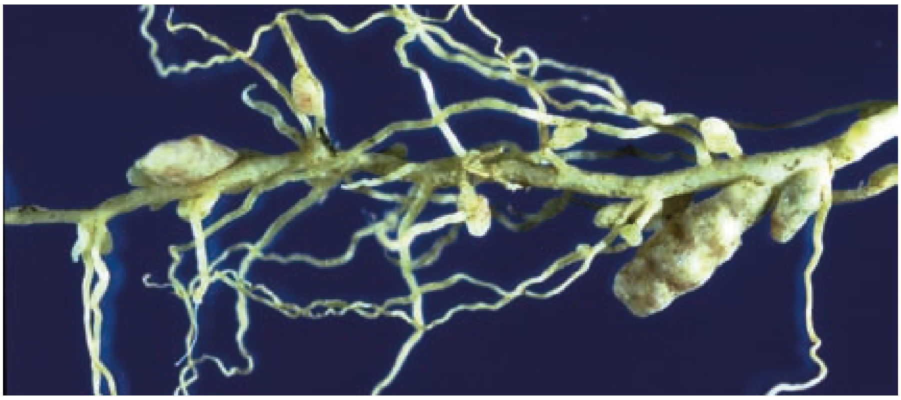
Reap what we **sow**

Nitrogen-based fertilisers have helped all but eradicate famine in large parts of the world. But reactive nitrogen in circulation has now doubled. **Owen Gaffney** asks, what effect is this having on the carbon cycle?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Nitrogen-fixing nodules on clover roots.

The German polymath Fritz Haber possessed an astonishing knowledge of politics, history and economics, but he lived for science. He was awarded the Nobel Prize for chemistry in 1919 for a patent he filed on 13 October 1908.

Haber's invention, 'the synthesis of ammonia from its elements', now known as the Haber-Bosch process, changed the world. He found a way of turning unreactive nitrogen gas in the air into the more-useful, reactive form of nitrogen, ammonia. It made possible large-scale production of nitrogen fertilisers for the first time. Farmers could grow more crops, faster and easier. It is reckoned the process is responsible for as many as two out of every five people alive today.

The Green Revolution in the sixties and seventies, which all but eliminated wide-scale famine in large parts of Asia, was down in no small part to systems founded on nitrogen-based fertilisers.

Applications for the Haber-Bosch process, though, were not all positive. A notable downside is that it allowed Germany to prolong the First World War. Nitrates, a necessary ingredient in many explosives, were in short supply. The new process gave munitions factories easy access to the raw ingredients they so desperately needed.

The global nitrogen cycle

Nitrogen is essential for life on Earth. About 78 per cent of the atmosphere is made up of nitrogen in its unreactive form of dinitrogen gas. To be any use it needs to be converted into a 'reactive' form. Nitrogen-fixing bacteria found in the roots of plants such as clover and pulses like peas, lentils and chickpeas do this job naturally. The Haber-Bosch process does the same job artificially, and on a grand scale.

Along with increasing amounts of reactive nitrogen being released from fossil-fuel burning, Haber's invention has significantly altered the global nitrogen cycle. Since the industrial revolution in 1860, human activity has doubled the amount of reactive nitrogen in circulation. Even with restrictions on nitrogen emissions in some countries, with the global population set to top nine billion by the middle of the century, the reactive nitrogen in circulation will likely increase not decrease in the future.

Nitrogen's effect on climate is linked to Earth's two great carbon sinks – the land and the oceans.

So how does this affect climate? Reactive nitrogen from farming and industry ends up on the land and in the oceans. Some of this – usually about one per cent – is then converted by bacteria into the powerful greenhouse gas nitrous oxide and released back into the atmosphere. One kilo of nitrous oxide has the same effect on climate as 296 kilos of carbon dioxide over 100 years. Its concentration in the atmosphere has increased by 15 per cent since 1860.

But its effect on climate goes beyond just nitrous oxide and is linked to Earth's two great carbon sinks – the land and the oceans. Between them they've soaked up around half the atmospheric carbon dioxide produced by burning fossil fuels since 1860. Before this date, carbon dioxide in the atmosphere was 280 parts per million. It is now at 385ppm and rising at a rate of around two parts per million a year. This rate appears to be accelerating and global economic activity is largely to blame. But new research suggests that these huge carbon sinks may be faltering. If they start absorbing less carbon than before, this would contribute to rising levels of atmospheric carbon dioxide.

FORMS OF NITROGEN AND THEIR USES

Nitrogen gas	Inert. In its liquid form it is used for cryogenic preservation
Ammonia, nitrite and nitrate	Fertiliser, explosives, rocket propellants
Nitrous oxide	Laughing gas, greenhouse gas
Nitrogen dioxide	Released from fossil-fuel burning. Toxic, ozone precursor, causes acid rain
Nitric oxide	Blood-vessel dilatory drugs, angina treatment
Proteins, amino acids, DNA, RNA	Building blocks of life

Ron Giling/Lineair/Still Pictures

Growing pains

Reactive nitrogen increases the growth rates of plants directly when farmers spread it on the land, and indirectly through nitrogen deposition from the atmosphere onto the land and oceans.

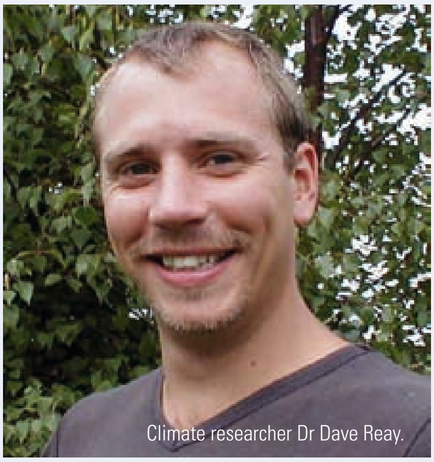
For carbon sinks on land – the forests and soils – even a nudge in the growth rate or death rate of trees, or the speed plants decompose, can have massive effects on how much carbon is taken up and stored in these reservoirs simply because they are so big – the forests of North America and Europe alone cover an area almost the size of Russia.

Some forests do seem to respond much more to extra reactive nitrogen than others. This seems to be due to differences in the age of the forests, the types of trees, and just how nitrogen limited they are. Understanding what is happening to the nitrogen cycle and how this is affecting the carbon cycle is an area of intense activity in the research community and remains a hot topic of debate.

Author and academic Dr Dave Reay from the University of Edinburgh juggles writing popular science books on climate change, teaching carbon management to post-graduates and investigating how nitrogen is affecting the forest, soil and ocean carbon sinks.

'Despite greater controls on emissions in some countries, there seems little doubt that the main carbon sinks will receive an increasing supply of reactive nitrogen in the next few decades,' he says.

All this extra reactive nitrogen floating around should boost growth in forests and among marine plankton. If these sinks get bigger, in theory they will take up and store more carbon. But, as usual, the real world is a little more complex.



Climate researcher Dr Dave Reay.

Reay's work highlights the need to build the nitrogen cycle into climate models.

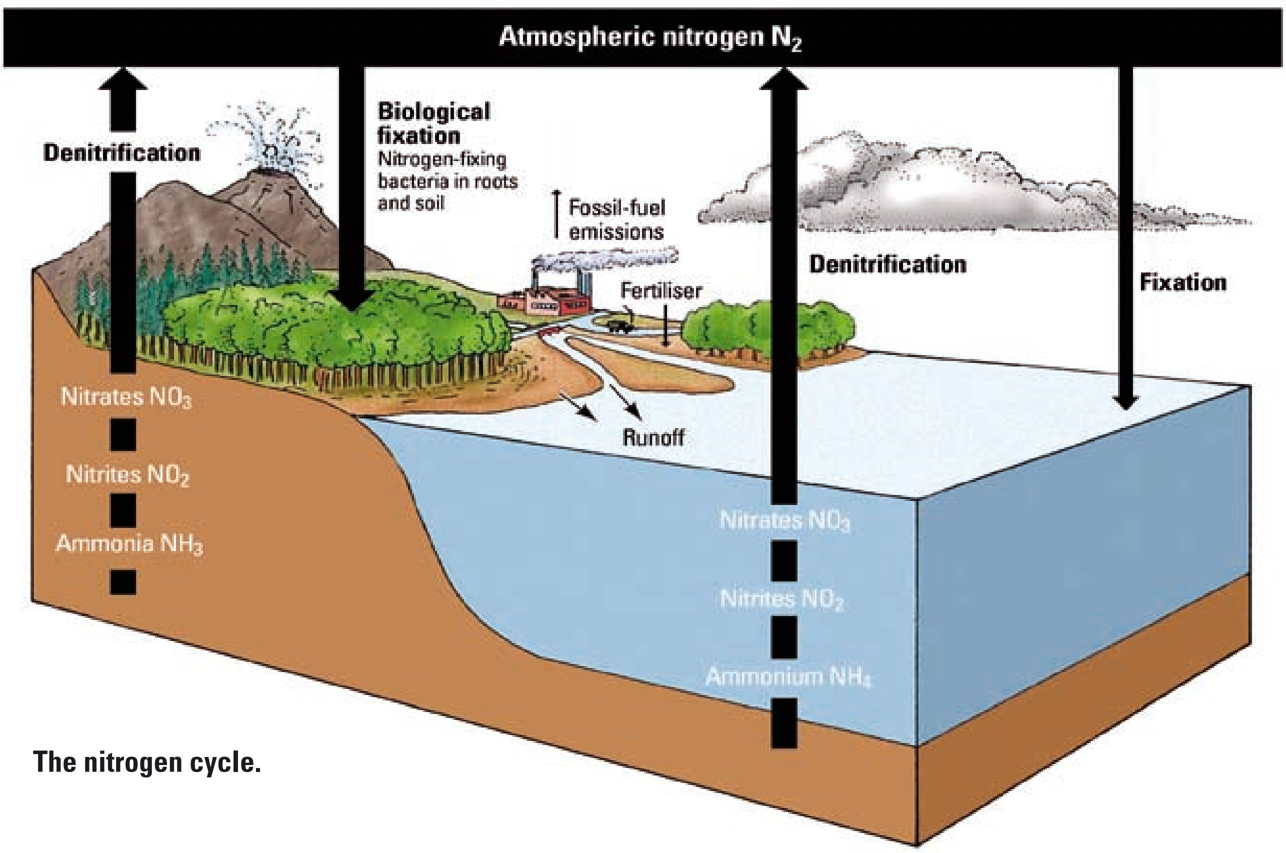
The best information we have on the influence of reactive nitrogen deposition comes from temperate and northern forests. Experiments show that each gram of nitrogen applied leads to an extra 40 to 200 grams of carbon stored either above or below ground. But there are negative effects.

'Chronic enrichment can lead to biodiversity loss,' says Reay.

Reay calculates that northern forests could draw down an additional 0.67 billion tonnes of carbon a year (GtC/yr) by 2030. Secondary forests in the tropics could draw down an additional 0.14 billion tonnes. For comparison, fossil-fuel emissions during the 1990s amounted to around 6.4GtC/yr. This suggests that nitrogen deposition in forests offers at least some hope of denting rising emissions.

But the jury is still out on soil carbon sinks. 'Evidence is contradictory,' says Reay. Some research suggests nitrogen enrichment will lead to less carbon stored in soils, other research predicts no change. Yet more research predicts carbon sinks may, in fact, increase.

Reay says, 'The majority of recent studies suggest reactive nitrogen may suppress soil carbon loss and so may serve to enhance soil carbon sinks.'



The nitrogen cycle.

NitroEurope

Nitrogen-based fertilisers have revolutionised farming but at what cost to the environment? In 2005, a major UK research programme Global Nitrogen Enrichment, or GANE, came to an end. The NERC-funded programme changed understanding of how nitrogen affects the environment. But quantifying damage from reactive nitrogen throughout Europe has been tricky.

In 2006, over 60 research institutions across Europe, Russia, China and Africa came together to start the NitroEurope initiative. The idea behind the project is to work out how reactive nitrogen affects Europe's greenhouse gas budgets.

www.nitroeurope.eu

Chronic enrichment can lead to biodiversity loss.

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The other major sink, the oceans, absorb about one quarter of the carbon dioxide from industrial emissions, or 1.5-2.2GtC/yr. The Atlantic draws down the most – 41 per cent, the Pacific 33 per cent and the Indian and Southern Oceans 25 per cent between them. Recent high-profile research papers have linked the increase in carbon dioxide in the atmosphere to a shift in the efficiency of the ocean carbon sink. It seems it is not absorbing as much carbon dioxide as before. This positive climate feedback could drive up global temperatures faster than before.

Reay thinks nitrogen deposition will have little effect on the oceans.

'Recent analysis has suggested that human nitrogen deposition may increase carbon uptake by marine plankton by around 0.3GtC/yr. This will be dwarfed by the effect of carbon dioxide in the atmosphere.' He concludes that nitrogen-induced increases in the strength of land and ocean carbon sinks are unlikely to keep pace with future increases in carbon dioxide.

It's likely that the amount of reactive nitrogen in the system will double between 2000 and 2030. By 2030, Reay's most optimistic scenario suggests increased reactive nitrogen in circulation will lead to the land and ocean carbon sinks storing ten per cent more carbon emissions from human sources than if nitrogen is not included in the calculations.

'But a more conservative estimate of one to two per cent is more likely,' says Reay.

While the plant growth this will cause may lead to an additional three billion tonnes of carbon dioxide leaving the atmosphere to be stored in forests, in doing so, it will increase nitrous oxide emissions to the atmosphere equivalent to releasing between 0.54 and 2.7 billion tonnes of carbon dioxide.

'Such pollution-swapping would greatly offset the net climate change mitigation benefits,' says Reay.

He adds that protecting existing terrestrial carbon sinks – stopping deforestation and other land-use changes – would be more useful in the attempts to curb warming.

Feeding the world

But the challenge is even bigger than this. Global population is set to rise to nine billion by 2050. Governments need to find ways of feeding one third more people. With the carbon and nitrogen cycles inextricably linked, it is evident that managing these cycles will fast become a delicate balancing act.

Reay's work highlights the need to build the nitrogen cycle into climate models. Early climate models focused on the atmosphere. Little attention was heeded to how the land, oceans and ice sheets affected climate. These days sophisticated 'coupled models' work like Lego: ocean, ice and land simulations can click into atmosphere simulations making a more robust and complete climate model.

Now work is under way to slot in a nitrogen model. At the International Geosphere Biosphere Programme's recent science committee meeting in Japan, scientists reported that work on a coupled nitrogen-carbon model is moving faster than anyone expected 18 months ago.❖

MORE INFORMATION

Dr Dave Reay is a senior lecturer in the School of Geoscience, University of Edinburgh. He is the author of popular science book *Climate Change Begins at Home* and *Your Planet Needs You*, 2009 (Pan Macmillan). For a chance to win a copy, see our competition on page 8.
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This article is based on a review paper in the journal *Nature Geoscience* 'Global nitrogen deposition and carbon sinks' (doi: 10.1038/ngeo230). The review paper, the first of its kind, draws on previous studies that looked at how reactive nitrogen affects specific components of the Earth system such as forests, soils and oceans. It is based on research conducted during Reay's NERC Fellowship.

Owen Gaffney is a science writer.