Does heavier rain mean a bigger sink?

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Reactive nitrogen, a known pollutant, has the ability to fertilize forests, thereby boosting land-based carbon sinks. Dave S. Reay looks at its potential to reduce atmospheric carbon dioxide concentrations.

At the mention of human-induced global change one's thoughts naturally turn to the enhanced greenhouse effect, in particular, the climate forcing resulting from the ~7 billion tonnes of carbon emitted annually as a result of human activities. The ice-core records and Mauna Loa CO_2 trends have become iconic images in climate-change science — clear evidence of human interference in the global carbon cycle. Yet there is another post-industrial trend that is no less significant in terms of its impact on the environment: the steepling emissions and deposition of reactive nitrogen.

In 1908, the German chemist Fritz Haber developed a method of nitrogen fixation that would allow global intensification of agriculture and eventually feed two out of every five people on earth. Haber's process, replicated on an industrial scale by Carl Bosch, involved combining atmospheric nitrogen with hydrogen at high pressure over a super-heated catalyst to form ammonia. Alongside rapid industrialization and rising emissions of nitrogen oxides (NOx) from fossil fuel burning, the intensification of agriculture and associated ammonia (NH_3) emissions has led to a fourfold increase in reactive nitrogen emissions compared with the pre-industrial period[1]. These burgeoning emissions have inevitably led to large increases in reactive nitrogen deposition to the Earth's surface, with far-reaching consequences.

Where the extra deposition ends up on areas already replete in nitrogen, such as most agricultural land and some forests and grasslands, it can lead to elevated emissions of the powerful greenhouse gas, nitrous oxide and to eutrophication and water quality problems due to an increase in nitrate leaching to ground and surface waters. Even in natural and semi-natural ecosystems that are able to mop up the extra nitrogen they receive, the chronic enrichment year after year can result in reduced biodiversity. All rather negative then. However, there is another effect of such nitrogen enrichment that has the potential to cover its multitude of sins. In many natural and semi-natural ecosystems, and particularly in forests, more nitrogen deposition can greatly increase primary production and reduce soil decomposition, which ultimately means that more CO_2 is taken out of the atmosphere and locked up in the terrestrial carbon sink[3].

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The intensification of agriculture is a major factor in the fourfold increase in reactive nitrogen emissions since pre-industrial times.

SMOKING GUN

In the 1980s, the global terrestrial carbon sink strength stood at 0.3 (0.9 Pg C per year, whereas in the 1990s this rose to 1.0 (0.6 Pg C per year, mopping up about one sixth of annual anthropogenic carbon emissions. Much of this large terrestrial carbon sink seemed to be associated with northern temperate forests growing between about 25° and 55°N (ref. 4). Forest regrowth, CO_2 fertilization, land use and climate change have all been suggested as drivers of this increase[5], yet throughout this period the forests were also experiencing an intensifying rain of reactive nitrogen. A long-running question has therefore been whether the large increase in terrestrial carbon sequestration — the so-called 'missing sink' — also reflected a response by these forests to elevated nitrogen deposition, and if so, to what extent.

The circumstantial evidence was strong, with a simultaneous increase of nitrogen deposition and carbon content in the northern forests having been observed since the 1950s[6]. Numerous studies have demonstrated increased forest growth in these regions resulting from nitrogen fertilization, with several reporting elevated carbon sequestration. In the US, for example, Pan *et al.*[7] estimated a 20% increase in carbon sequestered in forest biomass and an 18% increase in the carbon in soil organic matter over a 70-year period owing to chronic nitrogen deposition. Yet reports of limited incorporation of labelled nitrogen inputs and high losses to drainage water in other northern forests suggested that elevated nitrogen deposition has played only a minor role in boosting the size of the northern forest carbon sink[8].

Then, in their landmark paper published in *Nature* in June this year, Magnani *et al.*[9] demonstrated that net carbon sequestration in a range of temperate and boreal forests had indeed responded to elevated nitrogen deposition resulting from human activities. The effect in the forests studied was very large, always positive and demonstrated the indirect control of forest carbon fluxes exerted by humankind. Though some forests in these regions were likely to be nitrogen saturated, and therefore unresponsive to elevated nitrogen deposition, it seemed that the bulk of forests in this global engine-room of terrestrial carbon storage had responded strongly in the past to more reactive nitrogen and might therefore do so in the future.

So, can we expect rising reactive nitrogen emissions from human activities to boost carbon sequestration by northern temperate forests even further? Could this provide a mechanism by which the current growth rate of atmospheric CO_2 concentrations is significantly reduced?

FERTILE FORESTS

Despite greater controls on nitrogen emissions in some countries, there seems little doubt that northern forests will continue to receive an increasing supply of reactive nitrogen over the next few decades. Dentener *et al.*[10] estimated that reactive nitrogen deposition over much of Europe and North America in 2000 exceeded 4 kilograms of nitrogen per hectare per year. Using the IPCC's A2 emissions scenario up until 2030, they then projected an increase in deposition in these regions of between 10 and 50%. This scenario is rather pessimistic, assuming that rapid economic growth over this period will be combined with no additional emissions controls for air pollutants. If enhanced nitrogen deposition is going to significantly change the northern forest carbon sink though, then this is the scenario that will do it. For European forests, an average additional reactive nitrogen deposition rate of 2 kg N ha^{-1} yr^{-1} would appear to be towards the upper limit of what can be expected by 2030 relative to 2000.

If one assumes that key factors such as forest distribution and age class structure remain constant, using the near 1:1 relationship of wet nitrogen deposition (kg N ha^{-1} yr^{-1}) to average net ecosystem production (t C ha^{-1} yr^{-1}) provided by Magnani *et al.* one might expect to see an additional 0.3 Pg C uptake per year in the 149 million hectares of European forest. This would represent a huge increase, equivalent to sequestering annual anthropogenic greenhouse-gas emissions from the whole of the UK. In North America, with a total forest area of 771 million hectares (ref. 11), such a response would equate to sequestration of an additional 1.5 Pg C per year. Large increases in reactive nitrogen deposition to northern forests over the next few decades could therefore help to sequester an additional 25% of annual anthropogenic CO_2 emissions and so significantly reduce the growth rate of atmospheric CO_2 concentrations. However the caveats for such a projection are legion.

Nitrogen deposition can greatly increase primary production and reduce soil decomposition in forests.

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BACK DOWN TO EARTH

Firstly, it is very likely that additional controls on emissions of air pollutants will be put in place by many nations in the next 20 years or so, making the high deposition rates of the A2 scenario unrealistic. When Dentener *et al.* incorporated current legislation on air pollutant emissions controls into their projections of nitrogen deposition for 2030 relative to 2000 they found a 10–20% reduction in reactive nitrogen deposition over much of Europe and an increase of only 5–20% over North America. The assumption that northern forest area and age class structure in 2030 will be identical to that of today may also introduce significant error. Even if the area of forest were to remain the same, it has been shown that the age of a forest is a key determinant of its response to elevated nitrogen deposition, with mature forests showing only limited responses[4].

Finally, there's the extrapolation of the response of forest carbon sequestration to elevated nitrogen deposition given by Magnani *et al.* to all European and North American forests. Some of these forests are likely to already be nitrogen-replete or will become so in the near future, with little or no additional carbon sequestration as a result. More importantly, other studies have reported much smaller responses to elevated nitrogen deposition in these regions[12]. Examining the response of European forests to changing nitrogen deposition rates for the period 1960–2000, De Vries *et al.*[13] estimated an increase in forest carbon sequestration of around 25 kg C ha^{-1} yr^{-1} in both tree wood and soils for each additional kilogram of nitrogen deposition. Similarly, Hyvönen *et al.*[14] estimated additional carbon sequestration in trees and soil of around 36 kilograms of carbon per kilogram of nitrogen added, based on forest fertilization experiments in Sweden and Finland. These responses are <5% of what might be inferred from the results of Magnani *et al.* and, even under the high nitrogen deposition rates projected using the A2 emissions scenario for 2030, the increase in carbon sequestration by northern forests would be relatively minor.

Increasing reactive nitrogen deposition, it seems, does not provide a free ride to greatly elevated forest carbon sequestration. In coming decades it is the protection of the existing terrestrial carbon sink from deforestation and land-use change that should be the focus of carbon-sink management. Yes, there is some potential for enhancing the vegetation and soil carbon sinks through nitrogen addition, but as a cover for the many sins of reactive nitrogen emission it is the thinnest of veils. Relying on yet more air pollution to help address human-induced climate change is equivalent to the release of cane toads to tackle the cane beetle in Australia: an ineffective solution that creates a whole new set of problems.

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References

1. Fowler, D., Muller, J. & Sheppard, L. *Water Air Soil Poll. Focus* **4**, 3–8 (2004).
2. Phoenix, G. *et al. Glob. Change Biol.* **12**, 470–476 (2006).
3. Townsend, A. R. *et al. Ecol. Appl.* **6**, 806–814 (1996).
4. Churkina, G. *et al. Carbon Balance Management* **2** (2007) (doi:10.1186/1750-0680-2-5).
5. Hymus, G., Valentini, R. in *Greenhouse Gas Sinks* 11–30 (eds Reay, D. S. *et al.*) (CABI Publishing, Oxfordshire, 2007).
6. Turner, D. P. *et al. Ecol. Appl.* **5**, 421–436 (1995).
7. Pan, Y. *et al. Geophys. Res. Abs.* **8**, 09868 (2006).
8. Nadelhoffer, K. L. *et al. Nature* **398**, 145–148 (1999).
9. Magnani, F. *et al. Nature* **447**, 849–851 (2007).
10. Dentener, F. *et al. Glob. Biogeochem. Cycles* **20** (2006) (doi:10.1029/2005GB002627).
11. *Food and Agriculture Organisation Forestry Paper* No. 140 (FAO, Rome, 2001); ftp://ftp.fao.org/docrep/fao/003/Y1997E/FRA%202000%20Main%20report.pdf.
12. Högberg, P. *Nature* **447**, 781–782 (2007).
13. De Vries, W. *et al. Glob. Change Biol.* **12**, 1151–1173 (2006).
14. Hyvönen, R. *et al. Biogeochemistry* (2007) (doi:10.1007/s10533-007-9121-3).