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PERSPECTIVE

The 4p1000 initiative: Opportunities, limitations and challenges for implementing soil organic carbon sequestration as a sustainable development strategy

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Abstract Climate change adaptation, mitigation and food security may be addressed at the same time by enhancing soil organic carbon (SOC) sequestration through environmentally sound land management practices. This is promoted by the "4 per 1000" Initiative, a multi-stakeholder platform aiming at increasing SOC storage through sustainable practices. The scientific and technical committee of the Initiative is working to identify indicators, research priorities and region-specific practices needed for their implementation. The Initiative received its name due to the global importance of soils for climate change, which can be illustrated by a thought experiment showing that an annual growth rate of only 0.4% of the standing global SOC stocks would have the potential to counterbalance the current increase in atmospheric CO_2. However, there are numerous barriers to the rise in SOC stocks and while SOC sequestration can contribute to partly offsetting greenhouse gas emissions, its main benefits are related to increased soil quality and climate change adaptation. The Initiative provides a collaborative platform for policy makers, practitioners, scientists and stakeholders to engage in finding solutions. Criticism of the Initiative has been related to the poor definition of its numerical target, which was not understood as an aspirational goal. The objective of this paper is to present the aims of the initiative, to discuss critical issues and to present challenges for its implementation. We identify barriers, risks and trade-offs and advocate for collaboration between multiple parties in order to stimulate innovation and to initiate the transition of agricultural systems toward sustainability.

Keywords Carbon sequestration · Climate change · Food security · Soil

INTRODUCTION

In recent years, with rising atmospheric CO_2 concentrations, the role of soils in the global carbon cycle has been increasingly acknowledged. As a result and as a supplement to immediate and aggressive emissions reduction, an increase of soil organic carbon (SOC) sequestration has been promoted by scientists and policy makers as a prospective additional opportunity to partly counterbalance increasing atmospheric CO_2 concentrations (e.g. Lal 2004; https://www.4p1000.org/). The SOC pool of the terrestrial biosphere is estimated to be around 1500 Gt C to a depth of 1 m. Changes of this large pool may affect atmospheric CO_2 concentrations. Consequently, increasing SOC sequestration through environmentally sound agricultural practices has been advocated as an option to remove CO_2 from the atmosphere (Smith et al. 2016).

In 2015, the French government launched the "4 per 1000" (4p1000) Initiative at the 21st Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) as part of the Lima-Paris Action Plan. The Initiative promotes an innovative model for helping to mitigate climate change, through increase in SOC and contributing to climate change adaptation and food security. It is believed that increasing SOC enhances certain soil functions, thereby benefitting agricultural production (Lal 2004).

As agricultural activities and land use change account for about 25% of the CO_2, 50% of the CH_4 and 70% of the N_2O anthropogenic emissions (Hutchinson et al. 2007), enhanced SOC sequestration could help offset these emissions (Paustian et al. 2016). SOC sequestration could also help to fill the gap between the intended national contributions and the reality to achieve the Paris climate goal (Rumpel et al. 2018).

Moreover, increased SOC sequestration is likely to generate co-benefits helping to achieve several sustainable development goals, in particular those related to reducing hunger (SDG 2), extreme poverty (SDG1, 3), and improving the protection of the environment (SDGs 6, 11, 12, 14, 15) and the global climate (SDG 13) (Soussana et al. 2019). Particularly, the Initiative may have the possibility to contribute to SDG 15.3, by combatting desertification and restoring degraded lands through increasing SOC storage.

The 4p1000 Initiative mainly focuses on agricultural soils with low levels of SOC due to continuous cultivation and often unsustainable crop intensification practices (Pingali 2012). The Initiative encourages farm management practices that preserve and build SOC stocks while limiting carbon trade-offs. Adoption of these practices may lead to a transition towards sustainable agricultural production (Tilman et al. 2011; https://futurepolicy.org).

The objectives of this paper are to (1) discuss the aims of the 4p1000 Initiative and controversial issues concerning the Initiative, (2) highlight the potential of the 4p1000 Initiative to provide collaborative platform for policy-science-practice interaction and (3) proposes an implementation pathway from policy to action.

CRITIQUES OF THE 4P1000 INITIATIVE

The 4p1000 initiative was launched based on a thought experiment suggesting that a small increase of the SOC stocks of global soils (4 per 1000 or 0.4% of the standing SOC stock) would remove a significant proportion of CO_2 from the atmosphere, while simultaneously augmenting the capability of agricultural systems to adapt to climate change and to provide food security. The achievability of the Initiative's target of an annual increase in agricultural SOC stocks of 0.4% to a depth of 0.3–0.4 m globally has been intensively discussed and criticised (de Vries et al. 2018; VandenBygaart 2018).

As a policy goal, a single number, i.e. a quantity of carbon to be stored in soils that appeared to be easily attainable was clear and thus easier to communicate than multiple numbers for different regions or conditions. Articulation of a clear target by prominent promoters of the Initiative including well-respected scientists and policy makers was necessary to ensure inclusion of SOC on the global political agenda (Kon Kam King et al., 2018). The selection of this simplified 4p1000 target for increasing SOC sequestration may be interpreted as analogous to the selection of targets to limit global temperature increase to 2 or 1.5 °C above pre-industrial levels set by the UNFCCC and to targets for Sustainable Development Goals established by the United Nations in 2015. These are broad aspirational goals with much uncertainty about what is achievable, especially in relation to specific geographical locations. The climate science community was faced with similar criticisms when global warming targets were announced. We suggest that some of the controversy regarding the 4p1000 Initiative is attributable to the initial setting of an aspirational target of an annual SOC increase of 0.4% of the standing stock. The initial criticism was related to the suggestion that this could offset *all* fossil fuel emission and that it could therefore be used as an excuse not to drastically reduce CO_2 and other greenhouse gas emissions. This was seen as a complete exaggeration and dangerous. Moreover, the target was interpreted as a strong commitment rather than an aspirational goal. Criticism has also focused on the number, its calculation, significance and achievability. Further, there was ambiguity related to the presentation of the calculation of the quantity of SOC needed to partly offset anthropogenic CO_2 emissions without considering other greenhouse gas emissions (de Vries et al. 2018; Minasny et al. 2018). The initial statements were thus not framed precisely in scientific terms, which made the nature and the role of the target difficult to interpret.

More specific criticisms of the Initiative in relation to biophysical, agronomic and socio-economic issues are presented in Table 1 and discussed below. These include (1) biophysical limits (demands in terms of water, nutrients and energy), and other barriers such as (2) the trade-off effects, (3) climate change effects and (4) the socio-economic implications for the agricultural sector, including cultural issues and governance (van Groeningen et al. 2017; Baveye et al. 2018; de Vries et al. 2018; van den Bygaaert 2018; White et al. 2018; Poulton et al. 2018).

Biophysical limits and barriers

Under given constant conditions, SOC stocks will approach an equilibrium level depending on carbon inputs and outputs determined by pedoclimatic conditions, land use and management practices (Fig. 1). Regulation of SOC storage under equilibrium conditions is increasingly ascribed to SOC input (Fujisaki et al. 2018), soil-inherent pedologic characteristics (Barré et al. 2017) and the state of soil development (Schiefer et al. 2018). When land management changes, the equilibrium may be disturbed leading to SOC gain or loss. Following land use change (e.g. agriculture), SOC losses generally occur through increased microbial decomposition rates and through soil erosion (Sanderman et al. 2017). Agricultural practices also often decrease organic matter inputs. For example, in many regions of the world, biomass input into soil is reduced through burning of crop residues (http://www.fao.org/faostat/en/#data/GB), when these could otherwise be used

Table 1 Classification of the criticisms of the 4 per 1000 Initiative's target and explanation and proposed actions to respond to the criticisms

Criticism	Articles	Proposed explanation and action	Associated research needs
Poor calculation of target			
Inconsistent inputs for calculation	(de Vries et al. 2018)	Consistent communication and clear explanation of calculations	na
Global emissions number only reflect CO_2, not CH_4 and N_20, so the calculation of the offset is too low	(de Vries et al. 2018), (Baveye et al. 2018)	Explanation of calculations: only anthropogenic CO_2 emissions are targeted in the calculation of the Initiative, not all anthropogenic greenhouse gas emissions, Actions: non CO_2 GHG emissions should not be increased	na
Biophysical			
C storage is limited. Storage reaches an equilibrium value and the rate of storage starts to decrease once storage is initiated, so the potential for sequestering carbon sequestered will decrease rapidly over time.	White et al. (2018), Baveye et al. (2018), Schiefer et al. (2018)	Even additional storage over a few decades would help mitigate CO_2 emissions. Predictions must account for these dynamics	Assessments of the local/ regional/national C stocks and C storage potential considering time limits
Non-permanence of SOC storage	Baveye et al. (2018), Poulton et al. (2018)	Encourage the maintenance of best management practices	Vulnerability of SOC stocks
4p1000 per year (rate of sequestration over time) is not feasible quantitatively: estimates are too high globally but also locally	de Vries et al. (2018), White et al. (2018)	Even an additional storage, less that 4‰ would contribute to mitigate CO_2 emissions. Large variability of SOC storage rates depending on pedoclimatic conditions and management options implemented	Assessments of the local/ regional/national C stocks and C storage potential, using long-term observations and experimental farm plots
Insufficient biomass available	Poulton et al. (2018)	Implementation has to be spatially differentiated. Promote recycling and valuation of waste (circular economy)	SOC storage potential of organic wastes
Insufficient nitrogen and phosphorus available	van Groeningen (2017), White et al. (2018), Baveye et al. (2018)	Where possible, N-use efficiency needs to be improved. Implementation has to be spatially differentiated. Avoid use of synthetic or mined fertilisers by alternative practices (e.g. mycorrhizae, legumes, Plant Growth Promoting Rhizobacteria, rotations, waste management and circular economy)	Effects of nitrogen fertiliser on SOC storage in grasslands (has been better studied in cropland). Global estimation of the nitrogen fixing potential of agro-ecosystems. Development of new fertilisation strategies
Need for comprehensive greenhouse gas accounting (i.e. include non-CO_2 emissions such as N_2O, CH_4)	White et al. (2018), Baveye et al. (2018)	A net greenhouse gas balance must be provided for all projects. Avoid or adapt SOC storage strategies in situations with high risk (e.g. inhibitors, liming, timing nitrogen additions, slow release fertilisers, paddy water management)	Conditions conducive to N_2O emissions (nature of organic matter, pH, soil structure)
Not accounting for climate change (temperature increase)	Baveye et al. (2018)	Reinforces the need for the Initiative	Temperature sensitivity estimates have been based mostly on disturbed soil and laboratory incubations. Perform more in situ measurements
Enhanced mineralisation on addition of easily decomposable carbon (priming effect) could release more CO_2	Baveye et al. (2018)	Measure changes in SOC storage rates under field conditions, integrate enhanced priming effect if any	Modelling and experiments to quantify and reduce priming effects
Not all carbon is organic; inorganic carbon could release large amounts of CO_2 with temperature rise or microbial activity	Baveye et al. (2018)	Inorganic C dynamics must be accounted for in climate change modelling	Model temperature and microbial activity to assess climate impacts of inorganic carbon in soils

Table 1 continued

Criticism	Articles	Proposed explanation and action	Associated research needs
Better measurement and monitoring are needed to implement the initiative	White et al. (2018)	Use best available methods for measurement and activity. Improve and disseminate measurement guidelines.	Developing high through-put and low cost methods to monitor changes in SOC stocks
Many soils are already well managed therefore presenting limited opportunities to increase SOC storage	White et al. (2018)	Concerns only certain regions; the majority of agricultural soils is not managed sustainably	Maintain best management practices. Identify most promising sites
Socio-economic			
Farmers will not be able to adopt practices due to social and institutional and economic constraints (costs, need for continuous financial incentives)	White et al. (2018), Poulton et al. (2018), Baveye et al. (2018)	Address first farm sustainability (SOC storage is likely to also lead to success in sustainable production). Demonstrate the benefits of soil carbon and related incentives. Identify whether benefits outweigh costs. Capacity building. Develop policies.	Quantify the benefits of SOC increase on productivity and resilience, so that a monetary value can be attributed to SOC increases. Show levels of sequestration possible based on different carbon costs.
Political			
The 4p1000 is proposed to avoid making any changes in community lifestyle	White et al. (2018)	A strategy reducing the fossil fuel consumption of communities is out of scope for the Initiative but the Initiative contributes to the much broader Paris agreement of the UNFCCC	na
Overall credibility of the soil science community is weakened	Baveye et al. (2018)	Even additional storage of less that 4‰ would help mitigate CO_2 emissions. The 4p1000 Initiative is an aspirational target to contribute to climate change mitigation	Improve estimates of SOC sequestration potential at the local to the global scale

to increase organic carbon inputs. We suggest that improved management practices of agricultural systems are required in order to recycle carbon back to soil. These can be achieved through permanent soil cover, reduced carbon exports (e.g. recycling rather than burning crop residues) or following input of exogenous organic amendments (Chabbi et al. 2017; Chenu et al. 2019).

When management practices leading to increasing SOC stocks are applied, the sequestration rate will decrease as the SOC stock approaches a new equilibrium, beyond which further sequestration will be negligible (Fig. 1; Sommer and Bossio 2014; Chenu et al. 2019). Modelling has shown that increases in SOC sequestration can continue for 20 years globally (Sommer and Bossio 2014) and even up to 120 years for specific agricultural practices and pedoclimatic conditions (Poeplau and Don 2015). However, it is likely that SOC sequestration will not continue indefinitely and that its contribution to mitigating climate warming is time-limited. Permanence of SOC storage will not only depend on the continuity of best management practices but also on the forms of carbon that comprise SOC stocks and stability of pedoclimatic conditions, which may be compromised by climate change. SOC sequestration is only part of the solution to mitigate climate change and must be complemented with other mitigation initiatives that will lead to aggressive and urgent reductions in all greenhouse gas emissions.

Several authors have raised concerns about the nutrients needed for increasing SOC sequestration (de Vries et al. 2018; van Groeningen et al. 2017). In mineral soils, nutrients are needed to achieve increases in SOC sequestration because they (1) increase plant production and therefore carbon input into soil (Ladha et al. 2011) and (2) build up stable (mineral associated) SOC (Kirkby et al. 2014). In particular, estimates of the amounts of nitrogen and phosphorus required to increase SOC stocks on agricultural land globally were deemed unrealistic (van Groeningen et al. 2017; de Vries et al. 2018). The nutrient cost of SOC sequestration may be addressed by (1) optimising nutrient management through improved farm management practices (Ditzler et al. 2018), (2) incorporating spatially- differentiated SOC sequestration strategies into precision agriculture and (3) using green manure legumes instead of mineral fertilisers (Soussana et al. 2017). Use of exogenous amendments in the form of farm manure and compost may be part of improved nutrient management practices while additionally contributing to increasing SOC stocks (Diacono and Montemurro 2010).

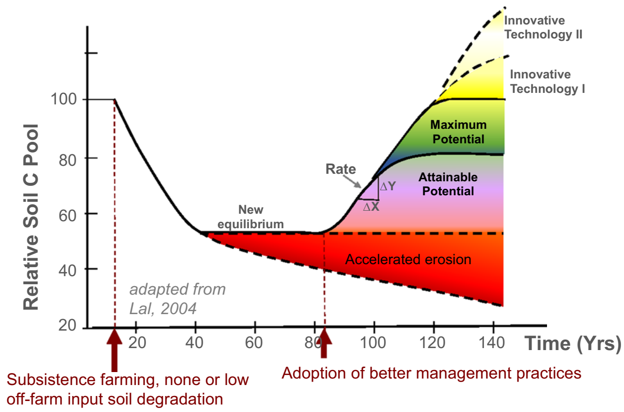

Fig. 1 SOC trajectories after adoption of improved management practices. Adapted from Lal (2004)

However, their local application could result in major carbon and nutrient transfers from other locations with no net increase in SOC sequestration, and possible increases in other greenhouse gas emissions (Powlson et al. 2011; Poulton et al. 2018). Exceptions are where the biomass would otherwise be burned or deposited into landfills. In this context, the recycling of organic wastes from domestic activities and urban areas as organic fertilisers is an opportunity to transfer organic carbon in ways that enhance SOC storage, ameliorate the nutrient content of soils and close nitrogen and phosphorus cycles at regional scales (Chabbi et al. 2017; Minasny et al. 2018; Nath et al. 2018). Use of amendments containing organic carbon in thermally stable forms, (biochar), while being a practical way of recycling organic wastes, may avoid inputs of nitrogen and phosphorus to form SOC because of their low concentrations of both elements. Peatland restoration is another option for sequestering SOC with minimal nitrogen inputs due to the high carbon to nitrogen ratios of peatland plants (Leifeld and Menichietti 2018).

Important biophysical issues that possibly limit SOC storage potential are related to the (1) inherent capacity of soil to store carbon in a stable form, (2) longevity of the additional stored carbon, (3) reversibility if C retaining practices are not maintained and (4) scarcity of crop residues or other biomass and nutrient inputs for soil amendment. We acknowledge these limitations, but suggest that there are many possibilities for improving nutrient and organic residue management at farm, region and national scales, which could be exploited to maintain and if possible increase SOC stocks and improve soil quality. As concluded by van Groeningen et al. (2017), a spatially diversified strategy is needed for climate change mitigation from agricultural soils. Research to develop new innovative technologies is also required.

Socio-economic barriers

The feasibility of SOC increases will depend on the abilities of farmers to implement changes to management practices as driven by their equipment, skills, operational and economic constraints. Farmers are likely to implement management changes only if there are clear co-benefits, in terms of yields and long-term economic profitability. Some authors have suggested that the achievement of 0.4% SOC increase will not be feasible since farmers are unlikely to adopt new management practices given the low trading price of carbon and more profitable alternative uses of carbon-rich materials (White et al. 2018; Poulton et al. 2018). However, the trading price of carbon is likely to increase with increasing focus on climate change mitigation and adaptation policies providing strong incentives for farmers (Frank et al. 2017). Adoption of novel practices or systems may also require cultural adaptation, as new practices present risks for farmers, when there is insufficient support from farm advisors or where there are vested interests. Smallholder farmers in developing countries may be less interested in change because they are more vulnerable to impacts on food security and community well-being (Lal 2019). In some developing countries, gender inequality, social exclusion, lack of land rights and/or tenure security, and lack of education impede the adoption of new practices, compounded by the lack of financial resources (Nath et al. 2018; Corbeels et al. 2019). However, there are documented ways to overcome these constraints in at least some locations (Pan et al. 2017). Support for information exchange, finance and capacity building can also enable farmers to adopt more innovative practices. One example is the adoption of biochar technology which, despite being a promising option to improve soil quality and increase SOC stocks (Marousek et al. 2017), remains unknown to many framers and uneconomic to implement due to high demand for organic residues from other sectors and high transportation costs.

RISKS AND TRADE-OFFS

Emissions of greenhouse gases and water use

Non-CO_2 greenhouse gas emissions with a much higher global warming potential may limit the climate change mitigation potential of SOC sequestration. These include N_2O emissions following mineral fertilisation, CH_4 and N_2O emissions from ruminant livestock and CH_4 and N_2O emissions from rice production systems. Practices promoted by the 4p1000 Initiative need to take them into account to ensure that net greenhouse emissions do not exceed the offset benefit from increased SOC sequestration. The trade-off effects between greenhouse gas emissions and SOC sequestration may be dynamic. For example, if fertiliser applications are not reduced, increases in SOC sequestration may no longer offset N_2O emissions when the system is approaching a new equilibrium for SOC storage (Lugato et al. 2018). These dynamic processes need to be evaluated carefully, and should be considered when actions to increase SOC stocks are undertaken.

One critical issue, not yet addressed, is the effect of SOC sequestration on the water balance of (agro-) ecosystems. For example, Jackson et al. (2005) showed that C sequestration in woody biomass reduced water availability for consumption because of increased water loss from the evaporation of intercepted rainfall. In many agricultural systems, irrigation is used to enhance productivity with variable impacts on SOC sequestration (Trost et al. 2013). Especially under arid conditions, water is needed for (1) additional biomass production and thus carbon release into soils, (2) microbial activity to transform plant litter compounds into refractory SOC and (3) compensation of water loss in plants, due to high evapotranspiration, as water is needed for photosynthesis. On the other hand, improvements in soil structure when increasing soil organic matter content have positive effects on soil water retention and infiltration (Pittelkow et al. 2015). These interrelationships need to be considered as well as the fact that water shortage following climate change may put at risk SOC in systems with permanent water-logging (exp. Paddy rice).

Avoiding emissions from SOC-rich soils

SOC-rich soils and organic soils are among the most fertile sites but some are heavily exploited for agricultural production, often at the expense of maintaining SOC stocks, leading to large releases of CO_2 to the atmosphere (Leifeld and Menichetti 2018). Globally, peatlands occupy only 3% of land area but are estimated to store about 600 Gt of SOC. This corresponds to around 20% of SOC stored in the first 30 centimetres of soils globally (Scharlemann et al. 2014). Natural peatlands are characterised by continuous water-logging, limiting organic matter decomposition because of low oxygen supply. For this reason, avoiding further drainage of intact peatland soils should be a priority. Many of these soils are under agricultural management and major contributors to greenhouse gas emissions. A recent analysis showed that degraded peatlands globally store ~ 80.8 Gt of soil C with emissions dominantly from tropical regions of ~ 1.91 (range 0.31–3.38) Gt CO_2-eq. $year^{-1}$ (Leifeld and Menichetti, 2018). The authors also showed that the global greenhouse gas emissions estimated from cultivated peatlands may completely offset the SOC sequestration potential of mineral soils. Therefore, in humid regions, careful management of water-logging may be required to ensure that losses from the large amounts of SOC stored in peatland soils are minimised.

THE 4P1000 INITIATIVE AS A COLLABORATIVE PLATFORM FOR POLICY-SCIENCE-PRACTICE INTERACTIONS

Increasing terrestrial biosphere carbon sinks could contribute to achieving the ambitious climate change mitigation target of limiting the increase in global average temperature to well below 2 °C above pre-industrial levels by offsetting emissions. The use of bioenergy with carbon capture and storage (BECCS), biochar and SOC sequestration have been presented as possibilities (IPCC 2006). It is apparent that SOC sequestration is the most viable option because it (1) has been tested, (2) is feasible at large spatial scales, (3) does not constrain the use of land and (4) provides potential co-benefits to meet other SDGs (Smith 2016). The 4p1000 Initiative attracted attention because it addresses many social issues related to agriculture that impact widely on communities and integrates engagement from many disciplines and sectors. The Initiative addresses global issues to mitigate greenhouse gas emissions and food security and, at the same time, local issues to improve soil quality and agricultural production. However, this broad application also leads to difficulties in engaging adoption to implement the necessary actions. While there are already other initiatives to promote SOC sequestration and improve soil quality, such as the Global Soil Partnership, the 4p1000 Initiative provides a platform to encourage interactions among scientists, policy makers and practitioners (farmers, NGOs, funders…). This tripartite collaboration is important to ensure that policy decisions are based on credible research and that scientific findings are implemented to meet local needs. The biggest challenge to the success of the 4p1000 Initiative is to stimulate collaboration across the breadth of collaborators to agree on actions and their implementation to achieve the target of the Initiative. It should serve as a catalyst to enhance information exchange and collaboration, leading to joint actions by a wide range of stakeholders.

THE WAY FORWARD

The controversy resulting from the initial articulation of the goal of the Initiative has been helpful to promote scientific rigour and policy debate to formulate action. After successful engagement with stakeholders, and elaboration of criteria to assess management actions by the Scientific and Technical Committee of the Initiative (Fig. 2), the next challenge is to build on tripartite engagement between policy makers, scientists and practitioners to promote implementation of best practices. To support the implementation, the 4p1000 Initiative must provide linkages with action plans, contributions and agricultural development projects at national scales. Progress was made at COP of the UNFCCC in Bonn in 2017, where discussion of agriculture and the role of soil carbon stocks were included for the first time in the Koronivia Decision on joint work of the subsidiary body for scientific and technological advice (SBSTA) and the subsidiary body for implementation (SBI) (UNFCCC 2018). Eight steps for achieving increased SOC sequestration were recently presented. These include protection of existing SOC stocks, e.g. in organic soils, promotion of C uptake through new practices and regulations, monitoring, reporting and verifying impact through advanced analytical techniques and data harmonisation. New strategies need to be tested and communities must be involved. Further, education, identification and coordination of policies as well as provision of financial support to help farmers, who use sustainable SOC improving practices is required (Rumpel et al. 2018). To increase public awareness about the necessity to increase SOC stocks, the Initiative promotes SOC sequestration to a wide audience, including farmers and land managers, agricultural suppliers of resources, other contributors to the supply chain, central and local governments, urban waste managers and consumers, etc. The 4p1000 Initiative will take advantage of existing online tools and create an interactive platform to support exchange between multiple partners with different roles and from different geographical regions and cultures. It is essential to communicate success stories of increasing SOC sequestration in different pedoclimatic conditions and different agricultural management systems. Moreover, further investment in research and the development of innovative technologies will be needed to provide stronger support for the 4p1000 Initiative. In addition, the Scientific and Technical Committee of the Initiative established a research programme (STC 2017). This programme comprises four pillars: (1) Estimation of the SOC storage potential, (2) Development of management practices, (3) Definition of the enabling environment and (4) Monitoring, reporting and verification. Within each of these pillars, key knowledge gaps have been identified and these need to be promoted to engage activities by research organisations and promote investment in these areas. To initiate implementation of C sequestering options that are relevant to local conditions and embrace farmer knowledge along with research findings, innovative learning networks linking farmers, technical assistance organisations, scientists and policy makers are also required. This can be achieved by establishing living labs and networks of demonstration farms to better communicate successful management practices based on rigorous research findings. The 4p1000 Initiative, as an international multi-participant programme, will facilitate adoption of the best management practices and innovative technologies by providing information and promoting international collaboration at all levels (Rumpel et al. 2018; Lal 2019).

CONCLUSIONS

The '4 per 1000' Initiative aims to increase carbon storage in agricultural soils and therefore contributes to mitigating climate change, adapting to climate change and increasing food security (http://www.4p1000.org). The Initiative has potential as an international multi-disciplinary platform combining a recommended research programme with a multi-stakeholder action plan to link scientific research and action. It aims to communicate and promote management actions to increase SOC sequestration through implementation of sustainable development practices. The main

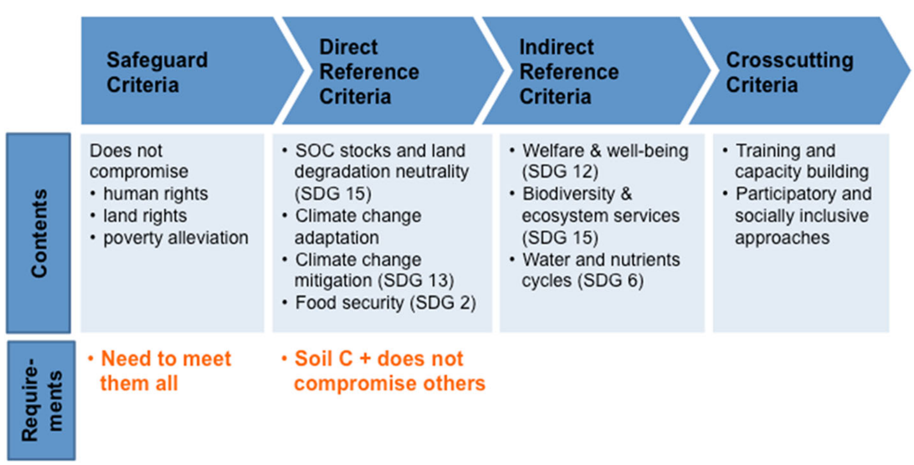

Fig. 2 Criteria that need to be met by management actions implemented under the 4p1000 Initiative (STC, 2017)

strength of the Initiative is that it provides a collaborative space for engagement and discussion between contributors (scientists, practitioners, NGOs, private sector and policy makers) from different educational and cultural backgrounds. With its simple message, the Initiative encourages widespread participation and adoption by many partners. Recent clarification of the initial message has strengthened the rationale for the Initiative. It is clear that SOC sequestration has the potential to offset greenhouse gas emissions to contribute to aggressive, large-scale, urgent reductions in greenhouse gas emissions, as well as to improving food security and climate change adaptation. However, the potential of soils to sequester SOC is limited by biophysical, socio-economic and political barriers. These need to be overcome by region-specific actions and the development and implementation of innovative technologies. While SOC sequestration can make a significant contribution to climate change mitigation, the more certain and principal benefits, especially those on degraded land, will be improvements in soil quality, contributing to food security and agricultural systems that are more resilient to climate change. To achieve this, priorities will need to be decided to ensure that actions are focused on sites and conditions where opportunities to increase soil carbon stocks are most likely to be successful. We conclude that the 4p1000 Initiative is likely to facilitate findings from site-specific studies, practical experiences and model predictions to be incorporated into future policy actions to encourage long-term adoption and implementation of sustainable development strategies.

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REFERENCES

Barre, P., H. Durand, C. Chenu, P. Meunier, D. Montagne, G. Castel, D. Billiou, L. Soucemarianadin, et al. 2017. Geological control of soil organic carbon and nitrogen stocks at the landscape scale. *Geoderma* 285: 50–56.

Baveye, P.C., J. Berthelin, D. Tessier, and G. Lemaire. 2018. The "4 per 1000" initiative: A credibility issue for the soil science community? *Geoderma* 309: 118–123.

Chabbi, A., J. Lehmann, P. Ciais, H.W. Loescher, M.F. Cotrufo, A. Don, M. SanClements, L. Schipper, et al. 2017. Aligning agriculture and climate policy. *Nature Climate Change* 7: 307–309.

Chenu, C., D.A. Angers, P. Barré, D. Derrien, D. Arrouays, and J. Balesdent. 2019. Increasing organic stocks in agricultural soils: Knowledge gaps and potential innovations. *Soil and Tillage Research* 118: 42–51.

Corbeels, M., K. Naudin, H. Guibert, E. Torquebiau, and R. Cardinael. 2019. Is 4 per 1000 soil carbon storage attainable with agroforestry and conservation agriculture in sub-Saharan Africa? *Soil & Tillage Research* 188: 16–26.

de Vries, W. 2018. Soil carbon 4 per mille: A good initiative but let's manage not only the soil but also the expectations: Comment on Minasny et al. (2017). *Geoderma* 292: 59–86.

Diacono, M., and F. Montemurro. 2010. Long-term effects of organic amendments on soil fertility. A review. *Agriculture for Sustainable Development* 30: 401–422.

Ditzler, L., T.A. Breland, C. Francis, M. Chakraborty, D.K. Singh, A. Srivastava, F. Eyhorn, J.C.J. Groot, et al. 2018. Identifying viable nutrient management interventions at the farm level: The case of smallholder organic Basmati rice production in Uttarakhand, India. *Agricultural Systems* 161: 61–71.

Frank, S., P. Havlík, J.F. Soussana, A. Levesque, H. Valin, L. Wollenberg, U. Kleinwechter, O. Fricko, et al. 2017. Reducing greenhouse gas emissions in agriculture without compromising food security? *Environmental Research Letters* 12: 105004.

Fujisaki, K., T. Chevallier, L. Chapuis-Lardy, A. Albrecht, T. Razafimbelo, D. Masse, and J.-L. Chotte. 2018. Soil carbon stock changes in tropical croplands are mainly driven by carbon inputs: A synthesis. *Agriculture, Ecosystems & Environment* 259: 147–158.

Hutchinson, J.J., C.A. Campbell, and R. Desjardins. 2007. Some perspectives on carbon sequestration in agriculture. *Agricultural and Forest Meteorology* 142: 288–302.

IPCC. 2006. 2006 IPCC guidelines for national greenhouse gas inventories. In *Prepared by the national greenhouse gas Inventories programme*, eds. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe. Japan: IGES.

Jackson, R.B., E.G. Jobbágy, R. Avissar, S.R. Baidya, D.F. Barrett, C.W. Cook, K.A. Farley, D.C. le Maitre, et al. 2005. Trading water for carbon with biological carbon sequestration. *Science* 5756: 1944–1947.

Kirkby, C.A., A.E. Richardson, L.J. Wade, J.B. Passioura, G.D. Batten, C. Blanchard, and J.A. Kirkegaard. 2014. Nutrient availability limits carbon storage in agricultural soils. *Soil Biology and Biochemistry* 68: 204–209.

Kon Kam King, J., C. Granjou, J. Fournil, and L. Cecillon. 2018. Soil sciences and the French 4 per 1000 Initiative—The promises of underground carbon. *Energy Research & Social Science* 45: 144–152.

Ladha, J.K., C.K. Reddy, A.T. Padre, and C.V. Kessel. 2011. Role of nitrogen fertilization in sustaining organic matter in cultivated soils. *Journal of Environmental Quality* 40: 1756–1766.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304: 1623–1627.

Lal, R. 2019. Promoting "4 Per Thousand" and "Adapting African Agriculture" by south-south cooperation: Conservation agriculture and sustainable intensification. *Soil and Tillage Research* 118: 27–34.

Leifeld, J., and L. Menichetti. 2018. The underappreciated potential of peatlands in global climate change mitigation strategies. *Nature Communications* 9: 1071.

Lugato, E., A. Leip, and A. Jones. 2018. Mitigation potential of soil carbon management overestimated by neglecting N_2O emissions. *Nature Climate Change* 8: 219–223.

Maroušek, J., M. Vochozka, J. Plachý, and J. Žák. 2017. Glory and misery of biochar. *Clean Technologies and Environmental Policy* 19: 311–317.

Minasny, B., D. Arrouays, A.B. McBratney, D.A. Angers, A. Chambers, V. Chaplot, and L. Winowiecki. 2018. Rejoinder to Comments on Minasny et al., 2017 Soil carbon 4 per mille. *Geoderma* 292: 59–86.

Nath, J.A., R. Lal, G.W. Siles, K. Dasa, and A.K. Das. 2018. Managing India's small landholder farms for food security and achieving the "4 per Thousand" target. *The Science of the Total Environment* 634: 1024–1033.

Pan, W.L., W.S. Schillinger, F.L. Young, E. Kirby, and G.G. Yorgey, et al. 2017. Integrating old principles and new technologies into win-win scenarios for farm and climate. Frontiers in Environmental Science. https://doi.org/10.3389/fenvs.2017.00076.

Paustian, K., J. Lehmann, S. Ogle, D. Reay, G.P. Robertson, and P. Smith. 2016. Climate-smart soils. *Nature* 532: 49–57.

Pingali, P.L. 2012. Green revolution: impacts, limits and the path ahead. *PNAS* 109: 12302–12308.

Pittelkow, C.M., X. Liang, B.A. Linquist, K.J. van Groenigen, J. Lee, M.E. Lundy, N. van Gestel, J. Six, et al. 2015. Productivity limits and potentials of the principles of conservation agriculture. *Nature* 517: 365–368. https://doi.org/10.1038/nature13809.

Poeplau, C., and A. Don. 2015. Carbon sequestration in agricultural soils via cultivation of cover crops—A meta-analysis. *Agriculture, Ecosystems & Environment* 200: 33–41.

Poulton, P., J. Johnston, A. MacDonald, R. White, and D. Powlson. 2018. Major limitations to achieving "4 per 1000″ increases in soil organic carbon stock in temperate regions: Evidence from long-term experiments at Rothamsted Research. *UK. Global Change Biology* 12: 3218–3221.

Powlson, D.S., A.P. Whitmore, and A.W.T. Goulding. 2011. Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European Journal of Soil Science* 62: 42–55.

Rumpel, C., F. Amiraslani, L.-S. Koutika, P. Smith, D. Whitehead, and E. Wollenberg. 2018. Put more carbon in soils to meet Paris climate pledges. *Nature* 564: 32–34.

Sanderman, J., C. Creamer, W.T. Baisden, M. Farrell, and S. Fallon. 2017. Greater soil carbon stocks and faster turnover rates with increasing agricultural productivity. *Soil* 3: 1–16.

Scharlemann, J.P.W., E.V.J. Tanner, R. Hiederer, and V. Kapos. 2014. Global soil carbon: understanding and managing the largest terrestrial carbon pool. *Carbon Manag.* 5: 81–91.

Schiefer, J., G.J. Lair, C. Lüthgens, E.M. Wild, P. Steiner, and W.H. Blum. 2018. The increase of soil organic carbon as proposed by the "4/1000 initiative" is strongly limited by the status of soil development—A case study along a substrate age gradient in Central Europe. *The Science of the Total Environment* 628–629: 840–847.

Smith, P. 2016. Soil carbon sequestration and biochar as negative emission technologies. *Global Change Biology* 22: 1315–1324.

Smith, P., S.J. Davis, F. Creutzig, S. Fuss, J. Minx, B. Gabrielle, et al. 2016. Biophysical and economic limits to negative CO2 emissions. *Nature Climate Change* 6: 42–50.

Sommer, R., and D. Bossio. 2014. Dynamics and climate change mitigation potential of soil organic carbon sequestration. *Journal Environmental Management* 144: 83–87.

Soussana, J.F., S. Lutfalla, R. Lal, C. Chenu, and P. Ciais. 2017. Letter to the editor: answer to the viewpoint "sequestering soil organic carbon: a nitrogen dilemma" by van Groenigen et al. (2017). *Environmental Science and Technology* 51: 11502.

Soussana, J.F., S. Lutfalla, F. Ehrhardt, T. Rosenstock, C. Lamanna, P. Havlík, and R. Lal. 2019. Matching policy and science: Rationale for the "4 per 1000 - soils for food security and climate" initiative. *Soil and Tillage Research* 188: 3–15.

STC. 2017. The '4 per 1000' Research Priorities. https://www.4p1000.org/sites/default/files/content/gov_cst_en_consortium_3-4-4p1000_research_priorities.pdf.

Tilman, D., C. Balzer, J. Hill, and B.L. Befort. 2011. Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Acadamy of Science USA* 108: 20260–20264.

Trost, B., A. Prochnow, K. Drastig, A. Meyer-Aurich, F. Ellmer, and M. Baumecker. 2013. Irrigation, soil organic carbon and N_2O emissions. *A review. Agronomy for Sustainable Development* 33: 733–749.

UNFCCC. 2018. Koronivia Joint Work on Agriculture (decision 4/CP.23).

Van Groenigen, J.W., C. Van Kessel, B.A. Hungate, O. Oenema, D.S. Powlson, and K.J. Van Groenigen. 2017. Sequestering soil organic carbon: A nitrogen dilemma. *Environmental Science and Technology* 51: 4738–4739.

VandenBygaart, A.J. 2018. Comments on soil carbon 4 per mille by Minasny et al. 2017. *Geoderma* 309: 113–114.

White, R.E., B. Davidson, S.K. Lam, and D. Chen. 2018. A critique of the paper "Soil carbon 4 per mille" by Minasny et al. (2017). *Geoderma* 309: 115–117.

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