restoration	Reduce the P concentration of lake water	{38}	*Controlling P inlet and prolonging residence time of water*					
			{43}	*Application of chemicals to bind P released from sediments*					
	Wetland restoration and constructed wetlands	Retain nutrient loss from upstream fields in wetlands	{39}, {40}, {41}, {42}	*Creation of wetlands in agricultural areas with substantial P losses*					

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4.4 Results of the inventory of innovative techniques

Table 5 presents the results of the inventory of innovative techniques already implemented in practice or ready for implementation in open air horticulture, clustered in 27 techniques, which is a summary of Tables 1, 3 and 4. Figure 1 gives an overview of the application time within one growing season or in the long term of the implemented innovative techniques. A description of the techniques can be found in Appendix 2.

Table 5 Inventory of the innovative techniques

Category		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	Crops and crop rotations: 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

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Before/at start growing season	During growing season	End of growing season	Long term
- Reduced/ploughless tillage	- Split nitrogen dose		
- Local varieties	- Determine nitrogen need by crop determinations		
- Fertilisation planning	- Determine nitrogen need by soil determinations		
- Split nitrogen dose	- Fertiliser placement		- Crop rotation
- Determine nitrogen need by soil determinations	- Fertiliser type (e.g. foliar, CRF)		- Fertiliser type (e.g. use of compost)
- Fertiliser placement	- Manure treatment products		- Reduced/ploughless tillage
- Fertiliser type (e.g. foliar, CFR)	- Irrigation based on moisture sensor	- Catch crops/cover crops/green manures	- Erosion control measures
- Manure treatment products	- Other techniques for improving water management	- Management of crop residues after harvest	- Measures for soils with high phosphorus

Figure 1 Implemented innovative techniques applied within one growing season or in the long term in _soil-grown_ horticulture

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5 Preparation of the first focus group meeting

The experts were asked to complement four tables. Table A included the inventory of innovative techniques; Table B gave an overview of the implementation rate of the already implemented techniques; In Table C, bottlenecks had been identified; In Table D, links to audiovisual material could be complemented. Questions addressed to the experts were:

1. Is the overview of innovative techniques complete? May we include:
   - Other techniques for improving water management (technique AA in Table 5)?
   - Manure treatment products (technique AB in Table 5)?
   - Erosion control measures (technique AC in Table 5)?
   - Measures for soils with a high P load (Technique AD in Table 5)?

   Other innovative techniques not yet mentioned in the Table could be inserted in the lower part of Table A.
2. For which techniques (already implemented) can we increase implementation? What factors increase implementation? For techniques with a lower implementation experts were requested to look for the bottlenecks leading to a lower implementation. Experts were invited to complement the implementation rate of already implemented techniques (Table B). An example of an inventory of bottlenecks for a specific region (Flanders) was given in Table 3 of the summary of the Benchmark study (http://www.ilvo.vlaanderen.be/Portals/69/Documents/Summary_benchmark_study.pdf).
3. The experts of the focus group were invited to further explore how to increase the implementation of these techniques, and select the most cost-effective solutions (Table C). Links with non-nutrient problems could be indicated.
4. The experts were asked to put links to audiovisual material in table D.

6 Themes discussed at the focus group

To allow the experts to prepare for the first focus group discussions, the themes and questions below were provided in advance:

- **Techniques and strategies**: an overview of techniques and strategies was made which are (a) innovative and implemented (focus: need to be expanded in their implementation), and (b) innovative but still to be implemented (focus: prove that it works). The main focus is on techniques working on field scale. Regarding implementation:
  - For which techniques can we increase implementation?
  - What factors increase implementation?
  - Bottlenecks and how to solve them?
- **Combinations of innovative techniques**: Several techniques and strategies are available or ready for implementation. Growers may combine several techniques, and use them in a proper way.
- **Extension**: Growers may implement these new techniques. *How can we bring the techniques to the field?* Although differences in operational extension activities between regions are not a topic as such, they might greatly affect the speed of information transfer. How can we inform farmers, how can we convince farmers, …? We can consider if lessons can be learnt from the recent activities regarding integrated pest management (IPM).

- **Data management/service platforms**: Growers have access to data sources (digital soil maps, weather data, fertiliser registers, …), several decisions support models and related applications, *but face the challenge to integrate all these data sources in their farm management.* Service platforms may help to solve this issue.
- **Define common issues**: Horticulture is diverse, with a variation in crops, cultivation techniques, … *What are the common issues?* Some of the future research and extension needs can be organised within European collaboration, as issues are relevant for several regions. The N-Expert (which is a further development of the KNS-system) is an example as it is already applied in several regions (Germany, Flanders, Denmark, Poland, …). Collaboration in research on N advice systems between these regions may help for gathering the necessary knowledge on different crops and soil types to improve the advice systems.
- **N, P and/or SOC**: Most techniques focus on reducing N losses. Much less attention is paid to reducing P losses from horticulture, and maintaining or increasing soil organic carbon levels in horticultural soil.
- **Nutrient legislation as a driving force**: N fertilisation is limited in most regions. *P fertilisation limits are only introduced in a limited number of countries*, although many regions cope with P concentrations in surface waters which are too high to prevent eutrophication.
- **Precision horticulture**? *Can we move from static to dynamic determination of crop nutrient demand?* Is research and extension focusing on a combined assessment of crop N demand, based on soil sampling, crop determinations and models needed? Or is the fertiliser placement equally important?
- **Technical and economic feasibility** (Table 2)**:** Can we give an European score to each of the techniques?

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APPENDIX 1

Benchmark study to evaluate innovative techniques for nutrient management in horticulture

Open field or greenhouse production of vegetables and ornamental plants is challenging because of the need to balance high productivity and sometimes late harvests with reducing nutrient losses to the environment. Growers urgently need to find and implement more sustainable strategies for the intensive production of vegetables, potatoes, flowers and ornamental trees. On request of the European Commission - DG Environment, a consortium of research institutions and extension research centers in Flanders (ILVO, UGent, Inagro, PCS, PCG and PSKW) performed a benchmark study to evaluate innovative techniques for nutrient management in horticulture in Flanders and other regions in Belgium, The Netherlands, France, Spain, Italy, Germany, Denmark, Switzerland and Poland. The benchmark focused on the current knowledge of sustainable and innovative techniques of vegetable and ornamental plant production. The techniques are related to both conventional and organic agriculture, are used both for vegetables and ornamentals, and include applications for horticulture in open air and greenhouse horticulture (both cultures in soil and soilless cultures). The selected techniques focus on innovative fertilisation, crop residues management, crop rotation, organic carbon management and soil quality practices in horticulture. The necessary information was gathered by visits to the selected regions.

The benchmark resulted in an overview of promising and existing techniques and strategies. All techniques are presented in clear fact sheets with details on the method, scientific background, involved subsectors and crops, effects on nutrient losses, implementation rate, bottle necks, technical and economic feasibility,… (Amery et al. 2013[*]). This compilation of the fact sheets of innovative techniques and strategies was presented at the international conference 'NutriHort: Nutrient management, innovative techniques and nutrient legislation in intensive horticulture for an improved water quality', 16-18 September 2013, Ghent (Belgium). The position of Flanders relative to other European regions concerning the implementation rate was assessed. For new techniques ready for implementation, the applicability and the economic and technical feasibility for Flanders was evaluated. In the proceedings of the conference, an extended abstract was published including an analysis of and discussion on the techniques (Vandecasteele et al., 2013). The techniques were discussed during a workshop at the conference. These results were used for an action plan for horticulture in Flanders.

An extended summary of the benchmark study is provided at http://www.ilvo.vlaanderen.be/Portals/69/Documents/Summary_benchmark_study.pdf.

[*]http://www.ilvo.vlaanderen.be/Portals/69/Documents/Book_fact_sheets_NUTRIHORT.pdf

APPENDIX 2

Table 6 Description of the innovative techniques mentioned in Table 5 (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	Crops and crop rotations: 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 6 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.

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Table 6 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.

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APPENDIX 3

NEV2013

Table 7 Presentation numbering at NEV2013 for the oral presentations. Poster presentation numbering (1-39) can be found at http://www.nev2013.org/wp-content/uploads/2012/07/NEV2013_POSTER-SESSION.pdf

1st SESSION: *The EU Nitrates Directive for Vegetable crops and the factors influencing soil nitrate load*

40 Luisa Samarelli
41 Elisa M. Suárez-Rey et al.
42 Koen Willekens et al.

2nd SESSION: *Factors influencing soil nitrate load, nitrate soil monitoring, nitrogen modeling and system*

43 Franz Wiesler
44 Renato Contillo et al.
45 Fabian Frick et al.
46 Fernandez P. et al.

3rd SESSION: *Crop systems and techniques to improve nitrogen fertilizer management in vegetable*

47 Rodney Thompson
48 Daniele Massa et al.
49 Francesco Di Gioia et al.
50 Marisa Gallardo et al.
51 Antonio Elia et al.

4th SESSION: *Tools and strategies to control environmental risks in vegetable crop*

52 Clive Rahn
53 Martin Armbruster et al.
54 Ian Burns et al.
55 Tremblay N. et al.

5th SESSION: *Presentation of regional case studies including open field and protected cultivation: strengths and*

56 Rodney Thompson et al.
57 Sidnei Jadoski et al.
58 Elisa M. Suárez-Rey et al.
59 Paolo Sambo
60 Angelantonio Calabrese et al.
61 Tim Große Lengerich et al.
62 Bart Vandecasteele et al.

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