

At COP21 in Paris (2015), a voluntary action plan, '4 per 1000 initiative: Soil for Food Security and Climate' was proposed, and is supported by 39 countries and more than 190 organizations as of June 2017.

This initiative sets a global aspirational goal to increase SOC stock at an annual rate of 0.4% per year (or 4 per 1000) in all land uses, including forests.

# General aim:

- Increase organic matter and promote soil C sequestration, through the application of appropriate farming and forestry practices in order to contribute to food security, climate change mitigation and adaptation to climate change.
- From the presentation of Gianna Braun (Federal Office for Agriculture and Food, Germany, supporting the 4 per 1000 Executive Secretariat)

# Role of SOC in the biosphere

- Soil structure
- Aeration
- Water retention
- Pollutant filter
- Soil stability
- Nutrient cycling
- Biodiversity
- Productivity

# How are soils linked to climate change ?

- More carbon in soil.
- Less carbon in the air.

Carbon sequestration in soils is...

- the process of transferring CO<sub>2</sub> from the atmosphere into the soil of a land unit, through plants, plant residues and other organic solids which are stored or retained in the unit as part of the soil organic matter (humus).

# Soil organic matter is a part of the global C cycle

- Retention time of sequestered carbon in the soil (terrestrial pool) can range from short-term (not immediately released back to the atmosphere) to long-term (millenia) storage.
- Different fractions of soil carbon have different “stability”.

Soils represent the largest terrestrial carbon reservoir

- Atmosphere: 589 PgC (GtC)
- Vegetation: 450-650 PgC
- Soil: 1500-2400 PgC



3 – 5  
times



2 – 4  
times

# Why have soils lost so much C?

- Main driver: Land-use change (incl. wetland drainage, biomass burning and removal).
- 1/3 of all anthropogenic greenhouse gas emissions was derived from land use changes between 1750 and 2011.



# Benefits of carbon sequestration

- Water infiltration
- Nutrient retention and availability
- Germination
- Stabilization
- Efficiency of inputs

# Management practices decreasing SOC sequestration

- Deforestation
- Biomass burning/residue removal
- Conversion of natural wetlands
- Bare fallows
- Overgrazing
- Continuous monocultures
- Intensive use of chemical inputs

# Management strategies for SOC sequestration (1)

## Farming systems management

- Complex rotations
- Mixed farming
- Agroforestry

## Management strategies for SOC sequestration (2)

### Water management

- Soil water storage
- Runoff farming
- Drip irrigation

# Management strategies for SOC sequestration (3)

## Soil fertility management

- Biological nitrogen fixation
- Mycorrhizae
- Biosolids
- Chemical fertilizers

# Management strategies for SOC sequestration (4)

## Erosion management

- Preventive measures
- Control measures
- Biological and engineering techniques

# Management strategies for SOC sequestration (5, 6)

## Mulch farming and tillage methods

- Crop residues
- Cover crops
- Plastic mulch
  
- Conservation tillage
- Conventional tillage

Agronomic interactions and soil carbon sequestration →  
Creating positive ecosystem carbon budget

- Through
  - Enhancing Environmental Quality
  - Improving Soil Quality



# Limitation in soil carbon sequestration

- Stored carbon is not permanent. A large proportion of it is labile and will be decomposed again.
- There is a maximum limit for soil carbon storage. Clay mineralogy and soil moisture regime are important influencing factors.
- Organic matter storing capacity varies depending on soil type, land use type, vegetation type, and climate type.



Contents lists available at [ScienceDirect](#)

## Soil & Tillage Research

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### Matching policy and science: Rationale for the ‘4 per 1000 - soils for food security and climate’ initiative

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# Stock of soil organic carbon to different depth.

Soil depth	SOC stock	Source
cm	GtC	
0 – 30	690 ± 90	Batjes (1996); Hiederer and Köchy (2011)
0 – 40	860	Interpolation, see Fig. S1 (S.M.)
0 – 100	1500 ± 230	Batjes (1996); Scharlemann et al. (2014)
0 – 300	2344	Jobbágy and Jackson (2000)

# Soil depth and the global 4 per 1000 target.

- Not accounting for C in permafrost, the world's soils contain a total SOC stock of about  $1500 \pm 230$  Gt C down to 1 m depth, which is equivalent to twice the amount of C as CO<sub>2</sub> in the atmosphere.

Soil organic carbon saved (GtC yr<sup>-1</sup>) by 4 per 1000 target.

Soil depth	4 per 1000 target SOC sequestration
cm	
0–30	2.8 ± 0.36
0–40	3.4
0–100	6.0 ± 0.92
0–300	9.4

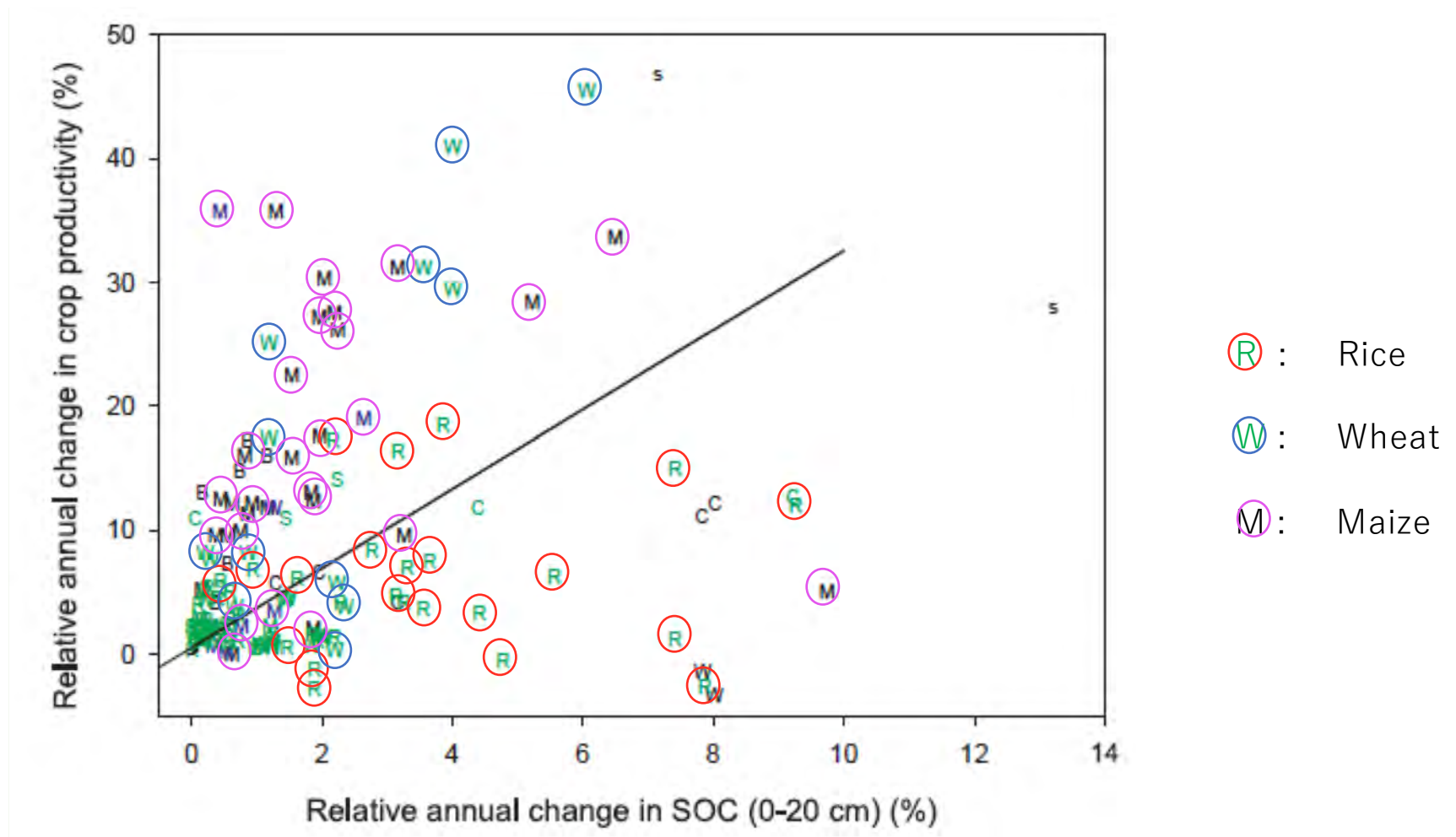
# The global 4 per 1000 target

- Top soil SOM can increase or decrease rapidly after changes in land use and agricultural practices (Conant et al., 2017) because it is directly connected to input from below-ground productivity, and because most of the decomposition occurs in the top soil.
- Thus, agricultural top soil SOC is frequently observed to increase at rates often equal or higher than the aspirational target of +0.4% per year.

# Co-benefits for food security and climate change adaptation.

- The corresponding field experiment data with corn, rice, wheat and beans show considerable scatter in the effects of improved agricultural practices, with some studies reporting large annual increases in crop productivity (up to +40%) and in topsoil SOC stocks (up to +8%) (Fig. 1).

Yield increase in response to soil organic matter increase.

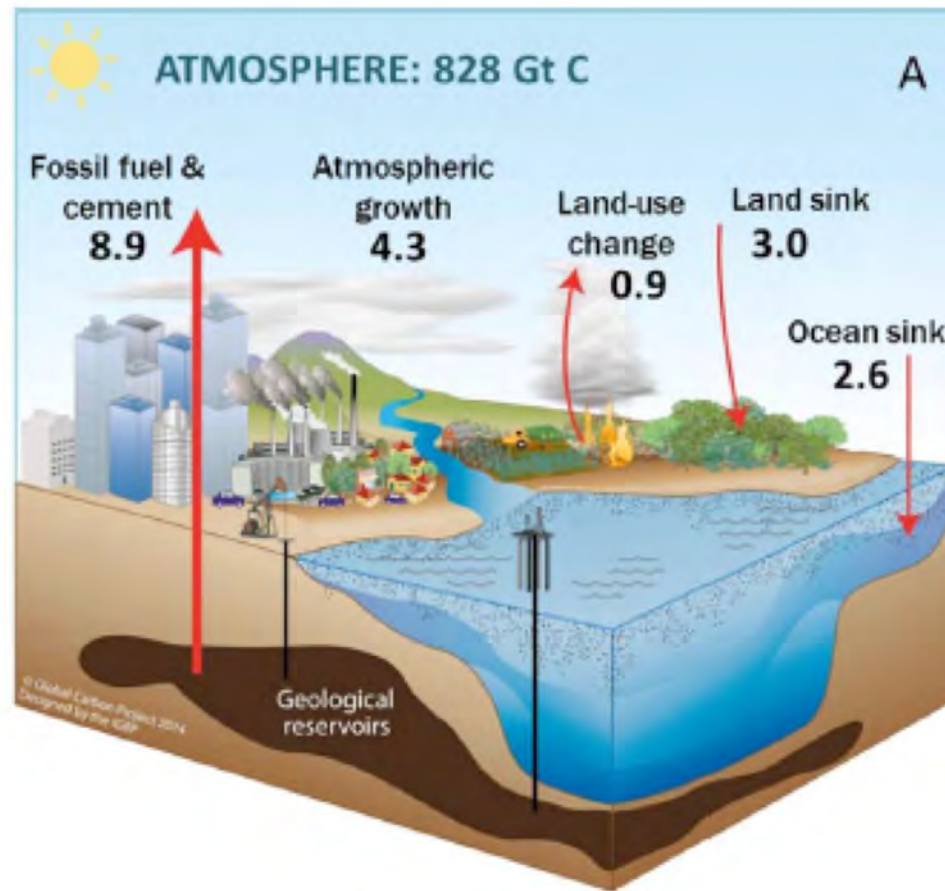




# Combining SOC sequestration and increasing crop yields.

- Despite this scatter, grain crop yield increases are significantly ( $P < 0.012$ ) and positively correlated with the relative change in SOC stock. On average, across these studies in Africa, Asia and Latin America, a 1.3% annual increase in crop grain yields was associated with a 0.4% annual increase in SOC stock (Fig. 1).
- This positive correlation confirms that there are win-win strategies combining SOC sequestration and increasing crop yields in developing countries.

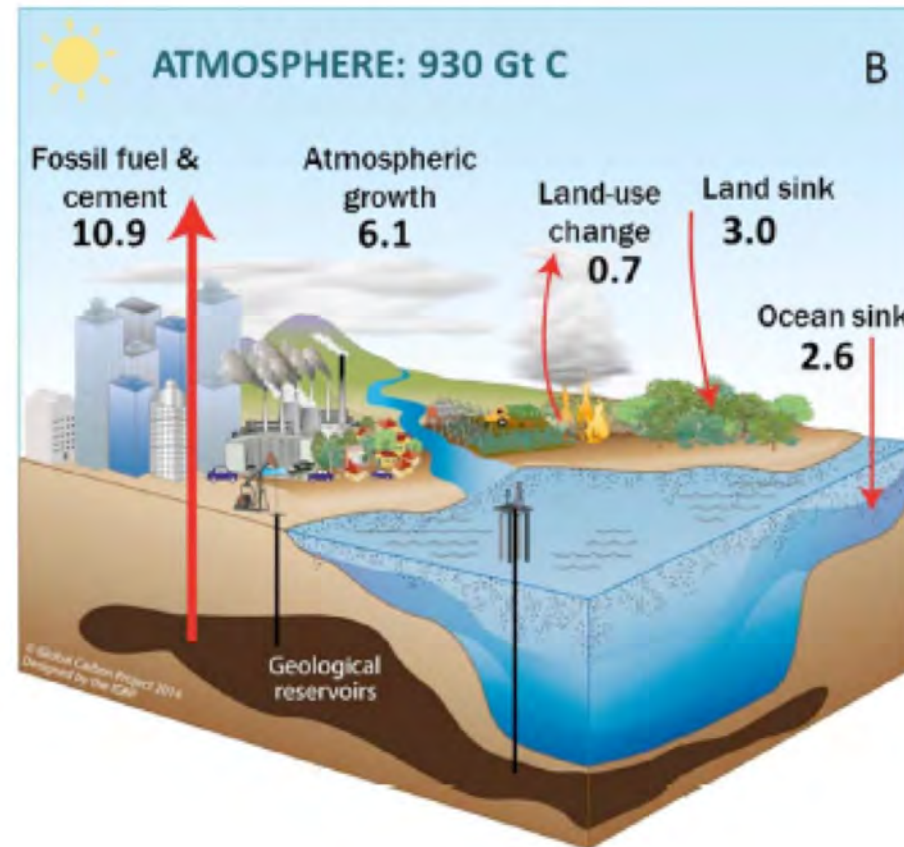
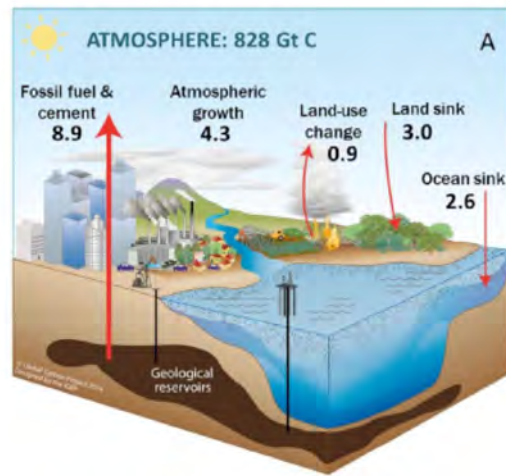
# Global carbon cycle in 2011 (A).



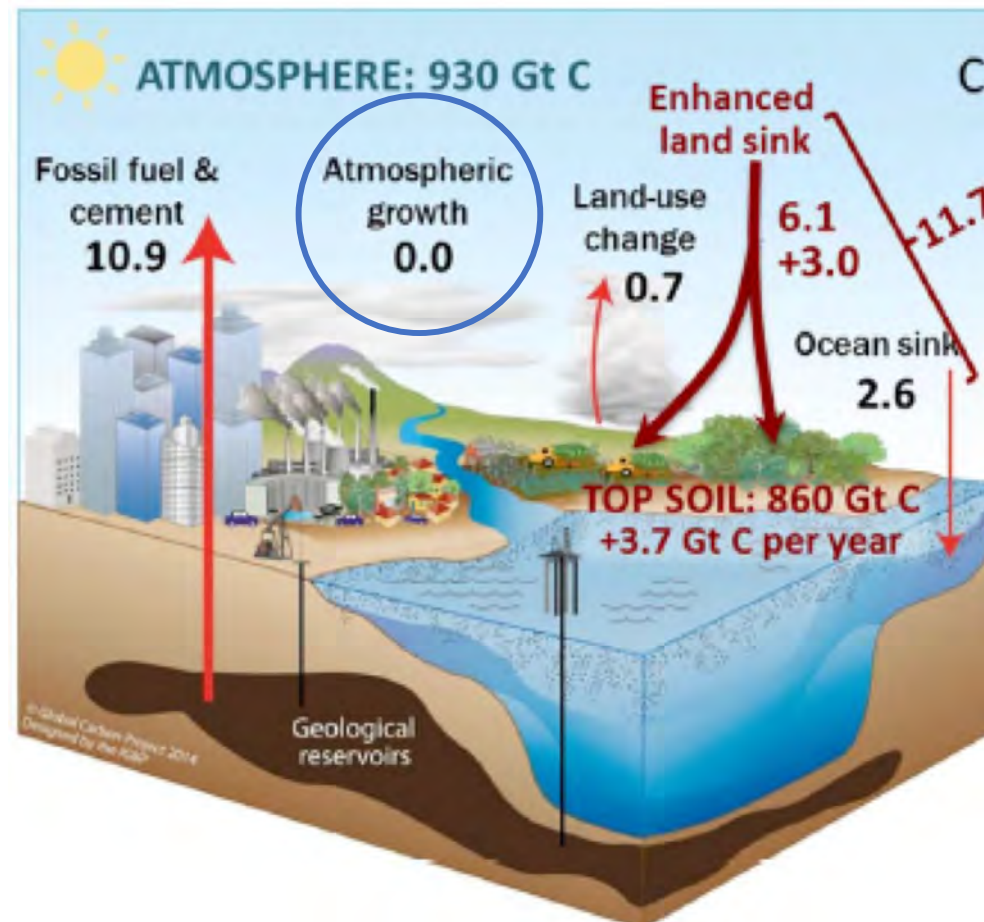
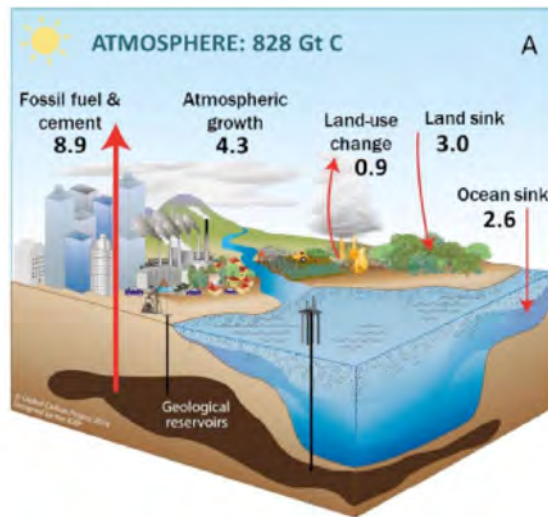
To which extent could the 4 per 1000 target contribute to atmospheric carbon stabilization?

- In the current state of the global carbon cycle (Fig. 2A), approximately half of the anthropogenic emissions of CO<sub>2</sub>-C are compensated by the land and ocean carbon sinks. Therefore, if it was at all possible to enhance within a few years the land carbon sink by fully harnessing the total technical potential of SOC sequestration across all land use types (3.4 GtC·y<sup>-1</sup>) and by halting net deforestation (0.9 GtC·y<sup>-1</sup>), the atmospheric growth of CO<sub>2</sub> (4.3 GtC·y<sup>-1</sup>) would be stopped.

Expected global carbon cycle in 2010-2040 without an enhanced land carbon sink (B).



# Expected global carbon cycle in 2010-2040 with an enhanced land carbon sink (C).



Why atmospheric carbon contents are equivalent between B and C?

A scenario with full implementation of the global aspirational **4 per 1000 target** and its effects on the land and soil carbon sinks.

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A. Baseline atmospheric carbon balance following conditional NDCs	GtCy <sup>-1</sup>
Emissions from fossil fuels and cement	10.9
Land carbon sink	-3.0
Ocean carbon sink	-2.6
Emissions from net land use change (tropical deforestation)	0.76

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+ 0.4% annual growth rate in SOC stock over a reference soil depth of 0-40 cm.



Full technical potential of biomass and soil carbon sequestration (Gt C y<sup>-1</sup>).

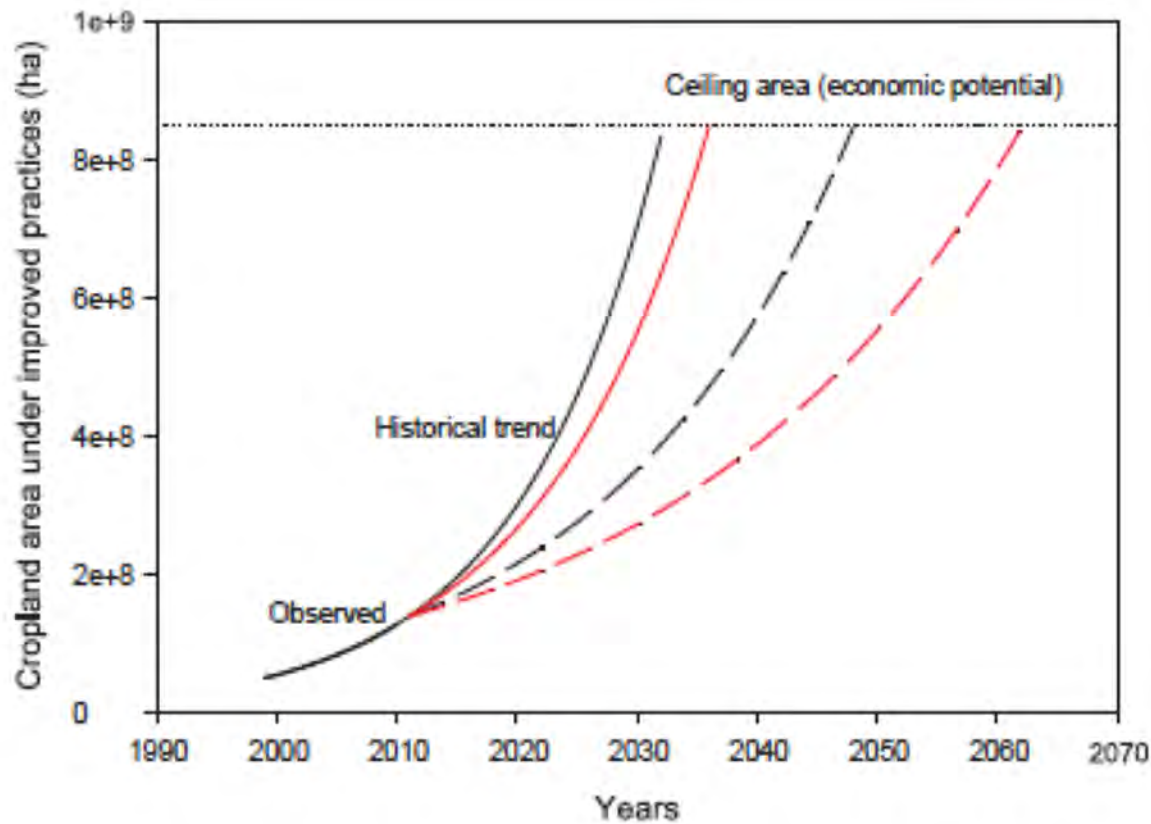
B. Land carbon storage scenario	Biomass GtC·y <sup>-1</sup>	SOC	Literature source
Agriculture (croplands, grasslands)	0.0	- 1.4	Smith et al. (2008); Lal (2010); Paustian et al. (2016)
Biochar	0.0	- 0.3	Paustian et al. (2016)
Enhanced root phenotypes (deep roots)	0.0	- 0.2	Paustian et al. (2016)
Agroforestry	- 0.6	- 0.2	IPCC (2000); Nair et al. (2009)
Salinized and desertified land	0.0	- 0.7	Lal (2010)
Secondary forest regrowth	- 1.0	- 0.5	Houghton et al. (2015)
Reforestation	- 0.8	- 0.4	Smith et al. (2016); Houghton et al. (2015)
Additional land carbon sink	- 2.4	- 3.7	
Total additional land carbon sink	- 6.1		
Net land carbon sink (GtC·y <sup>-1</sup> )	- 8.3		
Net atmospheric flux (GtC·y <sup>-1</sup> )	0.0		

# Full technical potential of biomass and soil carbon sequestration.

- Therefore, this technical potential scenario suggests that the land carbon sink could be enhanced by up to  $6.1 \text{ GtC}\cdot\text{y}^{-1}$ , of which 60% could take place as SOC sequestration (Table 2). With this enhancement, the net land C sink would in theory reach  $8.3 \text{ GtC}\cdot\text{y}^{-1}$ , thereby compensating, together with the ocean sink, the atmospheric growth of  $\text{CO}_2$  after 2030 or 2040.



Historical trend in the expansion of cropland area under conservation agriculture (1999-2011) and projected trends assuming similar (solid line, 8.9%) and reduced (dashed lines, 5%) annual relative adoption rate. Red lines assume 1.4% annual relative drop-out rate.



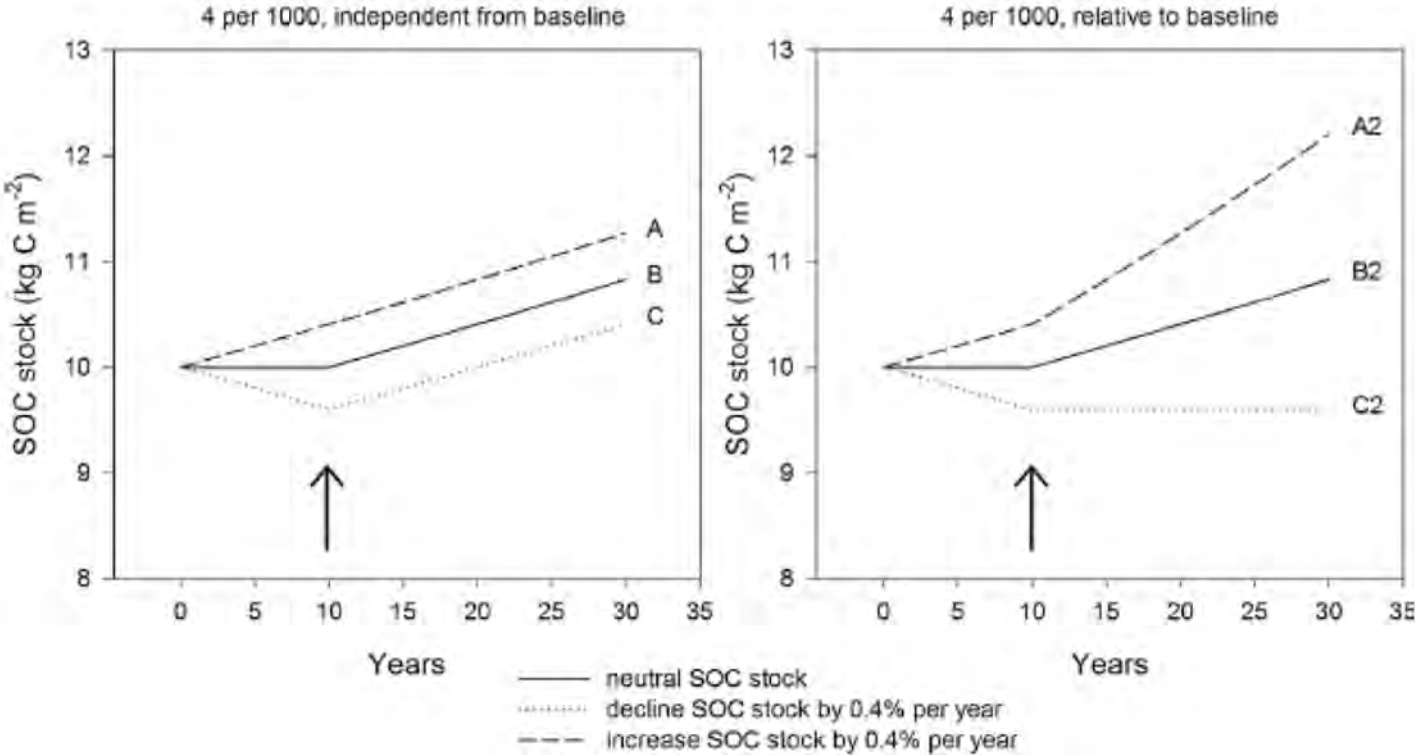
- This illustrates the rapid recent development (+8.9% area growth per year) during the last decade of agricultural practices contributing to soil conservation. If this historical relative growth rate was applicable to the future adoption of SOC sequestration practices, the ceiling area (corresponding to an economic potential of 850 Mha for improved cropland management practices) could be reached before 2030 (Fig. 3).
- Even assuming a lower adoption rate (+5% area per year), an economic potential corresponding to 850 Mha under agricultural practices enhancing SOC sequestration would be reached before 2050 (Fig. 3).

- Nevertheless, part of the cropland area having adopted practices enhancing SOC sequestration could revert after some decades to land degrading practices. For instance there has been large dis-adoption of CA in sub-Saharan Africa (Giller et al., 2009). If dis-adoption happened, on average, after 50 years (i.e. average annual drop-out rate of 1.4% per year, see Materials and Methods section), the ceiling area corresponding to the economic potential would be reached in the mid 2030's for the historical adoption rate (8.9% per year) and in the mid 2060's for the reduced adoption rate (5% per year) (Fig. 3).

# Permanence of SOC, adoption constraints and socio-economic barriers.

- Reaping the climate benefits of SOC sequestration requires an understanding that:
  - i) SOC will increase only over a finite period, up to the point when a new SOC steady-state is approached (Sommer and Bossio, 2014),
  - ii) the additional SOC stock will need to be monitored and preserved by adapting land management practices to climate change.

Hypothetical changes in SOC stock over 30 years assuming a 4 per 1000 increase, independent from baseline (left) and a 4 per 1000 change relative to baseline (right).



Should the 4 per 1000 aspirational target be considered as a fixed increase rate, or as a differential increase compared to a baseline?

Assuming a 4 per 1000 increase, independent from baseline (left)

- Implementing a 4 per 1000 target which is independent from the baseline requires establishing in all soils a relative annual increase by +0.4%. With this assumption, no change would be required for soil A, soil B would have to shift by +0.4% per year compared to its neutral SOC baseline and soil C by +0.8% per year compared to its declining SOC baseline (Fig. 4).

A 4 per 1000 change relative to baseline (right).

- This would result in soil management targets requiring stringent changes with degrading soils and, in contrast, no change when SOC already builds up at rates already higher or equal to 0.4% per year. In contrast, implementing a 4 per 1000 target relative to the baseline implies SOC stocks would all shift by +0.4% per year compared to their baseline, resulting in +0.8, +0.4 and 0% annual increase rates for soils A, B and C, respectively (Fig. 4, A2, B2, C2).



The land degradation neutrality (LDN) is defined as

- ‘a state whereby the amount and quality of land resource necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems’

- For the sake of consistency with the LDN principle and in agreement with findings showing that degraded soils have more potential for SOC sequestration (Minasny et al., 2017), priority could initially be given to the rehabilitation of degraded lands (i.e. 4 per 1000 target independent from the baseline). In a later stage, the relative to baseline 4 per 1000 target could be used, through the use of technologies that could raise SOC stock growth rate above 0.4% per year (e.g. Fig. 4A2).

Global mean of annual SOC sequestration at a rate of 0.4% per year and of N, P and S additional soil immobilization assuming C:N, C:P and C:S elemental ratio of 12, 50 and 71. Equivalent N, P, S fertilizer costs are also estimated.

C, N, P and S fluxes	Mean	s.d.	Fertilizer price (USD per t SOC)	Fertilizer price (USD.ha <sup>-1</sup> )
0.4% annual SOC sequestration (kgC.ha <sup>-1</sup> .y <sup>-1</sup> )	208	156	–	
Additional N immobilization (kgN.ha <sup>-1</sup> .y <sup>-1</sup> )	17.3	13.0	121	25
Additional P immobilization (kgP.ha <sup>-1</sup> .y <sup>-1</sup> )	4.2	3.1	27	5.7
Additional S immobilization (kgS.ha <sup>-1</sup> .y <sup>-1</sup> )	2.9	2.2	20	4.1

- This simple calculation shows that relying on inorganic fertilizers only would be, in most cases, too expensive to achieve the 4 per 1000 SOC sequestration target.
- Note that the mean estimate for annual N and P losses by erosion in agricultural lands reaches  $6.6 \text{ kgN}\cdot\text{ha}^{-1}$  and  $4.2 \text{ kgP}\cdot\text{ha}^{-1}$  (FAO and ITPS, 2015). The mean SOC stock of global croplands is estimated over 0–40 cm depth at  $52.0 \text{ tC}\cdot\text{ha}^{-1}$  with a standard deviation of  $30 \text{ tC}\cdot\text{ha}^{-1}$

# Soil C sequestration and Sustainable Development Goals.

- Soil C sequestration could bring direct benefits to three SDGs: SDG2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture; SDG13: Take urgent action to combat climate change and its impacts; SDG15: Protect, restore and promote sustainable use of terrestrial ecosystems sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (FAO, 2017).

# Conclusion

- The global aspirational goal of the 4 per 1000 Initiative appears as a technically feasible, no regret, and indispensable climate action. It can be regarded as (i) technically feasible, given its alignment with technical potentials estimated by IPCC, (ii) no-regret for its climate change adaptation and food security benefits, adding to overall climate resilience, and (iii) indispensable for its negative emissions.
- Turning the aspirational goal of the '4 per 1000' soil C initiative into social and economic realities is a challenge that will require the involvement of science to inform policy.

# A collaborative research program:

- 1) improved knowledge of the potential and implications (e.g. for yields, non-CO<sub>2</sub> GHG emissions, water cycle, etc.) of SOC sequestration;
- 2) co-design and assessment of agricultural and forestry strategies and practices;
- 3) defining and strengthening the enabling environment including cost-benefit and value chain analyses, economic and social dimensions, and policy options;
- 4) metrics and methods for low-cost monitoring, reporting and verifying of soil C sequestration;
- 5) training and capacity building (4 per 1000 research program, 2017).