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. This initiative aims at a yearly 4‰ (0.4%) increase in global agricultural soil organic carbon (SOC) stocks[1]. We question the feasibility of this goal, using basic stoichiometric arguments.

Implementing the 4p1000 initiative would require a SOC sequestration rate of 1200 Tg C yr^{-1} (ref 1). Assuming an average C-to-N ratio of 12 in soil organic matter (SOM), this would require 100 Tg N yr^{-1}. This equals ~75% of current global N-fertilizer production, or more than twice the current symbiotic N_2 fixation rate in all agricultural systems combined[2]. In theory, the current N surplus in global agroecosystems would be sufficient to provide the required 100 Tg N yr^{-1} (ref 3) and "mopping up" this surplus N would be environmentally beneficial as a means of decreasing a range of 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 (e.g. in Africa). Furthermore, intensive efforts will be made to decrease N surpluses over the coming decades[3]. 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. However, current global cropland residue N content is estimated as ~30 Tg N yr^{-1} (ref 4), i.e. far less than the 100 Tg N yr^{-1} required. Achieving the 4p1000 goal would therefore necessitate an unrealistically massive increase in N uptake in unharvested plant parts. A similar argument could be made for phosphorus.

Alternatively, a steady increase in the C-to-N ratio of SOM could in theory facilitate C sequestration without the necessity for extra N. However, it is difficult to see how such an increase (a rise in the C-to-N ratio of approximately 0.5 per 10 years would be required) could be achieved and sustained; with the exception of peat, soils globally tend to move towards a C-to-N ratio of 12 (ref 5) and we do not know of a mechanism to alter this.

As increasing soil C content is almost always desirable for improving soil quality and functioning, the 4p1000 initiative is laudable. However, we conclude that the stated 4p1000 goal of sequestering 1200 Tg C yr^{-1} in agricultural soils cannot be met due to stoichiometric constraints. Recent assessments of approaches to meet the 4p1000 goals did not consider these constraints[6,7]. We argue for a more spatially diversified strategy for climate change mitigation, concentrating effort on sequestering C in agricultural lands 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 over-grazed grasslands in cool, temperate or Mediterranean climatic regions especially in Asia, Europe and North America.

References

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