February 2020

Annual Project Report
January 2019 to December 2019
No. 91140002-APR2019

Soil Biology and Soil Health Partnership

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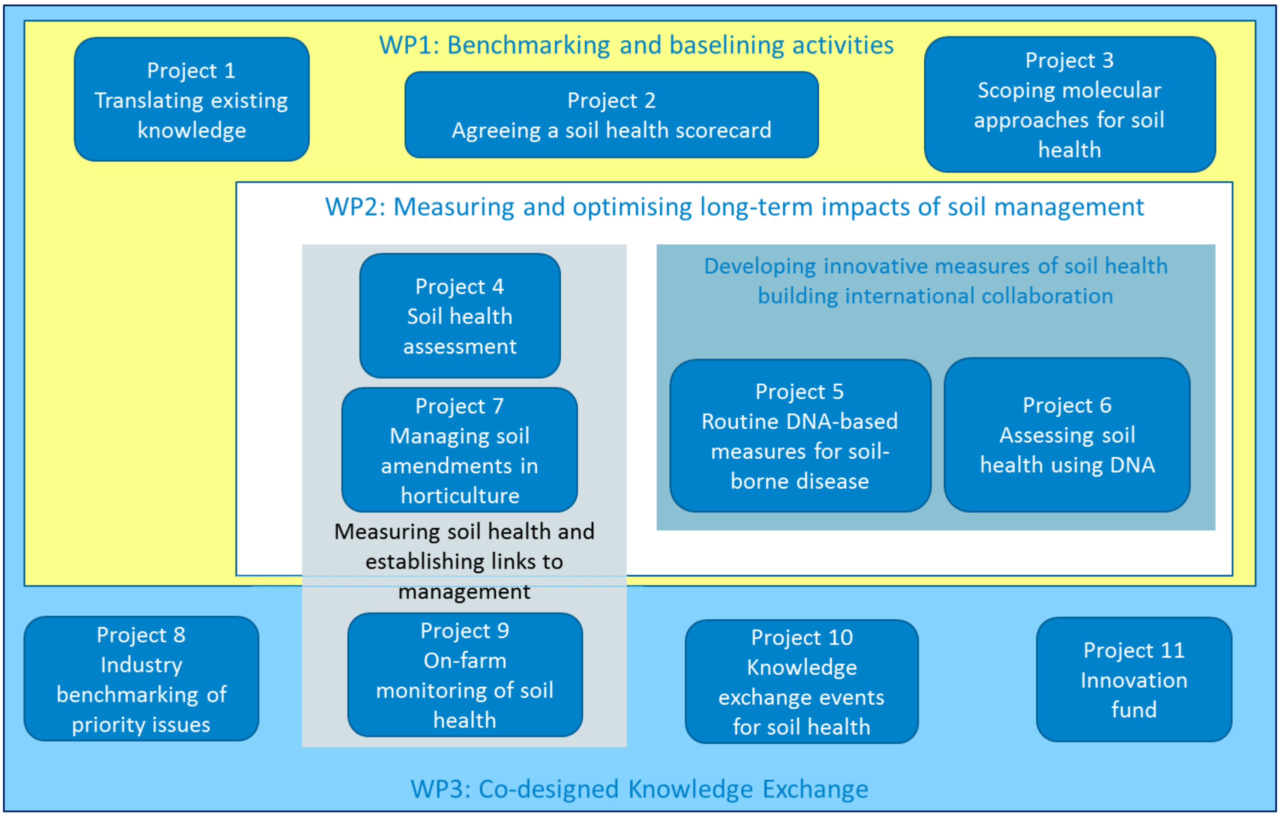
GREATSOILS

PARTNERSHIP OVERVIEW

Funded by AHDB and BBRO, the Soil Biology and Soil Health Partnership is a five-year (2017-2021) cross-sector programme of research and knowledge exchange designed to help farmers and growers maintain and improve the productivity of UK agricultural and horticultural systems through better understanding of soil biology and soil health. The overarching aims are to:

- Improve on-farm understanding of soil health by sharing current academic and industry knowledge in usable formats
- Develop and validate indicators of soil biology and soil health in research trials and on-farm

The programme comprises a series of interlinked projects.



In 2019, one project was funded through the Innovation Fund. The project is led by ADAS and is developing UK-relevant benchmarks for the indicators of soil biological activity: Potentially Mineralisable N (PMN) and CO_2 burst.

Further information can be accessed via www.ahdb.org.uk/greatsoils

COMPLETED PROJECTS

Project title	**Translating existing knowledge of management effects on soil biology and soil health for practitioners**		
Project number	91140002-01		
Start date	January 2017	**End date**	December 2017
Links	Final report Project 01 Supplementary information Project 01b		

Project title	**Selecting methods to measure soil health and soil biology and the development of a soil health scorecard**		
Project number	91140002-02		
Start date	January 2017	**End date**	December 2017
Links	Final report Project 02		

Project title	**Molecular approaches for routine soil-borne disease and soil health assessment – establishing the scope**		
Project number	91140002-03		
Start date	January 2017	**End date**	December 2017
Links	Final report Project 03		

Project title	**Identifying current understanding, knowledge gaps and confirming the key priority issues in understanding and management of soil biology and health**		
Project number	91140002-08		
Start date	January 2017	**End date**	December 2017
Links	Final report Project 08		

Access all reports at https://ahdb.org.uk/soil-biology-and-soil-health-partnership

ONGOING PROJECTS

Project title	**Soil health assessment**		
Project number	91140002-04		
Start date	01/06/2017	**End date**	31/12/2021

Project aim and objectives
The overall aim of this project (Project 04) is to quantify the effects of contrasting management practices on soil biology and health in relation to crop yield and quality, and to evaluate the use of simple tools for assessing soil health. The specific objectives are: 1. To quantify the effects of contrasting management practices and resultant soil conditions (organic matter, drainage status, structure and pH) on crop establishment, yields and quality across rotations including cereals, sugar beet, potatoes, horticultural crops and grass leys. 2. To evaluate the effect of contrasting management practices on weed and disease pressures for each crop in the rotation. 3. To evaluate the effects of contrasting management practices on key measures of soil biological, physical and chemical health. 4. To explore links between soil biology, soil structure and crop productivity 5. To provide a test bed for the development of DNA-based soil health tests (Projects 05 and 06) 6. As part of the whole Soil Biology and Soil Health Research Partnership programme, to translate the findings into simple measures of soil health, linked to measurable outcomes and practical management solutions (the integrated soil health scorecard).

Key messages emerging from the project
The prototype soil health scorecard has been successfully evaluated using data from two experimental sites in 2018/19: the long-term pH experiment at SRUC Craibstone near Aberdeen and the tillage experiment at GWCT Loddington. At Craibstone, a pH of 6.5 was seen to score most favourably (‘green traffic light – no action required’) for all soil properties assessed, although long-term cereal yields (48 year averages) were highest at pH 5.5-6.0. A pH of 4.5 was detrimental (‘red’ – investigate further) particularly for soil biological properties (earthworms and microbial biomass), with a pH of 6.0 and 7.5 borderline for these properties (‘amber’ - monitor). At Loddington there were no significant differences between the plough (1 year) and zero till (direct drill for 8 years) treatments, although earthworm numbers were lower (amber traffic light – monitor) following ploughing compared to the long-term zero till treatment (green – no action required).

Summary of results from the reporting year
A network of seven existing experimental sites with a history of different management practices and known differences in soil organic matter content, pH and drainage status/structure (key drivers of soil biological functioning) has been established covering a range of soil and agro-climatic conditions in Britain and rotations that include grass leys, cereals, sugar beet and potatoes. These sites provide the test bed for the methods confirmed from Project 02, and facilities to test and develop the molecular-based techniques (Projects 05 & 06). The following soil quality parameters are being evaluated at each of the sites (with sampling staggered across the lifetime of the project): pH, extractable P, K & Mg, organic matter (loss on ignition and dumas methodologies), total N, bulk density, penetrometer resistance, visual soil assessment of soil structure (VESS), earthworm numbers, respiration (CO_2-burst), microbial biomass carbon (MBC), potentially mineralisable N (PMN), nematodes, microarthropods and DNA measures of pathogens (Project 05) and beneficial biology (Project 05 and 06). The assessments will be evaluated in relation to any differences in crop health and productivity. The Craibstone Woodlands Field long-term pH experiment was sampled in October 2018. This site was established in 1961 and investigates the impact of different pH levels (ranging from 4.5 to 7.5 in 0.5 increments) on soil properties and crop performance of an 8-course rotation comprising: 3 year grass/clover ley, winter wheat, potatoes, spring barley, swede and spring oats (undersown with grass/clover). Each crop in the rotation is present every year enabling a comparison of the response of all crop types within the same season. The soil quality parameters outlined above were measured in four crops (2nd year ley, following winter wheat, potatoes and spring oats) at four pH levels (4.5, 6.0, 6.5 and 7.5). There was a clear effect of low soil pH on a number of soil properties – particularly nutrient availability and biological activity, as indicated by the number of earthworms, the size of the microbial biomass and its activity (respiration rates), with the highest number of earthworms measured at pH 7, and lowest at pH 4.5, and the highest microbial biomass measured at pH 6.5 and the lowest at pH 4.5, with intermediate levels at pH 6 and 7.5. There were also differences between crop types, with earthworm numbers highest in the grass ley and organic matter levels lowest in the oat crop grown at the end of the rotational cycle, prior to the three year grass ley. The soil mesofauna (e.g. collembola, mites etc) showed sensitivity to both crop type and pH; analysis of this dataset is on-going. Crop yields reflected the differences in pH, with highest yields (48 year averages) attained between pH 5.5 and 6.0. This work has been shared in a Research Case Study published September 2019 and the site also hosted an open day in autumn 2019 (see Project 10). The Loddington experimental site (arable rotation on a heavy clay soil) was sampled in September 2018. Here, two contrasting tillage regimes had been established the previous year (three replicate strips of a continuous direct drilled field were ploughed). There were no statistically significant differences in soil properties between the two treatments, although earthworm numbers tended to be lower (6/pit – amber traffic light) on the plough treatment compared to the long-term zero tillage (direct drill) treatment (10/pit – green traffic light). The majority of soil assessments were given a green traffic light according to the draft soil health scorecard, suggesting no action was required. The only

exceptions to this were for bulk density and maximum penetration resistance (to 30cm), which were considered to be high – red traffic light, suggesting evidence of some compaction on both treatments (>1.2 g/cm^3 for soils with an organic matter content > 6%, and > 2MPa resistance), although this was not identified using visual evaluation of soil structure (VESS scores of 2 for both treatments).

A further two sites were sampled in autumn 2019: the Gleadthorpe experimental site with a history or repeated organic material additions (broiler litter for 20 years, green compost, cattle FYM and slurry for 8 years compared to a control just receiving inorganic fertiliser) and the long-term crop rotation experiment at Craibstone (no fertiliser compared to full NPK fertiliser at recommended rates in 4 crops: potato, wheat, 3 year grass ley, oats undersown with grass/clover). These sites hosted open days in autumn 2019 (see Project 10 report). Results are currently being analysed from this sampling. The long-term organic material application experimental site at ADAS Terrington, which hosted an open day in May 2019, was due to be sampled in autumn 2019 as well, but has been postponed until 2020 due to the unprecedented rainfall in October, leaving the soils very waterlogged with no access to the site for sampling following sugar beet harvest.

Key issues to be addressed in the next year

- Complete analysis of the Craibstone and Gleadthorpe experimental sites
- Sample the Terrington organic material site and the Harper Adams, Loddington and Boxworth experimental sites in autumn 2020.
- Ongoing analysis of the growing database in relation to the soil health scorecard.

Lead partner	ADAS (Anne Bhogal)
Scientific partners	NIAB, SRUC, Fera, GWCT
Industry partners	NRM

Project title	Monitoring soil-borne disease (DNA measures)		
Project number	91140002-05		
Start date	01/04/2017	End date	31/12/2021

Project aim and objectives

Project 05 (Fera led) aims to demonstrate the value of robust molecular methods (reviewed in Project 03) to quantify the effects of management on soil health across a range of existing (long-term) trial sites and to better understand the link between soil management approaches and minimisation of soil-borne disease risk. Activities across Projects 04, 05, 06 and 07 aim to explore causal links between management and soil-borne disease control by providing some insight into the relationship between pathogen populations and the diversity and function of the overall soil microbiome.

Specific objectives of this project are to:

1. Validate a toolkit of qPCR assays for quantitative detection of the key intractable soil-borne pathogens in arable and horticultural rotations.
2. Establish relationships between pathogen distribution and concentration in soils and potential for disease development.
3. Evaluate the effects of soil management practices (rotations, amendments and cover crops) on the soil microbiome and survival of specific soil-borne pathogens in relation to overall soil health.
4. Design and demonstrate the benefits of an appropriate soil health testing service for growers and agronomists.
5. Integrate results of molecular testing for soil-borne disease risk with associated chemical and physical data to provide a robust soil health scorecard to enable effective on-farm decision support systems for farmers and agronomists.

Key messages emerging from the project

- Standardisation of procedures for soil sampling, DNA extraction from soils and target sequences for DNA amplification is key to understanding soil-borne pathogen distribution, spread and survival across a range of soil types, cropping systems management and disease control practices,
- Metabarcoding procedures can be used to investigate the effect of soil management on the overall bacterial and fungal soil microbiomes; however initial findings suggest that extraction method has a much bigger impact than management on the characteristics of the microbiomes.
- A number of qPCR assays have been validated for detection and quantification of a wide range of plant pathogenic soil-borne fungi.
- There is a need to better understand the relationships between detection of pathogens in soil and the risk of disease development so that the benefits of soil health monitoring can be clearly demonstrated.

Summary of results from the reporting year
Soil-borne pathogens Relevant qPCR assays were validated for *Sclerotium cepivorum, Phytophthora asparagi, Stemphylium vesicarium* and *Gliocladium catenulatum*. GBlocks were designed and validated for reliable quantification using qPCR. A DNA extraction method with larger soil starting volume was developed for increased representability when extracting field samples for pathogen assays. Field sampling and DNA extraction for soil pathogens has been completed at Project 07 sites (onion, raspberry, narcissus) and in the experimental plots (Project 04), the Cranfield asparagus trial site and three additional Wellesbourne onion trial sites (latter sites funded separately to the SBSH Partnership). Results correlating disease incidence and treatments were not significant in the onion, raspberry or daffodil trial sites. Neither the raspberry or daffodil sites showed significant disease levels in 2019 and these will be revisited in 2020. In the onion trials, it is possible that very high disease incidence levels masked any potential significant treatment differences. Greenhouse trials have also been initiated. Soils were inoculated with different populations of *Sclerotium cepivorum* for sowing with onions. However, the pathogen was not detected in soil after planting or at harvest and no disease developed. *Soil health – microbiome analysis* The result of the DNA extraction methods comparison work for the bacterial and fungal microbiomes is reported in Project 06. As part of Project 05 in 2019, work has been undertaken at Fera to meta-barcode bacterial and fungal microbiomes on soils sampled from long-term trials investigating the effects of pH (Woodlands Field). The bio-informatics pipeline for these analyses is now established. DNA has also been extracted and metabarcoding completed for the Cranfield asparagus trial and the NIAB STAR trial (continuous wheat x cultivation methods) – these are trials from beyond the Partnership work, where the treatments under investigation were felt to add significantly to the potential understanding gained within the PhD study. The analysis of samples from the STAR trial revealed some significant effects of sampling time (spring versus autumn) on bacterial and fungal diversity. Work is also underway drawing from the experience of the Fera Big Soil Community to create bacterial and fungal benchmark communities that are common to UK agricultural soils and that can be used to standardise interpretation of soil microbiome data obtained across different DNA extraction methods, sequencing platforms and reference databases. Work is also underway to consider and compare approaches to develop appropriate summary indices from the mass of data obtained, which should provide more targeted KE for these data types in future years.

Key issues to be addressed in the next year
• Initial data relating pathogen populations in soil to disease development for different crops and pathogens will be further investigated under glasshouse conditions

- Soils sampled multiple times across a grid pattern will continue to be analysed to investigate the distribution of individual soil borne pathogens and the diversity of bacterial and fungal microbiomes within a field.
- A visit to the SARDI team in Australia will take place so that we can effectively learn from how the commercial soil-borne disease testing service based on molecular methods was established and how it operates.
- The raspberry and daffodil sites will be revisited as they did not show significant disease levels in 2019.

Lead partner	John Elphinstone, Fera (until October 2019) then Joana Vicente, Fera.
Scientific partners	ADAS, NIAB, SRUC, SARDI
Industry partners	None

Project title	Assessing soil health using DNA		
Project number	91140002-06		
Start date	01/04/2017	End date	31/12/2021

Project aim and objectives

Project 06 will evaluate the use of DNA-based analyses to replace individual tests in an appraisal of overall soil health, with the following specific objectives:

6.1 To short-list targets for analysis for DNA-based approaches (from: molecular biomass; total bacteria and fungi; microbial community structure; functional genes; nematodes; microarthropods; earthworms).

6.2 To compare results from soil extracted DNA with current methods for assessing soil health used on the experimental sites in Project 04 and further evaluate the effects of soil management practices (rotations, amendments and cover crops) on the soil biological community and its function

6.3 To optimise the extraction of environmental DNA (eDNA) from soil.

6.4 To compare of results from soil extracted DNA and eDNA.

6.5 To evaluate whether molecular testing for soil health should be integrated with the soil health scorecard and with pest and pathogen diagnosis to provide information on the soil biological community. Ultimately to enable the further development of effective on-farm decision support systems for farmers and agronomists.

Key messages emerging from the project

Environmental DNA (eDNA) can be extracted from soil but the method does not always produce recoverable DNA. More evaluation is needed to compare the effectiveness, convenience and cost of this type of extraction in comparison with standard soil DNA extraction methods that lyse the cells of soil organisms ahead of extraction.

Different DNA extraction methods used on the same soil samples show similar types of bacteria and fungi within the soil communities; however, the method used markedly influences the estimates of the relative abundances of these types of bacteria and fungi. Standardisation of methods will therefore be important when comparing samples collected from different locations and at different times.

Between 100,000–200,000 DNA sequences were obtained for both bacterial and fungal groups from each soil sample from the Harper Adams trial. Use of the on-line databases has highlighted the large gaps in the records for soil-borne organisms. Although most of these soil micro-organisms can be identified at higher taxonomic levels (e.g. phylum, class or order), fewer can yet be accurately assigned at the levels of family, genus or species and even fewer linked directly to soil function.

Summary of results from the reporting year

Full sequencing of the DNA extracts from 2018 sampling (Loddington, Craibstone pH plots) is complete and work to extract and sequence the soil samples collected at research sites in 2019 (Gleadthorpe OM Materials experiment, Craibstone long-term fertilisation) is underway.

The comparison of extraction methods has shown a clear impact of the extraction method on the biological community described. Further work has combined the results from each extraction method either by pooling the extracted DNA (followed by a single sequencing step) or by pooling the sequencing results using bioinformatics. Both approaches confirm the hypothesis that the extraction approaches are targeting different parts of the community so that the additive results by both methods are similar. Results from the Harper Adams organic material amendment site show no evidence of major changes in the fungal or bacterial communities with OM amendment (though there are some small signals in some soil OTU/ organisms types). More evaluation will take place with Gleadthorpe samples (2019).

DNA has been extracted and metabarcoding completed for soils sampled from Craibstone (pH x rotations), Loddington (deep plough vs. min. till) and is underway for Gleadthorpe (organic material additions) and Craibstone (fertilisation). No effects of the treatments at Loddington were observed on bacterial or fungal diversity. Major effects of soil pH were observed on both bacterial and fungal diversity at Craibstone. eDNA extraction gave no recoverable DNA at pH 4.5 in the Craibstone pH plots; so no further sequencing was carried out with these extracts.

Use of the on-line databases has highlighted the large gaps in the records for soil-borne organisms. It is expected that data from this project will enable some updates to these shared databases as the work continues. Initial reflection on the data collated so far from the Harper Adams site highlights a small change in taxonomic diversity with organic materials additions as already predicted by the descriptive model. Hence no changes to the descriptive model have been needed as a result of this Project so far.

This information was brought together in a Research Case study published in Spring 2019 linking the work from Project 05 and Project 06 (together with the initial review from Project 03). This drew on the full sequencing data from the DNA extracts from the organic materials site at Harper-Adams to highlight the opportunity that molecular indicators have, but also the current challenges in implementing these as routine measures linked to practice.

Key issues to be addressed in the next year

- To bring together results from soil extracted DNA with the results of current methods for assessing soil health for the long-term pH experiment (Woodlands Field, Craibstone) and further evaluate the effects of pH on the soil biological community and its function
- To complete the evaluation (effectiveness, convenience and cost) of eDNA extraction in comparison with standard soil DNA extraction methods using the 2019 samples collected from the Gleadthorpe organic materials experiment.
- To consider how molecular testing for soil health could be integrated with the soil health scorecard and with pest and pathogen diagnosis to provide information on the soil biological community so that value, cost and hence the cost-effectiveness of this approach can be considered as part of the assessment in future years.

Lead partner	Bryan Griffiths, SRUC (until April 2019) then Christine Watson, SRUC
Scientific partners	NIAB, ADAS, Fera, University of Lincoln, GWCT
Industry partners	None

Project title	Managing soil amendments in horticulture		
Project number	91140002-07		
Start date	01/08/2017	End date	31/12/2021

Project aim and objectives

This project aims to quantify the effects of soil amendments and management on soil health in horticultural production systems. Specifically, the following inter-related objectives seek to gain a better understanding of the soil biology and key soil health metrics that should be recorded by growers in order to be able to manage soils to be good for plant health and development:

1. To identify three fields with a history of fungal and/or oomycete soil-borne diseases in preceding horticultural crops and quantify by qPCR the presence of up to six intractable soil pathogens to include at least one able to cause disease in the following horticultural crop;
2. To benchmark the composition of the soil microbiome to be able to analyse changes in the microbial community over the life of the subsequent crop, including the presence and quantity of any pathogens;
3. To carry out physical, chemical and visual assessments of the field soils in tandem with sampling for molecular assays and seek to determine any relationship between these;
4. To record changes in the soil microbiome over one to three years following the use of soil amendments;
5. To determine any relationship between the microbial population composition and levels of disease in onion, narcissus and raspberry as example horticultural crops;
6. To carry out knowledge exchange with growers on the usefulness of the various soil analytical techniques used in the Project for the assessment of soil health / soil disease suppression / pathogen levels of concern.

Key messages emerging from the project

There continues to be exceptional support for this work by the host growers as they are aware of the persistence of pathogens such as *Verticillium, Fusarium* and *Phytophthora* in soils, but with the exception of *Verticillium dahliae*, soil tests have been unavailable.

Chemical soil sterilants and fungicides have been used by growers, but legislation has started to remove these options, and although crop rotations are used by farmers and growers as a potential control method, there is a need for an understanding of how pathogen levels in the soil may correlate with disease severity.

Methods of improving the resilience of crops to pathogen attack by improving soil health, such as cover crops, green compost, digestate solids and biofungicides are used by some growers but there is little evidence of how these affect pathogen populations. This project is recording the effect of various non-chemical amendments on the incidence and severity of soil-borne diseases affecting onions, narcissus and raspberries, and seeks to relate these to the molecular quantification of pathogens within the soil (with results due in 2020 as part of Project 05). This will lead to a greater understanding of any benefit to growers of various non-chemical incorporations and the utilisation of novel soil diagnostic techniques.

Summary of results from the reporting year

Soil sampling for physical (visual evaluation of soil structure - VESS), chemical (organic matter, pH and extractable nutrients) and biological (respiration, earthworms and crop pathogens - including molecular testing/PCR) properties conducted at site selection in 2017 was repeated just prior to the establishment of raspberry and Narcissus in 2018 and onions in 2019. Post-trial sampling on onions was conducted in autumn 2019 and is due in the other two crops after harvests in 2020. Molecular identification and quantification of soil microbes before and after treatments is being reported as part of Project 05.

Raspberry cv. Maravilla polythene tunnel crop in How's Field, Tunstead, Norfolk:

This field had a high *Verticillium dahliae* microsclerotia content pre-planting (41.6 microsclerotia/g, Harris test). There are four treatments: control (no amendment), anaerobic digestate (50 t/ha), bio-fungicide and digestate plus biofungicide. Anaerobic digestate was incorporated in two 8 m long beds in each of six replicate blocks prior to planting raspberry modules in spring 2018, leaving two plots per replicate untreated. Established plants in one treated and one untreated plot per replicate received a standard 0.5% concentration drench of the biofungicide Prestop (*Gliocladium catenulatum*) at 10% of root ball volume on three occasions in 2018 and on similar dates in 2019 (20 May, 5 June and 22 October), with no phytotoxicity resulting. The 2019 fruiting canes were grown from two buds on the 2018 floricanes cut back after harvest (new primocane shoots from the stool will be fruited in 2020). The fruit was picked 19 times across the whole tunnel, with individual plots picked on 11 July 2019 during peak harvest. No significant difference between plots in either Class 1 fruit weight (mean 2.59 kg) or unmarketable fruit (0.4 kg) or berry weight (mean 6.4 g) was shown between the four treatments. The ten central plants per plot were assessed for Verticillium, twice during fruiting when a total of three of the 240 plants had wilting floricanes, and again on 22 October after floricane removal when 2019 produced primocanes were all symptomless. Soil samples were taken in all Prestop plots on 26 November for qPCR to compare with those taken in 2018 on 22 October. Further foliar and fruit assessments will be carried out in the final year of the crop in 2020.

Narcissus cv. Carlton in Orange Field, Terrington St Clements, Norfolk:

This field contained a high 14.2 microsclerotia of *V. dahliae* per g soil pre-planting (Harris test), but this is not a pathogen of the present crop type. *Fusarium oxysporum* is instead the cause of wilting in Narcissus and, although not found by PCR in the soil, it was found in half of the bulbs sampled at planting in August 2018. There were four treatments: untreated control, pig FYM, green compost and a biological control agent (mycorrhizal inoculation). Prior to bulb planting, either pig manure (35 t/ha) or green compost (50 t/ha) was incorporated in two treatments and two left untreated, with mycorrhiza granules added at planting to one of these. Each 10m 2-row bed was planted with approximately 1700 bulbs, with five replicates of cv Carlton. Foliage emerging in April 2019 showed thickening and distortion associated with roughening of the epidermis with impacted soil, and streaking of yellow and sometimes brown towards the leaf tips. These symptoms were unlikely to be fungal and assessment on 24 April 2019 showed no significant treatment differences (a mean 71% of plants affected with 6% of the leaf area per plot affected). At re-assessment on 3 May 2019 no treatment differences had developed. By 19 June 2019 no incidence of Fusarium wilting or other bulb disease had developed, the small amount of flowering had finished and the leaves were dying back with seasonal senescence. Fera grid sampled across all plots on 22 August 2019 for qPCR. The bulbs will be assessed in 2020 for Fusarium foliar wilt and then bulb rot incidence assessed at harvest.

Brown Onion cv. Rumba in Claypit Field, Shefford, Bedfordshire

A high 28.2 *V. dahliae* microsclerotia/g soil was present pre-planting (not an onion pathogen) and PCR found 438.6 pg/g *Fusarium oxysporum,* which can be an onion pathogen. On 31 August 2018 a commercial cover crop mixture of rye, vetch and phacelia was direct-drilled in three 11m wide strips set 11m apart, but established poorly. On 4 December 2018 four plots in each of the cropped and uncropped strips were marked out and the 24 plots soil sampled for qPCR. On 7 March 2019, 30 t/ha green compost (PAS 100 garden waste 0-30 mm) was spread on half of the cover-cropped and half of the uncropped plots, giving four treatments: untreated control, cover crop, compost, cover crop + compost. By 8 May 2019 the onions had emerged evenly across the four treatments and by 13 August 2019 the foliage of a few onions in each plot was yellowing (on average nine out of approximately 3300 plants per plot). Assessment of the onion bulbs for Fusarium symptoms was carried out when the bulbs were fully grown, when the foliage had collapsed, but not senesced, at the time of normal commercial harvest. Varying extents of leaf tip yellowing were seen to correspond with the severity of bulb internal browning and the presence of purple dry roots. On average across the treatments 90% of bulbs were categorised as unmarketable due to rot, and incubation of samples to obtain mycelial growth confirmed Fusarium to be the cause of rejection; there were no treatment differences.

Key issues to be addressed in the next year

- Any further development of Verticillium wilt in raspberry canes will be recorded and a fruit harvest taken for treatment yield comparisons.
- Any development of Fusarium in the Narcissus will be assessed by foliar yellowing and at harvest. Bulb rot is expected to arise from infestation on the bulbs, rather than from the soil.
- A final assessment of soil physical, chemical and biological properties will be undertaken at harvest of the raspberry and Narcissus crops' soils in tandem with sampling for molecular assays.
- In conjunction with the other projects in the partnership, examine the results from the various soil assessment methods and consider how they might indicate differences in soil health, and working with Project 5 determine whether pathogen levels in the soil determined by qPCR pre- or post-cropping can be related to crop disease incidence or severity.

Lead partner	ADAS
Scientific partners	Fera
Industry partners	Place UK, PS and JE Ward, F.B. Parrish & Son Ltd.

Project title	On-farm monitoring of soil health		
Project number	91140002-09		
Start date	01/08/2017	End date	31/12/2021

Project aim and objectives

In this project we will establish farmer-research innovation groups (8-15 growers per group) that link up a wide range of farms and farming systems across the country (encompassing a diverse range of climate, soil, rotations). We will ensure that the innovation groups include farmers with sugar beet, potatoes and or horticulture in their rotations, as well as reduced / zero-till cereal/oilseed rotations and grass-based systems. The overall aim of Project 09 is to measure the impacts of the broad range of innovations in management of soil health already present on commercial farms by working with farmer/grower groups to collate data on impacts of crop yield/ quality and measurements of soil health using paired field comparisons/ split field treatments.

The specific objectives project are to:

1. Establish 6-8 farmer-research innovation groups (8-15 growers per group) that link up a wide range of farms and farming systems across the country (encompassing a diverse range of climate, soil, rotations)
2. Support the use of a soil health scorecard approach (developed in Project 02) to ensure that it provides farmer-friendly soil assessment together with management data to collect a soil health dataset that can be linked to crop yield constraints and their extent over three cropping years within on-farm rotations
3. Work with at least one farmer in each group to establish on-farm trials that compare / contrast different management approaches alongside their normal practices (e.g. split field experiment) that dovetail and/or extend the range of treatments studied in the trials in WP2 (Project 04 and 07) and collate data on impacts of changed management on soil biology and health
4. Collate the data from all the farmer-research innovation groups and test and develop the descriptive model developed in WP1 (Project 01). Case studies of the innovative practices (both written and in video form) will be developed together with the farmer groups. Outputs from the model, these on-farm studies and the outputs of the research projects in WP2 will be used to develop a range of appropriate KE materials as part of Project 10.

Key messages emerging from the project

The presentation of data in the soil health scorecard format is valued by the farmer groups and has supported interesting discussions about different management systems and their impact on soil health and wider production and environmental outcomes.

The sampling and recording approach required for the soil health scorecard is not considered to be onerous and is able to be fitted into the busy autumn work schedule by most farmers in most years.

Linking the soil health scorecard and the management impacts tool will allow farmers to use the information from the soil health scorecard to identify the most relevant soil-improving practices for their soil and farming system.

Summary of results from the reporting year

Meetings of the eight farmer innovation research groups took place in winter / spring 2019. The first year's data were discussed with the individual groups. The presentation of data in the scorecard format was valued by the farmer groups and supported interesting discussions in the farmer group about different management systems and their impact. The results from the autumn sampling and a description of the overall on-farm programme was integrated into a Research Case Study in late spring 2019.

In autumn 2019, we have continued to test the sampling and recording approach and have added a further laboratory measurement (PMN) as a promising indicator of soil microbial activity to the on-farm scorecard. The autumn 2019 sampling campaign began with meetings of the current active farmer innovation research groups from early October – early November 2019; these were on farm visits which included a visit to review soil health practices at one of the participating farmers and a demonstration of the on-farm sampling protocol. Most groups are now linked with a member of an appropriate sector AHDB KE team; groups with only a few members have recruited more members through the AHDB KE contact and other partners as appropriate. In total, 42 soil health assessments have been made by the SBSH farmer innovation groups on 20 farms between early October and mid-December in this wet autumn; this is 75% of the samples identified and promised by the farmers (usually as paired on-farm comparisons). Where the expected samples were not taken, it was usually saturated soil conditions that limited access for sampling. These data are currently being compiled into the full scorecard format.

The scorecard approach has also been welcomed widely as a KE tool for reporting and supporting discussion of soil health. A farmer-facilitation fund group in Hampshire have worked with Elizabeth Stockdale directly and collected data using the same protocol (25 assessments). In addition, the Cereals & Oilseeds Monitor Farms have been using the approach to underpin discussions about soil health and the planning of soil-improving measures as part of the Monitor Farm programme - up to 6 assessments per farm were carried out for the AHDB KE teams on 7 Cereals & Oilseeds Monitor Farms. In total 111 on-farm soil heath assessments have been carried out using the on-farm protocol in 2019.

Members of all the on-farm research groups will meet to look at the findings of the Partnership projects to date, intended next steps and to share thoughts between farmers and the project research team in winter/spring 2020. Further soil health monitoring on-farm will take place in autumn 2020.

Key issues to be addressed in the next year

- On-going work with the farmer groups will expand sampling to new farms/fields and explore different paired field comparisons though sampling in autumn 2020.
- Evaluation and update of the management impacts tool using both research sites and farmer sites has been scheduled to take place in 2020 - results from the first comparison using Harper Adams site data will be presented in January 2020 (Partnership Management Group meeting).

- Continue to contribute to work that seeks to promote co-ordination and discussion amongst the providers and users of soil health data so that improved understanding rather than confusion results for farmers and growers.
- Identify and begin to develop the innovative practices which will be reported as SBSH case studies (both written and in video form) together with the farmer groups.

Lead partner	NIAB
Scientific partners	ADAS, SRUC, GWCT, ORC
Industry partners	NRM, Frontier, LEAF, Innovation for Agriculture, BASF, Wye & Usk Rivers' Trust

Project title	Knowledge exchange		
Project number	91140002-10		
Start date	01/01/2017	End date	31/12/2021

Project aim and objectives

Within the Soil Biology and Soil Health Partnership, this project aims to develop and disseminate co-designed KE outputs resulting from the knowledge gained mainly through the projects of the Soil Biology and Soil Health Partnership. We are also working to link and create a coherent set of inter-locking messages with the AHDB Research Partnership for the "Management of Rotations, Soil Structure and Water". The project will arrange a series of on-farm events to share knowledge of emerging findings and allow agri-business to provide inputs as critical friends to the partnership. All the outputs will be designed to be easily accessed, understood and implemented by farmers to aid them in the improved management of soil health.

The specific objectives for this KE project are to

1. Provide base-line understanding of soil biology and monitoring and management of soil health on farm at KE events in Year 1 of the project using workshops and demonstrations.
2. Use farmer-researcher interaction to co-design farmer-friendly KE material that supports the development of improved understanding of soil biology and practical advice relating to the monitoring and management of soil health.
3. Produce KE materials in formats influenced by co-design with famers to be made available through KE events within this project and as legacy KE through AHDB and BBRO media outlets and by other agreed means.
4. Present research outcomes demonstrating increasing understanding of soil biology, the use of the soil health scorecard and how management on farm affects soil health through workshops and demonstrations in Years 3 and 5 of the project.

Project activity

The SBSH programme was in its third (mid-programme) year in 2019 and as a result, three SBSH Partnership workshops were organised and hosted at SBSH Research Trial sites to provide research updates to famers and growers and also to allow an opportunity for the remainder of the programme to build farmer / grower feedback. Opportunity was provided at each event for a presentation/ field stop from the Rotations Partnership work; the SBSH Partnership also contributed to the GREATsoils Grower Platform Meeting - Tern Farm, Shropshire (July 2019). The SBSH Partnership also provided a significant input to the AHDB Cereals & Oilseeds Monitor Farm programme over the year.

The Partnership also contributed to five AHDB KE outputs:

- Measuring and managing soil organic matter https://ahdb.org.uk/knowledge-library/measuring-and-managing-soil-organic-matter ; this is associated with draft OM thresholds which have been provided for consultation.
- The soil foodweb – roles and interactions with soil functions; https://ahdb.org.uk/knowledge-library/soil-food-web

- "Principles of soil management" – a cross-sector underpinning guide. https://ahdb.org.uk/soil-principles
- Soil Health Special – podcast https://ahdb.org.uk/news/bonus-podcast-the-latest-on-soil-health
- Video – including farmer groups https://www.youtube.com/watch?v=ropFyiW6W9U&t=6s

Research Case studies

- Testing the effects of organic material additions on soil health. Long-term experimentation at Harper Adams University. (P4 output; published May 2019) https://ahdb.org.uk/knowledge-library/research-case-study-testing-the-effect-of-organic-material-additions-on-soil-health
- Testing the soil health scorecard; on-farm soil monitoring 2018-2019) (P9 output; published June 2019) https://ahdb.org.uk/knowledge-library/testing-the-soil-health-scorecard
- The role of molecular-based indicators for measuring soil health (integrated P5 and P6 output; published June 2019). https://ahdb.org.uk/knowledge-library/role-of-molecular-indicators
- Testing the long-term effects of soil pH on soil health. Woodlands Field, Craibstone. (P4 output; published September 2019) https://projectblue.blob.core.windows.net/media/Default/Imported%20Publication%20Docs/TestingTheLongTermEffectOfpH2965_190918_WEB.pdf

Partnership projects featured in the following in the past year	
Events	
SBSH programme events	
SBSH BBRO field workshop - sugar beet - Terrington	14/05/2019
SBSH field workshop - Craibstone	08/10/2019
SBSH field workshop - Gleadthorpe	18/11/2019
Contributions to other events	
AHDB Monitor farm event (near Brigg) on improving soil health	January 2019
SRUC and AHDB 'roadshows' (x4) in Scotland. Presentation on Soil health	January 2019
Scotgrass – Soil pit; interaction with farmers, consultants and industry about soil and soil quality	15/05/2019
Hampshire and Isle of Wight Wildlife Trust – Farmer /catchment meeting – Soil health	03/06/2019
Cereals – Soilpit with CFE and UK Soil Health Initiative	12-13/06/2019
GREATsoils Grower Platform Meeting - Tern Farm, Shropshire. Farmer representative	18/07/2019
AHDB Monitor Farm – Hale – Soil Health (E Stockdale)	07/11/2019
AHDB Monitor Farm – Huggate – Soil Health (A Bhogal)	13/11/2019
Farmers Weekly – Soils in Practice – South (E Stockdale)	14/11/2019
AHDB Monitor Farm – Duxford – Soil Health (E Stockdale)	15/11/2019
AHDB Monitor Farm – North Shropshire – Soil Health (E Stockdale)	26/11/2019
AHDB Strategic Farm West – results days; Baselining soil health (A Bhogal)	27/11/2019 and 11/12/2019

AHDB Monitor Farm – Downpatrick – Soil Health (E Stockdale)	09/12/2019
Press articles	
Farmers Guardian – press coverage of SBSH Partnership event at Craibstone, October 2019	
Conference presentations, papers or posters	
Future Foods Partnership conference; York (invited presentation – E Stockdale)	12/03/ 2019
CHAP Soil Health workshop – presentation (E Stockdale)	04/06/2019
Groundswell – platform presentation (Anne B, John E) and farmer interaction at the AHDB soilpit	26-27/06/2019
SRUC workshop - development of soil quality monitoring methods and management tool.	01/07/2019
Wageningen Soils Conference – presentation (E Stockdale)	27-30/08/2019
Fera Science Conference – posters on 2 PhD projects	18-19/09/2019
5th Annual BCPC DISEASES Review on Plant Diseases: Threats, tools and solutions. NIAB Conference Centre (E Chapelhow)	10/10/2019
LIC Pasture4Profit conference (Invited presentation - E Stockdale)	16/10/2019
Advances in Soil-borne Disease Etiology and Control, De Vere Orchard Hotel, Nottingham, UK (E. Chapelhow)	24/10/2019
Catchment Sensitive Farming Partnership, CSF Training Conference 2019 (series of workshops on scorecard approach for all CSFOs – E Stockdale)	03-04/12/2019
AHDB Agronomists Conference presentation - Starting with soil health (A Bhogal)	03-04/12/2019
PGRO Growers meeting – soil health presentation (E Stockdale)	10/12/2019

Scientific papers	
Other	
All Party Parliamentary Group science and Technology in Agriculture Discussion Group – meeting on Soil Health; House of Commons.	15/01/2019
MASTERsoil Farming Connect training	26-27/03/2019
Soil Security Programme Workshop – Soil Health indicators on-farm	20-21/05/2019
MASTERsoil Farming Connect training	03-04/10/2019

Lead partner	NIAB
Scientific partners	SRUC, ADAS, Fera, GWCT
Industry partners	NRM, Frontier, LEAF, Innovation for Agriculture, BASF, Wye & Usk Rivers' Trust

Project title	Developing UK-relevant benchmarks for the soil health indicators: Potentially Mineralisable N (PMN) and Solvita CO_2 burst		
Project number	91140002-11a		
Start date	01/04/2019	End date	28/02/2020

Project aim and objectives
To update the soil health scorecard benchmark values for PMN and CO_2 burst to more accurately reflect UK soils and climatic conditions.

Key messages emerging from the project

The determination of potentially mineralisable N (PMN) and CO_2-burst respiration are indicators of the size and activity of the soil microbial community, but current benchmark data are based on data largely derived from studies in the United States.

Analysis of the Hillcourt (for PMN) and NRM (for CO_2-burst) databases aims to develop UK relevant benchmarks for use with the soil health scorecard.

Preliminary results demonstrate that both PMN and respiration drop to negligible levels in subsoils (60-90cm), which is to be expected and re-assuring that the methods are indicators of biological activity.

A similar approach to the SOM benchmarking exercise undertaken in Project 02 of this programme is currently being evaluated in order to develop 'typical ranges' for broad textural groups (light, medium and heavy textured soils). These will be tested using data collected from Projects 04 and 09.

Summary of results from the reporting year

Assessment of the size and activity of the microbial biomass is considered to be a key indicator of soil biological health, and can be measured by a number of methods including:

- Chloroform extraction for determining the microbial biomass carbon pool ('MBC')
- CO_2-burst (using the Solvita paddle to measure CO_2 evolution) which gives a measure of microbial respiration (www.solvita.com);
- Potentially mineralisable N which measures the activity of microorganisms involved in the mineralization of organic N ('PMN').

The chloroform extraction technique is predominantly used by research organisations and is not currently offered by any of the main commercial laboratories in the UK (principally as it involves the use of chloroform with its associated Health and Safety implications). However, both PMN and CO_2 burst are currently offered by commercial laboratories, but benchmarking data for both largely comes from the United states ('The Cornell Framework' and www.solvita.com) where soils are very different and tend to be lower in organic matter than those in the UK. As a result, the 'traffic lights' that are currently proposed for these indicators within the soil health scorecard may not be appropriate for UK soils and cropping conditions.

Potentially mineralisable N benchmarking:
The Hillcourt Laboratory database of PMN analysis results (c. 400 top soils, 0-30cm) is largely comprised of medium and heavy textured soils (all arable sites), with less than 10% of samples being classed as light textured (e.g. loamy sand & sandy loam). Sampling of c. 26 sites in spring 2019 was undertaken to supplement this database, particularly with data from light textured soil types, but also to compare sampling depth (0-15cm and 0-30cm) as well as topsoil compared to subsoil concentrations in order to understand the 'extremes' of microbial biomass (PMN) possible within UK soils. Further sampling in autumn 2019 will add an additional *c.* 25 sample results from the farmer groups (Project 09) and look also at spatial variability of PMN across a field (utilising a BBRO managed field site, with a grid sampling pattern).

Four sites with contrasting textures (heavy, medium and light) compared topsoil (0-30cm) with subsoil (60-90cm) concentrations, and all reported minimal concentrations (< 3mg/kg) in the subsoil, compared to the topsoil (average of 24 mg/kg), which was re-assuring. Three sites (heavy, medium and light textured soils) also compared 0-15 cm (soil sampling depth recommended for the scorecard) and 0-30 cm (typical sample depth for routine soil mineral N sampling and within the Hillcourt database). PMN tended to be greater in the 0-15cm compared to the 0-30cm; this difference was marginal for light and medium textured soils (4-8% higher), but doubled (c.120% higher in the 0-15cm sample compared to 0-30cm) at the heavier textured site.

Initial analysis of the Hillcourt database demonstrated a good relationship between PMN and Soil organic matter (SOM - % Loss on ignition); $r^2 = 0.31$. A similar approach to the SOM benchmarking exercise undertaken in Project 02 of this programme was therefore taken in order to determine 'typical ranges' for broad textural groups (light, medium and heavy textured soils), with traffic lights allocated as follows: green (no action required) ≥ median value; amber (monitor) > lower quartile < median; red (investigate) < lower quartile. This has been provisionally determined for arable soils in England and Wales, using the Hillcourt database. On-going work will evaluate data obtained from SAC laboratories in Scotland and will also test the provisional benchmarks with new data obtained in autumn 2019.

_CO_2-burst benchmarking_
NRM hold a large database from their soil health index testing service which include analysis of soils for texture, organic matter (loss on ignition) and Solvita CO_2 burst (n=3676). 'Cleaning' of this database to remove samples from abroad, non-agricultural soils, permanent crops, subsoils, high organic matter soils (>20% SOM) and incomplete datasets reduced the database to 3408 samples from 'cropland' and 277 from grassland; the remaining database is currently being checked by NRM before benchmarks are determined; it is envisaged that the same approach to that used for PMN will be used. There were 9 paired topsoil and subsoil samples, which similar to PMN showed significantly lower respiration rates in the subsoil (13.5 compared to 122 mg/kg CO_2-C; P<0.01), which again was reassuring.

Key issues to be addressed in the next year
• Finalise the analysis of the Hillcourt and NRM databases, incorporating data from Scotland and the autumn 2019 sampling campaign • Produce UK-relevant benchmarks (‘traffic lights’) for PMN and CO_2-burst respiration for use in the soil health scorecard.

Lead partner	ADAS (Anne Bhogal)
Scientific partners	NIAB, SRUC,
Industry partners	NRM & Hillcourt Laboratories (latter – subcontractor for this project)