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VIEWPOINT

Beyond COP21: Potential and challenges of the "4 per Thousand" initiative

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Climate change negotiations at the 21st Conference of the Parties to the United Nations (UN) Framework Convention on Climate Change (COP21) in Paris (November 30 to December 11, 2015) were unique because soil carbon (C) and agriculture were on the agenda for the first time ever since COP meetings started 21 years ago. The "4 per Thousand" proposal calls for a voluntary action plan to enhance soil organic carbon (SOC) content of world soils to a 40 cm (16 in) depth at the rate of 0.4% per year. The strategy is to promote SOC sequestration through adoption of recommended management practices (RMPs) of C farming including conservation agriculture (CA), mulch farming, cover cropping, agroforestry, biochar, improved grazing, and restoration of degraded soils through soil-landscape restoration, etc. Theoretically, the world's cropland soils could sequester as much as 62 t ha^{-1} (25 tn ac^{-1}) over the next 50 to 75 years (0.8 to 1.2 t ha^{-1} y^{-1} [0.3 to 0.5 tn ac^{-1} yr^{-1}]) with a total C sink capacity of ~88 Gt (~97 billion tn) on 1,400 Mha (3,500 million ac). In addition, there is also SOC sequestration potential of grazing lands, forest lands, and degraded and desertified lands. With global implementation, SOC sequestration would restore soil quality, advance food and nutritional security, and improve the environment. This strategy of increasing SOC, with numerous cobenefits, would also minimize the tension between economic development and the imperative to curb greenhouse gas (GHG) emissions while achieving sustainable development goals of the UN. Including SOC sequestration and agriculture on the agenda of COP21 is an important first step. However, its implementation at global scale, especially by 500 to 600 million resource-poor farmers and small landholders, is a challenge that necessitates careful planning. The goal of the "4 per Thousand" proposal is extremely ambitious, but it circumvents the traditional defensive stance of national interest. It also has the benefits of promoting the Sustainable Development Goals of the UN, especially Target 2.4 (improving land and soil quality) and Target 15.3 (achieving a land degradation neutral world). Yet, rewarding farmers through payments for ecosystem services, based on the societal value of soil C (Lal 2004), would be a challenging but crucial step in implementing the "4 per Thousand" initiative.

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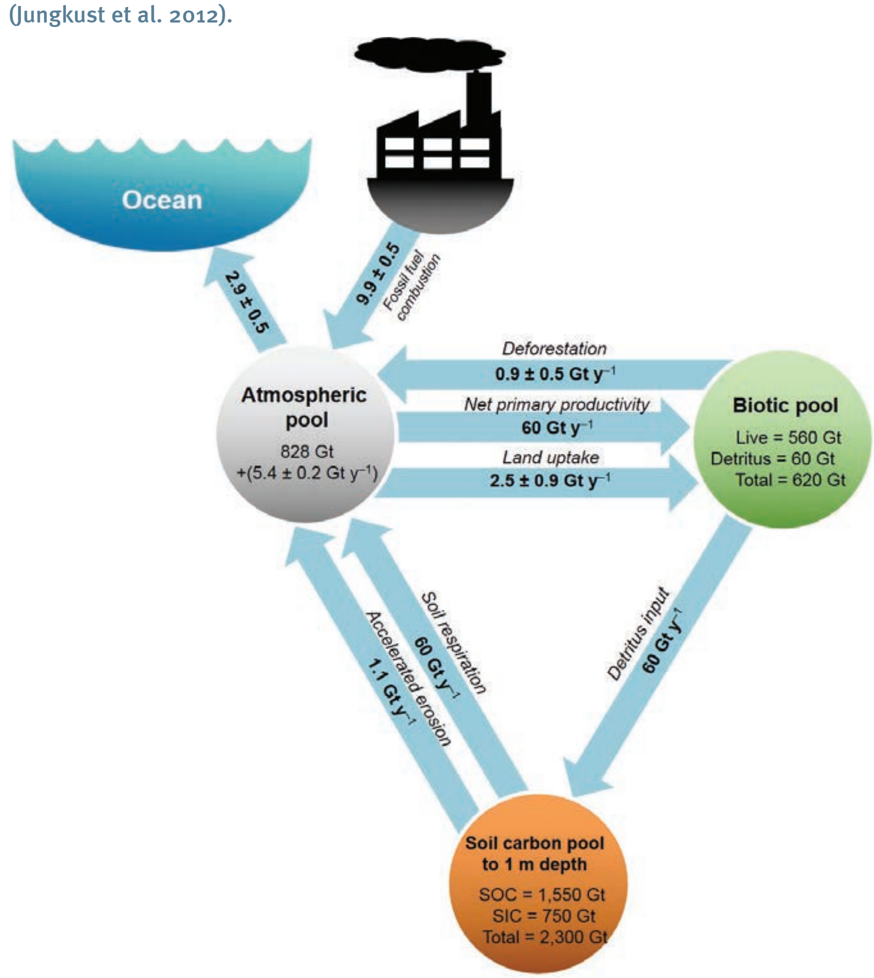
THE GLOBAL CARBON CYCLE

The soil C pool plays an important role in the global C cycle (figure 1). Even small changes in the soil C pool can translate into large changes in the atmospheric pool, because 1 Gt (1.10 billion tn) of the soil C pool is equivalent to 0.47 ppm of carbon dioxide (CO_2) in the atmosphere. Data on the current global C budget indicate that fuel combustion of 9.9 ± 0.5 Gt C y^{-1} (10.9 ± 0.55 billion tn C yr^{-1}) plus 0.9 ± 0.5 Gt C y^{-1} (0.99 ± 0.55 billion tn C yr^{-1}) of land use conversion is leading to atmospheric uptake of 5.4 Gt C y^{-1} (5.95 billion tn C yr^{-1}), or about 50% of the total anthropogenic emissions. The remainder 5.4 Gt (5.95 billion tn) is absorbed by ocean and the land-based sinks. Thus, land-based sinks are important to absorbing some anthropogenic emissions.

Figure 1

The importance of soil in the global carbon (C) cycle (Batjes 1996; Lal 2004; Le Quere et al. 2015). The data on fluxes are from Le Quéré et al. (2015).The data on the soil C pool do not include the recent data on the SOC pool in the permafrost (Jungkust et al. 2012).



HISTORIC CARBON LOSS FROM THE TERRESTRIAL ECOSYSTEM

Land use conversion and soil cultivation have been major sources of GHGs since the onset of settled agriculture. The land area covered by forest was 6.5 billion ha (16.1 billion ac) in circa 8000 BC and 4.0 billion ha (9.9 billion ac) in 2000 AD. Over 10 millennia, forestland has been converted to cropland (1.42 billion ha [3.51 billion ac]), grazing land (3.5 billion ha [8.65 billion ac]), and other land uses. As much as 40% of the planet's total land area has been converted into agriculture and plantations to produce grains, vegetables, fruits, milk, and meat to feed 7.3 billion people in 2015 and a projected 9.6 billion by 2050 (UN 2015). Some environmental impacts of deforestation and land use conversion, which may be exacerbated by global warming, include drastic perturbations of the global C and water cycles leading to (1) a strong depletion of the terrestrial C pool and the consequential enrichment of the atmospheric concentration of CO_2 with the attendant global warming, (2) high risks of droughts (e.g., in California, Texas, and elsewhere, including South America) because of changes in the atmospheric water vapor budget, and (3) loss of biodiversity.

Depletion of C from the terrestrial biosphere has and will adversely impact all ecosystems from which humanity derives numerous goods and services, including food, feed, fiber, fuel, shelter, and industrial raw materials. The most drastic impact of the emission of C is the accelerated greenhouse effect and projected global warming. The latter may lead to positive feedback and the attendant risks of increasing emissions from vulnerable terrestrial C pools in the tundra (due to melting of permafrost), along with those in boreal, alpine (e.g., the Himalayas and the Andes), and humid/subhumid tropical regions. Atmospheric concentration of CO_2 has increased from 280 ppm circa 1750 to 400 ppm in 2013 (Bello 2013) and is increasing at the annual rate of about 2.3 ppm. Similar increasing trends are observed in atmospheric concentrations of methane (CH_4) and nitrous oxide (N_2O) (WMO 2015), with dire consequences to these drastic alterations of atmospheric chemistry.

Historic emissions of C due to deforestation and land use conversion are estimated at 320 Gt (352.7 billion tn) since the beginning of agriculture circa 8000 BC to 1750 (Ruddiman 2003; Ruddiman et al. 2015) and 136 Gt (149.9 billion tn) from 1750 to 2010 (Houghton et al. 2012; IPCC 2014). They are projected at 30 Gt (33.06 billion tn) between 2010 and 2030 (Holdren 2008). Thus, total anthropogenic emissions from the terrestrial biosphere (vegetation, soil, wetlands, etc.) by land use conversion from the beginning of agriculture to 2030 are estimated at about 486 Gt (535.7 billion tn). In contrast, emissions from fossil fuel combustion from 1750 to 2002 are estimated at 292 Gt (321.9 billion tn) and projected at 200 Gt (220.5 billion tn) from 2003 to 2030 (Holdren 2008; Boden et al. 2013). The Global Carbon Project has estimated emissions from anthropogenic activities between 1870 and 2014 at 545 ± 55 Gt (600.8 ± 60.6 billion tn) C. Of this, 75% is from fossil fuel combustion and 25% from land use conversion (Le Quéré et al. 2015).

CARBON DIOXIDE ABSORPTION CAPACITY OF NATURAL SINKS

There has been considerable interest in the capacity of natural sinks for the uptake of anthropogenic emissions (Pan et al. 2011; Sarmiento et al. 2010; Fredlingstein et al. 2010; Le Quéré et al. 2009). Ballantyne et al. (2012) reported a trend of increase in the observed net CO_2 uptake by land and oceans during the past 50 years. For example, total anthropogenic emissions between 1959 and 2010 included 60 Gt (66.1 billion tn) from land use and 290 Gt (319.7 billion tn) from fossil fuel combustion with a total of 350 ± 29 Gt (385.8 ± 32.0 billion tn) of anthropogenic emissions. Of these, 158 ± 2 Gt (174.2 ± 2.2 billion tn) were absorbed by the atmosphere, and 192 ± 29 Gt (211.6 ± 32.0 billion tn) were absorbed by ocean and land-based sinks (Ballantyne et al. 2012). Thus, from the global perspective, net uptake of anthropogenic emissions by land and ocean-based sinks have continued to increase over the 50-year period between 1960 and 2010. Therefore, it is pertinent that the uptake capacity of land-based sinks (soil, forest, and wetlands) be enhanced through targeted management. This possibility of uptake of CO_2 by land-based sink is the rationale behind the "4 per Thousand" initiative discussed at COP21. Just governance and wise management (Montanarella 2015) are essential to enhancing land-based sinks and disrupting the self-reinforcing feedback between soil degradation and chronic poverty (Barrett and Bevis 2015).

THE FOOD AND NUTRITIONAL SCARCITY CONUNDRUM

In addition to the use of 40% of the ice-free terrestrial land area (3.75 billion ha [9.3 billion ac]) for growing crops (1.42 billion ha [3.50 billion ac]) and raising animals (3.5 billion ha [8.65 billion ac]), 70% of global fresh water withdrawals are used for irrigation. One-third (30% to 35%) of global GHG emissions (both direct and indirect) are contributed by agriculture (IPCC 2014). Total world grain production was 2.24 Gt (2.46 billion tn) in 2008 through 2010, and 2.47 Gt (2.72 billion tn) in 2013 through 2015 (FAO 2015). However, global demand will increase by 1 Gt (1.1 billion tn) of grains and 200 Mt (220 million tn) of meat by 2050 (FAO 2015). Feeding 7.3 billion in 2015 takes cropland area the size of South America (17.85 Mkm^2 [6.89 million mi^2]). It is argued that feeding 9.7 billion by 2050 would take the land area of South America plus that of Brazil (8.36 Mkm^2 [3.23 million mi^2]). If the new land is brought under production, the land area of managed ecosystems is projected to increase to 1.59 billion ha (3.92 billion ac) for cropland, 4.01 billion ha (9.90 billon ac) for pasture/grazing land, and 529 Mha (1,306.6 million ac) for irrigated land by 2050 (FAO 2012). However, bringing additional land area under agriculture and using additional water for irrigation are neither acceptable nor needed.

Indeed, expanding agricultural land area is not a prudent option; neither is that of increasing the area of irrigated cropland nor of intensifying the use of chemical fertilizers and pesticides. These trends would exacerbate the already severe problems of global warming, depletion of nonrenewable water reserves and eutrophication of surface waters, and extinction of not only plants and animals but also those of some fragile soils. The Hubbert curve also applies to soils, because there exists a "peak soil" concept along with extinction of key soil orders (Tennesen 2014) caused by soil degradation related to land misuse and soil mismanagement from the ever-increasing greed of resource-endowed farmers and the desperateness of resource-impoverished communities (Lal 2015b).

Yet, food demands must be met for 9.7 billion people by 2050, while also recarbonizing agricultural lands and rewilding depleted/desertified ecosystems, which are otherwise marginal for agricultural land use. In addition to producing food in vertical farms or skyscrapers (using aquaponics and aeroponics, and greenhouses in arid regions) and with manufacturing food (e.g., stem cell hamburger), there are also other important options for feeding humanity while recarbonizing the land, including the following:

1. Reducing food waste by 30% to 50% in both developed and developing countries.
2. Increasing access to food for 795 million hungry in 2015 by addressing poverty, inequality, wars, and political instability (e.g., the European migrant crisis of 2015).
3. Improving distribution by improving infrastructure, promoting regional trade, and alleviating poverty as per the sustainable development goals of the UN.
4. Increasing use of plant-based diets to save land through less consumption of meat (28 cal of grains produce 1 cal of meat for human consumption [Isaacson 2015] or 6 to 8 kg grains produce 1 kg red meat).
5. Accepting personal responsibility and recognizing that every human is a perpetrator and a victim.
6. Adopting sustainable intensification of agroecosystems by restoring degraded soils by C sequestration and rewilding the surplus land—using the best and saving the rest for nature conservancy.

Recarbonization of soil and the terrestrial biosphere by "sustainable intensification" implies producing more food from less land, water, chemicals, energy, and GHG emissions. This is the second rationale for implementing "4 per Thousand" initiative.

RECARBONIZING SOILS OF THE AGROECOSYSTEMS

The "4 per Thousand" strategy proposed by the French Government at COP21 in Paris in December of 2015 is based on the fact that most soils of agroecosystems are depleted of the antecedent SOC pool (because of erosion, mineralization, and leaching), along with concerns about the negative soil C budget of conventional practices. Conversion of natural ecosystems to managed agroecosystems leads to reduction in the antecedent SOC pool by 30% to 50% over 50 years in temperate climates, and as much as 75% in 10 to 25 years in the tropics (figure 2; Lal 2004). The SOC pool reaches a new equilibrium in soils not affected by wind and/or water erosion but continuously declines in erodible soils subject to a high climatic erosivity. However, the SOC pool can be increased by conversion to a restorative land use and adoption of RMPs which can create a positive C budget (input of biomass C exceeds the losses by erosion, mineralization, and leaching). The new equilibrium, corresponding to about two-thirds of the antecedent SOC pool, is often referred to "the attainable potential." Adoption of some site-specific, innovative land use/management practices can sequester additional SOC, which can reach the antecedent pool. The "maximum potential" of SOC sequestration corresponds to the "soil C sink capacity," which depends on a range of factors including texture, mineralogy, depth of soil solum, etc. The change in SOC divided by the change in time is the rate of SOC sequestration (Mg C ha^{-1} y^{-1}). In soils characterized by inherent constraints to biomass production under natural conditions (e.g. low pH, toxicity of aluminum [Al] and other metallic cations, high concentration of soluble salts, deficiency of available phosphorus [P] and other nutrients, extreme aridity, and low soil moisture reserves), it is technologically possible to increase the SOC pool above the antecedent level through alleviation of soil and environmental constraints by progressive adoption of innovative technologies that can create a positive soil/ecosystem C budget. Among a menu of RMPs that can create a positive soil C budget and lead to SOC sequestration are CA (Lal 2015a), biochar (Hansen et al. 2015), agroforestry (Lorenz and Lal 2014), desertification control through afforestation and establishment of vegetation cover (Lal et al. 1999), improved pasture management along with mixed crop-livestock systems (Herrero et al. 2010), water harvesting and recycling involving drip subirrigation, integrated nutrient management, and farming systems with a holistic/nexus-based approach (figure 2). Agricultural lands prone to erosion by tillage, water, and wind can be restored by applying the soil accumulated at the base of the slopes to severely eroded side slopes or hilltops. This practice is known as soil-landscape restoration (Lobb 2015). Collectively, RMPs can be included in C farming programs to also enhance soil's resilience against a changing and uncertain climate with numerous cobenefits.

However, there exists neither a panacea nor a silver bullet, and site- and soil-specific technologies have to be identified and fine-tuned considering biophysical, socioeconomic, cultural and ethnic factors. Furthermore, each of these technological options has its own footprint for C, nutrients, energy, and water (hidden or ecological costs), which must be empirically determined to compute the net C gains (figure 2). Practices which create a negative C budget lead to depletion of the SOC pool, and those which create a positive budget cause sequestration (table 1).

Measurement of GHG emissions, over the growing cycle, must be computed in terms of CO_2 equivalent with due consideration to the global warming potential of N_2O and CH_4 (IPCC 2014). The mean residence time (MRT), computed by dividing the SOC pool by the annual C flux at different spatial scales or by assessing soil profile characteristics, is important for evaluating the effectiveness of cultural practices to mitigate climate change. The SOC pool can also be related to soil quality (Mukherjee and Lal 2015) or functionality, agronomic productivity (Lal 2006), and use efficiency of inputs (Lal 2010a). Residue retention and recycling of nitrogen (N) and other nutrients (e.g., P and sulfur [S]) are also important to SOC sequestration (Lal 2014).

CHALLENGES OF IMPLEMENTING THE "4 PER THOUSAND" INITIATIVE

Climate change is a reality, and humans have not had to deal with such a drastic

Figure 2

Effects of land use change and management on the soil carbon (C) pool and dynamics (modified and updated from Lal [2005]).

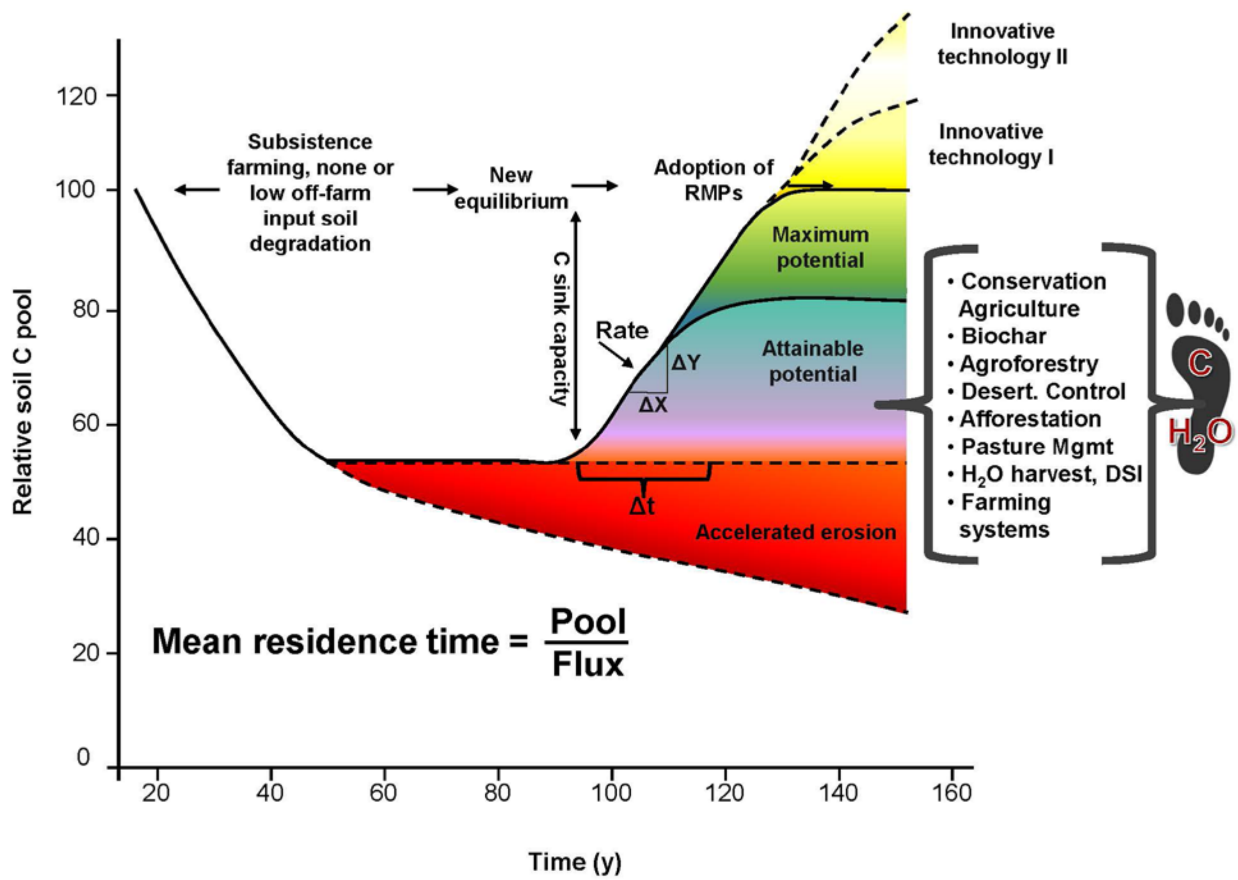


Table 1

The importance of soil management as source and sink of atmospheric carbon dioxide (CO_2).

Source	Sink
1. Deforestation	1. Afforestation and establishment of perennial cover
2. Biomass burning	2. Retention of crop residues and input of biomass carbon as surface mulch
3. Conversion of natural to managed ecosystems	3. Rewilding of agriculturally marginal lands
4. Extractive farming	4. Science-based agriculture to replace whatever (nutrients) are removed
5. Practices which aggravate soil erosion and create vegetative soil C budget	5. Conservation-effective measures that create a positive soil carbon budget
6. Drainage of wetlands	6. Restoration of wetlands and judicious management of water resources (harvesting and recycling)
7. Excessive tillage	7. Conservation agriculture
8. Simple rotations	8. Complex cropping/farming systems

climate/environmental change since 10 to 12 millennia ago. There is no other example in human history of a global threat with as far-reaching consequences as climate change in the twenty-first century (McNutt 2015). Thus, scientific knowledge must be translated into action because climate change can drastically impact the ecosystems that we depend on (Gattuso et al. 2015). With the objective of limiting global warming to 1.5°C (2.7°F), as agreed upon by COP21, humanity can only emit a finite amount of C between now and 2050 (Meinhausen et al. 2009). Yet, 20 of the previous meetings of the Conference of Parties of the UN Framework Convention for Climate Change have failed to reach any political consensus. Even COP21 in Paris did not objectively and critically discuss the basis of equitable distribution of the global C pie among all nations of the world:

$$(560 \text{ ppm} - 400 \text{ ppm}) \div 0.47 \text{ ppm } (\text{Gt C})^{-1} = 340 \text{ Gt } (375 \text{ billion tn}). \quad (1)$$

If the current policy continues to remain weak, it will lead to a long-term increase in temperature of 3.9°C (7.02°F; IEA 2014). There are numerous additional scientific and policy challenges to implementation of the "4 per Thousand" initiative.

Paucity of Scientific Data. Research data on rate of SOC sequestration, soil C sink capacity, effectiveness of RMPs for land use and soil/crop/animal management, and the magnitude of SOC sequestration and MRT are not widely available and are a high research priority. While the importance of SOC pool to agronomic sustainability has long been recognized (Jenny 1941), the societal value of soil C needs to be determined (Lal 2014). The importance of soil biota to SOC sequestration cannot be over-emphasized, because biota is the bioengine of soil restorative processes.

The Finite Capacity of Soil Carbon Sinks. Technical potential of SOC sequestration in the world's cropland and grazing lands is finite: 0.4 to 1.2 Gt (0.44 to 1.59 billion tn) C for cropland (Lal 2004), 0.3 to 0.5 Gt (0.33 to 0.55 billion tn) C for grazing lands, and 0.5 to 1.4 Gt (0.55 to 1.54 billion tn) C for restored degraded soils (Lal 2010b). The actual or attainable potential may as well be only one-third to one-half of the total technical potential of 0.4 to 1.2 Gt (0.125 to 0.45 tn ac^{-1} yr^{-1}) for cropland. Thus, SOC sequestration by itself cannot mitigate the humongous problem of climate change. Nonetheless, it must be integral to any menu of options, including adoption of RMPs that reduce energy use in agroecosystems and identify/develop no-C or low-C fuel sources.

The "4 per Thousand" proposal should be more about the concept than any specific numbers. The concept that soils and agriculture are solutions to the global issues of climate change, food insecurity, and environmental pollution is a major paradigm shift of historic significance.

Resource-Poor Farmers and Small Landholders. Restoring soil quality and decreasing risks of new soil degradation, so that existing SOC stocks are protected, remain a high priority, even more now than ever before. However, 500 to 600 million resource-poor farmers in developing countries are unable to adopt RMPs because of the weak institutional support and poor access to essential inputs. Yet, it is the degraded and depleted soils of small landholders (e.g., in southern Asia, Sub-Saharan Africa, the Caribbean, and the Andean region) that need urgent restoration through SOC sequestration. Promoting adoption of RMPs by small landholders will remain a major challenge.

Financial Commitments. Adoption of RMPs (e.g., residues retention, cover cropping, controlled grazing, converting agriculturally marginal lands to a perennial vegetation cover, and soil amendments) would require financial resources. Cost of additional N, P, and S for C sequestration must also be considered. Payments for soil C sequestration, at a just and fair price equivalent to the societal value of soil C (Lal 2014), would be essential. A protocol must be in place to implement such a scheme, backed by firm commitment of funding support. A supportive market approach can promote RMPs and C farming.

Permanence. The question of permanence is relevant. However, it is not an issue if farmers will continue to employ RMPs and restorative land uses. With implementation of later scenarios, SOC sequestration in stable microaggregates can have a MRT at a millennial scale. Thus, provision of incentives for continuous use of RMPs is a key issue that needs to be addressed, and success of the Conservation Reserve Program in the United States and set-aside program in Europe are relevant examples.

Implementation of the "4 per Thousand" Program. Despite all the rhetoric, the "4 per Thousand" proposal is not explicitly mentioned in the final COP21 document approved on December 12, 2015 (UNFCCC 2015). Article 2 of the proposal calls to limit the global warming to 1.5°C (2.7°F), but does not even mention the word "soil." This outcome should neither be surprising nor disappointing. Rather, it is a new challenge to soil scientists and agronomists. We should build upon the success of getting SOC on the agenda of COP21 to the next venue in Marrakech, Morocco, with good planning and strong determination. Each one of us has a strong role to play. While the 2015 International Year of Soil has been successful in enhancing awareness about the role of soils, the International Decade of Soils (2015 through 2024) has just started. We have a long way to go with the slogan "In Soil We Trust."

CONCLUSION

The adverse effects of land misuse and soil mismanagement on depletion of the SOC pool and degradation of soil processes are pervasive and can jeopardize the major ecosystem services essential to human wellbeing and nature conservancy. Thus, transition to sustainable soil management through adoption of RMPs is crucial to the future trends in climate, resource use efficiency, food and nutrition security, and human wellbeing. While SOC sequestration is finally receiving the scientific and political attention it deserves, effective implementation of the "4 per Thousand" program will involve a widespread adoption of RMPs at the global scale. Thus, science, practice and policies of SOC sequestration must be framed against the reality of the accelerated greenhouse effect, food and nutritional insecurity affecting billions of people, and aggravated risks of water pollution and biodiversity loss. The "4 per Thousand" proposal should be more about the concept than any specific numbers. The concept that soils and agriculture are solutions to the global issues of climate change, food insecurity, and environmental pollution is a major paradigm shift of historic significance. While the "4 per Thousand" program fills the need for a move toward soil quality restoration, SOC sequestration by itself is not enough to mitigate the anthropogenic climate change. It is also important to be realistic about its finite potential. Further, it is a change in the lifestyle of every citizen on earth that would be essential to addressing this serious problem of climate change. Sequestering C in soil and the terrestrial biosphere is only one of the numerous options of changing the lifestyle. Nonetheless, recarbonization of the terrestrial biosphere (soil and forest) may be our only hope to save us from ourselves. It is in this context that "4 per Thousand" proposal presented at COP21 is a historic landmark.

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