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Towards sustainable agroecosystems: reducing nitrogen losses

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Nitrogen is an essential element for life, and its cycling plays a crucial role in the Earth's biogeochemistry. The most abundant N species is N_2, which stabilizes our atmosphere. The remaining species are biologically available to organisms, collectively known as reactive nitrogen (N_r). With the development of the Haber-Bosch process, large amount of N_r has been manufactured as synthetic fertilizers and introduced to the Earth system through agricultural activities. However, the cycling of N within agricultural systems are not conservative enough so that substantial amount of N is leaked to the environment unintentionally, including NH_3 volatilization, nitrate leaching and runoff, N_2O and N_2 emissions from denitrification. These N losses cause negative impacts on air, water and soil quality, climate, biodiversity and ecosystems, and can be strongly influenced by both environmental conditions and management practices. Meanwhile, significant N loss also leads to low nitrogen use efficiency (NUE) and can affect crop yields, which is a common feature in some countries and regions with high N application to croplands.

A known limitation in current research is the compartmentalized study of individual Nr forms and species. Current studies often focus on single N loss or just N uptake (in harvested products), neglecting the systemic integrity. This limits our understanding of the critical processes in the N cycle. On the other hand, targeting multiple N pathways simultaneously, which is considered very challenging due to multiple compartments/matrices involved, requires an array of techniques and expertise. Here, we present observation-modelling studies across various spatial scales, from field measurements to national and global assessments. From these studies, we show success and lessons learned from a long-term trial that compared organic to conventional cropping systems. We discuss the advances and challenges in constructing complete N budgets for the agricultural systems by modelling, and evaluate the effectiveness of mitigation measures aimed at reducing N loss while improving NUE. These results have key implications for guiding the transition towards more sustainable agroecosystems.