COMMENTARY:

Aligning agriculture and climate policy

A. Chabbi, J. Lehmann, P. Ciais, H. W. Loescher, M. F. Cotrufo, A. Don, M. SanClements, L. Schipper, J. Six, P. Smith and C. Rumpel

The 4‰ initiative to sequester carbon in soils has the potential to connect sustainable development goals, enhance food security and mitigate climate change by utilizing waste organic residues.

Our climate is changing with potentially severe implications for human life if we are not able to limit the global average temperature increase to below 2 °C. Global models indicate that this target can only be met in the long term with negative emissions[1], that is, carbon removal from the atmosphere. It has long been suggested that carbon sequestration in soils may be a significant climate mitigation wedge[2]. Although much research has been devoted to increasing organic carbon (OC) sequestration by managing soils, it has not been part of negotiations for the United Nations Framework Convention on Climate Change. However, ahead of COP21, a voluntary action plan was proposed, which included the 4‰ initiative (www.4p1000.org), focusing on soil OC (SOC) sequestration to mitigate climate change and improve food security. Since then, public awareness of soils as C sinks has grown and the possibility of effectively counterbalancing anthropogenic emissions by increasing the OC content of soils has become an attractive alternative to other climate mitigation measures due to its numerous co-benefits. The soils of cultivated ecosystems may serve this purpose because they are already managed for food production, because they present opportunities for restoring SOC stocks due to historical losses, and because organic residues from various sources, often considered as a waste, could be used to build SOC.

Here we discuss the specific road map, implications, expected benefits and limitations of this initiative. We suggest a strategy to increase SOC sequestration by increasing C-use efficiency across sectors and itemize concrete scientific, socio-economical and political strategies to achieve this aim.

Connecting development goals

The 4‰ initiative is part of the Lima Paris Action Agenda and is supported by the United Nations Food and Agriculture Organization. Its goal is to increase SOC annually by 4‰ of its current stock through the implementation of economically viable and environmentally sound agronomic practices. If these practices were applied to all global soils, it would amount to a net CO_2 removal of 6 Gt C y^{-1} from the atmosphere, which would offset two-thirds of the annual anthropogenic CO_2 emissions (Table 1). Since not all global soils are managed, an achievable potential is more likely to be limited to ~1 Gt OC y^{-1} (ref. 3). This is, nevertheless, substantial and would offset the fossil-fuel emissions equivalent to those of a large emitter such as the European Union.

Moreover, increasing SOC storage, as proposed by the 4‰ initiative, is important for restoring agricultural soil quality, which has declined under intensive agricultural management. Indeed, high demand on soils for food production has led to SOC loss over the past century. When SOC is lost, soils become prone to erosion and may no longer be able to fulfil their multiple functions. The primary function of agricultural soils is food production, but they are increasingly used for provision of a range of other ecosystem services[4] at the nexus of agriculture, energy and environmental protection. Increasing SOC storage, as proposed by the 4‰ initiative, is thus crucial for restoring agricultural soil quality, and is also in the interest of landowners. Increased SOC storage may improve farmers' income through enhanced soil productivity, lower fertilizer requirements and sustained yields[5]. However, at present, these additional benefits to farmers remain largely unquantified.

Tackling national and global food security issues and climate policy together has strong political appeal and applies science to societal needs. The 4‰ initiative is a concrete example

Table 1 | Mass balance of the global stocks and fluxes to and from the atmosphere to elucidate the 2004–2014 data.

Carbon stocks and fluxes	
Atmospheric C stock* (Gt)	414
Top soil (0–0.3 m) organic C stock* (Gt)	690 ± 90
Total soil (0–0.4 m) organic C stock* (Gt)	860
Total soil (0–1 m) organic C stock* (Gt)	1,500 ± 230
Proposed 4‰ of total soil (0–1 m) organic C stock (Gt)	6.0 ± 0.92
Annual fossil-carbon emissions (flux to atmosphere)† (Gt y^{-1})	9.8
Annual land use change C emissions (flux to atmosphere)† (Gt y^{-1})	0.9
Annual net land C sink (2005–2014)*,† (Gt y^{-1})	-3.2
Annual net ocean C sink (2005–2014)*,† (Gt y^{-1})	-2.7
Rate of increase of atmosphere C (2005–2014)‡ (Gt y^{-1})	4.7

A negative sign indicates a flux from the atmosphere to the biosphere; ± values denote 1 s.d; units are given in brackets. *Does not include permafrost[14]; †GCP 2014, only includes CO_2 sources, does not include non-CO_2 sources of greenhouse gas emissions[15]; ‡http://go.nature.com/2nTK1oA and http://go.nature.com/2oVQyyC

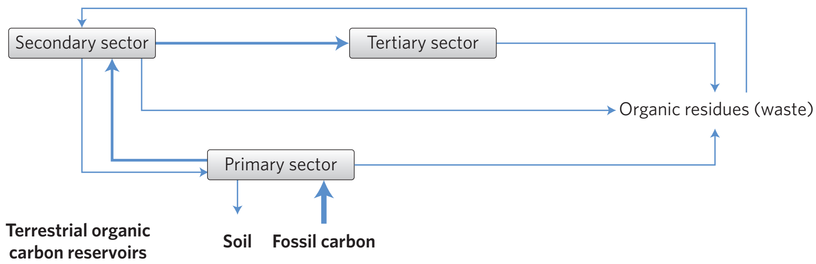

Figure 1 | Conceptual diagram depicting C flow in a system with C-use optimization among sectors. In such a system, organic wastes are transformed into soil amendments.

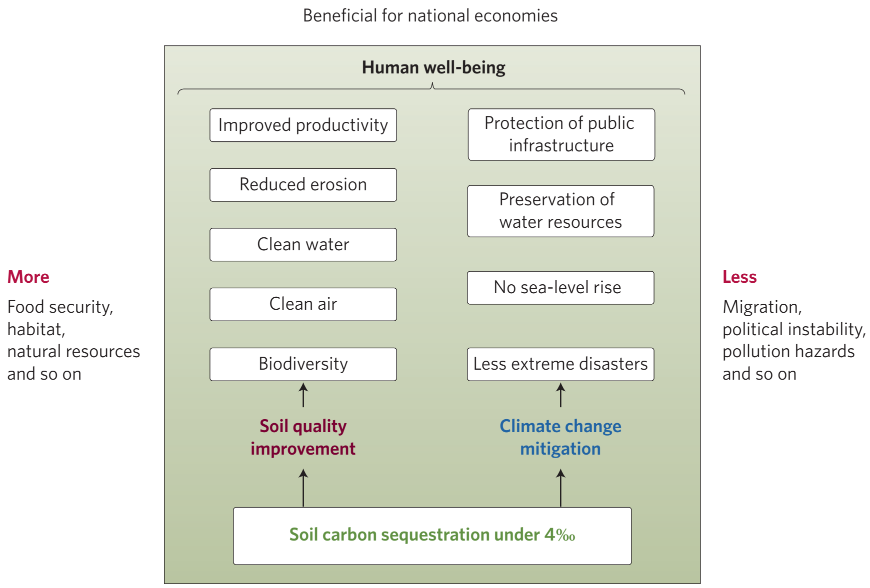

Figure 2 | Societal benefits gained from soil carbon sequestration.

of connecting the priorities of the sustainable development goals.

Improving OC flow connectivity

In addition to improved agricultural management, intensification of organic residue recycling as part of a circular economy may be a promising strategy for increasing SOC sequestration. Transformation of such waste materials is intended to generate organic amendments ready for agricultural use[6]. This requires improving the connectivity between organic residue production and transformation systems and needs to take into account the associated nutrient budgets. Moreover, site-resolved and time-resolved solutions have to be developed. Improvement in the C-use efficiency should bring together different socio-economic sectors, to identify:

- The most suitable soils to receive and store SOC, for example, soils which have been historically depleted, or those with mineralogical and physical properties favourable for SOC retention[7].
- Sources of organic wastes and their suitability.
- Appropriate, site-specific transformation strategies, including composting, pyrolysis and hydrothermal carbonization.

In a nutshell, we argue that the critical path of the 4‰ roadmap is to ameliorate OC (and nutrient) use efficiency to channel organic waste to soil pools, across sectors (Fig. 1), taking into account regional and societal differences in different parts of the world. This approach would greatly benefit from merging the development of digital agriculture and smart grids for energy and carbon. From a global perspective, across sectors, the effective implementation of organic waste recycling under the 4‰ initiative would benefit from improvement of the connectivity of organic matter flows. Organic matter use should be as diverse as possible and as long as possible before C returns to the atmosphere as CO_2.

Economic co-benefits and trade-offs

There are strong competing economic interests for the use of land and organic matter, for example, for biofuels[11] or for other purposes, such as livestock, home heating, and cooking. The important value of the 4‰ initiative is to broaden the view to multi-purpose beneficial soil management systems that take into account the various ecosystem services of productive, healthy soils with enhanced SOC content. However, while it is generally considered that SOC provides these services, this is not always the case[8]. There is a paucity of information demonstrating the benefits of increasing SOC across a range of different soils, agro-ecosystems and climatic zones. Here, scientific meta-analysis, data harmonization, improved data sharing and access as well as spatially-explicit data-driven and user-friendly modelling alongside large-scale experimentation (for example, http://www.anaee.com) would greatly facilitate the decision-making process about the real economic return of adding OC to cultivated soils.

The momentum derived from the 4‰ initiative shows rare political will. But political willingness itself will only make the 4‰ initiative effective for large-scale removal of CO_2 if it is accompanied by substantial social and economic investment, for example, by the rehabilitation of degraded soils. About 24% of the world's arable soils are degraded[9], and increasing their OC stocks is required for their rehabilitation. Degraded soils also have the largest potential for improving soil functionality through OC addition. One practical way to help reach the 4‰ goal is thus to demonstrate the quantitative co-benefits of SOC and their economic value to land owners, for conditions close to those they experience every day.

Balancing social priorities globally

Adoption of adequate management practices, as well as exogenous organic matter inputs, may face conflicting priorities concerning sustainable development goals in tropical and temperate regions. For example, while enhancing food production is still the major goal in many tropical countries, environmental protection policies may be of higher concern in temperate areas, where food supply is more secure. While social acceptance and legislation for use of transformed organic waste materials to increase SOC are necessary in temperate countries, resource availability and economic competition with other uses of organic wastes (for example, as a fuel, building material, or animal feed) may be a barrier in many tropical countries. Such utilization of local waste has short-term economic return compared to the long-term benefits of SOC sequestration.

In less-developed countries, the societal impact of adopting the 4‰ goals is likely to be much greater through improved food production than in countries with intensive agriculture. Food insecurity has been identified as a driver of conflicts[10] and migration[11]. Increasing soil fertility and food production in less-developed countries, to which SOC sequestration can significantly contribute, addresses inequity issues and global geopolitical challenges (Fig. 2). Therefore, for the first time, interests of developed and developing countries merge through the common objective to increase SOC contents.

The way forward

The 4‰ initiative was proposed as one approach to offset current CO_2 emissions, while contributing to food security and a healthier environment. Compared to other climate mitigation measures, the science basis to increase SOC stocks and to measure the effectiveness of C sequestration is mature. The basic processes leading to SOC sequestration have been identified[12] as have the management practices to be implemented[13]. Implementation of SOC storage under the 4‰ initiative is feasible even in developing countries, because it does not require new technological breakthroughs. Since SOC storage can be practiced on current agricultural land and grassland, it does not take land out of agricultural production, as is the case for, for example, afforestation.

However, there are scientific, political, and socio-economical issues with its large-scale implementation. We need to identify soils and agro-ecosystems most suitable to increase SOC sequestration and quantify the economic benefits of additional C storage for different soil types, climate zones, production systems and farming capabilities, beyond C credits. The connectivity of C flows across sectors needs to be assessed and optimized to maximize environmental and socio-economic benefits, before CO_2 is released back to the atmosphere. Detailed region-specific implementation options will have to be established to build concrete success stories. And finally, the implementation success of the 4‰ initiative will depend on our ability to improve global governance and regional collaboration between actors and across sectors, and to communicate the benefits of SOC sequestration through the consumer supply chain. ❐

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Author contributions

A.C. initiated the writing of the paper and led the work. C.R. wrote the first version of the manuscript and prepared the figures. All authors contributed with ideas, and participated in the writing of the paper.