GLOBAL CHANGE: NITROGEN – FORESTS – ALLERGIES?

Recent decades have witnessed a shift in the balance of nitrogen circulation processes in ecosystems. What does this mean for our forests, our atmosphere and the planet as a whole?

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The effects of climate change are making themselves increasingly known. Extreme weather events such as persistent droughts or violent rainstorms are becoming more frequent, with many countries noting growing numbers of days beating temperature records. Global climate change, largely driven by increasing concentrations of carbon dioxide in the atmosphere which are directly linked with increasing average air temperatures, is a verifiable fact accepted by the vast majority of people. Rapid industrial development is indicated as the main driver of these changes, since it involves combustion of fossil fuels; the process emits huge volumes of greenhouse gases into the atmosphere, in particular carbon dioxide and methane, which intensify the greenhouse effect. Industrial processes also release other pollutants, such as sulfur dioxide and nitrogen oxides. Their

increasing volume is directly linked with the rapid growth of the human population and our growing demands for energy and food.

Up until the early nineteenth century, population growth was slow and steady, therefore meeting food demands simply required expanding farming areas. However, the second half of the nineteenth century saw almost exponential population growth, resulting in a tripling of the numbers of people worldwide and an urgent need to produce vastly greater amounts of food. Since land resources are limited, increasing plant production required finding new ways of improving yields. Help came from scientific discoveries made in the early twentieth century, including methods of synthesizing ammonia from hydrogen and nitrogen, urea synthesis and the development of a fertilizer known as Nitrofoska containing essential plant nutrients nitrogen, phosphorus and potassium; one of these discoveries was deemed to be so significant as to win the Nobel Prize.

Nitrogen is a biogenic element, and alongside carbon, oxygen, hydrogen, sulfur and phosphorus it plays a key role in living organisms. In plant cells it is found as a component of organic nitrogen alkali, which in turn form monomers of nucleic acids (RNA and DNA), as well as playing a role in the transfer of energy (ATP, GTP), electrons and hydrogen cations. Nitrogen is also a component of compounds such as chlorophyll, cytochromes and cytokines, all of which are essential for the functioning of plant cells, as well as secondary metabolites which take part in reactions defending plants against pathogens. The main source of nitrogen for plants lies in mineralized compounds of the element (nitrate and ammonium ions) found in soil, and simple organic compounds such as urea and amino acids; their availability to plants depends on the type, pH and oxygenation of the soil and the presence of soil microorganisms. Nitrogen can be fixed (mainly in vacuoles) or assimilated into cellular structures; the processes occur both in the root and stem systems. Unfortunately, the majority of nitrogen found in soil exists in an organic form which is not accessible to plants. The availability of the element in soil is a factor limiting plant growth and development, and its shortages are supplemented with mineral fertilizers.

Synthetic mineral fertilizers vs. greenhouse gas emissions

Mineral fertilizers are manufactured on an industrial scale, and their consumption levels vary from country to country. Regardless of the major differences in the amounts of fertilizer used in different parts of the world, the overall use of nitrogen fertilizers has increased almost tenfold (from 11.3 million metric tons of N in 1961 to 107.6 million metric tons of N in 2013), while the use of phosphorus fertilizers has increased from 4.6 million metric tons to 17.5 million metric tons over the same period. Over 63% of mineral nitrogen fertilizers are consumed by China, India, the US, Brazil and Canada alone, and the use of mineral fertilizers in these countries increases linearly year on year. Additionally, mineral fertilizers are not just used in North American and Europe, but their use is spreading eastwards into Asia, accompanying the rapid development of farming in the region.

While the manufacture of mineral fertilizers has resulted in increased food production, it has also contributed to increased emissions of greenhouse gases carbon dioxide and nitrous oxide. In the last twenty years, the manufacture of synthetic fertilizers has contributed to a thirteen-fold increase of nitrogen generated by human activity in comparison with the preindustrial era, and the volume of nitrogen emis-

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sions now exceeds the volume of fixed nitrogen compounds. Additionally, significant volumes of nitrogen oxides are emitted into the atmosphere as a result of burning fossil fuels. The majority of nitrogen in mineral fertilizers is not fixed by plants and ends up in the hydrosphere or being converted by soil microbes. As a result, both the industrial revolution and the green revolution have contributed to more than doubling the volume of nitrogen circulating in the biosphere, and to unsettling the balance between individual stages of the nitrogen cycle. Cycles of various chemical elements, including nitrogen, affect biological, hydrological, atmospheric and geological processes. The nitrogen cycle includes stages of symbiotic bacteria fixing nitrogen from the atmosphere, plants using nitrogen compounds from soil, ammonification (decomposition of organic nitrogen compounds), nitrification (oxidation of ammonia to nitrates) and denitrification (reduction of nitrates to nitrites and particulate nitrogen).

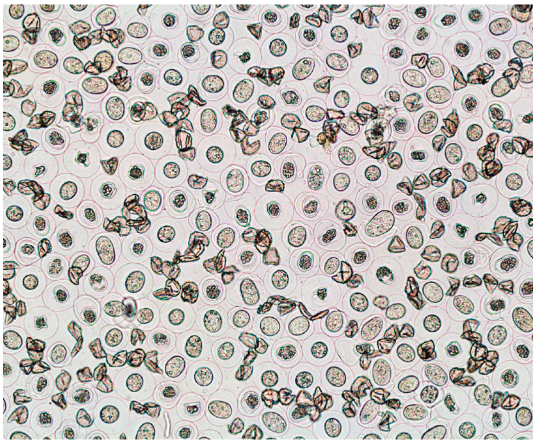
Additionally, air pollution does not have just a localized effect: nitrogen in the atmosphere can be transported over vast distances, reaching thousands of miles. This can lead to an increase in volume of biologically-active nitrogen compounds in land ecosystems previously regarded as having low fertility. The process is described as an increased deposition of nitrogen. Increased volumes of nitrates in the atmosphere, resulting from settling of particulate matter and rainfall, contribute to increased deposition of nitrogen in soil and vegetation. Annual deposition of atmospheric nitrogen varies depending on ecosystem, ranging from <2–3 kg N per hectare in Arctic regions to 10–20 kg N per hectare in subalpine regions. The majority of forest ecosystems in central and northern Europe are an example of ecosystems with a low fertility and availability of nitrogen in the soil, while the element itself (alongside phosphorus and potassium) is described as a key mineral factor limiting tree growth. Plants have adapted to the low availability of minerals in soil, in particular nitrogen, and as such its excess can cause stress. Increased emission of nitrogen into the environment can disturb natural element cycles, and as a result force ecosystems to adapt to new conditions.

Reduced biodiversity

Numerous studies indicate that increased levels of nitrogen in the environment lead to a reduction in biodiversity of vegetation in temperate climates, even at levels of 14 kg N per hectare over the course of a year. The effects of increasing deposition of nitrogen depend on many factors, although it most commonly drives transformation of plant habitats, including forests (for example disappearing moorlands). This becomes evident when we observe a shift in the species composition of herbaceous plants in mountain forests in temperate climate zones. Increasing levels of nitrogen in such environments are linked to the filtering effect of crowns of trees by capturing pollutants in the layer of wax or hairs covering needles or leaves. As these needles and leaves fall to the ground, they release nitrogen into the soil. Increased air pollution also makes rainfall acidic, which in turn results in increased acidification of soil. This means that growing levels of nitrogen in the environment can change species composition in plant habitats, which in turn can lead to the domination of nitrophilic species replacing those with lower requirements for nitrogen.

Plants vs. pathogens

Increasing levels of nitrogen in the atmosphere also disrupt relationships between plants and pathogens and, as such, can result in an increasing damage to specific plants (e.g. bilberries in boreal forests with annual accumulation of nitrogen in soil reaching 6 kg N per hectare) or the appearance of new pathogenic species, not previously found in a given ecosystem. Despite the fact that increased levels of nitrogen improve living conditions of trees, the resulting higher content of the element in plant tissues increases their nutritional value, which makes the tree more attractive to pests. The element plays an important role in carbon binding in plants. It has a twofold effect on plants in forest ecosystems. On the plus side, it enhances the efficiency of photosynthesis and drives a marked increase in mass; on the flip side, its surplus can result in lowered respiration, leaching of nutrients from the soil and, as a result, lowered energy levels stored in plants. Additionally, high levels of nitrogen oxides cause damage to the assimilation apparatus, presenting as red and ruddy discoloration to needles. The toxicity of nitrogen oxides is also linked with metabolic disorders in cells and the lowering of pH in the



Pollen grains of common yew in a germination medium *in vitro* cytoplasm and ion transport, therefore both an excess or shortage of mineral substances, including nitrogen, can have a negative impact on tree health, which can lead to dieback.

Reproductive processes

Plants utilize mineral substances for growth, reproduction and protection against parasites. The latest research indicates that increased levels of nitrogen in the environment have an adverse effect on reproduction, in particular affecting the quality and quantity of seeds and pollen grains. An increased availability of nitrogen significantly rises the numbers of seeds produced by the northern red oak; however, lower numbers of these seeds germinate since high numbers are damaged or eaten, perhaps due to their higher mass and/or content of nutrients such as carbohydrates or fats. It is also linked with lower survival rates of one and two-year-old seedlings of red spruce, eastern white pine and red maple, as well as lowered germination of seeds of common juniper. Despite the fact that the effect of surplus or deficiency of nitrogen on the condition of trees is well documented, little is currently understood about the effect of excess nitrogen on the processes of production of pollen – male gametes of seed plants. Increased availability of nitrogen corresponds to increased production of pollen in the English yew and common juniper; however, both species show that long-term availability of nitrogen has a negative impact on the germination potential of pollen *in vitro*. A lowered vitality of pollen grains is also a result of their direct interaction with air pollutants such as oxides of nitrogen, sulfur, and phosphorus. This interaction results in numerous disorders in biochemical processes and morphology of cellular structures in pollen. High availability of nitrogen may contribute to increased volumes of pollen being produced, and, since the pollen is of low quality, it may prevent the effective transfer of paternal genes.

Pollen vs. allergies

An increased availability of nitrogen contributes to higher levels of pollen being produced; additionally, as a result of climate change, trees bloom and pollinate for longer periods (an increase of between 13 and 27 days between 1995 and 2009). Numbers of pollen grains released by land plants, including trees, are vast to ensure wide distribution of genetic material and reproductive success of the species. During peak pollination season, the numbers of pollen grains in the atmosphere can reach several thousand per cubic meter. Research conducted in the US revealed the presence of between six and twelve thousand pollen grains per cubic meter for oaks, hickory and birches at peak pollination season in April and May; the figure reached fifteen thousand per cubic meter for juniper. Concentrations of pollen grains in the atmosphere triggering allergic reactions in over 90% of sufferers are just 80 grains per cubic meter for birch and 50 grains per cubic meter for grass. This means that accumulation of nitrogen in the environment can contribute to an increased production of tree pollen, which of course results in increased levels of grains in the atmosphere; in turn, this can lead to higher numbers of allergic reactions in sufferers (currently numbering approx. 10–30% of the population). Additionally, due to high volumes of nitrogen fixed in pollen grains, their intensive production can lead to an accumulation of biogenic elements in soils and lakes. And, since pollen grains are transported by air currents over vast distances, changes to soil properties and allergic responses occur not just on a local but a global level.

The rapidly growing population levels around the globe, driving increasing demands for food and rapid industrial development, may lead to further disruptions of element cycles, which could bring profound changes in ecosystems and have a powerful, negative impact on our lives and health.

A common yew – pollination

Photography by **Emilia Pers-Kamczyc**