SCIENCE NOTE: SOIL CARBON

75 YEARS 1947–2022

BRITISH SOCIETY OF SOIL SCIENCE

Soils contain more carbon than the atmosphere and plants combined.

Under certain conditions, with careful management, soils can absorb more carbon and act as an important *carbon sink*. This Science Note explores the importance of carbon in soils, how it behaves, and how soil carbon might be increased to help address the climate crisis.

Key points, based on current scientific evidence:

- Modern farming has reduced the amount of carbon held in some soils. These trends can be reversed over many years by switching to sustainable soil management (or 'regenerative agricultural/agroecological') practices such as minimum tillage (including reducing the amount of ploughing which takes place) use of 'cover' crops to protect bare soils between the main commercial crops, and application of bulky organic manures/composts.
- Improving soil carbon can improve soil health, making soils more resilient to climate change. These stocks naturally reach a balance where the amount of carbon 'going in' matches those 'going out'.
- Carbon enters soils as living, dead and decaying plant, microbial and animal material. This material is broken down by microorganisms with some carbon left behind as stable organic matter. Where the rate of decomposition is greater than the rate of addition, then soils will lose carbon over time. The reverse is also true.
- To hold more carbon in the soil than would naturally be present, less degradable forms of carbon such as biochar can be added. These should not be seen as a quick fix for climate change, as they can damage soils if used inappropriately.
- Where financial incentives are developed to encourage sustainable soil management or specific carbon input practices, it is essential that funders provide ongoing support to these schemes - with periodic testing of soil carbon. It can take many years to increase soil carbon, and although modelling can be used to estimate future carbon stocks in specific soils, this must be checked through localised testing over the long-term.
- It is also vital to protect the existing carbon stores in well-functioning permanent grasslands, moorlands, wetlands and woodlands by preventing ploughing/ cultivation or other carbon emitting land use change in these habitats.
- Sequestering carbon in soils and vegetation (by adding more carbon than is lost), is important for long term soil resilience and health, but becomes irrelevant as a response to climate change if governments do not also transition to eliminating the burning of fossil fuels.

Forms of soil carbon, and why it is important

Although the relative amounts vary over the range of different soil types, carbon is found in two main forms in soils:

- **Soil organic carbon (SOC)** made up of living and dead components of organisms, including fine plant roots, fungi, microbes and decomposing plants and animal residues, composed of about 60% of the total carbon in UK soils.
- **Soil inorganic carbon (SIC)** made up of minerals such as chalk. SIC is generally more stable than SOC, making up about 40% of total carbon in UK soil.

Within soil ecosystems there is a constant exchange of carbon between SOC and the atmosphere, and these interactions and transformations are part of the natural carbon cycle. SIC contents also vary but are much less relevant to the soil carbon cycle, and the focus of sustainable soil management is to maintain or increase SOC levels. These vary enormously (e.g. between soils under woodland or cultivated farmland and between peat soils or sandy mineral soils) but are typically <5% in most UK arable soils.

SOC has a profound influence on soil properties and functions. In general, a soil with a greater SOC content has a more stable structure, can absorb/retain more water, is less prone to erosion, has greater biological activity and better nutrient supply characteristics, when compared to the same soil with a smaller SOC content.

The potential for long-term storage of carbon in soils ('sequestration')

The largest stocks of soil carbon are found in peaty non-agricultural soils such as semi-natural grasslands, moorlands, peat bogs, woodlands and wetlands - as well as uncultivated permanent pastures. **It is important to protect these stores.** Significant long-term land use change such as conversion of cropped land to grass or woodland (on the right soils) has by far the biggest impact on SOC but is unrealistic as an option due to the continued need for these soils to produce food crops.

Common agricultural practices have meant that ploughed soils have lost some of the SOC that would have been present in the original uncultivated soil. SOC levels in these soils can be increased by either increasing inputs (e.g. from crop residues or use of cover crops and organic materials such as compost/animal manure) or decreasing outputs (e.g. by reducing tillage – the amount of ploughing undertaken). However, to be effective, these changes need to be continually sustained.

Changes in SOC are generally slow to occur and difficult to measure accurately. Positive changes in soil management, or 'regenerative agricultural/agroecological' practices, can cause SOC to increase over a period of decades until a new balance between carbon additions and carbon losses is achieved.

This balance will vary according to land use, soil type, soil management and climate. However, the quantity of carbon that can be stored in any soil is limited. This means that relatively large annual rates of carbon accumulation in the early years of sustainable management cannot be maintained indefinitely and rates will eventually reach zero as carbon losses match carbon inputs, keeping the carbon balance at its new (higher) level.

Carbon sequestration is also reversible and can have unintended consequences as, for example, long-term application of organic matter can lead to excess nutrient supply and damage the quality of rivers, lakes and coastal waters. Land use changes, such as creating new wetlands and woodlands, may also result in deforestation and cultivation elsewhere to grow the food that is not produced in land set aside for the carbon sequestration project i.e. 'displacement'. Furthermore, soil carbon increases cannot provide the single answer to climate change mitigation.

Soil carbon sequestration offers a useful tool in global efforts to tackle greenhouse gas (GHG) emissions, but the slow rate of change, the ease of reversibility in any soil carbon gains and the relatively small amounts that can be sequestered present significant challenges. It has been estimated that implementation of even the most extreme land use changes would only account for 2-3% of current (2019) UK GHG emissions.

A focus on soil carbon should not be seen as a 'quick fix' for climate change. However, maintaining or enhancing SOC levels can deliver a range of benefits for soil quality and functioning which can make soils more resilient to the impacts of climate change, such as the ability to cope with droughts and floods.

Despite limitations, the potential to store additional carbon in agricultural soils is leading to the development of schemes to pay farmers to adopt sustainable soil management practices. Soil-focussed schemes do not yet exist in the UK, but equivalents have been running in Australia and Canada for a number of years and the European Commission's Carbon Farming Initiative is due in 2021. Differences in the way protocols and carbon markets estimate sequestration make it difficult to be confident that climate benefits have actually been achieved and the costs associated with direct measurement of soil carbon make it impractical as a long-term monitoring option, leading to the widespread use of 'virtual models' in carbon schemes, rather than analysis of particular initiatives. It is essential that the validity of those models is checked through periodic field sampling and testing to confirm that soil carbon gains are genuine.

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Conclusions and Recommendations

Climate change is among the greatest challenges facing humanity and efforts are underway globally to reduce GHG emissions and capture those that continue to be emitted.

The counterbalancing need to remove carbon from the atmosphere and to reverse long term declines by adding carbon to soils, presents an obvious convergence of interests.

Soils are a significant reservoir of carbon, but land use changes over centuries have resulted in a proportion of this being lost from many soils. Although present in both organic and inorganic forms, it is SOC and more specifically soil organic matter that is critical to the functioning and resilience of soils in countries such as the UK. Addressing historic carbon losses provides clear potential for improving soil quality and for future carbon sequestration in soils.

In the UK context, it is essential that historic SOC declines are addressed if soils are to function effectively now and into the future; improving their resilience to climate change. However, this essential requirement creates significant potential for abuse at a time when governments, corporations and individuals are increasingly keen to offset their carbon emissions through sequestration initiatives.

Although this Science Note is based on a UK perspective, we recognise that the same issues apply internationally and there is a need for action on a global scale.

A fully referenced, technical version of this note is available at www.soils.org.uk.

We recommend:

- Farmers (and others holding large areas of land) are encouraged and rewarded for implementing sustainable soil management, or ‘regenerative farming’ practices.
- Local communities and individuals should be encouraged to follow similar practices on a smaller scale: planting cover crops, composting and using ‘reduced dig’ gardening methods.
- That soil carbon is not seen as a single solution to climate change mitigation. Its impacts will be meaningless unless accompanied by other initiatives such as the reduction in use of fossil fuels.
- Using sustainable soil management techniques to increase SOC levels can take decades, and those gains can be rapidly reversed. SOC increases will eventually reach new balances that can only be maintained by continuation of favourable management practices.
- That where there are initiatives to boost natural soil carbon stores through the use of materials such as basalt or carbonised biomass (e.g. biochar), the whole life cycle carbon costs of such techniques be carefully examined before any genuine sequestration benefit can be claimed. The source and chemical characteristics of biochars and rock dusts can be problematic from both regulatory and environmental perspectives, and users must be mindful of this.