Counting carbon on agricultural peat soils

M. Saunders[1], A. Premrov[1], F. Renou-Wilson[2], I. Clancy[1], R. Murphy[3], J. Connolly[4], L. Gilet[4], W. Habib[4], O. Fenton [3], P. Tuohy [5], D. Wilson[6]

[1] *Trinity College Dublin, School of Natural Sciences, Botany Discipline, Dublin,*
[2] *UCD School of Biology and Environmental Science, Science West, UCD, Belfield, Dublin,*
[3] *Teagasc, Crops, Environment and Land-Use Programme, Johnstown Castle, Co Wexford,*
[4] *Trinity College Dublin, School of Natural Sciences, Geography Discipline, Dublin,*
[5] *Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co Cork,*
[6] *Earthy Matters Environmental Consultants, Glenvar, Co. Donegal*

1. Introduction

Peatlands represent an integral part of the Irish landscape, covering approximately 1.46 Mha nationally, which represents approximately 21% of the land surface (Figure 1a) (Connolly and Holden, 2009). Globally, these ecosystems are one of the most important terrestrial carbon (C) stores. They are made up of accumulated organic material that is partially decomposed and sequestered over long-time periods (thousands of years) when the soil is waterlogged, as low concentrations of oxygen in the substrate limits decomposition. In Ireland, peat soils store approximately 2.2 Gt of C, which constitutes 62–75% of the total soil C pool (Renou-Wilson et al., 2022). However, over 90% of the peatland area in Ireland has undergone land use change, through drainage and conversion to agriculture, forestry or either domestic or industrial extraction (Fluet-Chouinard et al., 2023; Habib and Connolly, 2023). The spatial extent of grasslands on drained organic soils is estimated to be 339,000 hectares (EPA, 2024), however there is still some uncertainty on the total extent of peat-based grasslands in Ireland. This figure may increase closer to 500,000 hectares when shallow peats and soils with high organic matter are included (Gilet et al., *resubmitted*). These grasslands all act as a net C source though, with reported emissions in the region of 3.9 million tonnes of carbon dioxide equivalents (CO_2-eq.) per year (Tuohy et al., 2023; EPA, 2024).

National and international climate mitigation policies recognise the role that organic soils can play in reducing emissions of carbon dioxide (CO_2), and a focus on hydrology and water-table management (WTM) can reduce decomposition rates. There is a significant opportunity to explore options within the Irish agricultural peatland area to reduce C losses while balancing agricultural productivity and their impact on key ecosystem services within the wider landscape.

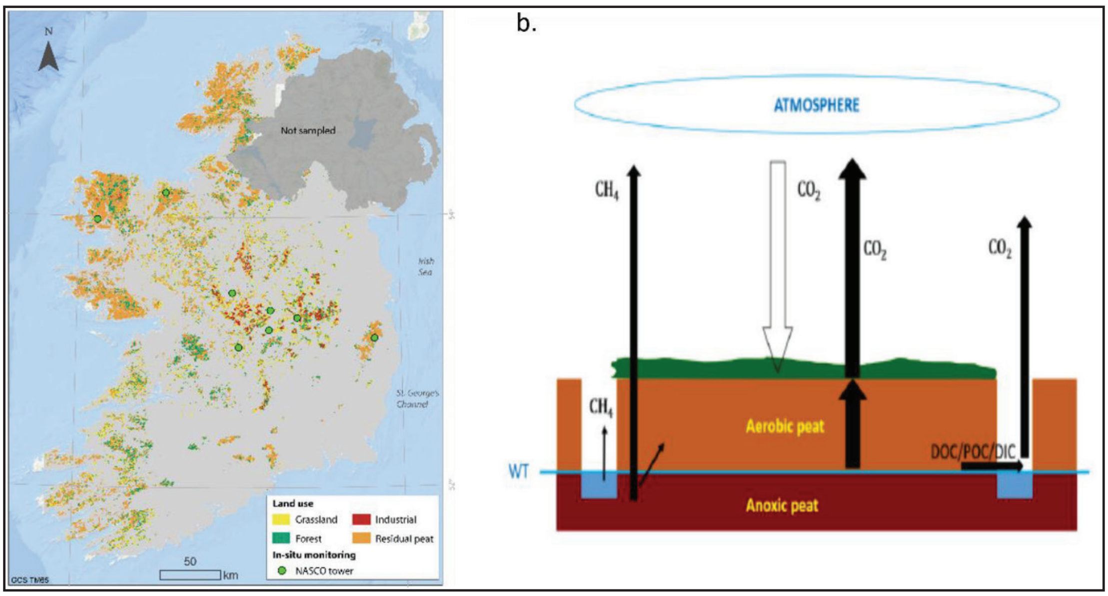

Figure 1a: Land use and the location of NASCO towers on peat soils (adapted from Habib and Connolly, 2023 by Louis Gilet, SmartBog and RePEAT projects). **Figure 1b:** An overview of the carbon (C) and greenhouse gas (GHG) dynamics of a drained peatland ecosystem under grassland management (Renou-Wilson et al., 2022).

2. State of Knowledge

An overview of the C and greenhouse gas (GHG) dynamics of drained peatland ecosystems under grassland is shown in Figure 1b. Carbon in the form of carbon dioxide (CO_2) is assimilated from the atmosphere through photosynthesis by the plants and is returned to the atmosphere via ecosystem respiration (R_{eco}), which is composed of two processes, autotrophic respiration (R_a, C released by the vegetation) and heterotrophic (R_{het}, C released by microbial decomposition of the substrate). When the water table is lowered, the depth of the aerobic layer increases and R_{het} tends to dominate the flux dynamics and a significant proportion of the C stored in the peat substrate is lost to atmosphere through microbial decomposition. In addition, the lower layers of the peat profile and the surrounding ditches are still wet and under anaerobic conditions can produce and emit methane (CH_4). Finally, additional C can be lost as dissolved and particulate C (DOC and POC) when water drains off the body of peat via open drainage ditches. These can also represent significant hot spots of CO_2 and CH_4 emissions (Peacock et al., 2021).

A comprehensive experimental assessment of C losses from drained organic soils under grassland in Ireland was undertaken by Renou-Wilson et al. (2015) as part of the CALISTO project. This work highlighted that nutrient status, extent of drainage, and variability in localised grassland management had the greatest impacts on the C and GHG dynamics of these systems. Nutrient poor sites, which represent a large proportion of the peat-based grassland area, under extensive grazing management with low rates of fertilisation tend to have low impacts on atmospheric warming. However, where the water table is increased and maintained 10 to 25 cm below the soil surface, sequestered C can be protected (Renou-Wilson et al. 2016). Modelling exercises have shown that emission reductions of 3 tonnes CO_2 per hectare can occur with each 10 cm increase in the height of the water table closer to the soil surface (Evans et al., 2021). Water table management becomes even more important at nutrient rich sites, which tend to be hotpots of both GHG emissions and losses of C through the fluvial pathway (Renou-Wilson et al., 2014). A review of peatland C and GHG fluxes from studies in Ireland compared default Tier 1 emission factors with country specific data and found that differences exist depending on land use and management/nutrient status (Aitova et al., 2023). Table 1 shows the Tier 1 and Irish estimated emission factors for both drained and re-wetted peat-based grasslands.

Peatland land use type	**Nutrient status**	**CO_2 EF (t C/ha per year)**		**CH_4 EF (kg C/ha per year)**		**N_2O EF (kg N/ha per year)**	
		Tier 1	**Irish**	**Tier 1**	**Irish**	**Tier 1**	**Irish**
Grassland	Nutrient poor	5.3 (3.7-6.9)	1.30 (0.04-2.6)	1.4 (0.5-2.1)	4.3 (2.6-15.02)	8.82 (1.9-6.8)	1.6
Grassland Nutrient rich	deep drained (5.0-7.3)	6.1 (3.7-6.6)	5.1 (1.8-21.8)	12 (-2.2-0.7)	-0.75 (4.9-11)	8.2	1.6
Rewetted grassland	Nutrient poor	-0.23 (-0.6-0.2)	0.85 (-1.6-3.3)	92 (3-445)	68.1 (20.9-115.2)	0	0

Table 1: Tier 1 and proposed emission factors for Ireland for CO_2, CH_4 and N_2O for agricultural grass-based peatlands. Data taken from Aitova et al. (2023). Values in brackets denotes the 95% confidence intervals.

The CO_2 emission factors for nutrient poor grasslands on peat from Irish studies are significantly lower than the default Tier 1 emissions, due to the lower intensity management in Ireland compared to the studies used to derive the Tier 1 emission factors, while emission factors for deep drained nutrient rich systems are similar to the Tier 1 emission factors. This difference, as well as a review of effective drainage of these grasslands (Tuohy et al., 2023) has had a significant impact in reducing the emissions reported in Ireland's National Inventory Report (NIR), as nutrient poor grasslands tend to be more widespread. The differences in the CH_4 emission factors for nutrient poor grasslands are due to the Tier 1 values being derived from deep drained sites with different climatic conditions, while Irish data are derived from shallow drained sites. The emission factors for N_2O are lower in the Irish context but lack certainty due to limited data.

Figure 1a shows the approximate location of the eddy covariance flux towers on peat soils in the National Agricultural Soil Carbon Observatory (NASCO). The flux towers will provide long-term estimates of the exchange of CO_2 and CH_4 between these ecosystems and the atmosphere. Some of the towers will also contribute to the EU-wide Integrated Carbon Observation System (ICOS). Further work is underway to enhance our understanding of the distribution of peat soils in Ireland in line with the Global Peatland Assessment (Gilet et al., *resubmitted*), their C and greenhouse gas dynamics and the impacts that WTM can have in reducing emissions and enhancing water quality.

Advances in the measurement of C and GHG fluxes and key environmental variables is crucial to provide data required to develop, validate and test model predictions of C dynamics. These models can be used as tools to understand the drivers of emissions and the impacts of land use/management scenarios at different temporal and spatial scales. This work and current activities, such as the CO2PEAT project will improve methodologies to report and verify C removals and emissions and will contribute to further refinement of higher IPCC (2014) tier reporting approaches.

Research into the hydrological dynamics and our ability to manage water tables in grass-based peats is currently under investigation in several projects (REWET, Carbosol, H2O, D-TECT, SMART CARBON FARMING) at various sites across the midlands and the west of Ireland. The REWET project will assess the availability and suitability of lands for rewetting, examine practical means of rewetting, assess the effects on hydrology, both at the designated sites and surrounding lands, and quantify associated impacts. The impacts of WTM on C and GHG dynamics are also being investigated on sites that represent a gradient of deep and shallow drainage and nutrient rich/poor status. Here, eddy covariance towers, part of NASCO, and state-of-the art automated chamber systems (Figure 2) combined with weekly manual chamber measurements are being used to address key knowledge gaps on the impacts of such interventions on components that dominate ecosystem C fluxes (R_a and R_{het}) and the application of various nutrient inputs on CO_2, CH_4 and N_2O emissions from agricultural peat soils. The refinement of water table control methodologies will allow for any implementation of such land use changes to yield maximal benefits on a per hectare basis and will inform strategies for the sustainable management of land resources, reduce the impact of GHG emissions, promote improved soil health and support sustainable habitats at all scales. Other projects will examine geospatial drainage status detection mapping of organic rich soils for NIR and policy support needs.

Figure 2: An eddy covariance tower and auto-chamber experiment investigating the impacts of water table management (WTM) on carbon (C) and greenhouse gas (GHG) dynamics on an agricultural peat-based grassland. Images provide by Ian Clancy.

3. Future Research Needs

There are still considerable uncertainties in the National Emission Inventory. It is important to further refine peat maps and country specific emission factors by assessing a greater range of sites, over the long-term, to better understand the impacts of peat depth, water table, management intensity, nutrient status and interannual climatic variability on the carbon and greenhouse gas dynamics of these systems. Further mapping and remote sensing of agricultural peatlands with particular focus on aligning GHG research on nutrient status and land use intensity to assess extensive, intensive and rough grazing would be beneficial to further disaggregate emissions and allow for the application of refined emission factors for these systems. Additional research is also needed on the development of models that will support higher IPCC (2014) tier reporting. The integration of modelling approaches, such as coupled and/or hybrid models and modelling platforms with integrated data-streams will allow us to effectively utilise the data, monitor and verify the observations, and refine the model predictions of C emissions from agricultural peat soils, under different management scenarios, and across different spatial and temporal scales.

References

Aitova et al. (2023). Mires and Peat, Volume 29. http://www.mires-and-peat.net/, ISSN 1819-754X.

Connolly, J and Holden, N. (2009). Irish Geography, Vol 42. https://doi.org/10.1080/00750770903407989

Environmental Protection Agency (2024). Ireland's National Inventory Report 2024 - Greenhouse Gas Emissions 1990-2022. PO Box 3000, Johnstown Castle, Co. Wexford, Ireland: Environmental Protection Agency (EPA), Ireland.

Evans et al. (2021). Nature 593, 548–552.

Fluet-Chouinard et al. (2023). Nature 614, 281–286.

Gilet et al. (In review, resubmitted). Geoderma.

Habib, W and Connolly, J. (2023). Regional Environmental Change. https://doi.org/10.1007/s10113-023-02116-0

IPCC (2014). 2013 Supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: wetlands. In: Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., et al. (Eds.), Intergovernmental Panel on Climate Change (IPCC), Switzerland, 2014. ISBN: 978-92-9169-139-5.

Peacock et al. (2021). Journal of Geophysical Research: Biogeosciences 126

Renou-Wilson et al. (2014). Biogeosciences 11, 4361-4379.

Renou-Wilson et al. (2015). Carbon Loss from Drained Organic Soils under Grassland – CALISTO. EPA Research report No. 141.

Renou-Wilson et al. (2016). Agriculture, Ecosystem and the Environment 222, 156-170.

Renou-Wilson et al. (2022). Peatland properties influencing greenhouse gas emissions and removal. EPA Research Report No 401. Environmental Protection Agency, Johnstown Castle, Ireland, 78.

Tuohy et al. (2023). Journal of Environmental Management 344, 118391.