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Payment for carbon sequestration in soils: A scoping study

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Soils are one of the world's biggest stores of carbon. The level of carbon storage depends on several factors, including the type of organic matter, climatic conditions and land management practices, both past and present. Scottish Government asked ClimateXChange to explore how the level of storage over time could be measured, and how this could help improve land management practices through a payment system.

Key points

- Agricultural soils (across pasture and arable) account for more than 10% of Scotland's estimated soil carbon. Changes in land management practices affect the balance between soil carbon accumulation and loss, with conversion from grassland to cropland as the largest single change that releases soil carbon on Scottish agricultural land.
- Evidence suggests there is large potential for increasing carbon storage in agricultural soils through changes in management practices. Any increase in carbon in the soil is likely to have a positive impact on soil quality, whilst the climate change mitigation benefit may be modest but positive in the longer term.
- Mechanisms for support through payments exist, but they are largely focused on wider benefits such as preventing soil erosion and there are none that currently specifically enable soil carbon sequestration.

Summary

The Scottish Government has set statutory targets for the reduction of greenhouse gas emissions through the Climate Change (Scotland) Act 2009. One approach is to increase the amount of carbon stored in soil. In the 2018 Climate Change Plan, the Scottish Government prioritised actions to improve carbon sequestration in Scottish soils, and committed to "investigate the feasibility of payment for carbon sequestration" (p.203).

How is carbon sequestered in soil?

Soils are one of the world's biggest stores of carbon. Carbon dioxide in the air is absorbed by plants through photosynthesis, and this organic matter is deposited in the soil as wood, leaf litter, dead root matter, animal waste etc. Micro-organisms in the soil decompose this organic matter. If the rate of accumulation is greater than the rate of decomposition, then the amount of carbon in the soil increases. However, if the rate of loss is greater, then higher quantity of greenhouse gases such as carbon dioxide and methane are released.

The level of carbon storage in the soil depends on several factors, including the type of organic matter, climatic conditions and land management practices, both past and present.

Current levels of carbon storage in Scottish soils

The majority of soil carbon in the upper 1m of Scottish soils (approximately 3000 Mt) is held in peatland and moorland soils. Cultivated agricultural topsoils account for approximately 250 Mt carbon. At a national scale, these soil carbon levels appeared to have stayed relatively stable over the past 20-30 years. Some soils are carbon depleted whilst others have reasonable levels.

Additional carbon storage potential of Scottish agricultural soils

Evidence suggests there is large potential for increasing carbon storage in agricultural soils through changes in management practices, with an estimated additional 'carbon storage potential' of 150-215 Mt. There is also potential for soils to lose carbon, and the 'potential carbon loss' for Scottish agricultural soils is estimated to be around 140 Mt. Preventing soil carbon loss – as well as enabling additional carbon sequestration – is therefore important for minimising atmospheric CO_2. There are substantial additional soil functional benefits of increasing soil organic matter (and thus carbon), such as increased water holding capacity, nutrient cycling, biodiversity maintenance and erosion prevention.

Influence of land management practices on levels of soil carbon in Scotland

It is known that changes in land management practices affect the balance between soil carbon accumulation and loss. Conversion from grassland to cropland is the largest single transition for releasing soil carbon on Scottish agricultural land. There is strong evidence that the addition of animal manures and other organic substance increases soil organic carbon. Existing evidence suggests positive carbon sequestration opportunities are strongest through changing cropland to forestry, mostly as above ground biomass. Opportunities exist for management practices to increase soil carbon sequestration, although the amount per unit of land area remains uncertain and would benefit from further research for different characteristics.

Current evidence demonstrates uncertainty in the soil carbon impacts of other management practices such as the application of natural quarried lime, balanced fertilization and irrigation, and the conversion to reduced tillage or no-till systems.

Influence of site-specific soil and climatic conditions on carbon sequestration

The overall effectiveness of agricultural management on soil carbon storage depends on the interaction of management practices with soil and climatic characteristics (including drought, waterlogging and extreme events). There is a need to accurately capture the impact of site-specific interactions between climate, soil, and management on carbon sequestration, which are less apparent in regional level assessments. Evidence suggests that there has been little change in carbon stocks for cultivated soils in Scotland in the last few decades. This static (as opposed to stable) state may be due to consistent

rates of inputs and losses in this period. However, this overall state masks the possibility of gains or losses in specific locations or land uses.

Monitoring, Reporting and Verification of soil carbon

The lack of detailed data does not preclude the development of support mechanisms to sequester additional soil carbon based on known good management practices. This implies the development of a system for Monitoring, Reporting and Verification (MRV) of management practices and subsequent changes in soil carbon where it is the activity that is monitored, reported on and verified. Verification could be achieved by current field inspections, remote sensing, and/or smartphone apps to assess soil organic matter and supported by actual soil carbon measurements to confirm management practice effectiveness.

Current regulation of soil carbon in Scotland

There are currently no regulatory compliance requirements relating specifically to soil carbon content or to undertaking specific activities to maintain or enhance it. Within the CAP Greening guidance there are some limited requirements that help protect soil carbon, albeit indirectly, such as regulations regarding the ratio of permanent grassland to the total agricultural area claimed. The ‘Good Environmental Conditions’ (GEAC) also has aspects that could help maintain soil carbon stocks, such as minimum soil cover and land management requirements to minimise erosion. However, soil carbon sequestration is a complex issue and thus quantifying how much existing measures, particularly CAP, already contribute to soil carbon amounts may not be realistic without additional research effort.

Potential for a system of payments for soil carbon sequestration

Mechanisms for payment for carbon sequestration currently exist in several forms, such as the Peatland Code, the Woodland Carbon Code and the Agri-Environment and Climate Scheme. The primary limitation of existing policies is that they are not soil carbon specific. Where they are relevant to soil carbon, they are focussed on wider benefits (i.e. prevention of soil erosion) rather than the specific process of soil carbon addition and the practical management activities that can make this happen.

An effective payment scheme for carbon sequestration in Scottish soils should:

- ensure longevity of the funding mechanism;
- have aims and objectives that can be put into a site-specific context (which requires skills sharing, training and awareness raising of best practices to meet objectives);
- be accessible and easily implemented, without excessive burden of administration and monitoring;
- be fair across the diversity of land management histories.

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Introduction

This report examines how Scotland's agricultural soils might sequester carbon as part of an overall approach to mitigate against, and adapt to, climate change. The Scottish Government has set statutory targets for the reduction of GHG emissions in Scotland through the Climate Change (Scotland) Act 2009. Agriculture contributes just under one-quarter of Scotland's greenhouse gas emissions (GHG) and with related land use is the second-largest emitting sector behind energy supply. The Scottish Government has prioritised actions to improve carbon sequestration in the land use sector within its current Climate Change Plan.

This project was commissioned in April 2018 to synthesise the current state of knowledge on soil carbon sequestration and identify the potential for practical funding mechanisms to support the storage of additional carbon in Scotland's soils. We used the available spatially-explicit soil carbon data to estimate carbon sequestration potential in Scotland, and identified the key issues concerning how this can be achieved (such as practical soil management, policy requirements and financial incentives).

Over the past 150 years, atmospheric carbon dioxide (CO_2) has increased by 30% resulting in global warming and climate change (IPCC, 2007). One approach to reduce the levels of atmospheric CO_2 is to increase the global storage of carbon in soil through appropriate management practices. Soil organic carbon (SOC) is a key component of soil organic matter that affects the physical, chemical, and biological properties of soil. There is considerable evidence that soil carbon influences several critical soil functions like nutrient dynamics, nutrient availability to plants, water holding capacity, aggregate stability and infiltration (Powlson & Whitmore, 2006). Improved mitigation measures in agriculture could significantly contribute to the removal of atmospheric CO_2 at relatively low cost (IPCC, 2006). Several studies demonstrated that carbon sequestration in agricultural soils produce a range of positive environmental, social and economic benefits.

We present here the evidence on current carbon stocks in cultivated soils in Scotland, carbon sequestration potential and management impacts on carbon sequestration. We also present the potential for a system of payments, in the context of mitigating, and adapting to climate change.

Background

Definition of carbon sequestration and carbon storage potential

According to the IPCC, carbon sequestration is "*a process of increasing the carbon content of a reservoir/pool other than the atmosphere*". Persistent increases of carbon in soil or plant material is treated as carbon sequestration. Recent literature argues that only recalcitrant carbon (organic material that doesn't easily decompose) should be treated as sequestered carbon but the residence time of soil carbon varies. Some fractions of soil carbon can exist for thousands of years whilst others persist for only a few days to months. This makes it difficult to differentiate soil organic carbon, so the definition based on residence time is arbitrary.

Mechanism of carbon sequestration

Soil micro-organisms decompose soil organic matter deposited into the soil (e.g. leaf litter, dead root matter). If the rate of soil microbial decomposition is greater than the rate of accumulation, the soil loses carbon in the form of carbon dioxide (CO_2) and/or methane (CH_4) to the atmosphere. If the microbial decomposing rate of added organic matter is less than the rate of carbon incorporation to soil, soil carbon accumulates. The rate of decomposition on the soil surface depends on the chemical composition of the added plant material, climate, soil acidity (pH) and moisture. Different sources of organic matter have different decomposition characteristics, and result in different soil organic matter fractions. Previous land management history and current practices affects soil carbon accumulation or loss as well as greenhouse gas emissions from soil which in turn are also affected by climate change. It is beyond the scope of this report to consider the different mechanisms affecting the rate of decomposition by biotic and abiotic processes on carbon sequestration. Instead we aim to present some practical management options that increases soil carbon.

Carbon sequestration is a reversible lock-up of carbon, so it is assumed that adapted management practice will continue to sequester carbon until it reaches a steady state as long as other biophysical characters remain the same.

Key Issues

There are several key issues that need to be highlighted in order to help understand the complexity of carbon sequestration into soils:

- **The amount of carbon that accumulates in soil is finite**: several long-term experiments (Poulton et al., 2018) demonstrated that the annual rate of soil carbon accumulation is non-linear; greater SOC accumulation is generally observed soon after the land management or land use change is implemented, slowing near the end as the soil reaches a new equilibrium.
- **Permanence of the soil carbon:** soil carbon sequestration/storage in agriculture soils can be reversible and non-permanent. Carbon sequestration occurs as long as land management that sequesters carbon is implemented and maintained. By changing land management soil might lose or gain SOC depending on adapted management.
- **Spatial variety of soils:** different soils have different capabilities to sequester carbon. The potential for sequestration is greater in soils with low organic carbon content, whilst potential decreases in soils with greater organic carbon content.
- **Trade-offs:** land management changes that sequester soil carbon may either increase / decrease fluxes of greenhouse gases like nitrous oxide (N_2O) and Methane (CH_4). In many situations these changes are far more significant than carbon sequestration because of their very large global warming potential (N_2O is 298 times and CH_4 is 25 times the global warming potential of CO_2 when considered on a 100-year time scale).

Summary on current state of soil carbon stocks in Scotland

Current storage of soil carbon in soils:

Several recent studies have been conducted in Scotland to estimate national-scale soil carbon stocks. Different estimates of Scottish soil carbon stocks exist, based on different methods, such as soil sample data (e.g., Chapman et al., 2013; Poggio and Gimona, 2014) and process-based models (Smith et al., 2010a, 2010b). In summary, estimates of total soil carbon stocks to 1 m depth vary from 2055 Mt – 3492 Mt (Chapman et al., 2013; Bradley et al., 2005; Rees et al., 2018). The evidence base therefore consistently reports overall current levels of soil carbon in Scotland of around 3000 Mt. The majority of this carbon is held in peatland and moorland soils. This report is concerned with agricultural soils – arable and improved grassland as defined by Scottish Government (2011).

Based on analyses of the National Soil Inventory of Scotland (2007-9) data, Chapman et al. (2013) estimated that Scottish arable soils contained 115 (±15.6) t ha^{-1} carbon and improved grasslands contained 138.1 (±21.4) t ha^{-1} carbon in the top 1m. Scaled to the overall area of arable and improved grasslands in Scotland, this equates to around 102 (±14) and 152 (±24) Mt carbon and is not dissimilar to that calculated by Lilly and Baggaley (2013).

Evidence on soil carbon stock changes in Scotland:

Overall, evidence shows little change in carbon content over the past 20-30-year period in cultivated soils in Scotland. A small number of extensive long-term studies on carbon stock changes across Scotland show that over the last 30-40 years, there has been little overall change in carbon stocks for Scotland. By resampling the National Soil Inventory of Scotland (NSIS) data Chapman et al, (2013) found no significant change in carbon stocks from 0-15 cm for soils under arable cropping for samples taken between 1978-88 and 2007-9 (179 soil profiles) nor did they find any significant change in carbon stocks to 1m depth for this land use. However, this overall stability masks the possibility of gains or losses in specific locations or land uses. An alternative is to use analogous changes that indicate SOC changes, i.e. changes in structure, biological activity, carbon fractions etc.

There are major challenges in monitoring and estimating rates of change in soil carbon (Smith, P., 2004b), however, largely due to the slow rates involved, affecting detection limits. Hence mapping stocks of carbon is more straightforward than mapping changes. Changes over a five to ten-year timescale can still fall within the best measurement errors possible. Focussing on measurement of the processes that can be influenced to alter carbon sequestration may therefore be more useful for monitoring change. Even though there has not been an observed overall change in carbon stocks across Scotland, the nature of agricultural soils, current crops and practices leads to great spatial heterogeneity which highlights opportunities to sequester additional carbon (Antle et al., 2003).

The lack of statistically detectable change in carbon stocks of Scottish cultivated soils masks a measured decline (4.03 to 3.7%) in carbon concentrations in cultivated topsoils observed from the NSIS datasets (Chapman et al., 2013). Although there were changes in concentration, a statistically significant increase in overall topsoil thickness (perhaps due to deeper ploughing) meant that there was no change in C stocks overall. This highlights one of the key difficulties in monitoring changes in soil carbon; stock estimates require measures of topsoil thickness, bulk density and C concentration while most existing data has only C concentration or C concentration and topsoil thickness. Many current methods to assess change in carbon eg Countryside Survey (Reynolds et al., 2013) or NSI England and Wales (Bellamy et al, 2005) rely on sampling to a fixed depth (often 15cm) which, based on the results from the NSIS, would have suggested declining carbon stocks in Scottish cultivated soils.

Evaluating the carbon sequestration potential in Scotland

The potential for Scottish cultivated topsoils to store additional carbon (calculated as the difference between the maximum observed and the median value from the Scottish Soil Database, and expressed as carbon storage potential, CSP) is estimated to be between 150 and 215 Mt (taking account of uncertainties in the predictions of key soil properties – see Appendix 1). Previous work (Smith et al., 2010b) has shown that cultivated grassland soils had, on average, 1.2% more carbon and arable soils

0.2% less carbon, than the calculated median. The median carbon stock for grassland was recalculated as 172 (±8) Mt and as 99 (±3) Mt for arable topsoils. The potential additional storage capacity for grasslands (calculated as the difference between the maximum observed and the median plus 1.2% carbon) was 60 Mt (range 48-86 Mt) and for soils under arable it was 88 Mt (range 78-104Mt) and based on the median minus 0.2% carbon.

There is also, however, potential for soil to lose carbon. Using the same methodology as above the potential carbon loss (PCL) was calculated to be 138 (±15) Mt. This emphasises the necessity to adopt management options that help retain the existing levels of carbon as well as options to increase carbon concentrations.

Figure 1 shows the distribution of arable and grassland land cover in Scotland based on the Land Cover of Scotland 1988 dataset (https://www.hutton.ac.uk/learning/exploringscotland/landcover-scotland-1988). The calculated potential carbon loss or gain for each individual soil type (soil series) and for each land use type (arable or grassland) was mapped to show those areas where there is greatest scope for storing additional carbon (Figure 2). The land cover map was overlain with the 1:250 000 scale soil map (Soil Map of Scotland) giving a combined map of soil series and land use. The calculated Carbon Storage Potential for each soil series/land use type could then be mapped.

Different soils have different capabilities to sequester carbon. Whilst, in general, the potential for sequestration is greater in soils with low organic carbon content and the larger potential losses are in soils with greater organic carbon content, this will depend largely on the soil type (as well as land use) and different soils will have different propensity for loss or gain.

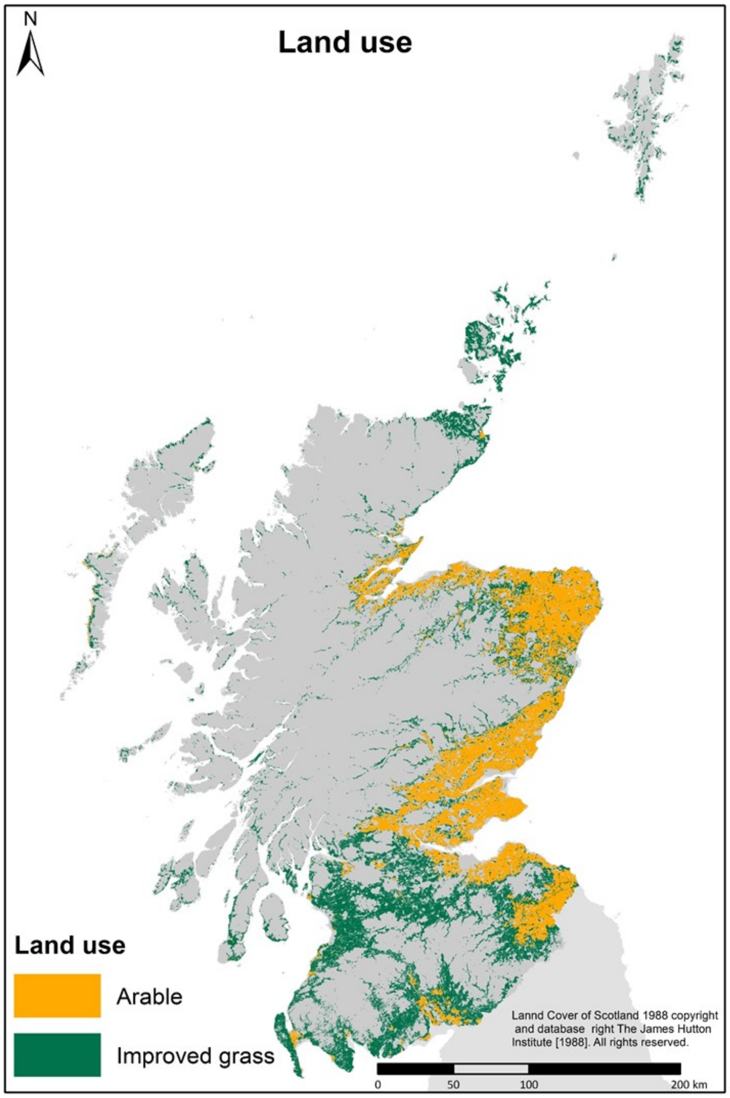

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Figure 1. Distribution of cultivated arable and improved (managed) grassland in Scotland based on the Land Cover Scotland 1988 dataset.

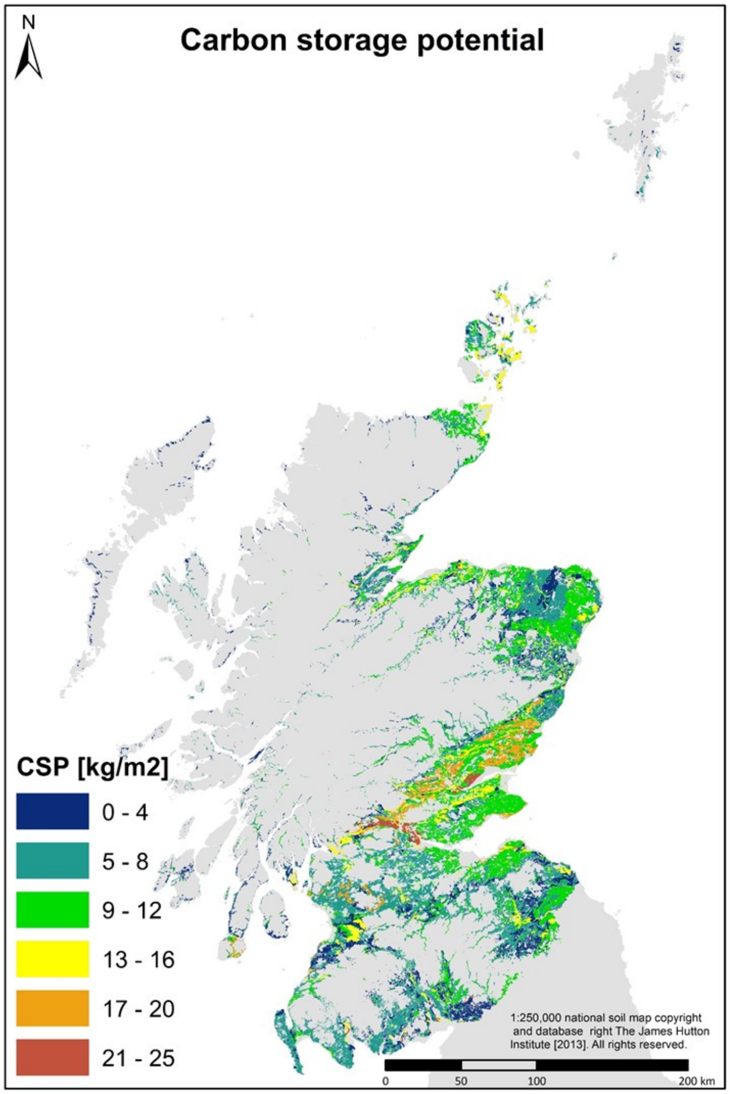

Figure 2. Carbon storage potential for top soils under arable and improved grassland.

Land management options to maintain or increase soil carbon

We know that when a new land management practice is adopted the balance in accumulation/loss of soil carbon changes. (Poulton et al., 2017; Johnston, Poulton, & Coleman, 2009; Smith, 2014; Gollany et al., 2011). It takes generally up to 20-40 years for the rate of SOC accumulation/loss to settle, and after 80-100 years of continuous practise the rate of change in SOC is expected to reach near to zero.

There is considerable uncertainty in quantifying the impacts of different management practices on carbon sequestration and GHG emissions (Smith, 2004), and this is further affected by spatial and temporal variability. Soil carbon sequestration can be achieved in agricultural soils by either reducing disturbance or increasing the carbon input. The potential for carbon sequestration of these measures are given in Table 1 below.

Tillage: Practices that have been suggested (e.g. by Smith 2004) as favouring carbon sequestration include changing tillage practices from conventional ploughing (inversion) for crop production to reduced or no-till (zero tillage) systems. The Scottish Survey of Farm Structure and Methods (2016) shows that the area of arable land cultivated in the past 12 months using conventional systems was 90% - an increase from 81% in 2013. Similarly, the areas using reduced or no-till was 10 % - down from 19% in 2013. Using multiple medium term (8 – 15 years) experiments (platforms) in Scotland and England with different cultivation and cropping systems McKenzie et al (2017) determined the carbon stored in the full profile depth of soil. Making appropriate corrections for any changes in bulk density, allowing for stone content and considering the full soil profile they found no advantage of carbon sequestration with the use of no-till or reduced tillage compared to conventional ploughing. This finding is consistent with Sun et al (2011). Recent work in Finland (Sheehy et al 2015) found improvement in soil stability under no-till associated with changes in carbon distribution within the soil. The potential to accumulate carbon under no-till or reduced tillage systems was limited compared to conventional ploughing. Increase in SOC from reduced tillage now appears to be much smaller than previously claimed by many studies (Powlson et al., 2011).

Addition of organic manure: The addition of animal manures and other organic amendments to arable soils has been a basis for crop production for centuries. The Centre for Sustainable Cropping at the James Hutton Institute's Balruddery farm compares a 6-year crop rotation under conventional and integrated managements. The integrated management includes using reduced tillage (for all crops apart from potatoes) and an annual application of PAS100 compost. For the first 6 years the compost application rate was at 35 t/ha. In the first crop rotation under this regime the carbon content in the integrated management was significantly greater than in the conventional treatment by approximately 6 kg/m^3 (McKenzie et al 2017). There is strong scientific evidence and consensus in use of organic substance to increase soil organic carbon but as this management is already in practice in Scotland, there is need to research the extent to which management can further develop.

Fertilization and irrigation: It is well established that increase in fertilization and irrigation increase the productivity leading to higher plant inputs to soil, leading to higher carbon sequestration (Fageria, 2012; Snyder et al., 2009). A life cycle analysis may be required, however, as the net carbon impact of irrigation and fertilisation might be minimal or negative when carbon costs of producing fertiliser and pumping irrigation water are considered (Snyder et al., 2009). In addition, excessive application of mineral fertilizer leads to N_2O emissions from soils, thereby rendering potential benefits to soil C sequestration void in relation to potential losses through the more potent greenhouse gas N_2O. There is need to balance the fertiliser requirement for optimal cost effective crop production and minimising GHG emissions.

Liming: the application of natural quarried lime is considered to improve soil quality leading to increases in soil organic carbon. Studies from Fornara et al. (2011) and Hopkins et al. (2009) demonstrated the significant increase in soil carbon following lime application. As pointed out in a recent review by Holland et al. (2018) the impact of liming on carbon sequestration and GHG emissions are complex and there are major evidence gaps in understanding the liming impact on estimating greenhouse gas (GHG) emissions for selected soil type, land use and management combinations. Due to the lack of consistent evidence on liming impact on carbon sequestration and GHG emissions it would be difficult to recommend liming as a measure for increasing carbon sequestration.

Land use change: Studies based on land use changes at Rothamsted (Poulton et al 2018) found returning arable land to woodland can lead to increases in soil organic carbon that continues even after 100 years. Short rotation forestry has also been demonstrated to increase soil carbon stocks, including at sites in North Lanarkshire and Fife, although not for all tree species (Keith et al 2015). Twenty-one years after a land use change from arable to forestry or to rough grassland on a site in Aberdeenshire found both systems lead to soil carbon accumulation (Baddeley et al 2017). This was greatest under the grassland, but there was increased carbon storage above ground with the trees.

Experiments to show the effects of conversion of arable land to forestry after 21 years in North-East Scotland showed that the greatest increase in carbon stocks occurred in the land that was not planted with trees but instead was left to develop an unmanaged grassland community such as that found in field margins, with the majority of this occurring in the soil rather than in the above-ground vegetation (Baddeley et al., 2017). These findings are important not only for identification of routes for increased carbon storage, but also in determining the risk of carbon loss from soil under the reverse transformation from forestry or grassland to arable. A concern is that the locations with the capability to support intensive agriculture may shift under climate change (Brown et al 2008), and changes in economics may influence land use choices with the risk that soil carbon could be lost when grassland is converted to arable.

Conversion from grassland to cropland has been identified as the largest single transition for releasing soil carbon on Scottish agricultural land. Converting cropland to forest is the most effective way of sequestering carbon, with conversion of arable to a ley (grass/legume)-arable rotation provided a gain of 1.6 tons of carbon per hectare per year. There are several practical aspects here that will limit the amount of grassland that could be converted to arable, such as slope angle, rooting depth etc.

The overall effectiveness of agricultural management on soil carbon storage depends on the interaction of management practices with soil and climatic characteristics. It is important to consider specific practices suitable for a wide range of soil types and environmental conditions that may be adopted by farmers in Scotland. In this report we present the technical/biological carbon sequestration potential but the practically feasible potential is likely to be much lower. Smith (2004), with expert knowledge estimated the realistically achievable potential to be about 20% of the biological potential. Any increase in SOC is likely to have a positive impact on soil quality, even if there is little or no impact on climate changes mitigation.

Table 1: List of practices to sequester soil organic carbon in agriculture soils (adapted from Rees. RM et al., 2017 and Smith et al., 2004)

Practice	Carbon sequestration Rates (t C ha^{-1} y^{-1})	Estimated maximum technical carbon sequestration potential in Scotland for next 20 years (Mt C) **	Confidence	Feasibility	Comment
Crop land					
Reduced tillage & no-tillage	0.0 – 0.21	0.0 – 3.7	L	M	Evidence from Scotland and elsewhere in the UK is for little or no increase in carbon storage but other benefits exist.
Increase residue return(e.g. ploughing in straw)	0.05 – 0.21	0.9 – 3.7	M	L	Crop residues have value (see 1 below).
Fertilization and Irrigation	> 0	NA	L	H	Net carbon impact of irrigation and fertilisation is minimal or negative when carbon costs of producing fertiliser and pumping irrigation water are considered (Schlesinger, 1999).
Organic manures to crops	0.5 – 0.8	8.8 – 14.1	H	H	This practice is already widely used in Scotland giving limited opportunity for further adoption. Limited manure availability at national scale might limit further expansion, GHG losses might be high, depending on application method.
Increase use of amendments e.g. urban composts	0.0 – 0.3	0 – 5.3	H	L	Such material has a value (see 2 below)
Crop rotation	> 0	NA	H	M	
Liming	Likely >0	NA	M	H	Already a part of normal production practice but GHG loses due to liming

					application are markedly different leading to potential changes in emissions between different gases making it difficult to recommend without further research
Catch crop (clover, mustard, chicory, winter radish, rye etc.,)	0.1 – 0.3	1.8 – 5.3	H	M	Economics of using crop cover may be unfavourable

Practice	Carbon sequestration Rates (t C ha^{-1} y^{-1})	Estimated maximum technical carbon sequestration potential in Scotland for next 20 years (Mt C) **	Confidence	Feasibility	Comment
Improved Grassland					
Change grazing intensity or grazing practice	0 – 0.1	0 – 2.0	M-H	M	Little impact
Increase grassland productivity	0 - >2	0 – 41.00	M	H	
Change land use (from cropping to permanent grass)	1.2 – 1.7	NA	M	L	Cropping is profitable and fits with current land-use, infrastructure and expertise. (3 below)
Other					

Convert cropland to woodland	0.6	NA	H	M	
Agroforestry	1.0 – 2.0	NA : There is a lack of quantitative information on the extent of agroforestry in Scotland	H	H	Evidance shows that all forms of agroforestry have the potential to sequester carbon although the benefits will vary depending on soil type, species, planting density and location. Maximum C-sequestration benefits on a per-hectare-basis might be achieved on the highly productive lowland areas.(Mike Perks et al., 2018; Matthew Saunders et al., 2016)
Permanent cover	0.62	NA	M	M	
Deep rooting crops	0.62	NA	M	M	These technologies are still under development and not yet available.
Perennial crops	>0	NA	M	M	
Crops with roots that are higher in lignocellulosic material.	> 0	NA	M	M	These technologies are still under development and not yet available.
Recalcitrant material (e.g. biochar, highly composted organic matter)	>0	NA	H	H	The amount of biochar that can be stored in a soils is depend on the type of biochar (concentration of material) and the depth to which it is incorporated.

1 Bailed cereal straw sells for approximately £50 per tonne. Some care is needed for this figure as “feeding straw” is VAT exempt while “bedding straw” incurs VAT. There are various transport costs. Deals are often done where the straw goes for bedding and is returned with the manure – but this requires transport distances to be reasonable. This already goes on so the opportunity to increase return is limited.

2 There is a wide range of potential materials including urban and vermicast composts, meat & bone meal, seaweed, slurry and fish waste. Farmers are reluctant to use many of these materials as quality is often uncertain and the risk of contaminants is high. Many contain plastics that are currently a major concern. Transport and application are significant costs. Costs/values will vary but these can all currently be traded. Hence little opportunity to increase use.

3 May be detrimental to food security. Cropped areas are generally drier and thus less suitable for permanent grass. Also, some industries relying on grazing are over supplied e.g. dairy and there is no scope for expansion.

NA (Not available) : if there is no estimate for carbon sequestration rate or arable/improved grassland areas for specific management practice we cannot estimate the carbon sequestration potential.

[**] We estimated maximum carbon sequestration potential by multiplying annual carbon sequestration rate with area of arable and improved grassland taken from LCS88 dataset multiplied by 20 (number of years).

Knowledge gaps – what kind of data would improve estimates of soil carbon sequestration potential?

Estimates of potential cultivated topsoil carbon loss and gain are based on existing data captured over several years or even decades (Lilly & Baggaley, 2013). Without ongoing detailed monitoring of soil carbon stocks and changes across Scotland, there is a limit to what can be extracted from existing datasets. Even the inclusion of remote sensing, which can provide information about changes to land cover (and by proxy the impacts of these changes on soil) is limited in what it can accomplish. Two (intertwining) strands of work are therefore suggested:

- improved modelling and data interpretation to make use of what we already have, and constant updating of this information through structure and planned field survey work (Buckingham et al., 2014).
- identification of biophysical and socio-economic constraints to the implementation of management options that influence soil carbon. Due to a lack of physical data from extensive surveys of the rate of change of soil carbon stocks, modelling may hold the key to assessing the effects of management at different locations.
- Development of a field-scale measuring tool

The movement of carbon compounds through the soil is partially understood and can be modelled using gaseous diffusion and hydraulic flow principles. However, the complexity and composition of soils mean the principles are difficult to apply in ways that enable us to consider both the small-scale (e.g. micrometre) processes and the large-scale (e.g. catchments) impacts of management change.

From a research perspective (rather than at a policy level), improved pore-scale modelling is vital to better understand and represent the mechanisms of carbon movement and transport through soil (Ball, 2013). To achieve this, a combination of numerical modelling and simulation of real soil environments will be necessary (e.g. Aitkenhead et al., 1999). There is a need, to accurately capture the impact of site-specific interactions between climate, soil, and management on C sequestration, which are lost in regional level assessments. There are several established soil carbon models like DNDC, ECOSSE, Roth C, DayCent et., that can be used as parts of model-based soil carbon monitoring systems. As yet the uncertainty associated with these predictions seems to be high due to lack of site-specific data. Resolving these uncertainties will require additional long-term site-specific data. With time, more data points are added to the database, so model accuracy will be improved. However, this does not preclude the development of support mechanisms to sequester additional soil carbon based on known good management practices.

Monitoring, Verification and Reporting (MVR) for Soil Carbon

Alongside the need to establish a soil carbon baseline, it is also necessary to develop a system for Monitoring, Reporting and Verification (MRV) of practices and subsequent changes in soil carbon. MRV approaches (sometimes also referred to as compliance schemes) can consist of a set of protocols (or rules or compliance requirements) to guide compliance and the processes through which to assess leves of success of incentivisation schemes. The section following this one explores options for payment mechanisms, but first we consider the issues of soil carbon MRV, as the establishment of the protocols for this may shape the form of payment mechanism.

MRV is an approach used across many sectors and can have different interpretations. Common definitions for each term are:

Monitoring: direct measurements or estimated calculations to determine how much of what is measured changes and who is participating and where.

Reporting: the means by which the results of monitoring and participation is communicated to relevant stakeholders.

Verification: procedures for checking and verifying the quality on monitoring and participation data and how it is reported. This can be internal to the MRV scheme or conducted by those external to it.

MRV schemes need to be robust, consistent, transparent and accurate. Thus MRV schemes require appropriate infrastructure (administration and data management) and trained staff to undertake implementation of protocols. With respect to linking MRV to payments, there are also requirements for procedures to justify withholding payments and handle disputed claims.Thus the existing CAP compliance process has parallels to an MRV scheme. However, in developing an MRV scheme (perhaps basing it on an existing infrastructure such as CAP) it is important to recognise the differences between things that are more easily measured e.g. confirming the type of crop in a field, and those that are less easily measured, e.g. temporal and spatial changes in soil organic carbon. We have established that measuring carbon pools in soils has constraints due to temporal variations and measuring small stock changes against a large background (e.g. Smith et al 2004b). The MRV thus has to be designed so as to allow for such difficulties.

At this point it is helpful to divide between the need to measure soil carbon changes for research and payment scheme MRV purposes. For research, e.g. to better understand the effectiveness of particular management practices, it is useful to have high spatial and temporal resolution measurements. For a payment mechanism and associated MRV scheme at the scale required however, this is not likely to be cost effective or practical. A viable solution to overcome this is to have a parallel approach of detailed research at a site-specific scale (e.g. experimental field / farm) to assess management practices, coupled with an MRV scheme that considers uptake and use of management practices by land managers. Thus it is the activity that is monitored, reported on and verified, rather than the actual soil carbon. This approach therefore matches the CAP type MRV scheme, and thus may be more viable in terms of implementation. Verification can be achieved by current field inspections and / or use of remote sensing (e.g. presence or absence of a cover crop). New opportunities have also arisen to use phone apps to assess soil organic matter, e.g. SOCiT[1], using location specific soils data and photographs of soil taken in the field.

A possible limitation is that this form of MRV has to assume that certain management practices result in positive soil carbon effects (for example see the Canadian Alberta State scheme detailed below). A soil carbon sequestration rate thus needs to be established per management activity. This raises the question as to how variable the rate is depending on soil-weather-management combinations. Thus taking this approach clearly also needs to link to the detailed research per activity to confirm likely soil carbon outcomes (e.g. Smith et al 2012).

This form of MRV scheme raises the potential to establish a minimum soil carbon change rate, based on the activity, against which a payment rate may be set. Should participants wish to seek a higher payment rate, then they could undertake detailed stratified field measurements to identify actual carbon sequestration amounts. This would further assist in establishing a long-term baseline.

MRV protocols

Any MRV scheme requires a certain level of investment to initialise and subsequently run. The scale of the MRV effort therefore needs to be commensurate with the scale of investment made in supporting the uptake and use of management practices for carbon sequestration goals. MRV protocols are normally designed to be scaled to the level of support and objectives for any payment mechanism.

There are many examples of existing MRV schemes for different purposes, e.g. forestry and deforestation (REDD[2]), emissions trading[3], energy etc. that may be adapted for soil carbon

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[1] SOCiT Soil Organic matter phone app: https://www.hutton.ac.uk/news/new-soil-carbon-app-scottish-farmers

[2] For example see: https://www.conservation.org/publications/Documents/FCMC_REDD-MRV-Manual-Summary.pdf

[3] For example see: https://ec.europa.eu/clima/policies/ets/monitoring_en

sequestration purposes. These may potentially be administered through the existing CAP support structure.

The compliance cycle determines the frequency with which MRV needs to occur. If the 'by analogy' approach of assessing use of management practices is used (as opposed to direct field measurements), then the cycle could be annually based. Verification of claims may be achieved by a combination of remote sensing and field visits.

Exploring options for payment mechanisms

There are three key types of potential mechanisms to provide financial incentives to encourage land use and management practices that work towards the realisable potential for soil carbon sequestration:

1. Adaptation of existing mechanisms for financial support, primarily the CAP, and / or:
2. Development of a voluntary 'Payment for Ecosystem Services' approach to fit alongside existing policies and support mechanisms.
3. Maintaining the current approach to soils governance (see below) but with a greater emphasis on training and knowledge exchange focussed on how best to sequester soil carbon.

The key issue centres on whether schemes to facilitate soil carbon sequestration need to be voluntary or compliance based. This is critical in respect of how best to achieve the level of participation by land managers and uptake of suitable practices that will make a sufficient contribution to overall carbon sequestration amounts. The following section provides an overview of the Payment for Ecosystem Services (PES) approach and the existing policy and support mechanisms for soil carbon sequestration.

Payment for Ecosystem Services (PES)

This approach assumes that there is a need for different land management practices to secure ecosystem services and that there will be a cost to the land manager in terms of a reduced return, which must be compensated for by payments. In the case of soil carbon, it is possible that changes in land management to sequester soil carbon may increase returns, for example due to improved primary production and / or increasing resilience to a changing climate and other drivers. Evidence suggests increasing soil carbon increases primary production, biological functions, improves aggregate stability and reduces bulk density (Diacono and Montemurro 2010).

Carbon Credits Schemes

Carbon credits traded on carbon markets are a privately funded source to support schemes for climate change mitigation. Most of the carbon credits come from offsetting schemes, where buyers such as governments, businesses or individuals can buy carbon credits to compensate for the emissions generated by their activities. However, current offsetting schemes may not be truly PES schemes on the grounds of additionality. The additionality of such schemes is more difficult to judge and depends on what reference is chosen. By definition, since the objective of offsetting is to compensate for emissions, no additional carbon is stored at the end of the process. However, when comparing the level of carbon emissions when emitters are able to compensate their emissions to what would have happened if no offsetting was possible, then offsetting does provide some additionality effect on climate change mitigation.

Carbon markets are susceptible to fluctuations in the price of carbon, thus there is volatility and uncertainty in the value of payments in the future based on sale of credits. Some high-profile emissions trading schemes (e.g. The Chicago Carbon Exchange) have ceased trading due to inactivity in the carbon markets. Verification of projects and how much carbon was sequestered was a compounding issue and one that is relevant to the consideration of schemes in the soil carbon context.

Potential for a system of payments, in the context of mitigating, and adapting to, climate change

In assessing the potential for a system of payments to facilitate soil carbon sequestration, it is important to identify the range of existing factors that influence the current state of soil carbon. These factors include:

- Existing policies, legislation and payments schemes:
- The institutional architecture affecting soils governance is complex, with a wide diversity of existing policies and legislation (McKee 2018), with no one policy designed specifically for the protection of soil (Scottish Soils Framework 2009, McKee 2018).
- There may not be conflict in policy goals at the high-level scale affecting soils, but there may be conflict or trade-offs at lower levels of governance.
- CAP Greening guidance: there are specific requirements that help protect soil carbon, albeit indirectly, i.e. the regulations require that the ratio of permanent grassland compared to the total agricultural area claimed must not decrease by more than five per cent and there are requirements for inorganic fertiliser and lime management and recording etc.
- There are no regulatory compliance requirements relating specifically to soil carbon content or to undertake specific activities to maintain or enhance it
- Statutory Management Requirements (2018) for cross compliance for the CAP Basic Payment Scheme do not specify requirements for soil carbon or soil organic matter (SOM) maintenance or enhancement.
- Good Environmental Conditions (GEAC): GEAC 4 - minimum soil cover (for erosion prevention) and GEAC 5 - minimum land management requirement reflecting site specific conditions to limit erosion, have aspects that could help maintain SOC stocks. GEAC 6 – Maintenance of soil organic matter is focussed on managing burning of moorland and stubble and ploughing of rough grazing or semi-natural areas, hence (other than stubble burning) does not relate to arable areas and a large portion of grassland in respect of maintaining or enhancing SOC.
- Economic imperatives and previous land uses: The amount of carbon in soils is partly a function of the land use history and economic decisions made by land managers.
- Land management knowledge and skill: it is generally well understood that soil organic matter has multiple benefits including improving soil fertility and water retention. However, the understanding of how best to maintain or enhance SOM (and by analogy soil carbon), is variable with land manager skill, farm and soil type and financial imperatives.

How soil carbon is referred to: An important issue is that policy documentation and guidance literature relating to soils (i.e. The Scottish Soils Framework) refers mostly to soil organic matter (SOM) and its importance as a fundamental property of soils, rather than soil organic carbon, or indeed carbon sequestration. Whilst SOM is a vital part of soil function and health and there is a relationship between the amount of SOM and soil carbon, it is important to re-emphasise the distinction between transient carbon in the soils as part of these soil functions, and that which is actually sequestered in the long-term.

Complexity of the issue: soil carbon sequestration is a complex issue and thus quantifying how much existing measures, particularly CAP, already contribute to soil carbon amounts may not be feasible. It is not specifically addressed in the current mix of policies, Statutory Management Requirements, GEAC, and General Binding Rules etc. that aim to achieve the ‘compliance’ aspect of ecosystem service delivery. Thus attributing increases or decreases of soil carbon to particular policies or practices resulting from them is at best problematic. The economic imperative and skills / knowledge (and motivations) of individual land managers and the decisions they have made on land use and management practises varies and operates within the various payment mechanisms to support agriculture and rural development. These, when combined with the diversity of Scotland's soil types and climate variability and spatial differences in land protection designation (i.e. Nitrate Vulnerable Zones, Environmentally Sensitive Grasslands etc.) results in a wide range in soil carbon amounts and a spatial distribution that is not yet fully understood. A final factor is the timescale over which it is possible to detect changes in soil carbon resulting from use of different land management practices supported by policies and payment mechanisms (i.e. CAP). It is therefore more likely that a better understanding of what works in sequestering soil carbon can be gained by considering the decisions and activities of specific land managers and their specific context.

Setting site-specific soil carbon baselines is a first step to any future monitoring programmes. Soil testing (for carbon, nutrients and pH) is a quick, straightforward and relatively low-cost exercise available to any land manager. The results can be stored in a database to create high resolution spatial data sets.

However, while measuring soil carbon concentration from field-scale samples is relatively cheap and straight forward, assessment of the results is complex; changes in the thickness of the topsoil (whether fixed or to the base of the topsoil) and in bulk density (the mass of soil per unit volume) can influence the total amount of carbon in the soil (the stock) while short-range temporal changes in carbon concentrations, spatial variability (e.g. more than one contrasting soil type in a field), adequate sample volume, when a sample is taken within a grass/arable rotation all add statistical uncertainty to the assessment of change over time. Slight variations in laboratory methods can also contribute to the uncertainty in assessing change over time, so common standards would be required for any national scheme.

In the absence of a regulatory mechanism for sequestered soil carbon (as opposed to SOM), three key questions arise:

1. Can the objectives of helping land managers achieve the realisable (achievable) potential for soil carbon sequestration be achieved by developing existing policies (in line with post CAP developments and setting regulatory compliance requirements), or;
2. Can a 'Payment for Ecosystem Services' (PES) scheme be used to facilitate changes in land management practices and land use decisions that will lead to achieving the realisable potential, or;
3. Is there a need to use both approaches?

To better address these questions it is important to understand two key elements of the definition of a PES scheme: 1) that it is voluntary, and 2) it is for actions that are above and beyond regulatory compliance requirements. The first requires sufficient up-take and participation to make a scheme effective, while the second raises the question of how we define the additionality of the scheme (the additional external benefits – see Figure 4 in Appendix 2 and therefore the basis for making payments.

Historically, a lack of routine monitoring to establish baselines and changes in environmental conditions has meant that schemes have typically been evaluated in terms of enrolment or expenditure rather than service delivery (i.e. Reed et al 2014).

Exploring existing policy mechanisms for payment for carbon sequestration:

Mechanisms for payment for carbon sequestration currently exist in several forms, examples of which are summarised in Appendix 3. The core elements of such schemes and their potential for success include

- the basis for price setting
- factors influencing participation
- the additionality in terms of benefits above regulatory compliance
- the requirements for monitoring and the length of contracts:

The primary limitation of existing policies is that they are not soil carbon specific. Where they are relevant to soil carbon, they are focussed on wider benefits (i.e. prevention of soil erosion) rather than the specific process of soil carbon addition and the practical management activities that can make this happen.

As soil is the fundamental medium from which we derive benefits from primary production, and exists across all land, there is the potential for a national coverage scheme that has the flexibility to enable site specific context variations (soil-weather-land manager preferences combinations).

SWOT analysis:

To Identify strengths and weaknesses, as well as opportunities and threats for possible interventions for additional carbon sequestration is presented in the table 2.

Table 2. SWOT analysis of possible incentives for additional soil carbon sequestration in arable land and improved grassland:

Mechanism	Strength	Weakness	Opportunity	Threat
Common Agricultural Policy (Basic Payment Scheme)	System and infrastructure already in place, national coverage. Compliance compulsory for receipt of payments, including to Greening (relevant locations).	Post Brexit uncertainty, administration costs, monitoring and evaluation. Soil carbon not currently part of compliance. Complex compliance rules.	Scotland specific post-Brexit scheme, could include soil carbon specific land management rules, baseline measurement and monitoring. High up-take as compulsory for subsidy payment.	Inadequate CAP replacement post Brexit. Insufficient funds to support measures and associated measurement and monitoring.
Greening (additional payment on top of CAP Basic)	Facilitates additional improvements to agricultural land. Applies to business level. Cross compliance requirement with GEAC.	Applies to permanent grassland, crop diversification and Ecological Focus Areas locations.	Adapt current greening practices to include a better focus on soil carbon management.	As for CAP Basic.
Agri-Environment and Climate Scheme (SRDP)	Flexible range of options for farmers to choose from. Payment compensates for loss of income	Competitive hence reducing up-take. Currently targeted areas only. Inputs based so hard to measure outcomes over short time periods.	Linking multiple environmental objectives within the same scheme. Apply nationally and increase the length of the contract beyond 5 years.	Current budget only sufficient for targeted areas, hence would need large increase to cover whole of Scotland.
Carbon Credits	Potential for win-win situation: improved soil fertility (yields ↑) and income from sale of credits	Reliant on a good price of carbon and viability of the carbon market.	Potential to underpin price of carbon to a minimum so as to achieve sufficient up-take.	Price of carbon stays low, or perceived by participants it’s likely to stay low therefore a poor investment reduces up-take.

Mechanism	Strength	Weakness	Opportunity	Threat
Payment for Ecosystem Services: Inputs based (e.g. analogous to Woodland and Peatland Codes)	Facilitates pro-active management. Can be sustained over long time period. Additional ecosystem services and biodiversity benefits.	Voluntary basis so potentially low up-take. Cost of and uncertainty in measurement and monitoring requirements. Relies on either private funds (carbon credits) or Government grants. Voluntary so potentially low up-take.	Currently oriented towards specific ecosystems (woodlands, peatlands etc.), so potential to increase range to agricultural land.	Insufficient funds to cover the scale of up-take required to achieve necessary sequestration goals. Need to identify additionality over compliance and good practice requirements.
Payment for Ecosystem Services : Outputs based	Places initial cost emphasis on land managers, reducing up-front costs for Government.	Long time required for sustained soil carbon sequestration, so results-based payment difficult to quantify. Possible limited up-take. Requires measurement and monitoring system investment.	Potential to develop long-term soil carbon gains by establishing localised (soil-weather combination) best practices over time.	Requires sufficient long-term incentives for land managers to make initial investments. Need to identify additionality over compliance and good practice requirements.
Soil Carbon specific PES (spatial targeting)	Can be variable spatially and by level of current soil carbon sequestration potential.	Needs location specific measurement, monitoring and verification.	Two parts to a scheme: incentivise land managers with low soil carbon (sequestration), and reward those with high (maintenance).	Likely to be a carbon credits-based scheme therefore vulnerable to carbon price and stability of markets.

Evaluating payments for ecosystem services used across the world:

Broadly, schemes have in the past been developed with a particular high-level objective such as biodiversity protection or water quality, instead of the fundamental ecosystem properties and process that enable ecosystems to deliver services, such as soil carbon. We identified three examples of schemes focused on soil carbon

- the Australian Soil Carbon Accreditation Scheme (ASCAS). This has had limited uptake and success, primarily due to failure of the carbon market to develop sufficiently and so gain sufficient uptake to keep momentum. ASCAS has not (as far as we can ascertain) functioned for many years now.
- In North America, soil carbon was traded through the Chicago Climate Exchange from 2005, but the CCE ceased trading in 2010. Thus from a carbon trading perspective, the long-term requirement for land management to sequester and retain soil carbon, implies the need for security in and longevity of the funding mechanism.
- In Canada the State of Alberta has a carbon credit scheme focussed on agricultural practices to reduce emissions, based on a number of protocols designed to reduce emissions. However, it includes a Conservation Cropping Protocol which specifically quantifies greenhouse gas emissions reductions from the following three activities:
- new carbon stored annually in agricultural soil;
- lower nitrous oxide emissions from soils under no till management; and
- associated emission reductions from reduced fossil fuel use from fewer passes per farm field.

It is designed to facilitate a shift from conventional to conservation farming. It uses a Performance Standard Baseline method to quantify increases in soil carbon based on 2006 Census data on rates of adoption of tillage practices or area of fallow, not individual farm baselines (e.g. not actually measuring soil carbon). The Protocol is a 106 page document detailing the establishing a baseline condition, identifying sources and sinks, quantification methods and documentation, record and evidence keeping, as well as integration with the claims to offsets.

- The protocol assumes a 20 year period for soils to reach saturation.
- It uses a soil carbon reserve discounting process to reduce risks of carbon loss from tillage etc.
- Brazil has established a Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Emission Agriculture (ABC Plan). It has an extensive range of measures that seeks to operate in multiple ecosystem types, including reducing deforestation the Amazon rainforest and efforts to cut emissions from agriculture. It is a credit initiative that provides low-interest loans to farmers who want to implement sustainable agriculture practices. These include no-till agriculture, restoring degraded pasture, planting commercial forests, biological nitrogen fixation, treatment of animal wastes and the integration of crops, livestock and forest. The goals include rehabilitating 15 million hectares of degraded pastures and increasing the area under zero tillage from 25 million hectares to 33 million hectares by 2020. Initial uptake was slow, with only 5 projects approved in the first year, representing USD 1.7 million in loans, but in 2014/2015, uptake increased significantly, with over 25,000 contracts being approved. These projects represented loans worth a total value of more than $4 billion.

However, agri-environment schemes have tended not to operate at the scales at which some ecosystem services must be managed for effective delivery e.g. carbon sequestration and water catchment management (Reed et al 2014). A benefit of the ABC approach may be that, as each contract is specific between land manager and location, the implementations of high-level specifications are adequately translated by individuals to suite their specific context. Hence land manager skill, training and best practice information dissemination become key factors in influencing success.

Putting this into a Scottish context, the salient points are:

- the need for longevity of the funding mechanism;
- the importance of enabling aims and objectives to be put into a site-specific context and how this implies the need for suitable skills sharing, training and awareness raising of best practices to meet objectives;
- making the scheme accessible and easily implemented, without excessive burden of administration and monitoring.

Evaluating non-monetary methods of incentivising land management for soil carbon sequestration

Potential exists to make greater use of knowledge exchange and outreach mechanisms to promote those management activities that are known to have likely soil carbon sequestration benefits. The challenge though is that it has been well recognised that soil organic matter (and by analogy soil carbon) has soil fertility benefits, but agronomic practises have in some cases failed to maintain appropriate SOM or carbon amounts.

One feasible opportunity is to make soil testing a requirement for new leasing contracts whereby it is stipulated that the SOC and / or carbon is measured (as currently happens with soil nutrients in some contracted cases) at the start of a contract and maintained during its lifetime. Testing for soil carbon is a quick, straightforward and relatively low-cost procedure, hence not a burden on setting up new lease contracts. The advantage of this is that the baseline is established at the start and costs of testing and monitoring can be included in the contract amount. However, this approach would only apply to arable and grasslands that operate on a leasing basis, and therefore is potentially limited in spatial extent. One more option is providing a default (initial) soil carbon baseline, on a temporary basis, by using imprecise soil carbon maps as long as uncertainties are acceptable. An improved baseline can be constructed over time using observations from field samples to supplement the carbon maps.

Conclusion

Sequestration Potential: Opportunities exist to increase carbon storage in agricultural soils by changing or refining management practices. Whilst there are opportunities to sequester soil carbon through these practices, there are also several fundamental limitations. Specifically, soil carbon accumulation is finite, as it reaches an achievable maximum. Some management practices like organic amendments and liming can aid sequestering of additional carbon but come with several limitations as stated in Table 1. When appropriate management is adopted soil organic carbon content moves towards a new equilibrium rather than increasing indefinitely. Soil within any field will be at a specific level of opportunity for additional sequestration, depending on: soil type; land use history; land manager skill, preferences and motivations. Variation in these makes attribution of increases of soil carbon to particular policies and practices highly problematic. A complete life cycle analysis would help to ensure some management practices (i.e. addition of compost) do not result in a net increase in GHG emissions. We found evidence to suggest that practices which sequester carbon might already be widely adopted in Scotland, thus the opportunity for additional adoption requires further investigation.

Observed Changes: There has been little observed change in carbon stocks for cultivated soils in Scotland in the last few decades (but the measurement methods are relatively insensitive and therefore there may be hidden changes below the detection limit). Attribution as to why there has been little change is complex due to the multiple factors influencing soil carbon stocks.

Baseline for measuring success: To support soil carbon sequestration efforts by land managers and measure long-term success of a payment mechanism, it is necessary to establish a baseline against which to monitor changes. There is a limited current state of knowledge on the baseline on how much carbon there is in soil and where it is, but this does not preclude the option to develop and implement a mechanism to support sequestration based on known good management practices.

It is feasible to undertake a combination of approaches to quantify a baseline including: field scale sampling; use of remote sensing and digital soil mapping; extrapolation from land use and management practice histories (e.g. Alberta State approach). An option is to make soil testing conditional (at the field scale) in order to receive any payment.

Such a baseline would also enable more reliable modelling to explore benefits and risks of different management practices and responses of soil carbon under climate change.

Land Manager Participation: A further requirement is in gaining sufficient up-take and long-term commitment by land managers. Conditions for compliance and payment schemes need therefore to be flexible enough to accommodate the context specific nature of achieving the realisable potential for soil carbon sequestration, backed up by best practice guidance, training and knowledge exchange.

A further issue to be addressed is in developing a mechanism that is fair across the diversity of land management histories. A balance needs to be found between not reward farmers for previously having degraded their soil (but where there is higher carbon sequestration potential), and not restricting earning potential from the mechanism by farmers who have already maintained high levels of soil carbon through good management.

References

Antle, J., S. Capalbo, S. Mooney, E.T. Elliott, and K.H. Paustian, 2002. "Sensitivity of Carbon Sequestration Costs to Soil Carbon Rates." Environmental Pollution 116: 413-422.

Aitkenhead, M.J., Aitkenhead-Peterson, J.A., McDowell, W.H., Smart, R.P., Cresser, M.S., 2007. Modelling DOC export from watersheds in Scotland using neural networks. Computers & Geosciences 33, 423-436.

Aitkenhead, M.J., Coull, M.C., 2016. Mapping soil carbon stocks across Scotland using a neural network model. Geoderma 262, 187-198.

Aitkenhead, M.J., Foster, A.R., FitzPatrick, E.A., Townend, J., 1999. Modelling water release and absorption in soils using cellular automata. Journal of Hydrology 220, 104-112.

Aitkenhead-Peterson, J.A., Smart, R.P., Aitkenhead, M.J., Cresser, M.S., McDowell, W.H., 2007. Spatial and temporal variation of dissolved organic carbon export from gauged and ungauged watersheds of Dee Valley, Scotland: effect of land cover and C:N. Water Resources Research 43, W05442, DOI:10.1029/2006WR004999.

Ball, B.C., 2013. Soil structure and greenhouse gas emissions: a synthesis of 20 years of experimentation. European Journal of Soil Science 64, 357-373.

Baddeley JA, Edwards AC and Watson CA 2017. Changes in soil C and N stocks and C:N stoichiometry 21 years after land use change on an arable mineral topsoil. Geoderma 303: 19-26.

Bellamy PH, Loveland PJ, Bradley RI, Lark RM, Kirk GJD. 2005. Carbon losses from all soils across England and Wales 1978–2003. Nature, 437, 245–248.

Brown, I., Towers, W., Rivington, M. and Black, H.I.J. (2008). The influence of climate change on agricultural land-use potential: adapting and updating a land capability system. Climate Research 37, 43-57.

Buckingham, S., Rees, R.M. & Watson, C.A. 2013. Issues and pressures facing the future of soil carbon stocks with particular emphasis on Scottish soils. Journal of Agricultural Science, Cambridge 152, 699-715.

Chapman S. J., Bell, J. S., Hudson, G..,Lilly, A.,.Nolan, G.., Robertson, A. H. J., Potts, J. M..,W. Towers, W.,2013. Comparison of soil carbon stocks in Scottish soils between 1978 and 2009, 64(4),455-465.

DEFRA (2013). Payments for Ecosystem Services: A Best Practice Guide. Ref: pb13932, 85p. Available at: https://www.gov.uk/government/publications/payments-for-ecosystem-services-pes-best-practice-guide

Diacono, M., Montemurro, F., 2010. Long-term effects of organic amendments on soil fertility. A review. Agron. Sustain. Dev. 30, 401–422. https://doi.org/10.1051/agro/2009040

Fageria, N.K., 2012. Role of Soil Organic Matter in Maintaining Sustainability of Cropping Systems. Commun. Soil Sci. Plant Anal. 43, 2063–2113. https://doi.org/10.1080/00103624.2012.697234

FORNARA, D.A., STEINBEISS, S., McNAMARA, N.P., GLEIXNER, G., OAKLEY, S., POULTON, P.R., MACDONALD, A.J., BARDGETT, R.D., 2011. Increases in soil organic carbon sequestration can reduce the global warming potential of long-term liming to permanent grassland. Glob. Chang. Biol. 17, 1925–1934. https://doi.org/10.1111/j.1365-2486.2010.02328.x

Gollany, H.T., Rickman, R.W., Liang, Y., Albrecht, S.L., Machado, S., Kang, S., 2011. Predicting Agricultural Management Influence on Long-Term Soil Organic Carbon Dynamics: Implications for Biofuel Production. Agron. J. 103, 234. https://doi.org/10.2134/agronj2010.0203s.

Holland, J.E., Bennett, A.E., Newton, A.C., White, P.J., McKenzie, B.M., George, T.S., Pakeman, R.J., Bailey, J.S., Fornara, D.A., Hayes, R.C., 2018. Liming impacts on soils, crops and biodiversity in the UK: A review. Science of The Total Environment 610–611, 316–332. https://doi.org/10.1016/j.scitotenv.2017.08.020.

HOPKINS, D.W., WAITE, I.S., McNICOL, J.W., POULTON, P.R., MACDONALD, A.J., O'DONNELL, A.G., 2009. Soil organic carbon contents in long-term experimental grassland plots in the UK (Palace Leas and Park Grass) have not changed consistently in recent decades. Glob. Chang. Biol. 15, 1739–1754. https://doi.org/10.1111/j.1365-2486.2008.01809.x

IPCC 2006. IPCC Guidelines for National Greenhouse Gas Inventories; Prepared by the National Greenhouse Gas Inventories Programme. IPCC, Japan.

IPCC 2007. Intergovernmental Panel on Climate Change, Fourth Assessment Report (AR4), Working Group 1, Chapter 2. Changes in Atmospheric Constituents and in Radiative Forcing, pp. 131–234. IPCC, Geneva.

Johnston, A.E., Poulton, P.R., Coleman, K., 2009. Chapter 1 Soil Organic Matter: Its Importance in Sustainable Agriculture and Carbon Dioxide Fluxes. Adv. Agron. 101, 1–57. https://doi.org/10.1016/S0065-2113(08)00801-8.

Keith AM, Rowe RL, Parmar K, Perks MP, Mackie E, Dondini M and McNamara NP 2015. Implications of land-use change to Short Rotation Forestry in Great Britain for soil and biomass carbon. Global Change Biology 7: 541-552.

Kuhfuss L, Rivington M. Roberts M. (2018). The 'Payment for Ecosystem Services' approach - relevance to climate change. CXC Report. https://www.climatexchange.org.uk/media/3271/payment-for-ecosystem-services.pdf

Lilly, A and Baggaley, N.J. 2013. The potential for Scottish cultivated topsoils to lose or gain soil organic carbon. Soil Use and Management, 29, 39-47.

Matthew Saunders, Mike Perks,Bill Slee,Duncan Ray,Robin Matthews (2016) Can silvo-pastoral agroforestry systems contribute to Scotland's emission reduction targets? , CxC report. (https://www.climatexchange.org.uk/media/2020/cxc-woodlands_agroforestry_policy_brief.pdf)

McKee A (2018) Soil Governance in Scotland – Mapping the Institutional Architecture. CXC Report May, 2018.

McKenzie BM, Stobart R, Brown JL, George TS, Morris N, Newton AC, Valentine TA and Hallett PD 2017. Platforms to test and demonstrate sustainable soil management: integration of major UK field experiments. pp 178. AHDB final report RD-2012-3786. https://cereals.ahdb.org.uk/media/1280245/pr574-final-project-report.pdf

McKenzie BM, Stobart R, Brown JL, George TS, Morris N, Newton AC, Valentine TA and Hallett PD 2017. Platforms to test and demonstrate sustainable soil management: integration of major UK field experiments. pp 178. AHDB final report RD-2012-3786. https://cereals.ahdb.org.uk/media/1280245/pr574-final-project-report.pdf

Mike Perks, Myroslava Khomik, Stephen Bath gate, Steve Chapman, Bill Slee, Jagadeesh Yeluripati, Deborah Roberts, James Morison (2018) Agroforestry in Scotland – potential benefits in a changing climate, CxC Report. (https://www.climatexchange.org.uk/media/3312/agroforestry-in-scotland-potential-benefits-in-a-changing-climate.pdf).

Poggio, L., Gimona, A., 2014. National scale 3D modelling of soil organic carbon stocks with uncertainty propagation — An example from Scotland. Geoderma 232–234, 284–299. https://doi.org/10.1016/J.GEODERMA.2014.05.004.

Poulton P, Johnston J, Macdonald A, White R and Powlson D 2018. Major limitations to achieving "4 per 1000" increases in soil organic carbon stock in temperate regions: Evidence from long-term experiments at Rothamsted Research, United Kingdom. Global Change Biology 24:2563-2584. Soil Governance in Scotland – Mapping the Institutional Architecture.

Powlson, D.S., Whitmore, A.P., Goulding, K.W.T., 2011. Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. European Journal of Soil Science 62, 42–55. https://doi.org/10.1111/j.1365-2389.2010.01342.x

Reed MS, Moxey A, Prager K, Hanley N, Skates J, Bonn A, Evans CD, Glenk K, Thomson K. (2014) Improving the link between payments and the provision of ecosystem services in agri-environment schemes. Ecosystem Services 9, 44-53.

Rees, R.M.; Buckingham, S.; Chapman, S.J.; Jones, S.; Lilly, A.; Mathews, R.B.; Morison, J.I.L.; Perks, M.; Vanguelova, E.I.; Yamulki, S.; Yeluripati, J. (2018) Soil carbon and land use in Scotland. Final Report to ClimateXChange, Rapid Evidence Assessment.

Reynolds, B., Chamberlain, P.M., Poskitt, J., Woods, C., Scott, W.A., Rowe, E.C., Robinson, D.A., Frogbrook, Z.L., Keith, A.M., Henrys, P.A., Black, H.I.J. and Emmett. B.A. 2013. Countryside Survey: National "Soil Change" 1978–2007 for Topsoils in Great Britain—Acidity, Carbon, and Total Nitrogen Status. Vadose Zone Journal, 12. doi:10.2136/vzj2012.0114.

The Scottish Government (2011) Definition of Land Types - https://www2.gov.scot/Topics/farmingrural/SRDP/RuralPriorities/Options/Biodiversitycroppinginbye/DefinitionsofLandTypes

Scottish Soils Framework (2009) The Scottish Soil Framework. May 2009, The Scottish Government.

Sheehy J, Regina K, Alakukku L and Six J 2015. Impact of no-till and reduced tillage on aggregation and aggregate-associated carbon in Northern European agroecosystems. Soil & Tillage Research 150: 107-113.

Smith, P., 2004a. Carbon sequestration in croplands: the potential in Europe and the global context. European Journal of Agronomy 20, 229–236. https://doi.org/10.1016/j.eja.2003.08.002.

Smith, P., 2004b. How long before a change in soil organic carbon can be detected? Glob. Chang. Biol. 10, 1878–1883. https://doi.org/10.1111/j.1365-2486.2004.00854.x

Smith.J.U, P. Gottschalk, J. Bellarby, S. Chapman, A. Lilly, W. Towers, J. Bell, K. Coleman, D.Nayak, M. Richards, J. Hillier, H. Flynn, M. Wattenbach, M. Aitkenhead, J. Yeluripati, J. Farmer, R. Milne, A. T homson, C. Evans, A. Whitmore, P. Falloon, P. Smith., 2010b Estimating changes in Scottish soil carbon stocks using ECOSSE. I. Model description and uncertainties Climate Research, 45 x, pp. 179-192

Smith, J. U., Gottschalk, P., Bellarby, J., Chapman, S., Lilly, A., Towers, W., Bell, J.S., Coleman, K. Nayak, D., Richards, M., Hillier, J., Flynn, H., Wattenbach, M., Aitkenhead, M., Yeluripurti, J., Farmer, J., Milne, R., Thomson, A., Evans, C., Whitmore, A., Falloon, P. and Smith. P. 2010b. Estimating changes in national soil carbon stocks using ECOSSE. Part II. Application. Climate Research, 45: 193–205.

Smith, P., Davies, C.A., Ogle, S., Zanchi, G., Bellarby, J., Bird, N., Boddey, R.M., McNamara, N.P., Powlson, D.S., Cowie, A., van Noordwijk, M., Davis, S.C., Richter, D.D., Kryzanowski, L., van Wijk, M.T., Stuart, J., Kirton, A., Eggar, D., Newton-Cross, G., Adhya, T.K. & Braimoh, A.K. 2012. Towards an integrated global framework to assess the impacts of land use and management change on soil carbon: current capability and future vision. Global Change Biology 18, 2089–2101. doi: 10.1111/j.1365-2486.2012.02689.x.

Smith,P. 2014. Do grasslands act as a perpetual sink for carbon? Global Change Biology, 20, 27082711.

Soil map of Scotland (partial cover): http://map.environment.gov.scot/Soil_maps/?layer=1#

Stolbovoy, V. & Montanarella, L. 2008. Application of Soil Organic Carbon Status Indicators for policy-decision making in the EU. In: Threats to soil quality in Europe. pp. 87–99. Institute for Environment and Sustainability Land Management and Natural Hazards Unit, Joint Research Centre. European Commission. EUR 23438 EN, Luxembourg.

Snyder, C.S., Bruulsema, T.W., Jensen, T.L., Fixen, P.E., 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agric. Ecosyst. Environ. 133, 247–266. https://doi.org/10.1016/J.AGEE.2009.04.021

Sun B, Hallett PD, Caul S, Daniell TJ and Hopkins DW 2011. Distribution of soil carbon and microbial biomass in arable soils under different tillage regimes. Plant and Soil 338: 17-25.

Appendix 1

Estimating soil carbon sequestration potential

In 2013, Lilly and Baggaley adapted a published method (Stolbovoy & Montanarella, 2008) to assess the potential carbon losses and potential carbon gains in Scotland's cultivated topsoils. They based the assessment on legacy data held in the Scottish Soils Database using a simple formula. They calculated an average carbon concentration, the observed maximum and minimum concentrations for individual soil types (soil series) from over 2700 measured concentrations. They assumed that the amount of additional CSP for each soil type could be estimated by calculating the difference between the average (median) and the observed maximum. The amount that could be potentially lost (Potential Carbon loss, PCL) was the difference between the average and the observed minimum (Figure 3). The original work by Lilly and Baggaley (2013) just considered cultivated topsoils and treated topsoils under improved grassland, rotational grass and arable as one dataset. For this report, this approach has been modified to separate grassland from arable topsoils as soils under arable agriculture potentially have a greater range of management options to increase carbon storage. As there is uncertainty in the database about whether a soil is continuously under arable, is part of a rotation with grass or continuously under grass (the records only show the land use at the time of sampling), it was not possible at this stage to recalculate the PCL or CSP using the soils database, however, using the information published in Smith et al (2010), the median values for each soil type used by Lilly and Baggaley (2013) were increased by 1.2% to represent grassland soils and decreased by 0.2% to represent arable soils.

The potential carbon loss or gain for each individual soil type (soil series) was firstly calculated and then by overlaying the 1:250 000 scale soil map (National soil map of Scotland; http://soils.environment.gov.scot/) with the Land Cover of Scotland 1988 map (https://www.hutton.ac.uk/learning/exploringscotland/landcover-scotland-1988) to give a combined map of soil series and land use the CSP and PCL could be calculated and mapped for all the cultivated topsoils in Scotland.

The results of the original analysis indicate that potential for Scottish soils to store additional carbon was estimated to be between 150 and 215 Mt (taking account of uncertainties in the predictions of key soil properties). The new analysis calculated median carbon stock for grassland as 172 (±8) Mt and for arable topsoils as 99 (±3) Mt. The potential additional storage capacity for grasslands (calculated as the difference between the maximum observed and the median plus 1.2% carbon) was 60 Mt (range 48-86Mt) and for soils under arable it was 88 Mt (range 78-104Mt) and based on the median minus 0.2% carbon.

Thus the calculated PCL and CSP values are different from those published in Lilly and Baggaley (2013) as the calculation was based on adjusted median values and also takes account of the area of arable and grasslands separately in the calculation, however, when combined with published sequestration rates, it provides a useful way of calculating the time needed to achieve this potential assuming changes in land management options.

Limitations of study: In this study Bulk densities were derived using a pedo-transfer function based on organic carbon content and texture classes. Again, stock of SOC are calculated using the derived bulk density from SOC. There is a degree of circularity in this methodology, whereby SOC contents are used to predict bulk densities which, in turn, are used to calculate carbon stocks.

Carbon storage potential

Carbon storage potential is calculated by subtracting the average SOC content for each Soil Typological Unit (STU) from the maximum SOC content for that STU. Please see Figure.3 for illustration of this calculation.

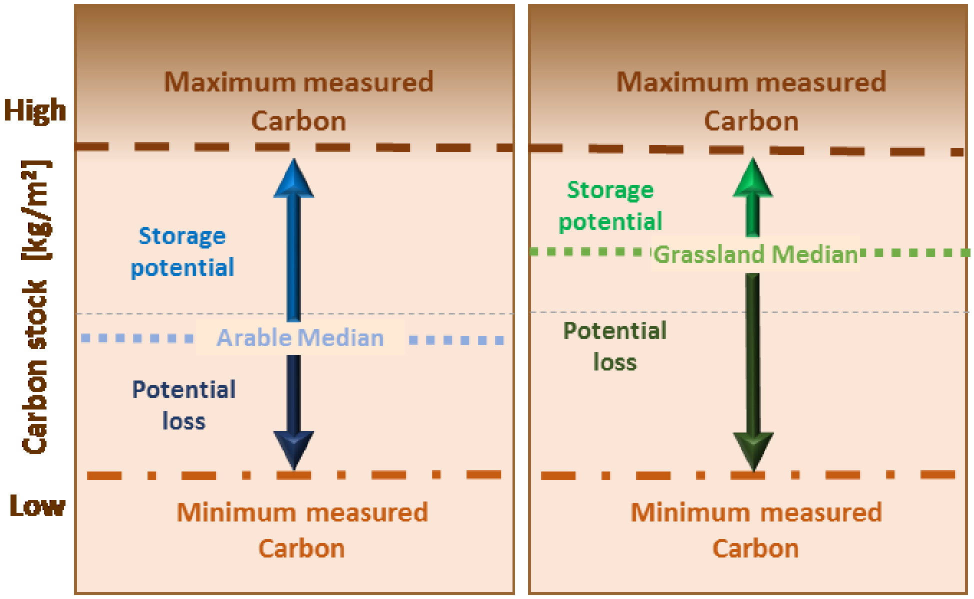

Figure 3: Schematic showing the calculation of Carbon Storage Potential (CSP) and Potential Carbon Loss (PCL) using adjusted median values for topsoils under arable cultivation and for topsoils under improved grass (Adapted from Stolbovoy & Montanarella, 2008). The grey dashed line represents the combined median for all cultivated topsoils.

Appendix 2: Payment for Ecosystem Services – the principles

The term Ecosystem Services (ES) is applied to encompass the goods and services we derive from Nature. They are commonly grouped into four categories:

- Provisioning: production of food, fibre and making available water.
- Regulating: climate control via the carbon cycle, hazard reduction.
- Supporting: water and nutrient cycles, soil formation, primary production.
- Cultural: recreational, cultural heritage and aesthetic experience benefits.

Soil carbon has a key role in all these categories due to its role in enabling soil functions.

PES schemes are examples of approaches to develop new forms of market and non-market interventions. The idea is that if some people benefit from ES, they should be willing to pay money for their provision when these are threatened or there is a wider societal benefit. In the case of soil carbon, the primary wider benefit to society is the removal of CO_2 from the atmosphere through sequestration of carbon (potentially from other organic sources) to help Regulate climate change. Additional benefits include improved soil fertility for Supporting and Provisioning services, whilst soil health underpins these and Cultural services by enabling biodiversity and resilient ecosystems.

A very broad definition of PES schemes is “any scheme or agreement where the individuals who benefit from Ecosystem Services offer a payment to land managers in exchange of the provision of these Ecosystem Services”. For further details see CXC report: The ‘Payment for Ecosystem Services’ approach - relevance to climate change (Kuhfuss, Rivington and Roberts 2018)

Key elements of a PES scheme and how they relate to soil carbon sequestration are:

- Participation is voluntary. Actions undertaken are above and beyond those needed to meet statutory and regulatory compliance.
- Success of the schemes thus depends on the level of participation and up-take and use of appropriate land management activities.
- Schemes must achieve a level of additionality, that is, benefits above what should be achieved by regulatory compliance or adherence to good practice.

Schemes can be:

- **Inputs** based (i.e. as favoured by CAP) seeking to cover the costs of activities needed to secure ES. These schemes make assumptions that actions will lead to target ES outcomes.
- **Payment by results** (outcomes) based, paying land managers on achieving objectives.

Carbon credits as part of offsetting schemes is an example.

- These schemes have the potential to allocate financial resources more efficiently, and with more flexible incentives that are more likely to facilitate innovation by landowners and managers (Reed et al 2014).

- For both these scheme types there is difficulty in measuring outcomes.
- There is a need for monitoring and measurement to evaluate success.
- The actors involved are: Providers (land managers); Buyers (financing the scheme); Beneficiaries (i.e. society). A buyer can also be a beneficiary (i.e. a contract between a land manager and Scottish Water for activities that reduce water pollution).
- The implementation of PES schemes makes sense in situations (in ideal scenarios) where the ES benefits are larger than the cost of providing these ES. Figure 4 below shows that, in these situations, implementing a PES scheme would lead to a win-win situation, where society as a whole is better off, benefiting from an increased production of public goods in the form of ES, while the land managers are (more than) compensated for the cost.

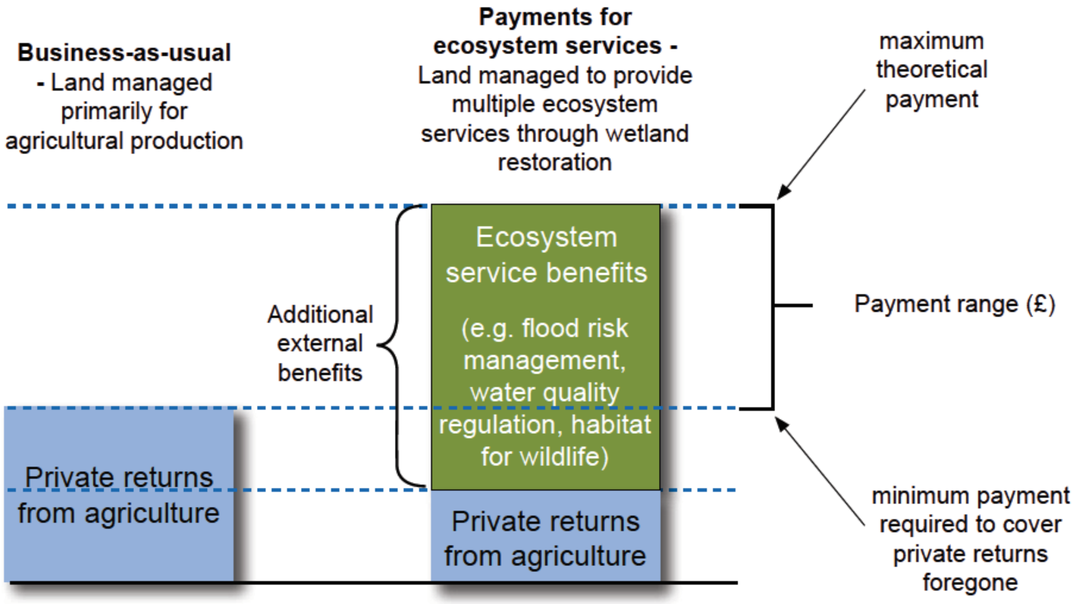

Figure 4. Example of the Payment for Ecosystem Services concept using wetland restoration (from: Defra 2013, p. 18).

Appendix 3: Existing PES schemes

Peatland Code: Inputs based scheme from sale of carbon credits from landowners to private individuals/ companies on voluntary market for restoration degraded peatlands, so not specifically aimed at soil carbon sequestration but GHG emissions reduction. UK scale, contracts 30-55 years. *Price setting:* Based on costs of restoration work. *Participation:* by self-selection, with limited up-take. *Additionality:* Payments must not cover action required by regulation, and must cover >15% of project costs. Payments must cover action which is otherwise not the most economically viable option for the land. *Monitoring:* Baseline established before the project, followed up in year 1, year 5, and every 10 years thereafter, measuring peat depth and peat health category.

Woodland Carbon Code: Inputs based to increase sequestration by coordinating sale of voluntary carbon credits between private companies and landowners for the creation of woodland. Carbon storage is the only service sold, but the scheme recognises co-benefits such as air quality, wildlife habitat, wood fuel etc. *Price setting:* Based costs of establishment and management of woodlands. *Participation:* by self-selection. Perceived as being successful c.242 projects covering 16,218 ha of woodland by June 2016, estimated 6 million tCO2 sequestered over 100 years project lifetime. UK scale, providers are locally based, not on organic soils >50cm depth. *Additionality:* Projects must not be under legal requirement to create woodland and show that without the funding woodland creation is not the most economically viable use for the land, funding must cover >15% of costs. *Monitoring:* baseline data collected from land use records and maps then after 5 years, and every 10 years thereafter. Carbon sequestered calculated directly from volume of timber.

Agri-Environment and Climate Scheme (SRDP): Competitive, input-based, offering payments to preserve and promote changes to agricultural practices that make a positive contribution to the environment and climate. It includes a wide range of options farmers can choose from to address multiple environmental challenges. A target area has been defined for each AEC option, participation selection based on assessment criteria (environmental benefit, scale, long-term benefits, feasibility and value for money). Applicant's holding must be within the target area for that option to be eligible. Covers multiple ecosystem types and ecosystem service objectives, particularly habitats and biodiversity, water quality, flood risk management. Contracts for 5 years, Scotland scale. *Price setting:* Annual payment compensates providers for all or part of additional costs and income foregone resulting from the environmentally beneficial management commitments undertaken. Payments take the format of grants and are based on nationally set standard costs. Annual budget c.£350 million for the whole 2015-2020 period, i.e. about £58 million a year. *Participation:* Low uptake estimated due to uncertainty around the long term availability of funding (Brexit), high administrative burden, and low levels of payments. Opportunity for more options focussed on practices for soil carbon sequestration. *Additionality:* that this type of scheme mainly attracts farmers who would have had environmentally-friendly land-management anyway in the absence of the scheme, leading to low additionality. This is partially addressed by competitive selection of providers and targeting. *Monitoring:* At least 5% of grant claims are inspected each year, with verification that the practices recorded and observable on site are compliant with specified requirements for the subscribed options.

Forestry Grant Scheme (SRDP): Competitive, inputs based, provides grants to land-managers for woodland creation and sustainable management of existing woodland. *Participation:* a key factor influencing decisions to establish woodlands. Applications that deliver the greatest benefits against budget priorities are selected through a scoring system. Issues arising from land tenure and tenancy as contracts up to 6 years for management options, 10 years for woodland improvement options, 20 years for woodland creation. Low uptake due to length of application process, uncertainty around the long term availability of funding (Brexit) and low economic attractiveness of forestry on agricultural land due to higher agricultural incomes and grants. *Payment setting:* Contributions to nationally set standard costs of establishment and maintenance. Higher payment rates are offered in priority target areas and priority woodland types. *Additionality:* woodland creation grants support creation of new

woodland only. Deep peat (>50cm) lands are ineligible. *Monitoring:* > 5% of grant claims are inspected each year, with verification that the area created and management of woodland is compliant.
Pumlumon Project, Wales (example of a PES scheme): An input-based ecosystem restoration initiative to achieve multiple ecosystem service benefits of biodiversity carbon and flood water storage, initiated by the Montgomeryshire Wildlife Trust (MWT). The emphasis is on farm level economic security to achieve changes in land management practices. *Price setting:* £50/ha where new scheme management practices implemented. *Participation;* survey of all farmers to determine interest. Considered as a successful scheme. *Additionality:* This scheme combines multiple objectives at different sites and is contradictory to CAP support in terms of livestock incentives. *Monitoring:* MWT acts as broker and carries out annual monitoring of maintenance of infrastructures. Contracts are 5 years initially, aiming to extend to 30. Risk of withdrawal of financial support by charitable trusts and re-direction of landfill tax. Pays farmers for maintenance, initial costs directly paid by MWT. Poor matching outcomes to payment, £50/ha regardless of action or outcome. Lack of permanence with funding only given for 5 years to maintain infrastructure

(See Kuhfuss, Rivington and Roberts 2018 for further details)