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Sequestering Soil Organic Carbon: A Nitrogen Dilemma

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To slow down rising levels of atmospheric CO_2, the "4 per 1000" (4p1000) initiative was launched at the COP21 conference in Paris (http://4p1000.org). This initiative aims at a yearly 4‰ (0.4%) increase in global agricultural soil organic carbon (SOC) stocks. If applied to all (also nonagricultural) soils, such a C sequestration rate could in theory fully compensate increases in atmospheric CO_2−C levels of 4300 Tg yr^{-1}. We question the feasibility of the 4p1000 goal, using basic stoichiometric arguments. Soil organic matter (SOM) contains nitrogen (N) as well as C, and it is unclear what will be the origin of this N.

Implementing the 4p1000 initiative on all agricultural soils would require a SOC sequestration rate of 1200 Tg C yr^{-1} (http://4p1000.org). Assuming an average C-to-N ratio of 12 in SOM,[1] 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.[2] In theory, the current N surplus in global agroecosystems would be sufficient to provide the required 100 Tg N yr^{-1}.[3] Moreover, such a "mopping up" of this surplus N by using it to sequester C in the soil would be environmentally beneficial as it would reduce N-related pollution impacts. However, these surpluses are not evenly distributed but highly concentrated in specific regions, notably China.[3] There are also substantial differences between land uses: surpluses are large in soils under intensive agricultural and horticultural management but small in low intensity grazed rangelands and small-holder arable cropping (for instance, in Africa). Even if the N surpluses were more evenly distributed, they would first have to be accumulated by crops in order to supply organic C to the soil. The rate of N accumulated in global cropland residue is estimated to be ∼30 Tg N yr^{-1},[4] far less than the 100 Tg N yr^{-1} required. Furthermore, as a consequence of environmental regulations, intensive efforts to decrease N surpluses are anticipated over the coming decades.[3] Thus, the increase in plant N uptake that is needed to meet the 4p1000 goals is unrealistic.

As plant material has higher C-to-N ratios than SOM, a steady increase in the C-to-N ratio of SOM could facilitate soil C sequestration without extra N. However, it is difficult to see how the required increase in the C-to-N ratio of SOM (0.05 per year) could be achieved and sustained; with the exception of peat, soils globally tend to move toward a C-to-N ratio of 12[1] and we do not know of a mechanism to increase this without also reducing the capacity of soil to supply N.

As increasing soil C content is almost always desirable for improving soil quality and functioning, the 4p1000 initiative is laudable. Since the 4p1000 initiative was introduced, several studies assessed approaches to meet its goals (e.g., ref 5). However, these assessments overlooked limitations imposed by nutrient availability. We conclude that the stated 4p1000 goal of sequestering 1200 Tg C yr^{-1} in agricultural soils is unlikely to be met, due to stoichiometric constraints.

We argue for a more spatially diversified strategy for climate change mitigation from agricultural soils. In agricultural soils with low C sequestration potential, mitigation efforts should focus on reducing non-CO_2 greenhouse gas emissions and on improving N retention. Efforts to sequester C in agricultural lands should concentrate on soils currently having a low C stock and where nutrients are available. These are likely to be soils that have become degraded due to long periods of intensive arable cropping or overgrazed grasslands in cool, temperate or Mediterranean climatic regions especially in Asia,

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Europe, and North America. We appeal to the environmental science community to redefine the 4p1000 goals within a spatially explicit action plan that takes into account the role of nutrients in sequestering soil C.

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Notes

The authors declare no competing financial interest.

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