Project title:	The application of precision farming technologies to drive sustainable intensification in horticulture cropping systems (PF-*Hort*)
Project number:	CP107c
Project leader:	Dr Lizzie Sagoo & Dr Paul Newell Price, ADAS UK Ltd
Report:	Annual Report, March 2016
Previous report:	None
Key staff:	Prof. Bryan Griffiths & Dr Joanna Cloy, SRUC (soil survey work in Scotland) Dr Barry Mulholland (ADAS Head of Horticulture - project director) Angela Huckle & Celia Van Sprang (ADAS Horticulture consultants - precision farming review) Daniel Munro, Dom Edwards, Gail Bennett, Martin Crookes, Daniel Jakes, Michael Morris & Geoff Bailey (ADAS field teams – soil survey work)
Location of project:	Soil structure survey – grower sites around the country
Industry Representative:	Andy Richardson, Allium & Brassica Centre
Date project commenced:	01/04/2015

DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- *Soil structure survey*: 75 fields covering a range of crops have been identified; pre-planting soil assessments are complete and post-planting soil assessments will be completed in spring 2016.
- *Precision farming review*: information has been collated on the potential of precision farming techniques to improve soil and nutrient management, and associated productivity and profitability in horticulture cropping systems.

Background

Improved soil and nutrient management is key to improving the productivity, profitability and sustainability of horticulture. Poor soil structure can be a key limiting factor for increasing crop production in cultivated systems (Hallet *et al*., 2012; Marks & Soane, 1987) and developing and facilitating industry uptake of good crop rotation and soil management practice forms a key part of the AHDB Horticulture strategic plan.

Precision technology can help to improve the efficiency of farm operations, including cultivation and better targeted fertiliser and agrochemical applications leading to cost savings and improvements in crop yields and quality. Precision farming involves measuring and responding to variability in soils and crops to optimise returns on inputs (i.e. fertiliser applications, soil cultivations etc.). Potential increases in marketable yield of high value crops makes precision farming an attractive option for many growers. Anecdotal evidence suggests that whilst uptake of GPS and soil mapping in horticulture is increasing, the development and uptake of other precision farming techniques such as controlled traffic farming (CTF), canopy N sensing and yield mapping has largely been focussed in broad-acre crops. Some of these precision farming techniques have direct relevance to horticulture and there is now interest from growers in their potential to increase yields and improve profitability and sustainability.

The aim of this project is to evaluate the current and future potential of precision farming techniques to optimise soil and nutrient management in horticulture, and to encourage greater uptake of any commercially available techniques with potential to increase yields and profitability within horticulture.

Phase one of the project (first 14 months; objectives 1-3) includes a field survey of soil structural condition under horticultural crop production and a review of precision farming techniques for improved soil and nutrient management.

Objective 1. To assess the structural condition of horticultural soils and establish baseline information on typical soil management practices across a range of horticultural crops.

Objective 2. To review the current available precision farming techniques used for soil and nutrient management and to assess their potential application in horticulture cropping systems.

Objective 3. Collate the outputs from the soil structure survey (Objective 1) and review (Objective 2) into a practical user friendly 'Guide to improved soil and nutrient management in horticulture'.

In Phase Two (years 2 & 3) the precision farming techniques with the greatest potential for uptake will be demonstrated and evaluated in field experiments on six commercial farms.

Objective 4. Project steering group meeting to agree the soil and nutrient management techniques to be assessed in field demonstration experiments on commercial farms in Phase Two of the project (Objective 5).

Objective 5. To carry out 6 field demonstration experiments to quantify the benefits (crop yield and quality and farm profitability) and trade-offs of selected soil and nutrient management precision techniques compared with conventional production on commercial farms (3 sites per year over 2 years).

Summary

Objective 1 – Soil structure survey

The soil survey has been stratified by crop type (perennial, biennial and annual); and for the annual crops selected is being carried out twice (pre- and post-planting/drilling) in 47 fields across 31 holdings. For the perennial crops (e.g. asparagus, apples) we are carrying out measurements prior to establishment at some sites and in the growing crop at other sites. A total of 75 fields covering a range of crops have been identified (Table 1).

Field measurements are being carried out during the late autumn to early spring period when soils are 'moist' or close to field capacity between September 2015 and April 2016, so that measurements in different fields are taken under comparable conditions. Table 1 shows progress to date with the soil survey.

Table 1. Soil structure survey stratification by crop type and progress (21/03/16)

Crop	**Number of fields**	**Pre-planting**	**Post-planting**
		Fields sampled to 21/03/16	
Cauliflower	15	15	1
Carrots	9	9	0
Onions	5	5	0
Leeks	5	5	1
Lettuce	10	10	0
Vining peas	3	3	0
Asparagus	6	2	4
Blackcurrants	6	2	4
Raspberries	4	1	3
Apples	6	2	4
Narcissus/cut flowers	6	1	1
Total	**75**	**55**	**18**

Objective 2 – Precision farming review

The precision farming review has engaged with industry, including the precision farming companies and machine manufacturers, growers, consultants and researchers to evaluate the potential for precision farming techniques such as controlled traffic farming, soil mapping, remote sensing of crop canopies, variable rate inputs and yield mapping, to increase crop marketable yield and profitability.

Relevant literature has been collected from a wide range of sources including published scientific papers, AHDB reports, conference proceedings and unpublished ‘grey’ literature. The review also includes a survey of precision farming companies and machinery manufacturers and a targeted survey of horticulture growers who have experience or interest in using precision farming techniques.

To date, interviews have been carried out with the following precision farming companies – AgLeader, Agrii, AgSpace/IPF/Courtyard, Agrovista, Airinov, CF Fertilisers, Fresh Produce Consultancy, Hutchinson’s, Precision Decisions, SOYL, Spectrum Aviation and Ursula. Machine manufacturers contacted as part of the review include AS Communications, Claydon, Cultivating Solutions, Great Plains, Grimme, Manterra and Sumo, although some commented that they were primarily focussed on the broad-acre arable market.

Grower interviews have been carried out with Allpress Farm (Jim Thompson), Barfoots (Neil Cairns), FB Parrish & Son (Paul Cripsey), G's (Emma Garfield), Glassford Hammond Farming (Philip Lilley), Jepco (Nick Sheppard), Overbury Farms (Jake Freestone), PDM Produce (Dermott Tobin), T.H. Clements (Mark Lyon), Vitacress (Andy Elworthy/Nataschia Schneider) and a Scottish producer of bulb flowers.

The combination of the literature review and the interviews with precision farming companies, machine manufactures and growers has provided a comprehensive overview of what precision farming techniques are available to growers to improve soil and nutrient management and more specifically how these techniques may be applied to horticultural crops.

Financial Benefits

This project will provide information on the state of horticultural soils and provide focused, practical and robust guidance on precision farming and other techniques to identify, avoid and alleviate soil compaction, thereby increasing opportunities to carry out field operations; reduce cultivation and other input costs; increase crop yields and farm profitability, while minimising environmental impact (an important consideration for growers in meeting the needs of assurance schemes, environmental audits and demonstrating sustainable soil management):

- Hallet *et al*. (2012) reported that avoiding compaction across a range of arable and horticultural crops can increase yields by 10% to 15%, which in field-vegetable crops such as dry bulb onions could increase gross margins by £1,300-£1,500/ha or 50% to 60% (Nix, 2013).
- Alleviating compaction can increase crop yields by 1% to 10% (Marks & Soane, 1987), although benefits are mainly confined to spring sown crops grown on sandy or light silty soils. However, better targeted sub-soiling in terms of the need for mechanical alleviation and the depth of operation could result in greater and more consistent benefits.
- Controlled traffic systems can also increase yields by 10-15% (e.g. Tulberg *et al*., 2001), which can result in increased revenue of *c*.£150 to £700 per hectare, depending on the initial yield and crop type. These benefits can be accrued within a few years of adopting best soil management practice.

The project will assess the potential for precision farming techniques to better target soil management and nutrient inputs to horticulture crops. The potential benefit of variable rate inputs (fertiliser/seed) is greatest in fields which are inherently variable, where it will result in a more accurate use of inputs and a more even marketable crop.

- Yara (2012) reported an overall yield increase in cereal yields of 3.5% with the Yara N sensor where the same intensity of N fertiliser was used.
- Knight *et al.* (2009) estimated that variable rate P and K fertiliser application in cereals and oilseeds could protect yield worth an average of £5/ha and save fertiliser worth £3/ha.
- IPF (Intelligent Precision Farming) estimate that their customers save £22/ha from applying P and K variably (www.ipf-uk.com).

Action Points

- Soil compaction can be a key factor limiting yields. A significant proportion of fields within the soil structure survey had moderate to poor soil structure.
- Growers can manage the impact of soil compaction by identifying and alleviating compaction where it has occurred and by avoiding soil compaction in the first place, where possible.
- Assess soil structure when soils are moist. If soils are compacted, identify the depth of compaction and target the depth of cultivations to just below the compacted soil layer.
- Precision farming tools such as soil mapping, canopy sensing and yield mapping can provide growers with valuable information about the variability of their soils and crops. Where growers have identified variability in their soil or crop, they should first seek to understand what factors are important in causing this variability before they try to manage it.

SCIENCE SECTION

Introduction

Technological innovation offers growers new opportunities to increase productivity and profitability. The overall aim of this project is to evaluate the current and future potential of precision farming techniques to optimise soil and nutrient management for improved profitability and sustainable intensification of horticulture crop production systems. The project work is divided into two phases. This annual report covers work delivered to date under Phase one and plans for Phase 2 work.

Phase One: Field survey of soil structural condition in horticulture and review of precision farming techniques for improved soil and nutrient management (first 14 months)

Objective 1. To assess the structural condition of horticultural soils and establish baseline information on typical soil management practices across a range of horticultural crops (perennial, biennial and annual).

Objective 2. To review the current commercially available precision farming techniques used for soil and nutrient management and to assess their potential application in horticulture cropping systems.

Objective 3. Collate the outputs from the soil structure survey (Objective 1) and review (Objective 2) into a practical user friendly ‘Guide to improved soil and nutrient management in horticulture’.

Phase Two: Field demonstration experiments to quantify the benefit of selected precision farming techniques for improved soil and nutrient management in horticulture cropping systems (years 2 and 3)

Objective 4. Project steering group meeting to agree the soil and nutrient management techniques to be assessed in field demonstration experiments on commercial farms in Phase Two of the project (Objective 5).

Objective 5. To carry out 6 field demonstration experiments to quantify the benefits (crop yield and quality and farm profitability) and trade-offs of selected soil and nutrient management precision techniques compared with conventional production on commercial farms (3 sites per year over 2 years).

Field survey of soil structural condition in horticulture

Background

Improved soil and nutrient management is key to improving the productivity, profitability and sustainability of horticulture. Poor soil structure can be a key limiting factor for increasing crop production in cultivated systems (Hallet *et al*., 2012; Marks & Soane, 1987). Developing and facilitating industry uptake of good crop rotation and soil management practice forms a key part of the AHDB Horticulture strategic plan.

Soil compaction was the principal issue identified by the AHDB Horticulture panel consulted in AHDB Horticulture project CP107. Intensive or frequent cultivations can be deleterious to soil structure as a result of the consequent oxidation of organic matter and weakening of soil structure. Soil compaction occurs when soil particles are compressed, reducing the spaces (pores) between them. Compacted soil contains few large pores, which are the main channels of water movement in soil, and consequently has a reduced rate of both water infiltration and drainage (DeJong-Hughes *et al.,* 2001). There is a strong link between soil type, land use practices and soil compaction. Soils can bind more effectively to resist deformation through the release of root and fungal exudates and there is a general positive relationship between soil resilience and soil organic matter content (Barre and Hallet, 2009; Gregory *et al*., 2009). Compaction also reduces the air content of soils, reducing biological activity including plant growth and faunal activity and restricts root growth, water storage capacity, fertility and stability. In most cases, measures to alleviate or prevent compaction would be expected to increase crop production and enhance other soil functions, but there are clear conflicts between the need to establish and harvest crops in restricted timing windows and the need to avoid compaction. Wet seasons such as the summer/autumn of 2012 and the winters of 2012/13 and 2013/14 present significant challenges for compaction impacts on soils, as the need to maintain continuity of supply and meet demands for extended season requirements from retailers can lead to crops being harvested during unfavourable weather and soil conditions (Balshaw *et al.*, 2013).

Objectives

To assess the structural condition of horticultural soils and establish baseline information on typical soil management practices across a range of horticultural crops (perennial, biennial and annual).

Materials and methods

The survey has been stratified by crop type (perennial, biennial and annual); and for the annual crops selected will be carried out twice (pre- and post-planting/drilling) in 47 fields across 31 holdings. For the perennial crops (e.g. asparagus, apples) measurements will be carried out prior to establishment at nine sites and in the growing crop at nineteen sites (Table 2). The soil structure survey sites are distributed from Cornwall in south west England to Perthshire in eastern Scotland (Figure 1). The pre-planting field measurements were carried out between late September 2015 and March 2016 when soils were 'moist' or close to field capacity. Post- planting field measurements will be carried out during the late winter to early spring 2016, so that pre- and post-planting measurements in different fields will be taken under comparable conditions.

Table 2. Soil structure survey stratification

Crop	**Number of fields**	**Pre-planting**	**Post-planting**
Cauliflower	15	15	15
Carrots	9	9	9
Onions	5	5	5
Leeks	5	5	5
Lettuce	10	10	10
Vining peas	3	3	3
Asparagus	6	2	4
Blackcurrants	6	2	4
Raspberries	4	1	3
Apples	6	2	4
Narcissus/cut flowers	6	2	4
Total	**75**	**56**	**66**

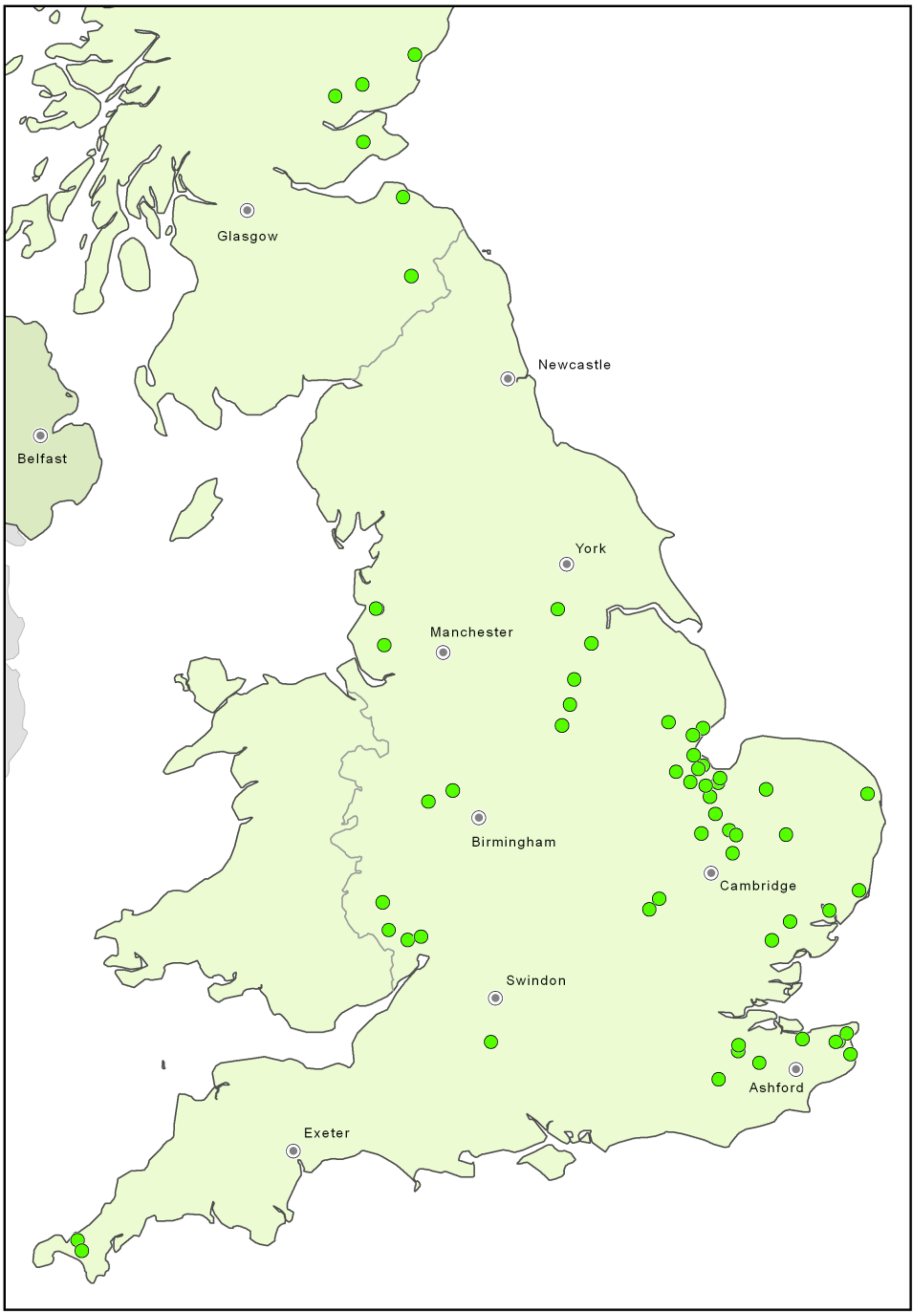

Figure 1. Location of soil structure survey sites in England and Scotland.

To characterise the topsoil at each field site, baseline topsoil samples (0-15 cm depth) were taken from each field, and analysed for:

- Soil pH (measured in water; 1:2.5)
- Particle size distribution (i.e. percentage sand, silt and clay content; laser method)
- Extractable P (Sodium Bicarbonate Extractable), K, and Mg (Ammonium Nitrate Extractable)
- Total N (Dumas)

- Organic matter (dichromate oxidation)
- Loss on ignition (LOI)

The soil structure survey focuses on topsoil and upper subsoil condition (to a depth of 60 cm). Firstly, a cone penetrometer was used to quantify the range and depth of (maximum) penetration resistance values at twenty randomly selected points across the main body of the field (pre-planting), and, for annual crops, across the drilled/planted area (post-planting) to a depth of 50 cm. For perennial crops, post-planting penetrometer measurements and subsequent assessments were carried out in the beds for asparagus and Narcissus/cut flowers; between the beds and alleyways in apple orchards; and in the wheelings for blackcurrants and raspberries.

Within each field and at each sampling occasion, the following measurements/assessments were carried out at the three points where the maximum, median and minimum topsoil penetration resistance values were measured:

- Dry bulk density (core cutter method):
    - Mid topsoil (10-15 cm depth)
    - Upper subsoil (30-35 cm depth)
    - Deeper subsoil (40-45 cm depth)
- Visual soil evaluations:
    - Visual Soil Assessment (VSA; Shepherd, 2000) – topsoil
    - Visual Evaluation of Soil Structure (VESS; Guimarães *et al*., 2011) – topsoil
    - SubVESS (Ball *et al*., 2015) – subsoil
- Cone penetrometer tests:
    - 40-60 cm depth (maximum resistance and depth of maximum resistance x 3)

Topsoil measurements and visual assessments provide detailed information about the physical condition of topsoils. Bulk density (BD) measurements at 30-35 cm depth provide an indication of the degree and extent of compaction issues in the upper subsoil, which are mainly due to the use of heavy machinery when soils are 'wet'. Deeper subsoil measurements, including bulk density measurements at 40-45 cm depth, SubVESS assessments at 30-50 cm depth and penetration resistance measurements at 40-60 cm will provide key information on the extent of subsoil compaction.

In addition to the compaction survey, a parallel grower survey of soil management practices was carried out at each of the holdings and 75 fields in the soil structure survey (Appendix 1). This includes questions on attitudes towards soil management, visual soil evaluation and specific soil management practices carried out on farm (e.g. use of soil visual evaluation methods, cultivation sequences and frequency and depth of sub-soiling). These soil management practices will be compared with the field soil structure observations to determine whether or not current soil management practices are appropriately tailored to actual observed soil structural conditions.

Update and discussion

Seventy three field assessments were carried out between late September 2015 and March 2016. Soil structural condition as assessed using VSA and VESS scores ranged from good to poor with some contrasts in soil structure prior to the planting/drilling of the same crop type reflecting differences in soil management and cultivation practices (Figure 2).

Figure 2. VESS assessments carried out pre-onions on medium soils in Beds (left; good structure) and Essex (right; poor structure).

Visual evaluations detected the presence of a cultivation pan at many sites. Initial assessment of survey data indicates that the presence of a cultivation pan tends to be related to the cultivation system, depth of cultivation and the inclusion of late autumn harvested crops in the rotation. VESS scores will be compared with the typical range of scores found in other surveys. For example, a survey of soil structure carried out in arable and grassland fields in Scotland in 2015.

Bulk density profiles (10-15; 30-35; 40-45 cm depth) will be compared with topsoil and subsoil 'trigger values' developed by the UK Soil Indicator Consortium (UKSIC; Table 3). From this assessment, we will be able to determine whether soil BD values under horticulture cropping are at 'concern' (may have implications for production) or 'action' (management intervention required) levels.

Table 3. Bulk density (Mg/m^3) trigger values for mineral and peat subsoils in the UK (source: Merrington, 2006).

Parameter	Bulk density (Mg/m^3)	
	Concern level	Action level
Clay > 50%	1.35	1.45
Clay ≤ 50%	1.50*	1.60*
Peats	0.50	-

* For sandy textures, the levels may be up to 0.05 Mg/m^3 higher.

The soil structure and soil management practice surveys will provide 'case study' evidence of soil structural conditions rather than statistical relationships between sectors or 'cause and effect' relationships between soil management practices and soil structural condition. The soil structure survey outputs will be used as a tool for dissemination to raise awareness of the state of UK horticultural soils and how practices can be improved. The soil management practice survey outputs can provide an indication of typical approaches to soil management in horticulture production systems through grower case studies (see below).

Soil management practice – example grower case study

Farm information

Horticulture farm, 690 ha: 90% owned, 10% tenanted.

Cropping: Apples 240 ha; Blackcurrants 72 ha; Fallow land 113 ha (could change); Pears 20 ha; Spring Beans 70 ha; Wheat 52 ha; Woodland 25 ha; unspecified 98 ha,

Predominant soil type: Medium

Baseline soil analysis:

	Extractable									
Soil pH	P (Index)	K (Index)	Mg (Index)	Topsoil texture	% sand	% silt	% clay	Loss on ignition (% w/w dry basis)	Soil organic carbon* (% w/w dry basis)	Total nitrogen (% w/w dry basis)
6.9	24 (2)	137 (2-)	83 (2)	Clay loam	36	42	22	4.3	3.4	0.2

* Acid dichromate - Walkley Black

Attitudes and approach to soil management

There were some issues with poor soil structure on the farm, which had led to waterlogging and surface ponding in places. The issues were linked to the large growing area of fruit orchards and plantations where machinery travels on the same wheelings on multiple occasions from year to year, and sometimes in less than optimal conditions (e.g. for spraying and harvesting).

Farm staff are aware of the potential for soil structural issues and visually assess problem fields and all apple orchards pre-cultivation, using a spade to dig into the topsoil and upper subsoil (to *c.*50 cm depth). Drainage is also maintained every 15-20 years at the end of each orchard cycle to try and ease waterlogging issues. All fields are subsoiled on a regular basis and, where possible, in optimal conditions. In apple orchards and blackcurrant plantations, grass alleyways and cover crops (e.g. mustard) are established after planting to improve soil structure and limit surface runoff.

Other measures used in the orchards include straw mulches, which are often spread on the soil surface to conserve moisture, and green compost which is spread after planting on areas with lower fertility. The main mitigation method for protecting soil condition in blackcurrant crops is working in optimal field conditions where possible. Crop residues (e.g. beans) are also incorporated ahead of blackcurrants. On the arable side of the business, land is also left fallow, mainly to help control blackgrass, but this may also have a positive effect on soil structural condition. The farm also uses soil mapping to assess nutrient and pH levels within fields.

Example crop rotation (sampled field):

- 2015/16 Blackcurrants
- 2014/15 Winter wheat
- 2013/14 Winter wheat
- 2012/13 Winter oilseed rape
- 2011/12 Winter wheat
- 2010/11 Spring beans
- 2009/10 Winter wheat

Table 4. Field, cropping and cultivation information for sampled field.

Field Size	6.3 ha	
Soil type	Medium: Clay loam	
Slope	Gentle to flat	
Manure Applications	None	
Field History (crop)	2014/15	Winter wheat
	2013/14	Winter wheat

Harvest method	Combine		
Residue management	Baled and removed August 2015		
2016 Crop	Blackcurrants		
Cultivations	**Implement**	**Cultivation depth**	**Carried out by**
	1) Top Down	40 cm	Contractor
	2) Disc	20 cm	Own staff
	3) Power harrow	10 cm	Own staff

Figure 3. Assessment of soil structure and consistence (for VSA score) carried out pre-blackcurrants.

Conclusions

The results of the soil structure survey will identify problem areas that must be focussed on in different horticulture sectors as well as providing a useful tool for dissemination, discussion and knowledge exchange that will help stimulate interest and develop awareness and industry expertise in soil management practices. The outputs will help determine the level of grower engagement and interest in soil visual evaluation methods and the extent to which soil cultivation practices address the common soil structural issues encountered in horticulture cropping systems.

Review of precision farming techniques for improved soil and nutrient management

Background

Precision technology can help to improve the efficiency of farm operations, including cultivation and better targeted fertiliser and agrochemical applications leading to cost savings and improvements in crop yields and quality. Data from the Defra Farm Practices Survey (2012) showed a notable increase in the number of holdings using precision farming techniques between 2009 and 2012. In 2012, 22% of holdings reported using GPS, 20% used soil mapping, 16% used variable rate application and 11% used yield mapping. The two most common reasons for using precision farming techniques were to improve accuracy (indicated by 76% of farms using precision farming techniques) and to reduce input costs (indicated by 63% of farms). The Farm Practices Survey (2012) did not distinguish between the types of holdings using this technology, although anecdotal evidence suggests uptake is greatest in the arable sector.

Precision farming involves measuring and responding to variability in soils and crops to optimise returns on inputs (i.e. fertiliser applications, soil cultivations etc.). Potential increases in marketable yield of high value crops makes precision farming an attractive option for many growers. Anecdotal evidence suggests that whilst uptake of GPS and soil mapping in horticulture is increasing, the development and uptake of other precision farming techniques such as controlled traffic farming (CTF), canopy N sensing and yield mapping has largely been focussed in broad-acre crops. Some of these precision farming techniques have direct relevance to horticulture and there is now interest from growers in their potential to increase yields and improve profitability and sustainability.

Objective

To review the current commercially available precision farming techniques for improved soil and nutrient management and their potential application to horticulture cropping systems.

Approach

The precision farming review focussed on techniques which can be used to improve soil and nutrient managements, including -

- Soil mapping (Electro-Magnetic Induction – EMI and soil brightness) to ‘zone’ fields and inform variable rate fertiliser (P, K, Mg and lime) inputs and soil management (i.e. variable seed rates and soil cultivations).

- Canopy sensing to inform variable N fertiliser applications– satellite and ‘on the go’ systems.
- Canopy sensing for crop surveillance.
- Use of high resolution imagery from UAV’s or manned aircraft for crop surveillance.
- Yield mapping – potential to yield map horticulture crops and the potential to use yield maps from cereal crops in the rotation to target management of horticulture crops.
- Controlled traffic farming.
- Targeted variable depth sub-soiling to remove compaction.
- ‘Novel’ technologies such as sensors using visible and NIR wavelength to estimate soil properties.

The review included a literature review, a survey of precision farming companies and machinery manufacturers and a targeted survey of horticulture growers who have experience using precision farming techniques.

The literature review included relevant published scientific and ‘grey’ literature in order to describe each technique, provide evidence of benefits, likely costs, trade-offs, limitations and applicability for horticulture crops. Sources for the literature review have included:

- Web of science search (for published scientific papers)
- Relevant AHDB published research reports.
- On-going (unpublished) relevant AHDB research projects.

Structured surveys of open and closed questions were produced (and agreed by the steering group) as a framework to engage with the precision farming companies and machinery manufacturers (Appendix 2). The aim of the survey of precision farming companies was to establish:

- Current penetration of precision farming techniques for improved soil and nutrient management in the horticulture sector, and
- Perceived benefits, opportunities and challenges of expanding the use of these precision farming techniques in horticulture.

To date, interviews have been carried out with the following precision farming companies – AgLeader, Agrii, AgSpace/IPF/Courtyard, Agrovista, Airinov, CF Fertilisers, Fresh Produce Consultancy, Hutchinson’s, Precision Decisions, SOYL, Spectrum Aviation and Ursula.

The aim of the machinery manufacturer’s survey was to identify:

- Novel soil compaction detection and alleviation techniques.
- Potential to adapt machinery for use of CTF in horticulture.
- Potential for yield mapping of horticulture crops.

Machine manufacturers contacted as part of the review include AS Communications, Claydon, Cultivating Solutions, Great Plains, Grimme, Manterra and Sumo, although some commented that they were primarily focussed on the broad-acre arable market.

The grower's survey was targeted at growers who have experience in using precision farming techniques. The aim of the grower's survey was to collect information on the benefits, challenges and limitations of the various precision farming techniques under different cropping conditions. Grower interviews have been carried out with Allpress Farm (Jim Thompson), Barfoots (Neil Cairns), FB Parrish & Son (Paul Cripsey), G's (Emma Garfield), Glassford Hammond Farming (Philip Lilley), Jepco (Nick Sheppard), Overbury Farms (Jake Freestone), PDM Produce (Dermott Tobin), T.H. Clements (Mark Lyon), Vitacress (Andy Elworthy/Nataschia Schneider) and a Scottish producer of bulb flowers.

A small number of companies and growers who were contacted as part of the review have yet to respond to the interview request. We have agreed a deadline of end April 2016 for completion of any other interviews; the precision farming review will then be delivered as an AHDB Research Review by 31/05/2016.

Results and discussion

Soil mapping

Variability in soil type (i.e. soil texture and organic matter content) is one of the main reasons for variation in crop yields within fields. Differences in soil texture, depth and organic matter content all influence crop performance and yields. More precise knowledge of the variability within fields, through soil mapping to define boundaries between soil types and remote sensing of crop canopies, enables this variation to be managed.

Soil mapping using Electro-Magnetic Induction (EMI) surveys or soil brightness maps are currently being offered commercially by several companies. EMI surveys are conducted in field and measure the apparent electrical conductivity (EC) of the soil, which has been shown to be a reliable way to delineate boundaries between soil zones with different physical properties. The geostatistical method of kriging is normally used to estimate conductivity in-between measurement points/passes and a soil EC map is produced. Soil brightness maps are obtained from satellite imagery and describe how intensively the surface layer of bare soil reflects incoming sunlight. Soil brightness provides an integrated measure of the combined effects of soil texture, organic matter content and soil moisture at the time the image was taken.

Electro-Magnetic Induction and soil brightness maps can be used to delineate soil management zones which can be used as a basis for variable seed rate/planting densities, and can be sampled separately (for pH, P, K and Mg) to create soil nutrient/pH maps which can be used to target variable rate application of fertilisers or lime.

Variable rate fertiliser inputs

Variable rate fertiliser applications aim to maximise the efficiency of fertiliser inputs, increasing yields and profitability and reducing the risk of diffuse pollution (N and P losses to surface waters and nitrous oxide emissions to the atmosphere).

Yara (2012) reported an overall yield increase in cereal yields of 3.5% with the Yara N sensor where the same intensity of N fertiliser was used. Knight *et al*. (2009) estimated that variable rate P and K fertiliser application in cereals and oilseeds could protect yield worth an average of £5/ha and save fertiliser worth £3/ha.

The potential benefit of variable rate fertiliser and lime inputs is greatest in fields which are inherently variable where it will result in a more accurate use of fertiliser nutrients and a more even crop. Consistent quality (e.g. nutritional content) is of particular importance in many horticultural crops and variable fertiliser rates should help to achieve this.

Soil mapping for variable rate P and K fertiliser (and Mg and lime)

Potential advantages of variable rate P and K fertiliser applications (and Mg and lime) include savings in fertiliser costs, potential for increased yields where lower index areas of a field would otherwise have been under-fertilised, and the longer term 'evening out' of within field soil nutrient variability, which should improve ease of management and help produce a more even crop.

The precision farming review found contrasting views from horticultural growers on the value of variable rate P and K applications; some growers have adopted variable rate applications and were happy with the approach, whilst others were unconvinced of the potential benefits. Both growers and precision farming companies noted that small savings in fertiliser were less important to horticultural growers than to broad-acre arable and grassland farmers. However, a number of growers and precision farming companies highlighted the value of soil nutrient maps in their own right (not necessarily as basis for variable rate fertiliser application), particularly for rented land where the grower doesn't necessarily have the field history and soil nutrient maps enables them to better understand the land they are renting.

Remote sensing of crop canopies to inform variable rate nitrogen fertiliser

Canopy sensors for N fertiliser management measure crop light reflectance and use this information to adjust N fertiliser rates. Canopy sensors can be satellite based (i.e. SOYL's SOYLSense and IPF's EyeCrop service) or tractor mounted (i.e. Yara's N sensor, the Isaria sensor or AgLeader's OptRx sensor). There is also potential for aircraft/drone mounted sensors; Airinov are currently offering variable rate N prescription maps from drone imagery for wheat and oilseed rape, however other UK operators of drones are not currently marketing them as a basis for variable rate N.

Canopy sensors are increasingly being used to variably apply N fertiliser on cereal and oilseed crops in the UK. The technology has the potential to improve N use efficiency over a wide range of crop types, however current R&D and validation work is focussed on broad-acre arable crops and grassland. The precision farming review identified two UK growers who have used the Yara N sensor to variably apply N to brassica vegetables (cauliflower and Brussel sprouts) and one grower in the Netherlands who is using the OptRx sensor to variably apply N to lettuce (this grower has adapted his application equipment to individual row control and mounted one OptRx sensor for each row of lettuce). In each of these cases the grower sets the target N rate for the field and minimum and maximum N rates and allows the sensor to vary N rate across the field based on the entered values.

Variable seed rate/planting densities

Variable seed rates can be used to try and achieve an even establishment across variable soils. Soil EC and soil brightness maps provide an indication of variation in soil texture across a field, and this information can be used to vary seed rates based on how differences in the soil are expected to affect yields/establishment, i.e.

- Areas of different soil textures may be expected to have different percent establishments and therefore to create an even crop the seed rate can be altered to take this into account; for example areas of high clay content or high stone content may be expected to have higher plant losses and therefore a higher seed rate is required to achieve an even crop.
- Inherently higher yielding areas may have the potential to support a higher density of plants and therefore justify a higher seed rate.
- Areas of a field which are known to suffer higher pest (i.e. slugs) or weed (i.e. blackgrass in cereal crops) competition can have a higher seed rate to compensate for this.

Variable seed rate is predominately used in cereal and oilseed crops. IPF report average yield benefits from variable seed rate of 13% for winter wheat and 5% for winter oilseed rape. None of the horticultural growers contacted as part of the precision farming review had used or were considering using variable rate seeding or planting. However, one of the salad growers reported using soil brightness maps as a basis for selecting certain salad crops for areas within a field by allocating crops that needed a small head weight to lighter land within a field, and crops that needed a heavier head weight to heavier land.

Remote sensing of crop canopies to monitor crop performance

Canopy sensing can also provide valuable information on the performance of the crop and can be used either spatially or temporally to help identify problems with crop performance, i.e. due to pest or disease damage. Resolution of imagery will depend on the source; satellite imagery is typically 5-20m resolution, imagery from manned aircraft is typically 5-20cm and imagery from drones can be down to 2-5cm. The primary value of canopy sensing to monitor crop performance in this way is as an agronomists tool to help target good or bad areas of the crop when crop walking; the canopy imagery can be used to identify problems in the crop, but is unlikely to be able to identify the cause or appropriate treatment of the problem.

High resolution imagery from drones or manned aircraft can also be used to count and size crops (i.e. brassicas and lettuces), and can in turn be used to predict supply and schedule harvest. The precision farming review identified a number of precision farming companies working with individual growers to develop a service specific to the individual grower. Most suppliers of this high resolution imagery were specifically targeting its application in high value horticultural crops.

Yield mapping

The variation in final crop yield represents the combined effects of spatially variable soil, environment and crop variables. Yield maps can be a valuable tool for understanding within-field variability in crop yield. If growers can pick out low yielding areas, particularly if these are low yielding over a number of years, this information can be used to target field investigations to identify and, where possible, remedy the cause of this lower yield, e.g. targeted sub-soiling to alleviate compaction in selected field areas. In this way a quick benefit can be gained from maximising yield across the whole farm. Yield potential may also be used to guide fertiliser requirements (e.g. high yielding areas may require more fertiliser). Yield maps are also potentially very valuable in assessing interventions, i.e. split fields/tramline comparisons for on farm testing of treatment comparisons such as different varieties, fertiliser rates, seed rates etc. with evaluation of effectiveness from yield mapping.

Yield mapping is most common for cereal and oilseed crops and the Defra Farm Practice Survey (2012) showed 11% of farms now use yield mapping. SoilEssentials have recently developed a yield mapping system for potatoes and other root crops (www.soilessentials.com). However, anecdotal evidence suggests very limited uptake of yield mapping for horticulture crops and the precision farming review did not identify any growers who were yield mapping their horticultural crops.

One of the precision farming companies identified the difficulties in quantifying spatial variability in yield as a barrier to uptake of precision farming services within horticulture as the effect and value of what growers can achieve with precision farming is difficult to quantify.

Managing soil compaction

Growers can manage the impact of soil compaction by identifying and alleviating compaction where it has occurred and by avoiding soil compaction in the first place, where possible. Alleviating soil compaction through deep soil loosening can be effective, however it is expensive; sub-soiling typically costs *c*.£50/ha (Nix, 2013). Soil compaction can be minimised/avoided by, for example, timeliness of field operations (i.e. not working the soil when it is wet), use of low ground pressure tyres and controlled traffic farming (CTF).

It is possible to map soil compaction over a field using GPS to record the position of multiple sampling points. Some precision farming companies currently offer compaction mapping as a commercial service to farmers. SOYL and Cultivation Solutions have also recently developed technology for variable depth cultivations. Variable depth cultivation can protect soil structure by correctly targeting the depth of cultivation and keeping the cultivator out of 'plastic' soil. Soil needs to be friable to cultivate successfully, with clay soils drying out more slowly than sandy soils therefore cultivating at a universal depth often leads to compromise in fields with variable soil types. To calculate cultivation depth for different soil textures SOYL use a soil EC survey combined with an on-farm field assessment to assess the depth of soil wetness in the areas of minimum and maximum EC readings.

Controlled traffic farming aims to confine soil compaction to the least possible area of permanent traffic lanes. The benefits of CTF include increased yields, lower production costs and benefits to the environment (Chamen, 2006). Demonstration of CTF in the UK has focussed on combinable crops; the main challenge in adopting CTF in horticulture is adjusting the machinery system. The precision farming review identified two growers who have adopted CTF within a horticultural rotation:

- FB Parrish & Sons have adopted CTF on their farm in Bedfordshire growing combinable crops, onions and potatoes.
- Barfoots of Botley are in the process of adopting CTF across their farms in the South of England; they are currently operating CTF on sweetcorn, courgettes and asparagus and expanding CTF to their other crops over the coming years.

Conclusions

Precision farming tools such as soil mapping and canopy sensing can provide growers with valuable information about the variability of their soils and crops. Better understanding of the variability within fields enables this variation to be managed. Where growers have identified variability in their soil or crop, they should first seek to understand what factors are important in causing this variability before they try to manage it.

Field demonstration experiments to quantify the benefit of selected precision farming techniques for improved soil and nutrient management in horticulture cropping systems

Background

In Phase Two (years 2 & 3) the precision farming techniques with the greatest potential to improve soil and nutrient management in horticulture will be demonstrated and evaluated in field experiments on six commercial farms. The project aims to encourage greater uptake of commercially available techniques shown in this project to have potential to increase yields and profitability within horticulture.

Objectives

Objective 4. Project steering group meeting to agree the soil and nutrient management techniques to be assessed in field demonstration experiments on commercial farms in Phase Two of the project (Objective 5).

Objective 5. To carry out 6 field demonstration experiments to quantify the benefits (crop yield and quality and farm profitability) and trade-offs of selected soil and nutrient management precision techniques compared with conventional production on commercial farms (3 sites per year over 2 years).

Approach

The project steering group met on 18/01/16 to agree the precision farming techniques to be assessed in the field demonstration experiments. The ADAS project team presented six options for field demonstrations and the group discussed the strengths and weaknesses of each of the techniques/options presented. The steering group agreed that the field demonstrations should focus on soil nutrient mapping, techniques to help growers understand variability, canopy sensing for variable N rate and controlled traffic farming.

Soil nutrient mapping & variable rate P and K

Site 1. Year 2 (2016). Bedfordshire

Background: Soil mapping for P, K, Mg and lime is well established and offered as a service by a number of precision farming companies. However, a number of the growers in the precision farming review questioned what the benefits to horticultural growers were and whether variable rate fertiliser applications (P, K, Mg and lime) ‘worked’. There is also a need to evaluate the different approaches to soil nutrient mapping (i.e. grid sampling or zone sampling) and the impact of different sampling intensities on the soil maps produced.

Aims:

- To evaluate the effectiveness of variable rate P and K applications on 'evening-up' soil indices, and
- To demonstrate options for soil nutrient mapping.

Approach:

- Data analysis to validate the effectiveness of variable rate P and K fertiliser applications (soil analysis data to be provided by SOYL).
- Detailed soil sampling of a single field based on grid and zone sampling methods and on different sampling intensities.
- Investigate why soil indices vary within the field (soil type, organic matter content, crop offtake etc.)

Focus on variability

Site 2. Year 3 (2017). G's growers, Cambridgeshire (salad crop)

Background: Precision farming tools such as soil mapping, canopy sensing and yield mapping can provide growers with valuable information about the variability of their soils and crops. Better understanding of the variability within fields enables this variation to be managed.

Aim: To demonstrate the precision farming tools available to identify variation and how best to use these tools to help quantify, understand and manage variability.

Approach:

- Use available precision farming tolls to gather information on variability within a single field (i.e. EMI scanning, soil brightness maps and canopy sensing).
- Detailed field investigations to understand the cause of measured variation.
- Produce a decision support checklist to guide growers through the process of assessing, investigating and managing variability.

Canopy sensing for variable nitrogen applications

Site 3. Year 2 (2016). Barfoots of Botley, West Sussex (tenderstem broccoli crop)

Site 4. Year 2 (2017). Location to be confirmed

Background: Canopy sensors for N fertiliser management measure crop light reflectance and use this information to adjust N fertiliser rates accordingly. Canopy N sensors are increasingly being used on cereal and oilseed crops in the UK. There is interest from growers in the potential of variable rate N applications to improve crop uniformity and yields in horticultural crops.

Aim: To demonstrate the potential for canopy sensing for variable rate nitrogen applications in selected horticultural crops.

Approach:

- Nitrogen response experiments within different areas/zones of a single field to understand how the optimum N rate varies across the field.
- Measurement of crop canopy and production of prescription variable rate N fertiliser maps.
- Validation of variable N rate using tramline comparisons of variable rate and standard rate.

Controlled traffic farming

Site 5. Year 2 or 3 (2016 or 2017). Barfoots of Botley, West Sussex

Site 6. Year 2 or 3 (2016 or 2017). Location to be confirmed

Background: Controlled traffic farming aims to confine soil compaction to the least possible area of permanent traffic lanes. The benefits of CTF include increased yields, lower production costs and benefits to the environment. Demonstration of CTF in the UK has focussed on combinable crops; the main challenges in adopting CTF in horticulture are adjusting the machinery system.

Aim: To demonstrate the benefits, limitations, challenges and trade-offs associated with adopting controlled traffic principles in horticultural crops.

Approach:

- Monitor changes in machinery set up and use; and associated costs, benefits, challenges and trade-offs.
- Detailed measurements of soil physical properties (soil structure) and soil health prior to conversion to CTF to provide ‘baseline’ soil information and enable longer term assessments of improvements to the condition of the soil.

Knowledge and Technology Transfer

Phase 1: Field survey of soil structural condition and review of precision farming techniques

Project meetings and knowledge transfer (KT) activities to date include:

- Initial project steering group meeting (22/05/15).
- Second project steering group meeting (18/01/16).
- Poster outlining the project exhibited at AHDB Smart Agriculture Conference (08/09/15), Elsom's Open day (14-15/10/15) and AgriTech East REAP 2015 Conference (Nov 2015).
- Presentation to Jepco and Anglia Salads agronomy staff (25/02/16).

The main KT output from the Phase 1 soil structure survey and precision farming review will be the 'Guide to improve soil and nutrient management in horticulture' produced at the end of Phase 1 (end May 2016).

Phase 2: Field demonstration experiments

Each of the 6 field experiment/demonstration sites will host an open day (3 open days in years 2 and 3). Dissemination and knowledge exchange activities at the demonstration plot sites will help growers to assess tools and techniques that would be most likely to improve soil and nutrient management practices and production efficiency on their farms. Each field demonstration open day will include:

- Demonstration of the precision/management technique 'featured' at that site. Including the relevant machinery/software, field demonstration plots and an economic cost-benefit analysis specific to the site.
- Soil pits for the demonstration of visual soil evaluation and information on methods to avoid and alleviate compaction.
- Promotion of the 'Guide to improved soil and nutrient management in horticulture' to encourage greater uptake of commercially available and profitable precision farming techniques within horticulture.

These open days will also be used to gather feedback on grower concerns about soil and nutrient management practices and production efficiency. This information will be used to inform the project steering group (growers and grower technical managers) and help identify further targeted and sector specific research and development questions to be pursued in the future.

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ACKNOWLEDGEMENTS

This project has been supported by a number of growers, industry representatives and commercial companies. We would like to thank members of the project steering group, the growers who have taken part in the soil survey, and the precision farming companies, machine manufacturers and growers who have contributed to the precision farming review.

The following have provided input to the project steering group: Andy Richardson (Allium & Brassica Centre & Industry representative), Jim Dimmock, Cheryl Brewster & Grace Choto (AHDB Horticulture), Clive Rahn (Plant Nutrition Consulting), Philip Effingham (Greentech Consultancy), Tim Chamen (CTF Europe), Ian Beecher-Jones, John Sedgwick (Produce World), Emma Garfield & Elzbieta Witkowska (G's Growers), Dermott Tobin & Lizzie Pritchard (PDM Produce), Richard Fitzpatrick (HMC Peas), Jonathan Blackman & Nigel Kitney (Hutchinson's) and Mark Holden (Adrians Cripps).

A total of 56 growers across England and Scotland have contributed to the soil structure survey and have provided information on soil management on their farm.

The following have provide input to the precision farming review: Paul Rose (AgLeader Technology), Jack Harris (Agrovista), Stuart Alexander & John Lord (Agrii), Vince Gilliingham (AgSpace/IPF/Courtyard), Simon Redhill (Airinov), Alli Grundy (CF Fertilisers), Rhun Jones (Cultivation Solutions), David Norman (Fresh Produce Consultancy), Oliver Wood (Hutchinson's), Clive Blacker & Charley White (Precision Decision), Simon Griffin & David Whatton (SOYL), David Wright (Spectrum Aviation), Alex Dinsdale (Ursula), Chris Harry Thomas, Will Munford & Mick Whitely (AS Communications), Jim Thompson (Allpress Farm), Neil Cairns (Barfoots), Paul Cripsey (FB Parrish & Son), Emma Garfield & Elzbieta Witkowska (G's Growers), Philip Lilley (Glassford Hammond Farming), Nick Sheppard (Jepco), Jake Freestone (Overbury Farms), Dermott Tobin & Lizzie Pritchard (PDM Produce), Mark Lyon (T.H. Clements), Andy Elworthy & Nataschia Schneider (Vitacress).

APPENDIX 1. Survey of soil management practices questionnaire

1) Farm Information

Q1) Total farmed area

Q2) Land tenure

Q3) Is the horticulture enterprise conventional or organic?

Q4) Main soil type? ***(Interviewer to pre-populate and check)***

Q5) Main land uses / farm enterprises

Q6) What do you consider to be your main farm type?

2) Field drainage

Q7) Do you mole drain or sub soil to improve drainage or to resolve any soil quality issues? *(timing, frequency, depth, choice of crop? How do you decide when you are going to mole drain/subsoil or is this a routine operation?)*

Q8) Have you invested in new drainage or maintenance of existing drainage for any part of the farm? *(brief details of area, soil type etc.)*

Q9) What else do you do to optimise soil condition?

3) Irrigation systems

Q10) Do you use irrigation on horticulture crops? Y / N.

If yes:

- Which crops?
- What irrigation/fertigation system do you use?
- Is the irrigation scheduling controlled or not?

4) Soil mapping

Q11) Have you soil mapped your horticulture cropping (or other) fields in any way? (e.g. soil scan, conductivity, electro-magnetic induction)

If so, how have you used the data?

5) Attitudes towards soil management

Q12) Are you confident that you can assess the structural condition of your soil?

If Yes – go to Q14

If No – to go Q13

Q13) Would you like to learn more about how to assess soil structure? Y / N

Q14) Is soil structural condition/compaction an issue for crop production on your farm? Y / N / Don't know.

If Yes:

- How do you tackle it (across various crops)?
- What are the key features of soil structure that impact on the crop (i.e. capping, shallow compaction, sub soil compaction, wind erosion)?

If No, why not?

Q15) Do you assess the structural conditions of your soils? Y / N. *If No, why not?*

If Yes:

- How?
- When?

Q16) Do you use a spade to visually assess your soils? Y / N. *If not, why not?*

If so:

- To what depth?
- How frequently?
- Do you target specific crops/fields?

Q17) Do you carry out deep cultivations (say, below 25-30 cm depth)? Y / N. *If not, why not?*

If so:

- For which crops?
- Do you adjust the depth of cultivations on the basis of visual assessments?

Q18) What other practices do you adopt to improve soil structure? (e.g. cover crops, green manures, use of mulches, fallow, grass ley, organic amendments, etc.)

Q19) What source(s) of soil management advice do you use if any?

APPENDIX 2. Precision Farming review questionnaires

Precision farming (PF) review – survey of precision farming companies

1. **Precision farming services**

   Thinking about the following 3 areas -

   a. **Tractor and machine control**
   b. **Targeted agronomy**
   c. **Data and record keeping**

      - Which PF tools/techniques do you currently offer?
      - How do these PF tools/techniques work?
      - How can these PF techniques benefit growers (yields/profitability)?
      - What are the costs to growers of adopting these PF tools/techniques?
      - Have these tools/techniques been developed in-house or by another company?
      - Has there been any independent testing of the PF tools/techniques being offered?
      - What R&D has been done?
      - Plans/priorities for future R&D?

2. **Market penetration**
   - For which crops do you provide PF services?
   - Which horticultural crops/rotations?
   - Do you market your company to the horticulture sector (generally/specifically)?

3. **Horticulture**
   - Generally, what experience do you have with applying PF tools/techniques to horticultural crops?
   - Are the PF tools/techniques you offer applicable to horticultural crops, if so which ones? If not, why?
   - Are there challenges in expanding the update of your PF tools in horticulture, if so what?

Precision farming (PF) review – survey of machine manufacturers

1. Yield mapping

- Overview of harvesting equipment, including crop types
- For which crops/machines do you offer a yield mapping facility?
- Do you offer yield mapping for any horticultural crops?
- What is the potential to yield map horticultural crops?
  - Crop types
  - Challenges
  - Any current developments

2. Guidance systems

- Do you offer guidance systems for horticulture crop machinery?
  - Crop types
  - Challenges
  - Any current developments

3. Controlled traffic farming

- What experience do you have with CTF?
  - Which rotations?
  - Have you adapted machinery for CTF?
  - Have you worked with any horticultural growers using CTF?

4. Novel soil compaction detection and alleviation techniques

- Do you have any experience with:
  - Variable depth cultivation?
  - Detection of soil compaction?
- Any relevant current R&D/areas for future development

5. Future developments

- Are you working on any other projects to change the nature of machinery in horticulture production systems?
- If so, what is the nature of the machinery and what is its main objective

Precision farming (PF) review – survey of horticultural growers adopting PF techniques

1. **Overview of farm**
    - What is the size of your farm?
    - What crops are grown (& what area)?
    - What rotations are used on the farm?
    - Location of farm and main soil types?

2. **Precision farming tools/techniques being used**

    Thinking about the following 3 areas -

    a. **Tractor and machine control**
    b. **Targeted agronomy**
    c. **Data and record keeping**

    - Which PF tools/techniques are being used?
    - For how long have they used them?
    - Why did you choose to adopt PF tools/techniques?
    - Which companies/advisers/other individuals or organisations have you worked with in adopting the PF tools/techniques?

3. **Benefits and limitations**
    - Have you seen benefits from use of PF tools/techniques?
        - If so what (yield/crop quality/profitability) – subjective/quantified?
    - What challenges have you faced in adopting PF tools/techniques?
    - What have been the costs in adopting PF techniques?
        - Equipment, advice, other costs

4. **Future plans**
    - Will you continue with the PF tools/techniques?
    - Will you expand the area/crops covered?
    - Are you considering adopting any other PF tools/techniques?