BAD FOR THE ENVIRONMENT, GOOD FOR THE CLIMATE

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Excessive amounts of nitrogen fertilizer and nitrogen compounds from fossil fuels pollute the soil, air, and water in different ways. But how do these substances affect our climate? An international team led by researchers at the Max Planck Institute for Biogeochemistry in Jena has taken stock of the various climate effects of nitrogen compounds.

When it comes to the environment, nitrogen is an essential element for life and a fertilizer, but too much of it makes it a pollutant: nitrogen compounds increase the concentration of particulate matter in the air and the nitrate content of drinking water, lead to eutrophication, reduce biodiversity, and damage the stratospheric ozone layer. When it comes to the climate, however, the situation is more complicated. Nitrogen compounds affect our climate in many different ways. Although elemental nitrogen, which makes up about 80 percent of our air, is climate neutral, all compounds of the element – known scientifically as reactive nitrogen – have a direct or indirect effect on the average global temperature, sometimes warming it and sometimes cooling it. For example, nitrous oxide, also known as dinitrogen monoxide, which escapes from fertilized soil, is almost 300 times more potent a greenhouse gas than CO_2. In contrast, aerosols, fine particles suspended in the atmosphere, are made up of other short-lived nitrogen oxides, mainly from the burning of fossil fuels. They block sunlight, which cools the climate. In addition, nitrogen inputs generally cause plants to grow more abundantly. They absorb CO_2 from the atmosphere, which also has a cooling effect. Nitric oxides also play a role in the destruction of methane, which cools the atmosphere, but at the same time, they lead to the formation of tropospheric ozone, which is a greenhouse gas and has a warming effect.

The international team led by Sönke Zaehle and Cheng Gong from the Max Planck Institute for Biogeochemistry has taken stock of the various effects. The bottom line: nitrogen that enters the Earth system as a result of human activities cools the climate. In climate research this is called "negative radiative forcing." In 2019, this cooling amounted to 0.34 watts per square meter. To put this in perspective, in the case of human-driven global warming, the atmosphere is heated by an additional 2.7 watts per square meter, mainly from greenhouse gases generated by the consumption of fossil fuels – according to the average for the years 2011 to 2020 given by the Intergovernmental Panel on Climate Change in its latest status report. This means that nitrogen emissions have reduced human-caused global warming by about one-eighth during this period.

During this period, the Earth was on average 1.1 °C warmer than in pre-industrial times. "The negative radiative forcing due to nitrogen input cannot simply be translated into a change in global average temperature, because there are local effects and the climate system reacts in a complex way to such changes in radiative forcing," says Sönke Zaehle, Director at the Max Planck Institute for Biogeochemistry. Without the extra nitrogen, however, the climate would have continued to warm. "This may sound like good news, but you have to keep in mind that nitrogen emissions have many harmful effects, for example, on health, biodiversity, and the strato-

Fossil fuel and agriculture are responsible for most emissions of nitrogen compounds, including nitric oxides, nitrous oxide, and ammonia. Nitrogen input has many harmful effects on the environment – but it also cools the climate.

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spheric ozone layer," says Zaehle. "The current finding therefore only improves the environmental balance of nitrogen inputs in one respect and is no reason to gloss over it, let alone see additional nitrogen inputs as a means to combat global warming."

The goal: less nitrogen and less CO_2

The researchers found the total impact of nitrogen from human sources by first determining the amounts of various nitrogen compounds that end up in the soil, water, and air. They fed this data into models that depict the global terrestrial nitrogen cycle and its effect on the carbon cycle, in other words, the stimulation of plant growth and ultimately the change in CO_2 and methane levels in the atmosphere. From the results of these model simulations, they used another atmospheric chemistry model to calculate the effect of anthropogenic nitrogen emissions on radiative forcing, or the amount of radiant energy that hits a square meter of the Earth's surface per unit of time. "Previous estimates based on literature studies have tended to be fragmentary, ignoring the fact that the processes of the global nitrogen cycle are spatially diverse, tightly coupled, and non-linear. Our calculations take these features into account," says Gong, postdoc at the Max Planck Institute for Biogeochemistry and first author of the study. "Nitrogen emissions should be reduced," says Zaehle. For example, by improving agricultural practices, it might be possible to use nitrogen more efficiently as a fertilizer. "This could, for example, reduce emissions of nitrous oxide, which contributes to global warming and damages the stratospheric ozone layer," Zaehle continues. "However, it is important to recognize that while reducing human nitrogen emissions benefits our health and ecosystems, it also has an impact on the climate. Consequently, greenhouse gas emissions, especially CO_2 and methane from fossil fuels, must also be reduced to a greater extent. Only then can we better protect our human health and nature and also mitigate climate change."