Project title:	“Growing Resilient Efficient And Thriving” GREAT Soils
Project number:	CP 107b
Project leader:	Ben Raskin, Soil Association
Report:	Final report, March 2018
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Key staff:	Liz Bowles - Project Director Ben Raskin - Project Leader WP 4 and involvement in WP 1,2,3 Simone Osborn – Project Manager Anja Vieweger – Project Leader WP1,2 Bruce Pearce – Scientific Supervisor Audrey Litterick – Project Leader WP3 Martin Wood – Technical involvement WP3,4
Location of project:	UK wide – with project leaders based in Bristol
Industry Representative:	James Brown Pollybell Holmes Farm, Wroot Road, Epworth, Doncaster
Date project commenced:	01 April 2015
Date project completed (or expected completion date):	31 March 2018

DISCLAIMER

[The results and conclusions for some of the work 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.

Ben Raskin

Head of Horticulture

Soil Association

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GROWER SUMMARY

Headlines

- Simple soil health assessment methods can be used by growers to assess the health of soils. The methods have been demonstrated in this project and are detailed in this report.

- Small measures to improve soil health in commercial horticulture production systems can have benefits in the short term. Longer-term plans for soil improvement should be considered by land-owners and those using rented land.

- Collaboration on measures to improve soil health is key, particularly among growers sharing the same land for crop rotations.

Background

AHDB Horticulture project CP 107b began against a backdrop of widespread acknowledgment by scientists and an increasing number of farmers and growers of problems with the state of UK soils. In the early part of 2018 (the final year of this project) the importance of improving the health of soils rose up the political agenda. The UK Government's recently-released 25 Year Environment Plan[1] contains 57 references to soil. Before that, in December 2017 a group of 32 scientists published a letter in *The Times* newspaper calling for soil organic carbon content to be adopted as the indicator of soil quality in agri-environment schemes.[2]

Many growers understand that some current farming practices can lead to soil degradation, including compaction, declining soil organic matter content, nutrient leaching and erosion. Growers often understand the importance of soil health, but when faced with difficult commercial demands, they are not always able to keep up to date with the latest research and best practice.

This project worked with growers to improve the health of soils by assessing and field-testing current grower-known methods of soil testing. It inspired and empowered growers to improve their soil by sharing up to date research and latest best practice via training and outreach events, and also by integrating soils knowledge, methods and tools into accessible practical information in AHDB Horticulture GREATsoils factsheets.

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[1] https://www.gov.uk/government/publications/25-year-environment-plan
[2] https://twitter.com/john_quinton/status/936227707486130177

Summary

Figure 1: Simon Day of Worth Farms, GREATsoils Field Lab participant

Improving the health of soils is fundamental to the agronomic, financial and environmental sustainability of horticultural enterprises. To improve soil health, fertility and function growers need clear methods and criteria to allow for simple, quick assessments and measurements.

This project set out to -

- evaluate soil assessment methods for growers;
- improve growers' confidence in 'reading the signs';
- offer opportunities to practice assessment methods with colleagues and advisors;
- disseminate the methods and approaches to a wide range of levy payers, growers, advisors and stakeholders;
- develop methods and approaches for practical soil health analysis and evaluation to enable confident choice of management options.

To do this the project team used a range of approaches including -

- grower consultation events;

- field trials to assess the efficacy of soil health testing methods in different growing systems;
- field labs to try out soil health improvement methods in practice;
- grower workshops to engage with growers around the country on the project and share knowledge and;
- a knowledge exchange programme which included
    - advisor/agronomist workshops,
    - project publicity via contractor attendance at horticultural events,
    - live online webinars and
    - publication of new AHDB factsheets .

The project -

• demonstrated that growers are keen to improve soil health. Seven hundred and fifty-five growers, farmers, and advisors attended 56 live events.

• promoted soil health within the wider horticultural agenda, with articles in major publications, and events and presentations and talks given at various fora.

• highlighted to growers that small measures to improve soil health are worth the effort eg using short-term green manures within a season.

• engaged with growers in England, Scotland and Wales at all scales of production, and from almost every sector in horticulture.

• identified as a key challenge the management of soil health in shared rotations where land is rented, and have established a way forward on this via a Field Lab working with three businesses collaborating to improve the soil health of shared field.

• built networks/connections, particularly through the Field Labs and Field Trials, that will continue beyond the project and provide long-term benefits to soil health and growers' businesses.

• identified growers who are innovative; these growers shared their knowledge and experiences to peers in the presence of the research team who also provided technical support to the growers.

• identified sets of the most useful and practical tools for soil testing for the different horticulture production systems - field vegetables, protected leafy vegetables and top fruit, see Table 1.

• facilitated constructive exchange of information between organic and conventional growers; focusing on shared challenges and how to address them.

Table 1. Usefulness of each soil assessment test in a particular growing system as rated by growers during the project. The results represent qualitative feedback from around 20 growers per system including the growers hosting the different Field Trials.

• Method	Field vegetables	Top fruit systems	Protected crops
Visual Soil Assessment (VSA)	😟	🙂	☹️
Earthworm Counts	🙂	😟	☹️
Soil Health Laboratory Test	😟	😟	🙂
Simple Infiltration rates	🙂	🙂	🙂
Simple Compaction Test	🙂	🙂	🙂

The main activities carried out in the project are summarised below.

Grower Trials

Review of existing methods of soil assessment

The soil assessment approaches that are available to UK growers were reviewed. The different methods were identified and categorised in a literature review and were then evaluated and rated by the growers to establish their usefulness and relevance in practice. This resulted in a two-paged summary GREATsoils 'Soil assessment methods' factsheet which is available on the AHDB website.

Field Trials

To assist growers to identify which soil assessment methods are most useful for them, methods and approaches were field-tested with six host farms in England and Scotland which had different growing systems. These were supplemented by a programme of open days to bring the findings to a wider audience.

In each case the growers selected the soil health tests that they wished to compare from a suite of possible options which had been chosen by growers at public consultations.

Alongside the soil health tests each of the farms also chose to test a soil health improvement method, for example introducing short-term green manures, or observing the impact of different planting times on cover crops and soil structure.

A ‘Rating soil assessment methods’ factsheet with system-specific recommendations was produced from the field tests: https://ahdb.org.uk/knowledge-library/greatsoils-rating-soil-assessment-methods.

Field Labs

Four grower-led Field Labs were conducted specifically for the GREATsoils programme and run in collaboration with the Innovative Farmers programme[3]. The Field Labs offered growers an opportunity to bring forward specific ideas or issues around soil health for investigating as a group.

The methodology and achievements and outcomes from each are summarised in the main report, included in the Appendices and were recorded on the Innovative Farmers portal which can be accessed for free.

The four Field Lab groups were:

1. **Improving soil health across a shared rotation; Lincolnshire**

Growers renting land within a rotation can often find it hard to justify investing in soil health measures as they might not reap the immediate benefit of the measures. This Field Lab brought together vegetable growers Jepco with two other businesses Loveden Estates and Worth Farm with whom they share land. The overall aim of the three partners was to improve soil organic matter and soil health in an arable / horticulture rotation and to deliver initial evidence for other farmers and growers that a joint strategic and long-term soil management approach is crucial for a long-term and sustainable improvement of soil health and soil fertility. The method adopted was for each business to bring mutually agreed cover crops into their rotation and to meet periodically to discuss progress. The field lab was successful with the group finding it useful to work together. A well-attended public meeting showed real interest in the approach. Year one showed some initial business benefits from use of the green manures which are summarised in the financial section below. The findings are summarised in the ‘Short-term green manures for intensively cultivated horticultural soils’ factsheet which is available on the AHDB website.

2. **The impact of whole digestate on soil health in field-grown vegetable crops on the Moray Coast; Moray Firth, Scotland**

With many consultants and Anaerobic Digestate companies promoting the benefits of digestates as soil improvers, this field lab set out to set up to determine whether the application

[3] http://innovativefarmers.org/

of separated liquid digestate made from farm-produced energy crops had any short-term impacts on aspects of the health of soils in Moray coast vegetable rotations.

There was no evidence from this short trial that digestate applied at 15 m^3/ha on three occasions (October 2016 / March 2017 / August 2017) had any deleterious effects on soil structure, microbial respiration soil earthworm populations. Neither did the digestate have any beneficial effects on these parameters. There may be benefit in repeating the tests every 2 years annually for a period of at least 10 years in order to further study the impact of digestate on soil properties, because it is well known that soil properties can take a very long time to change in a significant way.

3. Green Manures to Increase Nitrogen Availability; Lancashire

This field lab aimed to understand more about how three green manure mixtures, with varying proportions of leguminous species, could optimise nitrogen (N) availability to a following brassica crop. The trial compared the three green manure mixes against a no treatment control, and a normal farm practice control which received a synthetic N fertiliser. N availability was measured by taking soil samples pre-incorporation and 4, 10 and 20 weeks after incorporation of the green manure, the last sample being close to harvest. At the same time, the team measured N uptake by analysing the plant tissues of the green manures just prior to incorporation and of the crop plants 10 and 20 weeks after incorporation.

Initial results indicate that using green manures could, in round figures, enable a 50% reduction in N fertiliser application. The year 2017 was unusually dry between April and July, and the team estimated that in a more typical year (where higher rainfall might cause of N through leaching from the plots with no green manures) this could be higher.

Additional benefits from the green manures are also important, including improvements in soil fertility, reducing soil erosion, weed suppression and enhancing biodiversity.

4. Amendments for soil health in top fruit; Southern England and West Wales

In this Field Lab, a group of fruit growers looked at how various soil amendments (woodchip, biochar, green waste compost, and mycorrhizae) affect soil health outcomes including soil structure, weed control, soil pH, water retention and drainage. They were also interested in tree establishment, fruit quality, storability and yield.

There were no firm conclusions from this field lab; but this had been expected to be the case following a years work on soil health in perennial crops. The tree fruit trials are continuing beyond the life of the GREATsoils project, with extra funding from other projects.

Some initial findings from some growers in this group are that -

- Mulches have higher levels of potash than surrounding areas.
- Weed control is better in wood chip mulches than in compost mulches
- Compost has higher potassium (K) and trace elements.
- Soil conditions appeared wetter under Holly mulch than under Alder or Compost.

Eastbrook farm in Wiltshire had done some extension growth measurements and observed differences in treatments but these appeared to be due to variety rather than to the different treatments.

Tolhurst Organics on the Berkshire/Oxfordshire border observed -

- large quantities of mushrooms on ramial woodchip plots;
- ramial wood rotting on the surface turned black and mycelium growth was present on surface;
- very large number of worms present on ramial plots;
- that woodchip compost mostly decomposed to soil;
- evidence of slightly stronger growth on woodchip compost as opposed to ramial wood;
- similar root nodulation of clovers on both plots.

Knowledge Exchange

Soil health testing tool kit

Over the course of the project a library of resources for growers wishing to better understand and take action to improve their soil health was built. These add to and build on the existing resources available from the AHDB. Resources from this project includes the following:

AHDB Horticulture GREATsoils factsheets -

- Soil assessment methods
- Rating soil assessment methods
- Compost is good news for soil health
- A fresh look at soil testing for carrot production
- Engineering the landscape to secure asparagus production
- Biological tests for soil health
- Which nutrient management system to use?

- Short-term green manures for intensively cultivated horticultural soils
- Soil pH how to measure and manage it based on an understanding of soil texture
- Soil structure and infiltration
- Soil health and water supply
- Green manures improve soil health in apple orchards
- Testing soil health

GREATsoils Youtube films

GREATsoils: Salad grower Simon Gardner of G's Global, Cambridgeshire on low till cover crops for soil

GREATsoils: Improving soil health in orchards with James Smith, Loddington Farm, Kent

GREATsoils: Why managing soils is important with kale grower Chris Molyneux, Molyneux Kale Company, Lancashire

The following video clips are also available on the AHDB website

- Worm count
- Infiltration test
- Spade test
- Respiration test
- Compaction test

GREATsoils online webinars

All webinars can be accessed from the AHDB website.

- Soil Health and the bottom line
- Soil health and what to measure
- Managing soil health using organic manures
- Short term green manure strategies for intensive growers -
- Soil health for horticulture (project summary)

Field Lab reports

Final field lab reports are available in the appendices -

- Improving soil health and organic matter using cover crops in a shared rotation
- The impact of whole digestate on soil health in field-grown vegetable crops on the Moray Coast

- Green manures to increase N availability
- Amendments for soil health in top fruit

Other knowledge exchange activities

The project team delivered events for 755 attendees, including 14 field trial events, 14 field lab meetings, 23 soil health grower workshops; 5 presentations reaching over 50 horticultural advisors. Details are given in the appendices. In addition, the project delivered five online live webinars which are also available as recordings; and 8 YouTube videos. The impact of the project has been increased by a strong media presence, appearing in over 30 articles, and the project team were present at 35 conferences and sector events.

Grower workshops

A highlight of the project has been the series of grower workshops held over the past two years. There have been 23 events at host farms across the UK. The events covered field vegetables, protected leafy growing, ornamental nursery stock, protected cut flowers, top fruit and soft fruit.

The workshops provided up-to-date information on best practice for soil health testing, both from a theoretical and practical perspective, and also offered practical steps to address soil health issues. At workshops participants were invited to share their knowledge and experience, while also learning from expert guest speakers, and taking part in farm walks, looking at soil health in practice.

Advisor workshops

Advisors work with growers on a regular basis and so workshops were designed to update them on the main findings and outputs of the project in the last quarter or the project.

Attendance at our workshops surpassed our targets and positive feedback was received.

Media and outreach

Media: Media interest both from trade and mainstream media has been strong throughout the project, demonstrating that soil health is topical for the food production industry.

Highlights in Year 3 have been ‘Field Lab studies soil health across the rotation’ in the *Farmers Guardian*, ‘DIY soil testing’ in *Tillage Magazine*, ‘On farm trials look at methods of improving orchard soil-health’ in the *Fruit Grower*, and ‘Soil health – What should the doctor order?’ in

Soil Use and Management. Project articles also featured in the AHDB Horticulture Grower Magazine.

Overall the project has featured in 30 major articles, and the team has published 7 original blog posts.

Outreach: The project team have met growers and advisors at 35 conferences and sector events over the course of the project and built a network of growers via sign-ups at events, website, newsletters, and twitter. By the end of the project the network had 690 members as well as 1475 followers on Twitter. The team has kept this network informed of upcoming events and the latest project publications via the broadcast email, the 'GREATsoils bulletin'.

Summing up success of programme and legacy

Overall the project delivered on all its key objectives. Growers engaged with the programme of workshops, trials, and resources, while the wider sector has helped to amplify that work through the media and outreach elements of the project. The project will have a significant legacy, not just through the concrete outputs of AHDB factsheets, films, and webinars but through ongoing groups, trials and conversations that growers and advisors will continue to have. The project has helped to raise the profile of soil health in the growing industry and improved grower skills and confidence in assessing and improving soils' health.

Financial Benefits

Is there money in soil health?

Drawing accurate financial conclusions from soil health improvements is not easy, particularly in the short-term. There is also significant variation in the potential financial benefits depending on soil type and crops grown. The motivation for most growers is not short-term gain but long-term investment in the resilience of their soils and business.

However, financial incentive helps to convince growers to spend time and money on assessing and improving soil health. Anecdotal evidence was collected throughout the project to build a picture of how improving soil health also improves the profitability as illustrated by two examples.

JEPCO – short-term green manures

In 2017, JEPCO took part in a GREATsoils Field Lab, part-sponsored by Innovative Farmers (www.innovativefarmers.org). Part of the trial looked at the impact on agronomy of growing wholehead lettuce crops following an overwintered green manure (King's Italian ryegrass mix).

The grower felt that cultivations were easier and that JEPCO had used less diesel, particularly with its triple bed tiller, where around 10 litres per hour were saved. They also found that water infiltration into the soil was improved where the lettuce crops had followed green manures. For example, in late Summer 2017, following a wet spell when around 75mm of rain fell in just over 24 hours, the grower noticed that water disappeared off the beds a lot quicker where the lettuce had followed a green manure crop.

There was a 7.9 per cent increase in lettuce head weights where the crop was grown following the overwintering green manure. It is important to note that only a small trial area was planted and the trial was not replicated. The increased weights were down to both bigger heads and improved integrity of leaf structure. The grower felt that the improved leaf structure would potentially give a longer shelf life and that since the crop was more consistent in size and shape, harvesting was easier, which was likely to further reduce costs.

The grower admitted that the incorporation of the cover crop was challenging. However, he felt that there were clear indications of benefits to both soils and cash crops from growing the cover crop. The findings are documented in the GREATsoils factsheet 'Short-term green manures for intensively cultivated horticultural soils'.

Molyneux Farm – Nitrogen availability following green manures

This GREATsoils field lab aimed to compare how different green manures affect the availability of nitrogen (N) and key nutrients to a following spring green crop. N availability was measured via soil analysis and also tissue analysis of the green manure and crop plants.

Initial cost-benefit analysis from the one year trial showed that the cost per kg of nitrogen supplied by the green manure and the synthetic nitrogen were broadly similar. For the N treatment it was estimated at £0.12 £/kg, which was the same as the green manure 'Mix', a penny higher than the 'legume' and a penny lower than the 'non legume' (Table 2). Despite such small differences, with large volumes of product coming off the field, 1 pence per kg can add up to a large amount of money.

Table 2: Cost benefit analysis of Green Manures to Increase N availability field lab

Treatment	Cost of Field operations (£/ha)	Cost of treatment (£/ha)	Total Cost December (£/ha)	Cost per kg N added £/ha	Cost per kg N uptake £/ha (using NUE)	Cost per unit output crop Yield (£/kg)
Control	223	0	**223**	0	0	0.15
Green manure - legume	212.4	89.8	**302.2**	1.16	2.09	0.11
Green manure - non legume	212.4	109.7	**322.1**	1.99	2.64	0.13
Green manure - mix	212.4	106.45	**318.85**	1.26	2.23	0.12
nitrogen	264	98	**362**	0.73	1.25	0.12

Additional benefits from the green manures such as reduction in soil erosion, weed suppression and enhancing biodiversity are not included in the analysis, but would have a benefit to the soil and crop if green manures were included as a permanent part of the growing system.

The general conclusion of the project is that there are many methods of increasing soil health that will bring financial benefits and resilience to growing systems, but that finding the most cost-effect strategy for any particular business takes time and experimentation.

Action Points

1. Simple and practical soil assessment tools can be very useful to growers who aim to evaluate the health of their soils, who wish to monitor changes in soils over time (e.g. structure, fertility etc.), or who aim to assess the effects of certain soil management strategies and activities. Most of the soil assessment methods and tools do not need specialist knowledge or equipment.
2. Doing an infiltration test is a useful way to quickly assess compaction and soil structure. It is easy to do and generates results that are easy to translate into soil management strategies.
3. Earthworm counting has some use in field cropping, although growers need to ensure that this is done at the right time of year and in appropriate soil conditions.

4. Fruit growers can use the Visual Soil Assessment tool developed by Eblex/Dairy co (there is no specific horticultural one available).
5. For all systems the simple compaction test, using a blunt knife, soil probe or corer was a useful tool for soil structure and compaction assessment. Growers found it very fast, cheap and easy to use to locate areas of compaction and the more frequently they used the method the more able they became in estimating the depth of the compacted layer.
6. Laboratory-based soil biology tests (e.g. respiration, DNA fingerprinting) are developing rapidly and they are likely to have potential in the future. Protected cropping growers saw more potential in these tests than other crop growers.
7. Assessing soil health is a not a short-term activity; growers should be prepared to monitor improvements over the long-term.

Action points on improving soil health

1. Much of the learning from this project came from growers exchanging knowledge and experiences. Growers should be encouraged to talk to their neighbours, colleagues and other growers in different parts of the country about soil health.
2. There is likely to be a green manure/cover that will improve soil health in any particular growing system. Trialling different green manures and different sowing dates is important.
3. When improving soil health consider also the uncropped areas, improving the health of access routes or marginal areas will have an impact on the general soil health within the cropped area.

Soil Health Testing - Findings

- Routine analysis is essential. Do it well prior to every high value crop going in. Collect basic soil health information which affects crop yield and quality.
- Spend the time sampling properly – the results are only as useful as the quality of the sample itself.
- Choose your method (and ideally your soils laboratory too) and stick to them. It is important that variation in results is real, and not due to differences in methods or labs used.
- Look at what’s possible for your soil by assessing soil health in the field margins.

- Soil physical assessments are very useful, whether documented or not.
- Learn how to quickly assess whether soils are functioning as well as they could, given the crop, system and weather.
- Question why soils are in the condition that they are.
- Records should be kept to build up pictures of what is “normal” for particular fields in a particular rotation. The impact of management changes can then be measured against earlier results.

Methods:

Visual Soil Assessment - Conduct regular test digs. Look for evidence of good soil colours, healthy soil smells, good rooting, visible pore spaces and good structure versus mottling, anaerobic smells, compaction, limited rooting, deformed or horizontal roots, platyness and drainage problems. It was found that the Healthy Grassland Assessment Tool[4] can be a useful tool to score the VSA. Results were however found to be subjective and based on the interpretation of the tester - to build a picture over time they should be conducted by the same person. Growing systems where the soil had been “bed-formed” (for example for some root and field vegetables) using VSA did not prove useful as all visible soil structure was absent.

Earthworm counts - can be a useful indicator for soil fertility, health and organic matter, but can also be very time consuming. Results should be interpreted with care (since soil moisture affects the results so much). AHDB has published a factsheet on how to count earthworms and produced a counting earthworms record template; both of which are available on the GREATsoils website. In intensive growing systems earthworms may not be present. Also when heavy tillage machinery and tools are used, earthworm populations can decrease very quickly.

Soil Health Laboratory Tests - These are relatively newly developed laboratory tests, often providing an overall soil health index or score based on chemical soil health indicators (P, K, Mg, pH, total soil organic matter), physical indicators (texture) and biological indicators (respiration), with certain soil management recommendations derived from the results. Such laboratory tests were seen by the growers in the trials as potentially very useful in the future, once more information is available about soil biology indicators, and once useful testing procedures/protocols are developed for routine soil biology testing and monitoring over time.

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[4] The Healthy Grassland Assessment Tool was developed by EBLEX-DairyCo. Now AHDB Beef & Lamb and AHDB Dairy

Soil respiration measurements - Can be a useful blunt instrument to measure soil health, but it is not clear yet how results should be interpreted in terms of being able to recommend management options. Useful to test pre, during and post-crop in order to build a picture of what is normal for particular fields.

Simple Compaction Test – Although measuring compaction is very subjective with the result being the tester's interpretation of the resistance felt in probing the ground, it is quick and easy to perform. The test can be conducted with a compaction probe, but some growers prefer a blunt knife. With experience some growers stated that they were able to measure the depth of the compacted layer. This test was popular across all horticultural growing systems.

Simple Infiltration Rates - The test was seen by growers as a useful tool for assessing soil structure and compaction. Growers in all systems liked the test as it is easy to do and generates self-explanatory results. Depending on the soil type, structure or moisture content, it can take a long time to wait for 800ml of water to infiltrate into soil through a piece of drain pipe at several spots in a field which can result in growers losing patience.

SCIENCE SECTION

Introduction

This project focussed on bringing together existing scientific knowledge (literature review) and grower experience (grower consultation), with on-farm demonstration (Field Trials and Field Labs) and grower engagement (knowledge-exchange programme which included the workshops). In Work Package 1 a literature review was carried out on the wide range of soil assessment methods and tools that are currently available to growers in the UK. The most practice-orientated methods for the UK were selected from the large variety of soil assessment approaches from around the world. Similar approaches and tools were grouped together, and some of the innovative tools that are being developed in Europe and the USA were highlighted. The full literature review is available for a free online download from the AHDB website.

In Work Package 2, with input from growers during the consultation events in autumn 2015, the range of assessment methods were brought together under broad categories. Growers were asked to score each method according to skill, knowledge, time and labour requirements, as well as potential costs for the tools/lab test etc. This provided a basis for growers to assess which methods would be most suitable and relevant for their specific systems. A record showing how growers scored the different soil assessment methods is published in the 'Soil assessment methods' factsheet. The findings provided a basis for the development of recommendations and guidelines to more effectively assess the health of soils and inform more sustainable soil management in UK horticulture.

Work Package 2 included six demonstration Field Trials where growers tested and compared various potentially useful approaches and tools for soil health assessment. These were set up on six farms/holdings during spring 2016 and ran for 2 growing seasons until autumn 2017. The six sites were identified during the four grower consultation events in autumn 2015 and were chosen by the regional grower groups to represent relevant growing systems for the different UK regions. The highest priority in all the regional groups was a useful and reliable assessment and monitoring of soil organic matter and soil biology. Based on this outcome, the regional groups and trial host growers selected the most promising tools including those that were new or less familiar to them, to test and compare over two growing seasons. Together with the growers, a set of soil assessment recommendations were developed. These system-specific recommendations for field vegetables, top-fruit and protected cropping systems are available in the 'Rating soil assessment methods' factsheet.

The host growers also set up small Field Trials, addressing challenges through innovations within their specific horticultural systems. These trials compared, for example, the use of different cover crop mixtures in the alleys of a newly established apple orchard, varying sowing dates for overwintering green manures in field vegetables, short-term green manures in intensive protected and field lettuce production. This created a useful setting for the comparison of soil assessment tools with findings being published as factsheets.

Materials and methods

Grower consultation events during autumn 2015

Four events were organised across the UK to which all horticultural growers and advisors in the region were invited to join and discuss which soil assessment tools they regularly used, which they found most useful to base soil management strategies on, and of which they found interesting but had not yet tried themselves (Figures 2 to 8). What came through clearly was that most used spade tests/diagnosis, and they considered this an essential starting point in their soil assessment. The method is cheap, easy and quick, and can be started with little skill (though of course growers will get better at interpreting the results of their efforts with initial guidance and subsequent experience).

The benefits of other methods may depend on the scale of the operation. Some larger growers for example stated that they regularly use a mini-digger to dig larger and deeper soil pits to obtain a full picture of different soil horizons and the effects of their management. For smaller growers this approach might be impractical.

The growers also stated that some soil assessment methods, such as Visual Soil Assessment (VSA) are in fact only used once or twice. The grower would take the guide out to the field and follow the instructions step-by-step to assess and score different aspects of soil health. Growers then tend to carry out future assessments from memory and even adapt the methodology to suit their own site and system.

Growers also use a range of senses to assess their soils: smelling the freshly dug soil for instance, assessing its colour, feeling its texture between the fingers or even tasting small amounts of soil.

Biological testing in the laboratory is an area of increasing interest across all production systems. Many growers have little experience of monitoring soil biology but are aware of the importance of earthworms, for example, and the key role of soil organic matter for sustainable soil fertility and productivity. However, growers are still uncertain how much benefit they can gain from the results of these tests in terms of practical soil management. It was clear from the consultation events that growers find assessing and understanding soil organic matter, including its various components (e.g. the labile/active fraction) the most challenging aspect of soil health assessment. Regardless of the size or organisation of their business, this longer-term vision for more sustainable management of soil organic matter was one of the most important aims for the growers.

Figure 2: Grower consultation at Valefresco

Figures 3 and 4. Grower consultation at Kettle Produce, Scotland


Figures 5 and 6: Grower consultation at East Malling Research (EMR), Kent


Figures 7 and 8: Grower consultation at Produce World, Peterborough

Field Trials and comparison of soil assessment tools

The six host farms for the Field Trials were chosen by the members of the regional grower groups during the consultation events in autumn 2015. The sites covered a range of horticultural sectors and systems including field vegetables (leafy salads, carrots and brassicas), soil-based protected cropping (spinach and rocket), as well as top fruit orchards (apples). They ranged across major British growing regions from Scotland, East and West Midlands to Kent.

As all the regional groups had identified that their primary focus of interest was soil organic matter and soil biology, the host farms were asked to choose a number of system-specific soil assessment methods and tools from which they thought would be most useful. The selection was made by the host growers with help of the project team and informed by the literature review. The choice was deliberately left primarily with the growers, to ensure practicability and usefulness of the results for the different horticultural systems. Only one of the growers had previous experience with some of the identified methods. The final list of methods was surprisingly similar across the various systems. The different methods were tested and compared in the same field of the host farm over two years.

Each of the six growers selected a field and a crop/s in their rotation in which they wanted to conduct the comparison of soil assessment methods over the two years. To maximise outcomes for the growers and potentially increase the potential for comparison of soil assessment methods, each host also identified a small trial on soil health management to provide further context for this method comparison. Reflecting their strong interest in increasing soil organic matter and their ability to measure and monitor it, all host growers adopted a basic trial design, and several included additional green manures in their system and rotation. In most systems, the aim of the green manure was to increase and improve soil organic matter and soil biology; in some cases, a flowering green manure mixture was chosen to also attract and support beneficial insects, pollinators and natural predators (e.g. in the apple orchard or carrot fields).

A demonstration field day was held on each of the six locations each year (2016 and 2017). The events were public and open for all growers, advisors and other interested individuals in the region. The aim was to introduce the project and the specific experiments, as well as the methods being used with background from the literature and any preliminary results.

The six sites and their chosen experimental trial set-up are briefly described in the following Tables 3 to 8, and a short overview is given of each site in the following section.

Table 3: Field Trial site 1, aim of trial and soil assessment methods used.

Site 1				
System Conventional field vegetables	Host: Balbirnie Estates, (growing for Kettle Produce)	Region: Scotland	Aim of trial: Investigate the impact of crop residues and compost application on soil health (same parameters to be used as in baseline testing) during and after a **carrot** crop and prior to and after the following spring barley crop.	Methods compared: Earthworm counts, VSA/VESS and NRM soil health test.
Assessment dates: 6 Apr 2016, 13 Sep 2016, 17 May 2017, 2 Oct 2017	Field days: 7 Jul 2016, 28 Jun 2017			Host grower taking samples: 

Table 4: Field Trial site 2, aim of trial and soil assessment methods used.

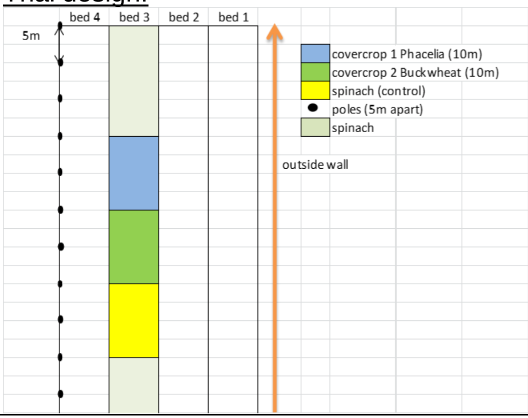
Site 2				
System: Conventional protected cropping in soil	Host: Valefresco	Region: West-Midlands	Aim of trial: Monitor two intensive rotations: (1) protected cropping with **spinach and rocket**, and (2) intensive **field lettuce** rotation. Investigate the effect of the short-term green manures, phacelia and buckwheat in protected cropping; and assess and monitor benefits of overwintering rye and vetch mixture in field lettuce rotation.	Methods compared: Earthworm counts and VSA in the field, NRM soil health test in protected cropping.
Assessment dates: 28 Apr 2016, 11 Oct 2016, 15 Mar 2017, 31 Aug 2017	Field days: 2 Dec 2016, 30 Oct 2017	Trial design: 		Phacelia: 

Table 5: Field Trial site 3, aim of trial and soil assessment methods used.

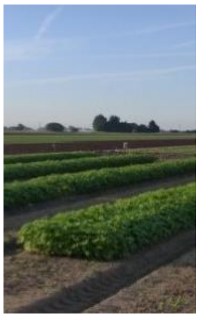
Site 3				
System: Conventional field vegetables	Host: JEPCO	Region: East-Midlands	Aim of trial: Investigate the effect of short term green manure strips on beds in an intensive **salad** rotation on soil biology, organic matter and crop health/quality.	Methods compared: Earthworm counts, VSA, NRM soil health test
Assessment dates: 21 Jul 2016, 26 Oct 2016, 22 May 2017, 8 Sep 2017	Field days: 6 Jul 2016, 26 Oct 2017	Trial design: 		Buckwheat: 

Table 6: Field Trial site 4, aim of trial and soil assessment methods used.

Site 4				
System: Organic field vegetables	Host: Taylorgrown	Region: East-Midlands	Aim of trial: Investigate the effect of flowering green manure strips in a **carrot** field (beds) on soil organic matter, biology and pests; as well as under-sown clover species in a new carrot field during the second year.	Methods compared: Earthworm counts, VSA, NRM soil health test, infiltration and simple compaction + pest/disease on at harvest
Assessment dates: 31 Mar 2016, 15 Dec 2016, 31 May 2017, 6 Sep 2017, 26 Oct 2017	Field days: 6 Jul 2016, 26 Oct 2017	Trial design: 		Green manure strip: 

Table 7: Field Trial site 4, aim of trial and soil assessment methods used.

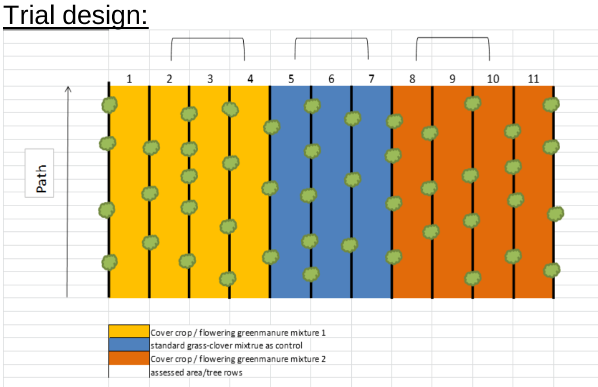
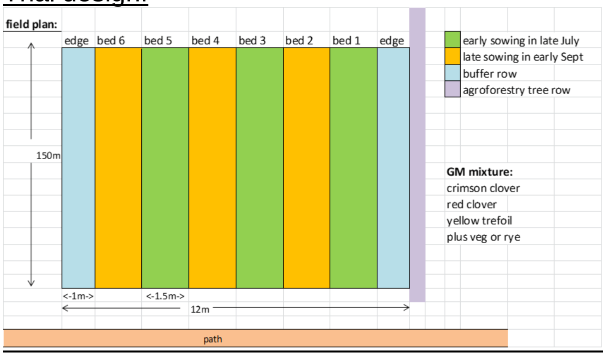
Site 5				
System: Conventional top fruit	Host: Loddington Farms	Region: South-East	Aim of trial: Investigate the effect of two green manure mixtures in a **new apple plantation** on beneficial insects and soil structure, organic matter and biology.	Methods compared: Earthworm counts, VSA, NRM soil health test, infiltration rates
Assessment dates: 22 Apr 2016, 25 Oct 2016, 11 Apr 2017, 24 Oct 2017	Field days: 30 Aug 2016, 26 Jul 2017	Trial design: 		Green manure in alley: 

Table 8: Field Trial site 4, aim of trial and soil assessment methods used.

<table>
<tr><td>Site 6</td><td></td><td></td><td></td><td></td></tr>
<tr><td><u>System:</u>
Organic field vegetables</td><td><u>Host:</u>
Tolhurst Organic C.I.C</td><td><u>Region:</u>
South-East</td><td><u>Aim of trial:</u>
Investigate the effect of an early (28/07) and late (05/09) sown green manure mixture after early potatoes (harvested in June) and before brassicas (to be planted in spring 2017), on soil organic matter, structure and biology in a stock-free horticulture system without animal inputs</td><td><u>Methods compared:</u>
Earthworm counts, VSA, NRM soil health test, infiltration rates</td></tr>
<tr><td><u>Assessment dates:</u>
16 May 2016 (earthworms only),
19 Jul 2016 (NRM + VSA),
6 Oct 2016,
2 May 2017,
27 Oct 2017</td><td><u>Field days</u>:
21 Nov 2016,
29 Aug 2017</td><td colspan="2"><u>Trial design:</u>

</td><td><u>Green manure in strips:</u>
</td></tr>
</table>

Soil assessment methods chosen to compare in the Field Trials

The grower consultation events in 2015 showed that the majority of involved growers were most interested in soil organic matter and soil biology assessment methods. They were aware of the crucial importance of soil organic matter on soil fertility and the sustainability and profitability of their growing system and business. In order to improve and increase soil organic matter, the growers wanted to identify useful, practical and cost-effective tools and assessment methods to reliably monitor soil organic matter and soil life, in order to gain reliable results to form the basis of soil management decisions and strategies.

The methods were chosen for their practical application ('easy' to use by the growers themselves), seemingly good cost-benefit balance, and promising/reliable results. The aim of the selection was on the one hand a) to assess if maybe one single tool might deliver results that are sufficient and comprehensive enough to inform soil management in a specific horticultural system; and on the other hand, b) to assess if, for certain horticultural systems, a specific tool combination (tool box) might deliver the most useful results.

With all the methods it is recommended that an assessment is made at least once a year, ideally during the same time of year and during similar climate conditions; for example, in spring and autumn before and after the main growing season, or before and after a particular crop in the rotation. At each of the six trial sites the selected soil assessment tools were used and soil samples were taken twice in 2016 and twice in 2017, in spring and again in autumn.

The methods were used, and samples were taken at random locations in each treatment of the trials, following the specific instructions of each method. It is important to note that, due to the nature of the trials (they are participatory farmer trials, not fully randomised scientific field trials) and due to the small amount of data from each site, full statistical analysis was not possible. The main aim of these Field Trials was the testing and direct comparison of the soil assessment methods by the growers, especially to gain feedback from growers on their usefulness and relevance in practice.

The methods selected are briefly described below.

Earthworm counts

Earthworms are some of the more common and easily assessable soil organisms and are widely accepted as an indicator for soil fertility, soil health and soil organic matter. In many soils and environments, monitoring earthworms over time and throughout growing seasons can deliver good information about soil organic matter (e.g. derived from the available food source), soil structure or fertility. Many growers were very interested in earthworm counts, but none had any previous experience with this approach. A number of methods are available for earthworm counts; for these trials the OPAL earthworm survey guide to earthworm assessment was selected (Figures 9 – 11). It is publicly available online and free to download here: https://www.opalexplorenature.org/soilsurvey

The guide offers a brief introduction to earthworms and explains the technique for sampling in a short and practical manner. It also comes with colour pictures for species identification to be used when the aim is to take the assessment one step further and identify which species are present on the farm, which ecotypes might be dominant or most affected by soil management. The species evaluation requires some previous experience, and in most cases a microscope to identify differences between the worms. For the Field Trials, however, the focus was on earthworm counts alone, and the basic method was followed (total number of adults; those worms that have a saddle, and total numbers of juveniles). The method is freely available; however, it is the method that requires most time and labour input among the chosen soil assessment tools.

AHDB subsequently published a factsheet on how to count earthworms and produced an earthworm count record sheet – both are available on the AHDB website.

Figures 9-11: Counting earthworms at Tolhurst Organics, October 2016

Visual Soil Assessment (VSA)

Due to the current lack of sector-specific visual soil assessment (VSA) methods for horticulture, the VSA tool used for these Field Trials is the Healthy Grassland Assessment Tool developed by EBLEX-DairyCo. (now AHDB Beef & Lamb and AHDB Dairy). This tool consists of a 2-page soil scoring sheet, with colour pictures to compare the sampled soil with, as well as a small pocketbook for some further detail and information (Figures 12–14). It provides practical instruction to sample a soil block with a spade and how to assess and compare the sample with the pictures and their scores. Also this tool is publicly available online and free to download at: http://beefandlamb.ahdb.org.uk/research/climate-change/climate-change-generic/grassland-soil-assessment-tool/

This tool was used in all field vegetable and top fruit experiments, although its usefulness in intensive horticulture systems, especially when growing on beds, is under discussion. In such situations, timing of assessment is very important: e.g. in early spring, just before the field is ploughed and prepared for planting/sowing, when an assessment of structure may be possible.

Figures: 12-14: VSA (left) at Loddington orchard (under green manure middle image and control grass alley right), October 2016.

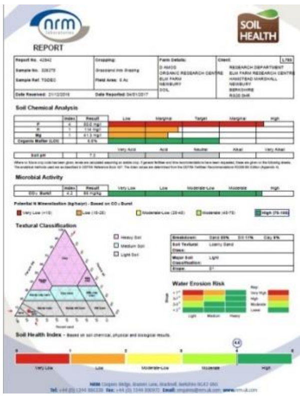
NRM Soil Health Test

This is a relatively newly-developed laboratory test, providing an overall soil health index/score based on chemical soil health indicators (P, K, Mg, pH, total soil organic matter), a physical indicator (texture) and a biological indicator (respiration rate), with certain soil management recommendations derived from the results.

Total soil organic matter content changes very slowly and increases in response to management interventions are difficult to detect in the short term, e.g. over 3-5 years, where changes are often <0.5%. Total soil organic matter is normally analysed in commercial laboratories by loss-on-ignition (LOI) or other laboratory methods that measure all fractions of organic matter in the soil, from the highly stable 'inert fraction' to the more reactive and manageable 'active/labile fraction'. It is the latter that growers are most interested in, effects of changes in soil management strategies may be observed relatively quickly. This fraction of soil organic matter also has a direct impact on nutrient availability. The labile fraction includes the soil microbial biomass (fungi, bacteria, etc.) and there are several lab tests currently available which relate to this fraction (e.g. food-web-tests, enzymatic activity, microbial biomass carbon, basal respiration rates, etc.). These tests are often relatively expensive (up to £150-200 per sample for food web tests), and interpretation of the results as well as correct sampling requires great skills and caution. Microbial communities in the soil often vary significantly during different seasons, weather, moisture levels, temperatures and even times of day! So, while these tests have great potential to provide useful information for soil management, it is crucial to be aware of the issues above when using them in practice. From a practical point of view, both microbial biomass and respiration rates could be used to assess labile soil organic matter fractions. The NRM soil health test includes a measurement of respiration rates, together with other relevant soil health parameters (e.g. total soil organic matter), and for a relatively affordable price per sample (around £45), this test was selected for the Field Trials. Each individual analysis result is allocated a score and a weighted average is used to calculate a Soil Health Index for the soil. Not many growers had experience with this test, but they were keen to trial it.

A number of soil samples (at least 12-20 per plot or replication) were taken with a soil corer into a bucket, mixed well, and a subsample of the mixed soil was sent immediately to the laboratory for analysis. The method for soil sampling for this test is similar to the sampling approach for standard soil analysis.

Time and labour costs are comparably small for this test but depending on number of samples (or replicates), the total analysis costs can become relatively high.



REPORT

Soil Chemical Analysis

Microbial Activity

Textural Classification

Water Erosion Risk

Soil Health Index

Figures 15 and 16: Soil sampling for NRM Soil Health Test in protected crops at Valefresco, April 2016, and example analysis result.

Additional methods used in the Field Trials

Further ideas for adapting the method selection for specific horticultural systems was discussed with the host growers individually during the first year of the Field Trials. Some growers concluded that they would also be interested in trying out a simple infiltration rate test using a drain pipe, as well as a simple compaction test using a blunt knife or thin soil corer. The additional methods are described below.

Simple infiltration rate test

A simple infiltration test was carried out at several locations throughout each field/plot. This involves taking a measured piece of drainpipe, hammering it into the soil to a depth of eg 30cm; and then pouring a measured amount of water into the above ground section of the drain pipe to see how long it takes the water to infiltrate into the ground. Details on how to do an infiltration test are available on the AHDB Greatsoils website as a video clip.

For most soils this was a very efficient method of checking for water movement within a soil and growers were keen to try it out themselves. On highly compacted or heavy soils, where average infiltration takes more than 10 minutes, growers tended to run out of patience and accept this in itself as a result! This test is easy to do, alternative sizes of drain-pipes can be used, as well as different amounts of water; however, it is crucial to keep using the same method in order for results to be comparable.

Figures 17-19: Simple infiltration rates measurement.

Simple compaction test

Soil compaction is often measured with a soil penetrometer (e.g. Dickey-John), a diagnostic tool that assesses the extent and depth of soil compaction. However, if a penetrometer is not at hand, or seen too costly to acquire, a simplified method is to use for example a blunt knife or a soil probe. The knife, probe or thin soil corer is pressed straight into the soil to get an impression of how much force or pressure is needed to insert the corer to a certain depth. This test is also repeated several times across the field/plot to get a better picture of compacted areas, or even location of compacted layers for the experienced user. The assessment of the simplified test is a subjective interpretation, and therefore should be performed by the same person each time to enable the comparison of findings.

Figures 20 and 21: Penetrometer and simple compaction tools such as blunt knife or soil corer.

Field days 2016 and 2017

During 2016 and 2017 one field demonstration day was organised on each trial site in each year. The exact dates of the events are shown in the site descriptions above, and numbers of participants ranged between 12 and 30 (Figures 22 to 31). In the first year the aim was to raise awareness of the project and the trials; in the second year the events focussed on the discussion of results and grower feedback. During each event, a workshop on soil health assessment and the different tools compared in the project was followed by a field walk led by the host growers, introducing the group to the trial site and explaining the motivations and expectations of being part of the project.

Figures 22-27: Field demonstration days 2016


Figures 28-31: Field demonstration days 2017

Results

The results of the six field trials are shown below, followed by the outcomes of the central questions of this work: feedback and recommendations from the involved growers about usefulness and practicalities of different soil assessment methods for different horticultural systems.

Here we present the results from the different field experiments that the growers decided to conduct during the growing seasons of 2016 and 2017. The results are shown per soil assessment tool. It is important to note that these additional grower experiments were not replicated/randomised field trials, and as such they should not be interpreted out of context. It was not within the scope of this project to run these ideas as actual field trials, restricting possibilities with regards to trial design, data collection, monitoring and therefore statistical analysis; many host growers also decided to change or adapt the experiment for the second season of the project. It is important to keep in mind that the main aim of these field comparisons trials was the testing and direct comparison of the soil assessment methods by the growers, especially to gain feedback from growers on their usefulness and relevance in practice.

Outcomes of earthworm counts

In some of the six growing systems, possibly due to the intensive nature of soil management in the specific horticultural systems or unsuitable timing in the rotation, we did not find many earthworms during the two years of sampling. Where the total number of worms was found higher than 20, the results are shown in a graph. Soil samples of 20x20x30cm were taken with a spade at three to five locations within one treatment or bed, depending on the trial design. As described above, numbers, length and adult/juveniles were recorded where possible; and where applicable, the results were then summed up per bed and per treatment. In some trial sites, also the additional step of species identification of adults was possible due to additional external funding: at Tolhurst Organics in autumn 2016 and at Loddington Orchards in spring 2018.

Site 1 – Balbirnie Estates, Scotland – field carrots

For this site in Scotland, an 18 cm square section was dug to a depth of 30 cm in four areas beside four of the locations used for the VESS assessments on 6 April 2016. An additional two assessments were made in the uncultivated field margins for comparison. All soil dug out of these sections was placed in a large plastic trug. This soil was carefully sifted through and all earthworms of all sizes were removed and placed in a white plastic bowl. The earthworms were then rinsed free of soil to make them easier to identify. Those present were sorted into sizes, the numbers of each size were counted and the adults were identified using the Opal Soil and Earthworm Survey guide. On the first assessment, a mustard solution was poured into the base of each pit in order to encourage deep dwelling earthworms to come to the surface of the pit, but no further earthworms did so. The mustard solution was not used on subsequent assessments, which were made using the same method on 13 September 2016, 17 May 2017 and 02 October 2017. Very low numbers were found in both years of the trial, with mean numbers ranging from 0 to 2 in the different treatments. The field margins were also assessed at this site, here a mean of 2.5 (adults) and 3.8 (juveniles) was found in autumn 2017.

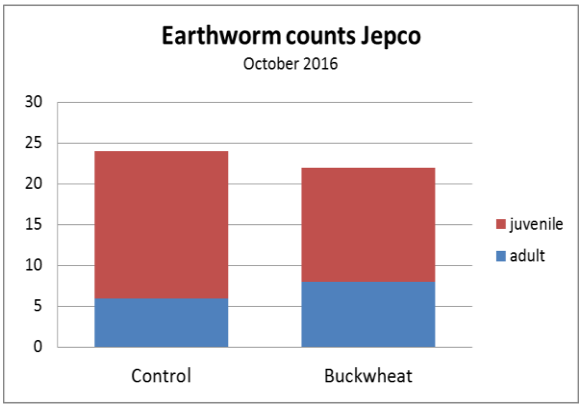
A full report of this site is shown in Appendix 4.

Site 2 – Valefresco, Hampton Lucy – protected cropping

There were no earthworms found in the protected cropping trial over the 2 years, which is probably due to the very intensive soil management and rotation. Rocket and spinach are grown in succession all year around and the soil is worked highly intensive in the top layer. In the Field Trial, at first sampling in October 2016 there was only one worm found, curled up for winter at location B (field plan given earlier). The sampling on the following three dates for earthworm counts did not show any worms either; however, the grower mentioned that he had found several worms himself towards a corner of the field close to the hedge, when he checked on the field the day before the sampling took place in spring 2017. (This was a great result for our trial in itself, as the grower was interested on his own to take some spade samples and check for earthworms, and we hope he was inspired to monitor the development of potential worm populations in their soils in the future).

Site 3 – JEPCO, Spalding – field lettuce

The Field Trial with a buckwheat short-term green manure as described above was run for only one year on this site. For 2017 a new concept of a trial was set-up as a GREATsoils Field Lab, where earthworm counts were performed in spring and autumn 2017. At the first sampling date 21 July 2016 at JEPCO, no earthworms were found. Figure 32 shows the total numbers found at the second sampling date, 26 October 2016. The results are summed up across all three 20m beds of control (total number found = 24), against all three 20m beds of green manure (total number found = 22); and split up into juveniles and adults. Samples were taken at 3 random locations in each bed. The second chart shows the average numbers results of 2017; a different field was used for this trial, but total numbers were also very low.



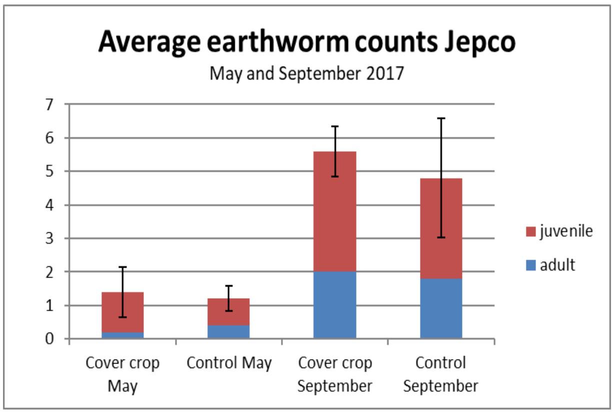


Figure 32: Earthworm counts at JEPCO 2016 and 2017

Site 4 – Taylorgrown, Houghton – organic carrots

In the first year's trial with a cover crop mixture sown in 4 beds of a carrot field, earthworm counts were conducted at on 31 March 2016 and 15 December 2016. There were only 11 worms found in March, all juveniles, but beds were already formed at the time of sampling and it was not expected to find many worms under such circumstances. But also in December, when the field was in ley (glover/ryegrass), only 6 worms were found in the entire field, 5 juveniles and 1 adult. In the second year of this trial site, a new field of carrots was used in the rotation for a new experiment design. We compared a number of clover species for their use in under sowing carrots on beds. Also this strategy was aimed at increasing soil health and fertility through the nitrogen fixing effect of the clover, but also to improve soil structure and carrot health and quality. In the second year, the earthworm counts showed very low numbers also in this field. The counts in spring 2017 found no worms at all, in autumn we found 0 in the control, and in total 1 to 3 in the different clover undersown beds.

Site 5 – Loddington, Maidstone – top fruit, apples

In 2016, earthworms were counted in April and October. In spring, we found 3 juveniles and 2 adult worms in the (to be) soil improver green manure alley, 3 juvenile worms in the (to be) control alley, and 4 juveniles in the (to be) pollinator green manure alley. In autumn the numbers did not improve much, which could be due to the recently set up new orchard and the heavy soil management that was needed to remove the old trees the autumn before. In October we found 9 worms in total, 1 juvenile under the soil improver green manure mixture, and 8 under the control alley.

In 2017, we sampled again in April and October and found especially in the autumn a growing population of worms in all three treatments. The majority of worms were juvenile at both sampling dates, however in October we found 6 adults in the control strip; they are all included in the total numbers of the graph below. The highest growth was found in the alleys with the pollinator mixture cover crop and in the control, where in the second year a good cover with grasses, clovers and some weeds developed. The results are illustrated in the graph below. Due to the interestingly growing earthworm population at this site, which would be expected after a new apple orchard is set up and the soil had some time to recover after the heavy management, we were able to take another closer look in spring 2018 and conducted a final, more detailed earthworm assessment to conclude the trial in this site. The outcomes of this final sampling are integrated in Figure 33.

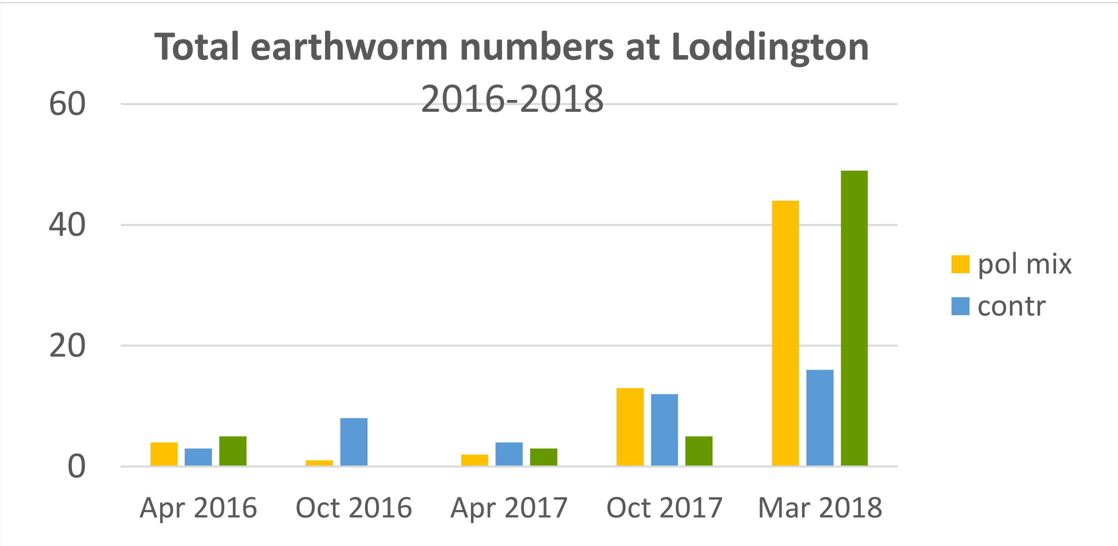


Figure 33: Earthworm counts at Loddington 2016-2018 (pollinator mixture, control and soil improver mixture)

When assessing the species found in the final sampling of spring 2018 some interesting points were found, but they need to be interpreted with caution because no independent replicates were taken. *Lumbricus castaneus* is an epigeic species (surface dweller in the organic litter layer) was not found in the control samples. *Aporrectodea longa* is an anecic species (permanent vertical burrower) was not found in the orchard alleys with soil improver mixture as cover crop. And endogeic species (who live in the top 10cm of soil) *Aporrectodea caliginosa* and *Allolobophora chlorotica* were found in higher numbers in the alleys with soil improver mixture cover crops. Figure 34 shows the total numbers of earthworms found in spring 2018 and the species identified per treatment (note: only adult earthworms can be identified at species level due to specific identification marks on their saddles).

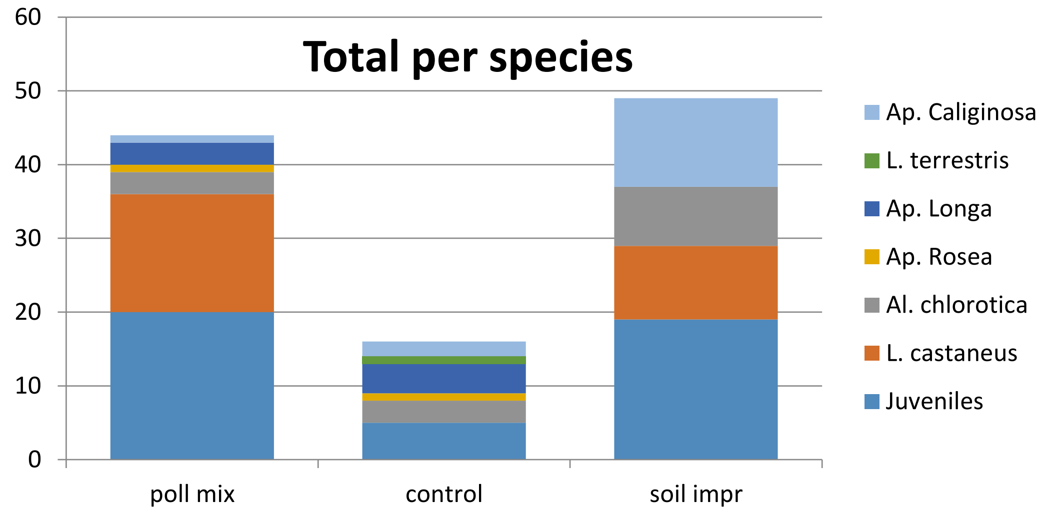


Figure 34: Total earthworms per species at Loddington in spring 2018. (pollinator mixture, control and soil improver mixture)

<u>Site 6 – Tolhurst Organics – potatoes/brassica</u>

In 2016, earthworms were counted on this site on 16 May and 6 October. In May, 9 worms were found in total, all juvenile and rather small. Samples were taken at 5 random locations in each bed. However, at the sampling date in autumn, 191 worms were found; again taken from 5 locations in each bed. The results are shown below for each bed (Figure 35), and were summarised for the early and late sown green manure (control). Also for this site, we were able to perform a species identification of the adult worms found in the field in autumn 2016. The four species that were identified are common and expected to be present in such more extensive field vegetable systems. It is notable that the total number of worms found in early sown green manure was larger in each bed compared to the later sown green manure beds.

In 2017, earthworms were sampled on 2 May and 27 October. Again, a relatively high number of worms was found on this site, and the graphs below illustrate the findings across the different beds and treatments. A generally lower total number was found in spring 2017 and in autumn 2016, but a similar picture between the two treatments indicates that the earlier sown green manure provided a small ‘head start’ for the earthworm population in this field.

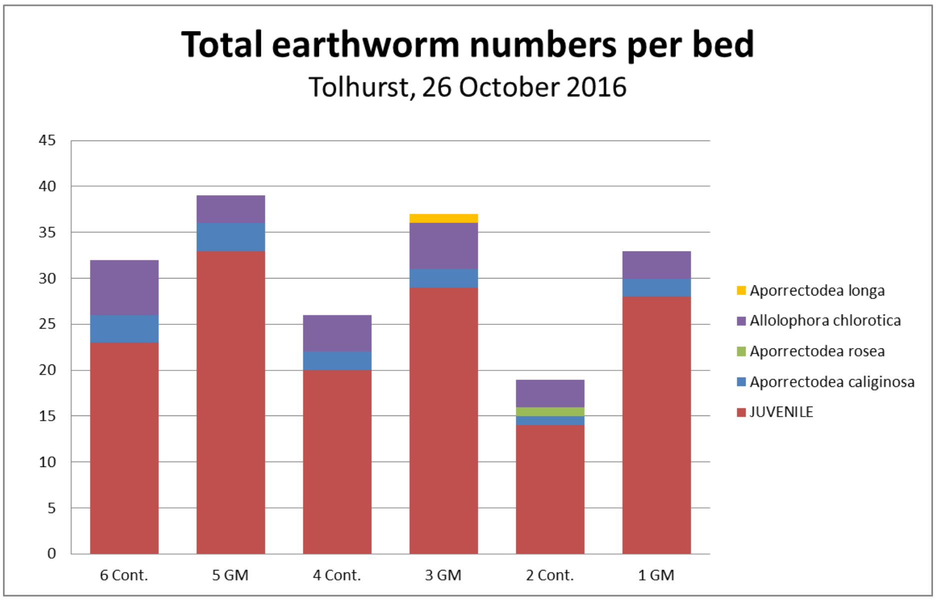


Figure 35: Earthworm counts and adult species per bed at Tolhurst Organics. (GM = early sown green manure, Cont. = late sown green manure).

Outcomes of Visual Soil Assessment

At some locations, it was not appropriate to perform a VSA test along with the worm counts, and NRM soil sampling because the soil had been “bed-formed” and all visible soil structure was absent (as is normal with beds formed for root crops and some other field vegetables). This was the case at sites 1, 3 and 4, where only one set of outcomes is shown in the results of 2016 below. This aspect was discussed in detail with the growers, especially with regards to usefulness and usability of the currently available VSA tools specifically for growers. The conclusions are detailed in the recommendations for the specific growing systems in the sections below.

Note that the Healthy Grassland Tool used for the VSA scores soils from 1-5, with 1 being ‘friable’ and 5 being compacted, so the lower the score the better.

Site 1 – Balbirnie Estates, Scotland – carrots

The visual assessment of soil structure (VESS) was used at this location in 2016 and 2017. Soil structure was poor in places within East Moss prior to the trial. There were some very firm aggregates and areas of compaction across the field. The structure of soil in the field margins was clearly much better (as is often the case), with no evidence of compaction and a well-developed structure with aggregates which were easily broken. The results of 2017 are shown in the table 9.

Table 9: Soil structure assessment East Moss Field 2016 and 2017

	VESS score		**Dickey John compaction probe reading** (lbs/square inch)	
Before trial (Sept' '16)				
Entire field	2.4		N/A	
Field margins	1.0		N/A	
During trial	**Spring 2017**	**Autumn 2017**	**Spring 2017**	**Autumn 2017**
No compost no straw	1.8	1.8	104	128
No compost + straw	2.2	1.8	120	102
Compost no straw	1.6	1.6	110	124
Compost + straw	1.6	1.5	112	98

[1]VESS scores based on Ball et al. (2012). A lower score means a better structure

Site 2 – Valefresco, Hampton Lucy – protected cropping

In the Field Trial of this site, first VSA assessments were conducted on 11 October 2016 when the entire field was green manure (rye and vetch). In 2017, we conducted the VSA test again on 15 March and 31 August; at all three sampling dates we chose a location close to the 8 points marked in the field map (see site descriptions above). The scores of the 8 sampling points (6 under cover crop during Winter 2016/2017 A-F; and 2 in the control strip G+H) are shown in Table 10. A positive trend can be seen over the 2 years, with scores improving steadily over the three sampling dates.

Table 10: VSA scores at Valefresco in 2016 and 2017

Location in field (see map above)	**VSA Score Autumn 2016**	**VSA Score Spring 2017**	**VSA Score Autumn 2017**
A	4	3	2
B	4	2.5	2
C	3	2.5	1.5
D	3.5	2	2
E	3	2.5	2
F	3.5	2.5	2
G	3	3.5	2.5
H	3.5	3	2.5

Site 3 – JEPCO, Spalding – field lettuce

At this site, the VSA method was used at 3 locations in each bed on 26 October 2016 (compare trial map above). The scores are shown in the table and summarised below.

On this scale of 1-5, the results of this site show that the green manure beds tended to score slightly better than the control beds. The average across the two different treatments were 1.9 in the control and 1.1 in Buckwheat. Although both scores are relatively good, the higher score in the Buckwheat beds might be due to additional organic matter added to the soil.

Site 4 – Taylorgrown, Houghton – organic carrots

The VSA method was attempted early post bed-forming in March 2016 but was deemed inappropriate due to the lack of structure and assessable indicators for this visual evaluation tool. The VSA was carried out at the second soil sampling in December 2016, after the field had been ploughed and drilled as a grass-clover ley during autumn. The sampling was done across the whole field. This method was not repeated in the second year of the experiment at this site, in 2017 the new field experiment was conducted comparing different clovers undersown in carrots and the results are shown in Table 11. Because of the intensive soil management and bed-forming activities for carrots, the grower decided that this method was not very useful as such. However, he stated that taking a spade sample at any point in time of the year gives him a good impression of the state of the soil, but the method and its recommendations does not relate very well to the system.

Table 11: VSA scores at Taylorgrown 2017

Plot	Sample	VSA Score Spring 2017	VSA Score Autumn 2017
Whole Field	1	n/a	2
Whole Field	2	n/a	2
Whole Field	3	n/a	2
Whole Field	4	n/a	1
Whole Field	4	n/a	2
Whole Field	5	n/a	2
Whole Field	6	n/a	2
Whole Field	7	n/a	1
Whole Field	8	n/a	1
Whole Field	9	n/a	2
Whole Field	10	n/a	2
Whole Field	11	n/a	2
Whole Field	12	n/a	2

Site 5 – Loddington, Maidstone – top fruit, apples

The VSA method was used at Loddington on 22 April and 25 October 2016, and on 11 April and 24 October 2017. The table below shows the scores measured at the different sampling dates. Samples were taken at 3 random locations in each assessed alley, see trial map above. The results from this site show a notable improvement of VSA scores under both green manure mixtures. During the main growing season from April to October 2016, the green manure visibly and rapidly improved soil structure and drainage. Also, the grower fed back the striking difference in look and structure of the soil under the alleys with green manure; and in this case, the 'draining' effect of the green manure extracting more moisture from the soil compared to the control alley was a very welcome side-effect. The green manure was left standing during 2017, only cut once in late in spring, to benefit and support overwintering insects and natural predators (e.g. hover flies etc.). The results show a slight trend of improving VSA results (the lower the score the better) over the 2 years of the trial (Figure 36). Indicating that the soils recover after the intensive management of planting the new orchard, and the control strip is able to 'catch up' with the green manure alleys, levelling out scores in the final measurement.

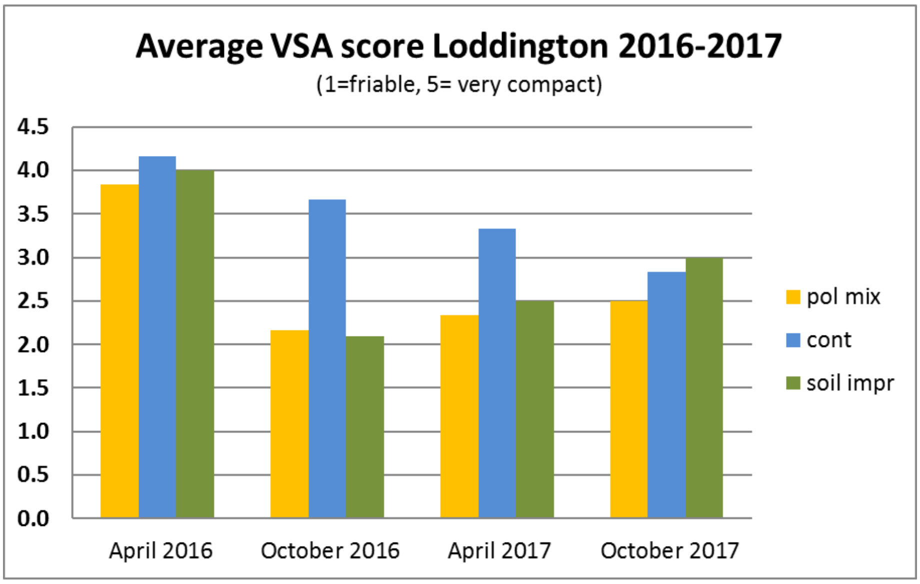


Figure 36: VSA scores at Loddington in April and October 2016 and 2017 (the lower the number the better!)

Site 6 – Tolhurst Organics – potatoes/brassica

Also at this site, the VSA was conducted twice in 2016, on 19 July and 6 October. The results are shown below. Samples were taken at 3 random locations in each of the 6 beds. The average score of early sown green manure was 1.2 in April 2016 and 1.1 in October 2016; and it was 1.3 and 1.6 respectively for the later sown green manure strips. Results showed that the early sown green manure could slightly improve VSA scores between July and October 2016. The results imply that soil structure tended to benefit from early green manure application, whereas the structure of beds with late sown green manure decreased slightly; which may be due to an additional soil management step in these beds for weed management between the two sowing dates. Also in this system, the grower decided that this method should not be repeated in the second year of the experiment. The main reason for him was the subjective interpretation of such methods: the test should be used by the same person each time, to be able to compare the results over time, as the interpretation of the outcome can vary quite significantly from person to person. On his holding he stated, it cannot be guaranteed that it will always be the same person assessing the soil. However, he also clearly found that he uses the spade a lot to dig a hole and assess the upper layers of his soils, and it is one of his most important tool to base soil management on; but it is not a method that is very easily transferred to another person.

Outcomes of NRM Soil Health Test

As of spring 2017, the laboratory we used for these Field Trials in England, NRM, had to slightly adapt the approach of their Soil Health Test and its scales. This meant, that the overall Soil Health Index that the test produced based on the different results a sample showed, now had a range from 1-6, instead of 1-5 in the years before. This was mainly due to very high outcomes of the CO_2 burst test for many soils types (as our own results show, several soil samples produced ‘off the scale’ results during 2016). This meant that we focussed on the actual results of the CO_2-burst test when comparing different years and samples with each other, rather than the overall Soil Health Index outcome.

<u>Site 1 – Balbirnie Estates, Scotland – carrots</u>

Soil Health indicators are given in Table 12 for the site at Balbirnie Estates. On 6 April 2016, each of the three fields was sampled across its entire area by walking in a “W” pattern and taking 32 sub-samples using a spiral augur to 20 cm depth. Sub-samples were mixed in a clean bucket and 500 g samples were sent to NRM laboratories for analysis. The laboratories applied methods commonly used for Scottish soils (e.g. microbial respiration, as measured by the Haney Brinton CO_2 burst test, as opposed to SOLVITA-based assessments for the rest of the trials).

Table 12: NRM Soil Health Test results from Balbirnie Estate 2016

Location: Balbirnie Estate	**Spring-16**		
Sample Ref.	**East field**	**East moss**	**New Inn**
Soil Chemical Analysis			
P (mg/l)	4.8	5.7	9.6
K (mg/l)	185.0	161.0	194.0
Mg (mg/l)	78.0	60.0	96.0
Organic Matter (LOI) (%)	4.3	4.1	4.1
Soil pH	5.6	5.5	6.5
Microbial Activity			
CO2 Burst (mg/kg)	20.0	148.0	19.0

<u>Site 2 – Valefresco, Hampton Lucy – protected cropping</u>

Table 13 below shows the outcomes of all NRM Soil Health Tests conducted at Valefresco in 2016 and 2017. It lists the results of the initial sample date in the protected cropping site before spinach sowing on 28 April 2016, and the results of the later sampling dates after the green manure was incorporated in October 2016 (Tables 13 & 14). The experiment was repeated twice in 2017 in a rocket crop. Also the field experiment was sampled for the NRM soil health test, at 3 dates in 2016 and 2017. The outcomes are shown in the table below. Please compare with trial designs and maps above. Samples were taken with a soil corer at 10 random locations in each bed, respectively around each sampling point in the field.

Table 13: NRM Soil Health Test results from protected crops at Valefresco 2016-2017

Soil Health Report										
	Apr-16	Oct-16			Mar-17			Aug-17		
Location: Valefresco	protected									
Sample Ref.	initial sample	control	phacelia	buckwheat	control	phacelia	buckwheat	control	phacelia	buckwheat
Soil Chemical Analysis										
P (mg/l)	47.6	50.2	62.2	62.0	59.8	73.4	67.2	50.8	54.8	51.6
K (mg/l)	134.0	103.0	99.1	137.0	168.0	144.0	168.0	107.0	130.0	127.0
Mg (mg/l)	104.0	96.7	108.0	103.0	82.4	85.1	95.8	92.8	64.8	76.1
Organic Matter (LOI) (%)	2.5	2.5	2.3	2.2	2.1	2.3	2.2	2.3	2.2	2.4
Soil pH	6.5	6.8	6.8	7.0	7.1	7.0	7.0	7.3	7.1	7.0
Microbal Activity										
CO_2 Burst (mg/kg)	36.0	44.0	40.0	44.0	72.0	72.0	72.0	48.0	69.0	69.0
Pot. N Mineralisation (kg/ha/yr)	45-75	45-75	45-75	45-75	75-105	75-105	75-105	45-75	45-75	45-75
Textural Classification										
Sand (%)	74	76	77	76	77	77	76	77	75	78
Silt (%)	13	12	11	12	11	11	12	12	13	10
Clay (%)	13	12	12	12	12	12	12	11	12	12
Soil Textural Class	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam
Major Soil Classification	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Soil Health Index	3.0	3.0	2.8	2.9	3.5	3.4	3.5	2.9	3.4	3.4

Table 14: NRM Soil Health Test results from field crops at Valefresco 2016-2017

Soil Health Report					
	Oct-16	Mar-17		Aug-17	
Location: Valefresco	field				
Sample Ref.	rye-vetch	rye-vetch	control	rye-vetch	control
Soil Chemical Analysis					
P (mg/l)	60.4	58.0	51.8	48.2	53.8
K (mg/l)	230.0	158.0	193.0	197.0	219.0
Mg (mg/l)	124.0	78.8	82.3	85.8	86.5
Organic Matter (LOI) (%)	2.8	2.4	2.2	2.4	2.5
Soil pH	6.6	7.1	6.9	6.7	6.5
Microbal Activity					
CO_2 Burst (mg/kg)	99.0	94.0	86.0	75.0	94.0
Pot. N Mineralisation (kg/ha/yr)	75-105	75-105	75-105	75-105	75-105
Textural Classification					
Sand (%)	70	71	68	63	64
Silt (%)	15	15	16	19	19
Clay (%)	15	14	16	18	17
Soil Textural Class	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam
Major Soil Classification	Medium	Medium	Medium	Medium	Medium
Soil Health Index	4.1	3.8	3.8	3.6	4.1

Site 3 – JEPCO, Spalding – field lettuce

Table15 shows the outcomes of all NRM Soil Health Tests conducted at JEPCO in 2016. Samples were taken with a soil corer at 10 random locations in each bed and then mixed for a sample in each treatment. Samples were taken in July and October, before and after the rye green manure.

Table 15: NRM Soil Health Test results from JEPCO 2016 and 2017

Location: JEPCO	Spring 2016		Autumn 2016		Spring 2017		Autumn 2017	
Sample Ref.	Control	Green manure	Contr	GrMa	Contr	GrMa	Contr	GrMa
Soil Chemical Analysis								
P (mg/l)	15.2	14.6	13.8	13.8	28.8	27.2	22.4	21.6

K (mg/l)	101.0	121.0	164.0	183.0	103	113	146	99.9
Mg (mg/l)	53.1	64.3	61.5	67.4	123	121	246	276
Organic Matter (LOI) (%)	2.8	2.8	2.7	2.6	2.7	2.8	2.7	3.0
Soil pH	8.0	8.1	8.2	8.1	8.1	8.0	8.1	7.9
Microbial Activity								
CO2 Burst (mg/kg)	33.0	32.0	57.0	60.0	72	75	57	55
Pot. N Mineralisation (kg/ha/yr)	45-75	45-75	45-75	45-75	75-105	75-105	45-75	45-75
Textural Classification								
Sand (%)	34	33	37	38	34	35	28	28
Silt (%)	50	51	50	49	52	52	56	56
Clay (%)	16	16	13	13	14	13	16	16
Soil Textural Class	Sandy Silt Loam	Sandy Silt Loam	Sandy Silt Loam	Sandy Silt Loam	Sandy Silt Loam	Sandy Silt Loam	Sandy Silt Loam	Sandy Silt Loam
Major Soil Classification	Medium	Medium	Med	Med	Med	Med	Med	Med
Slope	0˚	0˚						
Soil Health Index	2.3	2.4	3	3.1	3.8	3.8	3.3	3.1

Site 4 – Taylorgrown, Houghton – organic carrots

The soil health test was performed on 31 March 2016, when the beds were formed, but the carrots and green manure were not sown yet; and on 15 December 2016, when the field was ploughed and re-sown with over wintering cover crops. Samples were taken from 10 locations in each bed/field, and then mixed for one sample per treatment.

The initial idea on this site was to leave the flowering green manure beds standing over winter and serve as beetle bank for the next crop in 2017. However, the host needed to change this plan and was unfortunately not able to inform us in time to sample the beds again before ploughing. The results given in Table 16 show the outcomes of the two sampling dates, the baseline measurements in the formed beds in spring and the post sampling in December.

Table 16: NRM Soil Health Test results from Taylorgrown 2016

Location: Taylorgrown	**Spring 2016**		**Autumn 2016**
Sample Ref.	carrot beds	green man beds	whole field
Soil Chemical Analysis			
P (mg/l)	47.8	56.6	50.0
K (mg/l)	172.0	182.0	114.0
Mg (mg/l)	42.1	40.5	41.3
Organic Matter (LOI) (%)	2.5	2.4	6.6
Soil pH	7.3	7.4	7.3
Microbial Activity			
CO2 Burst (mg/kg)	20.0	23.0	86.0
Pot. N Mineralisation (kg/ha/yr)	25-45	25-45	75-105
Textural Classification			
Sand (%)	81.0	81.0	83.0

Silt (%)	12.0	12.0	11.0
Clay (%)	7.0	7.0	6.0
Soil Textural Class	Loamy Sand	Loamy Sand	Loamy Sand
Major Soil Classification	Light	Light	Light
Slope	0˚	0˚	0˚
Soil Health Index	4.4	4.2	4.0

In 2017, the host grower decided to set up a new small experiment, rather than replicating the same study for a second year in another field (following the carrot rotation). Instead he was interested in undersowing carrots with a number of different clover varieties (Yellow Trefoil, Berseem Clover, White Clover and Alsike Clover). The clover was sown by hand between carrot rows, 2 weeks after the carrots were drilled on beds in May 2017. The results (Figures 37 to 39) are only an indication of potential effects of undersowing legumes in carrots. Further trials would need to take place with replication of plots (randomised block design) over at least 2 seasons to be able to draw stronger conclusions and obtain a greater certainty of observed effects before basing any management decisions or changes to cropping systems on the data.

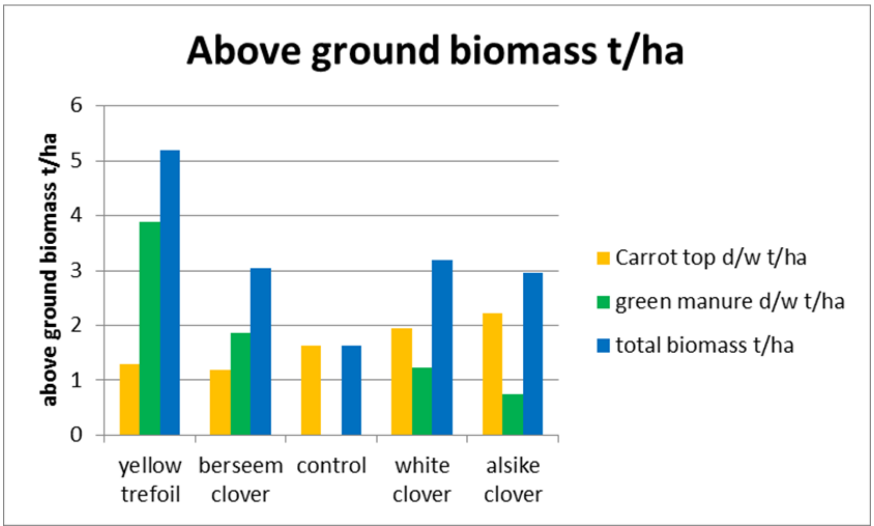


Figure 37: Results show increased total above ground biomass being added back to the soil after carrot harvest from under sowing treatments. Trend for increasing green manure biomass to reduce carrot top biomass. Also appears to be trend for carrot top biomass to increase with distance from headland.

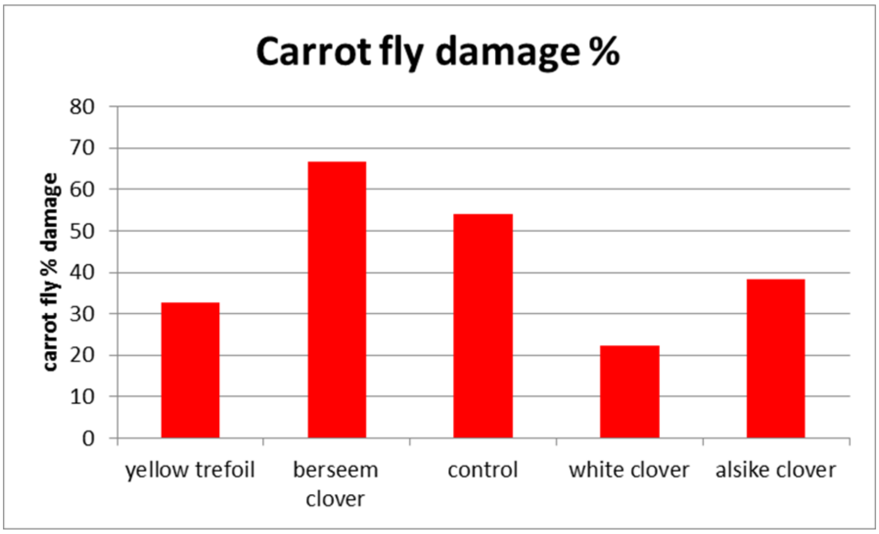


Figure 38: Results show carrot fly damage highest in control plot and berseem clover plot and therefore there may be potential for yellow trefoil, white clover and alsike clover to reduce carrot fly damage.

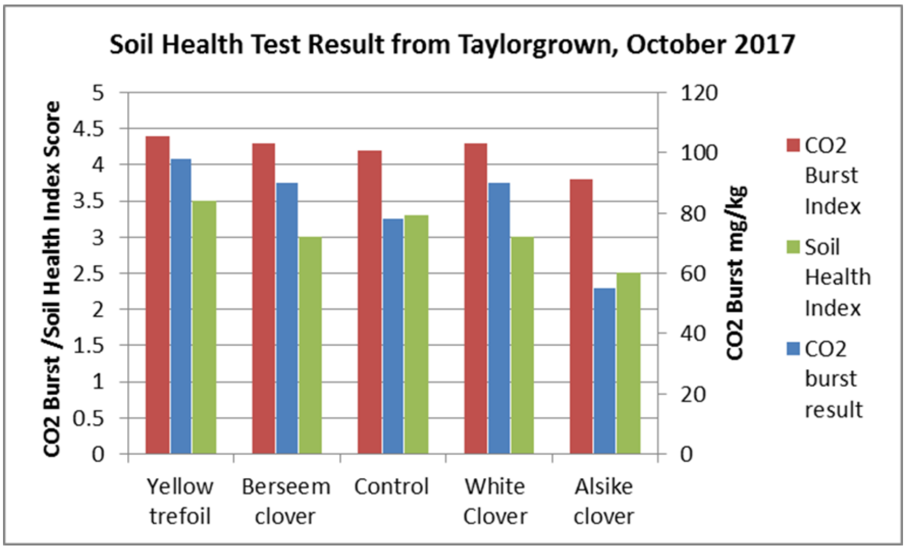


Figure 39: Soil Health test results from October 2017 at Taylorgrown. Yellow trefoil gave the highest CO_2 burst result and had the lowest negative adjustment for the health index. P index 2 for yellow trefoil and control. K availability lowest in Control plot.

<u>Site 5 – Loddington, Maidstone – top fruit, apples</u>

Also at this trial site, we have conducted an NRM Soil Health Test on 22 April and 25 October 2016, just before the planting of the trees, and after general harvest time (although the young trees did not produce a harvest yet). The samples were taken and mixed from 10 random locations in each treatment/alley. The sampling for this test was repeated again in spring and autumn 2017. The results are shown in Table 17 and Figure 40.

Table 17: NRM Soil Health Test results from Loddington 2016 and 2017

NRM Soil Health Test Report	Apr-16			Oct-16			Apr-17			Oct-17		
Location: Loddington	apple orchard											
Sample Ref.	Pol mix	control	soil imp mix	Pol mix	control	soil imp mix	Pol mix	control	soil imp mix	Pol mix	control	soil imp mix
Soil Chemical Analysis												
P (mg/l)	44.0	60.0	45.8	79.4	78.8	60.0	54.2	56.0	54.8	53.4	65.6	64.8
K (mg/l)	197.0	224.0	227.0	296.0	279.0	223.0	255.0	204.0	169.0	250.0	219.0	194.0
Mg (mg/l)	94.8	92.1	94.9	103.0	98.3	109.0	105.0	102.0	109.0	97.6	85.0	97.4
Organic Matter (LOI) (%)	6.0	5.4	5.3	6.4	5.2	5.3	6.5	5.4	5.3	6.2	5.4	5.8
Soil pH	7.6	7.6	7.4	7.2	7.7	7.6	7.3	7.6	7.5	7.6	7.8	7.4
Microbal Activity												
CO2 Burst (mg/kg)	> 162	> 162	> 162	> 162	148.0	> 162	222.0	186.0	204.0	231.0	155.0	213.0
Pot. N Mineralisation (kg/ha/yr)	75-105	75-105	75-105	75-105	75-105	75-105	105-123	105-123	105-123	105-123	75-105	105-123
Textural Classification												
Sand (%)	44.0	34.0	37.0	33.0	29.0	28.0	24.0	29.0	30.0	31.0	29.0	29.0
Silt (%)	32.0	37.0	35.0	38.0	40.0	41.0	41.0	39.0	39.0	41.0	42.0	43.0
Clay (%)	24.0	29.0	28.0	29.0	31.0	31.0	35.0	32.0	31.0	28.0	29.0	28.0
Soil Textural Class	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam
Major Soil Classification	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Slope	0˚	0˚	0˚	0˚	0˚	0˚	0˚	0˚	0˚	0˚	0˚	0˚
Soil Health Index	5.0	4.9	5.0	5.0	4.7	5.0	5.8	5.2	5.3	5.4	4.8	5.5

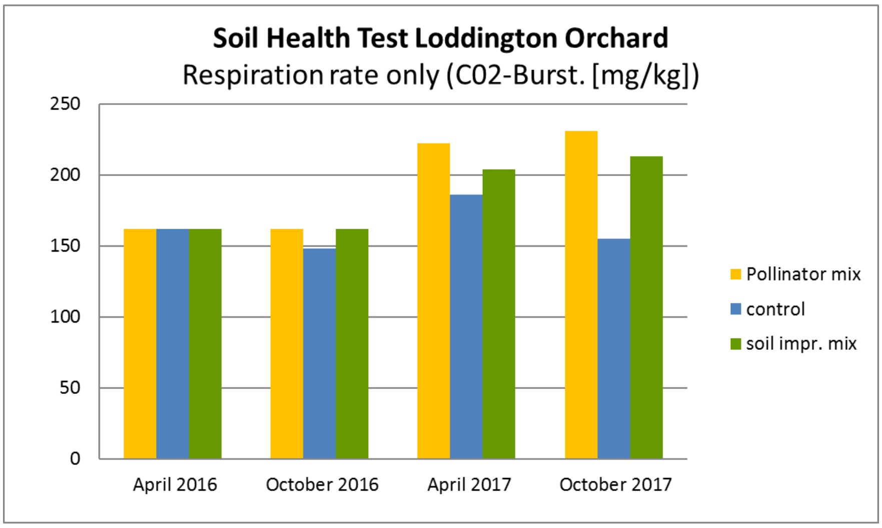


Figure 40: NRM Soil Health Test respiration rates results from Loddington 2016 and 2017

<u>Site 6 – Tolhurst Organics – potatoes/brassica</u>

On this site, we have sampled for the NRM Soil Health Test on 19 July and 6 October 2016, as well as on 2 May 2017 and 27 October 2017. Samples were taken from 10 locations in each bed, and then mixed for one sample per treatment. NRM test results are given in Table 18.

Table 18: NRM Soil Health Test results from Tolhurst Organics 2016 and 2017

NRM Soil Health Test Report								
NRM Results								
	Jun-16		Oct-16		May-17		Oct-17	
Location: Tolhurst Organics	field veg							
Sample Ref.	late sown	early sown	late sown	early sown	late sown	early sown	late sown	early sown
Soil Chemical Analysis								
P (mg/l)	32.0	35.6	25.2	25.4	27.8	26.8	37.2	32.0
K (mg/l)	149.0	115.0	93.5	72.9	93.1	99.5	99.8	92.1
Mg (mg/l)	82.7	73.7	80.8	75.9	65.9	60.3	63.0	57.2
Organic Matter (LOI) (%)	6.1	6.2	5.7	5.8	6.4	6.2	6.2	6.1
Soil pH	6.6	7.2	6.8	7.0	7.2	7.1	7.1	7.1
Microbal Activity								
CO2 Burst (mg/kg)	162	134	162	155	241	195	204	213
Pot. N Mineralisation (kg/ha/yr)	75-105	75-105	75-105	75-105	105-123	105-123	105-123	105-123
Textural Classification								
Sand (%)	56	52	48	53	45	51	49	50
Silt (%)	32	35	33	30	37	33	35	34
Clay (%)	12	13	19	17	18	16	16	16
Soil Textural Class	Sandy Loam	Sandy Loam	Clay Loam	Sandy Loam	Sandy Silt Loar	Sandy Loam	Sandy Silt Loar	Sandy Loam
Major Soil Classification	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Slope	0˚	0˚	0˚	0˚	0˚	0˚	0˚	0˚
Soil Health Index	5	4.9	5	4.9	5.7	5.4	5.6	5.6

Outcomes of simple infiltration rates test

In the following we show the results of the simple infiltration rates measurements on the various trial sites that have decided to use this test in 2017. This test was added to the list for the 2017 season, and some growers were very keen on trying this easy to use method in their fields. We used the test generally three times per plot/bed or treatment, but it became clear that this number of samples was not enough to gain a good overview of results, so the recommendation for this method going forward is to sample for example at five locations per sampling point or replication. Results for the different sites are given in Tables 19 to 23.

<u>Site 2 – Valefresco, Hampton Lucy – protected cropping</u>

Table 19: Simple infiltration rates test at Valefresco 2017

Sampling date	**Mar-17**	**August 2017**
Field		
Location	minutes	minutes
A	>10.00	3.26
B	>10.00	>10.00
C	>10.00	>10.00
D	4.53	2.15
E	>10.00	>10.00
F	>10.00	>10.00
G	3.04	>10.00
H	7.23	>10.00
Protected		
Location	minutes	minutes
phacelia	1.10	2.39
phacelia	3.26	1.48
phacelia	1.29	2.16
Buck wheat	2.28	3.40
Buck wheat	1.56	3.11
Buck wheat	2.35	3.47
control	2.02	3.33
control	1.49	3.58
control	1.37	6.14

<u>Site 3 – JEPCO, Spalding – field lettuce</u>

Table 20: Simple infiltration rates test at Jepco 2017

Treatment	**minutes**	**minutes**
	May 2017	September 2017
Cover Crop	3.13	1.47
Cover Crop	>10.00	1.55
Cover Crop	>10.00	1.87
Cover Crop	8.43	2.08
Cover Crop	1.12	1.35
Control	0.33	1.27
Control	>10.00	1.93
Control	5.33	1.55
Control	2.12	0.95
Control	3.17	1.40

Site 4 – Taylorgrown, Houghton – organic carrots

Table 21: Simple infiltration rates test at Taylorgrown September 2017

Treatment	minutes
Control	1.63
Control	2.32
Control	3.67
Yellow Trefoil	2.28
Yellow Trefoil	1.87
Yellow Trefoil	1.65
Berseem Clover	1.30
Berseem Clover	1.70
Berseem Clover	1.85
White Clover	3.63
White Clover	2.82
White Clover	2.55
Alsike Clover	2.13
Alsike Clover	3.42
Alsike Clover	2.23

Site 5 – Loddington, Maidstone – top fruit, apples

Table 22: Simple infiltration rates test at Loddington 2017

Sampling date	**April 2017**	**October 2017**
Alley/plot	minutes	minutes
1A pollinator mix	0.58	4.4
1B pollinator mix	1.54	2.4
1C pollinator mix	0.37	4.5
2A control	1.49	10.0
2B control	8.58	10.0
2C control	7.38	10.0
3A soil improver mix	0.46	1.4
3B soil improver mix	0.17	0.2
3C soil improver mix	0.58	>10.00

Site 6 – Tolhurst Organics – potatoes/brassica

Table 23: Simple infiltration rates test at Tolhurst Organics 2017

Sampling date	**May-17**	**October 2017**
Bed/plot	minutes	minutes
1A	4.48	3.33
1B	1.26	6.02
1C	1.34	1.24
2A	2.24	1.36
2B	>10.00	0.59
2C	>10.00	3.15
3A	5.10	>10.00
3B	6.03	0.47
3C	6.19	>10.00
4A	2.40	0.36
4B	6.24	0.39
4C	9.01	0.20
5A	5.04	1.31
5B	2.20	7.46
5C	8.54	2.31
6A	3.23	1.39
6B	>10.00	8.51
6C	4.52	0.49

Outcomes of simple compaction test

This test is one of the most subjective method that we compared in the Field Trials. The level of resistance felt when pushing a blunt knife or soil corer into the ground is a very personal experience and cannot be 'measured' as such. Nevertheless, growers could 'calibrate themselves' by practising the method and testing it in different fields and soils etc. The test was tried by a number of growers in our experiments as it can be a very fast, cheap and easy to use method to locate areas of compaction in a field; and with some experience, even the depth of the compacted layer can be estimated. So if a grower is confident enough and a bit experienced with this method, it may be a very useful approach for soil compaction assessment. Due to the nature of this tool, the results were not captured in numbers, but during discussions and its practical use by the growers, and their answers are reflected in the grower feedback.

Grower feedback on different soil assessment tools

During the two soil sampling dates in 2017 (spring and autumn) each of the host growers used the different soil assessment tools themselves in the field and gave feedback in form of a ranking table and questionnaire for each tool that they tested. They assessed each tool by a) costs to buy the tool/test; b) time input required; c) required knowledge to use the tool; d) required knowledge to interpret the results; e) impact of results on soil management; and f) would they use the tool in the future. The outcomes of these discussions with the growers in the field and their scoring sheets are shown in Table 24.

Tables 24: Grower feedback (ranking tools from 1 to 5, whereas 1 is low and 5 is high)

Valefresco in March 2017

Soil assessment method	Costs to buy the tool or test	Time input required	Required knowledge to apply tool	Required knowledge to interpret results	Impact of results on soil management	Would you use it in the future? y/n
Earthworm counts (OPAL survey guide)	1	3	2	1	n/a	y
Visual Soil Assessment (VSA – Healthy Grassland Tool)	1	3	2	2	1	y
NRM Soil Health Tests (Lab analysis incl respiration rates)	3	3	2	2	2	y
Infiltration rates (simple drain pipe test)	1	4	2	2		y
Compaction (simple knife test)	1	1	1	2	5	y

Valefresco in August 2017

Soil assessment method	Costs to buy the tool or test	Time input required	Required knowledge to apply tool	Required knowledge to interpret results	Impact of results on soil management	Would you use it in the future? y/n
Earthworm counts (OPAL survey guide)	1	1	1	2	3	y
Visual Soil Assessment (VSA – Healthy Grassland Tool)	1	1	2	3	4	y
NRM Soil Health Tests (Lab analysis incl respiration rates)	5	4	3	3	3	?
Infiltration rates (simple drain pipe test)	1	4	1	1	3	y
Compaction (simple knife test)	1	1	1	1	3	y

Jepco May 2017						
Soil assessment method	**Costs to buy the tool or test**	**Time input required**	**Required knowledge to apply tool**	**Required knowledge to interpret results**	**Impact of results on soil management**	**Would you use it in the future? y/n**
Earthworm counts (OPAL survey guide)	1	4.5	2	3	1	y
Visual Soil Assessment (VSA – Healthy Grassland Tool)	1	2	2	3	4	y
NRM Soil Health Tests (Lab analysis incl respiration rates)	3	3	1	3	4	y
Infiltration rates (simple drain pipe test)	1	3	2	2	4	y

Jepco September 2017						
Soil assessment method	**Costs to buy the tool or test**	**Time input required**	**Required knowledge to apply tool**	**Required knowledge to interpret results**	**Impact of results on soil management**	**Would you use it in the future? y/n**
Earthworm counts (OPAL survey guide)	1	3	2	3	2	y
Visual Soil Assessment (VSA – Healthy Grassland Tool)	1	3	2	3	4	y
NRM Soil Health Tests (Lab analysis incl respiration rates)	2	2	3	4	3	y
Infiltration rates (simple drain pipe test)	1	2	3	2	4	y

Taylorgrown May 2017						
Soil assessment method	**Costs to buy the tool or test**	**Time input required**	**Required knowledge to apply tool**	**Required knowledge to interpret results**	**Impact of results on soil management**	**Would you use it in the future? y/n**
Earthworm counts (OPAL survey guide)	1	5	1.5	5	3	y
Visual Soil Assessment (VSA – Healthy Grassland Tool)	1	5	1.5	5	3.5	y
NRM Soil Health Tests (Lab analysis incl respiration rates)	4.5	5	2	5	2	y
Infiltration rates (simple drain pipe test)	1	5	1	3.5	4	y

Taylorgrown September 2017						
Soil assessment method	**Costs to buy the tool or test**	**Time input required**	**Required knowledge to apply tool**	**Required knowledge to interpret results**	**Impact of results on soil management**	**Would you use it in the future? y/n**
Earthworm counts (OPAL survey guide)	1	4	5	5	1	maybe
Visual Soil Assessment (VSA – Healthy Grassland Tool)	1	4	1	1	0	n
NRM Soil Health Tests (Lab analysis incl respiration rates)	1	3	1	5	1	?
Infiltration rates (simple drain pipe test)	1	4	1	5	5	y

Loddington April 2017

Soil assessment method	Costs to buy the tool or test	Time input required	Required knowledge to apply tool	Required knowledge to interpret results	Impact of results on soil management	Would you use it in the future? y/n
Earthworm counts (OPAL survey guide)	1	4	4	5	2	y
Visual Soil Assessment (VSA – Healthy Grassland Tool)	1	3	1	2	4	y
NRM Soil Health Tests (Lab analysis incl respiration rates)	3	2	1	3	4	y
Infiltration rates (simple drain pipe test)	1	3	1	2	4	y

Loddington October 2017

Soil assessment method	Costs to buy the tool or test	Time input required	Required knowledge to apply tool	Required knowledge to interpret results	Impact of results on soil management	Would you use it in the future? y/n
Earthworm counts (OPAL survey guide)	1	4	3	2	3	y
Visual Soil Assessment (VSA – Healthy Grassland Tool)	1	3	2	2	3	y
NRM Soil Health Tests (Lab analysis incl respiration rates)	4	2	2	4	4	?
Infiltration rates (simple drain pipe test)	1	4	1	2	3	y

Tolhurst Organics April 2017

Soil assessment method	Costs to buy the tool or test	Time input required	Required knowledge to apply tool	Required knowledge to interpret results	Impact of results on soil management	Would you use it in the future? y/n
Earthworm counts (OPAL survey guide)	1	4	3	4	4	maybe
Compaction (simple knife test)	1	2	2	3	4	intuitive, subjective
NRM Soil Health Tests (Lab analysis incl. soil respiration rates)	3	2	2	4	4	y
Infiltration rates (simple drain pipe test)	1	2	2	2	4	y

Tolhurst Organics October 2017

Soil assessment method	Costs to buy the tool or test	Time input required	Required knowledge to apply tool	Required knowledge to interpret results	Impact of results on soil management	Would you use it in the future? y/n
Earthworm counts (OPAL survey guide)	1	4	2	3	4	y
Compaction (simple knife test)	1	1	1	3	4	y
NRM Soil Health Tests (Lab analysis incl. soil respiration rates)	5	2	2	4	4	y/n
Infiltration rates (simple drain pipe test)	1	2	2	2	4	y

Results of grower feedback and evaluation of different soil assessment methods

Figures 41-44: Grower workshops for protected, top-fruit and field vegetables systems 2017

Grower recommendations for specific horticultural growing systems

During the two soil sampling dates in 2017 (spring and autumn) each of the host growers used the different soil assessment tools themselves in the field and gave feedback in form of a ranking table and questionnaire for each tool that they tested. They assessed each tool by a) costs to buy the tool/test; b) time input required; c) required knowledge to use the tool; d) required knowledge to interpret the results; e) impact of results on soil management; and f) would they use the tool in the future. The outcomes of these discussions with the growers in the field and their scoring sheets, in combination with the outcomes of three system-specific grower workshops during autumn 2017 (Figures 41 to 50), led to the formulation of grower recommendations for soil health assessment in protected crops, top fruit systems and field vegetable systems. Results are document in the GREATsoils soil assessment methods factsheet which is available on the AHDB website.

Figures 45-50: Growers testing soil assessment tools in their field experiments

An alternative representation of the ratings (1-5) of the methods by the growers is shown in Figure 51.

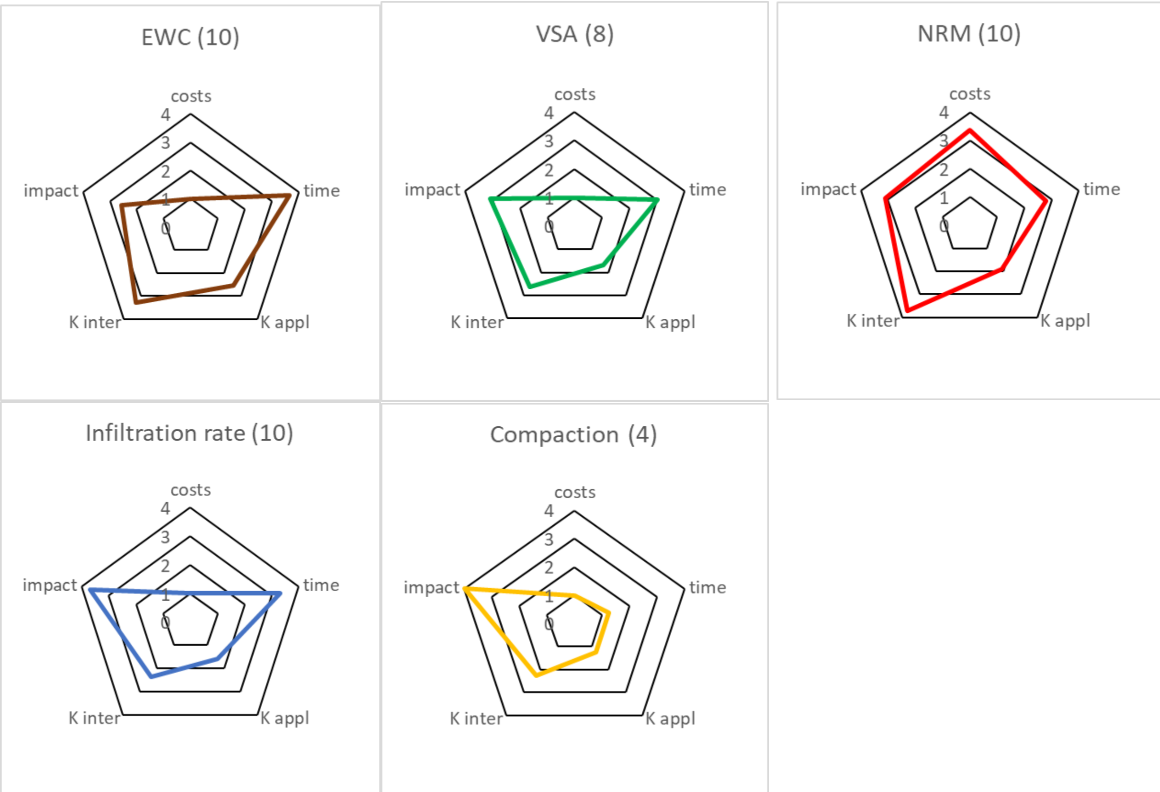


Figure 51: Answers of growers rating the soil assessment tools earthworm counts (EWC), visual soil assessment (VSA), NRM soil health test (NRM), infiltration rates and simple compaction test. The number in brackets indicates the number of responses received from the growers.

Table 25 shows a summary of the feedback received from growers throughout the project.

Table 25: Participating growers in the field trials and grower events in different horticultural systems rated the following methods and most useful

Method	Field vegetables	Top fruit systems	Protected crops
Visual Soil Assessment (VSA)	😕	🙂	☹
Earthworm Counts	🙂	😕	☹
Soil Health Laboratory Test	😕	😕	🙂
Simple Infiltration rates	🙂	🙂	🙂
Simple Compaction Test	🙂	🙂	🙂

Visual Soil Assessment (VSA) – The growers saw this tool as highly useful for more extensive horticultural systems such as top fruit systems or less intensive field vegetable systems. They stated that if the test is used regularly and on several locations in the field, it gives great insights of the general soil health in an orchard or a field. They highlighted that it assesses soil structure, but also root development (pattern and vigor), as well as soil smell and colour; and provides the opportunity to count earthworms in the spade sample that was taken already; all providing a practical and quick way of getting an impression of the health of the soil as well as the cash crop. However, many growers in the field vegetable and protected cropping sectors were more sceptical about its usefulness in intensive horticulture systems. Especially when growing on beds (e.g. carrots or lettuce) or in highly intensive rotations for protected crops, where the soil is worked very regularly and heavily, soil structure assessment in the top 30cm is not possible or useful during most of the year. In such situations, timing of the assessment is very important: e.g. in early spring, just before the field is ploughed and prepared for planting/sowing, when an assessment of structure is possible e.g. before or after a cover crop/green manure.

Earthworm counts – Earthworms are one of the more common and easily assessable groups of soil organisms, and are widely accepted as an indicator for soil fertility, health and organic matter. Many growers were very interested in earthworm counts, but none had any real previous experience with this tool. After trying it out, the participating field vegetable growers stated that the method can be very useful if a good base population of worms is already present in a field, and if a certain assessment routine can be adopted for long-term monitoring; but they also highlighted that expertise needs to be built up over time, and the relatively substantial time investment needs to be taken into account. As for many soil assessment methods, earthworm counts are most useful when repeated regularly, maybe twice a year over a couple of years, to get used to the method and get a feel for the 'normal' number of worms and natural fluctuations of populations in the specific field or soil. Finding 10 worms in a spade sample can be a lot in some soils, whereas in others it might be a very low result. As with all the methods used, several measurements should be make in a single field to obtain a representative result

Simple infiltration rates – We found that for most soils this is a very quick, easy and efficient method, and growers were excited about this simple test and keen to try it out themselves. This test was seen as a very useful tool for soil structure and compaction assessment by the growers. It is easy to use and generates self-explanatory results that are easy to translate into soil management actions and strategies. However, the method requires measuring the time it takes for 100ml of water to infiltrate into soil, and depending on the soil type, structure or moisture content, this can take a rather long time. So, while this tool was seen as highly useful and informative in lighter soils, and for example for a closer assessment of areas where compaction was previously suspected; in heavier soils, it may take over 10 minutes per sample, which tends to stretch grower's patience and therefore hampers the practical use of this tool under such conditions.

Simple compaction test – This simple test also gained very positive feedback from the growers, it was seen as useful tool for soil structure and compaction assessment, although it is one of the most subjective methods that was compared by the growers in this project. The level of resistance felt when pushing a blunt knife or soil probe into the ground is subject to personal interpretation and cannot be numerically 'measured'. Nevertheless, the growers can calibrate themselves by practicing the method and testing it in different fields and soils etc. The test was seen as a fast, cheap and easy to use method to locate areas of compaction in a field; and with some experience, even the depth of the compacted layer can be estimated.

Laboratory soil health tests, soil health index including respiration rates – This test was included in the study as many growers were very keen on increasing soil organic matter in their soils and are looking for a method to monitor organic matter over time. However, while the currently available lab tests for labile/active soil organic matter have great potential to provide useful information for soil management, it is crucial to be aware of the issues in relation to sampling and result interpretation when using them in practice. Such laboratory tests were seen by the growers as potentially very useful in the future, particularly for intensive horticultural systems such as protected cropping, once more information is available about soil biology indicators, and testing procedures/protocols are developed for routine soil biology testing.

Discussion

One aim of the Field Trial comparison of soil assessment tools was to (re-)connect growers with their soils, increase their confidence to assess and measure the health of their soils, and also to evaluate which indicators might be most useful and relevant to monitor soil health in their specific circumstances and horticultural systems. The secondary aim was to identify if certain horticultural systems, such as field vegetables, top fruit or protected cropping systems, might require their own specific soil assessment methods, combinations of methods or specific interpretation of results.

It was found, for example, that the visual soil assessment (VSA) tool is less relevant for intensive field horticultural systems, particularly those growing crops on beds. As the soil in these systems is worked very regularly and heavily, soil structure assessment in the top 30cm is not possible/useful for most of the year. However, if the fields are sown with cover crops over winter there would be an opportunity for an assessment with the chosen VSA tool, e.g. before and after cover crops. But growers also stated that taking a spade sample and looking at a specific soil or field (even in horticultural growing systems on beds), its colour, smell, plant rooting pattern/vigour etc. is seen as a very useful method at almost any point in time, as a practical and quick way of getting an impression of the health of the soil.

Also, earthworm counts can be more useful in some soils or systems than in others. Firstly, it is crucial to perform the counts in spring and/or autumn, when the worms are most active in the upper soil horizons. And secondly, when heavy tillage machinery and tools are used, earthworm populations can decrease very quickly. Ploughing, for example, will smear or close vertical worm tunnels, but generally may do less damage to earthworm populations and their habitat than for example rotating tillage machinery such as bed formers. Therefore, earthworm counts and interpretation of their results should take soil management into account. As for all newly adopted soil assessment methods, earthworm counts should be made at several locations within a field (with maybe a field margin for comparison), and repeated regularly, maybe twice a year over a couple of years, to get used to the method and get a feel for the 'normal' number of worms and natural fluctuations of populations in a particular field/soil. Finding 10 worms in a 20x20x30cm spade sample can be an acceptable number in some soils, whereas in others it might be a very low result. AHDB has published new guidance on how to count earthworms; this is available on the AHDB website.

The simple infiltration test received very positive feedback from almost all growers who tested this method, as it is very easy-to-use and generates self-explanatory results. However, the method required measuring the time it takes for a volume of water to infiltrate into soil, and depending on the soil type, structure and moisture content, this can take a rather long time. So, while this tool was seen as highly useful and informative in lighter soils, in heavier soils with poor structure it may take 20 minutes or longer for the water to infiltrate completely, which tends to stretch the patience of growers; tests were therefore terminated after 10 minutes. For soil in good health, the water should drain away within 2-5 minutes for light or medium soils.

The NRM soil health test includes the assessment of respiration rate (the burst of CO_2 produced following drying and re-wetting of the soil) as an indicator for soil biological health. This is a relatively newly-developed test suite that offers an overall soil health index with certain soil management recommendations derived from the results. As many growers expressed an interest in soil organic matter and how to measure and improve it, this test was chosen for our trials as relatively affordable laboratory test option. Total soil organic matter is difficult to increase in the short term, e.g. over 3-5 years, where changes are likely to be <0.5%. Total soil organic matter is often analysed by loss on ignition (LOI) or other laboratory methods that measure all fractions of organic matter in the soil, from the highly fixed 'inert fraction' to the highly reactive and manageable 'active/labile fraction'. It is the latter that farmers and growers are most interested in, as they can potentially see effects of changes in soil management strategies relatively quickly. The active/labile fraction of soil organic matter includes soil organisms (fungi, bacteria, etc.) and there are several laboratory tests currently available to measure components of the soil biological population (e.g. food-web tests, enzymatic activity, microbial biomass C or basal respiration rates, etc.). These tests are often relatively expensive (e.g. up to £150-200 per sample for food web tests), and the interpretation of results, as well as correct sampling requires additional skills. Microbial communities in the soil often vary significantly during different seasons, weather conditions, moisture levels, temperatures and even times of day! So, while these tests have great potential to provide useful information for soil management, it is crucial to be aware of the issues above when using them in practice. From a practical point of view, the respiration assessment used in the NRM test suite provides an estimate of soil microbial biomass and may therefore provide a measure labile soil organic matter. This is a topic in need of further study.

As the NRM soil health test includes a measurement of total soil organic matter, as well as other relevant soil health parameters (P, K, Mg, pH, etc.), and for a relatively affordable price per sample (around £45. This test suite was therefore selected for use in our trials to evaluate its value for growers and to assess its potential to reliably inform soil management strategies to improve soil health and fertility.

Conclusions

The recommendations developed in Work Package 2 are based on the practical experience of growers who have tested different soil assessment methods over 2 years, as well as the feedback from a larger group of growers and consultants. The main conclusions are:

There is an increased awareness over recent years by growers about their soils generally, and particularly the health and productivity of their soils.

Simple and practical soil assessment tools can be useful to growers who 1) aim to evaluate the health of their soils themselves, who 2) wish to monitor changes in the soil (e.g. structure, fertility etc.) over time, or who 3) aim to assess the effects of certain soil management strategies and activities.

The approach used in the project has stimulated a wider range of practitioners to spend more time and effort on their soil assessment methods, and in turn their soil management strategy. The host growers, for example, were able to inspire other growers during the field walks and by demonstration of the soil assessment tools.

Different horticultural systems may need different soil assessment methods.

Knowledge and Technology Transfer

Soil health testing tool kit

Over the course of the project we have built a library of resources for growers wishing to better understand and take action to improve their soil health. These add to and build on the existing resources available from AHDB and include factsheets, videos, webinars, demonstration open days and workshops (Figure 52 & 53) and advisor/agronomist events.

Figure 52: Attendees at a GREATsoils workshop at Huntapac in Lancashire

Feedback from the workshops on take home messages includes:

"*Continue on with cover crop trials."*

"Many ways that soil can be improved. Soil biology work must continue!"

"No one size fits all solutions, all farms have site specific problems and issues"

"Treat soils with respect and keep building for the future"

Figure 53: GREATsoils workshop feedback tweet

Advisor events

An important legacy for the project is to pass the learnings on to both growers, and the horticultural advisors who are working with growers. In the final months of the project we ran and presented at a number events specifically aimed at advisors. Feedback was very positive, and we reached over 50 advisors.

Sample feedback:

"Great event, knowledgeable speakers, Good to have specialists gathered together to share experience."

"Good level of detail that I could take away and introduce to my production system. Good shared knowledge from the audience also."

"Some new areas to think about!"

"Very interesting talks"

"Sums up the research from the three year programme very well."

"Good presenters, promoted participation and interaction."

"Good summary of project, put three years of research in to three hours!"

Feedback on take home messages included:

"*Soil health is complex and requires clear planning and preparation on individual farms."*

Events (Soil Roadshow)

Over the course of the project the team has been out talking to growers at 33 events around the country. This has provided an opportunity to share the learnings of the project and to get feedback. In Year 3 the team took part in four events including the UK Asparagus Conference in July where Martin Wood ran a GREATsoils session three times and there was good discussion amongst growers. Our target for the project was 18 key events, which we exceeded.

Media output

In Year 3 the GREATsoils project CP107b has been covered in 14 major articles across a range of industry publications including:

- HortiDaily
- Food and Farming Futures
- The Farmers Guardian
- The Vegetable Farmer
- Tillage Magazine
- The Fruit Grower
- Soil Use and Management.

In addition, we have published 7 blogs on elements of the project.

Twitter 1475 followers.

Full details are given in Appendix 5.

GREATsoils network

The project has been built up a network of growers via sign-ups at events, website, newsletters, and twitter. At the end of the year there were 690 members.

To keep the network engaged with the project events and outputs we sent round regular updates called the GREATsoils bulletin. Over the project we sent out 8 bulletins which had an open rate of around 45-50%.

This was not an indicator in the original proposal, however we believe tracking members who have signed up to be part of the network provides another good indication of grower engagement.

Appendices

Appendix 1 – Soil health testing recommendations for growers

Appendix 2 – Field Labs reports

Appendix 3 – Workshop and webinar attendance

Appendix 4 – Balbirnie Estates, Scotland Field Trial Report

Appendix 5 – Media output

Appendix 6 – Industry events

Appendix Field Labs Reports

2a – GREATsoils Field Lab: Improving soil health across a shared rotation

Purpose of group

Many farmers and growers rent land for short periods that that they may not return to for a number of years. Traditionally there has therefore been a reluctance to spend money on improving soil health from which you may not personally see a return. In this Field Lab, cover crop and manure application choice now have to work for all three businesses because the risks as well as any benefits affect them all.

The overall aim of the three partners was to improve soil organic matter and soil health in an arable / horticulture rotation. More specifically they were looking to:

- quantify short term benefits of cover crops for following cash crops – lettuces, potatoes and sugar beet
- reduce growing costs by developing more efficient rotations in the long term
- analyse the cost benefit of various cover crops and mixes
- evaluate ease of soil cultivation after cover crops
- jointly develop a long-term soil health strategy

This Field Lab aimed to deliver initial evidence for other farmers and growers that a joint strategic and long-term soil management approach of different parties using the same fields in a rotation is crucial for a long-term and sustainable improvement of soil health and soil fertility. They also hoped to initiate this idea and thinking process in other growers and farmers to collaborate on this particular agricultural challenge.

Triallists

- Jepco: Phillip Hubbard, Nick Sheppard - Salads
- Loveden Estates: Anthony Campling – Sugar beet
- Worth Farms: Simon Day – Potatoes

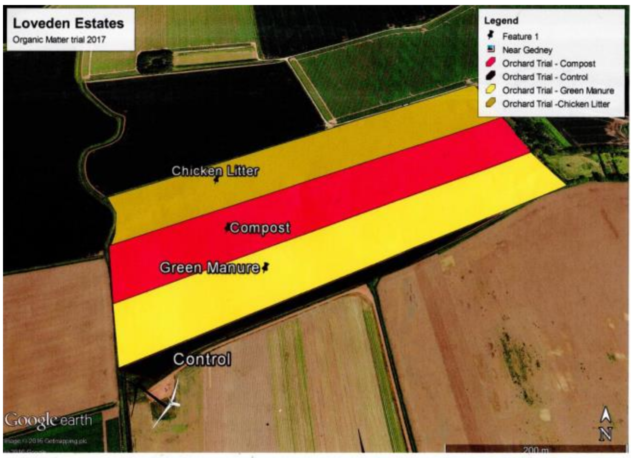
The trial site was based in Norfolk.

Trial concept

The project trialled a new approach of jointly working on the improvement of soil fertility and health. Taking into account that such approaches cannot be conclusively evaluated in one growing season alone (variation; e.g. from particularly wet or dry years); a main outcome of the project may be the initiation of a closer collaboration among the growers and farmers, and especially the development of a joint, long-term strategy to improve soil health and fertility, increasing production efficiency in general.

Year one of trial

Jepco – 6 fields – 200 acres oats, 70 acres Italian rye grass (IRG) and vetch sown in August / September 2016. Oats incorporated early spring IRG and vetch in May. Control strips left unsown



Figures 56 and 57: Loveden Estates: 21 ha field split into 4 parts.

- Compost
- Chicken litter
- Cover crop
- Untreated (control)

Mustard Autumn sown and compost and litter mix applied at a similar time. Followed by sugar beet in in 2017

Worth Farms: Field sown with PCN mustard mix in August 2016 with a strip left bare as control. Incorporated in November 2016 for best effect on PCN number. Into potatoes in spring 2017

Figure 58: Worth Farms

Measurements

- Soil analysis: before and after sowing of cover crops or fertiliser treatment. NRM soil analysis records (incl. P, K, Mg, pH, %SOM, texture and CO2-Burst

- Soil management: ease of seed bed preparation and general 'manageability' of the soil after a cover crop; evaluated by the growers e.g. using spot tests of tractor fuel use when in treatment area and in control area.

- Cover crop yield: through fresh and dry matter measurements.

- Effects on cash crops: health and quality of lettuce crops, measuring yield and shelf life; sugar beet yield and quality assessment (sugar content, purity of juice); health and quality of potatoes: yield, dry matter and skin finish.

The partners were also keen to collect feedback from growers on joint soil health management

Other more general records were also collected

- Sowing/planting dates of cover crops and cash crops,
- Dates of compost/manure applications incl. quantities,
- Cost of green manure seed used,
- Growing costs for the cover crops/manures and additional labour as far as possible,
- Date and quantities of any fertilisers and sprays used,
- Date cover crops topped,
- Incorporation cost if possible and methods used –ploughed, disced, etc.

Results

Jepco: Salads

The trial showed a 7.9% increase in lettuce head weights, made up of both bigger heads & improved integrity of leaf structure. The result was a positive increase in gross margin per ha. Cover crop cost was £240 per hectare in the trial area. This included all additional cultivations in establishing and incorporating the cover crop.

It was noted that improved leaf structure would potentially give a longer shelf life and there was a more consistent crop which meant harvesting was easier to arrange. This would likely further reduce costs.

The consequence of increased yields is that there would be a further reduction in crop production area to deliver same volume of sales.

Artificial nitrogen use on the lettuce has been further reduced by 10kg/ha.

Better water infiltration after heavy rain falls in the lettuce fields which have had an overwintered cover crop, compared to fields which were ploughed or left as an over winter stubble.

Loveden Estates: Sugar beet

The trial plots were plot tested in November using standard British sugar techniques, sampling 12 roots, to assess sugar levels. Although not yet statistically analysed Cover Crop and compost samples showed higher Sugar % levels and chicken litter trial showed lower sugar %. The higher nitrogen application trial demonstrated lower sugar % levels than would be expected.

Field harvesting was undertaken in January with plots harvested mechanically, and trailer yields taken from a 200m x 2.7m plot. These again have not yet been analysed properly yet but show a 0.5t/ha increase in Beet yield for all treatments. Sugar yield analysis is being undertaken to assess sugar yield per plot.

Financial analysis shows that the

- cover-crop treatment showed a Gross Margin improvement of about £200 per hectare over all costs,
- Chicken litter by about £100 and compost was cost neutral.

As a result, it would appear that a fodder radish/mustard cover crop is at least a break even economic option before sugar beet.

The plots have been drilled to winter wheat, and during ploughing it was noted that the compost had not totally broken down and could lead to longer term crop benefits. The plots will be reanalysed through the NRM soil samples, and wheat yield by combine yield assessment at harvest.

Data taken from Gatekeeper field Gross Margin

* note for Orchard A Control the Gatekeeper sheet fails to include base fertiliser – this has been added into the figures in table below. Four pages Gatekeeper sheets.

		Breakdown of Costs £ per Ha								Total £ per ha
Subplots		*Adjuvants*	*Fert.*	*Fungicide*	*Herbicide*	*Manure*	*Spreading*	*Seeds*	*Trace Elements*	
Orchard A	Control	1.68	309.57	48.16	197.42	0	0	201.24	2.64	760.73
Orchard D/03	Poultry	1.68	245.91	48.16	212.90	0	14.02	200.50	2.64	735.81
Orchard E/04	Compost	1.68	309.57	48.16	197.42	125.89	50.86	200.50	2.64	936.73
Orchard F/05	Cover crop	1.68	309.57	48.16	197.42	0	0	254.67	2.64	814.14

Yield data taken from harvest spreadsheet as average of the two trailers, with crop quality tested to give an adjusted sugar percentage, dirt tare etc calculated to provide a more accurate yield.

Fertiliser Breakdown		**Base compound**		
Subplots			***Nitrogen***	***Total***
Orchard A	Control	283.45	26.13	309.57
Orchard D/03	Poultry	99.03	40.37	245.91
Orchard E/04	Compost	283.45	26.13	309.57
Orchard F/05	Cover crop	283.45	26.13	309.57

Manures

3 Margins						
Subplots		***Yield t/ha***	***Price £/t***	***Gross Output £ ha***	***Variable Costs £ ha***	***Net Margin £/ha***
Orchard A	Control	134.8	22	2965.82	760.73	2205.09
Orchard D/03	Poultry	141.6	22	3115.20	735.81	2389.39
Orchard E/04	Compost	143.4	22	3154.80	936.73	2218.07
Orchard F/05	Cover crop	146.6	22	3225.20	814.14	2411.06

- Compost was paid for at commercial rate.
- Poultry litter was provided free delivered to site.
  Haulage charge may have been missed. Poultry litter is generally priced at around £7 -10 tonne, delivered to farm (c. £56 to 80 ha) - above these shown.

Figure 59: Lovedon Estate: Initial cost analysis

Worth Farms: Potatoes

Crop was harvested in September 2017 and boxes from sampled area were compared with boxes from trial area. There was no noticeable difference in tuber yield, damage, size or skin finish between the two areas. There was no PCN damage on either samples. PCN cyst numbers will be assessed in the spring and a further soil analysis carried out.

Next Steps

The Farmers are continuing with the trial, with following crop yields on trial plots being analysed to see if there is any long-term increase in yields and soil health.

What was interesting was that these benefits were seen as part of a process to improve soil health, and during discussions it was plain that all three businesses wanted to see further improvements. Reducing the dependence on ploughs, improving water retention and the potential to reduce fertilizer input costs were some of the long-term intentions across the all of the businesses.

This GREATsoils Field Lab is about more than just soil and yield, it's an example of neighbouring businesses who now work together and are aware of the consequences of their actions on others. They are committed to improving the soil they manage and are working together to improve them.

2b – GREATsoils Field Lab: The impact of whole digestate on soil health in field-grown vegetable crops on the Moray Coast

Purpose of group

A “Field Lab” was set up to determine whether the application of separated liquid digestate made from farm-produced energy crops had any short-term impacts on aspects of the health of soils in Moray coast vegetable rotations. The project work took place over 1.5 years at Mid Coul Farms, Inverness, Dalcross, IV2 7JJ.

Introduction to the study

The impact of liquid or whole digestate applications on soil health has not been widely studied to date. Many consultants and AD companies promote the benefits of digestates as soil improvers, but given that whole and liquid digestates typically contain very little organic matter, they are likely to have little benefit as soil improvers. In fact, recent Defra and WRAP-funded work suggested that the application of whole digestate sometimes resulted in reduced soil organic matter content. There is a clear need to better understand the impact of digestates on soil health parameters, hence the need for studies to address the subject. This project is necessarily short, and the results gained following only three digestate applications are not likely to provide all the answers required. However, some early indications of potential benefits and problems will be useful.

The outcomes will include development of best practice guidance for farmers based on the results obtained in the project. Guidance will focus on where, when and how to apply digestate in order to maximise benefits from the digestate and minimise any potentially harmful effects. The guidance produced as a result of this project will draw on several sources of information, including results from fieldwork. It will help the many farmers who now have access to whole or liquid digestate to make best use of it on their land.

Field trial methods

The farmer applied digestate at 15 m^3/ha to two fields of ryegrass with white clover (M8 and M10) on the following dates:

- 4 October 2016
- 24 -27 March 2017
- 25 – 27 August 2017

A control strip (where no digestate was applied) was left in each field for comparison. No additional bagged fertiliser was applied to either the control or the digestate-treated land. Treated and untreated areas of soils in the fields were assessed and sampled prior to the first digestate application and again around 1 to 3 weeks after the second and third digestate applications. The impact of digestate on soil health parameters was assessed as follows.

Soil sampling for lab testing

On 9 September 2016, the treatment areas in each of the two test fields were walked from corner to corner diagonally in both directions in order to determine whether it was appropriate to take single samples from across the area (it was) and in order to choose locations in which to dig soil inspection pits. Each area was then sampled immediately before the first digestate application (9 September 2016) and after the second and final digestate applications (29 March 2017 and 23 January 2018) by walking in a “W” pattern and taking 20 sub-samples using a spiral augur to 15 cm depth. Sub-samples were mixed in a clean bucket and 500 g samples were removed for testing. Samples from the first and third samplings were sent to NRM laboratories for analysis. Samples were also tested for soil respiration using Solvita gel paddles. These samples were placed in a cool box with ice packs until the tests could be set up according to the instructions for the Solvita soil test kits, in a room kept at 20°C.

Laboratory analysis

Each soil was analysed at the laboratory for the following parameters:

- pH (Scottish and ADAS methods)
- extractable phosphorus [P], potassium [K] and magnesium [Mg] (Scottish methods)
- extractable phosphorus [P], potassium [K] and magnesium [Mg] (ADAS methods)
- organic matter content (by the loss on ignition method)
- microbial respiration (as measured by the Haney Brinton CO_2 burst test). Test was done on the first and last sampling only.
- microbial respiration (Solvita gel paddles). Results were read after incubating the sealed jars of soil at 24°C for 24 hours (according to test instructions) using a digital plate reader.

Results are tabled in this report and the original PDF files are available as Appendices 1a and 1b[5].

In field measurements

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[5] https://www.innovativefarmers.org/field-lab?id=0436327a-05b3-e611-80ce-005056ad0bd4

Soil structural assessments and earthworm counts were conducted on 9 September 2016 (prior to digestate application) as shown below, and again on 29 March 2017 and 23 January 2018.

- Visual soil structure assessments - Soil assessment pits which were 20 cm square were excavated to a depth of 30 cm. Soil structure was assessed and determined in all four pits in each treatment area using the "Visual Evaluation of Soil Structure" guide (Digestate Field Lab Appendix 2: Ball *et al.,* 2012, Visual Evaluation of Soil Structure [VESS])[6].
- Earthworm counts - all soil excavated from the above pits was placed in a plastic trug as it was removed. The soil was carefully sorted through by moving it handful by handful into another trug in order to be sure that all earthworms present, of all sizes were located. The earthworms found were placed in a plastic bowl and were washed (to assist counting). Those found in the top 30 cm of each pit were then counted. The number of large, medium and small mature or immature worms in each pit was recorded.

The following additional in-field measurements were conducted on the same dates as the soil structure and earthworm assessments:

- Quadrat grass and weed counts in treated areas
- Germination tests (weeds germinating in samples of known volume of digestate spread onto sand or growing media – test conducted in late Spring 2017 only).

Results and discussion

The results of laboratory analysis, visual assessments of soil structure, earthworm counts and soil respiration are presented in Tables 26 to 31.

Particle size analysis confirmed that the soil texture in M8 was a sandy loam, which is typical of soils well suited to carrot production. The laboratory test results from the soils in both areas of M8 are shown in Table 26.

[6] https://www.innovativefarmers.org/field-lab?id=0436327a-05b3-e611-80ce-005056ad0bd4

Table 26: M8 field laboratory soil analysis results (one sample based on 20 sub-samples taken from each of the two treatments) before trial (values in black) and after trial (*values in shaded blue italics*).

Parameter	Unit	Value: No digestate	Value: Digestate	What does this mean?
pH[1]	-	6.1	6.0	pH is slightly below the target of 6.5 for vegetable rotations.
	-	*6.3*	*6.3*	*pH is around the target of 6.5 for vegetable rotations.*
Organic matter	%	4.2	3.7	This is a fairly typical organic matter level for this soil type in this region, though there would be benefit in increasing it.
		3.9	*4.1*	*As above*
Extractable nutrients				
P (status)[2]	mg/l	3.5 (L)	3.0 (L)	The Scottish method suggests that this soil is well below the target of "high" for P
"	*"*	*6.7 (M)*	*4.9 (M)*	*P status looks to have increased in both treatments, but this cannot be the case in real terms, since no P was applied in the control.*
P (index)[3]	"	19.4 (2)	18.2 (2)	The ADAS method suggests that this soil is below the target of "high" for P
"	"	*30.6 (3)*	*22.4 (2)*	*P status looks to have increased in both treatments (particularly control), but this cannot be the case, since no P was applied to control.*
K (status)[2]	"	57 (L)	85 (M-)	The Scottish method suggests that this soil is below or well below the target of "high" for K
"	*"*	*64 (L)*	*73 (L)*	*K status has changed little following the trial.*
K (index)[3]	"	56.4 (0)	92.3 (1)	The ADAS method suggests that this soil is below or well below the target of "high" for K
"	"	*76.6 (1)*	*74.5 (1)*	*K index has changed little following the trial*
Mg (status)[2]	"	140 (M-)	154 (M-)	This soil is at target for Mg
"	*"*	*121(M)*	*129(M)*	*Soil Mg content appears to have dropped slightly in both treatments following the trial.*
Mg (index)[3]	"	115 (3)	118 (3)	As above
"	*"*	*87.6 (2)*	*97.1 (2)*	*Soil Mg content appears to have dropped slightly in both treatments following the trial.*
CO_2 evolution[4]	mg/kg	40 (L)	62 (M)	This indicates that the soil is of low or moderate health status in terms of microbial respiration
"	*"*	*128 (H)*	*128 (H)*	*Microbial respiration was higher in both treatments after the trial than before.*

[1]pH was measured in water (ADAS method);

[2]Nutrients extracted using Modified Morgan's extractant (i.e. the method typically used by SAC to analyse Scottish soils. Soil status: VL=very low, L=low, M-=moderate (lower half of the range), M-=moderate (upper half of the range), H=high, VH=very high;

[3]Nutrients extracted using the ADAS method. Soil indices of 1 to 9 are allocated to the values, where 1 is regarded as being approximately equivalent to the SAC status of "low", 2 to "moderate", 3 to "high" and 4 "very high";

[4]As measured by the Haney Brinton CO_2 burst test.

Soil pH prior to the trial was slightly lower than the target of 6.5, but this would not cause problems for the crops in the rotation. The soil organic matter in both treatment areas in this field is fairly typical for soils of this type in this region of Scotland, although there would be benefit in increasing it.

The two different extraction methods have given slightly different results for soil P, K and Mg, which is quite often the case. The Olsen P method (developed by ADAS and used by English labs) often overestimates the availability of P in Scottish soils. Certainly soil extractable P was lower according to the Scottish method than with the ADAS method in all four cases.

It was well below target for P before the trial, but soil P concentrations appeared to have increased by the end of the trial. Given the relatively small amount of P applied in the digestate treatment (and none was applied in the untreated area of the field), this is unlikely to be a reflection of the true situation, since no fertiliser was applied to any part of the field during the trial. Odd results such as this are often obtained in un-replicated field trials where only single rather than multiple samples are taken for testing. Unless the differences between values for different treatments are very large and are similar when repeat sampling takes place, then it is likely that the results are due to natural variation in the soils within the field. If anything, both soil P and K concentrations are likely to have decreased slightly by the end of the trial, since the nutrients removed by two typical silage crops (yielding 23 and 12 t/ha for first and second cuts respectively in 2017) were not fully replaced by those present in the digestate applications. Soil K concentrations were lower than target both before and after the trial and had not obviously changed between the two test dates. The soil contained sufficient crop available Mg both before and after the trial.

The Haney Brinton soil respiration test soil respiration test showed that microbial respiration was low to moderate before the trial. Values were higher after the trial (indicating increased microbial respiration), but given that the results for the untreated area and the digestate-treated area were the same, the increased value has not happened as a result of digestate treatment. The increased respiration after the trial was likely due to the fact that there was by then a healthy, actively growing crop which was well established in both parts of the field. (When the tests were first done, prior to the trial, the grass/clover crop was young and the amount of root present in the soil was small.) Results have shown that the presence of a vigorously growing crop is more important for microbial respiration than whether or not digestate has been applied. This is a relatively new test, which can sometimes be difficult to interpret. Increasing numbers of growers are using the test and interpretation frameworks will develop as more results become available for different growing systems and soils.

Particle size analysis confirmed that the soil texture in M10 was again a sandy loam, typical of soils well suited to carrot production. The laboratory test results from the soils in both areas of M10 are shown in Table 27.

Soil pH prior to the trial was around the target of 6. It had fallen slightly by the end of the trial. It is normal for soil pH to fall over time and this happens most quickly in lighter soils. Lime will be required within the next year or two, to bring soil pH back to target. The soil organic matter in both treatment areas in this field is fairly typical for soils of this type in this region of Scotland, although there would be benefit in increasing it.

The two different extraction methods have again given slightly different results for soil P, K and Mg. Again, soil extractable P was lower according to the Scottish method than with the ADAS method in all four cases. The Scottish method suggested that the soil was below target for P, whereas the ADAS method suggested that it was on target (though the digestate-treated part of the field was below target after the trial). Some Scottish fertiliser advisors are now saying that the Modified Morgan's extractant (i.e. the method used by SAC in Scotland) results in a more appropriate fertiliser recommendation for Scottish soils.

Soil K concentrations were lower than target both before and after the trial and had not obviously changed between the two test dates. In this case, the ADAS method gave a lower result than the Scottish method did. This is often the case with Scottish soils. The soil contained sufficient crop available Mg both before and after the trial according to both soil test methods used.

Table 27: M10 field laboratory soil analysis results (one sample based on 20 sub-samples taken from each of the two treatments) before (values in black) and after the trial (*values in shaded blue italics*).

		Value		
Parameter	**Unit**	**No digestate**	**Digestate**	**What does this mean?**
pH[1]	-	6.4	6.5	pH is on target of 6.5 for vegetable rotations.
	-	*6.0*	*6.1*	*The pH appears to have dropped in both treatments following the trial.*
Organic matter	%	4.5	4.0	This is a fairly typical organic matter level for this soil type in this region, though there would be benefit in increasing it.
		4.1	*4.0*	*As above*
Extractable nutrients				
P (status)[2]	mg/l	5.6 (M)	7.8 (M)	The Scottish method suggests that this soil is below the target of “high” for P
“	*“*	*8.3 (M)*	*6.9 (M)*	*As above.*
P (index)[3]	″	28.2 (3)	27.6 (3)	The ADAS method suggests that this soil is on target of “high” for P
“	“	*29.6 (3)*	*23.4 (2)*	*P status looks to have dropped slightly in the digestate treatment and relative to the control, but this cannot really be the case, since no P was applied to control and same crop was grown in both treatments.*
K (status)[2]	″	89 (M)	47 (L)	The Scottish method suggests that this soil is below or well below the target of “high” for K
“	*“*	*79 (M)*	*71 (L)*	*K status has changed little following the trial.*
K (index)[3]	″	87.4 (1)	47.2 (0)	The ADAS method suggests that this soil is below or well below the target of “high” for K
“	“	*78.9 (1)*	*63.6 (1)*	*K index has changed little following the trial*
Mg (status)[2]	″	141 (M-)	147 (M-)	The Scottish method suggests that this soil is at target for Mg
“	*“*	*143(M)*	*131(M)*	*As above*
Mg (index)[3]	″	114 (3)	115 (3)	The ADAS method suggests that this soil is above target for Mg.
“	*“*	*103 (3)*	*88.1 (2)*	*As above*
CO_2 evolution[4]	mg/kg	98 (H)	40 (L-M)	This indicates that the soil is either “low/moderate” or “high” health status in terms of microbial respiration
“	*“*	*128 (H)*	*118 (H)*	*Microbial respiration was higher in both treatments after the trial than before.*

[1]pH was measured in water (ADAS method);

[2]Nutrients extracted using Modified Morgan’s extractant (i.e. the method typically used by SAC to analyse Scottish soils. Soil status: VL=very low, L=low, M-=moderate (lower half of the range), M-=moderate (upper half of the range), H=high, VH=very high;

[3]Nutrients extracted using the ADAS method. Soil indices of 1 to 9 are allocated to the values, where 1 is regarded as being approximately equivalent to the SAC status of “low”, 2 to “moderate”, 3 to “high” and 4 “very high”;

[4]As measured by the Haney Brinton CO_2 burst test.

Microbial respiration as measured using the commercially available Haney Brinton soil respiration test (Tables 26 and 27), is conducted on dried and re-wetted soils, but it is also possible to measure respiration under natural conditions. This is done using the Solvita gel paddle method, which farmers can do overnight in a warm room, with simple kits bought from Earthcare Technical in the UK. The Solvita kits were developed for prairie soils in the USA and experience is still being built on how best to interpret results for UK soils and farming systems. The results obtained were completely different to those obtained using the Haney Brinton CO_2 burst test, where soil respiration was higher in all four farmed areas after the trial than before (Table 28). Although the soil respiration was high in the field margins in comparison to the farmed land prior to and after the trial, microbial respiration was low to moderate or moderate in untreated and digestate-treated land in both M8 and M10 during and after the trial. In other words, there was no obvious difference between the soils in digestate-treated and untreated land, and no obvious difference between results in farmed land before, during or after the trial.

Table 28: M8 and M10 soil respiration (Solvita test scores[1] from plate reader)

Area tested	09 September 2016	29 March 2017	23 January 2018
M8 Field margins	79 (high)	-	65 (mod)
M8 no digestate	40 (low-mod)	45 (low-mod)	43 (low-mod)
M8 digestate	43 (low-mod)	48 (mod)	41 (low-mod)
M10 Field margins	75 (high)	-	62 (mod)
M10 no digestate	61 (mod)	52 (mod)	48 (mod)
M10 digestate	53 (mod)	47 (mod)	45 (low-mod)

[1]All scores are mean taken from two tests

The total additions of major nutrients from digestate applications are summarised in Table 29. No additional fertilisers were applied to either the control or digestate treated areas in either field. The value of nutrients applied in 1 t/ha, 15 t/ha and 45 t/ha are also summarised.

Table 29: Nutrient additions[1] from digestate applications in M8 and M10 and fertiliser required for a 35 t/ha hybrid rye crop.

	N	phosphate	potash	
Digestate*	**Total kg nutrient/fresh tonne of digestate**			
1 m³/ha	3.4	1.4	5.6	
	Available nutrient (kg/fresh tonne digestate)			
1 m³/ha	1.7[2] (50%)	0.7 (50%)	5.0 (90%)	
	Financial value (£/tonne digestate)[3]			**Total value (£)**
1 m³/ha	£1.11	£0.78	£2.30	£4.19
	Total kg nutrient/15 m³ of digestate			
15 m³/ha	51	21	84	
	Available nutrient (kg/15 m³ of digestate)			
15 m³/ha	26	11	76	
	Financial value (£/15 m³ of digestate)			
15 m³/ha	£16.90	£11.76	£34.44	£63.10
	Total kg nutrient/45 m³ of digestate			
45 m³/ha	153	63	252	
	Available nutrient (kg/45 m³ of digestate)			
45 m³/ha	77	32	227	
	Financial value (£/45 m³ of digestate)			
45 m³/ha	£50.05	£35.28	£103.32	£188.65
Fertiliser needed[4]	**Grass/clover ley with two crops of silage removed and one grazing period (23 + 12 t/ha crops)**			
	80	62	212	

[1]Figures based on average values from two sets of test results.

[2]The % of N which is available varies between around 10 and 60%! It depends on the time of year applied, the method of application, the soil type/depth and whether incorporated within 6 hours (SRUC, 2018).

[3]Digestate value based on fertiliser prices of: N = 65p/kg, phosphate=56 p/kg and potash = 41 p/kg. Total £value takes into account 50% of the total N content (though this will vary, see above), plus all of the P and K.

[4]N requirement for grass in Site class 3 (< 350 mm rainfall from April to September) on soil type other than a sand or shallow soil, with 20-30% clover content which had 2 silage cuts plus 1 grazing period. P and K requirement are based on the fact that the field is below target status for both nutrients.

No nutrients other than those present in the digestate were applied during the course of the trial. It is thought likely that two cuts of silage (estimated at 23 + 12 t/ha) will be taken from these fields and a single grazing period (sheep) will take place in late summer/early Autumn each year. If this is the case, then there will be an annual crop nutrient requirement of around 80, 62 and 212 kg/ha of N, phosphate and potash respectively. If only 30 m³/ha of digestate is applied in total each year and no additional nutrients are applied, this field will therefore be being gradually depleted in P and K nutrients as the years go by. The silage crop will also be short of N.

It is recommended that additional nutrients or at least an extra 15 m^3/ha digestate application is made in order to supply sufficient nutrients to promote optimal crop yield and quality. In fact, three applications of 20 m^3/ha per year would be more appropriate until soil P and K status reach the target status of “High”.

It is good practice to continue to apply digestate three times at 15 or 20 m^3/ha during the season, thus supplying somewhere between 52 and 82 kg crop-available N (depending on the volume of digestate applied and on other factors, primarily including the time of year), 32 kg crop available phosphate and 227 kg crop available potash/ha. Many farmers are applying more than this (e.g. 25, 30 or more m^3/ha) but 15 or 20m^3/ha minimises the chance of crop scorch and damage to earthworm populations. If a total of 45 m^3/ha is applied in three applications, then bagged phosphate fertiliser will have to be applied in order to maximise crop yield and build soil P status.

The results of soil structural assessments conducted in M8 and M10 showed similar results in that both soils had some degree of compaction in the farmed areas (Table 30). Greater numbers of firm aggregates and more evidence of compaction was found than might be expected in less intensively cultivated sandy loam soils. Given that the soil is regularly cultivated for root crops, the soil is not in bad condition, but there is room for improvement. It is likely that soil structure will gradually improve under several years of grass/clover ley, since the soil will benefit from the break in cultivation and from having a constant cover of vigorous vegetation.

The soil in the field margins had markedly better structure than the soil in the farmed area, which is very common, particularly when comparing field margin soil to soil in intensive rotations involving root crops. Importantly, there was no evidence of increased compaction in M8 where digestate had been applied three times. Soils in M10 to which digestate had been applied had very slightly poorer structure, particularly in January 2018, but differences were relatively small.

Regular inspections of soil structure, through frequent test digs, allocation of structure scores (e.g. using VESS) probe gave useful indications of the physical aspects of soil health. However, the systems typically used at present are more suitable for pasture soils and soils which are subject to less intensive cultivations than this one is. There is a need for a new, perhaps simpler system to assess the health of soils which are subject to frequent, intensive cultivations.

Table 30: Soil structure scores in M8 and M10 as assessed using the VESS method (Ball *et al.* (2012).[1]			
Area tested	**09 September 2016**	**29 March 2017**	**23 January 2018**
M8 field margins	1.2	1.3	1.3
M8 no digestate	2.3	2.2	2.3
M8 digestate	1.8	1.9	2.2
M10 field margins	1.1	1.3	1.2
M10 no digestate	1.5	2.0	1.9
M10 digestate	2.0	2.2	2.3

[1]VESS scores based on Ball *et al.* (2012). A lower score means a better structure. All scores are means taken from four test digs.

The results of earthworm counts conducted in M8 and M10 showed similar results in that both soils had very low earthworm numbers, typical of light soils which are in rotations involving intensive cultivations for root crops (Table 31). Lower numbers of earthworms were found than might be expected in less intensively cultivated sandy loam soils. The soil in the field margins had markedly more earthworms on all three counts than the soil in the farmed area, which is usually the case when comparing field margin soil to soil in intensive rotations involving root crops. Importantly, differences in earthworm numbers between digestate-treated and untreated soils were small and unlikely to be significant.

Table 31: Earthworm counts in M8 and M10

	Number of mature and immature earthworms per pit[1]		
Area tested	**09 September 2016**	**29 March 2017**	**23 January 2018**
M8 field margins	7.2	5.6	8
M8 no digestate	2.8	2.8	1.0
M8 digestate	2.3	1.5	2.5
M10 field margins	6.5	8.2	7.5
M10 no digestate	1.5	0.0	1.5
M10 digestate	1.0	1.0	1.5

[1]All values are based on the average of 4 pits dug per area.

Weed counts conducted in four quadrats in each treatment in each field showed that there were few weeds in total and no differences between the number of weeds present in digestate-treated and untreated grass/clover swards. There was no evidence of scorch following digestate treatment on either field at any time. Germination tests (50 ryegrass seeds/tray of soil treated with digestate at the equivalent of 15 m^3/ha (i.e. 1.5 l/m^2 or 0.15 ml/cm^2) were conducted in Spring 2017. Seed trays were kept watered and were kept outdoors at airambient temperatures. No difference was found between the germination rates or early seedling growth in untreated or digestate-treated soils.

Conclusions

- It is a good idea where possible to ensure that pH is at target of 6.5, soil P and K status are at target (of “High”) and Mg status is at target (of “Moderate” in the autumn prior to sowing a high value crop such as carrots, since crop yield and quality are likely to be affected if soil pH or soil nutrient status are significantly less than ideal.

- A single digestate application of 15 m^3/ha will provide approximately 33% of the N required, 18% of the P required and 36% of the K required whilst the soil is below target for P and K. Additional digestate applications AND bagged fertilisers will be required annually in order to supply sufficient nutrients for maximum yield of two cuts of silage.

- Regular inspections of soil structure, through frequent test digs and allocation of structure scores (e.g. VESS) give quick, useful indications of the physical aspects of soil health. There is a need for a new, perhaps simpler system to assess the health of soils which are subject to frequent, intensive cultivations.

- Where soil structure has been degraded by regular, intensive cultivations, it becomes more important than ever to cultivate and harvest when soil conditions are suitable (i.e. relatively dry), since weakly structured soils can be badly damaged if worked in wet conditions. If such damage is severe, it can take decades for soils to recover and this recovery is unlikely to happen if rotations continue to include regular intensive cultivations.

- Earthworm counts are a useful indicator of soil biology, but to count them properly is time consuming. Quick test digs (removal of a spadeful of soil) can also give an indication of earthworm numbers, but care should be taken when interpreting such “quick looks”, since it is very easy to miss small earthworms and since reliable, representative data can only be gained by averaging the number of earthworms found over many pits in a field, taken regularly at similar times of the year, every year.

- Soil respiration measurements are a relatively new method for estimating the biological life in soil. Further data must be gathered on different soil types, growing systems and using different methods in order to learn how to interpret the data gained and take actions based upon it.

- Weed counts conducted in four quadrats in each treatment in each field showed that there were few weeds in total and no differences between the number of weeds present in digestate-treated and untreated grass/clover swards. There was no evidence of scorch following digestate treatment on either field at any time.

- In summary, there is no evidence from this short trial that digestate applied at 15 m^3/ha on several occasions had any deleterious effects on soil structure, microbial respiration soil earthworm populations. Neither did the digestate have any beneficial effects on these parameters. It would be a good idea to repeat the tests every 2 years annually for a period of at least 10 years in order to further study the impact of digestate on soil properties, since it is well known that soil properties can take a very long time to change in a significant way. If continuing the work, it would be a good idea to ensure that both treatments were given the same fertiliser. Any treatment effects would then be due to the physical or biological properties of the digestate rather than to a lack or excess of fertiliser nutrients.

DIGESTATE FIELD LAB APPENDICES

1a and 1b. NRM soil analysis results

2. Visual Assessment of Soil Structure

3. OPAL guide to earthworm assessment

The Digestate field lab appendices can be viewed here:
https://www.innovativefarmers.org/field-lab?id=0436327a-05b3-e611-80ce-005056ad0bd4

2c – GREATsoils Field Lab: Green Manures to increase N availability

Summary

The Field Lab took place at the Molyneux Kale Company in Ormskirk, Lancashire and ran between April 2017 and March. It investigated how different combinations of green manure species can be used to optimise the supply of nitrogen available to a following spring greens crop. The contribution of green manures was assessed by:

- Measuring soil mineral nitrogen availability
- Nitrogen uptake of the green manures and Spring greens
- Yield and quality of the Spring green crop will also be determined (By Grower)
- Financial performance of green manures vs standard practice/ control plots

Three green manure mixes were tested with varying proportions of leguminous and non-leguminous species:

- **Non-legumes**: Buckwheat (20kg/ha); Stala phacelia - 50% CoverCoat (3kg/ha); and Aubade Westerwold ryegrass (6kg/ha)
- **Legumes**: Contea crimson clover (5kg/ha); Marco Polo Persian clover (4kg/ha); Akenaton Egyptian/Berseem clover (5kg/ha); Virgo Pajbjerg yellow trefoil 1 kg/ha)
- **Mixture:** Contea crimson clover (3kg/ha); Marco Polo Persian clover (2kg/ka); Akenaton Egyptian/Berseem clover (3kg/ha); Virgo Pajbjerg yellow trefoil (1kg/ha); Buckwheat (10 kg/ha); Stala phacelia - 50% CoverCoat (1kg/ha); and Aubade Westerwold ryegrass (3kg/ha)

The trial was designed with three replicates of each of the green manures and a control plot left as bare soil, in which no green manures were planted. We then split the control plots into two. One half (the 'scientific control') received no supplementary nitrogen until spring 2018. The other farm control 'nitrogen' plot received mineral N fertiliser according to standard practice.

The green manures were planted on 28 April 2017 and cut/ incorporated on the 19th July 2017. Spring greens were sown into all plots on 10 August 2017. The crops in the plots that had had green manures also received no N fertiliser until Spring 2018. N fertiliser will be applied to the whole trial in Spring 2018 to minimise the economic impact of yield loss on the plots.

Soil and tissue samples were taken from each of the plots and analysed at strategic intervals between July 2017 and March 2018 as indicated below:

Table 32: Timings of soil and tissue samples

Date	17 Jul (Pre-incorporation)	18 Aug (4 weeks after incorporation)	20 Oct (10 weeks after incorporation)	7 Dec (20 weeks after incorporation)	15 March (32 weeks after incorporation)
Standard Soil + OM + Textural Class					
Total Soil Nitrogen (Dumas)					
Soil Mineral Nitrogen test					
CF – Nitrogen Min test					
Tissue samples (Lab)	Green manures		Spring greens	Spring greens	
Tissue Samples (N Meter)					

While the soil analyses did not pick up many differences between treatments, when crop tissue and biomass data (i.e. N uptake by the plant and N content of the tissues) were analysed, it was revealed that the green manures could make an important contribution to N availability compared to fallow ground. This does demonstrate that relying on soil data alone can be unreliable, particularly, as we found in spring, when a crop was actively growing.

The data did not show that green manures are more effective than synthetic fertiliser at supplying mineral N, but they can reduce the application of mineral fertilisers by 40 – 50%, an important contribution to crop nitrogen requirements.

Although this study focused on N availability, we should not overlook the importance of green manures from other perspectives. Anecdotal evidence from this study suggests that green manures can lower soil moisture content (this may or may not be desirable). There is strong evidence suggesting a wide range of other benefits for agriculture including improving soil biology, organic matter levels, soil structure and drainage, enhancing pollinator populations and other beneficials.

Returning to the question of N availability, the contribution of green manures may have in fact been underestimated by this study because:

- The variability of the data from the control and the ‘nitrogen’ plots were, in many instances, more variable than in the green manure plots, although this was not the case in every instance.
- 2017 was unusually dry between April and July. In more typical years (i.e. those with higher rainfall in this period at this trial location), there may be higher losses of N through leaching/anaerobic loss from the control plots with no green manures. The very dry spring also contributed to a poor green manure establishment, that in a “typical year” could be expected to produce a greater biomass.

- Carrying out tissue analyses at the same time as the Spring soil analyses would have provided more robust data to draw stronger conclusions about the contribution of the green manures in this trial.

A cost – benefit analysis from data collected in December showed that the cost per kg taken up was significantly lower in the nitrogen treatment compared to the green manure treatments, but the cost per kg of product was very similar. In respect of the latter, for the N treatment it was estimated at £0.12 £/kg, the same as the ‘Mix’, a penny higher than the ‘legume’ and a penny lower than the ‘non-legume’. This may not sound like much, but with large volumes of product coming off the field, a penny a kg either way can add up to significant sum of money.

If the trial were to be repeated, tissue analyses would be taken in parallel with the spring soil sampling. While this has budgetary implications, it would unquestionably be a worthwhile investment in terms of increasing the quality of the data.

An open day was held on 27 March 2018, and a number of suggestions were raised for future work, centred around short term green manures including:

- Using spring beans as a short-term summer cover crop between harvesting of a brassica cash crop and the subsequent sowing of another.

- Monitoring the accumulation of N during the growth of short-term green manure crops to establish the optimal timing of destruction and incorporation to deliver maximum N to a following brassica crop.

These proposals will be put forward to Innovative Farmers for consideration in spring/ early summer 2018.

1. Aims

This Field Lab investigated how different combinations of green manure species can be used to optimise the supply of nitrogen available to a following Spring Greens crop. The contribution of green manures was assessed by measuring:

- Soil mineral N availability and Total Soil N
- N content of the green manures and nitrogen uptake of Spring greens
- Yield and N content of the spring green crop will also be determined
- Financial performance of green manures vs standard practice/ control plots

The trials took place at the Molyneux Kale Company in Ormskirk, Lancashire and ran between April 2017 and March 2018. **2. Methods**

2.1 Green manure mixes

We tested three green manure mixes with varying proportions of leguminous and non-leguminous species:

- **Non-legumes**: Buckwheat (20kg/ha); Stala phacelia - 50% CoverCoat (3kg/ha); and Aubade Westerwold ryegrass (6kg/ha)
- **Legumes**: Contea crimson clover (5kg/ha); Marco Polo Persian clover (4kg/ha); Akenaton Egyptian/Berseem clover (5kg/ha); Virgo Pajbjerg yellow trefoil 1 kg/ha)
- **Mixture:** Contea crimson clover (3kg/ha); Marco Polo Persian clover (2kg/ha); Akenaton Egyptian/Berseem clover (3kg/ha); Virgo Pajbjerg yellow trefoil (1kg/ha); Buckwheat (10 kg/ha); Stala phacelia - 50% CoverCoat (1kg/ha); and Aubade Westerwold ryegrass (3kg/ha)

2.2 Trial lay out

The trial was designed as a randomised complete block with three replicates of each of the green manure treatments and a control plot in which no green manures were planted. As the trial progressed the control plot was split into two to allow the farmer to compare the green manure treatments to his standard practice “farm control”. One quarter (the “scientific control”) received no supplementary nitrogen until spring 2018. The remaining area received N according to standard farm practice. The trial was laid out according to the following design:

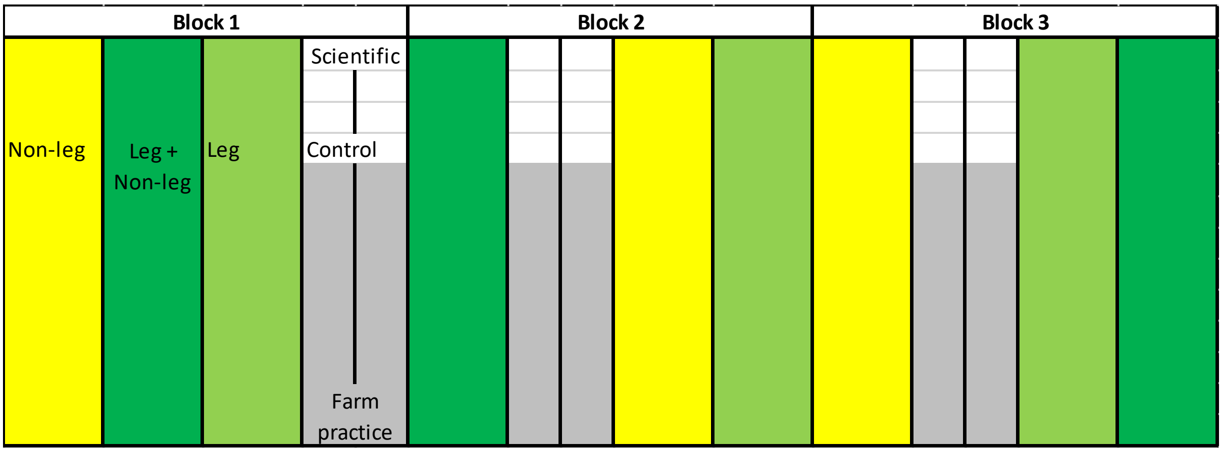


Figure 60: Trial layout

2.4 Managing the green manures

The green manures were planted on 28 April 2017 and cut/ incorporated on the 19th July 2017.

2.4 Managing the spring green crop

Spring greens were sown into all plots on 10 August 2017. The crops in the plots that had had green manures and the scientific control received no mineral N fertiliser until Spring 2018, with N applied in March after the last sampling, to minimise the economic impact of potential yield loss on these plots. The 'Farm control' received N fertiliser as per standard practice.

The original intention was to look at the crop at harvest of the farm practice to investigate differences in N uptake and soil mineral nitrogen supply at this time with December identified as a potential harvest date for the farm control. The farm control was ready for harvest by December, having had mineral nitrogen applied in September, making all December comparisons relevant. The scientific control crop and the green manure treatment crop were taken through the winter to Spring, with the trial coming to an end in March, with the application of mineral nitrogen across the trial to bring the crop to harvest for mid Spring.

2.5 Collecting the data

Soil and tissue samples were taken from each of the plots and analysed at strategic intervals between July and November as indicated in Table 33. At the October sampling an attempt was made to use the 'Laqua Nitrate Metre' to determine nitrate content of the crop tissue but difficulties in obtaining crop tissue sap and highly variable readings, meant that for this trial it was rejected as a proxy for crop tissue lab analysis. Additional work with the grower is due to take place that will include a further attempt to use the nitrate meter to test its suitability as a proxy for lab analysis.

Soil samples up to 20 weeks after incorporation had not shown the increase in available N in the green manure plots that was expected. The benefits were, however, showing up in the tissue analyses and biomass yields.

The grower, while working with a commercial fertiliser company (CF Fertilisers) had encountered a more sophisticated mineral N test developed by CF and analysed at Hill Court Farm Laboratories, that included additional available N through an incubation test of the soil sample. It was decided in consultation with the grower to use this test in the Spring as it was hoped it would be more revealing and help in determining legacy effects from treatments, rather than the standard mineral N test that provides a snapshot of plant available nitrogen on the day of sampling.

The test differs from the NRM laboratory Nmin tests previously conducted in that it also includes a measure of the amount of nitrogen that **will become** available for crop uptake through mineralisation between spring and harvest. It is calculated as follows:

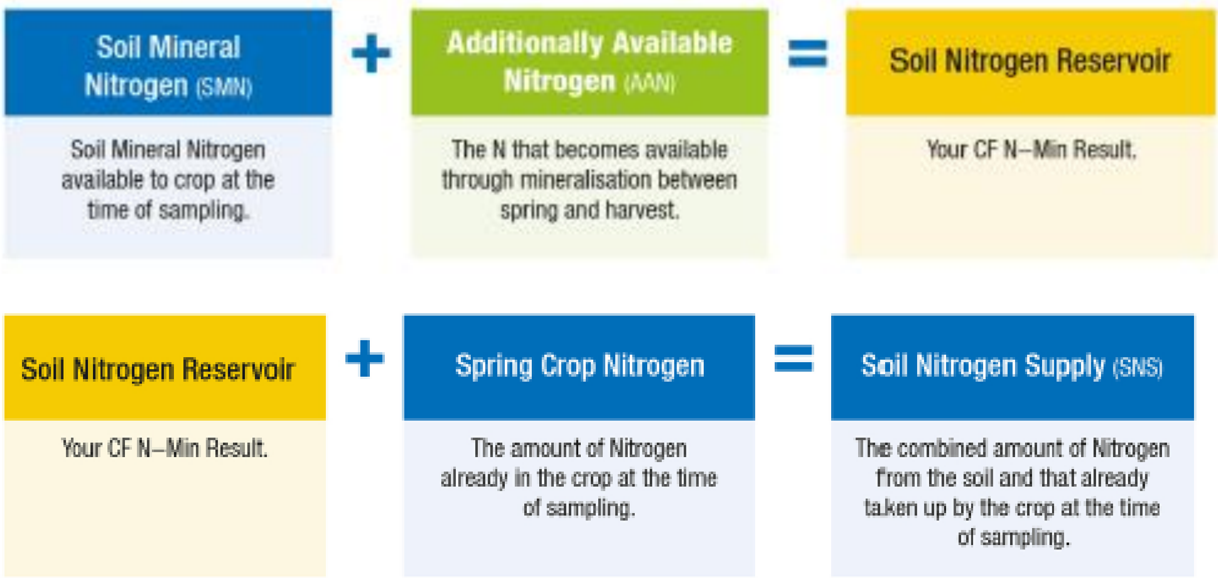


Figure 61: Mineral N test calculation methodology

The CF N-Min test also takes soil samples to a depth of 60mm instead of the 25mm used for the NRM tests. The results of this analysis are therefore not directly comparable to the previous Mineral N tests. It should also be noted that the laboratory running the test can analyse samples separately for 0-30cm (SMN + AAN) depth and 30-60cm depth (SMN) which can help separate crop available N with mineral N leached further down the soil profile, though for this trial the whole 60cm sample was analysed as one, making it impossible to discern how much mineral N was available or unavailable (too deep to be accessed by the majority of crop roots)

Table 33: Type and timing of samples taken/ analyses carried out.

Date	17 Jul (Pre-incorporation)	18 Aug (4 weeks after incorporation)	20 Oct (10 weeks after incorporation)	7 Dec (20 weeks after incorporation)	15 March (32 weeks after incorporation)
Standard Soil + OM + Textural Class					
Total Soil Nitrogen (Dumas)					
Soil Mineral Nitrogen test					
CF – N Min test					
Tissue samples (Lab)	Green manures		Spring greens	Spring greens	
Tissue Samples (N Meter)					

3. Results

3.1 Green manure crops

All three mixtures established well (Figure 62), and root development was excellent for deep rooting species (Figure 63). However, unusually dry conditions in spring slowed early growth.

There was some anecdotal evidence that the green manures reduced soil moisture (Figure 64).

Figure 62: Legume/ Non-Legume mixture

Figure 64: Impact of green manures on soil moisture (cover crops were planted on the right)

Figure 63: Root development on deep rooting green manure species

In terms of final green manure biomass assessed just prior to termination in July, there were no significant differences between dry weights of green manures, but there was a trend towards the legume/ non-legume mix having the highest dry mass per unit area, and the legume having the lowest (Figure 65).

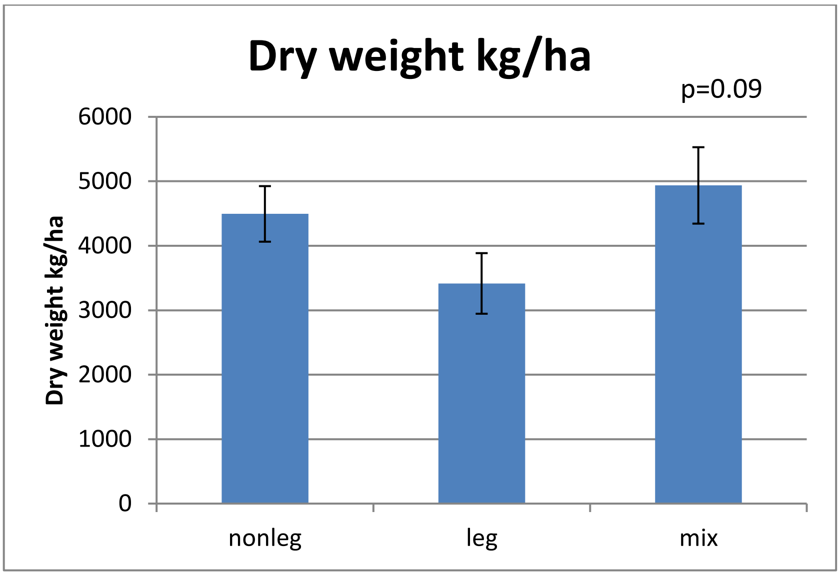
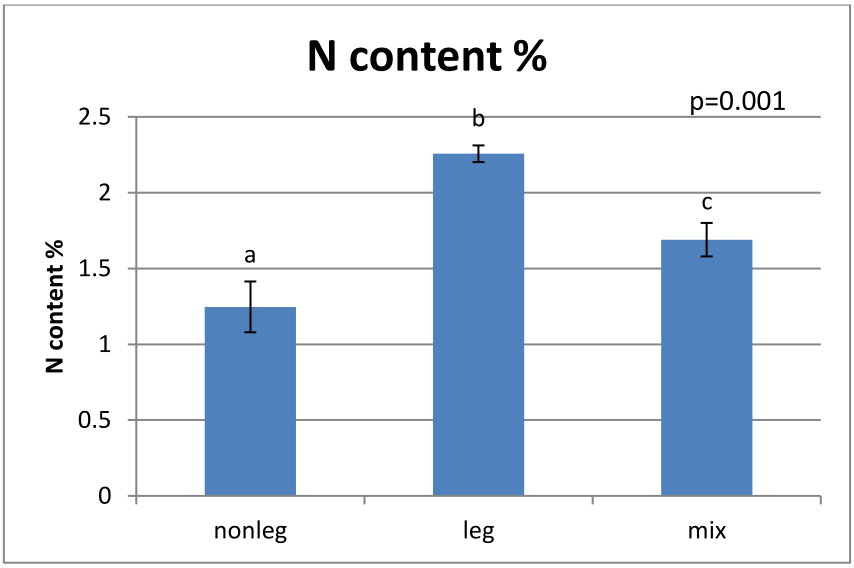


Figure 65: Dry mass of the 3 green manure mixtures (n=3)

However, as might be expected, there were significant differences between nitrogen content (%) of green manures. Legumes had the highest N content %, and non-legumes the lowest (Figure 66).



*The same letters (Tukey Test) mean no significant difference. So, in this example, all three green manure treatments are significantly different from one another.

Figure 66: N content of the 3 green manure mixtures (n=3)

In terms of the nitrogen incorporated into the soil (i.e. the combination of biomass and N content) there were no significant differences between the mixtures, but there was a trend for the' legume/ non-legume' mix and 'legume only' to have higher N content than the 'non-legume' (Figure 67)

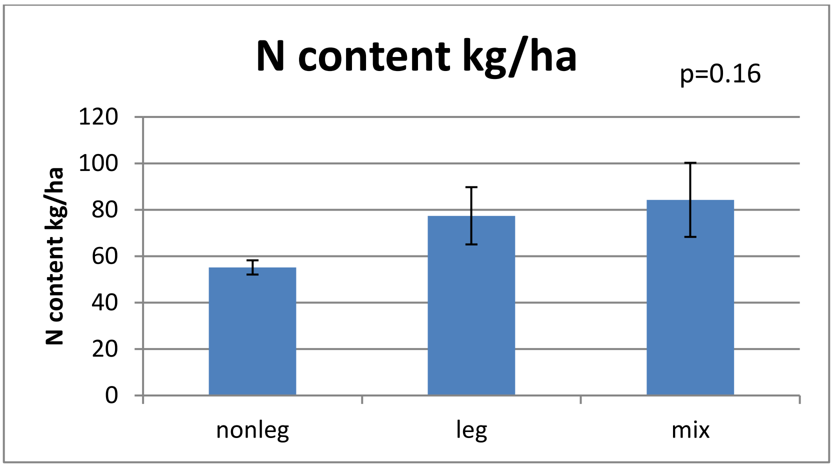
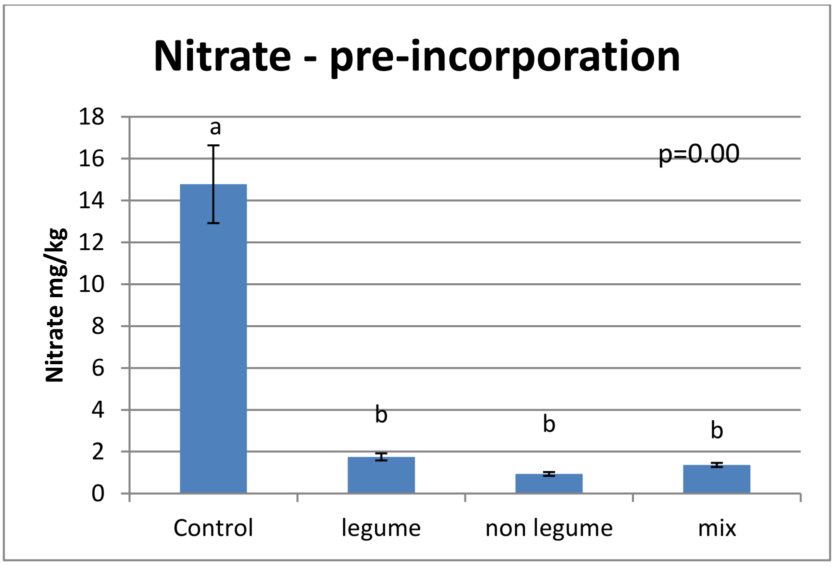


Figure 67: N content (total added to soil) for the 3 green manures (n=3)

3.2 Soil test results

3.2.1 Pre-incorporation of green manures (July 2017)

There was significantly higher soil nitrate in the control compared to the green manures (Figure 68). This was expected, with the difference being a measure of the nitrate taken up by the growing green manure crops compared to the control, where the nitrate remained in the soil. This is reflected in the total available nitrogen in the different treatments



*The same letters mean no significant difference. So, in this example, there is no significant difference between the green manure treatments, but the control is significantly different from all the green manures

Figure 68: Nitrate levels in control and green manures pre-incorporation (n=3)

However, there was no significant difference between the treatments in terms of ammonium (Figure 69).

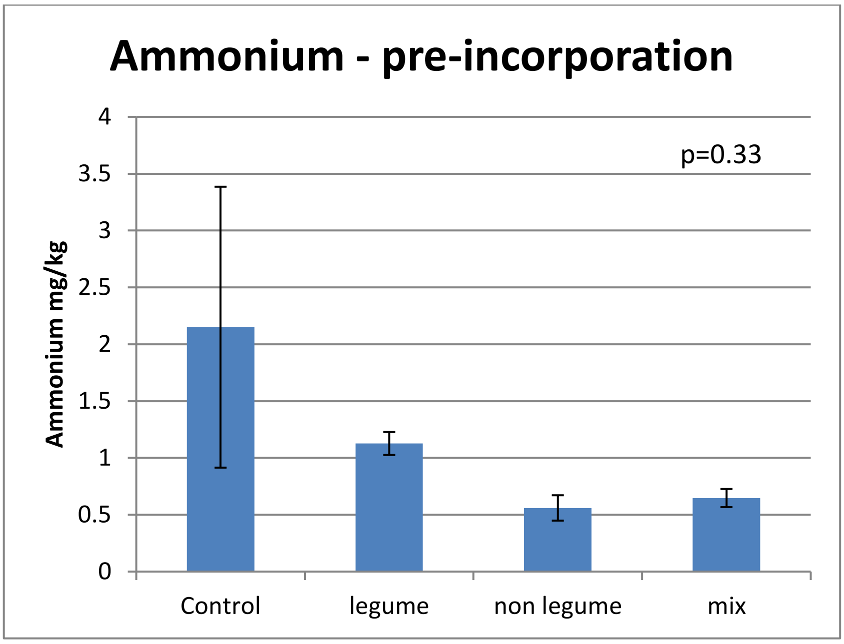


Figure 69: Ammonium in control and green manures pre-incorporation (n=3)

While total available N was higher in the control plots (Figure 70), there was no significant differences in total soil nitrogen (Figure 71). The 30kg/ha available N in the control plots was approximately 25kg/ha higher than the available N in the green manure plots.

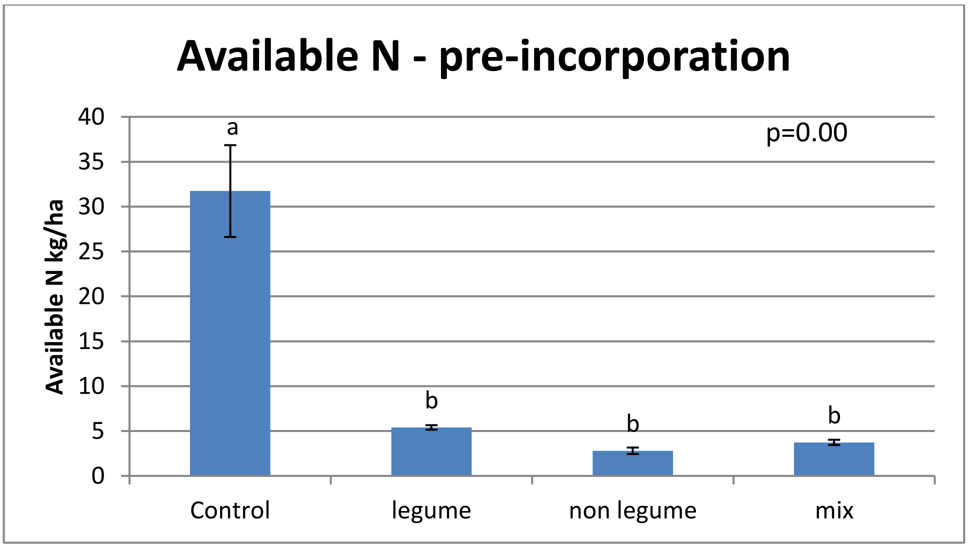


Figure 70: Available N in control and green manures pre-incorporation (n=3)

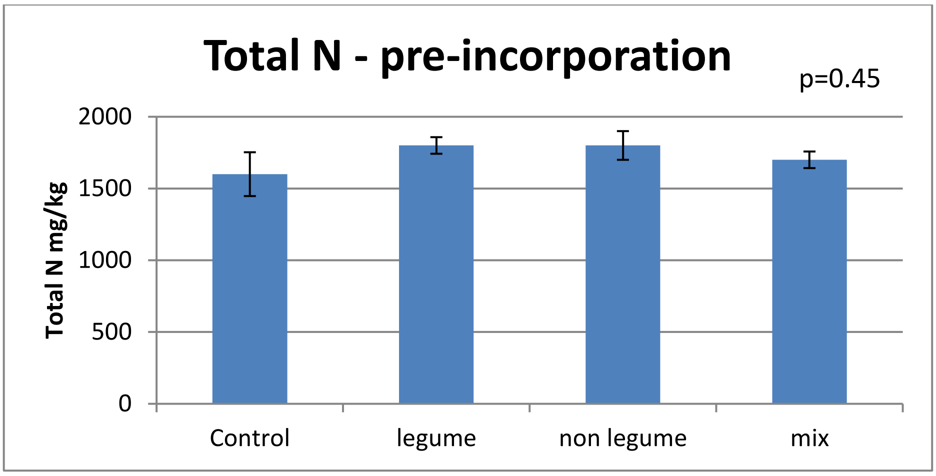
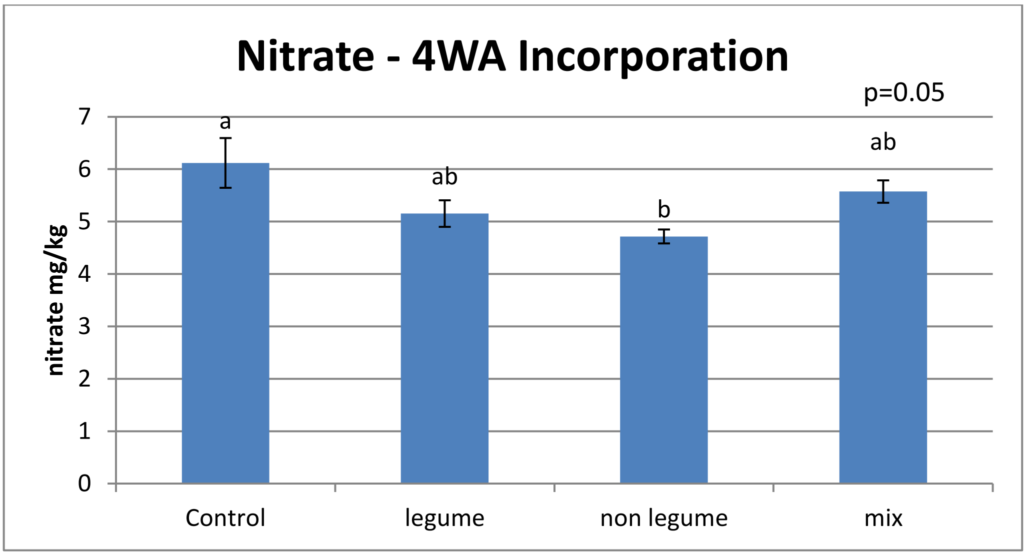


Figure 71: Total soil N in control and green manures pre-incorporation (n=3)

3.2.2 Four weeks after incorporation (August 2017)

By 4 weeks after incorporation, the picture had changed with respect to Nitrate levels (Figure 72) and available N (Figure 73). In both respects, levels in the green manure treated plots were comparable with the control, with the exception of the non-legume green manure plots, which were significantly lower.



*The same letters mean no significant difference. So, in this example, the control, legume and mix are not significantly different from one another. Similarly, the 3 green manures are not significantly different from one another, but the non-legume is different from the control.

Figure 72: Nitrate levels 4 weeks after incorporation (n=3)

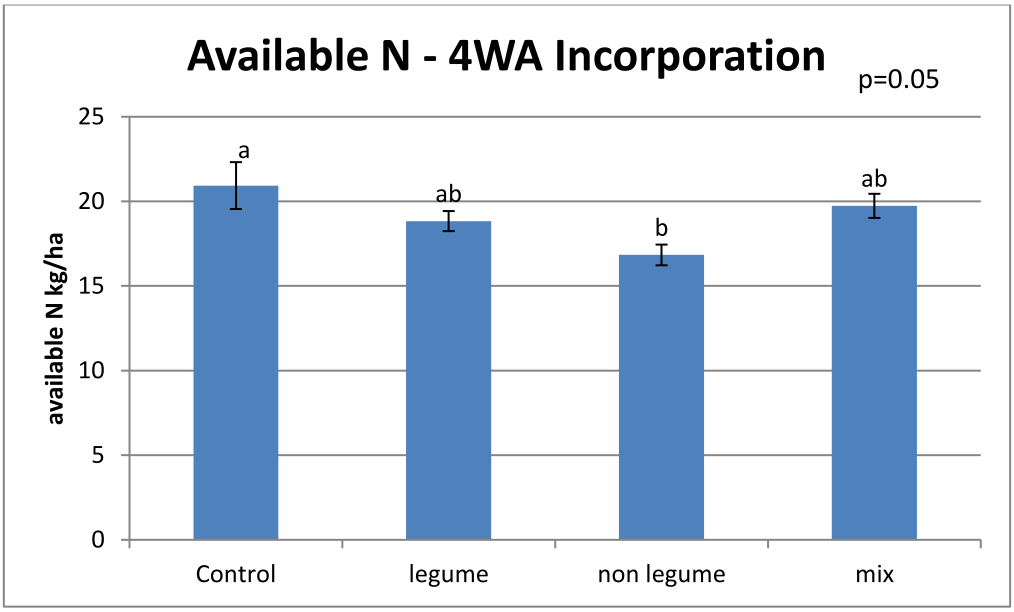


Figure 73: Available N 4 weeks after incorporation (n=3)

However, there were still no significant differences between treatments with respect to ammonium (Figure 74) and total soil N (Figure 75)

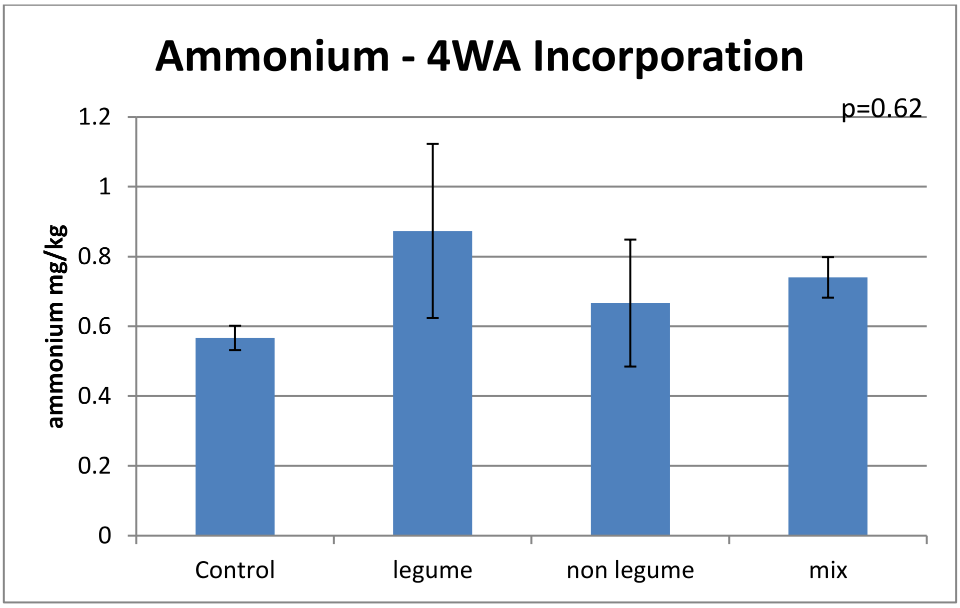


Figure 74: Ammonium 4 weeks after incorporation (n=3)

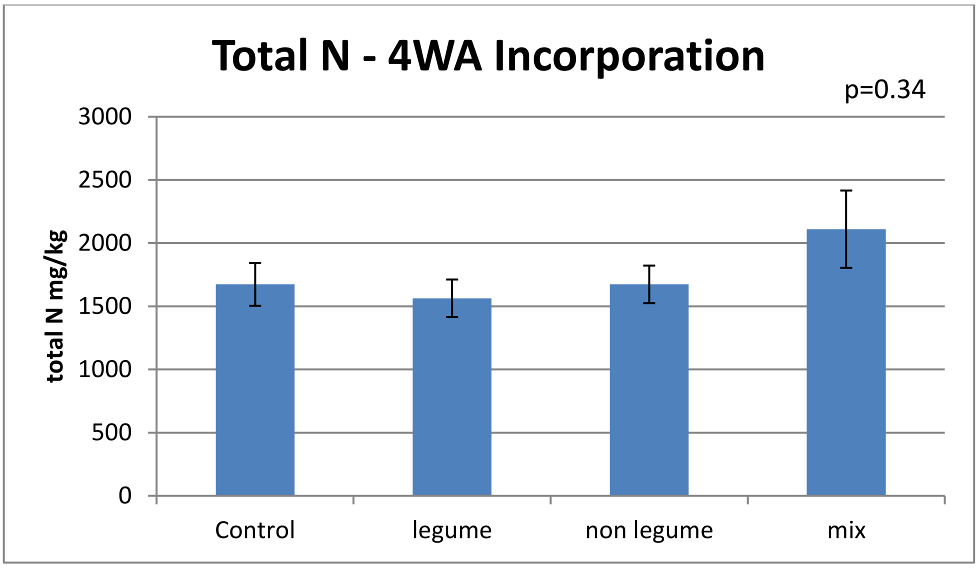


Figure 75: Total soil N 4 weeks after incorporation (n=3)

3.2.3 Ten weeks after incorporation (October 2017)

At this sample timing, 134 kg/ha of N had been applied (in early September) to the 'Standard Farm practice' plots, creating an additional treatment, 'nitrogen'.

In terms of nitrate levels (Figure 76), at this stage the data showed that levels were significantly lower in all the green manure plots compared to the scientific control and 'nitrogen' plots, and probably highest in the 'N Fertilizer' plots, although the data was variable. This was reflected in the Available N (Figure 77)

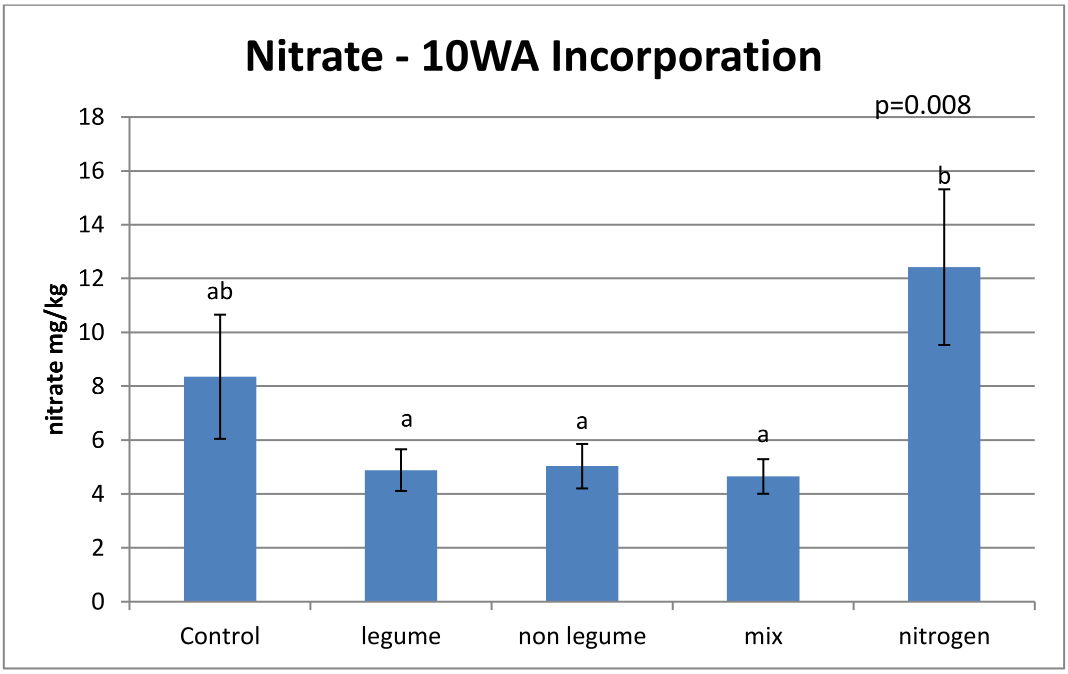


Figure 76: Nitrate levels 10 weeks after incorporation (n=3)

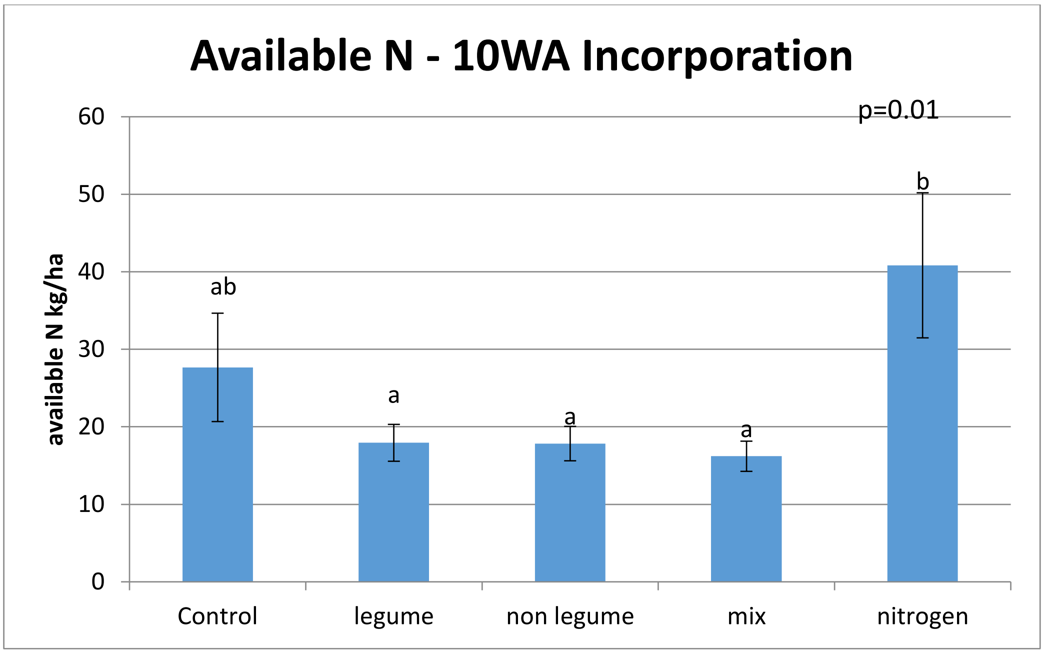


Figure 77: Available N 10 weeks after incorporation (n=3)

There were still no significant differences between any of the treatments with respect to Ammonium (Figure 78) and total soil N (Figure 79)

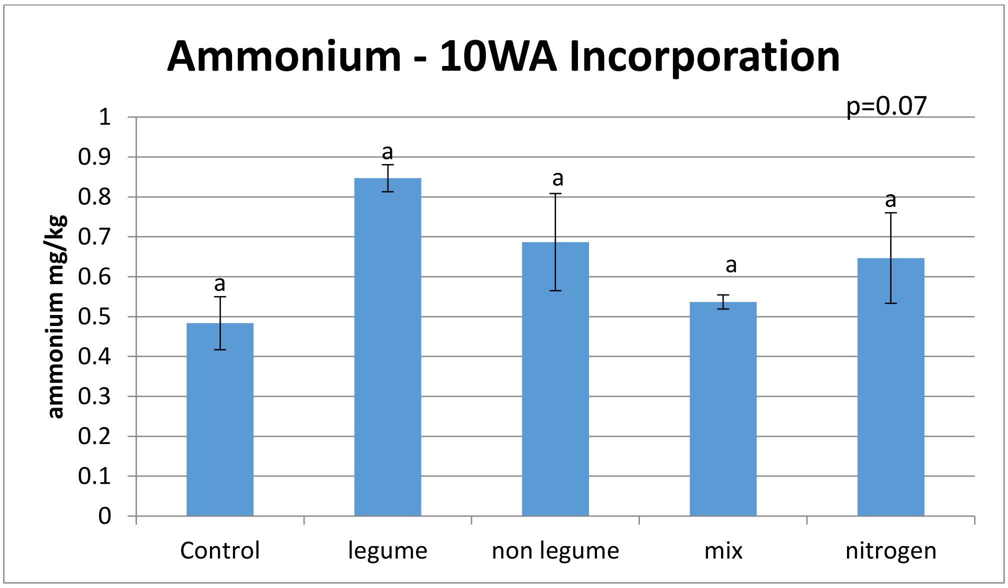


Figure 78: Ammonium 10 weeks after incorporation (n=3)

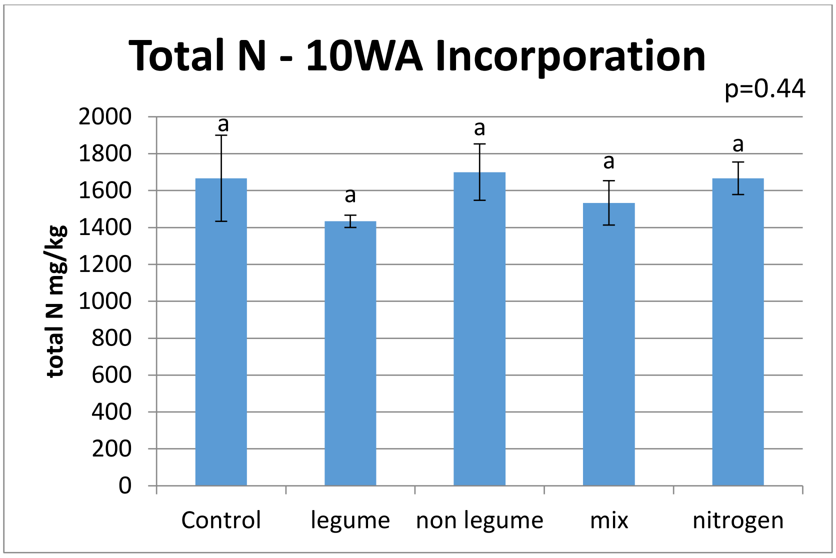


Figure 79: Total Soil N 10 weeks after incorporation (n=3)

3.2.4 20 Weeks after incorporation (December 2017)

By 20 weeks after application there were no significant differences between any of the treatments in terms of Nitrates (Figure 80), Available N (Figure 81), Ammonium (Figure 82) or total soil N (Figure 83). However, the data was more variable for the nitrogen treatment (with respect to Nitrates and available N) and the control (with respect to ammonium and available N) compared to the green manure treatments.

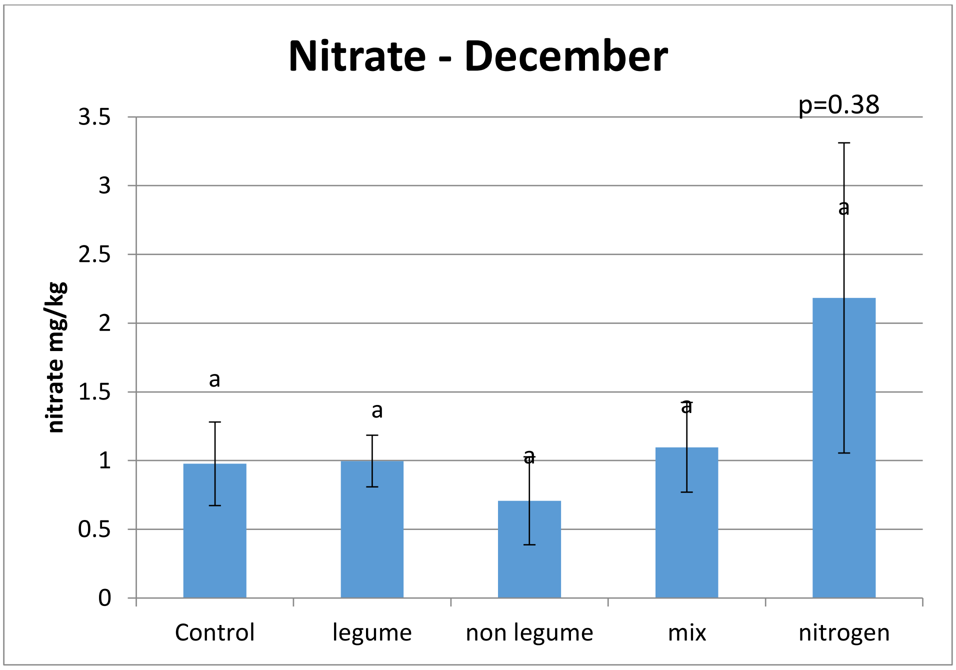


Figure 80: Nitrate levels 20 weeks after incorporation (n=3)

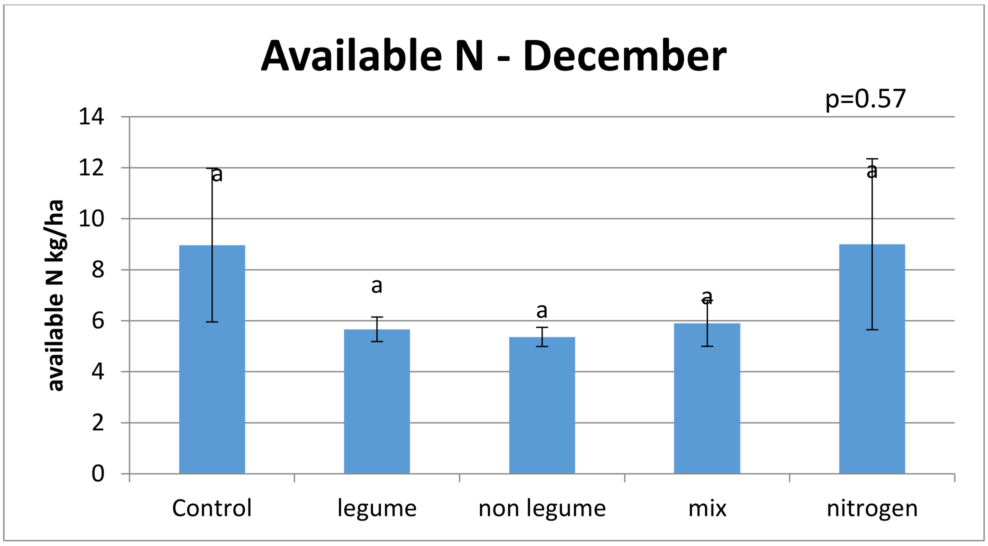


Figure 81: Available N 20 weeks after incorporation (n=3)

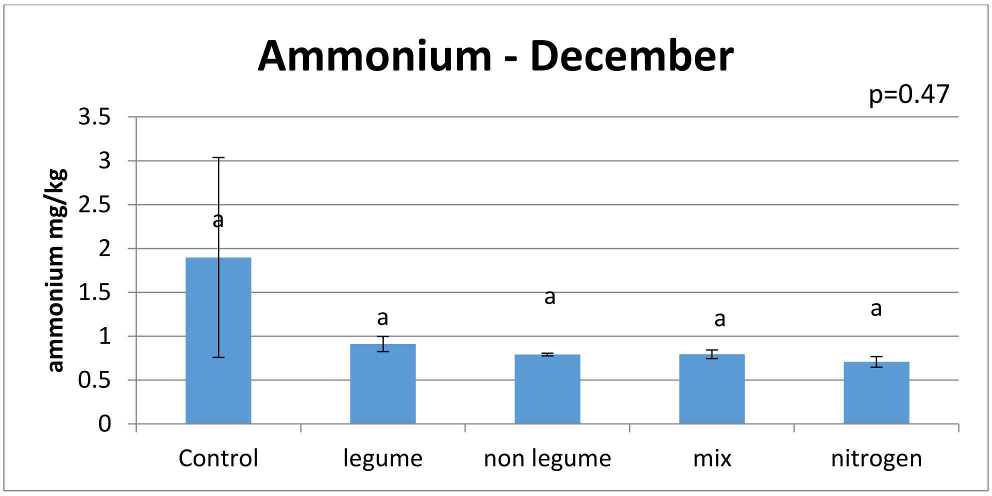


Figure 82: Ammonium 20 weeks after incorporation (n=3)

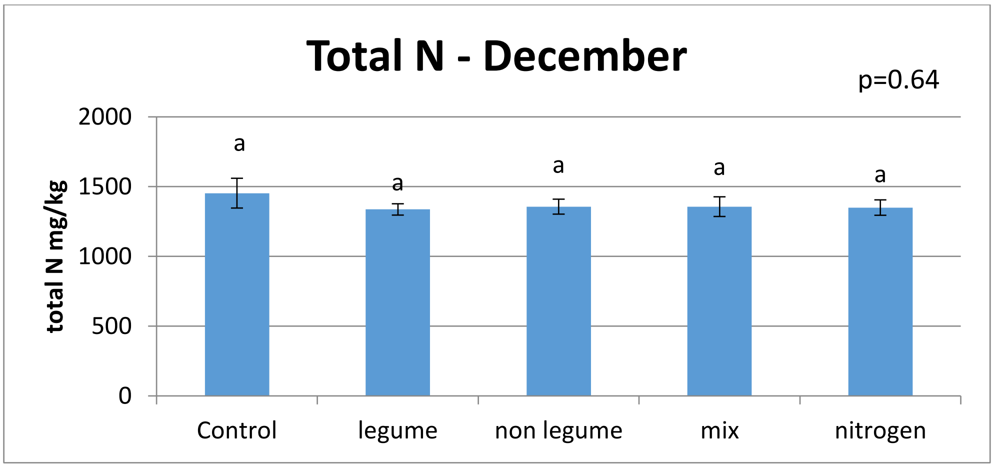


Figure 83: Total soil N 20 weeks after incorporation (n=3)

Combining all soil sampling data for soil mineral nitrogen from green manure incorporation in late July (0 weeks), mid August (4 weeks after incorporation), early October (10 weeks after incorporation) and early December (20 weeks after incorporation) helps to build a picture of soil mineral nitrogen availability following different treatments. Note that in July and August the Control was a single treatment. From October onwards the Control was split into Farm Control (Standard practice with nitrogen applied, and Scientific control with no applied nitrogen. The spike in available nitrogen for the Farm control treatment in October was due to mineral nitrogen being added in September. The green manure treatments had lower available nitrogen in July as the green manure crop had taken up nitrogen from the soil, with the control treatment having no actively growing crop or weeds to use available nitrogen.

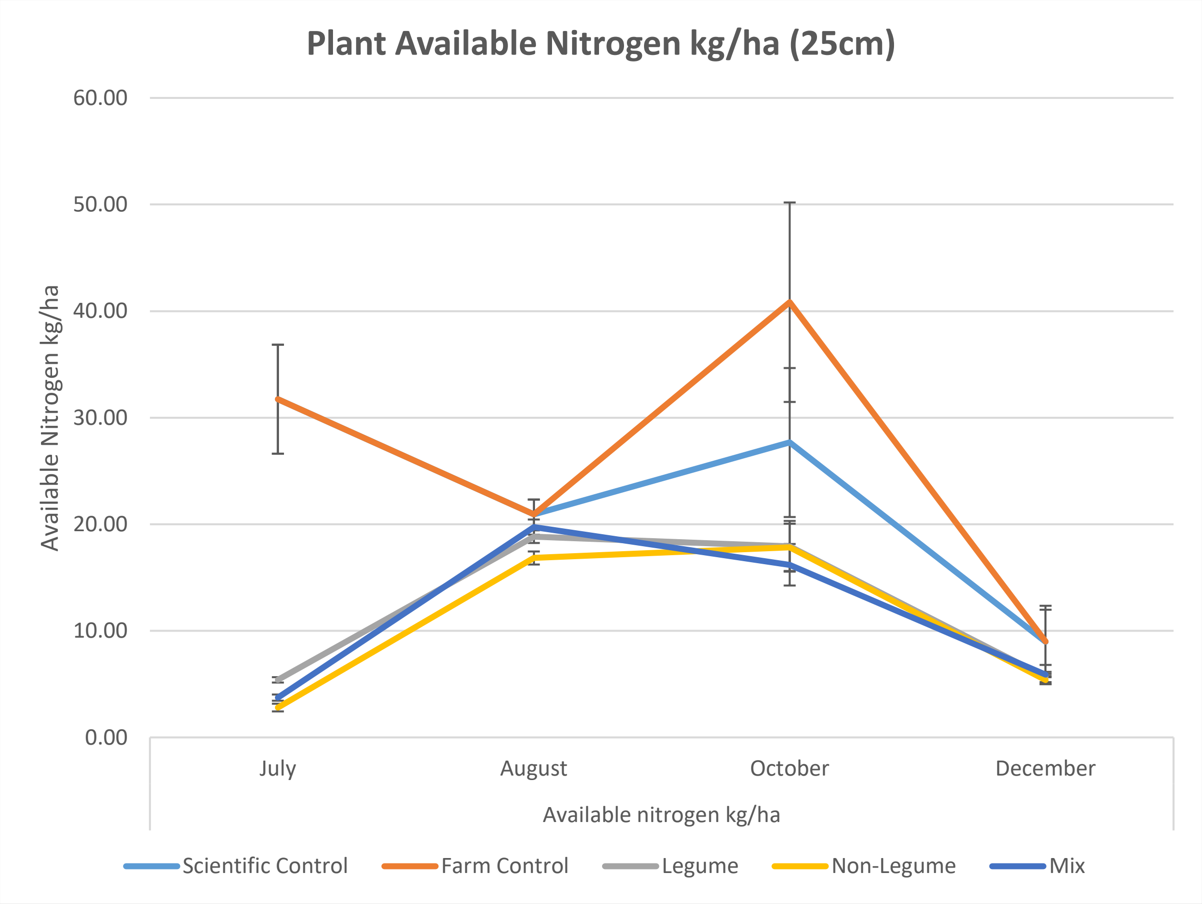


Figure 84: Soil mineral N for all treatments for 20 weeks after green manure incorporation (n=3)

4. Plant tissue results

Plant tissue samples of the spring green crop were taken 10 and 20 weeks after incorporation of the green manures (green manure plant tissue results were discussed in section 3.1)

4.1 Ten weeks after incorporation

At 10 weeks after incorporation the results show no significant effect from treatments on Dry matter yield (Figure 85) or N uptake (Figure 86) There was, however a trend towards both higher yield and N uptake from fertilised treatment and legume and non-legume treatments yielding higher than cover crop mix.

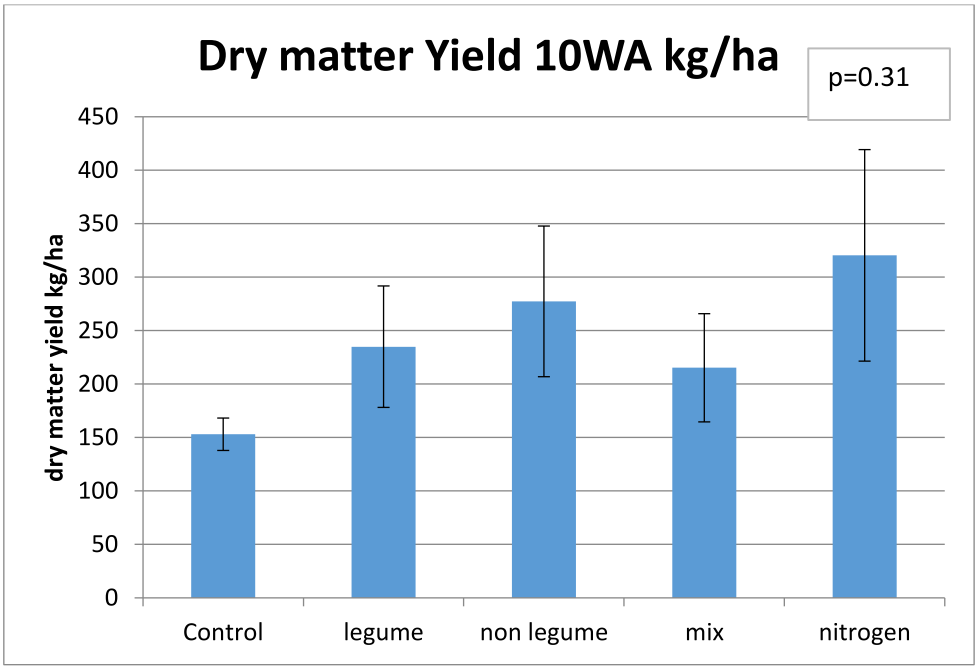


Figure 85: Dry Mass Yield of spring greens 10 weeks after incorporation (n=3)

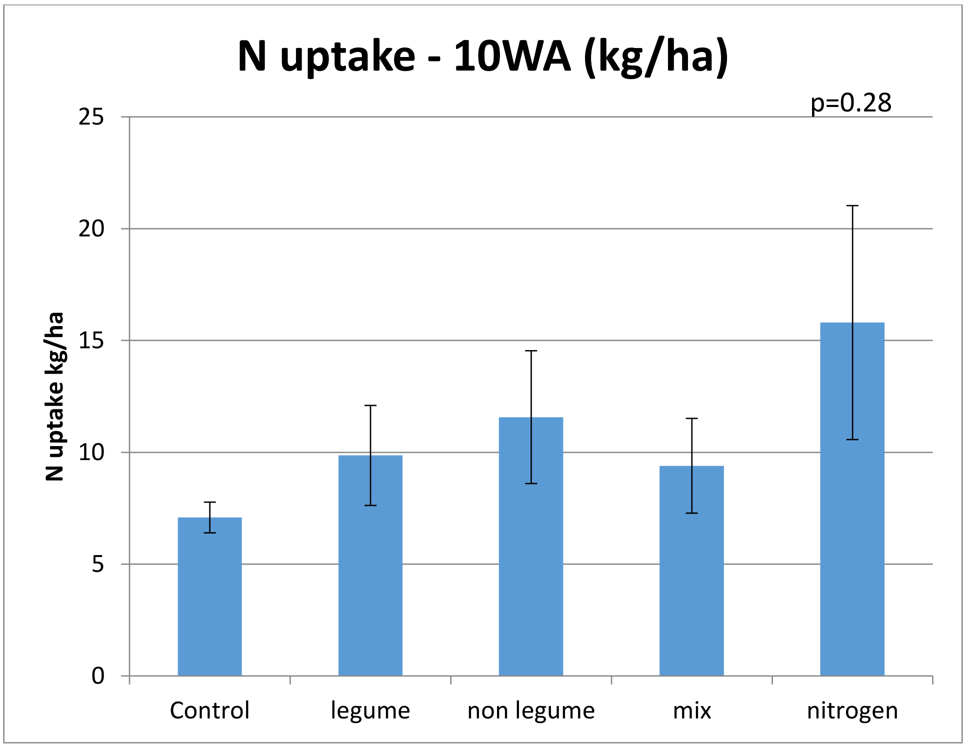


Figure 86: N uptake of spring greens 10 weeks after incorporation (n=3)

4.2 Twenty weeks after incorporation

4.2.1 Nitrogen

By 20 weeks after incorporation the data showed that, both in terms of Dry Mass Yield (Figure 87) and N content (Figure 88) and N uptake (Figure 89) green manures were the same as control, and all green manures the same as the nitrogen treatment, However, the nitrogen treatment was higher than the control.

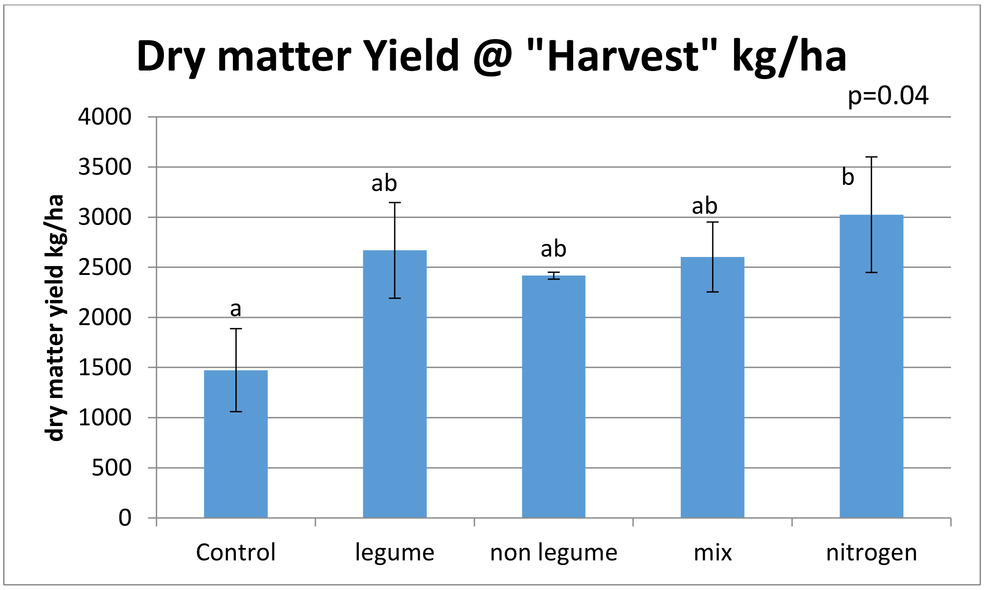


Figure 87: Dry Mass Yield of spring greens 20 weeks after incorporation (n=3)

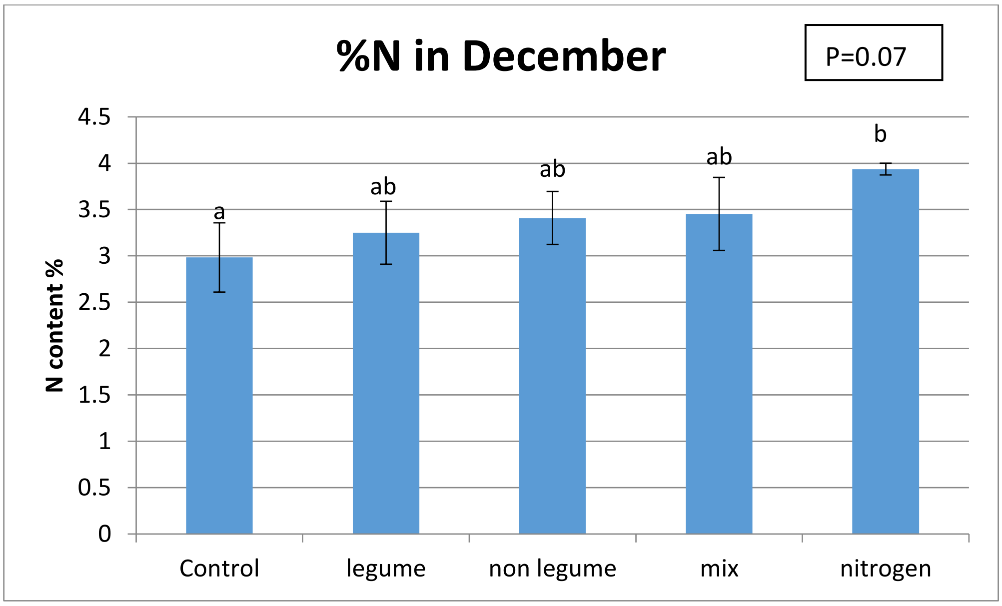


Figure 88: N Content of spring greens 20 weeks after incorporation (n=3)

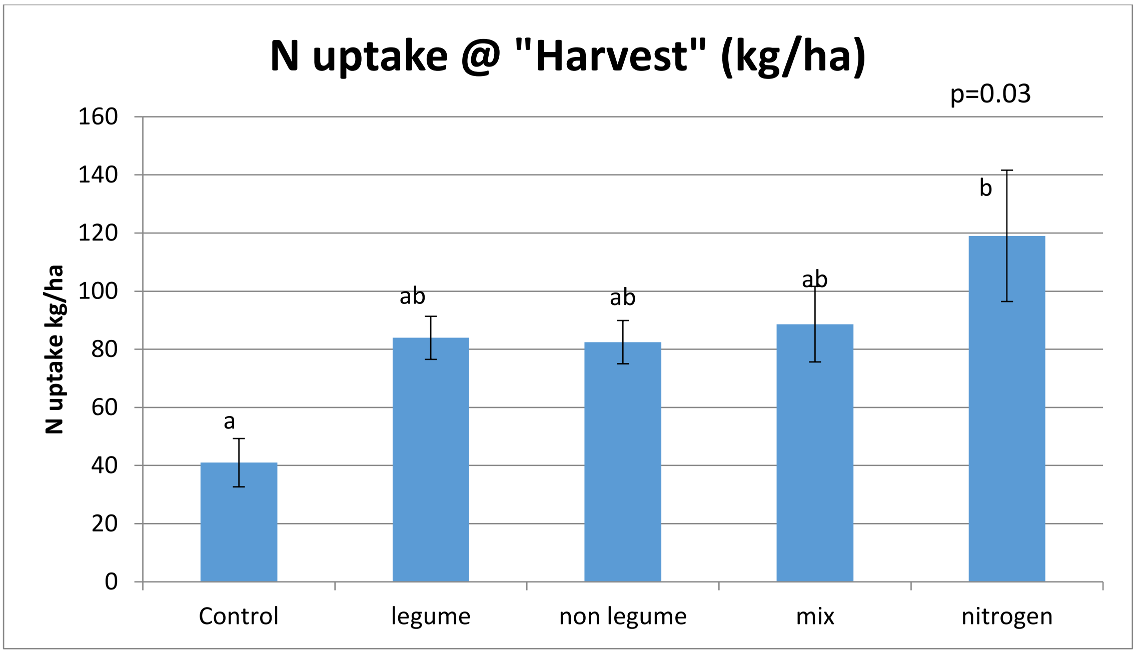


Figure 89: N uptake of spring greens 20 weeks after incorporation (n=3)

However, looking across all the graphs with respect to the crop 20 weeks after green manure incorporation reveals that although the statistical test used (the 'Tukey Test') showed non-significant differences between the green manures and both the scientific ('Control') and farm control ('nitrogen'), the data suggests a trend towards 3 treatment groups: the 'control', the 'cover crops' collectively and the 'nitrogen'. These three treatment groups appear to be adding approximately 40kgN/ha, 80kgN/ha and 120kgN/ha respectively. This suggests (by subtracting the latent soil N reservoir) that the green manure group could contribute approximately 50% (40kgN/ha) of the 80kg/ha supplied by the mineral N application in the first 20 weeks of crop production.

A more sensitive statistical analysis, orthogonal linear contrasts (OLC) compares groups of treatments based on a set of hypotheses, rather than simply comparing all individual treatments with each other.

The OLC test was used for yield data using the following four hypotheses (Table 34):

- Making an application (green manures or fertiliser) to the control gives a significantly higher yield.
- There is no significant difference between the 'Nitrogen Mineral N and Cover crop in terms of yield
- There is a trend towards a higher yield from legume containing green manures compared to the non-legume containing green manure

- There is a significant difference between the pure legume and legume/non-legume mix in terms of yield (higher for pure legumes).

Table 34: OLC analysis on dry matter yield kg/ha

Contrasts	p value
Treatment	0.03137 *
Treatment: Application vs Control	0.04311 *
Treatment: Mineral N vs Cover crop	0.15219
Treatment: Legume vs non-legume	0.08654 .
Treatment: Pure vs mix	0.04077 *

For N content (Table 35):

- There is a significant difference from applying N but no difference between mineral N and cover crop N treatments.
- There is no difference between Legume vs non-legume.

Table 35: OLC analysis on N content

Contrasts	p value
Treatment	0.05368
Treatment: Application vs Control	0.01098 *
Treatment: Mineral N vs Cover crop	0.88385
Treatment: Legume vs non-legume	0.2882
Treatment: Pure vs mix	0.13862

For N uptake (Table 36):

- There is a significant difference from applying N (either as fertiliser or green manure) but no difference between mineral N and cover crop N treatments.
- There is no difference between Legume vs non-legume
- There is a difference between the pure legume and a legume non-legume mix (mix gives higher N uptake)

Table 36: OLC analysis on N uptake

Contrasts	p value
Treatment	0.0243 *
Treatment: Application vs Control	0.0116 *
Treatment: Mineral N vs Cover crop	0.392
Treatment: Legume vs non-legume	0.1186
Treatment: Pure vs mix	0.0469 *

4.2.2 Additional Nutrients

In December at the planned harvest of the farm control a full foliar analysis for all macro and micro nutrients was performed.

Nutrient content results showed that content (%) of P, K, S, Mg, Ca, Na, Cu, Fe, B and Mo in the brassica were all non-significant. Nutrient content (%) of Mn (p=0.002) and Zn (p=0.001) in the brassica were significant. In both cases the “Farm control” treatment was significantly higher than all other treatments.

When nutrient content was combined with dry matter yield results showed a very similar pattern to the data for N uptake. In fact, of the nutrients analysed, P (p=0.05) (See Figure 90 for an example of how many other nutrient uptake results follow the pattern of N), K (p=0.06), Mg (p=0.03), Ca (p=0.04), Na (p=0.05), Cu (p=0.06), Zn (p=0.01) all gave the same results with the Tukey test giving the following output; Scientific Control = a; Legume =ab; Non-legume = ab; Mix = ab; Farm Control (‘nitrogen’) = b. As with N uptake, there is a trend towards three treatment groups for these nutrients, with the green manure treatment plots supplying up to 75% of the nutrients in the Farm Control standard practice plots.

The Tukey test suggested all treatments were the same for sulphur (S) uptake. For Mn the Tukey test indicated the Farm Control gave a significantly higher Mn uptake than all other treatments. Fe, B and Mo uptake were all non-significant.

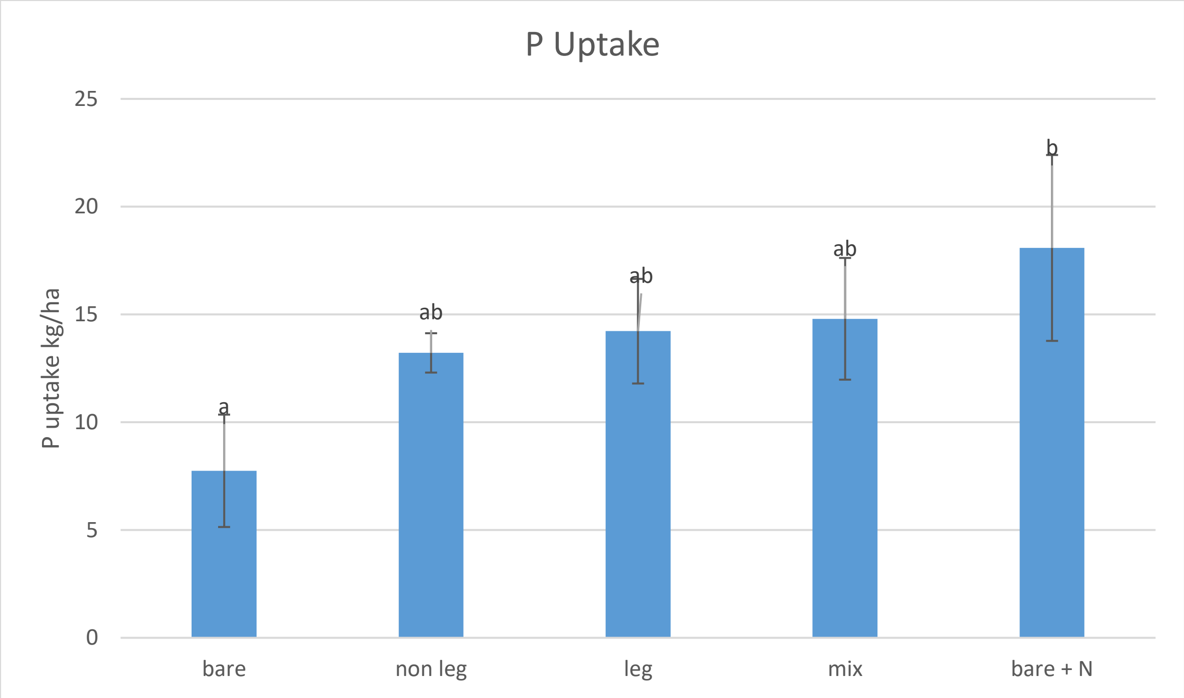


Figure 90: P uptake of spring greens 20 weeks after incorporation (n=3)

5. N min and Additional Available Nitrogen (CF.Fertilisers Testing)

5.1 What is the CF N-Min test and why was it done?

As highlighted in the methods section, soil samples up to 20 weeks after incorporation had not shown increased available N in the green manure plots compared to the control. Increases in N availability were showing up through crop sampling and tissue analysis.

In Spring a decision was taken through consultation with the grower to try a different mineral N test, offered through CF Fertilisers that, through an incubation test, would offer the additional available N to compliment the soil mineral N (nitrate + ammonium) data and provide more detailed information on N release over the growing season. This test includes a measure of the amount of N that will become available for crop uptake and therefore may help to determine potential legacy effects from the green manure treatments. It is calculated as follows:

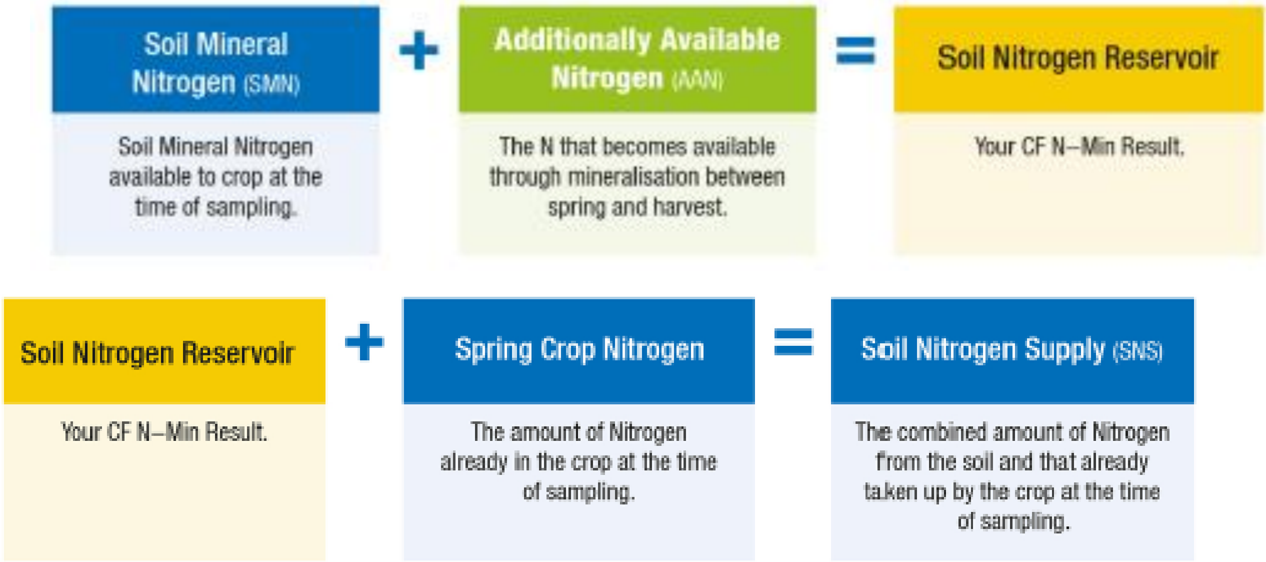


Figure 91: Mineral N test calculation methodology

The CF N-Min test also takes soil samples to a depth of 60mm instead of the 25mm used for the NRM tests. The results of this analysis are therefore not directly comparable to the those performed earlier in the trial but can be used to compare treatments at sample timing in March, and due to the additional available N test, to compare the treatments more long-term.

5.2 N-Min Results

The CF N-Min tests did not reveal any significant differences between the green manures and the control for available N in March (Figures 92 (nitrates); 93 (ammonium); 94 (Soil mineral N (nitrate + ammonium); 95 (Additional available N); and 96 (N reservoir).

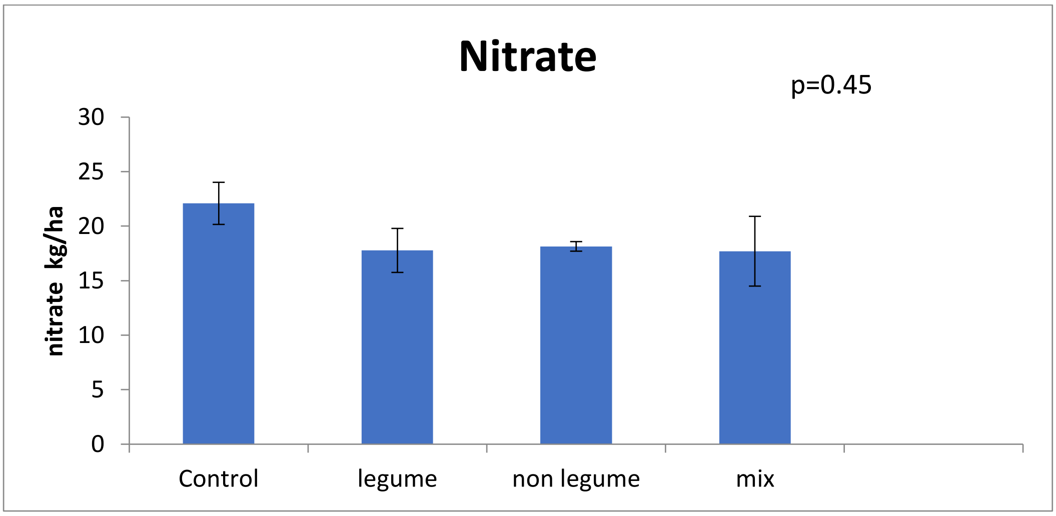


Figure 92: N-min Nitrates (n=3)

Mean nitrate = 18.9±1.1kg/ha

N.B. higher nitrate levels in control probably due to a very small thin crop leading to low levels of N uptake. This highlights the importance of taking tissue samples to compliment this data and provide a full picture.

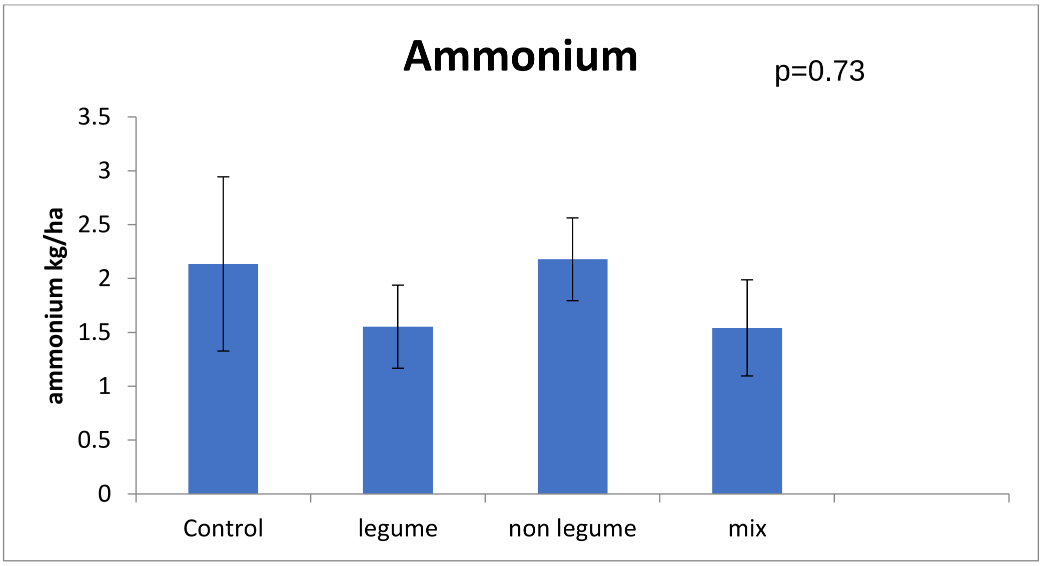


Figure 93: N-min Ammonium (n=3)

Mean ammonium = 1.9±0.2kg/ha

Ammonium results reveal no significant differences between treatments, meaning all treatments essentially the same according to the stats.

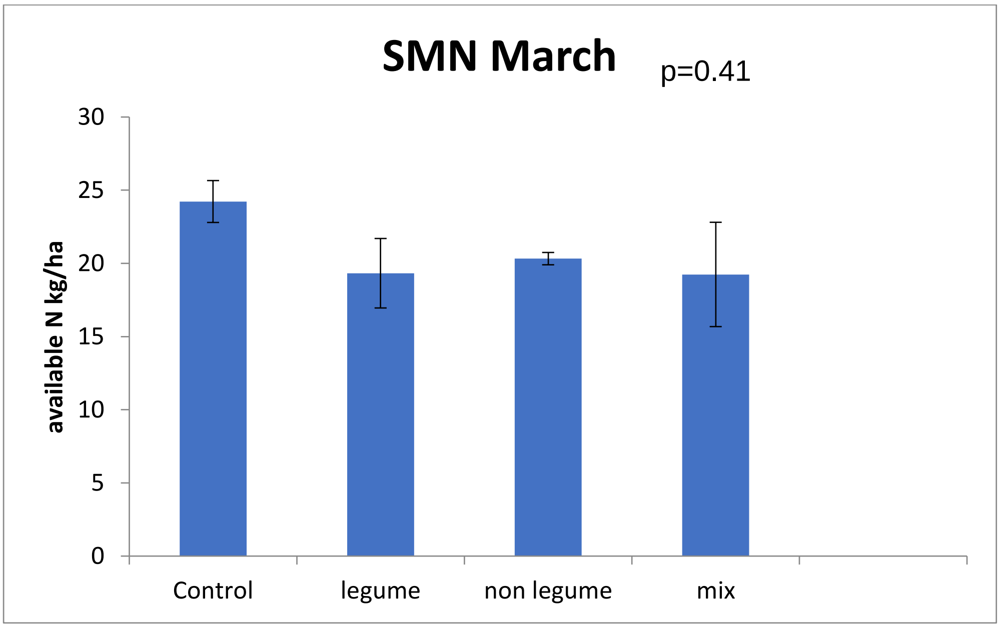


Figure 94: N-min Soil Mineral Nitrogen (n=3)

Mean SMN = 20.8±1.1kg/ha

Soil mineral N (Nitrate + Ammonium) results reveal no significant differences between treatments, meaning all treatments essentially the same according to the stats.

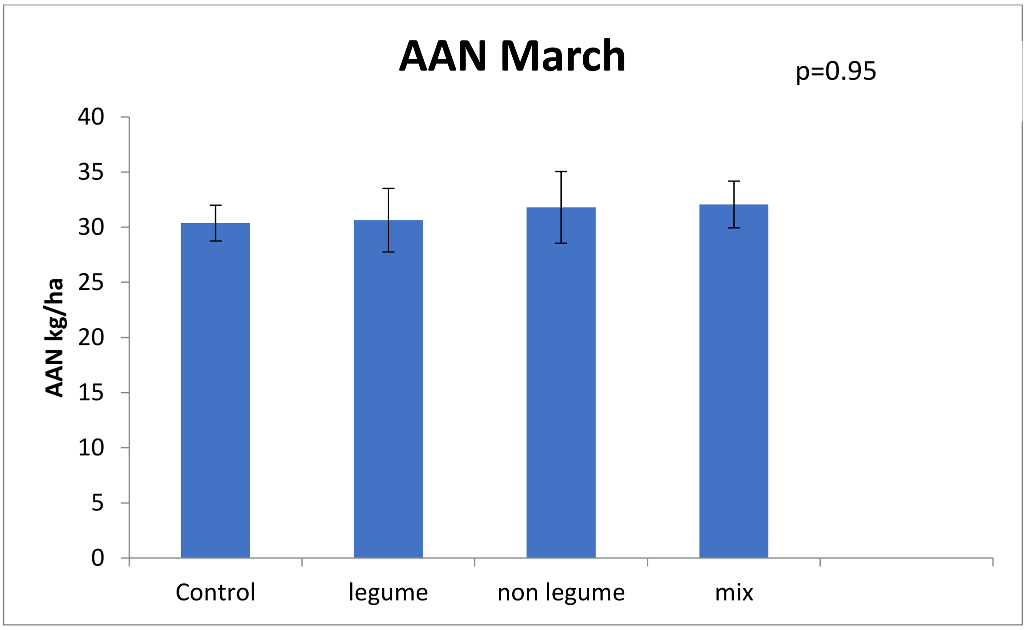


Figure 95: N-min Additional Available N (n=3)

Mean AAN = 31.2±1.1kg/ha

Additional available N results reveal no significant differences between treatments, meaning all treatments essentially the same according to the stats.

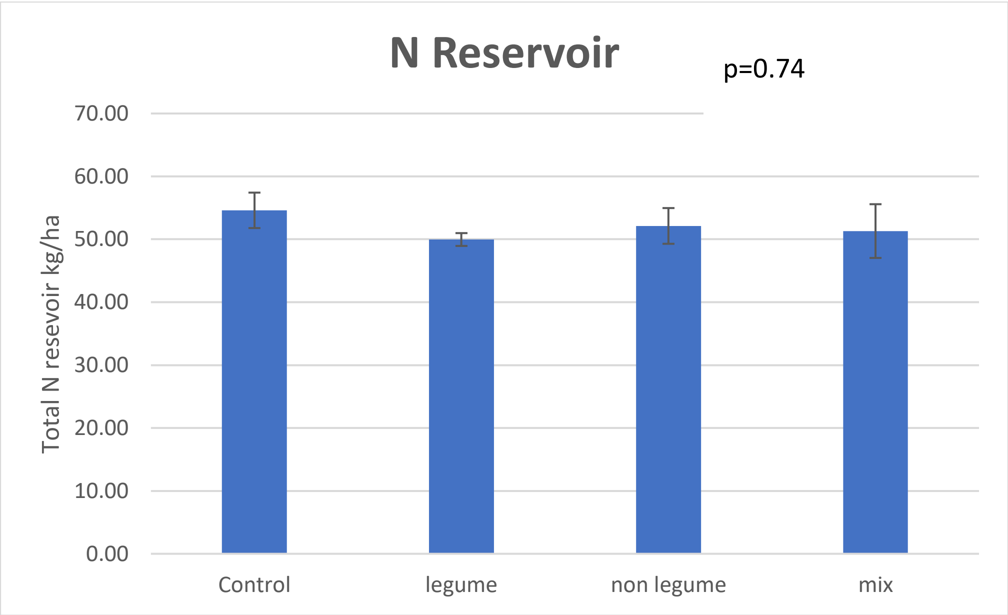


Figure 96: Nitrogen reservoir, March 2018 (n=3)

Mean N reservoir= 52.0±1.4kg/ha

Nitrogen reservoir (SMN + AAN) results reveal no significant differences between treatments, meaning all treatments essentially the same according to the statistical analysis.

Spring Crop N content data is missing to allow determination of the Total Soil N supply for the growing season from August to sampling in March. This shows the importance of collecting crop tissue data to use in combination with the soil data.

Results show that the soil N reservoir is the same across treatments, including the control but we know the crop was denser, and larger (from data collected in December) and had therefore taken up more N than the control treatment, which could establish a significant differences between the control and the three green manure treatments for SNS, and may help establish significant differences between green manure treatments for SNS supply.

Due to the poor crop growth in the control plots, the comparison of Soil N to the green manure plots is not a fair one but comparison between green manure treatments is. There is no evidence from this test alone that any of the green manure treatments is any better at supplying N to the following crop than any other and results did not establish legacy effects from the March soil sampling, in the form of higher Additional Available N.

Making a *huge* assumption that N uptake in the crop in December could act as a proxy for N uptake in March at the time of soil sampling the following figures can be derived (Table 37 and Figure 97);

Table 37: Soil N Supply, March 2018

Treatment	N reservoir kg/ha	N uptake (December) kg/ha	SNS Assumption kg/ha
Control	54.6	41.0	95.6
legume	50.0	83.9	133.9
non legume	52.1	82.5	134.6
mix	51.3	88.6	140.0

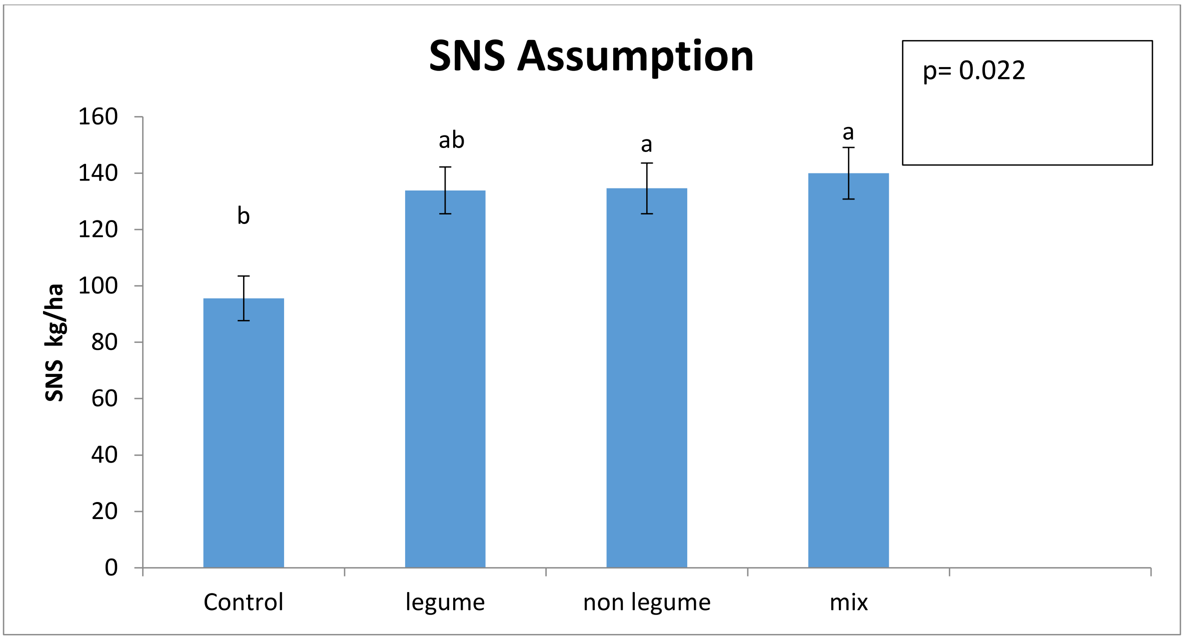


Figure 97: Soil N Supply, March 2018

The graph above shows the results of adding the N reservoir data (Figure 96) from March to the N uptake data in December (Figure 89) to provide an estimate of Soil N supply (SNS).

The data comes with a heavy caveat that tissue samples were not collected in March which would have provided a more accurate SNS but **making an assumption that N uptake between early December and early March did not change much (possible but unlikely as the spring green continues to grow slowly through the winter months),** this data provides an estimate of SNS from the different treatments.

An analysis of variance indicated a significant result with the Tukey HSD test showing that the mix and non-legume treatments have a significantly higher SNS supply than the control.

The legume treatment is not significantly different from either the other two treatments or the control according to the Tukey test but there is a strong trend towards this treatment giving a higher SNS than the control.

6. Nitrogen use efficiency (December)

The data collected up until December (when farm practice Control plots were due for harvest) was used to calculate N use efficiency (Table 38). The nitrogen, legume and legume/ non-legume mixtures showed a similar efficiency (55 – 58%), but the non-legume green manure was higher.

Table 38: Nitrogen use efficiencies

Treatment	Nitrogen Use Efficiency (NUE)
legume	55%
non legume	75%
mix	57%
nitrogen	58%

Latent plant available soil N was found to be 40.99kg/ha (calculated from untreated control crop uptake), and can be subtracted from N added by treatments.

On the nitrogen plots, 134kgN/ha (400kg/ha product @33.5%) were used and the crop took up 119.03 kg/ha N, giving a N use efficiency (NUE) of = 58%. In term of the green manures, the data showed that:

- Legume green manures added 77.42kg/ha N. Crop uptake was 83.93kg/ha N.
- Non-legume green manures added 55.17kg/ha N. Crop uptake was 82.46kg/ha N.
- Mix (legume and non-legume) added 84.29kg/ha N. Crop uptake was 88.65kg/ha N.

7. Nitrogen Replacement Value

Although the green manure treatments did not, for the most part show a clear difference to the controls in terms of N supply, there is evidence that at the sampling in December, the untreated scientific control had supplied approximately 40kg/ha of N, the Farm practice control with added N fertiliser had supplied approximately 120kg/ha and the green manures had supplied on average approximately 80kg/ha N. Subtracting the soil reserves in the untreated control from the treatments shows that up to half the N supplied by the mineral fertiliser application (from August to December) could be contributed by using one of the green manure crop mixtures, offering the potential to cut mineral N application by 50%. This suggests that if green manures and N fertilisers were used in combination, the former could help substantially reduce application of the latter.

Table 39 attempts to quantify this potential reduction. It shows that green manures could enable a reduction of between 47% and 39% depending on the green manure, at the N uptake N Use Efficiencies we calculated from the data.

Table 39. Nitrogen replacement value

Treatment	N added kg/ha	N Uptake (kg/ha)	N from treatment (kg/ha)	NUE %	N required to reach "Farm Control" kg N /ha	Yield December kg/ha
Control	0	40.99	0	n/a	78.04	1474.18
legume	**77.42**	**83.93**	**42.94**	**55**	**35.1**	2668.55
non-legume	**55.17**	**82.46**	**41.47**	**75**	**36.57**	2416.29
mix	**84.29**	**88.65**	**47.66**	**57**	**30.38**	2602.81
nitrogen	**134**	**119.03**	**78.04**	**58**	**0**	3024.63

8. Cost benefit of green manures

Records of the costs associated with each of the treatments were kept and the N Use Efficiency figures in Table 39 were used to calculate the cost of producing/applying the N taken up and hence the cost per kg yield in December (Table 40)

The cost per kg uptake was significantly lower in the nitrogen treatment compared to the green manure treatments, but the cost per kg of product was very similar. In respect of the latter, for the nitrogen treatment it was estimated at £0.12 £/kg, the same as the 'Mix', a penny higher than the 'legume' and a penny lower than the 'non-legume'. This may not sound like much, but with large volumes of product coming off the field, a penny a kg either way adds up to significant sum of money.

Table 40. Cost benefit analysis of different treatments

Treatment	Cost of Field operations (£/ha)	Cost of treatment (£/ha)	**Total Cost December (£/ha)**	Cost per kg N added £/ha	Cost per kg N uptake £/ha (using NUE)	Cost per unit output crop Yield (£/kg)
Control	223	0	**223**	0	0	0.15
legume	212.4	89.8	**302.2**	1.16	2.09	0.11
non legume	212.4	109.7	**322.1**	1.99	2.64	0.13
mix	212.4	106.45	**318.85**	1.26	2.23	0.12
nitrogen	264	98	**362**	0.73	1.25	0.12

9. Discussion

While the soil analyses did not pick up any differences between treatments, looking at crop tissue data and crop biomass yield (i.e. dry matter yield and nutrient content to provide N uptake by the crop), shows that green manures make an important contribution to N availability compared to fallow ground (see Table 36). This shows that relying on soil data alone can be unreliable.

N release from green manure incorporation is closely related to Carbon:Nitrogen (C:N) ratio with those crops with a higher C:N ratio (i.e. those with a higher proportion of C to N releasing N slower than those with a lower C:N ratio. It was expected that in the first 4 to 10 weeks after incorporation significant differences would have existed between the green manure treatments, particularly given significant differences in N content between all three mixes just prior to incorporation in July. This project did not pick up these hypothesised differences. In theory, the lower C:N ratio legume mix should have supplied more short term N, with the higher C:N non-legume mix supplying longer term N. It was expected that the legume/non-legume mixes would have been an intermediate between the two other green manure mixes.

Another surprising finding was that the mixes containing legumes, and hence able to fix N, did not appear to supply more N to the soil or crop than the non-legume mix.

The data does not show that Green Manures are more effective than synthetic fertiliser at supplying mineral N, but as Table 39 also demonstrates, they can potentially reduce the need for application of mineral fertiliser application by 40 – 50%, an important contribution to crop N requirements.

Although this project focused on N availability following green manures, additional benefits should not be overlooked including improvements in soil fertility, reducing soil erosion, weed suppression and enhancing biodiversity. Anecdotal evidence from this study (Figure 64) suggests that green manures lowered soil moisture content (this may or may not be desirable).

Returning to the question of N availability, the contribution of green manures may have been underestimated by this trial because:

- 2017 was unusually dry between April and July. In a more typical year (i.e. those with higher rainfall in this period), there may be higher losses of N through leaching/anaerobic loss from the control plots with no green manures.

- Green manure establishment and growth was less than expected, again due to dry conditions from drilling to termination.

- Carrying out tissue analyses at the same time as *the March* soil analyses the data would have been more complete and Soil N Supply from August to March could have been accurately determined, rather than relying on assumptions and crop tissue nitrogen data from December. This could have enabled more robust conclusions to be drawn about the N contribution of green manures.

A cost – benefit analysis showed that the cost per kg taken up was lower in the nitrogen treatment compared to the green manure treatments, but the cost per kg of product was very similar. In respect of the latter, for the N treatment it was estimated at £0.12 £/kg, the same as the 'Mix', a penny higher than the 'legume' and a penny lower than the 'non legume'. Despite this low figure, with large volumes of product coming off the field, 1 pence per kg can add up to large sums of money.

10. Next steps

If the trial were to be repeated, tissue analyses should be taken in parallel with all soil samplings. While this has budgetary implications, it would unquestionably be a worthwhile investment in terms of increasing the quality of the data.

An open day was held on 27 March 2018, and a number of suggestions were raised for future work in horticultural systems, centred around short-term summer green manures including:

- Using beans as a cover crop between harvest and the subsequent sowing

- Monitoring the accumulation of N during the growth of short term green manure crop to establish the optimal timing of incorporation to deliver N to a following brassica crop.

These proposals will be put forward to Innovative Farmers for consideration in spring/ early summer 2018.

2d – GREATsoils Field Lab: Amendments for soil health in top fruit

Purpose of group

Many growers are already using green waste compost or composted woodchip to add fertility and organic matter to their soils. There are also a range of products being promoted to boost the health of soils. Working out not only which of these will have an impact and assessing which give the best value for money is tricky.

This group is running on-farm trials to look at ways in which the health and fertility of its farms' soil can be improved. Triallists are seeking to improve crop quality by using various soil according to their own individual recommendations.

The triallists

1. **Boxford Suffolk Farms**: Robert England and Lucien Benke, Suffolk

Boxford are running two trials – one in an orchard and one in a glasshouse.

I. Testing the effects that digestate from their anaerobic digestion plant will have on the orchard's soil pH, cation exchange capacity, soil structure, and organic matter content.
II. Measuring how mixing biochar into coir affects the marketable yield and pest and disease resistance of strawberries.

2. **Eastbrook Farm:** Ben Raskin, Wiltshire

Trialling various soil amendments – woodchip mulch, enriched biochar, and mycorrhizal treatments – as and when they are planting new trees

They intend to measure tree extension growth, soil health, speed of cropping and soil infiltration rates. They are using a tree-tagging system to try and speed up the sampling.

3. **RHS Wisley:** Jim Arbury, Paul Kettell and Joe Olds - Surrey

Testing the effects of three different mulches – chipped holly, chipped alder and Wisley's own green-waste compost – on a mature apple orchard at the world famous garden. They intend to apply the woodchip every three years."

They want to improve the organic matter going into them and control weeds, as they are working to reduce herbicide use. They were not sourcing material in to do it but using materials from other parts of the garden, for instance from hedges that were coming out anyway

They are measuring the number of weeds, soil organic matter and nutrients.

4. **Liberty Orchards:** Alison Lemmey and Robert Imlach Dorset

Initially wanted to use apple pomace as a soil amendment. The idea was to mix the pomace with locally-sourced woodchip and biochar, and compost it, trialling it against using the pomace as a green mix. However they were unable to find a way to dry the pomace to make it usable in this form, and instead are intending to start a trial in Spring 2018 with woodchip and biochar.
They intend to measure the weed control, especially perennials like dock, pH of the soil, and yield.

5. **Le Manoir aux Quatre Saisons:** James Dewhurst and Anne Marie Owens Oxfordshire

2,500-tree orchard at Le Manoir – the heritage section of which boasts some 800 trees and around 100 different varieties of apples and pears.

They are adding enriched biochar to three sections of trees as part of the trial

I. Red Falstaff on M9 rootstocks - looking at scab.
II. Chivas Delight trees – looking at Brix levels.
III. Peach trees – looking at peach leaf curl.

6. **Tolhurst Organic:** Iain Tolhurst, Oxfordshire

Whilst this trial is on vegetables and not on a fruit farm, fruit growers will nevertheless find the results of this trial interesting. They are testing two types of soil amendments; a ramial woodchip and a composted woodchip. The trial is on a field that was growing squash but is set to produce potatoes in 2019. The squash crops were under-sown with a green manure mix. Composted woodchip and ramial woodchip were rotated across the field. Ramial woodchip is the smaller material from trees and hedges, chipped green whilst it is fresh, generally from broadleaf plants and chipped less than 9cm in diameter.

7. **Nantclyd Organic Farm** – Liz Findlay – West Wales

Trialling homemade windrowed compost made from: woodchip from hedge clippings, horse and poultry muck, grass, nettles, veg waste, weeds round poultry shed.
Liz grows strawberries in tunnels. The plants are in for at least 2 years in each place (sometimes 3) at a spacing of 5 plants per square metre. Historically they have grown through mypex, but are trying to reduce use of plastic, and have also found increased populations of mice and voles under mypex

Progress to date

Changes to soil health are not immediate, and this trial will be continuing beyond the life of the CP107b trial. In addition, although they have been engaged in the field lab from the start, not all triallists have managed to implement their trial yet for a number of reasons. Hence any results and findings here are interim. It should also be noted that a major objective of the field lab was to share testing and systems experiences and to get growers working together on a shared research question. Therefore, where no definite result is found this does not indicate that the field lab was a failure.

1. **Boxford Suffolk Farms**

Digestate on Apples - Initial soil samples taken and awaiting results

Figure 98: Adding digestate at Boxford Farms

Biochar with Substrate Grown Strawberries - No observable differences yet but will continue to observe and record through life cycle of plants.

Figure 99: Strawberries with biochar at Boxford Farms

2. **Eastbrook Farm**:

Barn Field - mix of treatments applied. In each row trees were treated with either biochar, mycorrhiza or nothing. Most trees (around 95%) were then mulched with a mixed species woodchip mulch.

Figure 100: Eastbrook field layout

Testing has only just started with a measurement of growth extension on three rows of cherries. These have been analysed by both variety and by treatment, though this is not yet telling us anything definitive. For instance, the left of the field (as you look at the map above) is very heavy and trees were planted into standing water. However they then had 6 weeks without rains, so that could have been an advantage or a disadvantage.

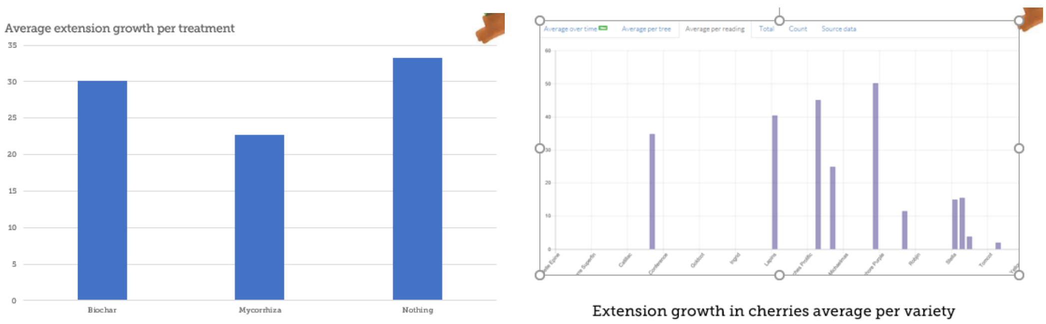


Figure 101: Eastbrook – average extension growth per treatment and per cherry variety

Withy Pump Field

Alternate rows of Perry Pears treated with enriched biochar. They are also now starting to mulch 95% of the trees with mixed species woodchip. No soil analysis has yet been done.

3. **RHS Wisley:**

- Mulches have higher levels of potash than surrounding areas.
- Weed control better in wood chip mulches than compost.
- Compost has higher K and trace elements.
- Soil conditions appeared wetter under Holly mulch than under Alder or Compost.



Holly woodchip mulch *Alder Woodchip Mulch* *Homemade compost mulch*

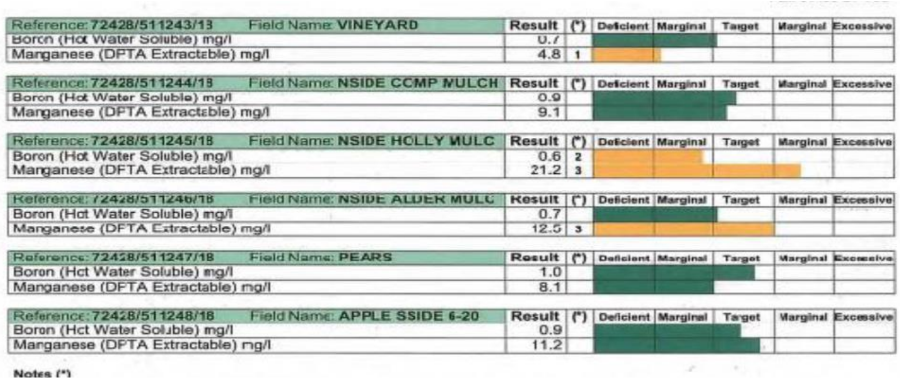
Figures 102-104: Mulches at Eastbrook Farm

SOIL ANALYSIS REPORT

Laboratory Sample Reference	Field Details		Soil pH	Index			mg/l (Available)		
	No.	Name or O.S. Reference with Cropping Details		P	K	Mg	P	K	Mg
511243/18	1	VINEYARD *No cropping details given*	6.2	4	2-	2	54.2	146	73
511244/18	2	NSIDE COMP MULCH *No cropping details given*	6.5	4	3	2	63.8	263	70
511245/18	3	NSIDE HOLLY MULC *No cropping details given*	6.0	4	3	2	55.2	254	73
511246/18	4	NSIDE ALDER MULC *No cropping details given*	6.3	4	2+	2	63.2	213	60
511247/18	5	PEARS *No cropping details given*	6.7	5	2+	2	75.0	202	79
511248/18	6	APPLE SSIDE 6-20 *No cropping details given*	6.2	5	2-	2	74.0	152	70

If general fertiliser and lime recommendations have been requested, these are given on the following sheets.

Figure 105: Macro Nutrient and pH Report, Eastbrook Farm



Reference: 72428/511243/18 Field Name: VINEYARD	Result	(*)	Deficient	Marginal	Target	Marginal	Excessive
Boron (Hot Water Soluble) mg/l	0.7						
Manganese (DFTA Extractable) mg/l	4.8	1					
Reference: 72428/511244/18 Field Name: NSIDE CCMP MULCH	**Result**	**(*)**	**Deficient**	**Marginal**	**Target**	**Marginal**	**Excessive**
Boron (Hot Water Soluble) mg/l	0.9						
Manganese (DFTA Extractable) mg/l	9.1						
Reference: 72428/511245/18 Field Name: NSIDE HOLLY MULC	**Result**	**(*)**	**Deficient**	**Marginal**	**Target**	**Marginal**	**Excessive**
Boron (Hot Water Soluble) mg/l	0.6	2					
Manganese (DFTA Extractable) mg/l	21.2	3					
Reference: 72428/511246/18 Field Name: NSIDE ALDER MULC	**Result**	**(*)**	**Deficient**	**Marginal**	**Target**	**Marginal**	**Excessive**
Boron (Hot Water Soluble) mg/l	0.7						
Manganese (DFTA Extractable) mg/l	12.5	3					
Reference: 72428/511247/18 Field Name: PEARS	**Result**	**(*)**	**Deficient**	**Marginal**	**Target**	**Marginal**	**Excessive**
Boron (Hot Water Soluble) mg/l	1.0						
Manganese (DFTA Extractable) mg/l	8.1						
Reference: 72428/511248/18 Field Name: APPLE SSIDE 6-20	**Result**	**(*)**	**Deficient**	**Marginal**	**Target**	**Marginal**	**Excessive**
Boron (Hot Water Soluble) mg/l	0.9						
Manganese (DFTA Extractable) mg/l	11.2						

Notes (*)

Figure 106: Micronutrient report, Eastbrook Farm

Next steps

- Weeding where necessary and possible herbicide on compost area.
- Mulch one row with Hornbeam wood chip.
- Mulch one more row with compost.

More tests will be done in year 2 of the trials.

4. Liberty Orchards

Will be implementing trials in Spring 2018 and starting to record data through the following year

5. Le Manoir aux Quatre Saisons:

Will be implementing trials in Spring 2018 and starting to record data through the following year

6. Tolhurst Organic

The trial is taking place on a block of 0.8ha

- Material applied in winter 2017 to an established green manure
- Application rate: 7.5l/ sqm or 60 cum/ha as per below Composted Woodchip (CSC) or Ramial Woodchip (RWC)

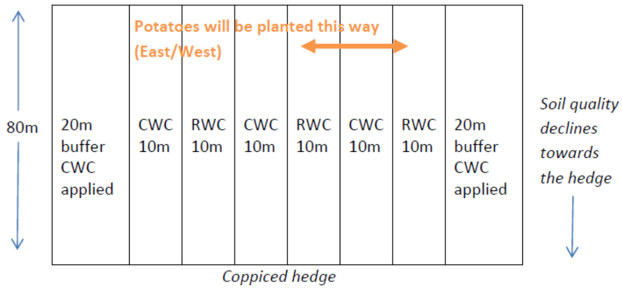


Figure 107: Trial layout Tolhurst Organics

The two substrates were analysed with the following results

Initial results: substrate analysis

	Fresh woodchip	Composted woodchip
pH	5.75	6.2
Density (kg/m3)	226.5	219
Dry Matter (%)	86.65	60
Dry Density (kg/m3)	196.1	131.4
Chloride (mg/l)	25.45	30
Phosphorus (mg/l)	42.75	53.5
Potassium (mg/l)	119.15	166.9
Magnesium (mg/l)	1.6	2.7
Calcium (mg/l)	4.85	9.4
Sodium (mg/l)	7.15	7.6
Total Soluble N (mg/l)	13.5	11.4
Sulphate (mg/l)	12.4	27.6
Boron (mg/l)	0.17	0.19
Copper (mg/l)	0.015	0.02
Manganese (mg/l)	0.13	0.08
Zinc (mg/l)	0.06	0.15
Iron (mg/l)	0.235	0.23

Figure 108: Substrate analyses, Tolhurst Organics

Further tests were done to measure biomass from the two treatments, and soil health measurements:

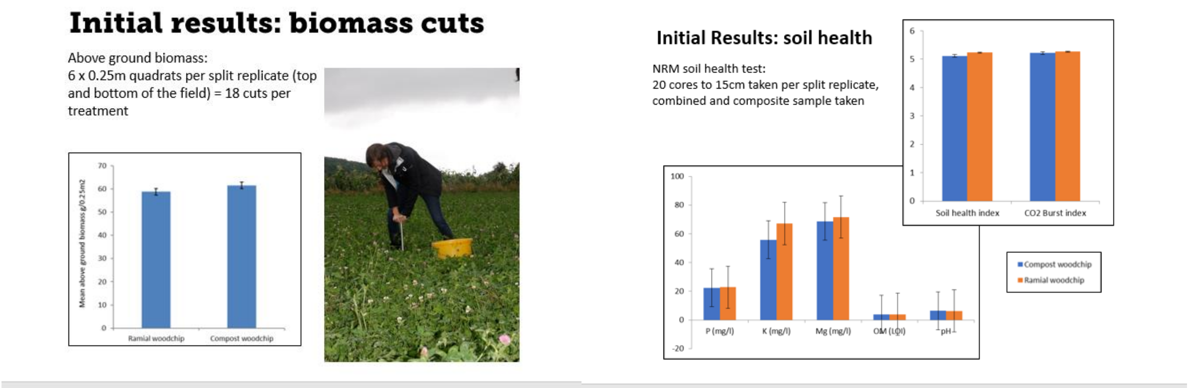


Figure 109: Biomass and soil health analysis following two treatments, Tolhurst Organics

Additionally some observations from the growers were recorded

- Large quantity of mushrooms on ramial plots
- Ramial wood rotting on surface all turned black and mycelium growth present on surface
- Very large number of worms present on ramial plots
- Woodchip compost mostly gone to soil
- Evidence of slightly stronger growth on woodchip compost as opposed to ramial wood
- Similar root nodulation of clovers on both plots
- As part of the soil tests that have been carried out so far, there is “evidence of slightly stronger growth with the woodchip compost, as opposed to ramial wood.”

7. **Nantclyd Organic Farm**

It was a small trial consisting of 2 beds of strawberries in tunnel side by side –

- On compost bed the compost was spread 1cm deep at most – intercropped with lettuce (whole head and loose leaf depending on time of season) after strawberries have cropped lettuce was removed + broad beans overwintered to the side of the bed
- They noticed earlier growth and averaged 15% better yield of strawberries from this row as compare with that from the mypex row. + all the extra yield from lettuce and beans.
- Though there was a little more weeding it was not a big issue – bit of chickweed over winter, Unintentionally the farm has developed purslane as weed (seems to get into compost) so they can harvest the weed for salad bags.

- The row with mypex had been fed well previous to planting but still did not perform quite so well.

Only 3rd year of compost on farm but seem to be growing better with each year of using compost, if there is a problem it's the pests that want to live in it – moles, voles, mice. This is bad under mypex but also present in compost bed.

This year have taken away all the mypex as they have seen the benefits. They will not be continuing this trial next year as they have been convinced of results from last years trial.

Continuation of the group

This field lab has been a good example of AHDB funding leveraging further money to expand farmer led trials.

- The European SuSTAiN farm project (funded in the UK by Defra) allowed the project team to do more detailed research for the trial at Tolhurst Organics.
- The innovative farmers Programme, has a funding pot that the group has accessed to allow it to continue working on the trials beyond the life of CP107b project.

The triallists intend to carry on working together for another 18 months and share their data recorded and experiences.

A further meeting is planned for early July 2018 at Boxford Farm.

Appendix 3 – Workshop and webinar attendance

Grower workshops – Soil Health and Farm Viability

Year 3

Date	Location/Host	Key topics	Attendees
10/05/17	Nottinghamshire, Naish Farms	Using Organic Manures to Manage Soil	16
13/06/17	Gloucestershire, Cotswold Seeds	Practical soil health tests – benchtop and in field. Practical green manures.	11
12/09/17	Carmarthanshire, Aberglasney Gardens	Assessing and managing soil conditions – theory and practical	14
20/09/17	Lancashire, Huntapac	Soil condition management and harvest machinery. Making better use of soils.	28
25/09/17	Dorset, Dorset Soft Fruit	Soil Amendments to improve soil fertility, condition and drainage	8
26/09/17	Leicestershire, Coles Nurseries	Soil health tests for nursery stock. Management of Verticillium wilt in hardy nursery stock – a soils perspective.	23
28/09/17	Lincolnshire, The Cut Flower Centre	Soil Health measurement methods for protected cut flowers. Management of Fusarium wilt in cut flowers – a soils perspective.	8
03/10/17	Essex, Anglia Salads	Evaluating soil conditions – soil testing and diagnostics. Remediation for soil health.	9
05/10/17	Warwickshire, The Warwick Crop Centre	Assess soil health to improve crop quality and yield.	11

		Challenges and approaches to tackling soil borne diseases.	
17/10/17	Kent, Intercrop	Managing and creating GREAT Soils: Addressing the challenges of managing soil health while growing salad leaf and vegetables outdoors.	17
16/11/17	East Lothian, Archerfield Walled Garden	Techniques for measuring soil health. Enhancing soil health – use of green manures.	16
10/01/18	Fife, Falkland Estate	Soil health assessment - summary of useful techniques with practical examples.	12
27/02/18	Yorkshire, Stockbridge Technology Centre	Practical assessments of soil health and fertility. Managing Soils Effectively for Commercial Vegetable and Glasshouse Production.	15

Year 2

Date	Location	Guest topic	Attendees
21/09/16	Cornwall, host - Riviera Produce	Soil compaction	20
06/10/16	Lancashire, host - Molyneux Kale Company	Using green manures for soil health	17
13/10/16	Pembrokeshire, Wales, host - Springfields Fresh Produce	Maintaining soil fertility and structure in a high rainfall area	13
27/10/16	Cambridgeshire, host - G's	Green manures	13
09/11/16	Lincolnshire, host Pollybell Farms	Green manures	11

09/11/16	Fife, Scotland	Compost and green manures for soil health	11
22/11/16	Staffordshire, host New Farm Produce Ltd	Managing run off and erosion	9
01/02/17	Worcestershire - host Agrii		35
22/02/17	Hants - host Laverstoke Park Farm	Using green manures for soil health	12
28/02/17	Sussex, host Rathfinny Wine Estate	Compost for soil health	26

Advisor workshops

Date	**Venue**	**Agenda**	**Attendees**
10/10/2017	Scottish Association of Independent Agricultural Consultants, near Stonehaven in Aberdeenshire	* What is soil health and why is it important? * AHDB GREATsoils project - aims and objectives * Measuring soil health - our findings and publications * Managing soil health – strategies to improve soil health * Current/recent GREATsoils field work (UK Farmer Field Trials) * Future work linked to GREATsoils * Conclusions	10
02/11/17	Girrick Monitor Farm event, Kelso		3
13/03/17	North Scotland SAC Consulting		5
26/02/18	Three Counties Showground, Worcestershire	* Introduction to AHDB GREATsoils * Soil testing - what's new? *What is soil health and why is it important? *Testing for soil health - what the growers said *Tools chosen to test + compare by growers: 1. Visual Soil Assessment (VSA) 2. Earthworm counts (EWC) 3. NRM soil health test (incl. respiration rate) 4. Infiltration rates (5. Compaction Q&A Management options 1. pH - getting the basics right	10
05/03/18	The Bell Inn, Cambridgeshire		24

		2. Green manures (including use of legumes and mixed planting) 3. Organic manures - compost and digestate 4. Mulches (improved water use and nitrogen use efficiency). 5. Cultivation – damage limitation 6. Rotation Further Q&A and discussion	

Field Trial Demos and workshops

Year 1

Date	Venue	Attendees
Autumn 2015	Kettle Produce, Scotland	9
Autumn 2015	Valefesco, Warks	12
Autumn 2015	East Malling Research Centre, Kent	8
Autumn 2015	Produce World	7

Year 2

Date	Venue	Attendees
06/06/16	Taylorgrown, Norfolk & Jepco, Lincs	24
30/08/16	Loddington Farm, Kent	25
21/11/16	Tolhurst Organic, Oxon	10
02/12/16	Valefresco, Warks	8

Year 3

Date	Venue	Attendees
28/06/17	Fife, Scotland	8
26/07/17	Loddington Farm, Kent	18
29/08/17	Tolhurst Organics, Oxon	19
26/10/17	Taylorgrown, Norfolk	9
30/10/17	Valefresco, Warks	18
02/11/17	East Malling Research Centre, Kent	14

Field Lab meetings

Improving soil health across a shared rotation
4 meetings – total attendees 45

Improving soil health with whole digestate in vegetables
3 meetings – total attendees 28

Green manures to increase N availability
3 meetings – total attendees 20

Amendments for soil health in fruit
4 meetings – total attendees 67

Webinars

	Attendees	Views
Soil Health and the Bottom Line	28	354
Soil health and what to measure	31	195
Managing soil health using organic manures	35	214
Short term green manure strategies for intensive growers	15	232
Soil health for horticulture (March 2018)	13	77

Appendix 4 – Balbirnie Estates, Scotland Field Trial Report

Report title: Soil health and quality in East Moss field before and after amendment with straw and compost

Assessment methods

Field trial design

After carrot harvest in April and early May 2017, East Moss field (OS Grid reference number: NO 30508/04583) was divided roughly into four. The Eastern half of the field had straw applied at approximately 50 t/ha and the Western half no straw, Figure 110. The Northern half of the field had compost applied at 20 t/ha and the Southern half had no compost. The entire field also had paper crumble applied at 24 t/ha.

The organic materials were cultivated in and the field was sown to spring barley in early May 2017.

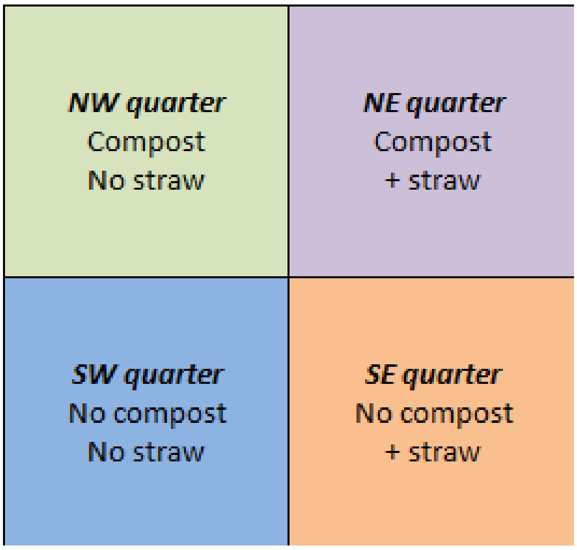


Figure 110: Field trial design

Initial sampling for lab testing

On 6 April 2016, the field was walked from corner to corner diagonally in both directions in order to determine whether it was appropriate to take single samples from across the field and in order to choose two locations in which to dig soil inspection pits. Each field was then sampled across its entire area by walking in a "W" pattern and taking 32 sub-samples using a spiral augur to 20 cm depth. Sub-samples were mixed in a clean bucket and 500 g samples were sent to NRM laboratories for analysis.

Subsequent sampling for lab and soil respiration testing

Each of the four trial areas were sampled across their entire area by walking in a "W" pattern and taking 32 sub-samples using a spiral augur to 20 cm depth. Sub-samples were mixed in a clean bucket to form a composite sample and 500 g samples were sent to NRM laboratories for analysis. Part of each composite sample was retained for soil respiration testing using Solvita gel paddles. These samples were placed in a cool box with ice packs until the tests could be set up according to the instructions for the Solvita soil test kits, in a room kept at 20ºC.

Laboratory analysis

Each soil was analysed at the laboratory for the following parameters:

- pH
- extractable phosphorus [P], potassium [K] and magnesium [Mg] (Scottish methods)
- organic matter content (by the loss on ignition method)
- microbial respiration (as measured by the Haney Brinton CO_2 burst test). Test was done on the first sampling only.

Soils were also testing for microbial respiration (CO_2 evolution) using Solvita gel paddles. Results were read after incubating the sealed jars of soil at 24ºC for 24 hours (according to test instructions) using a digital plate reader.

Results are tabled in this report and the original PDF files are available as Appendices 1a[7] and 1b[8].

Soil structural assessment

Visual assessments of soil structure were made based on the method described in Appendix 2 (Ball *et al.,* 2012, Visual Evaluation of Soil Structure [VESS])[9]. Five assessments were made in five locations chosen at random throughout the field on 6 April 2016. An additional two assessments were made in the uncultivated field margins for comparison. These assessments were repeated on 13 September 2016, 17 May 2017 and 02 October 2017.

Earthworm counts

An 18 cm square section was dug to a depth of 30 cm in four areas beside four of the locations used for the VESS assessments on 6 April 2016. An additional two assessments were made in the uncultivated field margins for comparison. All soil dug out of these sections was placed in a large plastic trug. This soil was carefully sifted through and all earthworms of all sizes were removed and placed in a white plastic bowl. The earthworms were then rinsed free of soil to make them easier to identify. Those present were sorted into sizes, the numbers of

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[7] https://www.soilassociation.org/media/15413/ft-appendix-1a-balbirnie-soils-results.pdf
[8] https://www.soilassociation.org/media/15414/ft-appendix-1b-balbirnie-soils-results.pdf
[9] https://www.soilassociation.org/media/15415/ft-appendix-2-visual-evaluation-of-soil-structure.pdf

each size were counted and the adults were identified using the guide in Appendix 3 (The Opal Soil and Earthworm Survey)[10]. On this first assessment, a mustard solution was poured into the base of each pit in order to encourage deep dwelling earthworms to come to the surface of the pit, but no further earthworms did so. The mustard solution was not used on subsequent assessments, which were made using the same method on 13 September 2016, 17 May 2017 and 02 October 2017.

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Results

The results of laboratory analysis, visual assessments of soil structure, earthworm counts and soil respiration are presented in Tables 41 to 46. The pH was too low in the field prior to carrots and liming to a target status of around 6.5 would have been desirable.

Table 41: East Moss laboratory soil analysis results (one sample based on 32 sub-samples taken from the entire field)

Parameter	Unit	Value	What does this mean?
pH[1]	-	5.5	pH is low. Target for vegetable rotation is normally 6.5.
Organic matter	%	4.1	This is a fairly typical organic matter level for this soil type, though there would be benefit in increasing it.
Extractable nutrients[2]			
P (status)	mg/l	5.7 (M-)	This soil needs P (target for a rotation including vegetables is high).
K (status)	″	161 (M+)	This soil needs K (target for a rotation including vegetables is high.
Mg (status)	″	60 (L)	This soil needs Mg (target is moderate)
CO_2 evolution[3]	mg/kg	148	This indicates that the soil is of high health status.

[1]pH was measured in water; [2]Nutrients extracted using Modified Morgan's extractant (i.e. the method typically used by SAC to analyse Scottish soils. Soil status: VL=very low, L=low, M-=moderate (lower half of the range), M-=moderate (upper half of the range), H=high, VH=very high; [3]As measured by the Haney Brinton CO_2 burst test;

[10] https://www.soilassociation.org/media/15416/ft-appendix-3-opal-soil-and-earthworm-survey.pdf

Soil P, K and Mg levels were also below targets (of “high” for P and K and “moderate” for Mg) prior to the carrot crop. Fertiliser recommendations for carrots (SAC Technical Note 649) would be 125 kg/ha of both phosphate and potash and 50 kg/ha MgO. It is understood that bagged fertilisers were applied prior to the carrot crop.

The total additions of nutrients and organic carbon from the bulky organic material applications are summarised in Table 42. The organic materials added differing and often large quantities of organic matter. Bagged potash was also added at 110 kg/ha, so K would not have been limiting in this crop.

Table 42: Nutrient additions from the organic amendments used at East Moss

Organic amendment (t/ha applied)	**kg nutrient/fresh tonne of material**			**kg nutrient applied at rate material used in 2017**		
	N	**phosphate**	**potash**	**N**	**phosphate**	**potash**
Green compost (20)	7.5	3.0	5.5	150*	60	110
Barley straw (50)	0.0	1.2	9.5	~ 0	60	475
Paper crumble* (24)	2.1	0.2	0.0	50*	5	0
Total applied in treatments						
No compost, no straw	(2.4 t/ha of carbon added)			50	5	0
No compost + straw	(20.4 t/ha of carbon added)			50	65	475
Compost, no straw	(5.5 t/ha of carbon added)			200	65	110
Compost + straw	(23.5 t/ha of carbon added)			200	125	585

*This N will be practically unavailable to the crop in the year of application

The bulky organic materials applications had a clear impact on soil pH and extractable P and K (Table 43). Paper crumble was applied over the whole field and it resulted in a marked increase in soil pH). Where straw had been incorporated, levels of both extractable P and K had increased after the trial (i.e. after both carrot and barley crops). Where no straw had been incorporated, slight increases in P were apparent, but K levels had gone down after the crops were grown. Magnesium levels were similar before and after the trial.

Table 43: East Moss soil analysis results (before and after field trial).				
		mg/l (index)		
	pH	**P**	**K**	**Mg**
Before trial	5.5	5.7 (M-)	161 (M+)	60 (L)
No compost, no straw	6.2	7.6 (M-)	128 (M-)	66 (M)
No compost + straw	6.2	7.2 (M-)	265 (H)	51 (L)
Compost, no straw	6.0	8.4 (M-)	115 (M-)	38 (L)
Compost + straw	6.1	11.5 (M+)	281 (H)	47 (L)

Soil structure was poor in places within East Moss prior to the trial (Table 44). There were some very firm aggregates and areas of compaction across the field. The structure of soil in the field margins was clearly much better (as is often the case), with no evidence of compaction and a well-developed structure with aggregates which were easily broken.

Table 44: East Moss soil structure scores (VESS)				
	VESS score		**Dickey John compaction probe reading (lbs/square inch)**	
Before trial (Sept' '16)				
Entire field	2.4		N/A	
Field margins	1.0		N/A	
During trial	**Spring 2017**	**Autumn 2017**	**Spring 2017**	**Autumn 2017**
No compost, no straw	1.8	1.8	104	128
No compost + straw	2.2	1.8	120	102
Compost, no straw	1.6	1.6	110	124
Compost + straw	1.6	1.5	112	98

[1]VESS scores based on Ball et al. (2012). A lower score means a better structure

After the carrot crop, shortly after trial set up and again in the Autumn, the soil was generally structureless. Aggregate strength was generally low however, and there was little evidence of compaction other than in a few areas in the "no compost + straw" treatment.

Earthworm numbers were low in the field before, during and after the trial (Table 45). Numbers were much higher in the field margins.

Table 45: East Moss mean earthworm numbers in spade-width, 30 cm deep pits

	Spring 2017		Autumn 2016	
Before trial	**Immature**	**Mature**	**Immature**	**Mature**
Entire field	4.8	1.8	0	0
Field margins	14	12.5	0	2.5

	Spring 2017		Autumn 2017	
During trial	**Immature**	**Mature**	**Immature**	**Mature**
Field margins	6.3	3	3.8	2.5
No compost, no straw	0.3	0	1.5	0
No compost + straw	0.3	0	2	0
Compost, no straw	0	0	1	0
Compost + straw	0	0	0.5	0

[1]VESS scores based on Ball et al. (2012). A lower score means a better structure

There were no clear differences in earthworm numbers between the four treatments in the trial.

Soil respiration was fairly high (indicative of a healthy soil with good microorganism populations) in the field margins and also throughout the field. It increased markedly in the two treatments including 50 t/ha of straw, but by the autumn, soil respiration values had returned to similar baseline levels of around 63 in all treatments.

Table 46: East Moss soil respiration (Solvita test scores[1] from plate reader)

Before trial	Spring 2016	Autumn 2016
Entire field	-	59
Field margins	-	63
During trial	**Spring 2017**	**Autumn 2017**
Field margins	-	65
No compost, no straw	60	63
No compost + straw	76	64
Compost, no straw	62	62
Compost + straw	76	67

[1]All scores are mean taken from two tests

Brief discussion of the results:

The soils in East moss required lime prior to the carrot crop. All three fields needed some P and K over and above crop requirement in order to bring the soils up to target P and K status. Bagged fertilisers were applied prior to the carrot crop to address crop nutrient demand.

The bulky organic fertilisers used after the carrot crop had a useful liming value and also added significant amounts of P and K. They helped bring soil P and K levels closer to the targets of "high". P and K will not have been limiting in the barley crop, so any differences between crops in the different treatments are unlikely to have been due to differences in availability of P, K or Mg. The bulky organic fertilisers added also contained large quantities of organic matter, which will have helped maintain soil organic matter levels in the field, particularly. The addition was greatest where straw, paper crumble and compost were added together, in which case around 24 t/ha of organic carbon was added.

Regular inspections of soil structure, through frequent test digs, allocation of structure scores (e.g. VESS) and the use of a compaction probe gave useful indications of the physical aspects of soil health. However, the systems used are more suitable for pasture soils and soils which are subject to less intensive cultivations than this one is. There is a need for a new, perhaps simpler system to assess the health of soils which are subject to frequent, intensive cultivations.

Soil structure prior to the carrot crop was typical of fields which have a root crop in the rotation. Structure was not poor other than in a few compact patches (for example in some of the wheelings), but there was certainly room for improvement. Soil structure after the carrot crop and once the spring barley crop was growing away was weak, but there was little evidence of firm aggregates or compaction, indicating that final cultivations had taken place in dry weather when the soil was in ideal condition for working. The areas of slight compaction and presence of firm aggregates in the “no compost + straw” treatment were thought to be due not to the treatment imposed but to the wet patches which were present in the lower areas in this (part of the field. The relatively weak structure in this field indicates that the soil will probably be badly affected if cultivations or harvest have to happen in wet conditions. For this reason, it is more than important than ever to try to cultivate or harvest only when soil conditions are ideal (easier said than done, when produce buyers will not wait...).

The earthworm counts in the uncultivated field margins during the first two worm counts were high in Spring, indicating that the soil pH was suitable for the worms, that there was enough food for them and that their numbers were not being reduced through cultivations. The earthworm numbers in the cultivated areas in Spring 2016 were considerably lower, and there were much higher percentages of juvenile worms and fewer adults. This situation is typical of cultivated fields and it is certainly worth attempting to undertake measures which aim to build soil organic matter and increase earthworm numbers. Earthworm numbers in Autumn 2016 were lower in the un-cultivated areas and there were no earthworms found at all in the cultivated areas. The low numbers in the uncultivated areas were likely due to low soil moisture content in the upper soil horizons, whereas the low numbers in cultivated areas were likely due to both low soil moisture content and the effects of recent cultivation for preparation of carrot beds.

Earthworms in all four quarters of the field after amendment with organic materials and during crop establishment were almost completely absent. This is common in soils which have had recent intensive cultivations, particularly in lighter soils which have had no routine applications of fresh organic matter. Earthworm numbers in Autumn 2017 were also very low, despite recent applications of bulky organic materials. The very low counts may also have been affected by the fact that the soil was fairly dry during counting. Earthworm counts are a useful indicator of soil biology, but to count them properly is very time consuming. Quick test digs (removal of a spadeful of soil) can also give an indication of earthworm numbers, but care should be taken when interpreting such “quick looks”, since it is very easy to miss earthworms, particularly the immature ones. Reliable, representative data can only be gained by averaging the number of earthworms found over many pits in a field, taken regularly at similar times of the year, every year.

Soil respiration scores were generally good across the field and in the field margins during 2016, indicating significant biological activity and good soil health. In Spring 2017, there were clear differences in soil respiration between the soil in treatments which had received straw or no straw. Those which had straw had higher respiration rates, indicative of higher soil microbiological activity. By Autumn, 2017, soil respiration values were again similar across the whole field, indicating that the increase in microbial activity following addition of organic materials was short-lived. Soil respiration measurements are a relatively new method for estimating the biological life in soil. The methods developed by the American Woodsend lab (e.g. Haney Brinton and Solvita) were originally developed for United States prairie soils, which are very different to Scottish soils. Further data must be gathered on different soil types, growing systems and using different soil respiration test methods in order to determine which tests are most appropriate for UK soils and also to learn how to interpret the data gained and take actions based upon it.

Conclusions

- It is a good idea where possible to ensure that pH is at target of 6.5, soil P and K status are at target (of "High") and Mg status is at target (of "Moderate" in the autumn prior to sowing a high value crop, since crop yield and quality are likely to be affected if soil pH or soil nutrient status are significantly less than ideal.

- Where economically viable, the use of bulky organic materials can have multiple benefits to both the health of soils and to the quality of current and subsequent crops. Benefits include:

  - Liming value (in the case of paper crumble and some composts and digestates);
  - Nutrient value (P, K, Mg, S and trace elements;
  - Organic matter which can improve soil water holding capacity, soil structure, nutrient retention and the activity of numerous soil organisms including microorganisms and larger soil fauna such as earthworms.

- Regular inspections of soil structure, through frequent test digs, allocation of structure scores (e.g. VESS) and the use of a compaction probe give quick, useful indications of the physical aspects of soil health. There is a need for a new, perhaps simpler system to assess the health of soils which are subject to frequent, intensive cultivations.

- Where soil structure has been degraded by regular, intensive cultivations, it becomes more important than ever to cultivate and harvest when soil conditions are suitable (i.e. relatively dry), since weakly structured soils can be badly damaged if worked in wet conditions. If such damage is severe, it can take decades for soils to recover and this recovery is unlikely to happen if rotations continue to include regular intensive cultivations.

- Earthworm counts are a useful indicator of soil biology, but to count them properly is time consuming. Quick test digs (removal of a spadeful of soil) can also give an indication of earthworm numbers, but care should be taken when interpreting such “quick looks”, since it is very easy to miss small earthworms and since reliable, representative data can only be gained by averaging the number of earthworms found over many pits in a field, taken regularly at similar times of the year, every year.

- Soil respiration measurements are a relatively new method for estimating the biological life in soil. Further data must be gathered on different soil types, growing systems and using different methods in order to learn how to interpret the data gained and take actions based upon it.

Appendix 5 – Media output

Press in Year 3

Organic Farming Magazine Spring 2017 Issue 124	**Increasing Soil Organic Matter**
Horti Daily, 05 April 2017	**"Soil health is behind everything we do"**
Soil Use and Management, Volume 33, Issue 2, April 2017	**Soil health – What should the doctor order?**
Farming Futures 19/06/2017	**Soil testing key to realising the value of healthy soils**
The Courier, Fife 21/06/2017	**Fife soil trial to boost yield with green compost to be reviewed**
The Scottish Farmer (Web) 21/06/2017	Free events focus on soil health and testing
Western Morning News, 21/06/2017	Testing is key to realising value of healthy soils
Horti Daily, 24/08/2017	**GREATsoils Trial Demonstration: Assessing the health of your soil**
Farmers Guardian 25/08/2017	**A boost for spring greens**
The Vegetable Farmer 01/09/2017	**Field Lab Studies Soil Health Across the Rotation**
Organic Farming Magazine Summer/Autumn 2017 Issue 125	**Working together for soil health**
Article for AHDB booklet for Elsom Seeds day	**Growers working together for long term soil health**
AHDB - The Grower - Oct/Nov 2017 print	Staying Grounded
Tillage Magazine online 18 Nov 2017	**DIY soil testing**
The Fruit Grower – 01/12/2017	**On farm trials look at methods of improving orchard soil-health**
Organic Farming Magazine Winter 2018	**Salads and soil health p.10**
The Vegetable Farmer 1 April 2018	**Organic additions can improve soil health**
Tillage Magazine Summer 2018	**Unlocking soil health**
ORC Bulletin – Spring 2018	**Practical soil assessment methods for different horticultural systems**

Press in Year 2

FPJ print/online, 22 April 2016	**Soil Association Launches Soil Project - online version corrected to include partners**
FPJ print article p 26, May 2016	**British Soils 'Need More Care'**
Organic Farming Magazine Spring 2016 Issue 212	**Full page image with project info - What is a healthy Soil?**
IOFGA Organic Matters Magazine Spring 2016	**How Do You Assess the Health of Your Soil?**
FPJ online, 3 March 2016	Livestock Would Improve Soils for Growers - uses image from GREATsoils day
AHDB Grower, June 2016	**Breaking New Ground**
Horticulture Week, 22 July 2016	**Cross-sector funding secured for crop studies**
Farmers Weekly, August 2016	**Mention for project and workshops in sidebar in article Why Future UK Harvests Hang in the Balance**
Organic Farming Magazine, Summer/Autumn 2016 Issue 213	**Soil Health**
Horticulture Weekly, 16 September 2016	**Herbs field day covers soil issues**
The Vegetable Farmer, December 2016	**Cover crops show benefits for soil health**
South East Farmer, 1 December 2016	Field Trials
Farming UK, 21 December 2016	**GREATsoils programme showcases peer-to-peer learning**
East Anglian Daily Times, 24 December 2016	Success with soil events
Fresh Produce Journal 13/01/2017	Info box - GREATsoils project in 2017
Fresh Produce Journal, 13/01/2017	**Soil Organic matter in the Spotlight [Dirty Talk]**
Organic Farming Magazine Winter 2017 Issue 214	**How taking care of my soil bears fruit**
Western Daily Press, 22 March 2017	**Keep your Soil Covered for Financial Gain**

Press in Year 1

Horticulture Week March 2016	**Funding Secured for Soil Project to Help Growers**
AHDB Grower July 2015	**Launch article**
Organic Farming Magazine Issue 119 Autumn / Winter 2015	**GREAT SOILS**
ORC Bulletin 119 Autumn / Winter 2015	**GREAT SOILS**

Blogs

Blog	Views to 31 March 2018
Low till – disturbing the soil less and less, Simon Gardner, G's	296
Farmers working together for soil health, Jerry Alford, Coordinator, Rotational Field lab	119
How I develop GREATsoils and cut costs - Phillip Hubbert, Jepco	297
Soil health is behind everything we do - Joe Rolfe, Taylorgrown	248
How taking care of my soil bears fruit - Paul Smith, Loddingtons	60
Does sowing green manures early improve soil quality? - Iain Tolhurst, Tolhurst Organics	50
Nurturing soil for intensive cropping - Steve Nickells, Valefresco	146

Videos

GREATsoils – Why managing soils is important, Chris Molyneux, Kale grower on Green Manures – 609 views

GREATsoils: Salad grower Simon Gardner of G's on low till cover crops for soil health – 355 views

GREATsoils: improving soil health in orchards with James Smith, Loddington Farm – 253 views

Soil test videos (released March 2018):

Worm count – 48 views

Infiltration test – 54 views

Spade test – 44 views

Respiration test – 45 views

Compaction test – 71 views

Soil tests summary – 108 views

Twitter

1476 followers – up from 933 at the end of the year two.

GREATsoils network

690 sign-ups via events and web form – up from 460 at the end of the year two.

Appendix 6 – Industry Events

Soils Roadshow – 33 events attended. 20 were "key" events as decided in our original plan.

2017/18
5 events attended in year three of the project of which **2** were "key" events as decided in our original plan (key events marked in bold).

Date	Description
16/06/2017	Cranfield AHDB Horticultural Soil Management Information System Stakeholder workshop – Jerry Alford Soil Association attended
18/07/2017	**Biennial Asparagus Conference – MW presenting**
4-5/01/2018	**Oxford Real Farming Conference – promotion AV, DA, BR, SO**
16/02/2018	Scottish Small Holders – AV presenting
17-28/02/2018	**Crop Protection in Northern Britain – AL presenting**

2016/17
15 events attended in year two of the project of which **9** were "key" events as decided in our original plan (key events marked in bold).

Date	Description
21/04/2016	**FPJ event - speaking slot - LB**
17/05/2016	Agritech East - SIG Event: A Sense of Place – Geomatics Meets Soils Health event. Provided slide and postcards for promotion.
14/04/2016	Reading soil health event – Promoted project AV
07/07/2016	**NOCC - stand - AV**
25/08/2016	**British Herbs field event – stand and demo - MW**
14/09/2016	**Growing Innovation - Rijk Zwaan Organic Open Day 2016 – presentation BR, MW**
06/10/206	**BCGA variety and trade exhibition carrot day – stand**
12-13/10/2016	**Elsoms Seed open day 2016 - AHDB stand with ADAS - MW**
19-20/10/2016	**National Fruit Show – stand - BR**
09/11/2016	**Farm Business Innovation – stand - BR**
04-05/01/2017	**Oxford Real Farming Conference – promotion – BR, AV**
1-2/02/2017	**ORC Conference – workshop AV, BR**
08/02/2017	Presentation to ProCam East - MW
22/02/2017	PFLA soils meeting – promotion AV
21/03/2017	BSSS drinks reception – poster and promotion, BR, Anna Becvar Earthcare Technical

2015/16

13 events attended in year one of the project of which **8** were “key” events as decided in our original plan (key events marked in bold).

- Grantham Centre, Sheffield University soil lecture - Promoted project BR
- 16th September **Rijk Zwaan Horticultural event** - Promotion and signup sheet BR
- **Soil Symposium** - 5 Nov 15 - stand, postcards and signup sheet, BR, AL, AV, LB
- **Onion conference** - 4 Nov 15 - attended with postcards MW
- **Reading University Soil Health Conference** - 18 Nov 15 - attended, and chaired conference session BR
- Innovative Farmers "Cracking Compost" event at GS grower Iain Tolhurst. Promoted GS and handed out postcards 8 Dec BR
- **Oxford Real Farming Conference-** 6/7 Jan 16 shared stand with Innovative Farmers, Review report, postcards and signup sheet BR, LB
- **ORC producer conference** session with 2 Paul Smith and Simon Gardner speaking (growers from the consultations) + stand with reports. 28/29 Jan AV, BR
- **Crop Protection in Northern Britain** – 23 Feb attending and speaking AL
- **Carrot Growers Conference** 22 March – sign ups BR

