Farm Carbon Cutting Toolkit

Soil Management to minimise Greenhouse Gas Emissions

Soil underpins the entire farm system. A healthy well-managed soil will support productive and healthy crops and pasture, which in turn supports a profitable and resilient farming system. A soil that accumulates organic matter will sequester carbon, be productive and increase productivity - a win, win, win situation.

Emissions from soil

Understanding scale and processes affecting greenhouse gas emissions from different soils and different soil practices is important to get a sense of the importance of soil.
Soils, like the oceans and the atmosphere are fundamentally important in relation to the planetary cycling of carbon and nitrogen, and therefore the release and uptake of greenhouse gasses (GHGs).
The continual flux of carbon and nitrogen and the different forms that these elements exist in underpins the dynamics of climate change. Understanding how the management of the soils that we farm fits in with these cycles enables us to make informed choices about the effect of our farming systems on our soils and the effect those practices can have on GHG emissions from our farm.
It is helpful to have a basic understanding of both the carbon and the nitrogen cycles to get a grasp of what's going on in the soil.
Emissions from soil is a complex issue; as such we have broken it down into the following areas. Use the top menu or the links below to navigate through the topics and find out how to manage soil to minimise emissions.

Soil Carbon Emissions

The Carbon Cycle

Over 99.9% of all of the earth's carbon is stored and fixed in the earth's crust - the lithosphere. This is around 60 – 100 million billion, or gigatonnes (Gt) with just under 0.01% of that stored as fossil fuels (5 - 10,000 Gt). All this carbon is fixed and does not participate in the earth's carbon cycle, until we bring fossil fuels into use and burn them when the carbon is then released as CO_2.
The next largest carbon store is in the oceans, mainly as dissolved CO2 but also as shells coral and other elements (38,000 – 40,000 Gt).

And the next largest carbon store is in the soil at 1,500 – 1,800 Gt stored as soil carbon. This soil carbon could have been added as a result of this year's cropping or could be a lignified residue from plant growth thousands of years ago that is resistant to microbial decomposition. The soil carbon is stored as organic compounds in the soil organic matter which is divided into three 'pools'.
Approximately 2/3 of all soil organic matter (SOM) is 'stable' and extremely resistant to decomposition and can remain unchanged for hundreds or even thousands of years; it is sometimes referred to as 'humus.' This stable pool is important for soil physical processes, particularly aggregate formation and it also influences the soil cation exchange capacities (the ability of soils to hold onto positively charged plant nutrients).

The remaining third is divided into the 'slow cycling' and 'active' soil pools, with a constant flux from one pool to the other.
The 'slow cycling' portion of SOM makes up just over half and is important for the release of nitrogen and phosphorus from the soil for crop growth. It is slowly broken down by biological and mechanical activity and has a turnover time of years to decades.
The rest of the SOM is 'active', and primarily made up of recently added plant residues in the early stages of decomposition and soil micro-organisms.
This active pool of soil carbon is important for nutrient release and GHG emissions, and it will have a turnover time of months to years.
The other carbon stores are the atmosphere (800 – 1,000 Gt, and increasing by 6Gt a year as a result of burning fossil fuels) and the biosphere; all living organisms on the earth (around 540 – 610 Gt).

Soil Carbon emissions

Soils emit greenhouse gasses as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4)
The largest emissions from soils are as CO_2 as a result of respiration by soil micro-organisms from the decomposition of the active SOM pool.
This active SOM pool has carbon constantly being added to by plants from their residues, roots and exudates, as these plants take CO_2 from the atmosphere to produce simple carbohydrates and all other organic compounds that enable them to grow. The additions and losses of carbon are relatively equal in a steady state system with a (very) gradual increase in SOM.
Agriculture and forestry influence the rates of carbon addition and losses to the SOM.
The most significant effect is from mechanical cultivation of soils. By cultivating soils the disturbance allows for greater oxidation of the slow SOM by soil micro-organisms with a consequent release of CO_2.
Soils contain between 30 – 90t carbon/ha at 30cm depth.
Depending on the a number of factors, primarily preceding cropping, soil type, intensity of the cultivation and moisture content, cultivated soils can lose 3t of soil carbon/ha/year.

The highest losses of SOM occur in the first year of ploughing out a permanent pasture and if cultivation continues over the next 25 years and can result in 25 – 40% of the original soil carbon being lost depending on the soil type.
Soil surveys in the England and Wales from 1978 – 2003 estimated that soil organic carbon decreased over that time by 0.6% /year, which would equate to a loss of 4.4 million t C/yr. Where SOM levels were higher than average, the rate of loss of soil carbon was also greater, as much as 2% per year.

Arable farming techniques for building carbon
Where land is under continual cultivation, as is much of UK arable land, reducing the frequency, depth and intensity of cultivations will reduce this soil carbon loss.
Changing your crop establishment system to reduce the frequency and intensity of cultivations will provide an immediate reduction in farm GHG emissions.
Techniques for arable cropping with no cultivations are being practised on a few farms in the UK but there is very little data yet to assess what is happening to the SOM under these systems.
Changes in land use (grassland to cropping, cropping to forestry etc.) has a significant global impact on GHG emissions but the UK has been a net 'sink' for carbon over the last few years.
Peat soils and soils with very high levels of SOM (>10% SOM) pose additional GHG challenges. Because of the very high levels of SOM, if these soils are cultivated (or drained) the resulting GHG emission can be 4x higher than the same action on an 'average' 5% SOM soil

Grassland Farming techniques for building carbon
See the FCCT Case Studies section for examples such as at Woodland Valley Farm.
Techniques include optimising stocking rates, appropriate sward species and root depth, and adopting permanent pasture.

Nitrogen Emissions

The Nitrogen Cycle

As in the carbon cycle, in the nitrogen (N) cycle the vast majority, 98% of the earth's nitrogen, is locked away in the lithosphere, 2% is in the atmosphere (the air we breathe is 78% N gas) and only 0.2% in the soil. It is this 0.2% that is the primary driver of the biochemical nitrogen cycle, and it is the movements of nitrogen in the soil that can give rise to N_2O emissions.
Emissions from UK soils as N_2O are less significant than CO_2, despite N_2O being 300x more powerful a GHG than CO_2.
N_2O emissions can be seen as a tiny (though significant, both as a GHG and as part of the biological processes that enable soil microbes to flourish) part of the nitrogen cycle and come about as a result of the action of denitrifying bacteria.
The soil nitrogen is present either as inorganic nitrogen (available for plant uptake) or organically bound nitrogen in the soil organic matter. In general over 90% of all soil nitrogen is in organically bound in the SOM. The majority is in the 'active' and 'stable' pools, and is

mineralised into inorganic nitrogen and made available for plant uptake, or loss from the soil, by the action of soil micro-organisms oxidising the SOM.
The process by which inorganic N is converted to N_2O is called denitrification and is carried out by a number of different bacteria. Denitrification can result in the release of nitrogen gas (N_2) as well as N_2O and as these are biological processes the rate at which this occurs is dependent on a number of factors.
The most significant factor in the production of N_2O is the availability of nitrate (NO_3) for the denitrifying bacteria to reduce. Plants take up N from the soil as ammonium, nitrites or nitrates, with the majority as nitrate. NO_3 is mineralised from the soil organic matter and is also added to soil as ammonium nitrate fertilizer. Some of the NO_2 will be rapidly taken up by plant growth, some will be immobilised into the SOM, some may be leached out of the soil and some is likely to be denitrified. If there is too much NO_3 for the plants to take up it is liable to denitrification and leaching.

Minimising emissions
Timing of fertilizer applications and quantities applied in relation to plant growth in the next 10 days and 'surplus' NO_3 in the soil is the major factor influencing N_2O emissions. **Ensuring that only appropriate amounts of fertilizer are applied as the crop is growing is essential** to reducing soil GHG emissions, minimising N_2O emissions from soil
The vast majority of denitrifying bacteria require relatively anaerobic conditions. Soils need to have a field capacity of over 60% for dentrification to occur and so improving soil structure and adequate drainage can be significant factors in reducing N_2O emissions.
Temperature, available carbon and pH are also important variables – the denitrifying bacteria will be most active in warmer soil conditions with higher SOM (and available soil carbon and energy) and with a pH of 7.0 – 8.0.

Methane emissions

Methane (CH_4) is not a significant GHG for UK agricultural soils, where the UK is more of a sink due to the action of soil bacteria converting the methane into more complex soil carbohydrates. Deciduous woodland with a relatively high pH soils has been shown to have the highest rates of methane uptake in the UK.
Soils which have had regular fertilizer additions or have high ammonium content have been shown to have much smaller populations of methanotrophic bacteria (those bacterial populations that remove methane) and are therefore not very effective methane sinks; while soils which have organic manures added to them have been shown to have higher than average populations of methanotrophic bacterial populations.
The main source of methane is from livestock – see the Livestock & Dairy section of the Toolkit for more information on reducing these emissions.

Farm Carbon Cutting Toolkit

Carbon sequestration

The science behind sequestration

Unlike any other industry except forestry, farming has the potential to sequester (absorb) carbon dioxide out of the atmosphere on a large scale. Plants and soils on farms have the potential to sequester vast amounts of carbon, giving farming the potential to be at the forefront of the fight against climate change.

Much of the biomass that commonly occurs on UK farms such as hedges, woodland and permanent pasture is already sequestering carbon at very significant levels. But with some careful management decisions this can be improved to maximise the rate at which carbon sequestration occurs. Furthermore, more biomass usually equates to better habitat for wildlife, particularly insects and birds.

Soil is the farmers' most important asset in so many ways. A soil that is continually gaining in organic matter, which is certainly possible, is a rich, healthy and resilient soil. Increases in organic matter lead to increased soil fertility, improved structure, healthier crops and carbon sequestration.

When plants photosynthesise they absorb carbon dioxide (CO_2). This CO_2 is turned in to sugars and then more stable compounds. In woody plants like trees this becomes lignin (wood), and suddenly the CO_2 that was once in the atmosphere has become a very stable form of elemental carbon.

Some of the plant's carbon compounds are also exudated (transferred) into the soil via the roots. Here the carbon compounds become organic matter and build soil organic matter, another very stable form of carbon.

Soils contain organic matter that is created from organic matter from animals, insects, plants and fungi. This organic matter is then decomposed by the vast array of micro-organisms in the soil ecosystem. About half of all organic matter is carbon, and in this form the carbon is very stable and can only turn back to CO_2 readily if significant oxidation occurs, such as cultivation.

Eventually soil organic matter turns in to the even more stable form of humus, a highly complex, fertile and stable substance that should be prized by every farmer.

Click on the pictures below to find some practical tips for managing on-farm resources to increase sequestration potential.

Managing soils for sequestration

Improving soils by building soil organic matter is a win, win situation for every farmer and grower.

Good soil management is central to sustainable farming everywhere. Healthy soils are any nation's greatest asset and, if well managed, can go on producing food, fibre and fuel for generation after generation. However much UK farmland is badly degraded, following farming practices that have not looked after the soil, effectively raiding the 'soil capital bank'.

Fortunately soils have an extraordinary capacity to regenerate quickly and become productive and stable again.

Healthy soils have numerous benefits for the farmer and society:

- Stable and resilient
- Resistant to erosion
- Easily workable in cultivated systems
- Good habitat for soil micro-organisms
- Fertile and good structure
- Large carbon sinks

Cultivation is bad for soil structure as it oxidises carbon, which is then released to the atmosphere. Minimise cultivation frequency and depth, also making sure soil is not too wet when cultivated

- Perennial crops (including grasses) are good for soil because they allow organic matter to build
- Diverse cropping systems (cultivated and grassland) are better for soil than monocultures
- Minimise machinery operations; compaction can be very bad for soils
- Build soil organic matter as much and as frequently as possible!

Soil Organic matter

Soil organic matter can be built with permanent pasture (preferably of mixed species), green manures, and additions of manures, composts and other sources of organic matter.
As micro-organisms build in healthy soils, their ability to decompose organic matter and create humus increases over time. Its ability to absorb organic matter also increases. Whilst degraded soils that become well managed will grow at the fastest rates, all soils can continue to build organic matter. Building soil organic matter is a holy grail for the farmer or grower and is also a win, win situation:

- Healthy soils produce healthy crops
- Crops growing in healthy soils give higher yields and higher profits
- Soils high in organic matter are resilient, stable and have good structure
- Carbon sequestration rates can be huge

Every hectare of land that raises its soil organic matter levels by just 0.1% (e.g. 4.2% to 4.3%) will sequester **8.9 tonnes of CO_2 per year.** This is an extraordinary figure, but in practice that is not just possible but being exceeded by farmers and growers building healthy soils.

Sequestration in farm biomass

All farms have biomass of some sort that is already sequestering carbon. By managing these assets well and increasing further the quality and quantity of permanent biomass the potential to sequester carbon and create wildlife habitat increases.

Hedges
Britain's landscape is full of hedges, but they can take many different forms. The higher and wider the hedge the more carbon it will sequester.
But also consider the frequency at which they are encouraged to throw out fresh growth. Traditional laying created hedges, in rotation, that grew vigorously, were stockproof and absorbed a lot of carbon. This can be replicated to an extent by well-planned mechanical management.

Woodland
Trees have an astonishing capacity to absorb carbon. Recent research has shown that all species absorb CO_2 right from planting into old age (200 years plus). However the peak period for sequestration is in a tree's teenage years! Depending on the species this ranges from years 10 to 45 after planting, where sequestration rates are in excess of 12 tonnes of CO_2 per hectare per year.
If your farm has a policy of continual tree planting you will ensure that there are always trees in the age-classes that maximise sequestration. Of course it also means you will always have a ready supply of timber!

Orchards
Traditional orchards are Britain's ancient form of agroforestry, with ancient trees providing fruit and wildlife habitat, whilst underneath the trees permanent pasture provides grazing for livestock. Carbon is absorbed in the wood of the trees and the grassland builds organic matter in the soil.
Modern bush orchards may not have the capacity for livestock grazing, but if well managed can still provide significant carbon benefits as well as high fruit and/or nut yields. It's their perennial nature which makes orchards so important in carbon terms. Orchards, whether bush or traditional, are important carbon sinks that, unlike woodland and hedges, also provide food for humans.

Field margins
Any grassland that is not cultivated is an important carbon asset, for organic matter can build and is not lost when cultivated. All fields have margins that are carbon sinks. Whilst there is always a trade-off between margin area and annual crops in a cultivated field, it's worth considering that margins have greater value than just being able to turn a tractor around on.
There are many novel ways to integrate perennial crops with annual crops, such as agroforestry. Forest gardens are a way of essentially creating woodland that is entirely edible and useful to humans as well as wildlife.

Coppice woodland offers potential for huge sequestration rates, meaning less land has to be given over to trees for the same carbon benefit. Coppice typically has a range of useful wood products following cutting, such as stakes, poles, weaving material and fuel. Any perennial crops are worth considering for carbon and other benefits, whether for biofuel like *Miscanthus* or even soft fruit like blackcurrants.