Counting Carbon On Mineral Soils

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1. Introduction

Measuring carbon sequestration on mineral soils at national level represent a challenge. The annual changes in carbon stocks are subject to yearly variations, making it even more difficult to detect and quantify the exact amounts of carbon sequestered or lost each year from different farming systems. To address these issues and develop a coherent solution for carbon accounting at national level, in Ireland we have built a roadmap to measure carbon sequestration which takes into account different scales of approach and methodologies. This requires the use of advanced tools that can track both short-term carbon emissions and long-term carbon storage.

The National Agricultural Soil Carbon Observatory (NASCO) and the Signpost Programme are coherently combining knowledge, infrastructures and tools to establish Irish specific emission factors for soil carbon sequestration for inclusion in the national inventory. Through these projects Ireland is developing the largest infrastructure in Europe to measure and report emissions and calculate C stored in the soil and biomass. We are at the initial stages of combining these datasets, and this integration will be expanded in the future to explore scenarios of carbon sinks and sources in Irish agriculture, moving towards a Tier 2 and Tier 3 approach rather than the current Tier 1. Integrating the datasets developed will allows us to create a comprehensive carbon budget for Ireland that captures both dynamic fluxes and stable storage. The advanced techniques and tools used will improve our ability to quantify carbon sequestration, helping soils act as more effective carbon sinks and contributing to climate change mitigation.

NASCO comprises of a network of eddy covariance towers that directly measure the rate of CO_2 exchange between the atmosphere and terrestrial ecosystems, providing real-time data on the rates of carbon sequestration and release. This information is crucial for understanding the dynamic processes of carbon uptake and loss at the field level. The soil campaign from the Signpost Programme effectively addresses spatial variability with standardised and scientifically sound sampling techniques for a more detailed and accurate assessment of C stocks as national baseline of soil C in Irish farming systems (Figure 1).

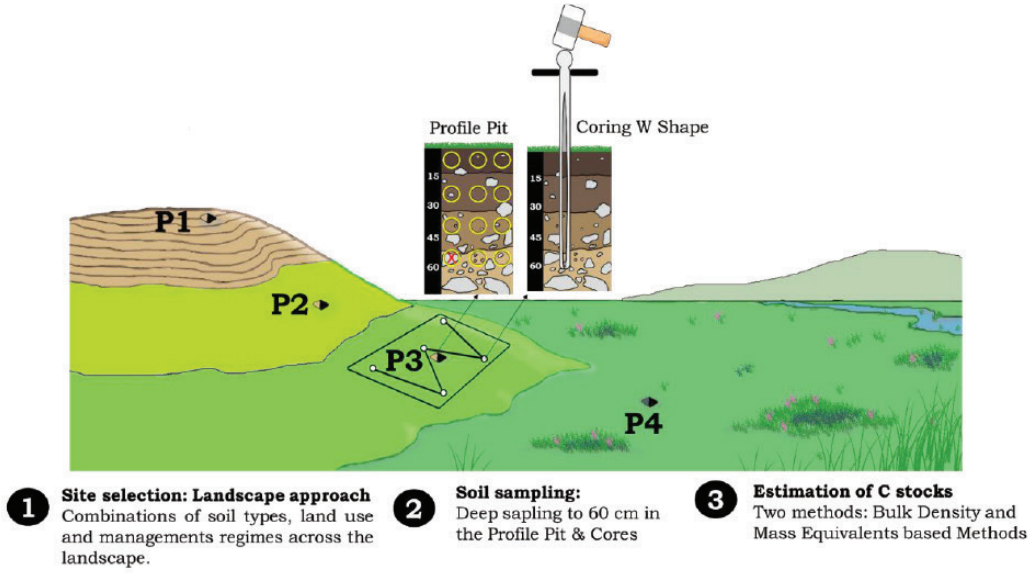

Figure 1: Method scheme for site selection and sampling within the Signpost Programme

2. Current Knowledge

Preliminary research from NASCO suggests that managed mineral soils are sequestering nearly 4.5 times more CO_2 than is reported in the NIR (Table 1), at a mean rate of 0.64 t C/ha per year or 2.34 t CO_2/ha per year. In order to validate these early research findings, long-term C flux measurements are required over different land-uses and management intensities, as is the overarching aim of NASCO and Signpost research.

Table 1: The IPCC Tier 1 emission factor (EF) for carbon sequestration on mineral soils and preliminary findings from the NASCO eddy covariance tower site at Johnstown Castle.

Units	Tier 1 EF	Measured Irish data
t C/ha per year	0.14	0.64
t CO_2/ha per year	0.51	2.34

However, it is important to note that managed pastures do not consistently act as a sink of C, and these systems are highly sensitive to management changes and extreme climatic events (Figure 2). For example, following conversion of grassland to forage crops at the Johnstown Castle site in 2005, the site shifted from a net sink of C to a net source in the following years, ranging from 1.9 to 6.9 t CO_2/ha per year. Similarly, during the 2018 heatwave, the Johnstown Castle grassland site transitioned from a net sink of C to a net source of C at a mean rate of 4.9 t CO_2/ha per year.

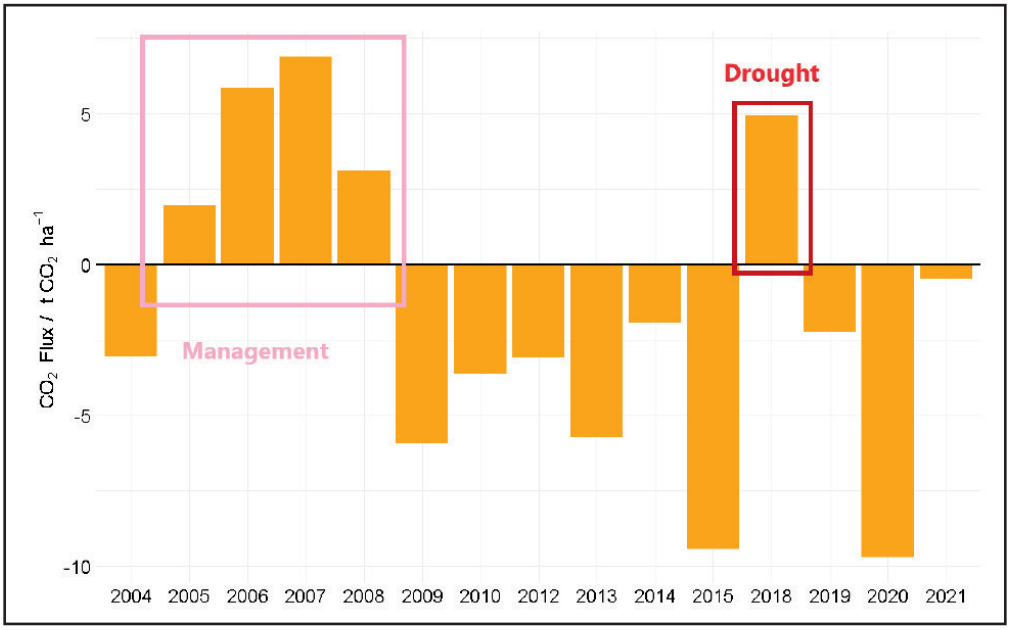

Figure 2: Preliminary findings from the Johnstown Castle NASCO site showing the long-term carbon balance in t CO_2/ha. Positive numbers represent net carbon that is emitted from the system to the atmosphere and negative numbers represent the net uptake of carbon from the atmosphere to soil and vegetation.

The SOC to Clay ratio, developed by Johannes et al. (2017), is a recognized soil quality indicator for European soils and it provides an understanding of the carbon that is bound to finer minerals such as clay. This ratio was calculated for topsoil data across all Signpost farms to assess the quality status of different farming systems. Preliminary results indicate that 92% of Irish farms, mainly grassland farms, are in good status in terms of soil quality, 6% moderate status and <1% poor status with both land use and soil type affecting the quality of the topsoil. Intensive grasslands have the highest capacity for carbon sequestration, especially on Luvisols, reaching values of 121 t C/ha for the entire profile (Castellon Meyrat et al., 2024). Intensive farms also show higher carbon stocks associated to deeper soil layers. This suggests the importance of considering subsoil carbon beyond the IPCC depth of 30 cm. Teagasc research has flagged the presence of significant carbon amounts below this depth in Irish soils (up to 40 t C/ha; Simo et al., 2019). The sampling on the

Signpost programme has confirmed that C stocks below 30 cm ranged from 18% to 30% of the overall C stocks for 60 cm, and were influenced by soil type, climatic conditions and land use. While soil type, and in particular clay content, set the potential size of the sink, land use has an overriding effect on the permanence of C. Short term management help to switch to higher or lower factor rate of C sequestration.

3. Implications for stakeholders

Research is also investigating various measures to generate scientific data and provide knowledge for different stakeholders, which will significantly enhance the national greenhouse gas inventory. Emissions from the land-use, land-use change, and forestry sector must be reduced in line with all other sectors to help Ireland achieve its 51% greenhouse gas reduction target. As science advances in measuring carbon and refining emission factors, the identified measures will deliver immediate carbon savings. Many of these measures also improve incomes, agronomic yields, and offer benefits to biodiversity and water quality.

a. Farmers

Collaborative research projects between Teagasc and universities, state and private bodies will provide the farming community with a quantification of the carbon sequestered through specific management practices on particular land-uses and soil types that will support sustainable, low carbon farming. Reduced C footprint of agri-food is becoming a key consumer demand globally and Teagasc research aims to provide a scientific basis and pathway for the Irish agri-food sector to promote itself as sustainable with a low climate impact. Signpost will contribute to developing and implementing tailored management practices for increasing SOC stocks and robust carbon accounting frameworks for sustainable agricultural systems. This will benefit farmers, land managers, and society in effectively managing their soils and could be incorporated into carbon farming frameworks.

b. Policy makers

Accurate baseline measurements of SOC quantification in depth and estimates of SOC sequestration rates that are specific across various soil types, land use scenarios, and management regimes, are essential in order to enhance the accuracy and precision of carbon estimates of Irish soils from a Tier 1 to Tier 2 levels. Irish specific SOC sequestration factors across the main mineral soils will be produced that can be inputted into national inventories. This will provide the basis for inclusion of agricultural soils into carbon trading schemes and life-cycle assessments (LCA's), which will assist the sector in terms of carbon credits and a reduced carbon footprint on agricultural produce. Flux measurements of CO_2 incorporated with C imports (e.g. animal excreta) and C exports (e.g. biomass removals) enable the calculation of C balances from different agricultural systems will help inform and underpin DAFM climate policy. Field scale measurements of GHGs, soil carbon stocks and biomass in combination with machine learning approaches to predict how changes in management and climate will impact carbon stocks from agricultural soils in the future, will enable policy measures to be tested and assessed.

c. Industry

The implications of this research for the industry are significant, as it supports the development of carbon farming practices that not only enhance carbon sequestration but also provide economic incentives for farmers, leading to more sustainable and profitable agricultural systems. In addition, fostering collaboration between government agencies, research institutions, agricultural organizations, and farmers is key to ensure the successful implementation and scaling of Tier 2 and 3 approaches.

4. Future research needs

The ongoing research on mineral soils will support the development of a Tier 3 model that can be used to quantify carbon sequestration associated with changes in land-use, land management and climate change. The mapping of soil types across Ireland needs to be improved to provide the necessary data to constrain

Tier 3 carbon models for individual farms. The development of a Tier 3 approach for carbon sequestration will facilitate the development of the national inventory and support carbon farming. This will include creating detailed, location-specific management practices, refining carbon sequestration techniques, and implementing advanced monitoring and modelling tools to maximise carbon storage in agricultural systems**.** To enhance current approaches to measure, report and verify (MRV) the net carbon sequestration potential of Irish managed agricultural soils, synergy and collaboration between parties working in this space, both public and private, is required. Ireland is a global leader in climate change research, evident from the extensive state of the art technology that is currently being utilized, and the multi-scaled approaches being implemented (soil sampling, ecosystem-scale flux measurement, remote sensing and earth observations of carbon uptake and complex empirical and process based modelling). Harmonizing individual efforts will strengthen Ireland's capacity to answer complex, whole system questions about the future state of soil carbon stocks in response to new management approaches to a changing climate.

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