Series Introduction: Can we relate fertilizer management to nitrogen losses?

Climate, soil, and nutrient management impact nitrogen (N) losses in predictable ways. By applying the 4Rs of nutrient stewardship, managers can make changes to N management practices for more sustainable outcomes. This entails minimizing N losses by supplying enough of the appropriate source of N when and where the crop demands it. However, optimizing N practices is complicated by:

1. The inability to readily measure all important fates of N, such as ammonia volatilization, nitrous oxide (N_2O) emission, and nitrate leaching;
2. Interactions among 4R management, soil, and climatic factors that limit yield and crop recovery of N;
3. The identification of management strategies that target multiple loss pathways (e.g., reduce ammonia volatilization, N_2O emissions, as well as nitrate leaching).

In this series, we are devoting one article to each of these three challenges.

John Deere

Part 1: Can Lower Nitrogen Balances and Greater Recovery by Corn Reduce N_2O Emissions?

By Tai McClellan Maaz, Rex Omonode, and Tony Vyn

Current methodologies to estimate N_2O emission are rate based. This means that emissions are calculated by multiplying fertilizer N rates by a single emission factor of 0.01 (IPCC, 2006). However, the microbial production of N_2O from a given nutrient application varies widely depending on how the soil interacts with local weather and the source, rate, timing, and placement of the nutrient applied. Therefore, the effectiveness of a single emission factor based on N rate is limited, and alternatives must be explored.

Nitrogen use efficiency indicators, such as N recovery or partial N balances, may relate better to N_2O emissions. The rationale is that these measures reflect the N not used by the crop and therefore at risk of loss. However, for a N use efficiency indicator to be useful, it must reliably relate to N_2O emissions across a range of management practices and environments.

In 2017, Omonode et al. published a study investigating this issue. The authors asked the following research questions:

Nitrous oxide (N_2O) emissions are related to N use efficiency indicators across a range of geographies and management conditions for North American rain-fed and irrigated corn. Suites of 4R management practices that reduce N balances through more efficient fertilizer recovery can reduce N_2O emissions. Performance indicators that estimate N surplus in the system, such as partial N balances when grain N concentrations are known, may be more effective than fertilizer N rate alone at predicting N_2O emissions. However, multiple indicators are needed to assess the sustainability of these cropping systems.

KEYWORDS:
use efficiency; nutrient performance; uptake; recovery; economic optimal N rate.

ABBREVIATIONS AND NOTES:
N = nitrogen; N_2O = nitrous oxide.

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Table 1. Definitions of N uptake, recovery efficiency, and N balance indicators.

Indicator	Calculation	Assumptions
Grain N uptake, kg/ha	Grain N	0.64 x aboveground N, if not reported
Total N uptake, kg/ha	Grain + stover N	Grain N / 0.64, if not reported
N recovery efficiency, %	(Total N uptake$_{fertilized}$ – total N uptake$_{unfertilized}$) / Applied N x 100	Nitrogen recovery is approximated by the difference in N uptake between fertilized and unfertilized corn relative to the amount of fertilizer applied
Grain-based net N balance, kg/ha	(Fertilizer N + manure N + rotational N) – grain N	Manure N = recoverable N; rotational N = N credits following legumes based on state/region recommendations
Crop-based net N balance, kg/ha	(Fertilizer N + manure N + rotational N) – total N uptake	Manure N = recoverable N; rotational N = N credits following legumes based on state/region recommendations
N surplus, kg/ha	Fertilizer N – Total N uptake	Manure is not factored into surplus calculation

1. Do increases in crop N uptake and recovery efficiencies and decreases in N surpluses reduce cumulative seasonal N_2O fluxes?
2. Are these relationships consistent across suites of 4R nutrient management practices?

These authors limited their study to North American corn production due to its importance; the region produces 37% of the world's corn supply and consumes about 13% of N fertilizer applied. In the United States, about 40% of N fertilizer consumed is applied to corn. The authors conducted a literature review to assess the cumulative seasonal N_2O fluxes relative to corn yield, crop N uptake, and grain N uptake. In total, 379 mean observations were collected from 25 papers that had more than three replications, at least two years of observations, with at least weekly in-season measurements of N_2O fluxes during most of the growing season, and more than three fertilizer rates (for rate-based studies) including control plots. The studies were conducted in Nebraska (1), Indiana (4), Ontario (3), Minnesota (6), Colorado (8), Kentucky (1), Quebec (1), and New Brunswick (1). Fifteen of the studies were conducted under rain-fed conditions, ten were irrigated, but one of the ten was partially rain-fed.

Of the total, 94 mean observations were focused on N rate treatments, 94 on N sources, and 191 on N rate or N sources in combination with timing and/or placement options. Data were used to calculate N recovery and N surplus or balances using indicators defined in **Table 1**. Aggregated across all soils, management, and climate conditions, single-factor linear and non-linear regressions were conducted to characterize the response of N_2O emissions, and each indicator, to N rate. The relationship of N_2O emissions to each indicator was also assessed across 4R practices. Finally, multiple regressions were conducted to identify whether a combination of indicators could more completely explain the observed variation in N_2O emissions.

How Does Nitrogen Rate Relate to Seasonal N_2O Emissions?

Cumulative N_2O fluxes were reduced most by optimizing N rate, followed by smaller effects of timing and source. Adding more fertilizer increased N_2O emissions. However, this study showed the following limitations in estimating N_2O emissions by just N rate.

Limitation 1: Large amounts of unexplained variation in emissions

Although N_2O emissions were best predicted by fertilizer N rate, this single variable only explained 43% of the variability.

Limitation 2: Inconsistency in emission factors

For global inventories, emissions of N_2O-N are estimated by multiplying fertilizer N rates by a single emission factor of 1%. However, emission factors are reported to vary from 0.07 to 1.7% (Asgedom et al., 2014; Burton et al., 2008; Gao et al., 2017; Maharjan and Venterea, 2013). The emission factor for corn in this study was 0.6%, less than the reported global average.

Emissions factors also varied across N source. Omonode et al. (2017) provide evidence that supports lower emission factors with polymer-coated urea and stabilized-N products containing urease with and without nitrification inhibitors (**Table 2**). Therefore, source can have an effect additional to N rate.

Limitation 3: The extent to which N rate can be reduced without agronomic losses

The economic optimal N rate (EONR), for the entire dataset can be easily calculated using the regression parameters reported by Omonode et al. (2017). Across all soils, management, and climates, the EONR was 215 kg N/ha (**Table 3**).

TAKE IT TO THE FIELD

Partial N balance can be used to evaluate on-farm performance of 4R practice implementation and to assure that reductions in N_2O emission have been achieved at optimal yields. Additional reductions in emissions, independent of N balance, may be achieved through use of urease/nitrification inhibitors.

The N fertilizer rate can be adjusted from the rate for maximum yield to that for optimum economic yield. Doing so reduces yield by less than 1% while reducing N_2O emissions by 11%. However, even with optimized N rates, 1.57 kg N/ha was emitted as N_2O, and N balances were largely positive. Nitrous oxide fluxes increased by approximately 5 g N/kg of fertilizer N as fertilizer rate increased from 130 to 220 kg N/ha. To put this into perspective, agronomic optimal N rates typically range from 150 kg N/ha in Minnesota to 220 kg N/ha in Indiana, corresponding with emissions of 1.0 to 1.6 kg N/ha. Other fertilizer management practices, such as source and timing, need to be considered for further reductions beyond the 11% achieved through optimizing fertilizer rate economically.

Table 2. Nitrogen source effects on seasonal N_2O emissions, fertilizer-induced emission factors, N recovery efficiencies, and crop-based net N balances.

		Nitrous oxide and N use efficiency indicator			
Location	N source	N_2O, kg N/ha	Emission factor, %	Crop net N balance, kg N/ha	N recovery efficiency, %
Colorado (irrigated)	Polymer-coated urea	0.92 b	0.36 b	23 a	54 a
	Stabilized urea†	0.59 c	0.21 bc	12 a	56 a
	UAN	0.74 bc	0.29 b	19 a	51 a
	Urea	1.14 a	0.45 a	22 a	54 a
Indiana (rain-fed)	UAN	2.35 a	1.23 a	20 a	53 a
	UAN + Nitrification inhibitor	1.69 b	0.58 b	9 a	58 a
Minnesota (irrigated and rain-fed)	Polymer-coated urea	1.17 ab	0.44 ab	-22 a	48 a
	Stabilized urea	0.86 b	0.26 b	-28 a	53 a
	Urea	1.46 a	0.60 a	-25 a	52 a

†Stabilized urea includes Agrotain® with urea, Agrotain®Plus with UAN, and SuperU®.

Do Increases in Nitrogen Use Efficiencies Reduce Cumulative Seasonal N_2O Fluxes?

Nitrous oxide emissions increased as total aboveground and grain N uptake increased. Therefore, emissions associated with higher N rates were not fully offset by increases in crop uptake of N. Instead, N use efficiency indicators were more suitable measures, and N_2O emissions decreased as apparent N recovery increased or N balances decreased. In general, the relationships of these indicators with N_2O fluxes were consistent across timing and N rate combinations.

The usefulness of N recovery and N surplus was demonstrated with the timing of fertilizer applications. Omonode et al. (2017) found that N_2O emissions were lower for the same amount of N taken up by the crop, or a given partial N balance, when fertilizer was applied at planting rather than side-dressed, or when N was side-dressed earlier (V6) rather than later (V14). These findings suggest that the benefits of in-season applications are only obtained when rates are more accurately adjusted to improve N use efficiency. Even during periods of rapid nutrient uptake, poor recovery and high N surpluses can increase N_2O emissions, particularly if environmental conditions are more conducive to losses between V6 and V14 (e.g., a warmer, wetter summer) rather than between planting and V6 (e.g., a drier, cooler spring).

However, the N fertilizer recovery indicator had limitations as a predictor of N_2O emissions. For example, the use of stabilized urea with inhibitors reduced N_2O emissions by 19 to 48%, with such emissions being less at planting than at side-dressing. However, this reduction in N_2O emissions did not correspond with enhancements in N recovery efficiency. Without leaching or denitrification data, it is difficult to assess whether the offset in N_2O emissions through the use of inhibitors came at the expense of later N losses through other pathways such as leaching. This latter concern is the topic of two articles to come, in which we discuss recent research that examined climate, soil, and management impacts on N_2O emission and nitrate leaching. **BC**

Table 3. N_2O emissions and indicators at economic optimal N rates based on the yield response of 84 mean observations at economic optimum and maximum yields.

Indicator	Equation	EONR*	Maximum
Grain yield, kg/ha	Quadratic	11,379	11,469
N rate, kg N/ha	Quadratic	215	247
N_2O emission, kg N/ha	Linear	1.7	1.76
Grain N uptake, kg N/ha	Linear	135	146
Total N uptake, kg N/ha	Linear	211	229
N recovery efficiency, %	Linear	54	49
Grain-based net N balance, kg N/ha	Linear	115	137
Crop-based net N balance, kg N/ha	Exponential	38	63
N surplus, kg N/ha	Exponential	-1	21

*Economic optimal N rates were calculated using regression parameters with the highest R^2 provided in **Table 1** of Omonode et al. 2017.

View Interactive Charts

Explore where values from Table 3 fall upon the response curve to nitrogen fertilizer.

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Dr. McCellan Maaz (e-mail: tmaaz@ipni.net) is director of the IPNI Nitrogen Program based in Peachtree Corners, GA, USA; Dr. Omonode is formerly with Purdue University, West Lafayette, IN, USA. Dr. Vyn is professor, Department of Agronomy, Purdue University.

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