Grasslands as a Carbon Store

July 2023

Introduction

This briefing highlights the value of species-rich and semi-natural grasslands as stable carbon stores with essential ecosystem services, in order to make the case for action by policy makers, researchers and land managers to protect, restore, maintain and create these grasslands. These actions can simultaneously tackle the biodiversity and climate crises, by reducing greenhouse gas emissions, sequestering carbon, and restoring biodiversity. Whilst trees and peatlands are now recognised for their role in climate change mitigation and adaptation, species-rich and semi-natural grasslands are often overlooked.

Key Points

- In Great Britain, permanent grasslands have recently been estimated to store **more than two billion tons of carbon to a depth of 100 cm**; it has also been shown that soil carbon at this depth is still sensitive to land management changes[i].

- There is evidence that **increased species-richness in grasslands** – particularly in communities of deep-rooting plant species and legumes – increases carbon sequestration[ii].

- However, grasslands rich in carbon and biodiversity are being destroyed at an alarming rate in the UK and around the world through degradation or conversion to other land uses; it is estimated that England and Wales **lost around 97%** of lowland wildflower meadows between the 1930s and 1980s[iii].

- Agriculturally improved grassland and semi-natural grasslands make up about **40% of the UK land cover** (9.52 million hectares), which is **29% improved grassland** and **11% semi-natural grassland**[iv].

- Grasslands that are **species-rich cover less than 1%** of the UK's land area[v].

- Species-rich grassland habitats are extremely high in biodiversity, providing a home for more than 20% of UK plant species[vi] and up to 40 species per square metre[vii].

- **Permanent grasslands are significant carbon stores**; approximately 90% of the carbon stored in grassland is in its soil and roots, which remains locked away in their undisturbed soil[viii].

- However, grassland soil carbon is underestimated. The most common carbon sampling methods **only measure the top 15 cm of soil**, despite research suggesting that 60% of grassland soil carbon is located below 30 cm depths[ix]. This is in comparison to other habitat carbon stores that are measured to 100 cm – and often do not take into account the diverse nature of our semi-natural grasslands.

- **Intensive land management practices, such as over-fertilising and ploughing, and disturbance of permanent grassland soils, releases the carbon back into the atmosphere.** For example, conversion of grassland into arable farmland, can cause a 59% decline in soil carbon stocks[xxi].

- Implementing less intensive land management practices, such as **reducing livestock density and fertiliser application, can increase species-richness and carbon sequestration** in permanent grasslands.

- These less intensive land management practices provide a wealth of other ecosystem services and **reduce greenhouse gas emissions, air and water pollution**, while also reducing input costs and improving soil health, which supports sustainable food production.

- When focusing specifically on soil organic carbon, **certain types of UK semi-natural grasslands can store more soil organic carbon per hectare than improved agricultural grasslands, arable land and woodland**. Mature broadleaf woodlands store more carbon overall than grasslands, due to the large volumes of above-ground woody biomass; in the context of increased wildfire risk, pests and disease, grasslands can be a more reliable carbon store because approximately 90% of their carbon is stored below ground[xii].

- There are still gaps in UK-based research on grasslands' existing carbon storage and their sequestration potential, especially for semi-natural and species-rich grasslands.

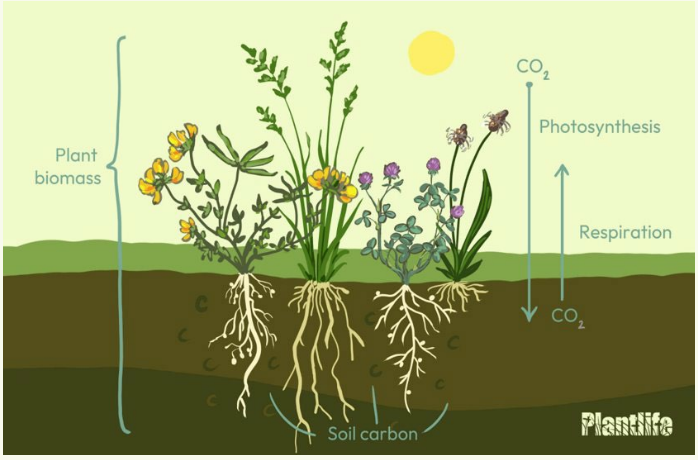
- Beyond carbon storage, species-rich grasslands also **provide important ecosystem services** that are unique to those habitats, including water supply and flow regulation, soil erosion control, support for pollinators and invertebrates, health and wellbeing benefits, cultural traditions[xiii] – as well as producing food in a traditional agricultural system.

What is the role of plants in the carbon cycle?

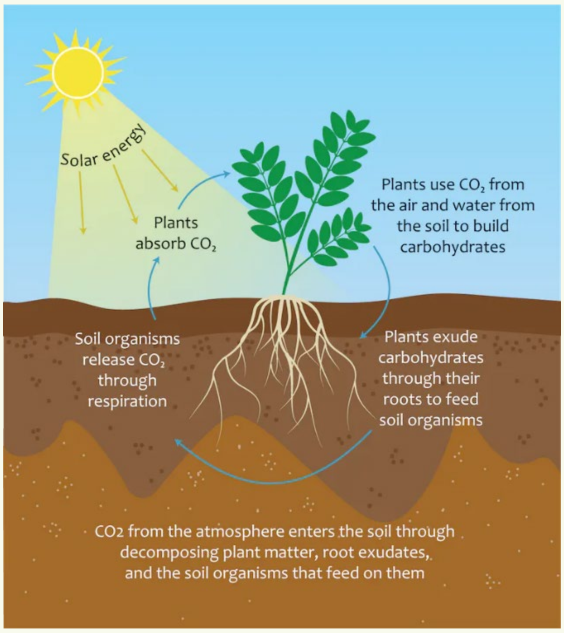
Life would not be possible without carbon; it forms the foundations of DNA, provides food, and regulates the planet's temperature. However, human activities are causing a steady increase in the concentration of atmospheric carbon dioxide (CO_2), which is the highest it has been for ~ 4 million years. This is the primary contributor to the devastating global climate crisis we are currently facing.

Carbon is cycled through different geological systems on Earth. As a key part of this carbon cycle, atmospheric CO_2 is absorbed by plants through photosynthesis.

Carbon can then be stored in living plant biomass, such as stalks and roots, or pass into the soil. Carbon enters the soil through compounds released from living roots (and their associated fungal partners) and soil organic matter, which is composed of dead plant litter and other organisms.



Meg Griffiths



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These carbon-based compounds are then consumed by soil invertebrates (worms and insects) and microbes (bacteria and fungi) or remain in the soil as organic matter.

The composition, activity and turnover of soil microbes play an integral role in the soil carbon cycle, contributing to greater below ground carbon storage and stabilisation of carbon stocks[xiv]. Research suggests management associated with species-rich grasslands (no or reduced fertiliser use) is associated with higher fungi and bacteria ratios[xv], which may also be linked to facilitating carbon storage in soils.

Carbon can be released back into the atmosphere from soils through natural processes, such as plant and microbial respiration, or disturbance from human activities.

Carbon sequestration in grassland habitats

Carbon in soil

In the UK, **more than a third of terrestrial (land-based) top-soil carbon is stored in grassland soils** (when measured at 0-15 cm depths)[xvi]. Much **more significant volumes of carbon are stored at greater soil depths**, yet this is often not included in carbon measurement and accounting tools.

It is estimated that **60% of soil carbon in grasslands is stored between 30-100 cm**[xvii] When measured to 100 cm depth, Great Britain's grasslands soils are estimated to store **more than two billion tons of carbon**[xviii].

Land management approaches

The UK has different grassland types, which can be broadly separated into improved (agriculturally managed to increase productivity) and semi-natural grasslands (some limited management).

Agriculturally improved grasslands and semi-natural grasslands make up about **40% of the UK land cover** (9,520 million hectares), and are the **largest category of land use**. However, much of this grassland is managed intensively or in ways that reduces biodiversity, which in turn limits the potential for carbon sequestration and storage in the soil.

The agricultural policy definition of 'permanent grassland' includes land which is regularly ploughed and reseeded, however the ploughing of soils releases large quantities of carbon into the atmosphere, meaning that these grasslands are not permanent carbon stores.

Intensive management practices, such as the use of fertilisers or pesticides, can reduce plant species diversity and productivity. They can also reduce organic litter inputs and increase soil exposure and compaction. These impacts lead to an **overall decrease in soil carbon**[xix].

Several studies have demonstrated that **intensive land use and management has lasting effects**[xx], including the **loss of carbon and biodiversity from grassland soil** which has taken decades to centuries to accumulate.

Artificial fertilization also inhibits beneficial root fungi (mycorrhiza) from functioning[xxi]. Drawing from an ancient evolutionary process, mycorrhizas store carbon in our soils and facilitate nutrient uptake in host plants[xxii].

Nationwide soil research has identified that **semi-natural grasslands contain greater carbon stocks than improved grasslands**[xxiii]. This may be due to the less intensive management practices, greater plant species richness, and undisturbed soils of semi-natural grasslands.

There is the **potential for further carbon sequestration and storage** for decades to come, through the maintenance and restoration of truly permanent, semi-natural grasslands, with undisturbed soils.

Whilst there are limited UK-based studies which estimate the amount of additional carbon that could be stored in grassland soils through changes to land management approaches, global studies suggest that approximately 2.3 – 7.3 billion tons of CO_2^e CO_2 equivalents per year (CO_2^e $year^{-1}$) could be sequestered through grassland diversity restoration efforts. A further 148-699 and 147 million tons of CO_2^e $year^{-1}$ could be sequestered in pasture through improved grazing management and legume additions respectively[xxiv].

The effect of grassland plant species richness on carbon sequestration

Species-richness and carbon

Scientific research shows that there is great **potential to increase the amount of carbon stored in grassland soils**. This can be through increasing the diversity of plants in grasslands, particularly communities of deep-rooting species by using appropriate management practices[xxv].

Plant diversity increases soil organic carbon in numerous ways:

- a higher variety of plants increases root carbon inputs through increases in root biomass and the carbon-based compounds they release into the soil[xxvi]

- greater plant species-richness is a key driver to increased diversity, abundance and activity of soil microbes, mycorrhizal fungi[xxvii] and ecosystem engineers (such as earthworms and ants), which facilitate greater sequestration and storage of soil organic carbon[xxviii]

Ecosystem and cultural services

High grassland plant species-richness also supports the provision of wider ecosystem services. Species-rich grassland habitats have been shown to **improve soil structure and nutrient cycling; provide pollination services to nearby cropland, wildflowers and trees; reduce soil erosion; purify water; mitigate against drought and flood events**[xxix]**, increasing resilience to the impacts of climate change**[xxx] and other drivers of environmental change.

Species-rich grasslands also enhance our lives through the provision of **cultural services**, such as aesthetic value[xxxi], recreation, supporting our health and well-being, and ecotourism.

How do grasslands compare to woodland and peatland

Carbon storage in woodland and peatland

It is well documented that, for the most part, peatlands hold the greatest carbon stocks of all habitats[xxxii].

There are variations in soil organic carbon estimates for both grasslands and woodlands, with some studies suggesting that **some semi-natural grassland soil carbon levels can exceed that of woodlands**[xxxiii].

Some studies found that, at 15 cm deep, the average soil carbon in an English 100-year-old broad leaf woodland is 48 t C ha^{-1} and 67 t C ha^{-1} for coniferous woodlands[xxxiv]. Another study estimated that **acid grassland holds over 90 t C ha^{-1}, while neutral grassland holds over 68 t C ha^{-1}**[xxxv]**, and floodplain meadows are estimated to hold over 109 t C ha^{-1}**[xxxvi].

The soil organic carbon stored in semi-natural grasslands is also estimated to **exceed that of arable land** (47 t C ha^{-1}) **and improved grassland** (67.2 t C ha^{-1})[xxxvii].

When taking into account above-ground storage, mature broadleaf woodlands store more carbon overall than grasslands due to the large volumes of above-ground woody biomass, which is estimated at 203 tonnes of carbon per hectare (in woodlands that are 100 years old)[xxxviii].

However, in the context of increased wildfire risk, pests and diseases in some areas, **grasslands offer a more stable carbon store than forests** because ~90% of their carbon is stored below ground, whereas woodlands store large carbon stocks in above-ground vegetation.

Right tree, right place, right management

Tree planting and woodland regeneration schemes are key parts of carbon sequestration and conservation efforts, following the principle of 'right tree, right place, right management'.

However, **inappropriate afforestation on existing species-rich grassland habitats can compromise their biodiversity and provision of ecosystem services**, and release soil carbon stocks during the land conversion process[xxxix]. Whilst this lost carbon is recovered over time, it can take decades if not centuries to recover to the original level of soil carbon stocks after disturbance due to land use change[xl].

The amount of carbon sequestered and stored by tree planting will depend on whether the trees are felled, how the timber is used, and the predicted increase in forest fires due to climate change[xli].

Deforested woodland plantation sites also offer opportunities to restore open habitats and planted ancient woodland sites (PAWS)[xlii].

Key Terms

Key Term	Definition
Carbon (C) sequestration and storage	The process of capturing CO_2 from the atmosphere and storing in a carbon pool, such as soil or oceans. Often reported as the weight of carbon per area and/or year, such as tonnes of carbon per hectare ($t\ C\ ha^{-1}$).
Permanent grassland	In agricultural policy, this is defined as land that has been in grass or other herbaceous forage, which has not been included in the crop rotation for 5 or more consecutive years. This definition can include grasslands which have been ploughed and reseeded during that time and excludes non-agricultural permanent grasslands such as parks, gardens and road verges. Definition: GOV.UK SFI improved grassland soil standard
Semi-natural / unimproved grassland	A habitat that is difficult to formally define but is usually where cutting, grazing or burning prevents succession to scrubland, but is otherwise unmanaged and with little to nil inputs such as fertilisers. Semi-natural grassland is often (but not always) species-rich and comprised of four broad habitat types: acid, calcareous, neutral and purple moor grass/rush grasslands. Definition drawn from: UK National Ecosystem Assessment 2011
Species-rich grassland	Semi-natural or unimproved grassland with little to nil inputs. Likely to be an existing, or restorable, priority habitat. To classify as a species-rich grassland, two of the following three criteria apply: 1) <10% rye grass and white clover cover; 2) >30% consists of wildflowers and sedge; 3) >15 vascular plant species per square meter, with a wide range of grass species. Definition: Defra Future Farming blog: maintain species-rich grassland
Semi-improved grassland	In a semi-improved grassland, some agricultural maintenance occurs but a diversity of plants is maintained. Two of the following three criteria should apply: 1) <30% rye grass and white clover cover; 2) >10% consists of wildflowers and sedge; 3) between 9-15 vascular plant species per square meter, including grasses. Definition: Defra Countryside Stewardship: assessment of eligibility for permanent grassland

Improved grassland	A species-poor grassland which has been agriculturally managed to increase productivity. For example, through fertiliser addition, drainage, herbicide use, ploughing and re-seeding. Two of the following three criteria apply: 1) >30% rye grass and white clover; 2) <10% cover of wildflowers and sedges; 3) species poor, with <8 species per square meter, including grasses. Definition: Defra Countryside Stewardship: assessment of eligibility for permanent grassland
Wildflower meadows	Use of this term here is from the widely referenced study (Fuller, 1987) estimating 97% of wildflower meadows lost in England and Wales between the 1930s and 1980s, which only assessed a specific type of grasslands – lowland hay meadows. Upland hay meadows and other species-rich grasslands were not included.
Reforestation	Planting of forests on lands that have previously contained forests but that have been converted to some other use. Definition: IPCC Glossary of Terms
Afforestation	Planting of new forests on lands that historically have not contained forests. Definition: IPCC Glossary of Terms
Some definitions have been adapted by Plantlife for the purpose of this briefing. Sources for the original definitions have been provided.	

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Sources

[i] Ward, S. E., Smart, S. M., Quirk, H., Tallowin, J. r. B., Mortimer, S. R., Shiel, R. S., … Bardgett, R. D. (2016). Legacy effects of grassland management on soil carbon to depth. Global Change Biology, 22(8), 2929-2938. https://doi.org/10.1111/GCB.1324

[ii] Bai, Y., & Cotrufo, M. F. (2022). Grassland soil carbon sequestration: Current understanding, challenges, and solutions, 608(August), 603–608.

[iii] Fuller, R. M. (1987). The Changing Extent and Conservation Interest of Lowland Grasslands in England and Wales: A Review of Grassland Surveys 1930-84. Biological Conservation, 40, 281–300.

[iv] Land Cover Map 2020 (25m rasterised land parcels, GB): Marston, C.; Rowland, C.S.; O'Neil, A.W.; Morton, R.D. (2022). Land Cover Map 2020 (25m rasterised land parcels, GB). NERC EDS Environmental Information Data Centre. https://doi.org/10.5285/a1f85307-cad7-4e32-a445- 84410efdfa70

[v] Trenbirth, H. (2022). Habitat extent and condition, natural capital, UK: 2022, 1–54. Available at: https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/habitatextentandconditionnaturalcapitaluk/2022#enclosed-farmland

[vi] Preston, C. D. (Christopher D., Pearman, D., Dines, T. D. (Trevor D, & Botanical Society of the British Isles. (2002a). New atlas of the British & Irish flora : an atlas of the vascular plants of Britain, Ireland, the Isle of Man and the Channel Islands, 910. Retrieved from https://www.nhbs.com/new-atlas-of-the-british-and-irish-flora-book

[vii] Webb, J.R., Drewitt, A.L. and Measures, G.H. (2010). Managing for species: Integrating the needs of England's priority species into habitat management.

[viii] Bai *et al* (2022).

[ix] Ward *et al* (2016).

[x] Guo, L. B., & Gifford, R. M. (2002). Soil carbon stocks and land use change: A meta analysis. *Global Change Biology*, *8*(4), 345–360. https://doi.org/10.1046/j.1354-1013.2002.00486.x

[xi] Guo *et al* (2002).

[xii] Dass, P., Houlton, B. Z., Wang, Y., & Warlind, D. (2018). Grasslands may be more reliable carbon sinks than forests in California. *Environmental Research Letters*, *13*(7), 074027. https://doi.org/10.1088/1748-9326/AACB39

[xiii] Bengtsson, J., Bullock, J. M., Egoh, B., Everson, C., Everson, T., O'Connor, T., … Lindborg, R. (2019). Grasslands—more important for ecosystem services than you might think. *Ecosphere*, *10*(2), e02582. https://doi.org/10.1002/ECS2.258

[xiv] Jackson, R. B., Lajtha, K., Crow, S. E., Hugelius, G., Kramer, M. G., Piñeiro, G., & Piñeiro, P. (2017). The Ecology of Soil Carbon: Pools, Vulnerabilities, and Biotic and Abiotic Controls. *Annu. Rev. Ecol. Evol. Syst*, *48*, 419–464. https://doi.org/10.1146/annurev-ecolsys-112414

[xv] Bardgett, Richard D. and McAlister, Erica (1999) *The measurement of soil fungal:bacterial biomass ratios as an indicator of ecosystem self-regulation in temperate grasslands.* Biology and Fertility of Soils, 29 (3). pp. 282-290. ISSN 0178-2762.

[xvi] Ostle, N. J., Levy, P. E., Evans, C. D., & Smith, P. (2009). UK land use and soil carbon sequestration. *Land Use Policy*, *26*, 274–283. https://doi.org/10.1016/j.landusepol.2009.08.006

[xvii] Ward *et al* (2016).

[xviii] Ward *et al* (2016).

[xix] Ward *et al* (2016).

[xx] Smith, S. W., Vandenberghe, C., Hastings, A., Johnson, D., Pakeman, R. J., van der Wal, R., & Woodin, S. J. (2014). Optimizing Carbon Storage Within a Spatially Heterogeneous Upland Grassland Through Sheep Grazing Management. *Ecosystems*, *17*(3), 418–429. https://doi.org/10.1007/S10021-013-9731-7/FIGURES/5

[xxi] Bardgett *et al* (1999)

[xxii] Malyan, S.K. *et al.* (2019). Role of Fungi in Climate Change Abatement Through Carbon Sequestration. In: Yadav, A., Singh, S., Mishra, S., Gupta, A. (eds) Recent Advancement in White Biotechnology Through Fungi. Fungal Biology. Springer, Cham. https://doi.org/10.1007/978-3-030-25506-0_11

[xxiii] Emmett, B. A., Reynolds, B., Rowe, E., Spurgeon, D., Brittain, S. A., Frogbrook, Z., … Woods, C. (n.d.). Countryside Survey: Soils Report from 2007.

[xxiv] Bai *et al* (2022).

[xxv] Bai *et al* (2022).

[xxvi] Fornara, D. A., & Tilman, D. (2008). Plant functional composition influences rates of soil carbon and nitrogen accumulation. *Journal of Ecology*, *96*(2), 314–322. https://doi.org/10.1111/J.1365-2745.2007.01345.X

[xxvii] John H. Bratton, (2003), Habitat management to conserve fungi: a literature review, 10-11.

[xxviii] Lange, M., Eisenhauer, N., Sierra, C. A., Bessler, H., Engels, C., Griffiths, R. I., … Gleixner, G. (2015). Plant diversity increases soil microbial activity and soil carbon storage. *Nature Communications 2015 6:1*, *6*(1), 1–8. https://doi.org/10.1038/ncomms7707

[xxix] Bengtsson *et al* (2019).

[xxx] Craven, D., Isbell, F., Manning, P., Connolly, J., Bruelheide, H., Ebeling, A., … Eisenhauer, N. (2016). Plant diversity effects on grassland productivity are robust to both nutrient enrichment and drought. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1694). https://doi.org/10.1098/RSTB.2015.0277

[xxxi] Southon, G. E., Jorgensen, A., Dunnett, N., Hoyle, H., & Evans, K. L. (2017). Biodiverse perennial meadows have aesthetic value and increase residents' perceptions of site quality in urban green-space. *Landscape and Urban Planning*, *158*, 105–118. https://doi.org/10.1016/J.LANDURBPLAN.2016.08.003

[xxxii] IUCN, Issues Brief, (2021). Accessed at: https://www.iucn.org/sites/default/files/2022-04/iucn_issues_brief_peatlands_and_climate_change_final_nov21.pdf

[xxxiii] Guo *et al* (2002).

[xxxiv] Vanguelova, E. I., Nisbet, T. R., Moffat, A. J., Broadmeadow, S., Sanders, T. G. M., & Morison, J. I. L. (2013). A new evaluation of carbon stocks in British forest soils. *Soil Use and Management*, *29*(2), 169–181. https://doi.org/10.1111/sum.12025

[xxxv] Emmett *et al* (2007).

[xxxvi] Lawson, C., Rothero. E., Gowing. D., Emma Rothero, David Gowing., Nisbet. T., Barsoum. N., Broadmeadow. S., Skinner. S. The natural capital of floodplains: management, protection and restoration to deliver greater benefits.

[xxxvii] Emmett *et al* (2007).

[xxxviii] Gregg, R., Elias, J. L., Alonso, I., Crosher, I. E., Muto, P., & Morecroft, M. D. (2021). *Carbon storage and sequestration by habitat: a review of the evidence*. Natural England Research Report NERR094. Natural England Research Report.

[xxxix] Bardgett, R. D., Bullock, J. M., Lavorel, S., Manning, P., Schaffner, U., Ostle, N., … Shi, H. (2021). Combatting global grassland degradation. *Nature Reviews Earth and Environment*, *2*(10), 720–735. https://doi.org/10.1038/s43017-021-00207-2

[xl] Ostle *et al* (2009).

[xli] Royal Society. (2001). The role of land carbon sinks in mitigating global climate change, (July), 35.

[xlii] Department for Environment, Food and Rural Affairs. (2022). *Keepers of time: ancient and native woodland and trees policy in England.* Available at: https://www.gov.uk/government/publications/keepers-of-time-ancient-and-native-woodland-and-trees-policy-in-england

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