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Preface

Mitigation of environmental impacts of nitrogen use in agriculture

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According to Giles (2005) nitrogen (N) pollution is the third largest threat to our planet after biodiversity loss and climate change. Considered the main factor for increasing agronomic yields at the field scale, N became an issue for environmental and – possibly – human health after 1970 when the amount of global reactive N at the catchment level increased rapidly (Galloway et al., 2008). Excess N affects aquatic systems (*e.g*. eutrophication of surface water and degradation of drinking water quality); the atmospheric environment (*e.g*. increased greenhouse gas emissions, air particulate matter and acid rain); and the soil ecosystem (*e.g*. altering the biologically-mediated carbon and N cycles). Nevertheless, N fertilizers, like all factors that contribute to increased farm yields, are essential to face the rise in food requirements for a growing world population coupled with the reduction in agricultural land. The number of studies conducted at the micro-scale (*e.g*. laboratory, pot and soil column) have multiplied to better understand the processes involved, and to engineer new management options and mitigation practices. Some of these practices could in turn be applied at the field or farm scale to sustain the farmers' income and crop yields while preserving soil, water and air quality.

Measurements of N fluxes are challenging because of the different temporal and spatial scales considered. Nitrogen transformations rates are highly variable and are affected by local soil environmental conditions. Therefore, results can change drastically when moving from one scale to another. Knowledge of N-related processes is considerable at the molecular scale, but declines with increasing scale, being minimal at the global scale (Gärdenäs et al., 2011). However even the landscape level is a major challenge for acquiring data and modelling N fluxes (Sutton et al., 2007).

Also, Urban (2005) and Cobo et al. (2010) highlighted the problem that the acquisition of data and understanding of biological processes generally occurs at small scales, while applications require some sort of upscaling. Anderson (2000) summarized and reviewed the different approaches used to aggregate from the study level to a macro-scale. Scaling is not merely choosing an appropriate amplification because environmental processes are often non-linear. When non-linearity and spatial heterogeneity are not taken into account, a loss of information and/or bias in the results may occur (Oenema and Heinen, 1999; Scoones and Toulmin, 1998).Therefore, scaling requires an understanding of the dynamics of the processes (Haila, 2002).

While most research in agricultural management has been carried out at a plot or field scale (Stoorvogel and Smaling, 1998), ecological studies need to be conducted at a broader scale to elucidate the mechanisms responsible for altering environmental functions of agro-ecosystems (Moreira et al., 2005; Thenail and Baudry, 2005). According to Pelosi et al. (2010), such a spatial scale mismatch limits the effectiveness of agri-environmental policies and mitigation practices (Kleijn et al., 2004; Concepción et al., 2008).

Environmental policy should be scale-specific, in the sense that it should address the scale of the targeted environmental problem (Acutis et al, 2000; Haila, 2002; Bassanino et al., 2007). Mitigation options may be evaluated individually (e.g. Beckwith et al., 1998; Grignani et al., 2007; Cuttle et al., 2007) or in combination (e.g. Johnson et al., 2002; Johnes et al., 2007; Lord et al., 2007), through the use of controlled experiments, while the economical and organizational viability of mitigation options should be assessed at the farm level (Payraudeau and van der Werf, 2005). However, to ensure that actions are sufficient to meet water quality targets, the environmental impacts should ultimately be verified at the catchment scale and under different agro-environmental conditions (Cherry et al., 2008). Cuttle et al. (2007) and Cherry et al. (2008) summarized the usefulness and sensitivity of different approaches commonly applied to assess the efficacy of mitigation actions on transport of nutrients from agricultural land to water.

Unfortunately, even after decades of studies, when mitigation of environmental impact of N use in agriculture is considered, the scaling issue is still unresolved (van Delden et al., 2011).

Within this context the 16th edition of the 'Nitrogen Workshop' held in 2009 in Turin, Italy was entitled "Connecting different scales of N use in agriculture". A Nitrogen Workshop is held every two years on topics related to the 'Nitrogen issue'. These meetings are an opportunity for scientists from different disciplines (agronomy, horticulture biology, mathematics, computer science, engineering, plant physiology, soil science, soil microbiology etc.) to meet and share their results and ideas about improving N management. The Turin meeting hosted 350 scientists and stakeholders from 39 countries from all over the world, and more than 300 papers were presented. It was focused on connecting scales – nitrogen cycle scales, (*i.e.* how bio-chemical processes affect the agro-ecosystem response); study scales, (i.e. how researchers are addressing the upscaling-downscaling issue); management scales, (*i.e.* how effective measures can be applied to control nitrogen release to the environment); and socio-economic scales, (*i.e.* outcomes of sustainability or mitigation measures) (Grignani et al., 2009).

This special issue comprises ten papers that were presented or evolved from presentations given at the Workshop. These papers aim at improving the understanding of processes that govern N dynamics in the crop-soil-atmosphere system, in order to develop scientific approaches and technical tools needed to mitigate the negative impacts of N use in agriculture on soil, water and atmosphere quality. Consistent with the main Workshop topic, research was carried out integrating disciplines and scales, including the dimensions of depth (processes in deep soil layer and groundwater) and time (long-term effects, future evolution of the climatic and socio-economic environment). The papers are presented in order of increasing spatial scale and complexity in terms of number and interdisciplinarity of considered variables.

Senbayram et al. (this issue) and **Jahangir et al. (this issue)** used pot incubations in the lab to study relations between N and C sources with the aim of reducing N_2O emissions. They both concentrated on a micro-scale in order to explore processes that occur in deep soil horizons.

Senbayram et al. (this issue) quantified the increase in denitrification caused by the addition of different carbon sources to the soil via fertilization or crop residue incorporation, and concluded that application of organic matter with high labile C content to fertilized agricultural soils may trigger denitrification-derived N_2O emissions. Therefore, organic amendments used as alternatives to mineral N fertilization may have contrasting effects on greenhouse gas emissions, as they favour C sequestration but provoke additional N_2O emissions.

Jahangir et al. (this issue) found that easily decomposable C residues, such as root exudates, are effective in promoting total denitrification of nitrates to N_2 in deep soil horizons. Consequently, deep rooted crops could reduce the denitrification-derived N_2O in certain conditions. This study highlighted the importance of subsoil in determining the impact of agriculture on air quality and the importance of integrating deep soil layers in all evaluations of gaseous losses from agriculture.

The impact of highly fertilized cropping systems on groundwater quality and the analysis of applicable mitigation practices were discussed in the papers by **Zavattaro et al. (this issue)** and **Constantin et al. (this issue)**. They used results from long-term experimental trials at the plot scale to propose mitigation strategies. **Zavattaro et al. (this issue)** presented a set of agro-environmental indicators for alternative maize-based cropping systems to propose feasible solutions to the N issue in intensive agriculture of southern Europe. Based on results from a long-term trial, they proposed a set of N-use efficiency indicators to facilitate comparison with other trials and to monitor the effects of environmental legislation. Simulated N leaching using the Daisy model was included among the indicators. The authors concluded that farmers have several options to ensure a high yield but low impacts on groundwater quality; including whole-plant harvesting and intercropping Italian ryegrass.

Constantin et al. (this issue) discussed the results of medium-term field experiments through a long-term simulation exercise using the STICS model. Their work studied the long-term effects of repeated catch crops on different soils within the context of climate change. The authors concluded that repeated catch crops sequester organic N, increase N mineralization and can lower N leaching if fertilization is consequently reduced. They predicted that equilibrium between organic N sequestration and N mineralization is reached after 23-45 years, depending on the site. The paper offers a good example of how mitigation options (catch crops adoption and fertilization reduction) should be managed together to achieve consistent results.

Morari et al. (this issue) and **Perego et al. (this issue)** discussed short-term data on large fields in equilibrium with standard farming practices. **Morari et al. (this issue)** studied groundwater N concentrations in large plots characterized by shallow groundwater under contrasting agricultural management practices. They demonstrated that up-flux from shallow groundwater may minimize the impact of N fertilization on groundwater quality because of the soluble N returning to the root system and because of enhanced denitrification. Under the conditions of their study, alternative management options (integrated and organic compared to conventional) scarcely affected the groundwater N concentration. Despite a lower N surplus, the impact of organic management on groundwater quality would be greater because of the poorer synchronization between N availability and crop needs. This work highlighted the need of including deep soil and groundwater components when evaluating low impact management practices.

Perego et al. (this issue) monitored a number of private farms across one region, in order to evaluate the sustainability of specific crop management practices and to propose alternatives. They found that N leaching at the field scale exceeded targets in most of the studied sites, and concluded that N leaching could be reduced mainly by reducing N surplus, but also by controlling irrigation. The strong dependence of nitrate leaching on the total N surplus supports the rationale for the derogation request by several EU Member States from the 170 kg N ha^{-1} of organic N limit imposed by European directives in Nitrate Vulnerable Zones.

The scale issue was explicitly coupled with the search for mitigation options in the paper by **Cordova et al. (this issue).** They analyzed interrelations between C and N cycles using a geostatistical approach. Nitrate- and ammonium-N spatial structures were different, the latter had a spatial dependence within a range of 25 m, but the former showed a pure nugget effect. Soil concentrations of both N compounds were not determined by the spatial pattern of light fractions of soil organic matter. The hypothesis that light C and mineral N were spatially correlated could have supported a patch distribution of mineral N fertilizers across a field using precision farming techniques. As this hypothesis was rejected, uniform application of N fertilizer probably would not exacerbate N losses, while other indicators should be used to modulate N supply.

Indicators of N-use efficiency at the farm scale were calculated for two sets of dairy farms with contrasting environments, organization and management strategies (grazed systems in Australia and confinement systems in USA) in the paper by **Gourley et al. (this issue)**. Feed N-use efficiency, milk urea-N concentration, manure collection and redistribution practices were investigated. Five farm types were identified across the two main sets, each determined by specific management options and constraints. While milk urea-N concentration showed that confinement systems better managed crude protein levels in the diet compared to grazing systems, manure management indicators showed ample possibilities for improvement. For most indicators between-farm variability was higher than that between regions. The authors concluded that in order to propose mitigation measures, benchmark values of indicators should be proposed to set environmental sustainability goals for farms.

The field, farm and catchment scale approaches were compared and integrated in the work by **Cherry et al. (this issue)** to assess the efficacy of mitigation measures. They calculated N budgets at the field and farm scales in England, within monitored catchments where mitigation measures were adopted. They concluded that the volunteer adoption of a set of mitigation options by farmers reduced the N surplus at both scales. However, in most cases changes could not be linked to the specific mitigation practice adopted. Field-scale budgets highlighted opportunities to improve manure management and utilize cover crops while farm-scale budgets showed the importance of reducing imported feed. Again, the results indicate that farm organization was crucial in choosing and applying appropriate mitigation strategies.

Moreau et al. (this issue) integrated historical, social, landscape, economical and agronomical approaches to analyze a catchment in northern France where severe mitigation of detrimental N impacts was needed to prevent widespread algal blooms in the coastal area. The integration of different temporal and spatial scales and approaches identified farming systems with the lowest impacts and the factors that influenced them in recent decades. After a scenario analysis and the definition of the potential environmental impact of the dairy systems, the authors concluded that the expansion of a low-input grass-based farming type was the only solution that could significantly decrease N fluxes and achieve water quality targets. The importance and novelty of this work is the complexity of the data and the integration of multidisciplinary approaches to direct agriculture and farm organization towards environmental and economical sustainability on a catchment basis.

The collection of papers in this special issue offers a series of possible actions to mitigate the negative effects of excessive reactive N in the environment. The interlinks between C and N cycles and the importance of the soil water status have been clarified in the papers by **Senbayram et al. (this issue)**, **Jahangir et al. (this issue)**, **Morari et al. (this issue)** and **Cordova et al. (this issue)**, while interlinks between management practices are discussed in the papers by **Zavattaro et al. (this issue)**, **Constantin et al. (this issue)** and **Perego et al. (this issue)**, and implications of adopting mitigation strategies on the farm organization structure are outlined in the papers by **Gourley et al. (this issue)**, **Cherry et al. (this issue)** and **Moreau et al. (this issue)**. Modelling was often used to connect scales in terms of time or space. This collection contributes to the discussion of methods and approaches to develop sustainable agricultural systems. It demonstrates that only a comprehensive, holistic approach can identify mitigation strategies that consider the whole farm organization and sustainability and address both water and air quality protection.

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Ordered list of papers:

1. Senbayram M., Chen R., Budai A., Bakken L., Dittert K., this issue. N2O emission and the $N_2O/(N_2O + N_2)$ product ratio of denitrification as controlled by available carbon substrates and nitrate concentrations.

2. Jahangir M.M.R., Khalil M.I., Johnston P., Cardenas L.M., Hatch D.J., Butler M., Barrett M., O'flaherty V., Richards, K.G., this issue. Denitrification potential in subsoils: A mechanism to reduce nitrate leaching to groundwater.
3. Zavattaro L., Monaco S., Sacco D., Grignani C., this issue. Options to reduce N loss from maize in intensive cropping systems in Northern Italy.
4. Constantin J., Beaudoin N., Launay M., Duval J., Mary B., this issue. Long-term nitrogen dynamics in various catch crop scenarios: Test and simulations with STICS model in a temperate climate.
5. Morari F., Lugato E., Polese R., Berti A., Giardini L., this issue. Nitrate concentrations in groundwater under contrasting agricultural management practices in the low plains of Italy.
6. Perego A., Basile A., Bonfante A., De Mascellis R., Terribile F., Brenna S., Acutis M., this issue. Nitrate leaching under maize cropping systems in Po Valley (Italy).
7. Córdova C., Sohi S.P., Murray Lark R., Goulding K.W.T., Robinson J S., this issue. Resolving the spatial variability of soil N using fractions of soil organic matter.
8. Gourley C.J.P, Aarons S.R., Powell J.M., this issue. Nitrogen use efficiency and manure management practices in contrasting dairy production systems.
9. Cherry K., Mooney S.J., Ramsden S., Shepherd M.A., this issue. Using field and farm nitrogen budgets to assess the effectiveness of actions mitigating N loss to water.
10. Moreau P., Ruiz L., Mabon F., Raimbault T., Durand P., Delaby L., Devienne S., Vertès F., this issue. Reconciling technical, economic and environmental efficiency of farming systems in vulnerable areas.