Soils and climate change

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Abstract

- Soils contain vast reserves (ca. 1500 Pg C) of carbon, about twice that found as carbon dioxide in the atmosphere. Historically, soils in managed ecosystems have lost a portion of this carbon (40–90 Pg C) through land use change, some of which has remained in the atmosphere.

- In terms of using soils to mitigate climate change, soil C sequestration globally has a large, cost-competitive mitigation potential.
- Nevertheless, limitations of soil C sequestration include time-limitation, non-permanence, displacement and difficulties in verification.

- Despite these limitations, soil C sequestration can be useful to meet short-term to medium-term targets, and confers a number of co-benefits on soils, making it a viable option for reducing the short term atmospheric CO_2 concentration.

Introduction

- In this short review, I outline recent evidence of potential responses of soils to climate change, and then outline recent evidence on the possible role of soil C sequestration in climate mitigation, and discuss some limitations associated with this method of climate mitigation.

The impact of climate change on soils.

Soils in the global carbon cycle

- Globally, soils contain about 1500 Pg of organic carbon, about three times the amount of carbon in vegetation and twice the amount in the atmosphere. The annual fluxes of CO_2 from atmosphere to land (global Net Primary Productivity [NPP]) and land to atmosphere (respiration and fire) are each of the order of 60 Pg C y^{-1}.
- The size of the pool of soil organic carbon (SOC) is large compared to gross and net annual fluxes of carbon to and from the terrestrial biosphere.

- During the 1990s, fossil fuel combustion and cement production emitted 6.3±1.3 Pg C y^{-1} to the atmosphere, while land-use change emitted 1.6±0.8 Pg C y^{-1}. Atmospheric C increased at a rate of 3.2±0.1 Pg y^{-1}, the oceans absorbed 2.3±0.8 Pg C y^{-1} with an estimated terrestrial sink of 2.3±1.3 Pg C y^{-1}.

- Soil carbon pools are smaller now than they were before human intervention. Historically, soils have lost between 40 and 90 Pg C globally through cultivation and disturbance.

- Small changes in the soil organic carbon pool could have dramatic impacts on the concentration of CO_2 in the atmosphere.
- The response of soil organic carbon to global warming is, therefore, of critical importance.

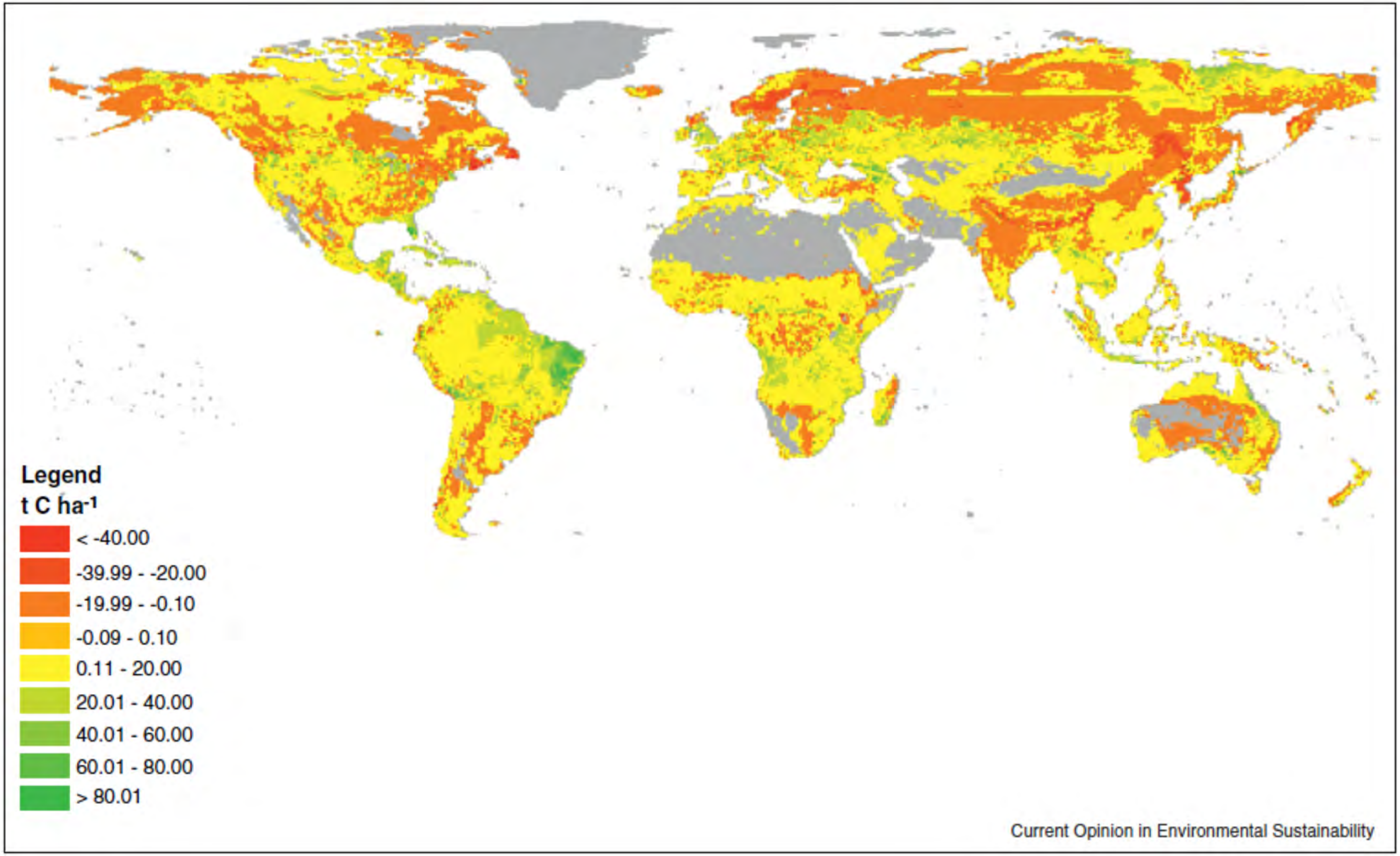
The response of soils to future climate change

- The level of SOC in a particular soil is determined by many factors including climatic factors (e.g. temperature and moisture regimes) and edaphic factors (e.g. soil parent material, clay content, cation exchange capacity).

Fig. 1

- The spatial heterogeneity in the response of SOC to changing climate shows how delicately balanced the competing gain and loss processes are, with subtle changes in temperature, moisture, soil type and land use interacting to determine whether SOC will increase or decrease in the future.

Figure 1



Average trend in SOC stock change 1971–2100 across 10 climate scenarios (after Gottschalk *et al.*, 2012).

- Given this delicate balance, we should stop asking the general question of whether soils will increase or decrease in SOC under future climate as there appears to be no single answer. Instead, we should focus on our research efforts on improving our prediction of factors that determine the size and direction of change, and the land management practices that can be implemented to protect and enhance SOC stocks.

The role of soils in mitigating climate change

- Increasing soil C stocks to combat climate change (soil carbon sequestration)

Carbon stocks in the soil can be increased in managed ecosystems by optimising ‘best management practices’.

- Increased carbon stocks in the soil increase soil fertility, workability, water holding capacity, and reduce erosion risk.
- Increasing soil carbon stocks can thus reduce the vulnerability of managed soils to future global warming.

Management practices effective in increasing SOC stocks

- Improved plant productivity (through nutrient management, rotations, improved agronomy),
- Reduced/conservation tillage and residue management,
- More effective use of organic amendments, land-use change (crops to grass/ trees),
- Set-aside, agroforestry, optimal livestock densities,
- and legumes/improved species mix.

- While these measures have the technical potential to increase SOC stocks by about 1–1.3 Pg yr^{-1},
- the economic potentials for SOC sequestration were estimated to be 0.4, 0.6 and 0.7 Pg C yr^{-1} at carbon prices of 0–20, 0–50 and 0–100 USD t CO_2-equivalent^{-1}, respectively.

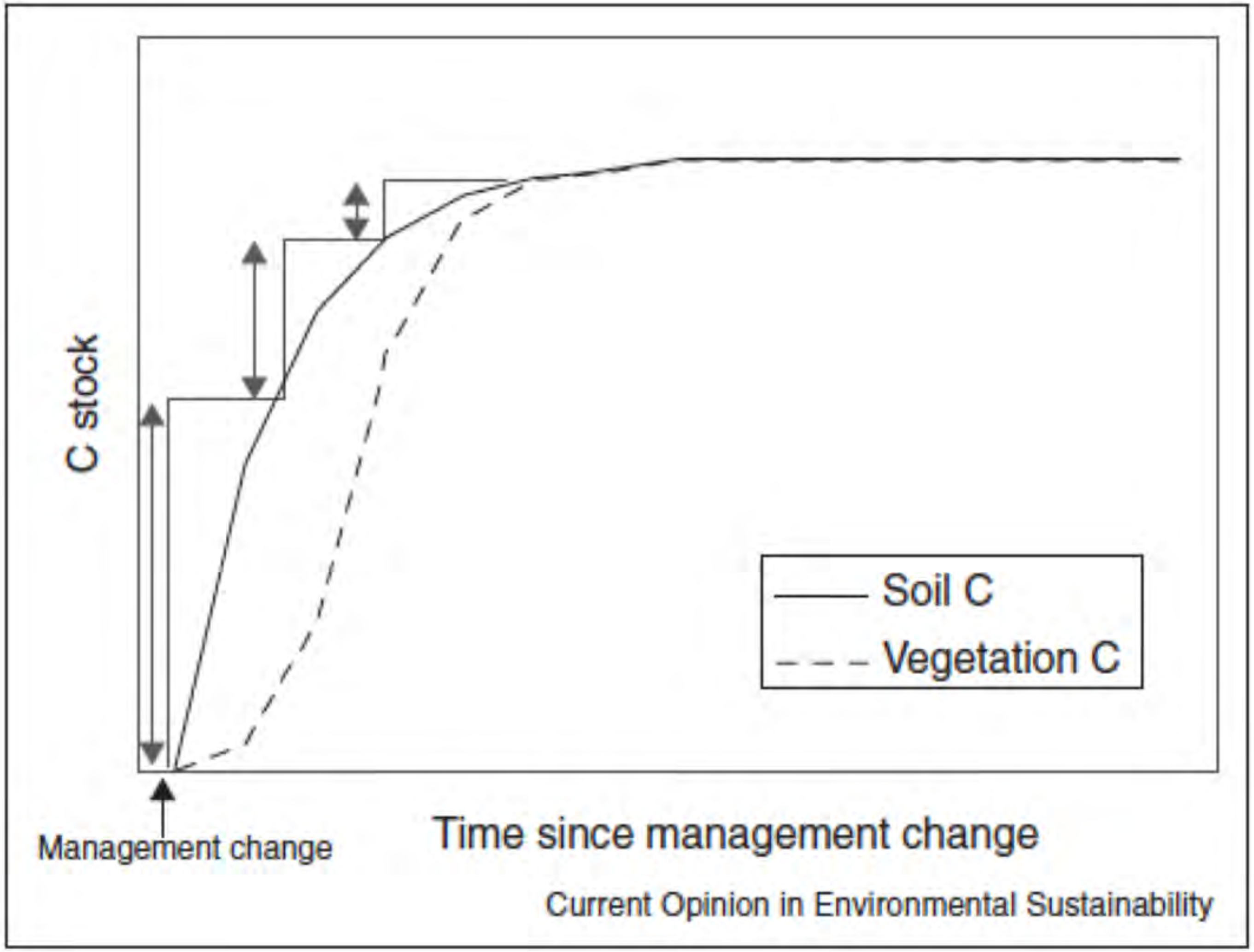
- A small loss of C from permafrost or peatlands could offset this potential sequestration,
- but the increase in SOC engendered by improved management is expected to also reduce vulnerability of the soils to future SOC loss under global warming.

- As such, soil carbon sequestration can, in many respects, be regarded as a ‘win-win’ and a ‘no regrets’ option.

Drawbacks associated with soil carbon sequestration as a climate mitigation measure

- Saturation of the carbon sink
- Non-permanence
- Leakage/displacement
- Verification issues
- Total effectiveness relative to emission reduction targets

Saturation of the carbon sink



- Carbon sequestration in soils (and indeed in vegetation) is therefore time-limited and finite.
- Improved management needs to be maintained indefinitely to maintain the higher soil carbon stocks, but with no additional sink benefit.

Non-permanence

- A soil carbon stock that has been increased by improved soil management will rapidly lose carbon unless the improved management is maintained.
- The rate of C loss is more rapid than the rate of gain.
- Carbon sequestered in the soil (and in vegetation) is non-permanent, presenting a risk of future release

Leakage/displacement

- If the organic matter applied to the area gaining in carbon would otherwise have been applied in another area, the other area would lose carbon.
- Displacement/leakage also occurs where land use change to increase carbon stocks in one area leads to land use change that causes carbon release in another area in a process termed indirect land use change.

Verification issues

- Changes in soil carbon are small compared to the large stocks of carbon present in the soil, meaning that the change in carbon stock can be difficult to measure, presenting problems for monitoring, reporting and verification.

Total effectiveness relative to emission reduction targets

- Soil carbon sequestration is an important climate mitigation strategy, but it is not a panacea for greenhouse gas emission reduction.
- Only a fraction of the reduction can be achieved through sinks.

- The carbon that humans are currently releasing through fossil fuel use has been locked up in the geosphere for hundreds of millions of years, and was accumulated over many millions of years.
- Using the biosphere to capture this geospheric carbon does not add up — the geospheric carbon released is too large for the biosphere to effectively store.

- Given this knowledge, reducing carbon emissions is obviously more important than attempting to sequester the carbon after it has been released.

Conclusions 1

- In terms of using soils to mitigate climate change, soil C sequestration globally has a large, cost-competitive mitigation potential.
- Soil C sequestration can be useful to meet short term to medium term targets, especially if these targets are large.

Conclusions 2

- Increasing soil C stocks provides many co-benefits in terms of soil fertility, workability, water holding capacity, nutrient cycling, reduced emission risk and a range of other positive soil attributes.

Conclusions 3

- These arguments for using carbon sequestration for climate mitigation need to be weighed against the limitations discussed above, for example, time-limitation, non-permanence, displacement and difficulties in verification.

Conclusions 4

- Despite these limitations, soil C sequestration may have a role in reducing the short term atmospheric CO_2 concentration, thus buying time to develop longer term emission reduction solutions across all sectors of the economy.