BRITISH SOCIETY
OF SOIL SCIENCE

LAND USE FOR NET ZERO

Guidance Note for Land Managers
Soil Carbon: What are carbon stocks and how can they be measured?

Around 30% of the Earth's surface is land. The way we use and interact with land will have an impact on climate change. Land and soil can contribute towards climate change mitigation for example, by removing carbon dioxide from the atmosphere and providing locations for clean energy production.

The evidence and guidance provided in this Land Use for Net Zero series will help us to understand where we should focus our efforts and the trade-offs involved in each of them, to support our collective aims to achieve net zero.

V1 - JUNE 2023

What are carbon stocks and how can they be measured?

Soil has a critical role to play in climate change mitigation by regulating atmospheric greenhouse gases (GHGs). Global soils are the dominant natural land-based carbon sink, holding more carbon than all terrestrial habitats combined (*soil carbon stock*). There is a significant opportunity to increase soil carbon stocks and reduce GHG emissions from many agricultural soils by changing management practices and how land is used. It has been estimated that soil carbon sequestration could initially remove between 0.8 and 1.5 Gt C per year from the atmosphere [1]. The significance of soil carbon has been explored in the BSSS Science Note on Soil Carbon [2].

There is growing interest from *carbon finance schemes* in the economic value of soil carbon, since increasing soil carbon stocks may help the agricultural supply chain, wider industries and national governments to meet voluntary and regulatory obligations for emission removals and emission reductions, particularly GHGs [2]. The financial value that can potentially be placed on soil carbon can help farmers and other land managers change practices or systems by working more closely with nature.

Government-funded incentive schemes can help finance soil management practices that deliver improvements in soil health along with wider environmental benefits such as improved water quality [3]. Although these practices may also change soil carbon stocks and GHG emissions, UK public finance does not at present, specifically incentivise soil carbon increases. There are however opportunities to combine public incentives and private finance to introduce management practices that can meet the different aims of these schemes [3].

The majority of private carbon finance schemes combine soil carbon stock increases and soil derived GHG emission reductions to calculate a net gain in soil carbon. This is expressed as units of carbon dioxide equivalents (CO_2e). In this guidance note, we focus on key considerations regarding the monitoring, reporting and verification of soil carbon stocks for carbon finance schemes.

Key facts about soil carbon stocks in agriculture

- Carbon finance schemes only consider the amount of organic carbon in soils as tonnes per hectare (t/ha) to a defined soil depth (e.g. 0-30cm, 30-60cm, 60cm and deeper) converted into a CO_2 equivalent
- It takes time to substantially increase soil carbon stocks, typically decades
- Soil carbon stocks will eventually reach a plateau (i.e. equilibrium) where no further carbon will be stored
- How much stock a soil will hold and how quickly it will reach equilibrium depends on various factors including: soil texture, new and past management, weather conditions and soil nutrient status. Field verification is therefore essential
- Soil carbon stocks are easily reversible and will need continual management to permanently maintain them
- There is limited UK evidence on combined management impacts (e.g. reduced tillage and cover cropping) on changes to soil carbon stocks
- As the ultimate aim is to reduce atmospheric GHG concentrations a key consideration is the need for "permanence" of soil carbon [4].

What are *soil carbon finance schemes*?

Financing for soil carbon is an innovative private investment tool intended to provide economic incentives for farmers and land managers to move from 'business as usual' management to alternative land management strategies. The reductions or removal of soil based CO_2e units can be purchased, or financed, by companies wanting to offset emissions from other sources (e.g. carbon credits). In some instances, this is financed by companies wanting to reduce emissions across the supply chains (Scope 3 emissions reductions, also known as insetting) (see page 7).

Schemes generally combine the measurements of soil carbon stocks with the predictions of derived GHG emission reduction to fully quantify the effects of soil management change on soil carbon. In the case of Scope 3 reporting, this usually means integrating soil carbon data into carbon calculators. For the voluntary carbon market, this typically requires the use of the soil carbon data in more complex process-based models.

The marketplace for soil carbon is still rapidly evolving and landowners need to consider which finance option best suits their specific circumstances. There will be a range of implications depending on the scheme, such as ongoing costs, contractual obligations, taxes, property values and agreements with supply chains. All of these may impinge on future land uses and reduce flexibility.

Voluntary schemes, including the Peatland Code and the Woodland Carbon Code, and agricultural subsidy schemes do not make payments specifically for agricultural soil carbon stocks and are focused on other environmental benefits. As a result, it is currently possible for landowners to obtain payments from both voluntary schemes and private schemes (sometimes known as 'stacking payments').

What is Monitoring, Reporting and Verification (MRV) and how is it used to demonstrate increased soil carbon stocks?

Whether participating in public or private finance schemes, all require evidence that substantive (i.e. measurable) changes to soil carbon stocks, usually alongside GHG reductions, have been maintained over the finance period and beyond (i.e. demonstrate "permanence"). This evidence is commonly captured under the headings of monitoring, reporting and verification (MRV).

Since changes in soil carbon occur slowly [5] long-term monitoring is required to show the relatively small change against the existing soil carbon stock [6]. Private *carbon finance schemes* could be looking for small changes of around 2.5 to 5 tonnes soil C per hectare over a period of five years, and accurate MRV will provide the data to test and prove whether these changes are actually taking place.

Although there is no universal standard for MRV, general principles set by the Integrity Council for the Voluntary Carbon Market (ICVCM) can be used to consider the reliability of different MRV approaches [7] (see appendix, page 10). Detecting change can be challenging: for example at a national scale, the Northern Ireland Soil Health Nutrient Scheme aims to detect change in soil carbon stocks on all farms in Northern Ireland [8]. This will require adequate representative sampling with the number of samples per farm informed by using standard statistical techniques.

Monitoring
This commonly requires sampling and measurement of soil carbon stocks every three to five years to establish whether there has been a significant change from the baseline due to management changes in a soil carbon project. Measurements can be used directly to demonstrate change in soil carbon stocks and used in mathematical modelling to quantify CO_2e changes, often in combination with GHGs. This will usually take place alongside the collection of field and farm management records for the period.

Reporting
This process produces a monitoring report, which provides all necessary information about a soil carbon project over a defined monitoring period. It would typically include information on the soil carbon changes reflecting any leakages (indirect GHG emissions from an activity that was designed to decrease or eliminate emissions) or reversals of soil carbon in that period. The report is generally submitted to the organisation issuing the soil carbon credits or overseeing the finance scheme.

Verification
This is the process by which suitably skilled and qualified individuals check the monitoring report. Many carbon finance schemes require independent verification.

Ongoing work with organisations such as the British Standards Institution aims to establish common MRV standards in the UK and globally for the Voluntary Carbon Market (VCM) and Scope 3 emissions in particular (e.g. ICVCM, Science Based Targets Initiative (SBTI) and The Greenhouse Gas Protocol). This work should allow MRV standards to align with the Intergovernmental Panel on Climate Change (IPCC) recommendations to ensure that there is harmonisation of CO_2e across carbon finance schemes and countries offering carbon credit incentives. Our overview of MRV aligns with IPCC recommendations.

Despite the competing interests of some organisations, and range of current MRV techniques, we recommend that where possible the same MRV process is used across all schemes, to allow landowners, and in future the wider industry, to share and compare data.

What techniques are used to monitor, report and verify the carbon stock in the soil?

Before participation in a *carbon finance scheme*, it is essential that initial soil carbon stocks are known, as these provide the baseline against which changes can be assessed and valued.

Due to the number of variables, we would recommend that expert advice is obtained before starting the process. Although a MRV process may look effective on paper, in practice it may need to be altered to reflect a range of external factors such as hydrology, topography and soil depth variability. An expert will be required to establish the baseline values for the soil, find out what potential the land has to store carbon, and whether it is achievable within five to ten years (the usual term of a *carbon finance scheme*) before deciding on next steps. Having specialist advice and using land managers' own knowledge will allow changes to be made as needed and predictions for soil carbon storage updated. At this stage, it is also worth considering whether participating in a *carbon finance scheme* is right for you as an individual land manager: whether your aims are for purely environmental purposes: to increase carbon stocks, or for the associated finance, and if these aims could be achieved using other practices.

The main components in monitoring are set out below:

Sampling Design

The sampling strategy deployed and number of samples to be taken, will depend on a number of factors including the number of fields being sampled, the variability of soils in the sampling area, current land use and the level of change in carbon stock that a project wants to detect, e.g. to test for increases in soil carbon stocks of 5 t/ha over five years, more samples will be needed than if for 10 t/ha over the same period. The number of samples and their location will reflect the scale of the reporting of the soil carbon stocks. Although soil carbon stock changes may differ from field to field, schemes often look to detect change at farm or project, rather than field, scale. Sampling strategies should also reflect, where relevant, the need to collect carbon stock data for a "measure and model" approach where the finance scheme is forecasting change in net carbon emissions using mathematical models.

Field Sampling

IPCC guidance indicates that sampling soil carbon stocks should be done at depths of 0 – 30, 30 – 60 and 60 cm and beyond, as a 30 cm assessment does not take account of potential soil C sequestration deeper in the soil profile [9]. The bottom depth for sampling should reflect the depth of the soil and depth of management influence. It should also consider depth changes in soil bulk density, with an adjustment for stone content, as the carbon stock analysis will not be accurate if this is omitted [9-11].

Physical soil sampling will need a specialist (often a soil scientist) to visit the land, dig soil pits, take intact soil cores for bulk density measurement and submit samples for lab testing of soil carbon content [12]. To capture natural variation in soil carbon stocks, a large number of soil samples is often required [6].

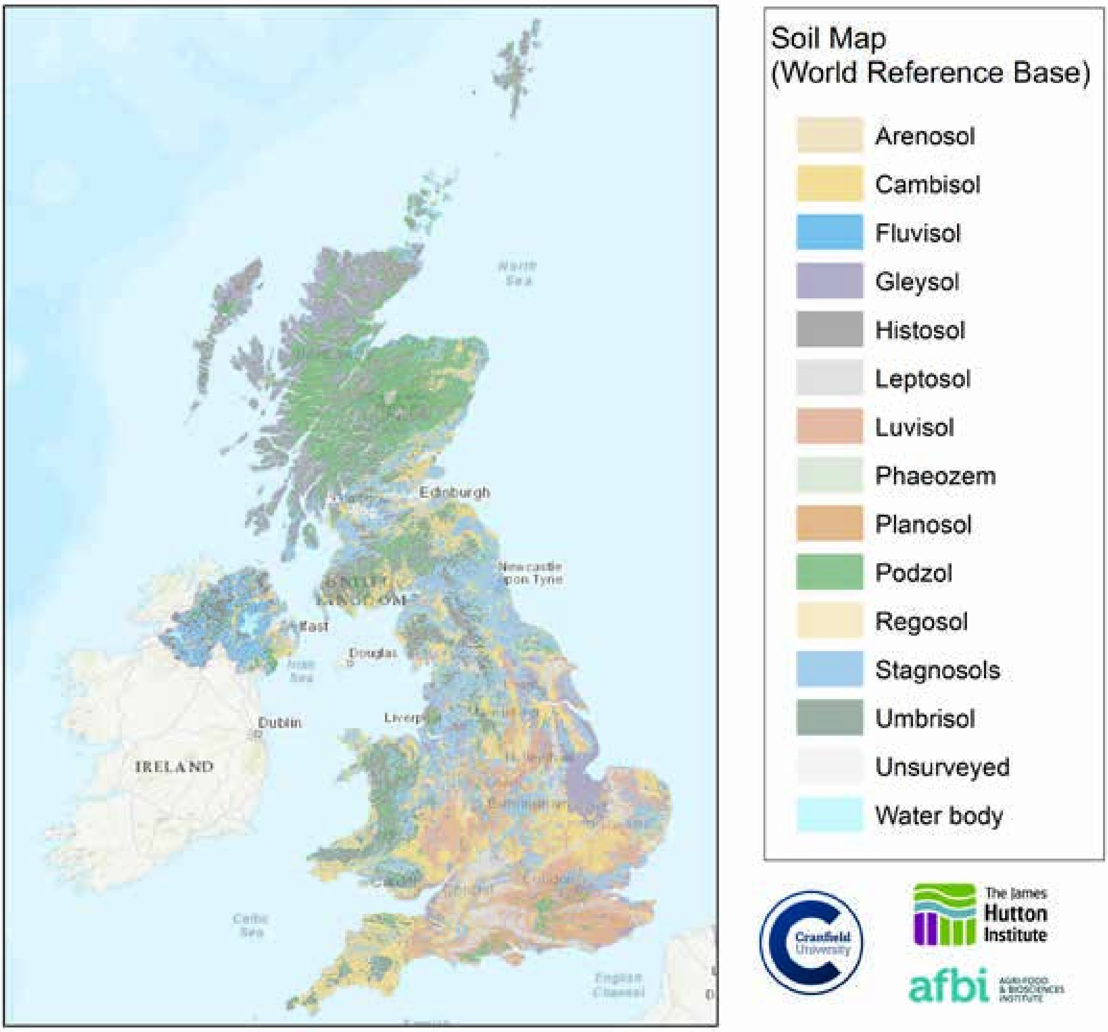
Analytical methods

The calculation of soil carbon stock (tons per hectare) requires the analysis of both soil organic carbon content (SOC%) and fine dry bulk density (g cm^{-3}). Monitoring change will also calculate stock changes using "equivalent soil mass" which will require analysis of soil fine dry mass [13].

There are British Standards Institution (BSI) and International Organization for Standardization (ISO) standard methods for the laboratory analysis of soil organic carbon content using elemental analysis by dry combustion and the analysis of dry soil bulk density [14]. These methods are both widely adopted by commercial laboratories, although it is important to ensure that dry soil bulk density includes the analysis of fine dry bulk density and not only total dry bulk density.

There are alternative methods, but finance schemes will often indicate which laboratory methods are acceptable to their projects, including how to take into account errors and uncertainties that any analytical method will introduce into the calculations of soil carbon stocks.

Some labs may employ loss-on-ignition (LOI) as an alternative method from which to estimate SOC% using a conversion factor [15]. However, LOI is not generally acceptable to VCM schemes [16]. Sensor methods, including UV-visible, Near or mid-Infrared Spectroscopy (UV-vis, NIRS, MIR) and Laser-Induced Breakdown Spectroscopy (LIBS), are increasingly being used to predict soil carbon content and bulk density from laboratory samples and, in some cases, from the field and via remote sensing (using satellite or drone images). None of these methods measure soil carbon stock directly. Instead, they rely on mathematical models to predict SOC% and bulk density using various datasets, from terrain to soil texture [17-20]. These models require calibration to local conditions and therefore still rely on physical soil samples, where soil organic carbon and bulk density have been measured directly. Remote sensing also relies on images of bare soil, which limits its application.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

What could a change in land management practices do to soil carbon?

The greatest and most rapid soil carbon increase can be achieved through land use change, for example from arable to permanent grass (figure 1) or to woodland, as the soils under these types of land have permanent plant cover and are relatively undisturbed. However, there are some land use changes i.e. grassland to woodland, which do not always make rapid soil carbon increases and can sometimes have a negative impact [21]. Furthermore, the implications of land use change for food security need to be considered.

Arable soils typically have more potential for storing carbon through management changes. The amount of soil carbon can be increased through additional inputs, for example crop residues, cover crops, use of organic materials, or the inclusion of grass leys in arable rotations, or decreasing the loss of carbon into the atmosphere, via improved management such as reduced intensity or depth of tillage [2].

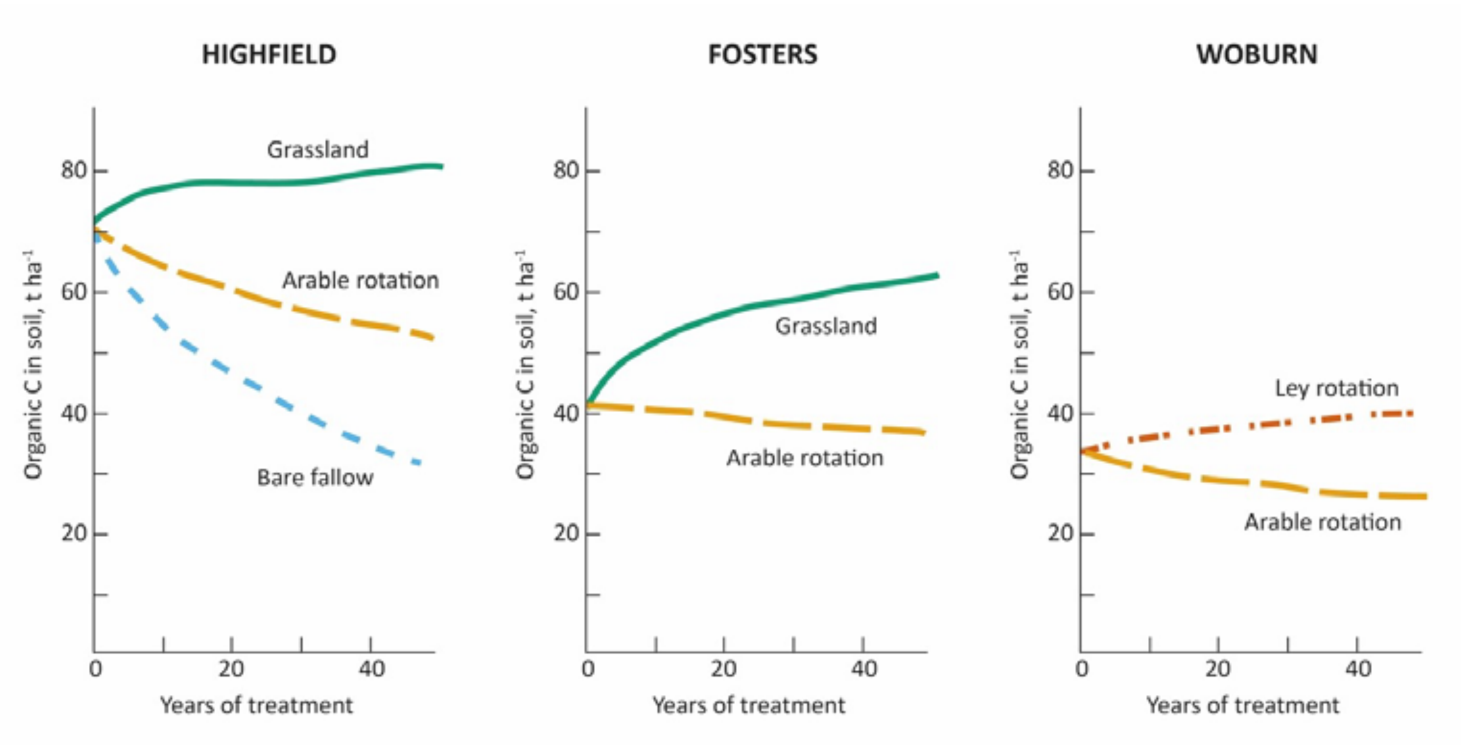


Figure 1: Change in SOC under grass/arable and ley arable rotations. Adapted from [22]

What are the challenges in using soils as carbon stores? How permanent are the changes?

We know that the amount of carbon that accumulates in the soil is finite [23]. Carbon storage can be retained only as long as sustainable land management practices are implemented and maintained. The rate of soil C sequestration is usually highest in the years immediately after the land management changes are introduced, and slow down over time and as the soil reaches a new equilibrium level (Figure 2).

There can be unintended consequences of management changes to store more carbon, as the process may either increase or decrease GHGs emissions from soils such as nitrous oxide (N_2O) and methane (CH_4). In some situations, these emissions can be more significant than the carbon which may have been removed from the atmosphere via the soil management scheme because of the large global warming potential of these gases (N_2O has 273 times and CH_4 has 25 times the global warming potential of CO_2 when considered on a 100-year time scale) [24]. MRV therefore typically models the impact of management changes on soil derived GHGs in combination with soil carbon and checks that unintended emissions are not exceeding the value of the carbon stored within the soil.

Potential unintended consequences, together with challenges associated with robust MRV, and the ease with which increases in soil carbon stocks can be reversed, mean that soil carbon should not be seen as a 'quick fix' for the landowner, *carbon finance system* or governments [25]. However, increasing soil carbon, and therefore long-term changes in management to maintain soil carbon could also reap benefits with improved soil health, wider ecosystem benefits and resilience to climate change.

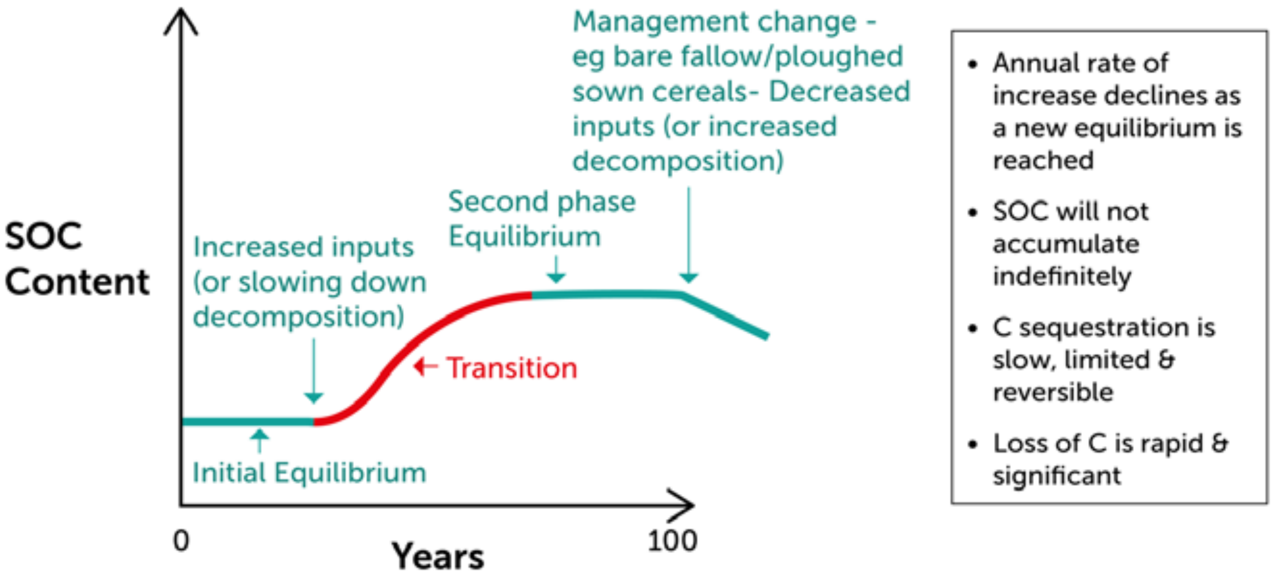


Figure 2: SOC accumulation rates change over time. Based on findings in [22] and principles outlined in [26]

Scope Three Emissions

Organisations are increasingly measuring and monitoring reductions in GHG emissions as part of their road to net zero. The IPCC Greenhouse Gas Protocol defines three scopes of emissions reductions to help focus net zero efforts.

Scope 3 refers to emissions that are beyond an organisation's direct control but are emissions that the organisation is indirectly responsible for across its value or supply chain e.g. purchased goods such as milk bought from a farm by a cheese making company.

Mandatory reporting of Scope 3 emissions, along with Scope 1 and 2*, is now required by The International Sustainability Standards Board (ISSB). Many organisations around the world are using the ISSB standard to report and demonstrate their commitments towards net zero to investors, customers and governments.

Scope 3 emissions from field-level agricultural production and land-use change account for more than 80% of all GHG emissions from the global food supply chain and there is growing pressure to reduce GHG emissions from agriculture to meet beyond-farm gate demands and commitments to meet net zero.

Reduced GHG emissions associated with soils, e.g. by altering manufactured fertiliser use, can be calculated and reported via various tools e.g. farm carbon calculators, which follow current guidance from the GHG Protocol. Standards that define how to calculate and report emissions removals through increased soil carbon stocks are expected in late 2023 with the publication of an updated GHG Protocol Land Sector and Removal Guidance.

*'Scope 1' GHG emissions are those from sources owned or controlled by the reporting entity and can include soil N_2O from fertilisers and vehicles. 'Scope 2' GHG emissions are indirect, associated with the production of electricity, heat, or steam purchased by the reporting entity. 'Scope 3' encompasses all other indirect emissions.

Recommendations

There can be significant differences between *carbon finance schemes* in their requirements for measurement and monitoring of soil carbon stocks. Before signing up to any scheme, it is important to consider that:

- soil carbon credits can only be sold once through the Voluntary Soil Carbon Market
- soil carbon removals remain with the land and can be transferred across the supply chain e.g. for Scope 3 reporting
- there may be financial and non-financial consequences, such as taxes and potential reduced income from other contracts, of signing up to any scheme and these should be considered when selecting a scheme
- for reliable measurement of soil carbon stocks, field sampling should be carried out in conjunction with an appropriate sampling design, approved analytical methods and reliable modelling, where relevant
- field sampling must go to depth, ideally below the management layer, to ensure that soil carbon stock changes are captured
- measurement of soil carbon stocks requires analyses of soil carbon content and fine dry bulk density, along with soil dry mass for change assessments
- carbon removals from soils (i.e. increased soil carbon stocks) should be considered alongside carbon reductions from soils (i.e. reduced greenhouse gas emissions)
- permanence in soil carbon stocks requires a long-term commitment to changing how soil is managed
- expert advice from an independent advisor will support you in making the right decision for you and your land.

When considering a soil carbon stock monitoring scheme, the choice of MRV should be informed by the relevant incentive programmes (e.g. VCM or Scope 3), along with the long-term aims of the land manager. Robust MRV to monitor soil carbon stocks will require substantial effort and investment. Whether farmers commit to schemes to invest in soil carbon stocks, there remain clear benefits to increasing soil carbon to improve soil health and help alleviate climate impacts.

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Appendix

The Integrity Council for the Voluntary Carbon Market has developed 10 Core Carbon Principles which set out the key principles for high-integrity carbon credits:

A. GOVERNANCE

Effective governance

The carbon-crediting program shall have effective program governance to ensure transparency, accountability, continuous improvement and the overall quality of carbon credits.

Tracking

The carbon-crediting program shall operate or make use of a registry to uniquely identify, record and track mitigation activities and carbon credits issued to ensure credits can be identified securely and unambiguously.

Transparency

The carbon-crediting program shall provide comprehensive and transparent information on all credited mitigation activities. The information shall be publicly available in electronic format and shall be accessible to non-specialised audiences, to enable scrutiny of mitigation activities.

Robust independent third-party validation and verification

The carbon-crediting program shall have program-level requirements for robust independent third-party validation and verification of mitigation activities.

B. EMISSIONS IMPACT

Additionality

The greenhouse gas (GHG) emission reductions or removals from the mitigation activity shall be additional, i.e., they would not have occurred in the absence of the incentive created by carbon credit revenues.

Permanence

The GHG emission reductions or removals from the mitigation activity shall be permanent or, where there is a risk of reversal, there shall be measures in place to address those risks and compensate reversals.

Robust quantification of emission reductions and removals

The GHG emission reductions or removals from the mitigation activity shall be robustly quantified, based on conservative approaches, completeness and scientific methods.

No double counting

The GHG emission reductions or removals from the mitigation activity shall not be double counted, i.e., they shall only be counted once towards achieving mitigation targets or goals. Double counting covers double issuance, double claiming, and double use.

C. SUSTAINABLE DEVELOPMENT

Sustainable development benefits and safeguards

The carbon-crediting program shall have clear guidance, tools and compliance procedures to ensure mitigation activities conform with or go beyond widely established industry best practices on social and environmental safeguards while delivering positive sustainable development impacts.

Contribution toward net zero transition

The mitigation activity shall avoid locking-in levels of GHG emissions, technologies or carbon-intensive practices that are incompatible with the objective of achieving net zero GHG emissions by mid-century.