Best Nitrogen Management Practices to Decrease Greenhouse Gas Emissions

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Agricultural soils are the main source of human-caused emissions of the greenhouse gas (GHG) nitrous oxide (N_2O) to the atmosphere. Those emissions are often expressed per area of land use or as a percentage of the fertilizer application rates. In a recent scientific journal article, we argued that N_2O emissions should instead be related to agricultural production. In a meta-analysis of 19 independent studies that report both N_2O emissions and crop yield, we show that N_2O emissions per unit of harvested product are stable as long as the aboveground N surplus remains low. We conclude that the aims of optimal agricultural production and low GHG emissions are remarkably similar and might best be achieved through implementing best management practices (BMPs). Management should be focused on optimizing fertilizer N use efficiency (NUE) rather than on simply reducing fertilizer N application rates.

Nitrous oxide is a potent greenhouse gas. Per gram, its atmospheric warming effect is approximately 296 times as strong as carbon dioxide. The rise in atmospheric N_2O concentration since the start of the industrial era has been largely due to increased agricultural activity; agricultural soils and their management are by far the largest source of man-made N_2O emissions. This is mainly due to increased use of commercial fertilizer-N, either applied directly to the soil or indirectly through recycling as manure (Crutzen et al., 2008). As worldwide fertilizer N demand is expected to rise from 100 million metric tons (M t) in 2006 to >135 M t in 2030, N_2O emissions are widely expected to rise in the future. It is estimated that every kg of newly fixed fertilizer N will eventually lead to an emission of 30 to 50 g N_2O-N, either directly from the soil or indirectly after other N deliveries to water resources or the atmosphere.

Despite these potential effects on N_2O emissions, as well as other N losses to the environment, fertilizer N remains essential to global crop production. Highly productive agricultural systems are often associated with relatively large N losses to the environment, including N_2O emissions. This is because the relationship between crop productivity and fertilizer N input is not linear, but follows the well-known diminishing return function. Therefore, simultaneous achievement of large yields and high NUE is inherently difficult (Cassman et al., 2003).

Although both GHG emissions and NUE are linked to N application rates and soil management, studies on both issues have been largely disconnected in the past. However, there have been some efforts to link the two in order to find some sort of combined optimum. For example, BMPs such as balanced N management and crop rotation have been shown to decrease N_2O emissions (Snyder et al., 2009; Adviento-Borbe et al., 2007). In our article, we expand on the concept of linking agronomic productivity to environmental sustainability (Mosier et al., 2006). We postulate that, instead of assessing N_2O emissions in terms of fluxes per ha or per unit of applied fertilizer N, we should focus on N_2O emissions per unit of harvested product. Such "yield-scaled N_2O emissions" should be minimized in order to achieve cropping systems that are both highly productive and environmentally sustainable.

Abbreviations: GHG = greenhouse gas; N_2O = nitrous oxide; BMPs = Best Management Practices; N = nitrogen, GWP = global warming potential.

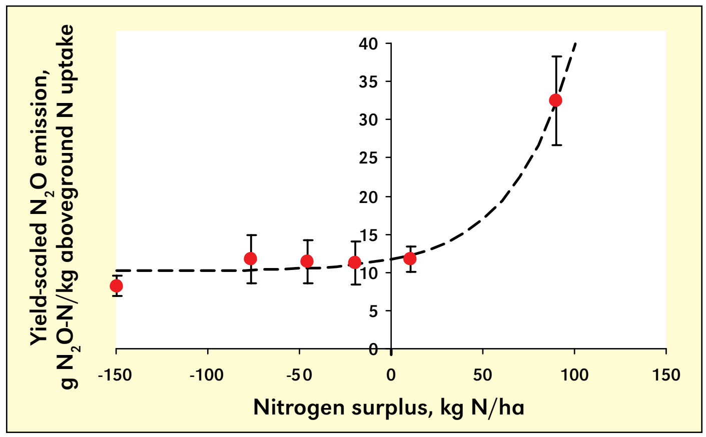

Figure 1. Meta-analysis results of the relationship between N surplus and yield-scaled (i.e. expressed per unit of aboveground N uptake) N_2O emissions. Nitrogen surplus was defined as above-ground N uptake minus N application rate.

We tested this concept in a meta-analysis of studies published on both N_2O fluxes and yield data (Van Groenigen et al., 2010). In our analysis, we explored relations between NUE, N surplus, and yield-scaled N_2O emissions in order to find the optimal combination of agronomic productivity and GHG emissions.

Data Analysis

A literature survey of peer-reviewed publications that reported both N_2O emissions and total N accumulation in crops in agricultural systems was carried out. A total of 19 studies encompassing 147 observations were included, with more than half of the studies located in North America and the remainder located in Europe, Asia, and Oceania. Crops included maize (corn), wheat, potato, onion, and flooded rice. Total inorganic and organic N (manure or sludge) input ranged between 0 and 802 kg N/ha with both an average (and median) value of 134 kg N/ha. The N surplus was calculated as the amount of applied inorganic and/or organic N minus aboveground N uptake (grain plus residue).

Yield-scaled N_2O emissions showed no increase up to a small N surplus of approximately 10 kg N/ha (**Figure 1**). At a surplus of 90 kg N/ha, (yield-scaled) N_2O emissions increased more than three-fold. An increase in N_2O emissions when more N is applied than is taken up by the crop has been observed and is predicted to be a common response. With a larger N surplus, more mineral N is available in the soil for N_2O emissions. It is of interest that within the range of a N 'deficit' of approximately 150 kg N/ha to a small N surplus of approximately 10 kg N/ha, total N_2O emissions/ha did not change significantly. This probably reflects the capacity for crops to take up moderate rates of applied N during the growing season, before N_2O emissions might be stimulated by wetter conditions.

Yield-scaled N_2O emissions showed a significant and negative relationship with NUE (**Figure 2**). This is a clear indication that agronomic aims of increasing fertilizer NUE are directly linked to GHG efficiency by minimizing N_2O fluxes. Yield-scaled N_2O emissions decreased from 12.7 to 7.1 g N_2O-N/kg N uptake when NUE increased from 19 to 75%.

Because of the wide variety of agroecosystems included in this study, N_2O emission variability remains large, even after accounting for N application rates. Specific factors such as weather, crop type, crop residue quality, soil type and fertilizer type, will all significantly affect N_2O emissions (Mosier et al., 1998). For our findings to result in actual fertilizer recommendations, agroecosystem-specific relationships between N_2O emissions and yield will have to be established. Routine reporting of yield and above-ground N uptake in N_2O emission studies would therefore be of great benefit. Such data are relatively inexpensive and easy to collect, compared with N_2O flux measurements, and the data would provide much insight in the crop-, climate-, and management-related variations in yield-scaled N_2O emissions.

For a full assessment of the GHG efficiency of agricultural production systems, including carbon dioxide and methane effects, an integral lifecycle analysis (LCA) would be needed. However, N_2O emissions are often a decisive factor in the GHG budget of agricultural production systems (Robertson et al., 2000), making our observed relationships significant when developing policy on reducing GHG emissions.

Conclusion

Our results suggest that the best management options for 'N_2O-efficient' agronomic production are similar to those promoting agronomic efficiency in general. Rather than focusing on small N application rates [as the Intergovernmental Panel on Climate Change (IPCC) Tier 1 default N_2O emission standard might suggest implicitly] management practices should be aimed at maximizing uptake of applied N in the crop, while achieving high yields. Our analyses show no significant differences in the amount of N_2O emitted per unit of crop N uptake up to a N surplus of 11 kg N/ha. The adoption of BMPs, which can be implemented without a reduction in total yield or total-N accumulation in the crop (Adviento-Borbe et al., 2007), should be considered as a strategy for N_2O reduction. Agroecosystem-specific relationships will be needed to translate our findings into fertilizer recommendations. We recommend routine reporting of yield and crop N uptake rates in N_2O emission studies to facilitate such an analysis. We postulate that, in a world with a growing demand for food, fuel, and fiber, expressing N_2O emissions as a function of land area or fertilizer application rate is not helpful and may even be counter-productive. Emissions of N_2O should be assessed as a function of crop N uptake and crop yield. BC

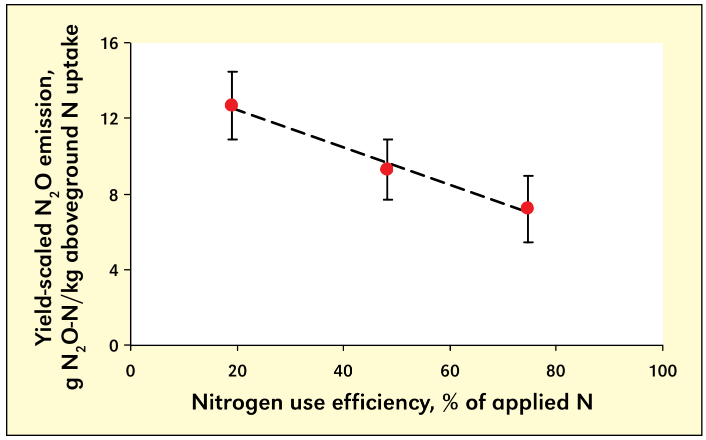

Figure 2. Meta-analysis results of the relationship between N use efficiency and yield-scaled N_2O emissions. NUE is expressed as apparent recovery efficiency (in %) of applied N.

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