Partnership Summary Report

Soil Biology and Soil Health Partnership

Project 91140002

2017–2022

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Introduction

Funded by AHDB and BBRO, the five-year Soil Biology and Soil Health (SBSH) Partnership (2017–2022) was a cross-sector programme of research and knowledge exchange. The programme was 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.

Soil physics, chemistry and biology are interlinked, and all play a role in maintaining productive agricultural and horticultural systems. While physical and chemical properties of soil are relatively well understood, the same was not necessarily true for soil biology at the start of SBSH Partnership. Interest in soil health has been increasing over the last decade and a range of indicators for soil biology had been developed through research. These indicators, however, often had not been produced in parallel with the necessary guidance and tools to allow them to be used effectively to support management decisions on farm.

This report provides an integrated summary across all the SBSH Partnership work. Detailed reports are also available on a project-by-project basis, together with the broad base of KE outputs generated through the SBSH Partnership via www.ahdb.org.uk/greatsoils.

Aims and objectives

The key aims of the SBSH Partnership were to:

- Improve understanding of the factors affecting soil biology and identify management options to improve soil health
- Develop and evaluate molecular tools for measurement of soil microbial communities, including soil-borne pathogens
- Develop approaches for on-farm measurement of soil health to support practical decision-making

To deliver these aims, the SBSH Partnership was formed of three interlinked work packages (Figure 1). An Innovation Fund was also established that allowed additional studies/ activities to be commissioned after the start of the SBSH Partnership to develop the findings of the research projects or add additional objectives to support understanding of soil biology and best practice management of soil health.

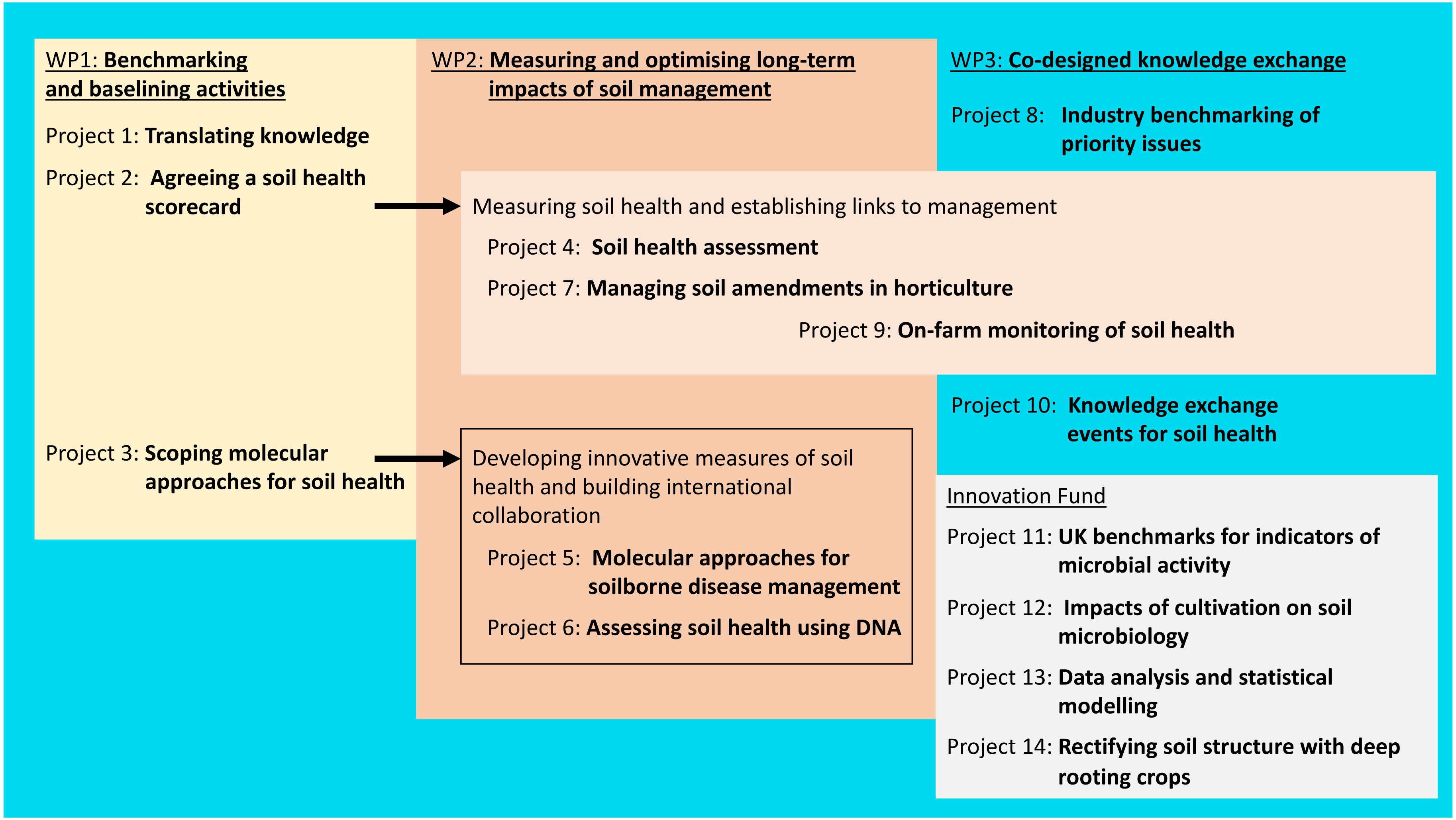

Figure 1: Overall structure of the Soil Biology and Soil Health Partnership showing the links and interactions between the projects within three Work Packages.

The specific objectives, presented by work package, were to:

Work Package 1: Benchmarking and baselining activities

- Update scientific reviews of soil biology and soil health, especially as applicable in temperate UK cropping systems and develop a descriptive model that summarises the drivers of soil biology and soil health, and links to crop health and yield (Project 1)
- Develop a visual tool that provides an easily understood summary of the effects of soil management on soil biology and soil health (Project 1)
- Identify and recommend a complementary minimum set of existing methods to measure soil health on-farm and an interpretation framework, which can be used to support practical decision-making, within an integrated soil health scorecard (Project 2)
- Review molecular approaches that can be applied to assess soil biological function in cropping soils (Project 3)
- Recommend a toolkit of appropriate molecular diagnostics for detection of specific indicators of soil biological communities (occurrence, activity and interaction) (Project 3)

Work Package 2: Measuring and optimising long-term impacts of soil management

- Quantify the effects of contrasting management practices on soil biology and health, in relation to crop yield and quality, and evaluate the use of simple tools for assessing soil health (integrated soil health scorecard) (Projects 4, 9, 11 and 14)
- Utilise existing long-term experimental sites to explore the key drivers of soil biological functioning – i.e. soil organic matter, drainage status and pH – and how they can be managed (Projects 4, 6, 12 and 13)
- Quantify the changes brought about by the use of soil amendments for selected horticultural crops, utilising a combination of qPCR of pathogens, at least one biocontrol fungus and metabarcoding of the wider soil microbe population, together with other physical, chemical, and biological measures of soil health (Projects 7 and 5)
- Further develop and stimulate the use of molecular tools for the detection and quantification of soil-borne pathogens and demonstrate the value of regular and standardised assessments of propagule densities in soils (Project 5)
- Demonstrate the value of next generation sequencing methods (metabarcoding of the entire soil microbiome) to aid understanding of complex interactions between soil management practices, biodiversity and the suppression of soil-borne pathogens (Project 6)
- Evaluate the use of DNA-based analyses to replace individual tests in an appraisal of overall soil health (Project 6)

Work Package 3: Co-designed knowledge exchange

- o Work with the agri-food sector, including farmers, growers, advisors, researchers and the wider agri-business sector, to confirm the key priority issues for the sector with regard to soil biology and the management of soil health (Project 8)
- o 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 (Project 9)
- o Develop and disseminate KE outputs (Project 10)

Ten inter-linked projects were developed at the outset to enable the research teams to deliver the SBSH aims and Work Package objectives most effectively. Projects 11-14 were developed as part of the Innovation Fund. Detailed reports are available separately for each project.

Project No.	Short Title (with link to Final project report, where available)	Lead	Start Date	End Date
WP1 – Benchmark and baselining activities				
01	Translating existing knowledge	SRUC	01/01/17	31/12/17
02	Agreeing a soil health scorecard	SRUC	01/01/17	31/12/17
03	Scoping molecular approaches for soil health	Fera	01/06/17	31/12/17
WP2 – Measuring and optimising the long-term impacts of soil management on soil biology and health				
04	Soil health assessment	ADAS	01/06/17	28/02/22
05	Routine DNA-based measures for soil-borne disease	Fera	01/04/17	28/02/22
06	Assessing soil health using DNA	SRUC	01/04/17	28/02/22
07	Managing soil amendments in horticulture a) Onions; b) Narcissus; c) Raspberry	ADAS	01/09/17	31/08/21
WP3 - Co-designed knowledge exchange				
08	Industry benchmarking of priority issues	NIAB	01/01/17	31/12/17
09	On-farm monitoring of soil health Annex 1: Soil heath scorecard data	NIAB	01/08/17	31/12/21
10	Knowledge exchange events for soil health	NIAB	01/01/17	31/12/21
Innovation Fund projects				
11	UK benchmarks for indicators of microbial activity	ADAS	01/04/19	31/03/20
12	Impacts of cultivation on soil microbiology	GWCT	01/04/20	31/03/21
13	Data analysis and statistical modelling	NIAB	01/02/20	28/02/22
14	Rectifying soil structure with deep rooting crops	ADAS	01/10/20	30/09/21

Ways of working

The SBSH Partnership brought together an interdisciplinary team across 12 organisations with relevant research and knowledge exchange expertise in soil health including 5 research organisations (NIAB, SRUC, ADAS, Fera, University of Lincoln) and a number of NDPBs, NGOs and private sector companies (Natural England, Game and Wildlife Conservation Trust, Wye & Usk Trust, NRM, Frontier, Organic Research Centre, BASF). These collaborative partnerships ensured that relevant soil biology, integrative soil health/ quality measurement, soil management, cropping systems, environmental and socio-economic expertise were fully integrated into the SBSH Partnership from the outset. Partnership working with other AHDB projects and other research and industry partners was further expanded during the SBSH Partnership. This collaborative approach provided the specialist knowledge and understanding needed to deliver the applied research and KE in support of the SBSH Partnership's aims.

Seven existing long-term experimental sites with a history of different management practices and known differences in soil organic matter content, pH and drainage status/structure were studied across projects within the SBSH Partnership covering a range of soil and agro-climatic conditions and rotations with grass leys, cereals, sugar beet and potatoes (Projects 4, 5, 6, 13). Three trials were also established in horticultural crops (onions, narcissus, raspberry) to study the effects of organic and biological amendments (incorporated pre-planting) on soilborne pathogens and soil health (Projects 7 and 5). The work on raspberry also tested three annual applications of a biofungicide (Prestop, *Gliocladium catenulatum*). The impacts of cover crops and mulches (used for erosion control) in asparagus on soil pathogens and the soil microbial community were studied in partnership with Cranfield University in a long-term trial (Project 5).

At these sites, crop yield and quality were assessed, and soil health assessments were undertaken for topsoil in the autumn, at least once at each site, between 2017 and 2020 (Projects 4 and 7). Measurements included: visual soil assessment of soil structure (VESS), pH, extractable P, K & Mg, organic matter, earthworm numbers (the main Soil Health scorecard measures), together with CO_2-C burst, potentially mineralisable N (PMN), microbial biomass carbon (MBC), bulk density and penetrometer resistance (Projects 4 and 7). Detailed measurements of the soil mesofauna and microbial communities (Project 6) and targeted soil pathogens (Project 5) were also made in parallel on most sampling occasions.

The SBSH Partnership also recognised that many farmers and growers were already taking the initiative to understand the health of their own soils and that there was existing work on-farm considering ways to optimise soil biology. The Partnership therefore worked closely with farmers, growers and advisers to draw together and build on knowledge and experience to create accessible guidance and tools to help farmers improve soil health. 8 farmer-research innovation groups, including 75-100 farmers and advisers involved in, or interested in, implementing innovative management practices to enhance management for better soil health, from a wide range of farms and farming systems across the country (encompassing a diverse range of climate, soil, rotations) worked within the SBSH Partnership (Project 9). Farmers within the groups have implemented a range of practices, at least partly to improve soil health. These are mainly system-oriented approaches (i.e., increasing OM input, reducing tillage intensity, increasing cropping/sward diversity); but have also included some tactical interventions, such as slurry inoculation, application of molasses or compost teas; companion cropping and CTF systems. The farmer-research innovation groups evaluated and applied the Soil Health scorecard approach to compare / contrast different management approaches and to collate data on the impacts of changed management on soil biology and health (2018-2021). The SBSH Partnership also worked closely with the AHDB Cereals and Oilseeds Monitor Farms from autumn 2019 onwards, as well as other farmer groups from beyond the Partnership, to pilot the Soil Health scorecard approach. As part of, or working with, the SBSH Partnership, 287 Soil Health scorecards were collected on farm between 2018 and 2020 across a range of farm system and soil types, together with 22 sites in orchards (Project 9). Direct engagement with the farmer groups during the process also helped to shape the SBSH Partnership outputs, identify research and KE gaps as well as to shape new research questions.

The agri-food industry has a huge breadth of experience and depth of understanding of the practical issues involved in the management of soils within a rotational context and their implications for crop yield and quality. The SBSH Partnership established strong co-operative relationships across the industry from the outset (Project 8). Co-construction of knowledge in this way ensured that the research partnership was strongly founded on the actual, rather than researcher-perceived, needs of the industry and allowed a challenge to the programme design and focus of projects. Crucially, the SBSH Partnership took an open knowledge-sharing approach with key players in the agri-food sectors throughout its research and KE activities to help direct the work and maximise the practical relevance of its findings for current farming systems.

Findings

Improving our understanding of the factors affecting soil biology and identifying management options to improve soil health

The SBSH Partnership updated existing scientific reviews of soil biology and soil health, especially as applicable in temperate UK lowland farming systems, and summarised how management practices affect the biological, physical and chemical properties of soil and overall soil function. Some of the management options were specific and well-studied i.e., reduced tillage, use of organic amendments, retention of crop residue, fertiliser addition, liming, controlled drainage, controlled traffic, and use of pesticides. However, other options considered were more general and less specific such as conservation agriculture (combining zero tillage with cover crops), increasing plant diversity (e.g., intercropping) and organic farming. The review found that there were still gaps in the knowledge for the less common management options, especially in considering interactions between soil type and climate, and much less consideration of the impacts of management options when adopted in combination (Project 1).

The information was translated from the format of a scientific review into a descriptive model which allowed the important interactions (environmental, soil, crop, management) contributing to soil health to be summarised semi-quantitatively. This approach enabled the development of a visual tool that summarised the key interactions affecting soil biology and health, which was specifically targeted at building grower understanding to develop improved soil management. To generate the visual tool the effects of the management options were modified semi-quantitatively according to soil type (light, medium or heavy), UK climatic zone (cool & dry; cool & wet; warm & dry; warm & wet) and general rotation type (combinable cropping; cropping with late-harvested crops; grassland). The visual tool presented the likely magnitude of the effects of representative management options (reduced tillage; no-tillage; cover crops; carbon-rich or nitrogen-rich organic amendments) on a suite of biological, physical, chemical and economic outputs (development in Project 1; final evaluation in Project 6).

The integrated measures of soil health together with detailed measures of soil microbial and mesofauna communities collected across the sites/years by the SBSH Partnership showed clearly and consistently across the range of measures tested that differences between sites were greater than differences between management practices at a single site (Projects 4, 6 and 13). Inherent soil characteristics together with site factors such as slope, climate and hydrology establish the ‘potential’ of any site, whether expressed in terms of yield, soil health or the size, activity and diversity of mesofauna and microbial communities.

The following conclusions can be drawn about the impacts of management practices from the trials carried out within the SBSH Partnership:

- Optimising pH (6.5) maximises nutrient availability, biological activity and crop productivity (Projects 4 and 6)
- Inclusion of grass leys (2–3 years) improves soil organic matter, nutrient status, biology and structure (Projects 4 and 6)
- Organic materials (particularly bulky, high dry matter materials) are a valuable source of organic matter and nutrients and promote soil biological activity when used regularly (Projects 4, 6 and 13). The findings suggest that low-clay soils may be more responsive to organic amendment treatments.
- Short-term application (often a single application) of organic amendments in the horticultural crop trials had little effect on soil health, and no measurable impact on crop disease or crop performance (Projects 7 and 5). Multiple annual applications over the rotation are likely to be required before any effect is measurable.
- Intensive cultivations reduce soil penetration resistance, bulk density, and earthworm numbers (Project 4).
- Ploughing in a long-term no-till field reduced microbial activity and functional diversity (i.e. the range of different substrates that the microbial population could break down). However, the ploughed plots in no-till fields did not have a different overall soil health status compared with direct drilling (Projects 4 and 12). These data suggest that a strategic tillage operation, e.g. to control weeds, in an otherwise no-till rotation need not lead to a significant decline in soil function.

The SBSH Partnership was able to show a positive relationship between grain yield and some indicators, particularly soil organic matter (SOM), and nutrient status across the long-term organic amendment trials (Project 4 and 13). At other sites, it was also possible to directly link measures of ‘sub-optimal’ soil health with poorer yields (Projects 4, 9 and 13) e.g. low pH, compaction (high VESS score).

There is currently limited evidence to guide best practice on the use of vigorous rooting crops to remediate soil structure. A targeted review identified that such crops may benefit topsoil structure after multiple years in reduced or no-till cropping systems (Project 14). It is likely that tap-rooted species are most suited to improving soil structure in compacted soils.

Current nematode and mesofauna community analysis approaches aren't suited to routine commercial application as the methods required are laborious, requiring specialist identification skills (Project 6). There are existing nematode community-based indicators that showed the potential to distinguish sites and management treatments. A relatively simple characteristic of the mesofauna community, such as the total density of springtails, or the ratio of mites and springtails (as % Collembola), might also provide a simple indicator linked to soil organic matter cycling, and properties likely to enhance soil function in an agricultural context (Project 6). DNA-based methodologies may also offer a more practical and affordable solution for these analyses in the future.

At the end of the programme, the descriptive model and accompanying visual tool were evaluated using the data collected during the SBSH Partnership. This evaluation validated the embedded qualitative relationships (Project 6). Therefore, the descriptive visual tool can provide useful indications for farmers and consultants considering a change to management by highlighting both positive impacts and challenges for soil biology and soil health that arise from different management practices.

The use of molecular tools for measurement of soil microbial communities, including soil-borne pathogens

Procedures for sampling soil and then extracting DNA were reviewed and evaluated within the SBSH Partnership (Project 3). Where DNA extraction methods were compared, it was shown that DNA extraction method had a larger impact on the measured biological community than a range of long-term organic amendment treatments in one long-term trial (Project 6). A method that aimed to extract only extracellular DNA was not effective at recovering DNA from soil; no extracts composed of only extracellular eDNA could be obtained. For soil-based work, the project concluded that effective extraction of DNA from soils requires methods that also lead to cell lysis and hence the intra-cellular DNA of soil microorganisms is measured along with extracellular DNA. When the data were pooled across extraction methods, the total number of species recorded was significantly higher than separate extractions. Therefore, it is likely that the different extraction approaches targeted different parts of the soil microbial community. However, the pooled data also showed no effect of organic amendment treatment on the total number of species or community composition; organic amendment had a small effect on relative species richness. The project confirmed that standardisation of DNA extraction methods is important when comparing samples collected from different locations and at different times (Project 6).

Once soil DNA extracts are available, two approaches are considered most suitable for routine analysis of taxonomic or functional markers i) quantitative PCR (qPCR) for detection and quantification of specific markers, and, ii) next generation high throughput sequencing for analysis of whole soil communities (Project 3). Some technical challenges remain to be fully overcome in the application of these technologies to ensure a representative and unbiased analysis of soil microbiological communities and their function.

qPCR – pathogen detection

Quantitative PCR (qPCR) was successfully used to detect and quantify individual pathogens as well as biocontrol agents, including rhizosphere populations of *Gliocladium catenulatum*. Over 20 different qPCR assays were validated as suitable for use and controls were developed that allow reproducible quantification of the target organisms in these soils (Project 5). However, quantification of *Verticillium dahliae* in soil by qPCR requires further evaluation as the results found did not correlate well with those determined by the Harris test.

In collaboration with scientists from the South Australian Research and Development Institute (SARDI), developers of the industry award-winning PREDICTA® molecular soil testing service, the SBSH Partnership confirmed that molecular approaches in routine soilborne disease testing can reduce cost and increase speed and accuracy. However, within the SBSH Partnership, attempts to relate disease incidence to pre-planting levels of *Fusarium oxysporum* in onion and daffodil and *Verticillium dahliae* in raspberry trials were unsuccessful due to excessively high inoculum in the onion and very low detected inoculum levels in the other crops (Project 5). More work is needed to investigate the relationship between soilborne inoculum levels and disease risk further. Validation of DNA testing approaches for the UK would require extensive monitoring over many seasons and locations and could not rely on data obtained from isolated trials, such as those investigated in this project.

Meta-barcoding – describing the soil microbial community

The SBSH Partnership developed a standardised approach to DNA analysis, building on the use of the same methods across multiple studies with high variation, to gain a broader understanding of management impacts on soil biology (Project 6).

For the soil microbial community, site significantly affected microbial community composition. However, strong divergent trends were also found for multiple taxonomic diversity indices in response to pH, supporting previous findings that small changes in soil pH can produce changes in community composition. Because of this strong impact of pH treatment, it was possible to identify specific taxa and to infer functional divergence between microbial communities. This represents one of the first attempts to assess the feasibility of functional analysis based on DNA, alongside the broader assessment of soil health (Project 6). In contrast, a smaller impact on microbial community composition occurred in response to other management change, including long-term fertiliser treatments, organic amendment or tillage (Project 6).

The SBSH Partnership has demonstrated that soil meta-barcoding is able to test the extent to which bacterial and fungal diversities change in response to management and the need to assess the magnitude of those changes across multiple datasets. However, as the costs of measurement are still very high for each sample and no UK-wide benchmarking framework can currently be established, the SBSH Partnership findings do not currently support the use of soil metabarcoding for routine soil health monitoring on farm.

Measuring soil health on-farm to support practical decision-making

The SBSH Partnership evaluated 45 biological, physical, and chemical indicators of soil health and considered how these could be integrated into a soil health scorecard to give a ‘snapshot’ overview of soil health (akin to a car MOT or school report), designed to be repeated in the same field location on a rotational basis (Project 2). The indicators were scored using a logical sieve approach considering relevance to both agricultural production and environmental impact and practical aspects including sample throughput; sample storage; necessity of single or multiple visits for sampling; ease of use; ease of interpretation sensitivity; cost; standardisation and UK availability. The potential list of indicators was reduced to 12 (visual assessment of soil structure (VESS), bulk density, water infiltration, pH, routine nutrient measures (P, K, Mg) , SOM, microbial biomass, respiration, nematodes and earthworms) that were further evaluated in the field during the SBSH Partnership (Projects 4, 7 and 9). To create a scorecard, a ‘traffic light’ system was used to provide a visual overview of the status of each indicator. Green status indicates that no further action is need beyond continuation of rotational monitoring. Amber and red status for any indicator indicates that further review and investigation is warranted to consider whether remedial action is possible and needed. Wherever possible, the thresholds were linked to the risk of reduced yield and sub-optimal soil conditions/function (e.g. environmental risk where available P is very high). The SBSH Partnership also used simple site characteristics (rotational land use, soil texture group (light, medium, heavy) and climatic zone) to support more detailed benchmarking where data were available and the indicator measurement showed distinctions as a result of these factors; this was most marked for SOM (Project 2).

The farmer innovation-research groups found the field protocol relatively easy to follow, especially when shown (as part of field days or as a video reminder) rather than solely read. When the principles and the protocol were described to growers in other systems (perennial row crops), they were rapidly able to adapt the protocol and then apply the new protocol effectively within their own systems (Project 9). The farmer groups confirmed that although the timing of sampling when soils are moist and warm (mid-autumn / early spring) was not ideal, in terms of a fit to a lull in farm workload, it could be implemented in practice. Over >80% of farmers who agreed to collect their own Soil Health scorecard data completed both the field data collection and sampling submission processes. The practical considerations (including cost) identified by famer groups meant that measurements of bulk density, penetration resistance, microbial biomass and nematodes were not taken forward as on-farm indicators within the SBSH Partnership. The farmer innovation-research groups discussed how the regular monitoring of soil health could be integrated into farm practice. Across all groups, the most common rotational crop is a first cereal (often, but not always winter wheat). The groups that were sampling in cropping systems matched their sampling timing (post-harvest in the stubble or cover crop after a cereal and after the soil has wetted up, usually October/November), to allow the most effective benchmarking between fields/farms. Within farms, farmers used their knowledge of the differences in inherent soil properties to select sampling sites within the project. For many farmers the intention was to select sites that would continue to be monitored in the future as network of farm sites alongside other targeted sampling e.g. for nutrient management or tillage optimisation.

The size and activity of soil microbial biomass is considered to be a key indicator of soil biological health. However, the ‘standard’ method of assessment which uses a chloroform extraction is not currently offered by any of the main commercial labs in the UK due to the hazardous reagents required. Two alternative commercially available methods can be used to infer the size and activity of the microbial community: (i) potentially mineralisable nitrogen (PMN) which measures the amount of N readily decomposed under controlled (anaerobic) conditions, and (ii) CO_2-C burst which measures the amount of C released as CO_2 when a dried soil is rewetted. These processes are both dependent on the size and activity of the soil microbial biomass. The SBSH Partnership collected UK data to derive threshold values that are relevant for UK agro-climatic conditions (Project 11). Evaluation of the guideline values using data from sampling at the long-term experimental sites clearly demonstrated that these revised values were more sensitive at identifying treatment differences (due to variations in organic matter content and pH) than the thresholds derived from US data. The SBSH Partnership confirmed that adding an indicator of microbial activity to the Soil Health scorecard potentially gives some additional detail on soil function at relatively little extra cost. However, care is needed when interpreting CO_2-C burst data for calcareous soils (Project 9).

Monitoring using the Soil Health scorecard in the long-term experiments found that the suite of measurements included on the scorecard (i.e., VESS, pH, routine nutrients (P, K, Mg) SOM, earthworm count, PMN and CO_2-C burst) and their benchmark values do identify situations where soil health is potentially 'sub-optimal', either limiting production and/or increasing the risk of negative impacts on the environment (Project 4). These results confirmed that there is a link between the soil characteristics included in the Soil Health scorecard and soil function thereby confirming their value as indicators of soil health. Further statistical analysis of 247 on-farm Soil Health scorecards also established SOM, VESS, pH and nutrient (P, K, Mg) availability were the most important explanatory measures (Project 13). The Soil Health scorecard data distinguished sites from one another in a way that cannot be explained simply by consideration of the variables singly or in simple clusters.

The farmer innovation-research groups liked the overall Soil Health scorecard and confirmed that it gave a useful visual health check – some indicated that they would also like to see a single soil health score. Farmers particularly valued the VESS scoring and considered that capturing photos provided a clear record and often gave further information when reviewed in the office that could be missed in the field. Overall, consultation and review during the SBSH Partnership has supported the use of the multi-factorial framework and no indicators were removed from the Soil Health scorecard. Review of the indicators in light of the data collected with the SBSH Partnership led to:

- Reduced thresholds for the earthworm number benchmarks in grassland.
- Strong confirmation of the value to farmers and advisors in providing simple benchmarks for SOM; minor updates were made in the presentation of the benchmarking tables compared with those presented for consultation during the SBSH Partnership.

The farmer innovation-research groups recognised that just knowing some numbers about soil, even having an integrated assessment of physical, chemical and biological properties with comparison to relevant benchmarks won't improve soil health. In the project, the Soil Health scorecards collected by the farmers supported informed discussion within and across farmer innovation-research groups about the range of soil management practices already used and the practices that might be adopted to maintain/ improve soil health. In particular, the groups valued the way the presentation of data within the Soil Health scorecard quickly identified areas where improvement can be made through management or where more detailed assessments or more regular monitoring are needed to clarify the problem. The discussions in the farmer innovation-research groups fed into separate work facilitated by the SBSH Partnership team for the UK Soil Health initiative to identify best (and least-worst) practices that minimise deleterious impacts on soil quality, particularly for productivity and in relation to direct impacts on air and water quality. This co-produced information on sustainable soil management has been brought together in farmer-facing resources for many soils and farming systems:

www.cfeonline.org.uk/environmental-management/soils/uk-soil-health-initiative-guides/

Overall, the discussion with farmer innovation-research groups highlighted that although general guidance is useful to inform practice choice, the best soil husbandry is always site and season-specific, and each action needs to be informed by observation.