Article title: Soil carbon farming has the potential to bridge the global emissions gap
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Soil carbon farming has the potential to bridge the global emissions gap

Key message

Agriculture is a significant emitter of greenhouse gases but increasing average soil organic carbon in cropland and pasture by 1 per cent globally, could lead to carbon sequestration of 311 GtCO2e, the equivalent of the 2030 emissions reductions gap.

Abstract

There is growing interest globally in soil health and the role that enhanced soil organic carbon (SOC) can play in climate change mitigation, resilience, and food security. Different initiatives for SOC sequestration (SCS), such as Project Drawdown, '4p1000' and RECSOIL have been proposed yet SCS commitments and targets are missing from the Nationally Determined Contributions (NDCs) to the 2015 Paris Agreement and the UNFCCC Global Stocktake. This paper asks whether a single, locally relevant target could be developed for SCS that would encourage widespread adoption of soil carbon removals practices by farmers and land managers globally? We used 210,00 local soils profiles from the World Soil Information System to assess the SOC potential of 2,352 million ha of agricultural land, identified with the Landsat Global Land Cover classification. Based on the local characteristics of the carbon sequestration capacity of soils, we found that a one percent average increase in SOC storage in croplands, pasture and irrigated fields would have the potential to sequester 84.9 GtC or 311 311 $GtCO_{2\text{-}e}$ [range 159 – 447 $GtCO_{2\text{-}e}$]. This represents more than a decade of the emission reductions needed to have a chance of remaining on a 2°C or 1.5°C or Net Zero pathway. We argue that a one per cent target is easy to communicate and understand, especially as most farmers and land managers who regularly test their soils are familiar with the soil carbon percentages of their land.

Key words

Soil Carbon Sequestration (SCS); Soil properties; Soil carbon storage potential; Carbon farming; Land classification; NDC; Emissions gap; Net Zero pathway.

Background

Soil contains more carbon than the atmosphere and vegetation combined; more than half of this carbon stock is associated with soil minerals and can be stored for periods of up to 10,000 years (Batjes 1996; Georgiou et al. 2022). Soil carbon is also a major contributor to soil health delivering a range of benefits such as improved agricultural yields and nutrient dense crops (Lal 2016), maintenance of biodiversity and support to a wide range of ecosystem including the capacity to absorb, store and filter water, resilience to climate change and extreme weather events, drought and floods (Iizumi and Wagai 2019; Rumpel and Chabbi 2021).

However, decades of intense agricultural production and land use change have caused widespread loss of soil carbon through erosion and emissions from topsoil, causing the Food and Agriculture Organization to declare that the worsening state of soils is at least as important as the climate crisis and the destruction of the natural world above ground (FAO 2015). In response, there has been renewed interest in establishing policies and legislation that go beyond historical instruments to address soil erosion, degradation, and loss of functionality towards introducing soil carbon sequestration (SCS) as a Negative Emissions Technology (NET) for land-based carbon removals and as a nature-based solution for reversing biodiversity loss and climate adaptation.

To date, SCS has been introduced into legislation by several countries, for example Australia (Clean Energy Regulator 2022), and is considered within the European Union proposal for a Soil Law (European Commission 2023). There have also been several initiatives such as Project Drawdown, ‘4 per mille’ (Soussana et al. 2019) and United Nations Food and Agricultural Organisation ‘Recarbonization of global agricultural soils' (RECSOIL). Yet explicit formal measures to increase biogenic carbon removals via SCS occur in less than 15 per cent of the Nationally Determined Contributions (NDCs) to the Paris Agreement on Climate Change and are missing from the first Global Stocktake (Wiese et al. 2021; UNFCCC 2023).

The 2022 Emissions Gap Report (UNEP 2022) draws attention to the fact that food systems are now responsible for one third of greenhouse gas emissions every year. These come from agricultural production (39 per cent), land use changes (32 per cent) and supply chain activities (29 per cent) (Crippa et al. 2021; Tubiello et al. 2022). If current trends were to continue, then by 2050 the contribution of food system emissions could increase by 60–90 per cent taking the world far away from a “net zero” pathway (Mbow et al. 2020).

Food systems therefore need to go beyond simply limiting agricultural emissions and decarbonising supply chains (Costa et al. 2022) and move towards a rapid scaling-up of carbon removals through land-based carbon farming using the growing scientific knowledge about SCS NETs such regenerative agricultural practices biochar application, enhanced weathering, and large-scale afforestation and reforestation (Singh et al. 2023).

The question we asked was whether a single, locally relevant target could be developed for SCS that would encourage widespread adoption of soil carbon removals practices by farmers and land managers globally?

Approach

As a first step we identified a total of 2,352 million hectares (Mha) of agricultural land, using the Landsat Global Land Cover classes of croplands, cropland/other vegetation mosaic and irrigated/paddy fields across Europe (375 Mha), Africa (272 Mha), North America (357 Mha), South America (276 Mha), Asia (1009 Mha) and Australia (63 Mha) (Figure 1). We thus used a more conservative estimate of the area of agricultural land compared to the 4,889 Mha considered by UN FAO (see Data FAO 2022) to reduce uncertainties in attribution of land use.

We then estimated the volumetric effect (tCO_2e) of increasing organic carbon in topsoil (0-30 cm) for every 10 m pixel based on the most probable soil type, bulk density, and coarse fraction. Information on soils came from 210,000 geo-referenced soil profiles, comprising more than 6 million records in World Soil Information Service (see Data WoSIS) and covering all the major soil groups across the climate-edaphic space. Data were reprojected to the Behrmann Equal Area at 1 km resolution. The resulting values for soil organic carbon per cent were converted to tonnes per hectare using following equation: SOC (t/ha) = Soil depth * SOC (per cent) * Bulk Density * (1- Coarse Fraction).

Results

The analysis showed that a one per cent average increase globally in soil organic carbon in croplands, pasture and irrigated fields would have the potential to sequester 84.9 GtC or 311 $GtCO_{2\text{-}e}$ [range 159 – 447 $GtCO_{2\text{-}e}$], where the uncertainty arises from estimates of bulk density and the coarse fraction of soils.

The global GHG emissions in 2030, based on current policies, have been estimated at 58 GtCO2e (UNEP 2022). The figure of 311 GtCO2e therefore represents more than a decade of emission reductions at 15 GtCO2e per year for a 66 per cent chance of staying below a 2°C pathway, or eight years of a reduction of 23 GtCO2e to have a higher possibility of keeping on a 1.5°C pathway.

Discussion

Without significant changes to global emissions reductions, we are likely to see an increase in global temperatures of 2.8°C. Based on new and updated NDCs, projected emissions in 2030 will only be reduced by 0.5 GtCO2e, meaning that even with a full implementation of NDCs, we will be far from being on track to reduce GHG emissions by 45 per cent over the next eight years. SCS presents an opportunity to enhance carbon removals across the world and at the same time address critical issues such as food security and enhancing resilience to extreme climate-related events.

Critics of SCS cite the difficulty of ensuring long-term storage and sequestration of carbon with respect to temperature increases (Wang et al. 2022), changes in ecosystem functions and loss of soil microbial activity (Patoine et al. 2022), soil stabilisation (Hartley et al. 2021) and mineralogical capacity (Georgiou et al. 2022). However, to overlook the potential opportunity that SCS represents for GHG removals does not make sense; we need to implement as many viable NET approaches as possible.

The focus should therefore be on supporting activities to improve soil carbon storage as a first stage towards increasing the long-term sequestration trajectory of the terrestrial carbon sink, even in marginal lands in arid areas or where there are ancient soils with very low levels of soil carbon. While this may be challenging, reports of long-term increases in soil organic carbon across a wide range of farms globally indicate that certain practices are succeeding (e.g., Knox et al. 2023). These include sustainable livestock production practices; regenerative agriculture and agroecology; application of lime or gypsum to remediate acid, sodic or magnesic soils; establishing, re-establishing or rejuvenating pasture; altering stocking rates, and duration or intensity of grazing; retaining stubble after crops are harvested; converting from intensive tillage practices to reduced or no tillage practices; modifying landscape or landform features to remediate land; using mechanical methods to add or redistribute soil; using legume species in cropping or pasture system; and using cover crops to promote soil vegetation cover or improve soil health or both.

Is a one per cent target better than approaches such as RECSOIL or the 4 per mille approach? The underlying methodology used in our calculation is based on data and information about local soil types and current land use rather than a generic calculation based on an estimate of the global carbon stock. It is therefore a better reflection of local carbon storage and sequestration capacity of soils. In addition, most farmers and land managers regularly test their soils and are familiar with the soil organic matter or carbon percentage of their land; this means that using a target based on a percentage increase is far easier to communicate and understand.

Suitable financial instruments and policy measures will still be needed to support the poorest farmers and landowners shift their agricultural practices towards implementing SCS (Crippa et al. 2021). But adopting SCS practices globally will not only mean greater food security for the millions of small-holder farmers but ensure that millions of hectares of land will contribute to the solution of achieving net zero outcomes by 2050 rather than being the cause of climate change.

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Figure

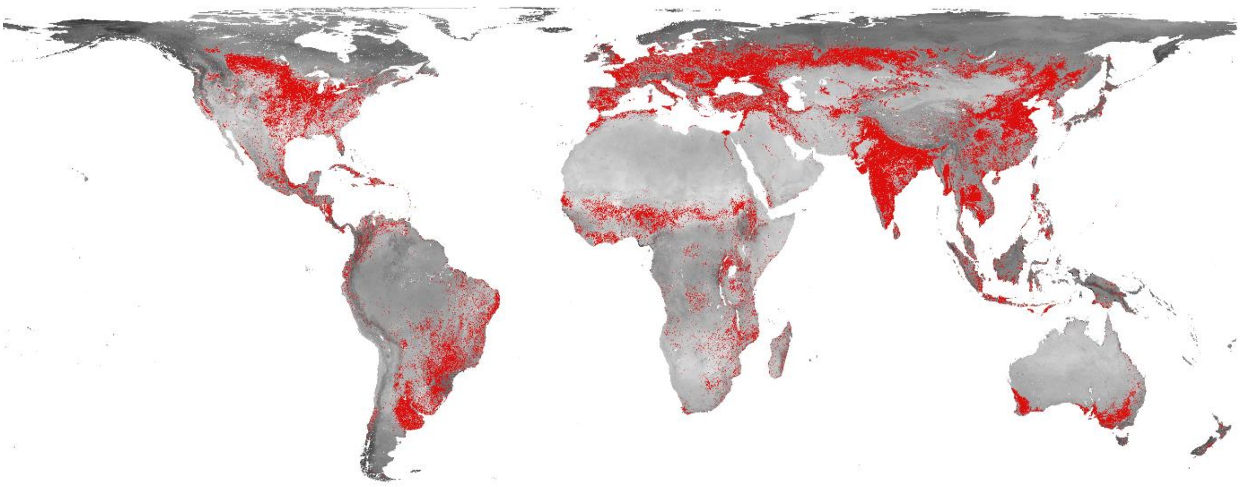

Figure 1 Map of the Landsat Global Land Cover classes croplands, cropland/other vegetation mosaic and irrigated/paddy fields used in the analysis.

Data

All the data used in the analysis are publicly available.
Food and Agriculture Organization of the United Nations (2021) http://www.fao.org/food-agriculture-statistics/data-release/data-release-detail/en/c/1454718/
All the soils data used in the analysis can be found at the World Soil Information System (WOSIS) https://www.isric.org/explore/wosis.

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Author contribution statement

JMG formulated the ideas, reviewed the calculations, and wrote the manuscript; KM undertook the calculations.

Authorship: Ethics and inclusion

The responsibilities were agreed between the two authors; recognition of the organisations involved in the local data collection is provided through the World Soil Information Service https://www.isric.org/explore/wosis

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.