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Research Letter

Exploring Climate-Smart Land Management for Atlantic Europe

Rogier P. O. Schulte,* Lilian O'Sullivan, Cait Coyle, Niall Farrelly, Carsten Gutzler, Gary Lanigan, Gemma Torres-Sallan, and Rachel E. Creamer

Core Ideas

- Managing soil organic carbon is an essential aspect of climate-smart agriculture.
- Combining component research, we derive a soil carbon management concept for Ireland.
- Optimized soil carbon management is differentiated in accordance with soil type.
- Existing policy tools can be tailored to incentivize climate-smart land management.

Abstract: Soils can be a sink or source of carbon, and managing soil carbon has significant potential to partially offset agricultural greenhouse gas emissions. While European Union (EU) member states have not been permitted to account for this offsetting potential in their efforts to meet the EU 2020 reduction targets, this policy is now changing for the period 2020 to 2030, creating a demand for land management plans aimed at maximizing the offsetting potential of land. In this letter, we derive a framework for climate-smart land management in the Atlantic climate zone of the EU by combining the results from five component research studies on various aspects of the carbon cycle. We show that the options for proactive management of soil organic carbon differ according to soil type and that a spatially tailored approach to land management will be more effective than blanket policies.

Soils store three times the amount of carbon located in the atmosphere and four times more carbon than aboveground vegetation (Lal, 2008). Soils can be a source or sink of anthropogenic carbon. Sources include methane emissions from paddy rice production and carbon dioxide (CO_2) emissions emanating from the oxidation of soil organic carbon (SOC) as a result of land use change, land degradation, or drainage of wet organic soils (Lal, 2004). Conversely, soils can be a sink of atmospheric carbon through carbon sequestration, which may be enhanced through land restoration or land use change from arable to either grassland or forestry. Annual global greenhouse gas (GHG) sources and sinks from the agriculture, forestry, and other land use (AFOLU) sector amount to approximately 10 Gt and −2 Gt CO_2 equivalent (CO_2e), respectively, equating to 20% and −4% of global anthropogenic GHG emissions (FAO, 2014). Reducing soil emissions and augmenting sinks provides a promising approach to partial offsetting agricultural GHG emissions (Smith et al., 2008). This has received further prominence by the "4 per 1000 initiative" (http://4p1000.org/understand) launched at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP 21) in December 2015.

Under the European Union (EU) Climate and Energy Package 2020 (http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm), however, individual member states are currently not permitted to use the land use, land use change, and forestry (LULUCF) sector to offset emissions from other sectors to meet their 2020 GHG reduction targets. This has presented a significant challenge to the incentivization of climate-smart land management, as the augmentation of soil carbon stocks does not translate into "credits" for EU member states. This policy is now due to be revised with the adoption of the European Council's Conclusions on the Climate and Energy Framework 2030 (European Council, 2014) and the recent proposals by the European Commission, which allow for flexibility in using

R.P.O. Schulte, L. O'Sullivan, C. Gutzler, G. Lanigan, G. Torres-Sallan, and R.E. Creamer, Teagasc, Crops, Land Use and Environment Programme, Johnstown Castle, Wexford, Ireland; C. Coyle, CERIS, Dep. of Environmental Science, Institute of Technology Sligo, Sligo, Ireland; N. Farrelly, Teagasc, Crops, Land Use and Environment Programme, Mellows Centre, Athenry Co. Galway, Ireland; G. Torres-Sallan, Dep. of Life Sciences, Univ. of Limerick, Limerick, Ireland; R.E. Creamer, Dep. of Biological Soil Quality, Wageningen Univ. and Research Centre, Wageningen, the Netherlands.

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*Corresponding author (rogier.schulte@teagasc.ie).

Abbreviations: CO_2e, CO_2 equivalent; GHG, greenhouse gas; LULUCF, land use, land use change, and forestry; SOC, soil organic carbon; UNFCCC, United Nations Framework Convention on Climate Change.

the land use sector to offset national emissions (European Commission, 2016) for the period 2020 to 2030.

This policy shift will now allow for the proactive management of SOC as an additional mitigation option to reduce national GHG emissions. While the scientific literature lists numerous land management practices that may be applied to increase SOC, discussions on policy instruments to incentivize such management have been generic and aspirational to date, specifically in relation to grasslands in pedo-climatic regions where SOC concentrations have not been depleted to levels at which they are limiting agricultural production. In this letter, we bring together the component research from five studies on the SOC cycle to derive a coherent framework for the climate-smart management of land for one of these regions, the Atlantic climate zone of the EU.

Procedures

In our study, we focused on Ireland as a typical national example of the Atlantic climatic zone. Land use in Ireland is dominated by grass-based livestock production, with grassland and rough grazing accounting for 80 and 11% of agricultural land, respectively (DAFM, 2015). The associated soils are characterized by high SOC contents (typically 5–15%) (Fay et al., 2007), reflecting the prevalence of permanent pasture and wet soil conditions. All soils have been mapped at a scale of 1:250,000 and correlated to the World Reference Base for soil classification in the Irish Soil Information System (http://gis.teagasc.ie/soils/).

We considered the following aspects of the SOC cycle that are relevant in the Atlantic climate zone:

1. *Maintenance of existing SOC stocks.* We used the results and the indicative soil carbon storage map by Schulte et al. (2015) and Coyle et al. (2016). Most (53–75%) of the current SOC stock in Ireland is contained in peat soils (Fig. 1a), which occupy 21 to 25% of the land area and store an estimated 1500 to 1600 Mt carbon (Gutzler et al., unpublished data). With emissions from Irish agriculture (excluding LULUCF emissions) ranging from 18 to 20 Mt CO_2e yr^{-1}, these stocks are equivalent to almost three centuries of national agricultural GHG emissions.
2. *Reduction of existing SOC emissions.* Artificially drained wet soils represent the single largest source of SOC losses from land in Ireland, their impact given further prominence by the recent upward revision of emission coefficients in the IPCC Wetlands Supplement (IPCC, 2014). "Emission hotspots" are associated with intensively managed, drained, histic soils; these hotspots (Fig. 1b) are responsible for 59% of all estimated annual emissions arising from land drainage, even though they account for only 18% of the land area to which the Wetlands Supplement applies (i.e., histic and humic soils under agriculture, excluding land that is too steep or rocky for drainage), a mere 6% of the total agricultural area (Gutzler et al., unpublished data).
3. *Prevention of new SOC emissions.* The recent phasing out of EU milk quotas has led to a resurgence of drainage works on poorly drained, yet fertile soils. The installation of drainage systems extends the grass growing and grazing season but is associated with losses of SOC as a result of oxidation. Using carbon pricing, O'Sullivan et al. (2015) assessed the cost–benefit ratio between increased productivity and carbon losses for contrasting grassland soils. At current carbon prices (<€10 $tonne^{-1}$ CO_2e), the financial benefits from increased productivity outweighed the financial "penalties" arising from the associated increase in GHG emissions. However, when using the 2030 carbon price projections adopted by the European Commission, this ratio was reversed for some areas (yellow in Fig. 1c), which we have labeled as "emission sensitive soils" that are at risk of becoming new emission hotspots.
4. *Enhanced long-term sequestration in grasslands.* Grasslands (on mineral as well as organic soils) already contain large amounts of SOC and are, on balance, sequestering carbon (Abdalla et al., 2013). Recently, Torres-Sallan et al. (2015) used the Irish Soil Information System to assess the recalcitrance of SOC and found a pool of stable carbon associated with soil aggregates <250 μm at depth in soils subject to clay illuviation that has heretofore not been taken into account. Figure 1d depicts the geographical distribution of these soils with additional potential for long-term carbon storage.
5. *Enhanced sequestration through land use change (afforestation).* At 11%, Ireland has the lowest forestry cover among EU member states. Therefore, conversion of farmland to forestry is considered one of the most viable land management options within the current LULUCF accounting framework. However, not all soils or regions are equally suitable for new afforestation. Farrelly and Gallagher (2015) identified 1.3 million ha of marginal agricultural land on which competition from other demands on land use is low (Fig. 1e). By contrast, the 2.4 million ha of productive agricultural land is likely to be the focus of agricultural intensification as part of Ireland's Food Wise 2025 Strategy (www.agriculture.gov.ie/foodwise2025), while 0.9 million ha of potentially suitable land is subject to national and EU designations where existing habitat conservation is prioritized.

Using ArcGIS, we combined the results of these studies into one integrated map for SOC management. Where overlaps occurred, we layered the maps in reverse order of their geographical extent, resulting in the following priority ranking: emission hotspots > emission sensitive soils > suitability for afforestation > enhanced grassland sequestration > current SOC storage.

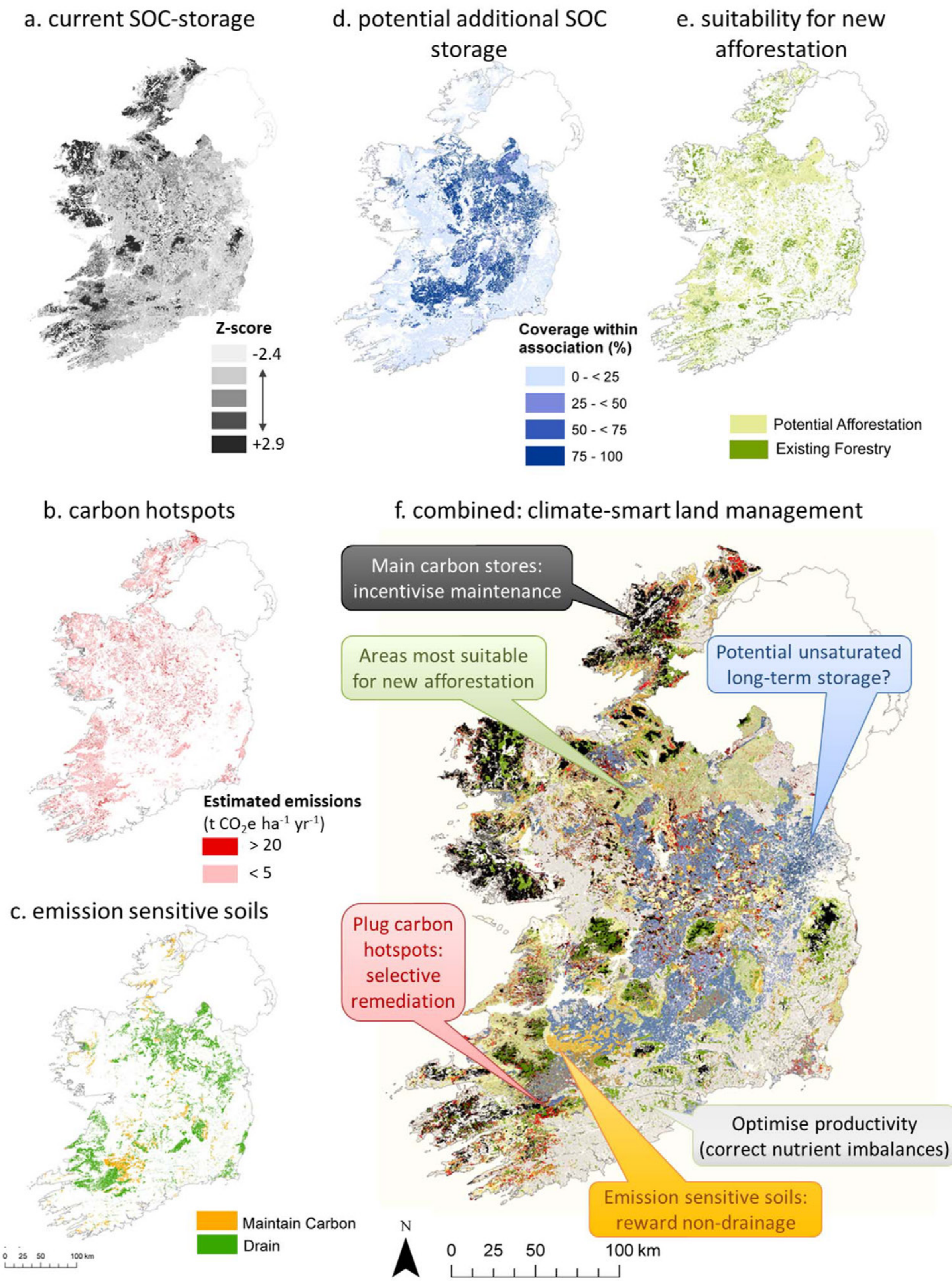

Fig. 1. Indicative maps showing the geographical distribution of soil organic carbon (SOC) stock and fluxes of relevance to climate-smart land management in Ireland. (a) Current SOC stocks: relative carbon storage capacity (z-scores) of soil × land use combinations. (b) "Emission hotspots" associated with drained organic soils: estimated annual loss of CO_2 per hectare. (c) "Emission sensitive soils" indicating soils that would release CO_2 in response to drainage works: modeled annual loss of CO_2 per hectare following drainage. (d) Soils subject to clay illuviation, which store stable carbon at depth: percentage of area within the soil association covered by soils with argic properties. (e) Existing forestry and soils most suitable for new afforestation: marginal soils not subject to environmental legislation. (f) Map combing the five aspects of SOC dynamics (a–e).

Results and Discussion

The combined map (Fig. 1f) shows the resulting mosaic of management options for climate-smart land management. It illustrates that SOC may be managed most efficiently if management practices are targeted toward the appropriate flux or pool of the SOC cycle, which may differ between soil types and regions. This suggests that tailored land management policies will prove more cost-effective than blanket policies and will minimize unwarranted competition between land use categories. While the spatial resolution of our study is insufficient for the spatial demarcation of land use, our combined map provides a coherent framework for the tailoring of existing policy instruments toward soils and regions where they can be applied most effectively. Examples include the following:

- *Maintenance of carbon stocks on peat soils.* In the past, peat soils were at risk of overgrazing by sheep, which was one of the unforeseen side effects of the EU payments for direct support to farmers in disadvantaged areas. The restructuring of these payments in 2003 resulted in a decline in sheep numbers from 4.7 million to 2.5 million ewes over the period 1992 to 2015 (http://www.cso.ie/px/pxeirestat/Database/eirestat/Livestock%20and%20Farm%20Numbers/Livestock%20and%20Farm%20Numbers_statbank.asp?SP=Livestock%20and%20Farm%20Numbers&Planguage=0). In addition, a large proportion of this area has since been designated as EU NATURA 2000 sites, providing additional protection. Therefore, significant changes in land management have already taken place, which are contributing to the maintenance of carbon stocks.
- *Remediation of emission hotspots.* Emissions from intensively managed drained peat soils may be reduced significantly through rewetting or extensification. As either type of intervention will reduce the agricultural productivity of the land, such measures would be eligible for financial support from the exchequer under the Green Low-carbon Agri-environmental Scheme (GLAS). Targeting of the policy instruments toward the true hotspots will maximize the cost-effectiveness of such measures.
- *Prevention of drainage on emission sensitive soils.* New drainage works are currently subject to Environmental Impact Assessment (EIA) requirements; these have thus far focused on the impacts on the ecological integrity of the land. However, the same mechanism could also be used to assess the impacts on CO_2 emissions. In addition, the nondrainage of poorly drained land is a recognized criterion for the designation of land within the new delineation of Areas of Natural Constraints within the EU (Van Orshoven et al., 2013), which receive significant financial compensation for their reduced potential for agricultural production.
- *Afforestation.* The cost-effectiveness of the national afforestation scheme may be enhanced by spatial targeting of financial incentivization measures.
- *Enhanced grassland sequestration.* While our research has identified the soils that show potential for additional long-term carbon storage at depth, further research is required on the specific management practices that increase the rate of this SOC sink.

Some areas of the map remain blank, suggesting that none of the aforementioned management strategies are particularly relevant for these soils; these areas coincide with the most productive regions of Ireland that are characterized by Cambisols. International evidence suggests that SOC stocks on these soils may be augmented by optimizing productivity through sustainable intensification, such as by rectifying soil nutrient imbalances (Smith et al., 2008), with co-benefits for the aquatic environment. The management of this spatial interaction between agriculture and the full spectrum of ecosystem services (e.g., water quality, carbon sequestration, biodiversity, nutrient cycling) is the subject of the European LANDMARK (LAND Management: Assessment, Research, Knowledge base) project (Schulte et al., 2015).

Conclusions

To date, management of the LULUCF sector has been largely limited to the regulation, monitoring, and reporting of land use change. By themselves, these measures are unlikely to fully deliver on the significant potential of the sector for offsetting GHG emissions, which has been recognized in the recent reframing of EU and UNFCCC policy contexts. The framework for climate-smart land management presented here provides the next step toward proactive management of the LULUCF sector, with a view to broadening and diversifying the menu of options for the mitigation of climate change.

Climate-smart land management does not necessarily require radically new policy initiatives. An array of existing governance instruments is available to incentivize management of SOC. Customization and targeting of these instruments to manage carbon fluxes in contrasting soil × land use combinations will enhance their cost-effectiveness for both primary producers and the exchequer.

While the SOC management options assessed in this letter are specific to the agro-climatic context of farming in Atlantic Europe, our framework of differentiated incentivization is transferable to other regions and farming systems, allowing the LULUCF sector to fulfill its potential in contributing to meeting future GHG reduction targets in the emerging policy environment.

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