Conclusions

Halving nitrogen waste by 2030: a socio-political challenge based on sound science

This XXI[st] edition of the International Nitrogen Workshop entitled "Halving N waste by 2030", hosted by the ETSIAAB, Universidad Politécnica de Madrid, and organised by the CEIGRAM and INIA-CSIC, brought nearly 300 participants together, the majority of them in person, and received **nearly 300 contributions from authors from 40 countries**, presented in this book. This edition hosted sessions dedicated to research at the level of agro-food systems, and also around public policies and their costs and benefits, thus making ample room for systemic approaches and social sciences. We summarise below the key conclusions drawn by the session chairs from all the keynotes, roundtables, and regular and special sessions of this meeting.

The keynote by Mark Sutton introduced the "**N waste**" concept, as the waste of resources and money from anthropogenic reactive N (with potential severe consequences for the environment and food security), and showing the possibility of halving N waste by 2030 through both technical and structural measures. The ongoing increase in the price of inputs since 2021, such as synthetic fertilisers, could accelerate the implementation of measures in this direction. The **regular sessions** that followed shed light on the links between the different scales and the methodological complementarities for exploring the reduction of N waste in agricultural systems and surrounding ecosystems.

At the **cropping system scale**, Xin Zhang and Laura Cárdenas argued that it is important to harmonise definitions and estimates of N use efficiency at all levels and to clarify national greenhouse gas inventories in order to better adapt measures to reduce N pollution and estimate the contribution of agricultural practices to climate change. Nandula Raghuram presented the state of research on rice breeding to improve the N use efficiency of this cereal at the plot level: slow-germinating and long-duration varieties give high yields at low N doses, and among 20 N-responsive traits, six are related to N use efficiency. Other scientific communications showed that the adjustment of the dose, date or tillage during N fertilisation, the choice of the N source according to regional specificities (e.g. natural or synthetic urease or nitrification inhibitors, coated urea, combined with irrigation, biochar enriched with nutrients and residue-based fertilisers) or a change in crop rotation influences ammonia emissions and improves N use efficiency and yields. They concluded that these factors and strategies need to be considered when designing public policies that aim to reduce N waste. There has also been significant progress in measuring ammonium and nitrous oxide fluxes worldwide, but there is still a need to extend the area covered by these measurement systems, to measure the different forms of N simultaneously on a frequent basis so as to increase our understanding of N losses and to consider indirect nitrous oxide emissions. Finally, N use efficiency, cycling and functionality in pasture and grassland systems is challenged by climate change and intensification, but is supported by improved fertiliser decision support, increased N fixation, mixed grassland, recycling of human excreta and treatments to mitigate N losses.

At the **livestock or mixed systems** scale, Aimable Uwizeye highlighted that the growth of the livestock sector, which has been especially concentrated in regions with low production costs, has seriously altered the N cycle. Consequently, there is significant room for improvement of N use efficiency at all stages of the life cycle of animal products, both to reduce environmental pressure and to increase farmers' income. The communications of this regular session emphasised that predictive feeding as well as new housing strategies and technologies can potentially increase N use efficiency and decrease losses at the farm level. Regarding manure management, slurry acidification is one of the most widely studied practices that demonstrates its ability to reduce N

emissions (ammonia and nitrates but not nitrous oxide) when applying animal excreta to agricultural land. However, the achievement of N loss reduction targets for some regions and countries will not be possible at the national and regional scales without recourse to a reduction in livestock numbers. Finally, modelling is useful to assist farmers in decision making, to assess systems and to support public policy making. Combining measurement approaches and modelling in decision support tools helps even more to identify climate change mitigation measures at the farm level.

At the **agro-food system** scale, Gilles Billen described how an agroecological bifurcation would have a stronger abatement impact than a "Farm to Fork" strategy implementation (or other current measures proposed by national and transnational public institutions) and has the potential to halve N waste. As stated by further communications, comprehensive and integrated analyses have made impressive progress in recent years, both in terms of new methods and extensive data sets with components that were previously poorly documented (e.g. GHG emissions, air pollution and energy flows). The ambitious target of halving N losses has led to an even wider range of non-prescriptive scenarios of possible solutions.

At the **landscape scale**, Estela Romero showed that human decisions on nutrient and water management, as well as river and estuary modifications, are clear drivers of N transport from land to sea. Jill Baron, using the example of Rocky Mountain National Park in the United States, supported the need to change legislation and subsidy rules to significantly reduce N pollution, since voluntary implementation of best management practices by farmers is not enough. The rest of the communications concluded that excess N inputs to agricultural systems are evident in contrast to natural ecosystems in most countries. However, there is still a N input deficit in some of the world's countries. Measuring and monitoring reactive N is therefore central to understanding these excesses. Excessive N inputs pollute surface and groundwater as well as coastal areas. Therefore, it seems important to integrate water quality and aquatic ecosystems into global and regional assessments of N flows, and specifically to recycle reactive N. Taking into account variations in soil organic N stocks in budgetary approaches is also important, given that it can be a source of decorrelations between N use efficiency and losses.

The two **roundtables** of private and public actors in the fertiliser and feed sectors provided an opportunity to hear their views on the scientific research conducted and presented at the workshop and how it is being used, the evolution of the products they operate and finally their vision of the future and the role they intend to play. The **fertiliser industry** highlighted the influence of the concept of N use efficiency on nutrient and environmental policies and conveyed a vision of a carbon-neutral society in the future using hydrogen as an energy carrier and using ammonia (converted from hydrogen) for energy storage and transport. For its part, the **feed industry and policy makers** highlighted the progress made in the last few decades in animal feeding to increase efficiency and reduce N excretion. To advance even further, it is important to increase the use of local feed resources and avoid raw materials with a high environmental impact.

The **special sessions** deepened the interest of remote sensing tools to improve N use efficiency at the plot level as well as to exchange on public policies and their costs and benefits to reduce N losses. Urs Schmidhalter opened the special session on **remote sensing and precision agriculture** by presenting the state of the art of the potential of this tool to optimize N fertilization, i.e. increase N use efficiency and thus reduce N waste. Following this path, further communications underlined that it is nevertheless necessary to extend the use of these sensors within farms and to continue research to consolidate the understanding of the spatial and temporal dynamics of N in plants and soils using data from these sensors. As for **public policies** designed to reduce N pollution, they generally aim to repair the negative impacts of other public policies and differ from one country to another, i.e. depending on the socio-economic context. Recent public policies, faced with a growing demand for efficiency, voluntarily integrate participatory approaches. The success of these

approaches is nevertheless mixed (depending on the level of demand). Furthermore, these public policies should promote strategies involving stakeholders in the implementation of a N **circular economy**, especially concerning water streams. In addition, they should not conflict with climate policies. **Cost–benefit** analyses of these policies support decision-making processes at all scales. A key method for these analyses is benefit transfer, but the uncertainties are considerable and not well understood when the scales are large and the time horizons long.

These rich **convergent or complementary conclusions** obtained at **different scales** and with **different methodologies** reinforce the benefit of integrating **diverse spatial and system scales** within the same meeting, together with **social and policy science**. We now know that a wide range of measures can reduce N losses, that halving these losses requires both **technical and structural changes** and that the **benefits outweigh the costs**. Despite this key knowledge, implementation is not easy and requires complex public and private actions and interactions and in some cases raises conflicts of interests. The policy and social dimensions have to be reinforced to reduce N waste as soon as possible and should be present in upcoming N workshops. The perspectives of the research presented during this workshop as well as the high level of uncertainty surrounding the political and environmental context over the short term (e.g. geopolitical instability, global peak oil, climate change), announce a XXIInd edition of the N workshop already rich in content and debate on strategies to halve N wastes by 2030.

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