Farm Stock KTIF Project – KTIF / 002 / 2021

Soil Health – A Route Towards Net Zero for the Scottish Livestock Industry

Project Report

1. PROJECT TITLE

1.1 Title

Soil Health – A Route Towards Net Zero for the Scottish Livestock Industry

1.2 Overview of the Lead Company

Based in Selkirk, Farm Stock (Scotland) Ltd (FSS) was the lead organisation in this project. It is a farmer owned livestock marketing co-operative with over 1,000 individual shareholder members and a total database of around 1,500 sheep and cattle producers across central, southern and western Scotland. Created in 1996, it is jointly owned by 6 regional livestock marketing co-operatives and has an annual turnover of approximately £20m handling around 160,000 sheep and 6,000 cattle each year.

The co-operative is managed by an executive team responding to a farmer board and the business has grown rapidly in the last 5 years and has an ambitious growth strategy in place. With its current and intended position in the marketplace, FSS is a well-respected and recognised force in the red meat supply chain from farmer producers right through to retailers, with a proven track record in delivering projects and commitments, creating the confidence of stakeholders throughout the supply chain.

2. EXECUTIVE SUMMARY

2.1 Overview

Farm Stock (Scotland) Limited (FSS) was awarded a KTIF grant on 10/11/2021. The 100% grant of up to £69,878 covered a project entitled A Route Towards Net Zero for the Scottish Livestock Industry to be run over the period 10/11/2021 to 31/03/2022 and for completion by 31/03/2022.

The operational group comprised of FSS, providing overall project management and the selection, access to and co-ordination of the participating farmers, KBevan Consulting providing specialist knowledge and consultancy in improving productivity and efficiency at both farm and chain levels of the livestock sector, SoilEssentials Ltd providing the required specialist soil sampling techniques and subsequent analysis and soil scientist Dr Bill Crooks, who as a soil and water specialist contributed practical soil management expertise to both farmer meetings and the project report.

The project was designed to help the Scottish agricultural industry meet the Scottish Government's net zero targets by becoming more efficient specifically, through better management of soil health and also to provide the Scottish Government with a snapshot of soil health across a representative sample of Scottish livestock farms.

2.2 Main Findings

The main findings of the project were:

1. Soil health is universally accepted as important but means different things to different people.

2. A soil health scorecard provides a practical decision and support tool to help farmers better assess and manage the soil in their fields. Based on the scorecard piloted in this project, the soil health of the 40 fields surveyed was generally good.

3. Robust sampling and testing protocols are critical to the validity of many of the measures used in the scorecard. For example, whole field assessment of phosphate could be meaningless where there is significant variation within that field. Effective soil sampling techniques need to be reinforced and expanded so that they are more useful on identifying the effects of management variables such as stock camps.

4. Tests for directly assessing a soil's biology are not available or are difficult to interpret.

5. Measuring soil organic matter (SOM) using the loss on ignition method is possibly the most cost-effective way of estimating how much carbon is sequestered in a field's soils.

6. Measuring changes in a field's soil carbon levels to the level of accuracy required by Intergovernmental Panel on Climate Change (IPCC) is technically challenging and very expensive. But such measurement is necessary to better calibrate the value of the cheaper loss on ignition SOM measure.

7. Visual Evaluation of Soil Structure (VESS) is an excellent self-assessment tool, but it needs to be expanded to cover direct management options that arise from individual assessments. It also needs to be modified to include a process of identifying compaction layers within the profile.

8. Compaction is one of the major factors affecting soil health on livestock farms.

9. Though not included in the scorecard, use of Nitrogen Use Efficiency (NUE) benchmarks could also help farmers minimise their environmental footprint.

10. Use of synthetic (bagged) nitrogen on Scottish beef and sheep farms is modest if this group of farmers is representative. However, that should not imply that room for improvement in synthetic nitrogen use does not exist.

11. While good soil health is important in helping farmers contribute to the nation's net zero goals, the impact of its optimisation through management, must be considered as part of the way farmers manage their overall businesses.

12. Best practice management should be based on sound scientific principles supported by evidence from robust trials completed under Scottish conditions.

13. To increase the likelihood of good uptake, communication of best practice should be via channels that farmers best respond to. Given people learn in different ways, a mix of approaches is probably best. Framing these practices from the production standpoint, may also encourage better take up.

2.3 Main Impacts

The project has four impacts:

- Piloted a scorecard that helps livestock farmers check the soil health of their fields.

- Provided SG with an indication of the state of soil health on the improved pastures of Scottish beef and sheep farmers across southern Scotland.

- Piloted a Nitrogen Use Efficiency (NUE) tool for livestock farmers.

- Given the information provided by the scorecard and NUE tool, identified the actions available to livestock farmers to manage their soils to minimise environmental impact whilst improving productivity.

2.4 Issues Arising

Issues arising from the project are:

1. Soil health is an emotive issue with the biology or biodiversity of soils an area of specific contention. The science of soil biology is less advanced creating the opportunities for dispute. A lack of objective and proven biological soil tests that can be readily interpreted by farmers, is a problem that needs resolving.

2. Accurate soil test results depend on precise sampling, processing and testing. If farmers are to collect and submit most of the soil samples as part of any future conditions attached to support, they will need clear guidance and the right equipment. Likewise, laboratories must apply common testing protocols and feedback of results.

3. Measuring soil carbon to the standards set by the IPCC is far more exacting than generally suggested in the current debate. Care is therefore required in choosing how soil carbon is defined and measured in future government schemes.

4. Compaction is perhaps the biggest issue affecting soil health on Scottish livestock farms. Some sort of low-cost probe to allow farmers to objectively measure compaction would be particularly useful.

5. The NUE metrics appear to offer potentially useful ways to improve on-farm nitrogen efficiency. However, their relationship with economic farm performance needs further research as there may be some trade off.

6. Farmers view soil health primarily through the prism of production. Ensuring achievement of government environmental goals regarding soil health, may therefore be best achieved by working through that prism.

7. Soil health should not be viewed in isolation. Farming involves a complex system so best practice often means taking a holistic approach to management.

8. Communication with farmers has become heavily concentrated on-line in recent years. That may be convenient for the provider, but the experience of this project was that face-to-face meetings in small groups where discussions are free flowing though directed, are better at transferring knowledge.

9. A generalised target of “healthy soils” can help set priorities at a farm, watershed, and regional scale. However, the crucial decision-making process at the field level remains challenging due to the lack of specific soil quality targets and the often-contradictory implications of individual management decisions. For example, a healthy mixed grass/clover sward has benefits for soil health, climate change and for farm profitability but the establishment and maintenance of such a sward requires a good pH status, suitable land quality and appropriate seed but will also require additional inputs and management, each of which has their own fixed costs and carbon footprint.

3. PROJECT DESCRIPTION

The project was designed to demonstrate to both the Scottish Government and producers how attention to soil health benefits both agricultural production and the wider environment. It endeavoured to show how Scottish beef and sheep (drystock) farmers can contribute to reducing climate change and moving towards net zero by identifying and encouraging soil management practices that

- Optimise soil carbon levels
- Raise NUE
- Improve flock productivity
- Lift profitability

4. FINANCE

4.1 Sum awarded

The total sum awarded for the five-month project to be completed by 31/03/2022 was £69,877.

4.2 Detail of spend

Project spend was on budget as detailed below

	Grant Awarded	1st Claim Adjusted Budget	Actual Spend
Project Development	£6,200	£7,350	£7,350.00
Project Management & Delivery	£47,118	£45,968	£45,731.67
Farmer Groups	£14,500	£14,500	£14,450.00
Travel & Subsistence	£2,060	£2,060	£1,789.87
Total	**£69,878**	**£69,878**	**£69,321.54**

5. PROJECT AIMS/OBJECTIVES

5.1 Related to Application

This project aims to:

- To help the Scottish agricultural industry meet Scotland's lower emissions target by demonstrating how livestock farmers can better manage soil health.
- To provide Scottish Government with a snapshot of soil health across a representative sample of Scottish livestock farms.
- Pilot three tools with 20 sheep farmers across southern Scotland to assess soil health (including carbon levels), nitrogen use efficiency and livestock productivity.

- Use the benchmarks generated, to work with these farmers to trial an approach for improving soil health management that could be rolled out across the industry.

As a result, the project will help meet Scotland's net zero targets by:

- Establishing the scope for storing more carbon in soils.
- Promoting and embedding the practices that improve soil carbon management and reduce nitrous oxide emissions, the most potent GHG.
- Increasing emissions intensity, through lifting grassland productivity and, consequently, livestock performance.

6. PROJECT OUTCOMES

6.1 How aims / objectives were achieved

6.1.1 Selection of a representative farmer group

1. Twenty farmers split into four equal groups covering central and southern Scotland were drawn from the co-operatives affiliated under the Farm Stock umbrella. Only improved land was assessed as rough grazing, by definition, receives no fertiliser or manure applications.

2. Each farmer was asked to nominate their worse and best fields (10ha maximum size) from their improved land.

3. One farm in each group (the focus farm) was subject to a more detailed soil testing process and hosted one farm meeting.

4. The farms were classed as follows:

Type	Enterprise balance	Status	Number
Hard hill	Mainly sheep		5
Hill	Mixed cattle and sheep		4
Hill	Mixed cattle and sheep	In conversion	1
Upland	Mixed cattle and sheep		5
Upland	Mixed cattle and sheep	Organic	1
Upland	Livestock and crops		1
Upland	Mainly dairy plus sheep		1
Lowland	Crops and sheep		1
Lowland	Sheep only		1
Total			20

6.1.2 Collection of baseline information

1. In December, SoilEssentials tested the fields of the four focus farms as follows.

    a. pH tested for ¼ha grids (12 cores/¼ha).
    b. Soil organic matter (Loss On Ignition [LOI]) tested at 1ha grid level.
    c. Soil carbon tested to IPCC standard 30cm depth using the bulk density technique (2 per field) by NRM laboratories.

d. Plant available phosphate (P) and Potash (K) tested at 1 ha grid level.
e. Primary nutrients (P,K,Mg,Ca,Na,Co,Se,Cu) tested per field level from pooled sample.
f. SoilEssentials KORE basic package.
g. Soil Health (Eurofins) tested per field.
h. Soil biology (*SoilBio)* tested per field.

2. Later in December and during January the remaining 16 farms were soil tested at a less detailed specification.

    a. pH tested for ½ha grids (12 cores/½ha).
    b. Soil organic matter (Loss on Ignition) tested per field from pooled sample.
    c. Soil carbon tested to IPCC standard 30cm depth using the bulk density technique (1 per field).
    d. Primary nutrients (P,K,Mg,Ca,Na,Co,Se,Cu) tested at field level from pooled sample.

3. Land, production, fertiliser, lime and manures data was collected. Current productivity was estimated using the Scottish Farm Advisory Service Livestock Production calculator and a new Fert_NUE calculator (tool submitted with report). Where available a recent carbon footprint was used to crosscheck key figures.

6.1.3 On-farm meetings (completed January)

1. To explain and discuss the overall concept of soil health.

2. To demonstrate, using the two fields identified by the focus farmer, how to complete a physical soil assessment (ie, a VESS[1]).

3. To review the soil test results for those fields in situ.

4. Based on the collected information and previously collected production and fertiliser data, decide on the soil health of that field and, where applicable, actions for better managing soil health.

6.1.4 Webinars (completed February)

1. These 1.5 hour Zoom webinars pulled together the discussions from the farm visits to summarise the management actions available to improve soil health.

2. A record was provided for future reference along with where to find related sources of soil health information (PDF copies of webinars submitted with report).

6.1.5 Completion of scorecards / action plans

1. A new holistic measure of soil health (the scorecard) was created to help the farmer judge a farm's current soil health.

2. The scorecard pulled together data collected into a coherent checklist for each field (Appendix 1).

[1] Slide 1 (vidacycle.com)

3. Also, data was input into a prototype Nitrogen Use Efficiency (NUE) tool to measure how well nitrogen was used on each farm. This new agro-environmental calculator was constructed from EU guidance[2]. An example report is shown in Appendix 2.

4. Then using all the benchmarks collected, each farmer was mentored to:

   a. Make an overall judgement on the soil health of the individual fields.

   b. Where relevant, list actions to improve (or maintain) that field's soil health.

   c. Embed better soil management into their farm planning to achieve continuous improvement.

6.1.6 Analysis of aggregated data collected

1. The overall dataset collected was analysed to tentatively indicate:

   a. The current state of soil health across improved grassland in central/southern Scotland.

   b. Whether soil carbon storage is near optimal levels and, if not, potentially how much more carbon could be stored.

   c. The likely NUE of Scottish livestock farms and the potential for improvement.

6.2 Milestones

Key milestones during the project were stated in section 6.1.

7. LESSONS LEARNED

7.1 Issues/Challenges

7.1.1 Soil health needs an agreed definition

1. There is general agreement that good soil health is important for both economic and environmental sustainability. However, it is also an emotive subject with terms such as regenerative and, by implication, degenerative or damaging often linked to how soils are managed. An agreed definition of health for Scottish agricultural soils would provide clarity and reduce disagreement.

2. This project piloted a soil health scorecard based on a model developed as part AHDB's Great Soils programme. In addition, the findings from a recent ClimateXChange report[3] were incorporated into a scorecard with 28 indicators covering the following areas.

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[2] EU Nitrogen Expert Panel (2016) Nitrogen Use Efficiency (NUE) – Guidance document for assessing NUE at farm level. Wageningen University, Alterra, PO Box 47, NL-6700 Wageningen, Netherlands. Found at: www.eunep.com

[3] Monitoring soil health in Scotland by land use category – a scoping study (2021). Neilson, R. et al.

a. Background
b. Chemical
c. Physical structure
d. Biology

The scorecard evolved based on feedback from farmers with the final guidance version shown in Appendix 1.

3. The chief weakness of the scorecard is the measurement of soil biology. The two tests used in this project were either undeliverable (SoilBio) because of testing problems or provided difficulty in the interpretation of information (Eurofins). In addition, worm activity, though covered in the January meetings, is a less useful test in mid-winter, as is the burying of cotton underpants test.

4. The level of organic matter and carbon in the topsoil is, however, a good broad indicator of both soil biology and health and its usefulness is considered further in the next two sections.

5. On reflection agrichemical usage should also have been scored for each field. Drystock farmers are typically low users of chemicals, but for completeness the levels of pesticides, herbicides, etc should have been recorded given their potential impact on soil biodiversity.

7.1.2 Soil health appears good based on the scorecard used

1. Most farmers concluded that their fields scored either good or excellent based on the scorecard. Only a small number of fields were rated poor, mainly due to physical limitations caused by drainage / compaction problems.

2. Chemical scores

    a. **Acidity (pH)** – based on previous technical studies (eg, FAS TN714 Liming Materials and Recommendations) the presumption was that tested fields would reflect a generally higher level of acidity (lower pH) than recommended (6.0 for grassland; 6.5 for arable production). That the 20 farmers were also to nominate a "poor" as well as "good" field also added to the expectation of acidity being below target.

    For the "good" fields the pH ranged from 5.6 to 6.8 and just five fields (25%) had a requirement for lime. Only one field in this group had a pH below 5.7 with all the others being at least 5.9 or higher.

    Within the "poor" field group, 11 fields (55%) had a lime requirement, and six fields had a pH of less than 5.7. Within this group there were two fields that had a pH of less than 5.5 below which key management options such as sward renewal become unviable.

    Grid sampling revealed some variation; however this was often caused by obvious constraints within a field (eg, rushy, wet patches, steep braes).

    Calcium lime was the main lime type used and the mean application was 0.43t per improved hectare (farmers were asked for their annual application average over the last few years).

b. **Phosphate** – of all the main nutrients, phosphate was lowest relative to recommended target (medium-low [4.5-9.4] for grass only; medium-high [9.5-13.4] where clover important).

For the “good” field group, the mean was 6.85 but with a big standard deviation of 4.95 and eight of the fields (40%) were below target and will need to account for this shortfall in their nutrient management plans. The median was 5.98. Notably the dairy/sheep farm scored by far the highest score at 26 (next highest 11.3).

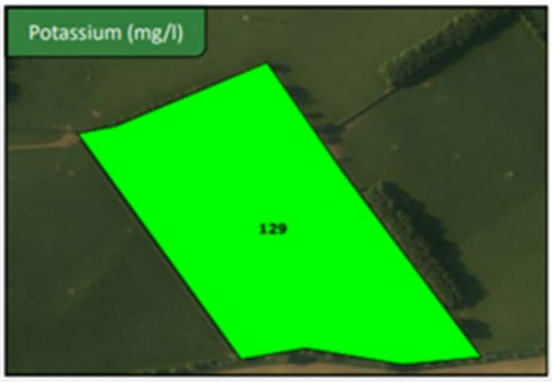
For the poor fields, the mean was 4.35, standard deviation 2.27 and median 3.81. Within this group, 55% (13 fields) were below target for P.

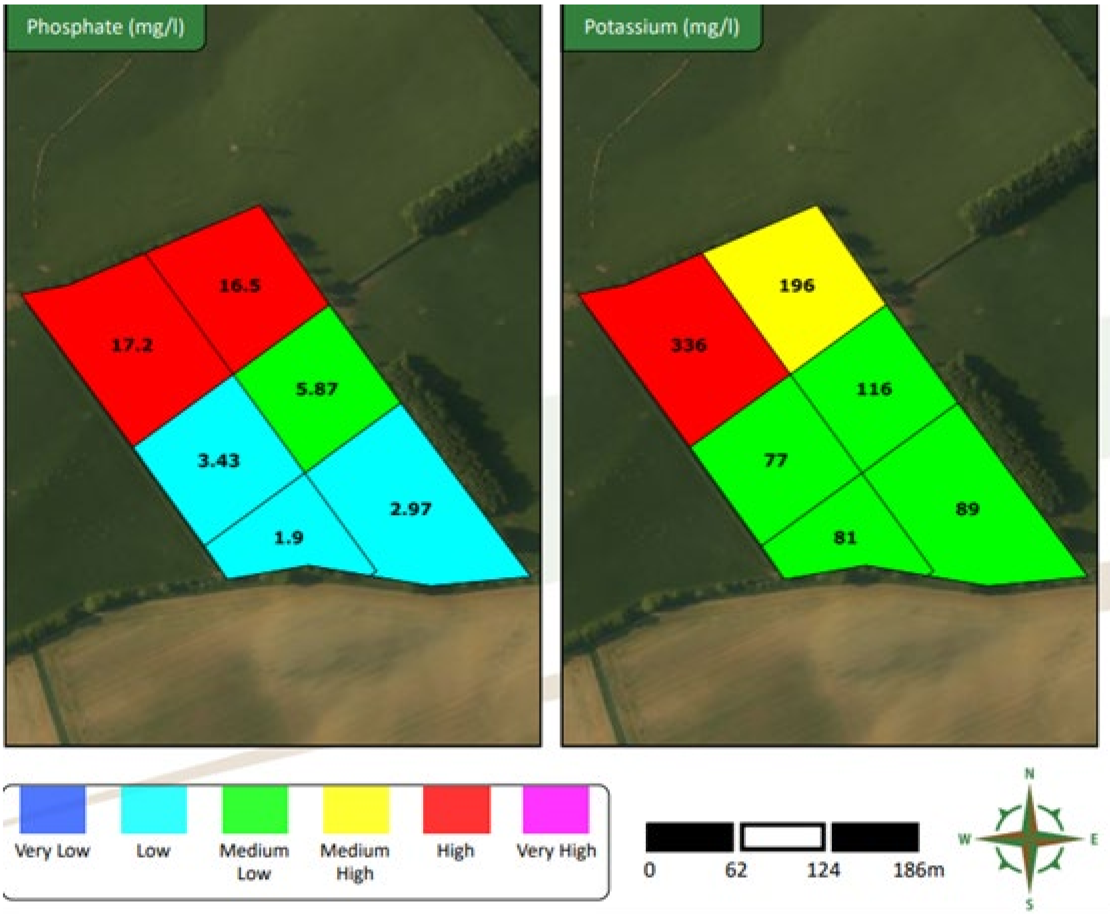
In 2021, the mean phosphate application was 16kg P/ha from bagged products, with most being in water soluble form.

Organic manures provide additional phosphate, but the contribution was generally low as limited quantities are produced by drystock farms compared to dairy farms. Farmer understanding of the value and use of organic manures is covered in a later section.

However, from the environmental standpoint phosphate levels were good at these levels, reducing the risk of water pollution.

The grid sampling on the four focus farms raises questions as to the usefulness of testing at field level as the following illustrations shows. The overall score for the 6.6ha field was 7.4 (that is, just below target for a clover-based sward). But sampling at the 1 ha level reveals a wide range that leads to very different conclusions regarding soil health and appropriate future management.





c. **Potash** – the second most important nutrient after nitrogen, potash levels were generally on target (medium [76-200]).

For the best fields, the mean was 168 but with a large standard deviation of 74 and a median of 143. Three fields tested in the low 300's, well above target. The poor fields tested only marginally lower (mean = 150; SD = 55; median = 143).

In 2021, the mean potash application was 21kg K/ha from bagged products.

Organic manures are relatively rich in potash, but as with phosphate the contribution is on average low, as limited quantities are produced compared to dairy systems.

From the environmental standpoint, potash levels for the farms tested indicate a generally limited risk to water quality.

However, the grid sampling on the four focus farms suggest that tests completed at the field level can conceal variability mainly because of livestock causing fertility drifts with high recordings indicating where stock "camp".

d. **Nitrogen** – there is no readily available soil test for nitrogen, so the focus was on what levels of this key nutrient the participating farmers used and is examined in section 7.1.4 (Nitrogen Use Efficiency).

e. **Other nutrients** – magnesium and calcium were the other main nutrients tested for. High magnesium levels were noted as above target on a couple of farms where magnesium lime had been applied consistently.

Sulphur is the other important nutrient applied after N, P and K, but its availability is estimated from plant tissue testing. Not all of the farmers apply sulphur, nevertheless the mean application was significant at 10kg S/ha.

3. Physical scores – The scorecard draws together the following information to help the farmer form a judgement on the physical state of a field's soil.

    a. **Topography** describes the steepness and aspect of the field.

    b. **Water** source and location affects how livestock may graze a field thereby movement of nutrients.

    c. **Land Capability for Agriculture (LCA)** is a national grading system that combines a soil's physical characteristics with climate to score its production potential.

    d. **Surface assessment** involves scoring the state of the sward and level of poaching and wheelings.

    e. **Texture class** is a key measure capturing the balance between silt, sand and clay in the topsoil.

    f. **Topsoil depth, stoniness** and **sub-soil** are important characteristics in upland soils.

    g. The state of a field's **drainage** is critical to soil health so especially careful assessment is required given the aging field drainage systems across much of Scotland.

    h. The **Visual Evaluation of Soil Structure (VESS)** is a physical assessment that ranks a soil from sq1 (good structure) through to Sq5 (poor structure). The four meetings on the focus farms were used to demonstrate the system to the participating farmers. An aide memoire[4] was provided plus the following video.

A guide to the Visual Evaluation of Soil Structure (VESS) | Information helping farmers in Scotland | Farm Advisory Service (fas.scot)

The eight fields examined on the focus farms were mainly good. Textures generally reflected the benefits of fields being used for pasture rather than crops. Two were compromised by compaction caused by machinery and/or livestock, where corrective action would be helpful.

Self-assessment by farmers was consistent with that on the focus farms. That is, generally good but with poor fields typically showing drainage problems caused by the combination of drainage system age/efficacy and compaction caused by livestock and/or machinery. Several farmers had reported how corrective mechanical action (eg, use of a sward lifter) had markedly improved physical structure in some instances, though stone content was a limitation on such intervention. Examples of VESS inspections by participating farmers are collated in Appendix 3.

[4] VESS score chart Slide 1 (bbro.co.uk)

Assessing the level of compaction on plant rooting is especially important given the combination of animal and machinery weight upon soils that often have drainage issues. Bulk density is an objective measurement of compaction. The NRM soil carbon test did measure bulk density. But the method used is laboratory based and would need to be cross checked by direct infield measurements which was beyond the scope of this project. Regardless, given the very low number of cores taken per field, the measure was not included in the scorecard.

4. Biological scores – measurement of a soil's biology and biodiversity is the least developed part of scoring soil health. This scorecard used several established and new measures.

    a. Organic matter is closely linked to the soil biomass so, in principle, the higher a soil's organic matter percentage, the better its soil biology. Soil organic matter was calculated from a pooled sample using the loss on ignition method (**OM% LOI**). While this score was at the field level for 16 of the farms, the four focus farms were tested at the 1ha grid level.

The field level results for the poor fields were better than the good fields. The mean for the poor fields was 11.4% (SD = 4.61) compared to 10.31% (SD = 3.39) for the good fields. The lowest figure was 4.2% for a good field. The best score was 25.9% on a poor field subject to drainage limitations. The median score was identical for both groups of fields at 9.9% and the mode 9.2% based on all fields.

Variation within a field was significant for several of the 8 fields grid tested. The presence of stock camps, where animals rested after grazing and dunged and urinated most, probably explained some of the variation. The relationship observed between stock camps and measures of soil organic matter (SOM) will need further investigation as it may be an important management factor for optimising SOM levels in fields.

The Hutton Institute's SIFSS website has a location specific tool that each Scottish farm can check their OM%/LOI score against (click on the footnote)[5]. Further analysis could check individual field scores against the SIFSS database. The farmers were also shown how to access JHI's Soil Organic Carbon Information (SOCIT) app.

In the same factsheet the following table provides benchmark OM%'s for England and Wales lowland grassland farms. Most of the fields tested in this project would score either "target" or "high" against those benchmarks.

[5] Factsheet SUPPLEMENTARY - Measuring and managing organic matter on farm.pdf (windows.net)

England and Wales – Grassland – all climates (N.B. lowland)

%OM	Light	Medium	Heavy
<1			
1-2			
2-3			
3-4			
4-5	Target		
5-6	Target	Target	
6-7	Target	Target	Target
7-9	High	Target	Target
>9	High	High	High

b. A small proportion of organic matter binds to soil particles or becomes part of the aggregates that produce the crumbly texture of topsoil. This is the organic fraction in the soils that contains fully sequestered soil carbon. Measuring soil carbon to the standard recognised by the IPCC is technically more exacting and consequently expensive. In this project, NRM laboratories measured soil carbon using the bulk density Dumas method, which is based on a discrete 30cm soil core, not a pooled sample. Owing to cost, just one core was taken in the fields of the 16 farmers, but two cores for the eight fields of the focus farms, so the following results are only indicative.

Again, the poorer fields scored slightly higher than the better fields. The mean of the poor fields was 122t/ha (SD = 40) with the good fields 112t/ha (SD = 33). The median of the poor fields was also slightly higher (109 cf. 105t/ha). The range extended from 50 to 214t/ha.

There are no recognised benchmarks as to what are low, moderate and high soil carbon levels for Scottish grassland soils. Sandy soils, for instance, will naturally hold far less carbon than clay soils. However, to give participating farmers some idea of scale, the following ranges were noted on the scorecard – low <60t/ha; 60-120t/ha moderate; >120t/ha high.

For those fields where precision LOI measures were taken in conjunction with Soil Carbon Check measurements there was the opportunity to directly compare two different approaches to estimating soil organic content. Table 1 shows an example of these results for two fields from one study farm. Both methods are based on combustion but the NRM – SOM is a derived estimate based on the direct measuring of soil carbon produced during combustion while the SAC – LOI is based on the mass change following combustion.

Table 1 Example results for two fields where separate precision LOI and Soil Carbon Check measurements were taken

Field	Precision LOI (%) results SAC laboratory	SOM (%)- Derived from direct Soil Carbon Check measurements – NRM carbon check
Field A	6.5 to 8.1	3.2 , 3.2
Field B	9.0 to 10.5	7.2, 8.8

Reconciling these different results to provide a single estimate of SOM at the field level was not possible for this example given our current state of knowledge on the impact of sampling techniques and analytical processes.

As these tests are used commercially, this inconsistency needs to be recognised before results are pooled for benchmarking purposes across differing farms and over time. It also raises the importance for transparency and uniformity in the methods and assumptions that are made to either directly measure or derive SOM content values at the field level.

Notably, the organic matter percentage results from the LOI sample were all above those produced by the NRM test. It is presumed that this reflects that the latter is estimated over the 30cm profile tested, though this requires further research to confirm.

c. A **Soil Life Monitor** test was completed at Eurofins laboratory in Wolverhampton for each of the eight fields on the focus farms. The test is based on phospholipid fatty acids (PLFAs) analysis. While the tests were completed correctly the usability of the results was disappointing. This is further discussed in the following section.

d. A novel new SoilEssentials test called **SoilBio** was applied on the focus farms. Unfortunately, SoilBio was undeliverable within the time period due to capacity issues at the James Hutton Institute. Until such capacity issues are properly addressed these biological tests are not useful in a farm scale

e. Two informal, but reliable, measures of soil biology were also discussed: counting worms and burying cotton undies. Feedback from farmers completing the VESS examination was that worm levels were surprisingly good given that worm activity is lower and less predictable and uniform over the winter months. Several farmers will be undertaking the cotton undies test this season[6].

7.1.3 Soil measurement protocols critical

1. Whatever definition of soil health is agreed, the tests used must be completed correctly to provide true and consistent measurement. Reliable results depend on how the soil sample is collected and then how it is tested. Moreover, to be of any use, the results must be presented in a way that is easy to understand by a farmer.

2. Collecting a representative soil sample must account for timing, location within field and to what depth.

3. Sampling at field level gave misleading results on some of the fields where grid sampling provided greater detail. A pooled sample is influenced by where within the field and the number of cores taken. The larger the field and more variable the soil types within that field, the more care is required in the sampling design. Grid sampling provides more accuracy but at an increased cost. An interim pragmatic approach is to divide a field on observed productivity (eg, known stock camps) and limitations (eg, wet areas) to get a better representation at lower cost.

[6] Cotton strip test_instructions_digital.pdf (beeflambnz.com)

4. SoilEssentials was subcontracted to complete all sampling and handling to provide consistency and reduce sampling error. The cost of field sampling, sending to the relevant testing laboratory and relaying of results for the main measures is summarised in Table 2.

5. After collection, the soils were analysed at the SAC laboratories where the recognised Scottish tests were applied (eg, Morgan test for phosphates). Several farmers noted that often their soils went for testing in England where different analysis is used (eg, Olsen for phosphates). It is also understood that some fertiliser companies send their samples to the continent for testing. Clearly this leads to potential variability and adds some confusion in how results are expressed. A comparison table was added at the base of the scorecard for clarity even though all tests were completed using the Scottish system. SAC's colour code system also adds some confusion to interpreting results as too the interchangeable use of "moderate" and "medium".

Table 2 – cost of sampling and testing (all ex-VAT and assumes a 6ha field)

Test	Level	Sampling & Admin cost £	Laboratory cost £	Total cost Per field* £
P, K and OM% (LOI)	Per field	13.20	16.50	29.70
P, K and OM% (LOI)	@ 1ha grid	79.20	99	178.20
Primary nutrients incl. pH	Per field	13.20	62.70	75.9
pH	@ 1/2ha grid	Included in total cost		102
pH	@ 1/4ha grid	Included in total cost		138
Soil carbon (NRM)	10 cores/field	80	750	830
Soil health (Eurofins)	Per field	40	120	160
Soil biology (SoilBio)	Per field	40	150	190

* Savings on sampling costs possible where multiple tests undertaken

6. The commercial testing of soil organic matter and carbon levels is relatively new. Two tests were compared in this project:

    a. Loss on Ignition (LOI) based on a pooled sample drawn from that collected to test for P and K.

    b. A specific test to measure soil carbon based on the bulk density (Dumas) method. The procedure is exact to comply with IPCC standards. Individual cores are GPS recorded and, if soil depth sufficient, taken to 30cm. because of the high cost of measurement only two cores per field were taken for the four focus farms and one per field for the other 16 farmers. The results gained are therefore only indicative given the cost. The test was completed by NRM in England. Currently no Scottish laboratories support this test.

7. To accurately measure the soil carbon of a field is very expensive. For example, a requirement of say 10 cores for a 6ha field would be a cost of £750 for the laboratory test alone. A New Zealand report by Mudge et al[7] goes into great detail on what is required. ArkZero[8] is a current Northern Irish project assessing soil carbon on their drystock farms. This work is closely linked to the soil carbon research at Devenish Lands farm in the Irish republic.

Given the high cost and sampling accuracy required, is the cheaper LOI method a sufficient indicator of the soil carbon levels required for good soil health? The OM% figures produced by LOI method do appear consistent with the NRM carbon results, but far more cores are required per field to confirm any relationship.

Further detailed research is also necessary to establish whether the soil carbon levels on these farms are near their optimum or steady state. JHI's interactive SIFSS database was used to quickly check a small number of fields and the broad conclusion was that most examples examined scored moderate or good.

8. Objective testing of soil biology and biodiversity proved difficult. The ClimateXchange report noted in footnote 2 recommended testing for:

    a. Bacteria and archaeal diversity (DNA methods)
    b. Fungal and nematode diversity (DNA methods)

SoilBio was the experimental DNA test used but proved undeliverable.

A second (non-DNA) test provided by Eurofins though successfully completed was difficult to interpret. Despite being asked, Eurofins supplied no suitable set of interpretative guidelines.

9. Compaction appears a key factor limiting soil health on the farms covered in the project. Bulk density is a specific test for compaction and potential for greater run-off (reduced water infiltration). The NRM soil carbon test measured bulk density based on the cores sampled. However, only one core per field was taken for most farms though two per field for the four focus farms, so indicative rather than representative. Moreover, exactly how well the core is taken especially where a high stone content exists may also influence the resulting density.

The approach used by NRM to measure soil bulk density (as with most commercial labs) is based on the use of fully processed soil samples (disturbed method based on milled and dried sample). It is done to allow for the meaningful interpretation of results and should not be used to make "in-field" management decisions.

[7] Design of an on-farm soil carbon benchmarking and monitoring approach for individual pastoral farms. MPI Technical paper 2020/02. Mudge, P et al.

This report assessed the design requirements to accurately measure the small changes in soil carbon on grassland farms which would be expected in five years. That is, the level of accuracy likely to be required if measuring changes in carbon for commercial trading schemes.

[8] [Home | ARCZero (arczeroni.org)]

The recently released IEMA guidance[9] on soil evaluation in the planning process has highlighted Soil Bulk Density (SBD) as a key soil health indicator but a reliable and meaningful in-field test could not be found for this project.

10. A final caveat of this study is the representativeness of the 20 farmers involved. The selection was not based on a randomised process so some bias must be factored in.

7.1.4 NUE a useful metric but needs developing

1. Nitrogen use efficiency (NUE) is a relatively new agro-environmental measure developed to encourage farm management that decreases nitrogen losses while maintaining agricultural productivity. It is an attractive as it draws together a wide range of management data and therefore provides a basis for assessing different management systems. For this project an excel calculator was created based on international guidelines[10] to estimate the NUE of the participating farmers.

2. NUE measures the total nitrogen (N) inputs into a farm and the N output exported from the farm in harvested products. The farm data required is largely the same as that required to complete a carbon audit using Agrecalc. Two benchmarks are produced:

    a. **NUE %** - the ratio of N into the farm to N exported (%). Livestock farms are generally low (10-25%) with crop farms high (65-80%). But very high figures indicate "mining" of the soil which implies poor management.

    b. **Nitrogen surplus** – the potential loss of N to the environment (kg/ha), so generally the lower the better.

3. Table 3 shows the results by farm type alongside key production variables.

Table 3 – NUE results

Farm Type & number	NUE %	N Surplus Kg/ha	Synthetic N applied Kg/ improved area	Stocking rate GLU/ adj.forage ha	% beef BeefGLUs/ total GLUs	Production LWT/ adj.forage.ha
Hard hill (5)	16%	31	57	0.77	34%	218
Hill (5)	14%	44	53	0.86	39%	293
Upland (7)	20%	104	68	1.37	58%	451
Lowland (2)	82%	See note below				

Notes:
1. The N surplus figure is based on Utilised Agricultural Area; synthetic nitrogen is normally only applied to improved land so rough grazing is excluded; and, stocking rate and production is, by convention, based on the forage area where rough grazing is adjusted to improved land typically at a ratio of 3 to 1.
2. The upland group includes one organic producer.
3. One of the hill farms is in conversion to organic.
4. The two lowland farms both had the same NUE but with very different systems so no analysis attempted.
5. One farmer did not provide input data.

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[9] IEMA - Launch of New EIA Guidance on Land and Soils

[10] Nitrogen Use Efficiency (NUE) guidance document for assessing NUE at farm level (2016). EU Nitrogen Expert Panel.

4. While the averaged results suggest consistency within farm types, there was often a large range of variation within each type. For instance, some smaller hill farms used more inputs to increase stocking rate to boost production. The dataset was too small to establish any clarity on explaining NUE in terms of system differences. Even so, based on this study, the following factors should be explored first in future work.

    a. Stocking rate.
    b. Enterprise balance (specifically the proportion of cattle given the typically longer winter/silage requirement of cattle raising the use of synthetic N).
    c. Overall N availability whether originating from the bag or clover.

5. Unlike a carbon audit where higher production often improves the overall position because of greater emissions intensity, in the NUE calculation extra production has limited impact because of the low N in meat and wool. It was notable how some of the most productive farms had low NUE percentages and high N surpluses.

6. The implication of the previous point is that the relationship between economic performance and NUE needs further research. In short, higher production is normally associated with better economic performance with the relationship between output prices to input costs setting the optimal point. Consider, for example, acquiring extra feed to finish lambs in the autumn. Normally an August application of synthetic N (to grow extra pasture) is far more economic than feeding lamb concentrate. Basing the decision on NUE, concentrates would be favoured.

    The Scottish Farm Business Survey could be used for investigating NUE and economic efficiency further.

7. Other points of note from the NUE analysis:

    a. Use of synthetic N was generally low (57-68kg N/ha across the main three farm types covered). Just two of the 17 farms covered by these types exceeded 100kg N/ha. For comparison, dairy farmers are more likely to average around 200kg N/ha. On most of the farms the “grazing only” ground received a single annual application in the spring (typically 30-40kg N/ha). For fields used for silage (and grazing) an annual application of 120-150kg N/ha was more typical.

    b. Estimating the quantity of N supplied from clover fixation is very subjective. Further research is needed to establish how this key source of N affects NUE, especially given the jump in interest in multiple species swards (where clover is important).

    c. This rudimentary calculator is sufficiently flexible to handle intricate situations (eg, muck for straw deals).

7.1.5 Mixed awareness of soil health and how to manage it

1. The farmers involved were aware of soil health but only at a general level. Some of that awareness came from the recent negative narrative that conventional farming was damaging soil health and that soils were generally in a poor state of health.

2. When farmers were pressed on soil health, their appreciation was generally limited to the chemical attributes of a field’s soil with most participating farmers testing soils for pH, P and K. The problems caused by compaction were also appreciated although the linkage to physical soil health generally needed explanation. And

while soil carbon was a recognised term thanks to the ongoing public debate about grassland and sequestration of greenhouse gas emissions, the biological health of a soil was typically limited to appreciating that lots of worms was a positive indicator of soil biodiversity.

3. At the outset, most of the farmers viewed soil health from a production rather than environmental standpoint. Farmers were mostly aware of how poor soil and nutrient practice could harm water quality. But they were less aware of the impact of how air quality and greenhouse gas emissions are affected by soil and nutrient management. The balance, hopefully improved, thanks to the project explaining the win-win of healthy soils to both the environment and production.

4. The on-farm meetings were the most popular part of the project. The small groups took full advantage of a practical soil specialist to watch and ask questions. As important, was the learning from the farmer-to-farmer discussions where experiences were shared. Good facilitation hopefully helped.

5. In addition to the data collected via soil testing, farmers were asked to complete two calculators to provide data needed to fill in the scorecards for the 2021 production year.

    a. ProdCalc tool –
        i. Stocking rate
        ii. Balance of cattle to sheep
        iii. Liveweight produced

    b. Fert_NUE tool –
        i. Fertiliser (N, P, K and S) applied
        ii. Lime applied
        iii. Organic manure applied
        iv. Nitrogen Use Efficiency (NUE)

Farmers were also asked to submit a recent carbon audit to provide a crosscheck if one had been completed. Around half provided audits, which were all Agrecalc except one.

6. Most farmers required help with completing these tools mainly because of limited spreadsheet/computer skills and difficulty with reconciling livestock numbers. Any requirement for farmer submission of data as part of any future conditionality will need to allow for the equipment, computer and budgeting skill levels of the farmer population. Accurate livestock reconciliations underpin a whole raft of important production metrics: the SCOTEID system could help with such reconciliations. Training and specific smart phone apps may be required to achieve successful and accurate self-reporting by farmers.

7. The options for managing soil health were informally discussed at the on-farm meetings and then methodically covered in the two February webinars. Farmer awareness of the options was generally good, though the specific impact of these actions on soil health (particularly the environmental consequences) required spelling out. This was to be expected as these actions overlap into other important management areas particularly nutrient budgeting and grazing management. The options covered were.

    a. Use of fertilisers
    b. Use of organic manures

c. Reseeding best practice
d. Role of multi-species seed mixes (especially clover content)
e. Dealing with compaction
f. Field drainage
g. Matching feed requirements to pasture growth profile

8. The completion of the scorecards required significant help. Only a few farmers completed the scorecards satisfactorily with limited mentoring. Most had difficulty because of their lack of confidence with spreadsheets even though the scorecard evolved (based on early feedback) to largely a menu-based approach (see Appendix 2). Of course, there were a lot of indicators to score and rationalising these could perhaps make the scorecard less intimidating. Completing the scorecards was also hindered by very wet soils through February (and much of March) delaying physical field assessments. While lambing, calving and spring work also, understandably, diverted attention from mid-March onwards.

9. There is a lot of guidance available on the web to help farmers better manage their soils and nutrient use. The Scottish FAS website is an excellent resource on the subject, but it would be interesting to establish how often farmers use it. Making guidance user friendly is only successful if farmers know where to access it. Where on-line help is in the form of technical notes and interactive scientific databases, knowledge transfer may be disappointing. For instance, the Hutton Institute's Soil Information for Scottish Soils (SIFSS) is an excellent resource but is rather esoteric.

7.1.6 Scoring soil health limited if used alone

1. Good soil health is a necessary but not sufficient condition for good productivity. Several of the poor fields included in this project were unproductive thanks to poor nutrient budgeting and/or grazing management rather than soil health.

2. By implication, healthy soils may still result in negative environmental impacts if, for instance, the wrong fertilisers or organic manures are used in the wrong quantities at the wrong time. Likewise, poor grazing management can result in spikes in air and water pollution.

3. Therefore, to improve both the environment and productivity, the benefits of good soil health should form part of an integrated management systems approach.

7.1.7 Management of unimproved grassland may be of greater significance to soil health on drystock farms

1. On many hill and upland farms, much of the land is unimproved and was excluded from this project. Given that this type of land covers a substantial part of Scotland's agricultural area, a soil health scorecard for farmers to assess their rough grazing would also seem appropriate.

8. IMPACTS

The project has had four main impacts:

- Piloted a scorecard that helps livestock farmers check the soil health of their fields.
- Provided SG with an indication of the state of soil health on the improved pastures of Scottish beef and sheep farmers across southern Scotland.
- Piloted a Nitrogen Use Efficiency (NUE) tool for livestock farmers.
- Given the information provided by the scorecard and NUE tool, identified the actions available to livestock farmers to manage their soils to minimise environmental impact whilst improving productivity.

9. COMMUNICATION & ENGAGEMENT

9.1 Engagement during the project

During the relatively short life of the project, communication and engagement was undertaken through a range of channels that are described below.

Three members of the operational group (FSS, KBevan Consulting and SoilEssentials Ltd) met at the outset of the project to agree the plan for delivering the project. The specialist knowledge and expertise of a fourth member Dr Bill Crooks, was brought in later for the practical on-farm meetings and demonstrations. As chair of the lead organisation, Ian Watson led and coordinated the project and ensured that agreed actions were communicated and delivered. The group communicated regularly to review project progress and update the plan as required.

In terms of engaging with participating farmers. On-farm meetings and demonstrations were completed in January, to explain and discuss the overall concept of soil health and to review soil test results in situ and eight 1.5 hour webinars were completed in February pulling together the discussions from the farm visits and summarising the management actions available to improve soil health. At the end of each month, farmers were emailed a project update.

An interim report was submitted to the Scottish Government in January.

Due to the short duration of the project and the dependence on data collection and analysis, there was no communication during the project to either the Farm Stock community or the wider industry as a whole with this being saved until data analysis is complete and conclusions are drawn.

9.2 Communication of findings

There are essentially four distinct audiences to communicate the results to, each with different levels of interest in the findings

- Project partners and participants will receive a summary of the report’s key findings. They also received monthly updates throughout the project (can be supplied if required)
- The Scottish Government, as the funding body, will receive this report

- ➢ The FSS community will receive the key messages from the project through newsletters, weekly bulletins social media and the FSS website

- ➢ Once approved and signed off by the Scottish Government, the key messages from the project will be shared with the Scottish livestock industry via press releases coordinated between the project partners.

10. KEY FINDINGS AND RECOMMENDATOIONS

1. Soil health is universally accepted as important but means different things to different people.

***Recommendation** – define soil health in terms that can be measured and agreed upon by all stakeholders.*

2. A soil health scorecard provides a practical decision and support tool to help farmers better assess and manage the soil in their fields. Based on the scorecard piloted in this project, the soil health of the 40 fields surveyed was generally good.

***Recommendation** – use the scorecard from this pilot as a basis for one that could be used as part of the National Test Programme.*

3. Robust sampling and testing protocols are critical to the validity of many of the measures used in the scorecard. For example, whole field assessment of phosphate could be meaningless where significant variation within that field. Effective soil sampling techniques need to be reinforced and expanded so that they are more useful on identifying the effects of management variable such as stock camps.

***Recommendation** – protocols should be designed in consultation with soil scientists to get cost-effective accuracy*

4. Tests for directly assessing a soil's biology are not available or are difficult to interpret.

***Recommendation** – if an objective soil biology test is a priority, the options for meeting that need require urgent review.*

5. Measuring SOM using the loss on ignition method is possibly the most cost-effective way of estimating how much carbon is sequestered in a field's soils.

***Recommendation** – commission research to confirm the robustness of LOI for this purpose.*

6. The use and value of direct measurement of SOM as part of the standard agronomic testing could not be clearly established within this study. SOM levels, irrespective of how they were measured, could not be linked to measurable outcome such as increased yield or reduced inputs costs.

***Recommendation** – clarification on the exact purpose of monitoring SOM levels on livestock farms needs to establish.*

7. Measuring changes in a field's soil carbon levels to the level of accuracy required by IPCC is technically challenging and very expensive. But a representative sample of

fields nationally should be tested at this detailed level to calibrate the accuracy of the cheaper loss on ignition SOM measure.

Recommendation *– if not already happening, contract an organisation with the suitable expertise (eg, Hutton Institute) to test a representative sample of Scottish farms, covering all farmed soil types, to establish and monitor changes in actual soil carbon levels. New Zealand has recently started a long-term trial that provides an exemplar*[11]*.*

8. VESS is an excellent self-assessment tool, but it needs to be expanded to cover direct management options that arise from individual assessments. It also needs to be modified to include a process of identifying compaction layers within the profile.

Recommendation *– commission the work required to develop VESS as noted above.*

9. Compaction is possibly the major factor affecting soil health on livestock farms.

Recommendation *– Finding a low cost in-field bulk density test should be a priority.*

10. Though not included in the scorecard, use of Nitrogen Use Efficiency (NUE) benchmarks could also help farmers minimise their environmental footprint.

Recommendation *– trial use of a NUE tool as part of the National Test Programme. Particular attention is required to accurately gauge the contribution of nitrogen from clover.*

11. Use of synthetic (bagged) N on Scottish beef and sheep farms is modest if this group of farmers is representative. However, that should not imply that room for improvement in synthetic nitrogen use does not exist.

Recommendation *– renew guidance on how best to use synthetic nitrogen to complement clover nitrogen while minimising environmental impact.*

Recommendation *– encourage the use of protected urea to minimise the adverse impact of urea and CAN nitrogen fertiliser on emissions, air and water pollution.*

12. While good soil health is important in helping farmers contribute to the nation's net zero goals, its management must be considered as part of the way farmers manage their overall businesses.

Recommendation *– encouraging farmers to better manage their emissions may be better achieved by taking a more holistic approach rather than focusing directly on soil health.*

13. Best practice management should be based on sound scientific principles supported by evidence from robust trials completed under Scottish conditions.

[11] Funded by the New Zealand Agricultural Greenhouse Gas Research Centre, Kiwi scientists have just started a long-term nationwide study to assess whether soil carbon stocks under New Zealand agricultural land are increasing or decreasing, and how land use contributes to that change. About 500 farm sites will be sampled to a depth of 0.6m. This sampling intensity is designed to detect a minimum change of 2 tonnes of carbon per hectare (over the period 2019–2030) on their main farm types.

***Recommendation** – future trial work into best practice affecting soil and nutrient management should be required to report on the implications for farm emissions.*

***Recommendation** – where necessary, current best practice should be reviewed to ensure consistency with national net zero goals.*

14. To increase the likelihood of good uptake, communication of best practice should be via channels that farmers best respond to. Given people learn in different ways, a mix of approaches is probably best. Framing these practices from the production standpoint, may also encourage better take up.

***Recommendation** – use the National Test Programme to trial the most effective ways of increasing the take up of soil management best practice.*

11. CONCLUSION

1. Soil health needs clarity of definition. But based on the basis (scorecard) piloted in this project, the soil health of the 40 fields surveyed was generally good.

2. While soil health was generally good, it seems largely a consequence of farm management in general, rather than specific actions to manage the soil. Better awareness of the positive actions' farmers can take to manage their soils may not significantly improve the health of their soils, but it could improve their emissions profile, lower air and water pollution and, perhaps most importantly from the farmers viewpoint, lift profitability.

3. Conditionality, trialled as part of the National Test Programme, provides an opportunity to nudge farmers into adopting better soil management practices. But to be successful, the logistics of sampling and testing must be of a uniformly high standard.

4. The pilot considered only the improved, or in-bye, areas of livestock farms. Rough grazing covers a far larger area of Scottish livestock farms. How farmers manage the health of these areas, which includes large peatland areas, is perhaps more important to helping Scotland meet its environmental goals.

5. The positive relationship between healthy soils, and in particular higher SOM levels, and increases in farm profitability has been assumed but this study could find no direct link. The exact value to the Scottish livestock sector and for wider society from the monitoring and improvement of soil test variables such as SOM levels needs to be established.

Appendix 1

Soil Health Scorecard for field named: Field name here

Measure	Score	Comment
Size	#ha	[redacted]
Topography	Steep/easy/flat/aspect	Besides shape of field, is it north or south facing.
Water	Good/ok/poor	Is location of water troughs causing a fertility drift? Do burns increase run-off risk from cultivations?
Organic	No/yes/inconversion	
Land Capability for Agriculture	eg, 4.1	Click on below link and click on "view the map" below the 3rd pane along (partial cover) When map comes up pop in your postcode at top and then use mouse to find field. If you click on "Legend" on left of screen it will show capability for all the classes. [Capability maps | Scotland's soils (environment.gov.scot)]
Current use	TGRS/PGRS/etc	If reseeded in recent years, when.
Grazing system	[redacted]	First, if grazing only or cut and grazed. Second, is grazing system mainly set-stocking or mainly rotational grazing or mixture of both.
Performance	Good/ok/poor	Basically, are you happy with what the field is giving you. Are there parts underperforming because of potential soil health issues (eg, low P or K, compaction, bad drainage). Such variation should influence how you test your fields.
Bagged fertiliser	Low/moderate/high	Note what field got last year. Use whatever measurement system you're comfortable with eg, bag (1 cwt) to the acre of 20-10-10 in April.
Organic manure	Annually/sometimes/never	For instance, moderate level of slurry each year onto aftermath.
pH / Lime	Avge for field (eg, 5.9)	Where field sampled into grids what variation/range across the field. Are some parts of the field not limed as physically impossible (eg, too steep, rocky or wet). What lime (and type) has it received in last few years?
Clover %	None / Low (<20%) /moderate (20-40%) / high (>40%)	Remember clover is the "canary in the mine" so if the field was reseeded in last few years and clover failed, soil health may be the reason so warranting a soil or herbage test in your action plan.
Annual rainfall	eg, 1040ml	Don't worry if figure not readily available as not essential. You'll no doubt be aware of how your rainfall pattern affects the timing of any cultivations.
Surface assessment	Good/moderate/poor	As per AHDB Healthy Grassland Soils handbook (p4); G = sward intact / no poaching / few wheelings

		M = surface poached / wheelings in places / more weed species P = surface capping / soil exposed / severe poaching / poor sward quality
Texture class	Silty sandy loam	As per AHDB Healthy Grassland Soils handbook. Excellent step-by-step guide on page 11 if you need any help. Note any natural changes of texture within field as these can have a major impact on management.
Topsoil depth	eg, 25 cm	Again, note if variable across field.
Stoniness	Low / moderate / high	
Subsoil	eg, clay, or limited as rock below 15cm.	
Drainage	None required (good) Drained and working well Drained but problems Poor drainage a major problem	If free draining, then simply say drainage not an issue but drying out in summer may be a point to note. Where drainage a very brief description of state of system. For instance, though 1970's works well given periodic repair of odd wet area.
VESS (overall) topsoil score	1. very good 2. good 3. moderate 4. poor 5. very poor	Score the <u>overall</u> topsoil first. See pages 12-14 plus photos, etc on subsequent pages. 1-3 acceptable 4-5 management action required
VESS limiting layer (within topsoil)	Example 1 – moderate over good (2=overall/2=limiting layer) Example 2 – poor over moderate (3=overall/4=limiting layer)	Then score the limiting layer <u>within the overall</u> topsoil. *"The limiting layer is an area of more compacted soil, where the soil particles have been pushed together, leaving little space for water or air. The depth of the limiting layer will help identify its cause and determine its remedy (page 13)".* Top 10cm "intact" (p.18 = score 2) due to grazing livestock as apart from an application of fertiliser, field sees no machinery. But grass roots still penetrating well. Top layer "compact" (p.22 = score 4) due probably to slurry spreading and silaging over many years. Needs effort to break topsoil apart and rooting clustered. But soil layer below less tightly structured and breaks apart easier.
OM % (LOI)	eg, 8.8%	16 of the 20 farms tested will have just one OM% per field. So simply note that in second column. The four farms visited will have more detail so opportunity to comment on variation of OM %'s across the field.

Carbon (NRM)	eg, 90t/ha	Remember this figure relates to a single 30cm core taken in the field (the 4 visited farms will have 2 cores per field) so may not accurately represent overall field level. Just state the figures in the second column. Interpret the carbon (NRM) figure and OM% (LOI) figures together, but with care. There are no simple fixed benchmarks of what is low/moderate/high because of the natural variation between soils due to what they are formed from (eg, thin sandy soils will generally have lower OM/carbon than deeper silty clay loams and peaty soils). That said, based on the results for the 40 fields tested in this project tentative bandings are; <60t/ha = low 60-120t/ha = moderate >120t/ha = high Remember! The OM% (and related carbon level) is considered a prime indicator of soil health given its central role in the biodiversity of a soil. If you have used the JHI SOCIT carbon app to get a soil carbon reading, do also include here and comment. Even if the result is at odds with the NRM tested figure.
P	eg, 5.3	Lookup from the table at the bottom of this guide which band the figure places the phosphate level of the field within. Then simply note in this comment column something like "5.3 indicates phosphate level at the low end of medium low so below target". See the webinar slides where we covered target levels of P and K. For the 4 farms where P was grid tested, comment of variation is an issue.
K	eg, 71	Again, use the table below to identify within which band the potash level for the field sits. In this example, 71 indicates that potash is at the top end of low so well below target. As for phosphate, the 4 farms visited were tested in more detail so note any variation and its relevance.
Mg	High	Just note what band this figure sits within.
Other nutrients		Note anything of relevance with other nutrients here. An indication of abnormal levels may lead you to run follow-up tests (eg, livestock blood tests, or plant tissue tests).
Biology		The experience of this project suggests that explicit testing for the biology of soils lags well behind

		chemical tests. The cotton underpants tests is worth doing to provide a broad indication. Likewise, a healthy worm population would suggest good soil biodiversity. But the best indicator you have is the organic matter (and carbon) level of the soil; that is, higher levels of both generally indicate better biology.
Overall health	*Choose from.* *Excellent* *Good* *Satisfactory* *Poor*	*Watch! From the scores you have noted above you are deciding on the health of the soil in the field: not the performance of that field.* *A field with good soil health (ie, pH, P and K levels, good structure and high OM% and carbon) can underperform just because you have applied insufficient fertiliser to the crops requirements that year and, for instance, your grazing management needs tweaking.*

Actions based on scoring:

Look for the obvious from what you have noted above. Remember that we discussed typical actions for improving soil health at the farm meetings and in the two webinars. Importantly, we discussed how these actions <u>must fully account for minimising any negative environmental impact</u>. The slides for the latter are attached. Some examples of actions:

1. **Apply lime to lift pH.**
2. **Use a sward lifter to reduce compaction.**
3. **Apply dung to aftermaths to provide nutrients and build organic matter.**
4. **Oversow rather than fully reseed to improve clover content.**
5. **Test P&K at bottom half of field where pasture growth is poor.**
6. **Bury some old pants to check biological activity.**
7. **Increase annual P levels immediately to meet annual crop requirements and start rebuilding overall P level if prices return to normal levels.**

SAC (Scotland)	Extractable Phosphorous	Extractable Potassium
Very low	0 – 1.7	0 – 39
Low	1.8 – 4.4	40 – 75
Medium low	4.5 – 9.4	76 – 140
Medium high	9.5 – 13.4	141 – 200
High	13.5 – 30.0	201 – 400
Very high	> 30.0	> 400

Appendix 2

NUE Calculator (Tier 1)

Farm type	Upland	
Farm size	165	ha

N Output	**Output**	**Total kg**	**N (g/kg)**	**N Total (g)**	**N kg per ha**
Amount of N harvested in crop products	Barley		17.0	0	0
	Wheat		20.8	0	0
	Oilcrops (OSR)		23.7	0	0
	Oats		18.1	0	0
	Straw		5.4	0	0
	Silage (grass)		8.5	0	0
Amount of N in sold animals	Cattle liveweight	23,910	28.3	676,653	4
	Sheep liveweight	31,770	21.3	676,701	4
Amount of N in sold animal products	Milk (whole)		4.7	0	0
	Wool	1,216	3.0	3,648	0
N Output Totals				**1,357,002**	**8**

N Input	**Input**	**Total kg**	**N (g/kg)**	**N Total (g)**	**N kg per ha**
Amount of N fertilisers	N fertiliser	4416	1000	4,416,000	27
Amount of N in imported feed and fodder	Barley		16.3	0	0
	Oats		16.3	0	0
	Hay		16	0	0
	Silage (grass)		8.5	0	0
	High energy concentrate	12000	52.2	626,400	4
	Low energy concentrate		25.8	0	0
	Medium energy concentrate		43.9	0	0
	Soy beans		56.4	0	0
Amount of N entering the farm via biological N fixation	Clover <25% of sward	109	20000	2,180,000	13
	Clover >25% of sward		150000	0	0
	Red clover sward (pure sward)		250000	0	0
Amount of atmospheric N deposition	Highlands & Islands		2000	0	0
	Rest of Scotland	165	4000	660,000	4
Amounts of seed and planting material	Barley		17	0	0
	Wheat		20.8	0	0
	Oats		18.1	0	0
Amounts of bedding material	Straw	100000	5.4	540,000	3
	Saw dust			0	0
Amounts of imported manure	Cattle FYM		8.4	0	0
	Degased cattle slurry		2	0	0
	Sheep FYM		8.4	0	0
	Solid poultry manure		21	0	0
N input via irrigation water					
N Input Totals				**8,422,400**	**51**

Nitrogen Use Efficiency (NUE)	**16%**	
Farm N surplus	**43**	**kg N/ha/yr**

Appendix 3a – examples of use of VESS by participating farmers

Appendix 3b – examples of use of VESS by participating farmers

Appendix 3c – examples of use of VESS by participating farmers