Geoderma xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Geoderma

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

Letter to Editor

Rejoinder to Comments on Minasny et al., 2017 Soil carbon 4 per mille Geoderma 292, 59–86

ARTICLE INFO

Handling Editor: Dr. Jan Willem van Groenigen

1. Introduction

We thank the authors for their thought-provoking comments on our paper. Most of the commentators agree that soil organic carbon (SOC) sequestration is important for improving the quality of soil, however they argue that we have overstated the potential of soil carbon sequestration. We welcome the comments and appreciate that the issue of SOC sequestration has always been somewhat factious (Schlesinger, 2000). We shall address the significance of the quantity "4 per mille", reported sequestration rates, the limitation of carbon sequestration with time, and nutrient requirements. We clarify that our paper (Minasny et al., 2017) mainly deals with potentials for the 20 countries and regions, where SOC sequestration can also be seen as a way to improving the resilience of the soil to future climate change, that is, improving adaptation rather than mitigation. We believe that in some parts of the world where food security is threatened, the benefit of soil carbon management for adaptation should be stressed more than for mitigation. This is the reason why the 4 per mille initiative explicitly includes food security (Chabbi et al., 2017; Soussana et al., 2015).

We need to add that the "4 per mille Soils for Food Security and Climate" initiative is just one of many national and global initiatives on SOC sequestration for mitigating climate change. The Intergovernmental Technical Panel on Soils (ITPS) of the Global Soil Partnership (GSP) discussed incorporating the topic of SOC in the IPCC Assessment Report (ARs), from AR6 onwards. The IPCC has also put a focus on soil in their upcoming special report "Climate Change and Land" (http://www.ipcc.ch/report/sr2/). The recent FAO Global Symposium (GSOC17) assembled experts engaged in FAO, GSP and its ITPS, IPCC, UNCCD-SPI and WMO activities to work together for the common goal of appropriate SOC management as part of overall sustainable soil management within the climate change mitigation and adaptation, sustainable development, Land Degradation Neutrality (LDN) and food security agendas (http://www.fao.org/about/meetings/soil-organic-carbon-symposium/en/). The Global Research Alliance on Agricultural Greenhouse Gases (GRA) focused on opportunities to reduce agricultural greenhouse gas emissions and increase soil carbon sequestration while still helping to meet food security objectives (http://globalresearchalliance.org/about/). The Common Agriculture Policy in the EU is currently being revised to include the potential use of SOC as an indicator.

The 4 per mille initiative was launched at COP21, where the Paris Agreement was adopted, and one of the main aims of the Paris Agreement is to stop the planet from warming an additional two Celsius degrees. The two-degree target, although suggested by scientists through modelling work, was chosen more for political and pragmatic reasons whereby countries could agree on a target that they could work towards (Tollefson, 2015). And of course, there are many scientific critiques of this target (Knutti et al., 2016). Similarly, the 4 per mille initiative comes from a politically-driven aspiration, and our paper (Minasny et al., 2017) is a response to such an aspiration, to seek and outline possibilities based on current knowledge. The important concept is that soil and agriculture are part of the solution, and it is an interim and evidence-based solution that we can implement. Now we shall respond to each of the commentaries.

2. De Vries (in this issue)

2.1. *The rationale behind the initiative*

De Vries is concerned by the fact that we have made an erroneous interpretation of the 4 per mille initiative. De Vries is correct, if we follow the following quote, (http://4p1000.org/understand), the 4‰ initiative claims that: "A 4‰ annual growth rate of the soil organic carbon stock would make it possible to stop the present increase in atmospheric CO_2". Therefore the objective of 4 per mille would be to mitigate the annual increase in CO_2 in the atmosphere, around 4.3 Gt C yr^{-1} (Le Quéré et al., 2014, 2015, 2016). The official source of the 4 per mille initiative considers a global SOC stock of 1500 Gt C (to 1 m depth) and if we multiply it by 0.4%, we obtain 6 Gt C, which is more than the annual CO_2 increase in the atmosphere, but less than the fossil fuel emissions.

However, if we quote from Ademe (2015), "An annual 4 per 1000 (0.4%) increase in organic matter in soil would be enough to compensate the global emissions of greenhouse gases". This is again true, if we restrict these emissions to CO_2 emitted by fossil-fuel combustion which is estimated at 8.9 Gt C (for 2004–2013 according to Le Quéré et al., 2015) and the global SOC stocks of 2400 Gt C (to 2 m depth) and the ratio 8.9/2400 is used to derive the 4 per mille figure (in fact, it should be 9.6/2400 = 0.4%).

Even more remarkable is that the first appearance of the 4 per mille figure in the literature (to our knowledge) is from Balesdent and Arrouays (1999) who wrote (translated from French): "A relative increase of total SOC stocks by 0.4% would mitigate the global fossil fuel emissions". These

http://dx.doi.org/10.1016/j.geoderma.2017.05.026
Received 2 May 2017; Accepted 2 May 2017
0016-7061/

authors based this estimation on a global SOC stock of about 1600 Gt C down to 1 m (Batjes, 1996) which, when multiplied by 0.4% gives 6.4 Gt C, close to the annual fossil-fuel emissions during the 1990s. Since the 1990s, the estimates of SOC stocks have been refined to 2400 Gt down to 2 m, and the emissions have increased in a similar proportion, and thus the 0.4% figure remains.

Now, if we quote Soussana et al. (2015), "Over a meaningful depth for carbon sequestration, i.e. 0–40 cm, the 4‰ target would result in a carbon sequestration that could peak at 3.5 billion tons C per year (Gt C yr^{-1}) when considering soils from all biomes. Agricultural soils have a technical carbon sequestration potential between 0.7 and 1.2 Gt C yr^{-1}, while the potential from all other land uses (including forests and integrated systems like agroforestry) could reach 2.5 Gt C yr^{-1}." Indeed, if we sum 2.5 Gt C and the average of the range 0.7–1.2 Gt C, we come to 3.45 billion tons C per year, which fits the target especially when combined with stopping deforestation, i.e. a reduction of 0.9 Gt C yr^{-1} according to Le Quéré et al. (2015).

Finally, in his comments, De Vries (2017) wrote: "Multiplying 8.6 Gt C by 0.4% equals 3.4 Gt C yr^{-1} and combining this aim with stopping of deforestation, it leads to 4.3 Gt C yr^{-1} being the correct scientific rationale behind the initiative."

So, what do we learn from all these figures? No matter how the calculation is made, 4 per mille is the result which is claimed. Is 4 per mille a magic number? We believe not. But we believe that it is a worthy aspirational target that has also become a slogan in helping the promotion of sustainable soil management and global soil security.

2.2. Implausibility of upscaling results to the global scale

We concur that a large portion of grasslands is unmanaged rangeland used for rough grazing. However, we believe that there is a potential for C sequestration in these systems. We think that many grazing lands are degraded because they are unmanaged or poorly managed. Lal (2016) stated that the technical potential of SOC sequestration in the world's cropland and grazing lands is finite: 0.4 to 1.2 Gt C yr^{-1} for cropland (Lal, 2004), 0.3 to 0.5 Gt C yr^{-1} for grazing lands, and 0.5 to 1.4 Gt C yr^{-1} for restored degraded soils (Lal, 2010). Restoring degraded soils by management is indeed one of the main challenges of the developing world. We acknowledge that the sink related to unmanaged rangeland or degraded soils, because of their relative areal importance within the cultivated lands category, warrants more scientific attention in order to decrease current uncertainties (Milne et al., 2016). In that perspective, FAO's Livestock Environmental Assessment and Performance (LEAP) Partnership has mandated a Soil Carbon Stock Changes Technical Advisory Group to build common ground on the assessment of Soil Carbon Stock Changes with emphasis on grasslands and rangelands. (http://www.fao.org/ag/againfo/home/en/news_archive/2016_LEAP_call_technical_cooperation_soil-carbon-stock-changes.html).

We recognize that some limitations to SOC sequestration may occur because of lack of nutrients such as N and P. However, it is not a solution to rely only on chemical fertilizer and N deposition to solve nutrient deficiency. Nutrient management may be improved by many techniques (legumes, grazing management, agroforestry, etc.) and there is also an enormous potential for waste recycling, especially from large cities. The nutrient limitation is also highlighted in a viewpoint by van Groenigen et al. (2017): "Implementing the 4p1000 initiative on all agricultural soils would require a SOC sequestration rate of 1200 Tg C yr^{-1}. Assuming an average C-to-N ratio of 12 in SOM, this would require 100 Tg N yr^{-1}. This equals an increase of ~75% of current global N-fertilizer production, or extra symbiotic N_2 fixation rates equaling twice the current amount in all agricultural systems." This is only true if we consider SOC sequestration as an extra effort in addition to producing crops. SOC sequestration should be the outcome of improved farming practices that increase productivity, which in turn build up organic matter. The main feedback of N fertilization is through increased crop yields. The relationship between fertilizer N and SOC is not straightforward, as shown by Alvarez (2005), Ladha et al. (2011), and Lu et al. (2011). The missing argument from this is that increased SOC has a positive feedback on soil condition and quality (improved soil structure, infiltration, nutrient cycling, etc.) and crop productivity. As recently demonstrated by Sanderman et al. (2017), a higher carbon return management system results in a soil with more carbon, which supplies more nutrients back to the crop, and increases crop productivity. Improving productivity for food security thus attenuates the dilemma outlined by van Groenigen et al. (2017).

Lastly, we agree with De Vries that the large number (or range) given by us is common in other papers such as those from Smith et al. (2008) and Paustian et al. (2016). We think this range is a question of being less-or-more optimistic. If we consider only managed soils, and rely only on chemical fertilizer and atmospheric deposition for nutrient management, our number is definitely an over-estimate. If we believe, like other authors, that there is a large technical potential in soils that are not managed or poorly managed at present and disruptive technologies are developed, then our estimates are more realistic.

3. VandenBygaart (in this issue)

We agree with VandenBygaart (in this issue) that the value of 8.9 Gt of C emissions per year represents only part of the total greenhouse gas emissions from anthropogenic sources. This is exactly what we say in the introduction of Minasny et al. (2017) and also above in reply to De Vries' comments, in which we refer to the 'annual greenhouse gas emissions from fossil carbon'. We acknowledge that soil carbon sequestration may be more rapid and efficient in topsoil than in deeper layers. This is the reason why Soussana et al. (2015) based their calculations on the top 40 cm. Indeed, as we stated earlier in this rejoinder, even taking topsoil only, many authors gave similar potentials of C sequestration in soils (e.g. Lal, 2004, 2016; Smith et al., 2008; Paustian et al., 2016). For instance, Paustian et al. (2016) came to an overall mitigation potential near 2.2 Gt C yr^{-1}. Lal (2016) stated that, theoretically, the world's cropland soils could sequester as much as 62 t ha^{-1} over the next 50 to 75 yr (0.8 to 1.2 t ha^{-1} yr).

VandenBygaart cites a short communication by Sommer and Bossio (2014) that stressed the limited potential of soil C sequestration. However, these authors used one of the most pessimistic IPCC scenarios of future global emissions. VandenBygaart further stated that mitigation potentials also have to consider economic reality and the cruel truth that we must be able to feed a population of over 9 billion people by 2050. We agree with this statement, and thus soil carbon sequestration should be part of food security. We did not consider economic constraints to carbon sequestration potential in our paper but we briefly addressed some issues around carbon markets in the discussion section. Indeed, the carbon price may constitute a limiting factor in some regions if it stays as low as at present. However, we preferred to talk about a carbon sequestration potential, and we also believe that many issues will not be solved only by carbon trading. In line with Lal (2016), we believe that SOC sequestration would not only help to mitigate climate change but would also restore soil condition and advance food and nutritional security. This is especially the case in large parts of the world affected by soil degradation, such as Sub-Saharan Africa (Perez et al., 2007; Milne et al., 2016). Studies from China demonstrated that grain production and also the sustainability of productivity were promoted with elevated soil organic matter levels (Pan et al., 2009). Therefore, increasing the soil's organic C pool is indeed helpful for attaining an increasing and less variable crop production under climate change impacts.

As outlined in our paper, 4 per mille will not be feasible everywhere — it will work in some places, achieve greater than the target in others, or in some places, not be achievable at all. We chose to be positive, but some would argue that as scientists we need to be realistic, and not overly optimistic. We would be more worried if future generations asked why we didn't do it now.

4. White et al. (in this issue)

White et al. (in this issue) comment that the 4 per mille concept is flawed as "it implies that soil carbon will increase indefinitely each year by a slightly bigger increment as the amount of carbon in the soil increases." We acknowledge that carbon sequestration tends towards a new equilibrium (or asymptote) over time and we showed in Fig. 15a diminishing increment in SOC as time elapses. White et al. (in this issue) argue about a '*contradictory statement*' for the US that 'a target for SOC increase of 68 Mt yr^{-1} by 2025 would, *if compounded at 0.4%*, reach 75 Mt yr^{-1} by 2050', and they say this is unrealistic. We think the rate of sequestration is not unrealistic. We showed in Figs. 15 and 16 that carbon sequestration can occur at a rate larger than 0.4% for more than 60 yr in some situations. However, we agree that '*if compounded at 0.4%*' then the target might be unachievable, which is what is mentioned in our paper (p. 74) "Achieving this level of C sequestration would require a greatly increased investment, either from public or private sources."

White et al. (in this issue) state that the figures in Minasny et al. (2017) for average rates of SOC increase for several of these practices are too large. Our values are in line with other literature considering their large uncertainties, e.g. West and Post (2002) found the sequestration rate from a change from conventional tillage to no-till (NT) as 0.57 ± 0.14 t C ha^{-1} yr^{-1}, and crop rotation as 0.2 ± 0.12 t C ha^{-1} yr^{-1}. For afforestation and grassland establishment, the average rates according to Post and Kwon (2000) are 0.34 ± 0.56 t C ha^{-1} yr^{-1} and 0.33 ± 0.50 t C ha^{-1} yr^{-1}. Of course it varies a lot with climate, and smaller values were found in Australia. Excluding organic amendments from the calculation, assuming that it is merely transferring C material from one site to another, maybe justified especially in cases such as farmyard manure in intensive cattle production systems. However, even in this case, managed properly this transfer may lead to more-or-less sequestration. More importantly, a large part of potential organic amendments in the world is largely under-utilized (Chabbi et al., 2017), such as for instance urban wastes and sewage sludges and thus these have the potential for a true contribution to abating GHG. In addition, there is a large amount of crop residues that have been mismanaged (Smil, 1999) and burnt (Streets et al., 2003).

We also acknowledge that some literature reviews have pointed out that there was limited potential for no-till agriculture to mitigate climate change, and as outlined in our paper, it is already practised in large parts of the world. Overall, the SOC accrual rates associated to various managements used in Minasny et al. (2017), may not be fully representative of the range of cultivated soils around the globe. They may be unrepresentative in the sense that their mean or median may give an unbiased picture of global accrual potential of cultivated soils. The scientific community still needs to carry on with i) gathering and assembling results from an increasing number of local studies, as is done in Minasny et al. (2017), ii) focusing on understudied areas (Smith et al., 2012) and iii) developing process-based models which might help extrapolating results of local studies, despite current limitations (Luo et al., 2016).

White et al. (in this issue) mention that a true abatement required calculation of the net changes in all the GHGs. We accept this, however, performing a complete calculation of the net change in all emissions is outside the scope of this study. White et al. (in this issue) give a nice example related to cattle production to stress their point. We could argue that net changes can also be under-estimated when taking only C sequestration into account. Numerous factors exist such as fuel consumption reduction in reduced tillage systems, or decrease of mineral N application when using legumes in a rotation.

White et al. (in this issue) argue that experimental yields may be higher than real farm yields. We used not only experiments but also legacy data that are available in numerous countries. Moreover, we feel that it is a simplistic approach to link carbon sequestration to yields. Maintaining or increasing SOC is critical to maintain or increase yields in many parts of the world, and in turn increase SOC. However, in some parts of the world, the highest yields are obtained in the most intensively cultivated areas which have in turn the lowest SOC stocks. This is for instance the case in France (Angers et al., 2011) where the regions showing the highest wheat yields are among those having the lowest SOC contents and the largest carbon saturation deficit.

White et al. (in this issue) further state that the Minasny et al. (2017) 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. We concur that getting the economic framework right is one of the keys to enhancing SOC. This is again outside the scope of our paper that aims primarily at giving carbon sequestration potentials and comparing them to the 4 per mille initiative.

5. Baveye et al. (in this issue)

We appreciate the comments from Baveye et al. (in this issue). The authors consider the 4 per mille initiative as a 'credibility issue for the science community' and we fully understand their point of view, even if we do not share it. Indeed, their comments have gone much further than a discussion on the validity of the 4 per mille concept. They have raised a number of interesting issues on ethics, social and political behaviour which are worth considering.

In their introduction, and similar to the other critical reviewers, Baveye et al. (in this issue) state that the 4 per mille initiative aims to "compensate for global emissions of greenhouse gases by anthropogenic sources". We do not claim this statement, and the 4 per mille initiative concentrates on anthropogenic CO_2 emissions, not on global greenhouses gases. Baveye et al. (in this issue) follow their discussion by the following statement: "The idea, based on back-of-the-envelope calculations is deceptively simple…". Baveye et al. (in this issue), and perhaps others in the scientific community, might not be aware of the scientific discussions that took place before and during the launching of this programme (http://newsroom.unfccc.int/lpaa/agriculture/join-the-41000-initiative-soils-for-food-security-and-climate/), and especially that the 4 per mille initiative will include a proposal for a research programme, and that it will be guided by a scientific committee (http://www.agropolis.fr/pdf/actu/4-per-1000-comite.pdf). Perhaps Baveye et al. (in this issue) and others have not been aware that discussions about the 4 per mille initiative have taken place under the auspices of the International Union of Soil Sciences (IUSS) representing the global union of soil science societies.

Baveye et al. have adopted a polemical style and multi-faceted approach for their commentary to which we respond in a collegial spirit with a view to making concerned scientists aware of the situation. The research community has provided insights to the 4 per mille concept. Simple ideas may appear deceptive to some, but our view is that arguing all the complexities, often does not deliver practical solutions for the planet or humanity; we are advocates of Ockham's razor. Considerations of the behaviour of farmers, car manufacturers, industrialists, and oil or gas producers are beyond the scope of our work. We concur that "to have net C storage or C stock increase in the soil, the sink has to be larger than the source", which is basically the principle of the 4 per mille concept and graphically demonstrated in Fig. 1 of Minasny et al. (2017). Note that Fig. 1 of Minasny et al. (2017) does not show arrows nor implies fluxes.

We wrote in our paper that the capacity of soils to sequester carbon is time constrained, which is stated clearly in the reports from France, New Zealand and Chile. Some countries reported that a new equilibrium will be reached (e.g., UK, Canada) and some others indicate that for some soils the maximum has already been attained (e.g., Scotland, New Zealand, Chile, USA, Belgium) and that the main challenge for these soil is not to lose the accumulated carbon. We referred several times to this finite potential in the discussion, at the beginning by stating on the finite capacity of the soil C sink, then in Section 3.1 in which we talked about reaching a new equilibrium, in Section 3.2 where we discussed the duration issues in Fig. 14, and in Sections 3.3 and 3.4 where we elaborated on time and critical limit issues. We were clear that soil carbon sequestration is reversible and stressed this in a large number of situations.

Baveye et al. (in this issue) then question the influence of spatial temperature gradients on carbon stocks in soils, and “the effect that temperatures rising globally over time as a result of climate change may have on these stocks”. Our Figs. 2 and 13 clearly show the global effect of temperature on the world's carbon stocks. We acknowledge that rising temperatures may have deleterious effects on soil carbon sinks, especially in extreme situations, mainly by accelerating mineralization in the cold climate regimes (permafrosts, northern hemisphere peats) and by reducing net primary production in hot-and-dry areas. However, in the intermediate situations, which are indeed those where increasing SOC is feasible, the effect of rising temperature is still under debate (Bradford et al., 2016), which is complicated by the fact that not only temperature but precipitation and extreme events will change, and also by the fact that changes in land use may have a very large effect on C stocks. For instance, Fantappiè et al. (2011) showed that climate change had a small influence on SOC variations in Italy. Minasny et al. (2012) found management practices have overridden the increase temperature in Indonesia and Korea, and similar results were found in China by Pan et al. (2010). Preliminary results from Stockmann et al. (2015) on worldwide changes in SOC over time suggest that land cover change is the primary agent that influences SOC changes over time, followed by temperature and precipitation. Arrouays et al. (2002) indeed acknowledged the effect of temperature on SOC dynamics but their report concluded that the overall effects of land use and soil management will be much more important for the forthcoming decades.

Baveye et al. (in this issue) cite the paper from Crowther et al. (2016) to support their argument about potential effects of temperature increase. The cited results are based on an extrapolation of a linear model fitted to 49 field experimental sites that modelled C decreases linearly as a function of temperature and time. Robinson (2007) based his results on a ‘simple mass balance model’ with a calculation of a global SOC sink of 2.69 Gt yr^{-1}, incorporating estimates of root-C which was previously underestimated. He further assumed that the SOC pool in the top metre of soil should decrease at a rate of 0.7% yr^{-1} in a twenty-year period. Given the uncertainties on stock estimates and presumed decrease, these calculations are highly uncertain. We feel that the relation between microbial activity and soil organic matter in a changing climate is still speculative, given the current state of knowledge (Bradford et al., 2016). Nevertheless, implementing C sequestration management will still be beneficial if climate warms up and has an effect on SOC. It will result in avoiding (additional) losses.

Following the style of Baveye et al. (in this issue) we could say that this concept is ‘deceptively simple’ and that much research is still needed to fully understand the interactions between biological activity and carbon sequestration mechanisms. Further, Baveye et al. stressed “the many obviously tricky questions we still have about the fate of organic (and inorganic!) carbon in soils, as well as about the microbial processes that control it”. We agree and surely not all carbon is in organic form, and indeed carbonates may represent a large stock of carbon in soils, and they are rarely estimated. We recognize that carbon lost from carbonates should be studied in more detail. The 4 per mille initiative refers to organic carbon only. We recognize that it is again an uncomplicated approach, but we advocate that although there are many trials and data on SOC changes, data on changes related to carbonates are largely unavailable. The tricky issue of nitrogen is discussed in our reply to De Vries (in this issue). The recent review by Dignac et al. (2017) discussed many of the technical issues in more detail.

As discussed in our previous response to White et al. (in this issue), we recognize that some “management changes implemented to sequester more carbon in soils could lead to increased emissions of other, more potent greenhouse gases”. But we also know that some management changes could lead to decreased emissions of these gases. Therefore, we agree wholeheartedly that full management and a holistic perspective of GHG emissions is necessary. We also concur that SOC sequestration should be framed in the context of all ecosystem services linked to soils, but this was not the objective of our paper. There are still many remaining questions about what is called the “priming effect” and its potential effects on subsoil layers. But we fear that the story of “priming effect”, as formulated by Baveye et al. (in this issue), may be interpreted as: “never add new carbon to soil, you'll lose the old stuff and destroy the soil structure”. That would be an inaccurate and unfortunate interpretation.

Baveye et al. (in this issue) fear that policy-makers will, deliberately or not, misinterpret our statements. Saying that decision-makers may take this opportunity to “slow down dramatically the development and adoption of long-term solutions” is clearly making a case on assumptions about their intentions. This is another debate; we have chosen to write what we think is our best guess at the truth, not on how we think the policy-makers will interpret our best guess.

Theatrically perhaps, Baveye et al. further suggest that soil scientists adopt the Machiavellian view that the end justifies the means. We indeed believe that farmers in Australia, France and other parts of the world are more and more aware of the need to increase soil organic matter. Our discussion is not motivated by requests for additional funding but it is driven by the provision of a short- to medium-term solution to a global existential problem. Baveye et al. (in this issue) then argue that the initiative will lead to politicians not sponsoring more fundamental research but will focus on more applied large-scale monitoring. They support their statement by the methodological debate that followed the publication of Bellamy et al. (2005). It is worth noting that this intense debate came about because Bellamy et al. found a large SOC decrease of 0.6% yr^{-1} in the topsoil of England and Wales from 1978 to 2003. We do not agree that large-scale soil monitoring is costly and complicated. When talking about large-scale soil survey and monitoring, we should keep in mind that most of the cost is in taking samples properly, after which, applications can be found on an amazing series of soil properties such as demonstrated in several countries for SOC, pH, phosphorus, K, trace elements, Si, PAH, pesticides, microbial DNA, etc. Baveye et al. prefer to jump to the “latest technology instruments”, which could be useful. But let the technology evolve a bit, and this will allow the instrument-driven users to work on samples from the monitoring programmes; this is already the case for a number of ‘-omics’ technologies such as successfully shown in France. The goal of wide-extent soil monitoring is not as a funding scheme for a small group of scientists, but rather to provide an independent assessment of stocks and changes (Pan et al., 2010; van Wesemael et al., 2011). In addition, the empirical data generated raise new scientific questions (Gardi et al., 2009; Louis et al., 2016), which might not be apparent from hypothesis-driven experiments alone.

We shall not comment on the discussion about hunger in Africa and about the biochar issues. This is outside the scope of our work. We have not promised the moon, but we do attempt a small commitment for the earth.

Finally, we support that we should “decuple our efforts to educate the public at large, and especially policy-makers, about how imperative it is to protect soils and preserve the essential services they render for human populations.” We hope that all soil scientists share this opinion and we welcome and encourage the efforts the soil science community has put into this endeavour. We concur that the beauty and importance of soils should be incorporated at all levels and forms of education and including policy-makers.

We do not think of this initiative in terms of subterfuge; we think plainly, and state openly, it is the right and honest way to help persuade land managers, policy-makers and society of the importance of soil for climate and food security, engaging farmers, scientists, and marketers.

6. Conclusions

While acknowledging objections outlined by four groups of commentators, who represent part of a spectrum of current views of soil scientists, it is the considered opinion of the authors of Minasny et al. (2017), from some 20 counties and regions worldwide and representing many biomes and land uses, that 4 per mille *sensu lato* is a challenge worth pursuing. By accepting this challenge we put ourselves in a positive conceptual framework which opens up new scientific challenges, including measurement, modelling, monitoring, reporting and verification. There are fundamental questions with respect to soil organic carbon which remain to be answered. Optimized practices for enhancing soil carbon will be region- and site-specific and this will raise new questions and generate new soil knowledge.

In summary:

- We reiterate that the 4 per mille is more of a concept (or even a slogan) than the actual number itself. It is also an aspirational target that will help in the promotion of sustainable soil management.
- The Minasny et al. (2017) paper shows that the SOC sequestration goal of the 4 per mille initiative is seen as a worthy pursuit for scientists from 20 countries and regions from various parts of the world. This goal is not achievable everywhere, and moreover it is finite in time/duration.
- Most commentators acknowledge that 4 per mille is a timely and useful initiative, even if they disagree with the figure itself.
- We recognize that we've been optimistic. Should we be optimistic or pessimistic? Should we talk about the potential or should we stay with more-or-less ‘reasonable’ guess? We believe it is better to be optimistic with an aspirational target and use the best empirical evidence to achieve this rather than being pessimistic and say it is unachievable.
- The paper and subsequent discussion demonstrate that the soil science scientific community is already engaged actively in investigating the 4 per mille initiative.
- We recognize that economic and social aspects need further investigation and hope that the 4 per mille initiative will create the opportunity to join these scientific communities to the soil science one.

Disclaimer

Given his role as Editor in Chief, Dr. McBratney had no involvement in the handling of the letters to the editor or the response by the authors. Dr. Van Groenigen was responsible for handling all item.

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