



Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Letter to Editor

A critique of the paper 'Soil carbon 4 per mille' by Minasny et al. (2017)

ARTICLE INFO

Handling Editor: Dr. Jan Willem van Groenigen

Keywords:

Soil organic carbon
Carbon sequestration
Cost and benefits
Greenhouse gas abatement
Climate change

The aspirational concept — '4 per mille Soils for Food Security and Climate' — was launched at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change in Paris in December 2015. According to Minasny et al. (2017), the concept is based on the crude calculation that if anthropogenic emissions of fossil carbon (C) are 8.9 G (G) tonnes (t) per annum and the global soil C stock to 2 m soil depth is 2400 Gt, then the annual increase in global soil organic carbon (SOC) required to offset these emissions is 8.9/2400, or approximately 0.4% or 4‰ (4 per mille). Minasny et al. (2017) support this concept suggesting that, if achieved, it could 'effectively offset 20–35% of global anthropogenic greenhouse gas emissions'. We submit that the 4 per mille concept is flawed and we challenge the optimistic conclusions of the Minasny et al. (2017) paper for the following reasons.

Taken literally, the 4 per mille concept implies that soil carbon will increase indefinitely each year by a slightly bigger increment as the amount of carbon in the soil increases, in an analogous way to the effect of compound interest on money in a bank. This is unrealistic.

Minasny et al. (2017) recognize, as have many other authors (e.g. Lal, 2004; Lam et al., 2013; Sanderman et al., 2010), that 'the potential to increase SOC is mostly on managed agricultural lands' through the implementation of best or recommended management practices. However, the figures they quote for average rates of SOC increase for several of these practices are too high.

To match an increase in SOC, converted to t CO₂-equivalent (e), to an equivalent abatement of greenhouse gas (GHG) emissions ignores, as the authors have done, the need to calculate the *net* changes in all the GHG, including methane (CH₄) and nitrous oxide, that may occur as a result of the management change. Only in this way can the true abatement of a practice change be evaluated.

Changes in crop yields and associated changes in soil properties as measured in research experiments can rarely be matched on commercial farms.

The paper does not address the financial incentives/disincentives that farmers may need to take into account when considering whether to change their farming operations in the expectation of sequestering SOC. For those farming for profit, this consideration is crucial.

We briefly elaborate on these points as follows.

Soil carbon dynamics. There is evidence in the literature that, upon a change in farm management or land use, such as adding farmyard manure to soil, converting from conventional tillage to no-till or from cropping to pasture, SOC approaches a new steady-state equilibrium value asymptotically (Smith et al., 1996). The asymptote is reached when the overall rate of organic matter decomposition in the soil equals the annual input rate of organic material. This is contrary to the 4 per mille concept that envisages SOC increasing exponentially. Minasny et al. recognize this reality, giving examples in their Figs. 15 and 16 of the diminishing increment in SOC as time elapses. However, they also include the contradictory statement attributed to the USEPA on p.74 that 'a target for SOC increase of 68 Mt./yr by 2025 would, *if compounded at 0.4%* (our italics), reach 75 Mt./yr by 2050. Clearly this is unrealistic.

The time span for the attainment of the new equilibrium can vary up to 100 years (Smith et al., 1996; Soussana et al., 2004) depending on several factors, including the soil texture and structure, the amount and type of extra organic material that is added each year, and environmental conditions such as temperature, soil moisture and degree of soil disturbance.

Estimates of C sequestration rates. Minasny et al. (2017) summarize SOC accumulation rates for various countries and climatic conditions as: afforestation (~0.6 t C/ha/yr), conversion to pasture (~0.5 t C/ha/yr), organic amendments (~0.5 t C/ha/yr), residue incorporation (~0.35 t C/ha/yr), no or reduced till (~0.3 t C/ha/yr), and crop rotation (~0.2 t C/ha/yr). Whereas the figures for afforestation and conversion to pasture can be justified, from the data given in their Table 1 we calculate the median values for residue incorporation (including stubble retention), no or reduced till, and crop rotation to be 0.19, 0.16 and 0.09 t C/ha/yr, respectively. We exclude organic amendments from the calculation because in most cases this is merely transferring C material from one site to another and is therefore not a true contribution to abating GHG emissions (Powlson et al., 2011). There is much variation in the data reported from different countries, but the figures we have calculated for the three practices are approximately half those given by Minasny et al. (2017). Furthermore, Powlson et al. (2014) concluded from a literature review that there was

limited potential for no-till agriculture to mitigate climate change.

It is instructive to compare these results with other sources such as the Australian government's Carbon Farming Initiative (CFI), whereby farmers can earn C credits for storing C in the soil for a long period. In the current scheme, three project management activities (PMAs) were recognized for crediting purposes for 25 or 100 years – sustainable intensification (involving nutrient management, new irrigation, managing soil acidity or pasture renovation), stubble retention and conversion to pasture (Australian Government, 2015). The sequestration values were derived from the Full Carbon Accounting Model (FullCAM) for four regions of different sequestration potential ('zero', 'marginal', 'some' and 'more'). For those regions where 'more benefit' was expected, the values for the three PMAs quoted above were 1.65, 0.73 and 0.84 t CO₂-e/ha/yr, respectively, corresponding to 0.45, 0.20 and 0.23 t C/ha/yr. Clearly, the designers of the CFI were taking a more conservative approach to C sequestration potential than might be deduced from the figures of Minasny et al. (2017).

Calculating true C abatement. An underlying principle of any C sequestration scheme is that true abatement of GHG emissions must be calculated from the net change in emissions resulting from a practice change. We illustrate this point using the methodology of the Australian CFI. For example, White and Davidson (2016) found that for stubble retention on New South Wales (NSW) or Victorian wheat farms the net C abatement was 0.66–0.68 t CO₂-e/ha/yr (0.18 t C/ha/yr) for the 'more benefit' regions. This figure agrees well with the figure of 0.19 t C/ha/yr for stubble retention we calculate from Minasny et al. (2017), primarily because the net change in emissions for the change from no retention to stubble retention is very small. However, the net C abatement for conversion to pasture (irrigated or dryland) grazed by cattle or sheep was much smaller than 0.23 t C/ha/yr, except for a change to dryland sheep in NSW, primarily because of the CH₄ emissions from the grazing animals.

Experimental yields versus real farm yields. Davidson and Martin (1968) showed from a meta-analysis of yields for a range of crops that district farm yields consistently fell below yields for individual crops obtained in experiments in the same district. This difference occurs because in research trials, factors other than the studied factor are intentionally optimized, whereas on real farms this is often not the case – for example, in respect of economic factors that influence farmers' management decisions (see below). Davidson and Martin (1968) concluded that when some factors are in limited supply under farm conditions, 'we can expect farm yields are much smaller than their experimental counterparts'. In this case the return of C materials to the soil will be smaller and hence gains in SOC smaller than reported in experiments. As Minasny et al. (2017, p.80) acknowledge, 'in most countries, sequestration rates are mostly based on long-term experiments and soil legacy data'. Hence in those examples drawn from experimental results (e.g. Chan et al., 2011; Majumder et al., 2008; Powlson and Johnston, 2015), estimates of SOC increase should probably be discounted when applied to real farm situations.

Costs versus benefits of C sequestration. A major determinant of whether farmers can be persuaded to 'farm carbon' is whether the practice change required is financially viable. Minasny et al. (2017) make brief reference to the Australian government's CFI and to Paustian et al. (2016), who wrote about C trading and the C credits that might be needed to persuade farmers to change their practices to store more soil C. White and Davidson (2015) used the CFI methodology to analyse the cost-effectiveness of a change from cropland to pasture using Australian examples. At a time when the Australian government's legislated price of a C credit was AUD24.15/t CO₂-e, the change was not cost-effective for a farmer, except for irrigated wheat or dryland cotton converted to cattle or sheep. The main determinant of this outcome was the price of wheat, which was relatively low at AUD200 per t, and the low value of dryland cotton. However, this analysis did not include the farmer's costs in making the change (extra fencing and watering for example).

We conclude that getting the economic framework right is the key to enhancing soil C sequestration. It may well be that a taxpayer subsidy, through government intervention as in Australia and California for example, is the best way forward, unless soil C can be shown to be such a valuable commodity that it has a tradable value well above present levels: currently USD3.3/t CO₂-e in the voluntary international C market (Hamrick and Goldstein, 2016) or less than USD10/t CO₂-e for 75% of global emissions under government mandated schemes (World Bank, 2016). Through science we should be able to quantify more precisely the benefits of SOC increase on soil productivity and resilience, so that a monetary value can be attributed to SOC increase, rather than relying on the 'motherhood statements' made at present. Another area in which science can make a significant impact is in better methods of measuring SOC change in the field (e.g. De Grujter et al., 2016) to give more certainty to farmers and policy makers, and in identifying spatially, at a high resolution, those areas where the most significant changes in SOC are likely to be achieved.

For the reasons given in our analysis, we believe that a global GHG offset of 20–35% through soil C sequestration is a gross overestimate. However, we agree with Minasny et al.'s (2017) statement that 'only radical land use change coupled with enhanced C sequestration technology has the potential to mitigate climate change'. We think it important not to be unrealistically optimistic about the potential for soil C sequestration as a GHG abatement mechanism, given the claims made by various commercial companies and organic farming organizations for the more or less unlimited potential of soil C storage to solve the GHG problem (e.g. www.sba.asn.au/sba/bioccs.asp; www.healthysoils.com.au; <http://02f.e55.myftpupload.com/wp-content/uploads/2016/03/Rodale-Institute-White-Paper-1.pdf>). For farmers to change to a practice that stores more soil C (and is not a common practice already in the district) they must be able to do it at no net cost, or preferably at increased profit, which is not often the case when a C credit is less than USD10/t CO₂-e. However, for productive farmers that do make the change, while not contributing much to abating a nation's GHG emissions, the money paid could be seen as a taxpayer contribution to improving the resilience of the soil under future climate change, that is, improving adaptation rather than mitigation.

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