Navigating greenhouse gases

The Scottish Government's Strategic Research Programme (SRP) for environment, land, agriculture, food and rural communities 2016-2022 is delivered by the Scottish Environment, Food and Agriculture Research Institutes (SEFARI). The SRP is the mid-to-long term research component of the Scottish Government's Strategic Portfolio. In addition to the SRP, this includes the underpinning of SEFARI national capability resources and, in partnership between SEFARI, Scottish Universities and Agencies, the policy-facing Centres of Expertise. SEFARI Gateway is the Knowledge Exchange (KE) and Innovation Centre for the Strategic Portfolio. The Gateway enhances access to the individual and interdisciplinary expertise and innovation within this Strategic Research Portfolio, strengthening and building new partnerships with policy, agencies, sector organizations and across civic society.

This booklet represents the collated outputs from a SEFARI Gateway-funded Fellowship, undertaken by Dr Gemma Miller, Scotland's Rural College (SRUC) with the National Farmers Union Scotland (NFUS). The SEFARI Gateway Fellowships embed a researcher or team of Portfolio-funded researchers with a policy team, agency or sector organisation, with a key focus on working in partnership to deliver to Scotland's National Outcomes and Sustainable Development Goals. This Fellowship sought to clarify the impact of Scottish agriculture on the climate and wider environment, and covered, through a series of fact sheets, infographics and discursive online blogs.

NFUS President, Martin Kennedy and his team in responding to the Fellowship's work noted:

> *Although, as yet, the science is not 100% definitive, using the most up-to-date data* available at the moment has allowed us to set a baseline to work from. This not only highlights where Scottish agriculture is currently, but means we are supported by robust scientific evidence to move the industry forward in a positive manner. We will continue to engage with the climate change debate, and support future climate change action.'*

https://www.nfus.org.uk/news/blog/vice-presidents-blog-15-june-2020

*Data were accurate at the time of writing(Mar 2022), but certain key metrics may have been updated in GHG inventories published since

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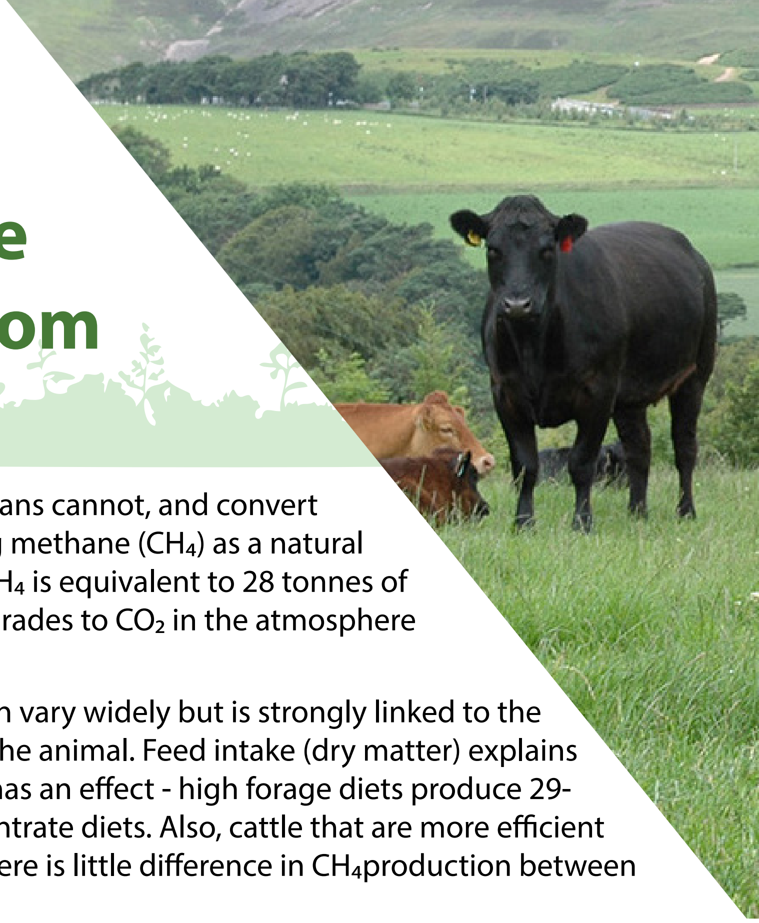
How can Scottish beef producers reduce methane emissions from their cattle?



Ruminants have the ability to digest forages that humans cannot, and convert them into protein for human consumption, producing methane (CH_4) as a natural by-product. CH_4 is a greenhouse gas and 1 tonne of CH_4 is equivalent to 28 tonnes of carbon dioxide (CO_2). CH_4 (half-life ~12 years) also degrades to CO_2 in the atmosphere (half-life 50-200 years).

The volume of CH_4 produced by individual animals can vary widely but is strongly linked to the level of feed intake and feed conversion efficiency of the animal. Feed intake (dry matter) explains most of the variation in CH_4 production but diet also has an effect - high forage diets produce 29-35% more CH_4 / kg dry matter intake than high concentrate diets. Also, cattle that are more efficient produce less CH_4 per kg of milk or live weight gain. There is little difference in CH_4production between breeds.

There are several ways that beef producers can reduce CH_4 emissions from cattle.

Genetics: Around 25% of the variability in cattle CH_4 production can be explained by genetics. Sires with low CH_4 production tend to produce low CH_4-emitting offspring. It is also important to ensure that breeding for reduced CH_4 doesn't impact on production, e.g. by reducing the animal's ability to digest fibre.

Feed additives: Feed additives either alter the chemical pathways in the rumen, suppress digestion or suppress rumen microbes. There are three feed additives for which solid evidence of CH_4 reduction has been identified to date. Other additives have insufficient supporting evidence or variable results

Can technology play a role in methane reduction in the future?

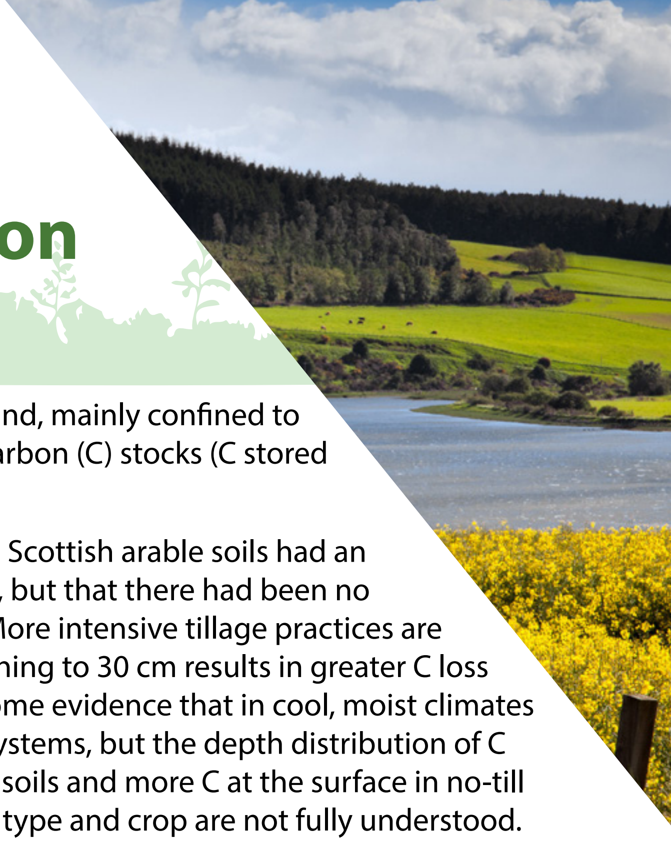
Efficient finishing: Up to half of a beef animal's lifetime CH_4 is produced during the finishing period. In 2019, 43% of cattle did not meet target grades at the abattoir. Automatic weighing platforms and advanced camera technology may help ensure cattle are slaughtered at the optimal time and so help reduce the carbon cost per unit product produced.

Emissions scrubbing: New technologies in development may be able to capture CH_4 emitted by individual cattle and convert it directly to CO_2, or from groups of cattle in sheds and use it for power generation.

Animal Health: Poor health status can impact on an animal's lifetime productivity and efficiency. Technologies that alert stockmen to potential disease early (before clinical signs are visible) and development of rapid pen-side diagnostic tests could prompt more timely interventions. These advances, coupled with the development of vaccines to protect animals and sustainable disease control strategies, will help reduce emissions through improved health and efficiency.

Strategy	Mitigation Potential	Limitations
Dietary lipid (oils & fats)	8-14%	May affect animal performance if above 70 g/kg feed. Expensive.
3-nitro oxypropanol	13-29%	No limitations identified to date, but not approved for commercial use yet.
Nitrate	18-23%	Risk of toxicity - NOT recommended unless slow release technology is developed

What are the impacts of Scottish arable production on climate change?



In 2018, there were 574,000 ha in arable production in Scotland, mainly confined to the East coast. Arable systems have an impact on both soil carbon (C) stocks (C stored in the soil) and greenhouse gas (GHG) emissions.

Soil C: The National Soil Inventory for Scotland showed that Scottish arable soils had an average C content of 1.2% (half that of improved grasslands), but that there had been no significant change in arable soil C between 1978 and 2009. More intensive tillage practices are conventionally thought to lead to more soil C loss e.g. ploughing to 30 cm results in greater C loss than ploughing to 7cm or direct drilling. However, there is some evidence that in cool, moist climates there is no difference in soil C stocks under different tillage systems, but the depth distribution of C in the soil will be different (e.g. more C at depth in ploughed soils and more C at the surface in no-till systems). The interactions between soil C, tillage system, soil type and crop are not fully understood.

Greenhouse Gas Emissions from arable soils are extremely variable even within one field and depend on weather conditions, soil type, soil compaction and distribution of crop residues. This means that measuring GHG emissions accurately is very difficult. Soil disturbance during ploughing causes a peak in CO_2 emissions in the short term. Deep ploughed soils produce more N_2O than minimum or no-till systems due to the disrupted structure of ploughed soil.

The impact of organic and inorganic fertilisers on nitrous oxide (N_2O) emissions is described here.

Including N-fixing legume crops (such as peas, beans or clover leys) in arable rotations will reduce the need to use inorganic fertiliser. Legumes do not require any fertiliser input and the residues may provide N for the following crop. Modelled potential benefits of including legumes in arable rotations in East Scotland found an 11% reduction in N_2O emissions and a 19% reduction in N fertiliser requirements, and an on-the-ground trial with faba beans found that they can fix over 300 kg N ha^{-1} , with up to 100 kg N ha^{-1} available in residues for the following crop.

Legume crops only make up a small proportion of arable production in Scotland, and barriers to uptake include variable yields between years and a lack of processing facilities. There is potential for further legumes to be grown in Scotland, but the possible GHG abatement that could be achieved with wider uptake is currently unknown.

Challenges and Opportunities from Climate Change

Climate change will have both positive and negative impacts on the suitability and productivity of crops in Scotland.

Challenges: Warmer and wetter winters may see some pests and diseases spread further North and West and become more prevalent. For instance, potato blight and phoma stem canker in oilseed rape are both predicted to become more widespread in Scotland. The risk of drought in summer will rise, which will increase the need for irrigation and restrict growth of some crops. Heavy rainfall and flooding will also become more common, causing delays to harvest and reduced yields.

Opportunities: The range of some crop diseases may decline allowing expansion of the crop13 in Scotland. The yield of certain crops may also increase, for example, it has been predicted that oilseed rape yields in Scotland may increase by 0.5 t ha^{-1}.

Climate change: could also result in the expansion of land suitable for cultivation on the East coast and Southern Scotland.

What are the climate impacts of forestry on shallow peat soils?

Tree planting is a climate change mitigation strategy which has received a great deal of attention, with various political parties pledging to increase tree planting rates across the UK. The Committee on Climate Change recommend a minimum tree planting rate of 15000 ha per year by the mid-2020s if Scotland is to achieve net-zero emissions by 2045. To achieve this ambition, substantial areas of new woodland will need to be created both on improved and upland rough grazing, and productive agricultural land (e.g. riparian planting, shelterbelts, agroforestry).

Approximately two-thirds of Scotland is covered by high carbon (C) content soils with varying depths of peat (organic layer). Afforestation (tree planting) should be avoided on deep peat (>50 cm deep organic layer) because it leads to significant losses of soil C. However, afforestation on other soils can lead to net carbon sequestration and is common on shallow peat (organic layer < 50 cm deep). There are three phases of forestry that can affect the greenhouse gas (GHG) balance and C sequestration: tree planting, tree growth and tree harvesting. There are few studies in Scotland, the UK, or globally that take full account of the GHG balance and changes in C stocks (C stored in the soil, litter and trees) from forestry on shallow peat soils.

Planting: Tree establishment on shallow peat soils requires cultivation and drainage to improve survival and growth . Soil disturbance will lead to losses of soil C. The amount lost will depend on the level of disturbance, e.g. shallow ploughing will result in more C loss (~83% soil disturbance) than excavator mounding (~12% soil disturbance). Soil C loss will also be greater the deeper the peat layer is. Drainage may lead to increased C loss due to leaching and organic matter decomposition, although there is some evidence that a fraction of this C can be sequestered in clay soils underlying peat. Drainage will lead to a short-term increase in nitrous oxide (N_2O) emissions but will also reduce methane (CH_4) emissions as the water table lowers. However, the loss of soil C overshadows any changes in N_2O and CH_4 emissions.

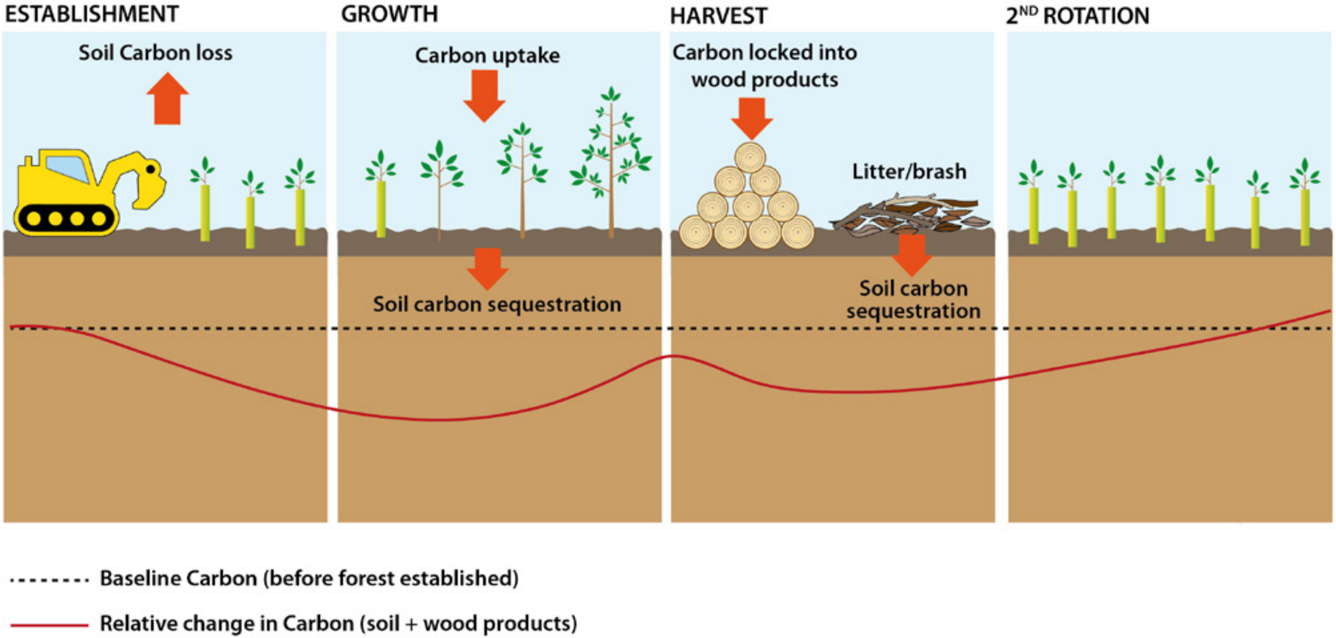
Growth: During growth, C is sequestered in the tree biomass, the amount will depend on the tree species, yield and rotation length. Repeated surveys of afforested shallow peat soils showed that C had accumulated in the litter on the forest floor and the soil C stock (including litter) increased by ~0.6 t C ha^{-1} y^{-1}.

Harvesting: The impacts of thinning on shallow peat C and GHG exchange are poorly understood but will result in a loss of biomass and soil C. Clear-felling of forestry can lead to an increase in soil C leaching into waterways for up to 4 years after clear-fell. The recovery of soil C after harvesting can be enhanced by leaving brash and litter on the ground, ensuring minimum additional soil disturbance, and through new inputs from the next forest rotation. Measuring GHG fluxes from clear-felled sites is difficult due to the variability in emissions across the site and the seasonal variation in emissions. Carbon dioxide emissions have been shown to decrease after clear-felling, while CH_4 emissions changed from a net sink to a net source and N_2O emissions increased slightly.

What is the net greenhouse gas balance of forestry on shallow peat soils in Scotland?

The soil C lost through leaching, oxidation and decomposition from shallow peat soils, due to the disturbance by soil preparation for forest creation, clear-felling and reforestation is compensated for by the C accumulation over two forest rotations. Overall, there is likely to be net C sequestration in forestry on shallow peat soils when C uptake, CH_4 emissions reduction and the benefits of using wood products are taken into consideration.

Forestry on shallow peats



What is the potential of managed grasslands in Scotland to sequester carbon?

Carbon (C) sequestration, the permanent removal of C from the atmosphere, will be needed to meet Net-Zero emissions in agriculture. On a global scale, it is believed that grassland soils have a huge potential to sequester C, but is this true for Scotland?

Managed grasslands in Scotland hold approximately 172 million tonnes of carbon (MtC) and available data suggest that there has been little change in soil C stocks in recent decades (the C stock being the C already sequestered in the soil).

There is a lack of evidence on the potential for Scottish managed grasslands to sequester C, and the UK Greenhouse Gas Inventory does not currently take account of sequestration that may be occurring on areas where land use has not changed (e.g. long-term grasslands). However, one detailed 7 year study of a grazed, fertilised and occasionally mowed permanent grassland in SE Scotland found that soil C stocks were stable (e.g. not sequestering or losing C). Soil C is important for soil health, fertility, water and nutrient availability and increases resilience to extreme weather. Therefore, it is extremely important to maintain existing soil C stocks.

What can farmers do to maintain grassland carbon stocks?

Grazing management: There is a lack of evidence related to grazing management and carbon stocks in managed grasslands in Scotland. However, it is widely accepted that over-grazing reduces soil C stocks.

Increasing grassland productivity leads to increased C inputs through plant roots. This can be achieved through fertilisation (inorganic or organic i.e. manure) and seeding with high-yielding grass species and legumes. Liming increases the pH of acidic soils which makes them more productive, but it also increases CO_2 emissions from soils. The net effect on soil C stocks is uncertain.

Challenges

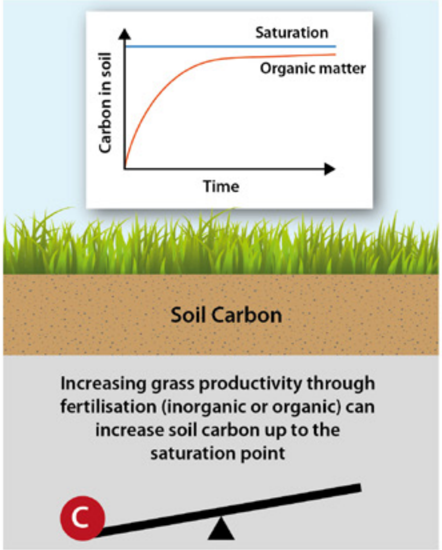
Limited capacity: Soils have a limited capacity to sequester C, the capacity depends on the soil type and management. After a change in management, rapid C sequestration slows (~20 years) and typically reaches a new equilibrium (within ~100 years).

Permanence: Disturbing soil leads to rapid C loss. To maintain C stocks, the same management needs to be continued indefinitely. Soil C can be lost much more easily than it can be sequestered.

Trade-offs: The nitrogen in fertiliser helps increase grass productivity, but if too much is applied it creates an excess of nitrogen in the soil. This excess nitrogen can be used by soil microbes to produce nitrous oxide (N_2O), and so N_2O emissions increase with fertiliser application. 1 tonne N_2O (half-life 114 years) is equivalent to 298 tonnes CO_2 (half-life 50-200 years).

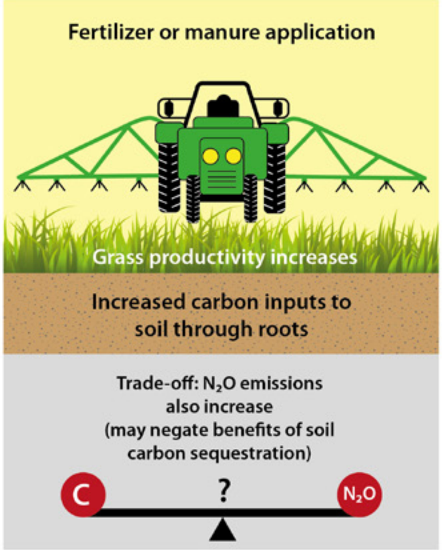
Measurement: Differences in methods used to measure soil C can lead to wide variation in estimates of soil C stocks, with values differing by up to 31% for Scottish soils. This uncertainty has implications for detecting if soil C stocks are increasing or decreasing.

Grassland Soil Carbon Sequestration



Soil Carbon

Increasing grass productivity through fertilisation (inorganic or organic) can increase soil carbon up to the saturation point

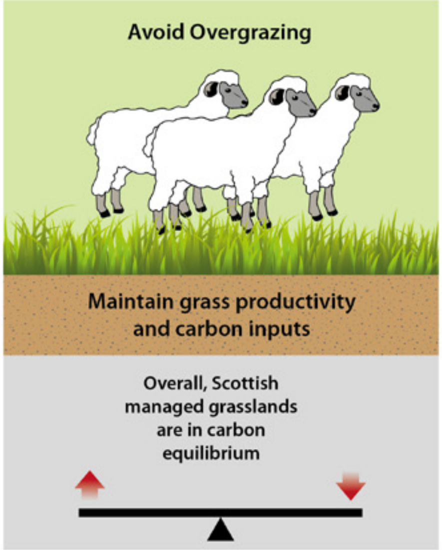


Fertilizer or manure application

Grass productivity increases

Increased carbon inputs to soil through roots

Trade-off: N_2O emissions also increase (may negate benefits of soil carbon sequestration)



Avoid Overgrazing

Maintain grass productivity and carbon inputs

Overall, Scottish managed grasslands are in carbon equilibrium

Options for mitigating agricultural nitrous oxide emissions

Nitrous oxide (N_2O) does not receive as much media attention as carbon dioxide or methane, but it is a powerful greenhouse gas (GHG) in its own right. One tonne of N_2O (half-life 114 years) is equivalent to 298 tonnes of carbon dioxide (half-life 50-200 years).

N_2O is produced through two biological processes: 1) Nitrification, which is the breakdown of ammonia to nitrate (releasing N_2O) when there is oxygen available, and 2) Denitrification which is the breakdown of nitrate to N_2 (releasing N_2O) when there is a lack of oxygen. Agricultural N_2O emissions can be either direct or indirect:

The largest source of direct N_2O emissions is from application of inorganic and organic fertilisers to soils (including the deposition of manure and urine by grazing livestock), and accounts for ~25% of GHG emissions from agricultural soils. Direct emissions are also released from stored manure, by crop residue returns (especially N-rich legumes) and cultivation of organic soils.

Indirect N_2O emissions are those that arise when N leaches into waterways or is lost to the atmosphere as ammonia or NOx. This 'escaped' N is emitted as N_2O further downstream or when it is redeposited on soils from the atmosphere.

How can farmers reduce N_2O emissions?

Optimise timing of fertiliser application:

1. **Avoid wet weather:** when the weather is wet soil pores fill with water and become depleted in oxygen, creating a peak in N_2O emissions. For example, soils on the west coast of Scotland, where there is greater annual rainfall, lose a higher proportion of applied N as N_2O than elsewhere in Scotland. Improving soil drainage and alleviating soil compaction will help prevent soils becoming saturated.
2. **Match crop N requirements:** Avoid over-fertilising and use split applications to maximise crop N uptake and prevent indirect N_2O emissions due to leaching. Test soil pH and nutrient status and consider options for optimising fertiliser types for specific crop N needs and local soil and climate conditions.

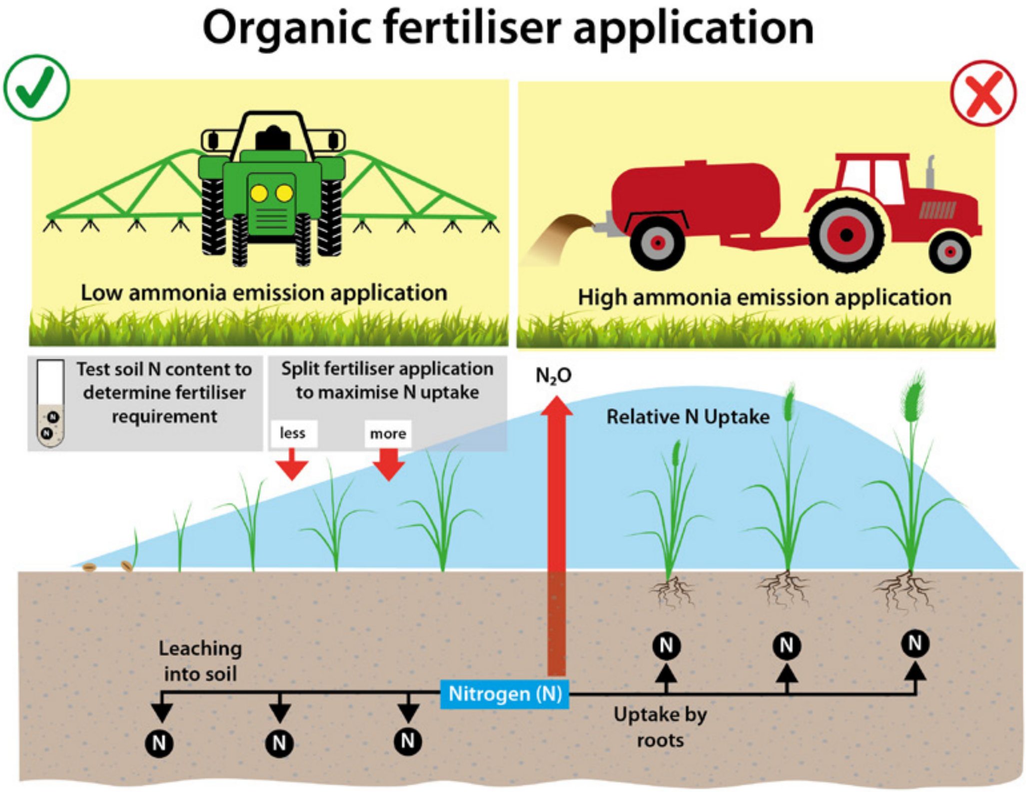
Adjusting the amount of fertiliser or manure applied to soils to avoid application of N in excess of requirements for the particular crop or grass yield will leave less N available for nitrification and denitrification. This will also minimise N losses and lower indirect N_2O emissions as less nitrate will be leached.

Increasing pH in acidic agricultural soils by liming will increase crop productivity and may decrease N_2O emissions. However, the extent to which emissions are reduced depends on soil type, temperature and whether N is present as nitrate or ammonium in the soil. The net effect of liming on GHG emissions is uncertain and likely to vary from farm to farm.

Application of nitrification inhibitors, such as dicyandiamide, to limit the amount of nitrate in the soil for denitrification. Trials in Scotland with nitrification inhibitors showed a reduction in N_2O emissions of up to 20% in grassland and 37% in arable soils fertilised with ammonium nitrate.

Storing manure and slurry in covered lagoons rather than open mounds or pits will reduce N_2O emissions by creating a low oxygen environment, preventing the formation of nitrate for denitrification, and reducing indirect N_2O emissions by preventing loss of ammonia to the atmosphere. However, this may be counteracted by increased methane emissions. Acidification of cattle slurry stores reduces indirect emissions by reducing ammonia release to the atmosphere and also reduces methane emissions.

Reducing livestock dietary protein to match animal requirements can reduce direct emissions by reducing N excretion in urine and indirect emissions by lowering ammonia emissions from manure.



What are the climate impacts of agriculture on Scottish uplands?

Around half of Scotland's land area is considered upland and includes moorlands, peatlands and semi-natural grasslands. These habitats provide several important ecosystem services which include carbon (C) storage, water quality regulation, flood mitigation, biodiversity conservation, and recreation. The Scottish uplands are managed for three main agricultural activities: rough grazing, shooting (red grouse and red deer), and commercial forestry. Here, we focus on the climate impacts of practices for grazing and game management.

What are the impacts of grazing on Scottish upland soil C?

Rough grazing for sheep and cattle makes up 59% of Scottish agricultural land. Wild red deer also graze extensively on Scottish upland areas.

Grazing has an impact on upland vegetation composition, which may reduce the potential for soil C sequestration on highly organic upland soils. However, grazing pressure only partly explains changes in vegetation composition, with climate change and soil acidification also playing a part. Overgrazing may cause localised soil erosion, leading to a loss of soil carbon, although there is a lack of recent evidence for Scottish uplands.

How can grazing be optimised to help mitigate climate change?

Reduce grazing pressure by lowering stocking densities or restricting the length of time animals graze any particular area. A study on a grazed upland area in Central Scotland predicted that, over a 100 year time frame, excluding sheep or grazing sheep at 0.9 ewes ha^{-1} led to C sequestration of 14 tonnes C ha^{-1}, whilst stocking densities of 2.7 ewes ha^{-1} led to a loss of 24 tonnes C ha^{-1}.

What are the impacts of Muirburn on greenhouse gas emissions and soil C in the Scottish uplands?

Muirburn is a traditional method of burning to revitalise vegetation on uplands to improve grazing for sheep and habitat for red grouse. There is little information on the effects of Muirburn on greenhouse gas (GHG) emissions and soil C from Scottish uplands, although limited evidence is available from the UK.

Greenhouse gas emissions: Carbon dioxide (CO_2) is lost from the vegetation during burning and CO_2 emissions from plant respiration increase after burning, but CO_2 uptake also increases as the vegetation regenerates. Studies estimating methane (CH_4) emissions show no significant change compared to unburnt areas and there are no data on the effect of prescribed burning on nitrous oxide (N_2O) emissions.

Carbon stocks: Burning also changes the composition of the vegetation but there is little evidence of how this affects soil C. The severity of the impact depends on the intensity of the fire, with hotter fires burning into the peat, leading to significant C loses. There is some evidence that Sphagnum mosses (the building blocks of peat) can recover from fire as long as some is left alive, but soil C losses due to runoff and erosion after burning are subject to debate. Partially burnt vegetation in the form of charcoal of black carbon may also be sequestered in the peat, adding to the C stock.

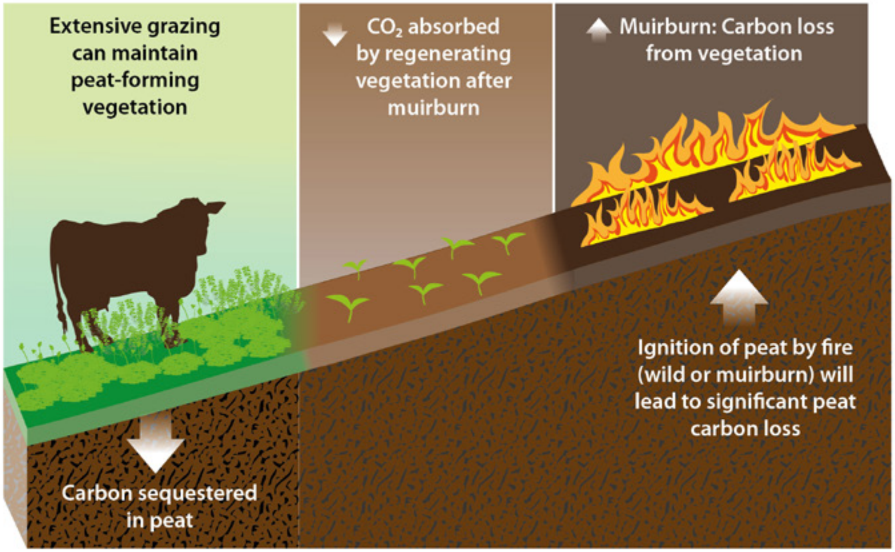
How can the impacts of burning be reduced?

Well managed burns following the guidance laid out in the Muirburn Code (2017) will help keep adverse impacts to a minimum.

What are the benefits of restoring drained Scottish uplands for greenhouse gas emissions and soil carbon?

Much of Scotland's upland area has been subjected to drainage. Drainage was historically used to improve upland vegetation composition for grazing sheep, but now is more likely to be used for forestry. Drainage lowers the water table which leads to decreased CH_4 and N_2O emissions but increased CO_2 emissions and soil erosion. It also alters the vegetation composition, with the loss of peat forming Sphagnum mosses. Drained peatlands are estimated to emit between -0.05 (net uptake) and 5.5 (net emission) tonnes of CO_2 equivalents per hectare per year.

There are very few studies measuring GHG emissions from Scottish uplands where drains (grips) have been blocked and there are limited studies from the UK. Most studies do not measure all GHGs and so the net effect is very uncertain. Grip blocking may reduce C leaching in runoff, but an increase in soil C sequestration would require the re-establishment of Sphagnum mosses in the grip.



Appropriate grazing and careful muirburn can maintain and/or increase upland carbon stocks