PART 2: Effects of 4R Management, Climate, and Soil Variables on Nitrogen Losses

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Nitrogen (N) fertilizer is critical for meeting yield and crop quality goals. However, N management also has multiple environmental impacts. Unrecovered N may be emitted to the atmosphere through volatilization, nitrification, and denitrification processes, while nitrate (NO_3^-) can travel to surface and groundwater through runoff and leaching pathways. These losses can have unintended consequences. For example, even though <3% of fertilizer N is typically emitted to the atmosphere as nitrous oxide (N_2O), this trace gas has 265 times the global warming potential of carbon dioxide and depletes stratospheric ozone. Nitrate in groundwater and surface waters can impair drinking water or lead to eutrophication in water bodies important to recreation, lake- and ocean-shore residents, and the fishing industry.

Farm managers face the major challenge of maintaining or increasing yields while reducing N losses. Fertilizer management can be fine-tuned to minimize N losses by supplying enough of the appropriate source of N when and where the crop demands it. However, climate and soil factors also affect crop performance and the biological processes that regulate N losses. Optimizing N inputs is further complicated by the existence of multiple pathways through which fer-

SUMMARY

Climate, soil, and 4R Nitrogen (N) management impact N losses in measurable ways. However, nitrous oxide (N_2O) emissions and nitrate (NO_3^-) leaching respond differently to changes in fertilizer management and environmental conditions. Strategies that target multiple pathways may be necessary to combat N losses.

KEYWORDS:

nitrification inhibitors; side-dress nitrogen; nitrous oxide losses; nitrate leaching; soil carbon.

ABBREVIATIONS AND NOTES:

N = nitrogen; NO_3^- = nitrate; N_2O = nitrous oxide.

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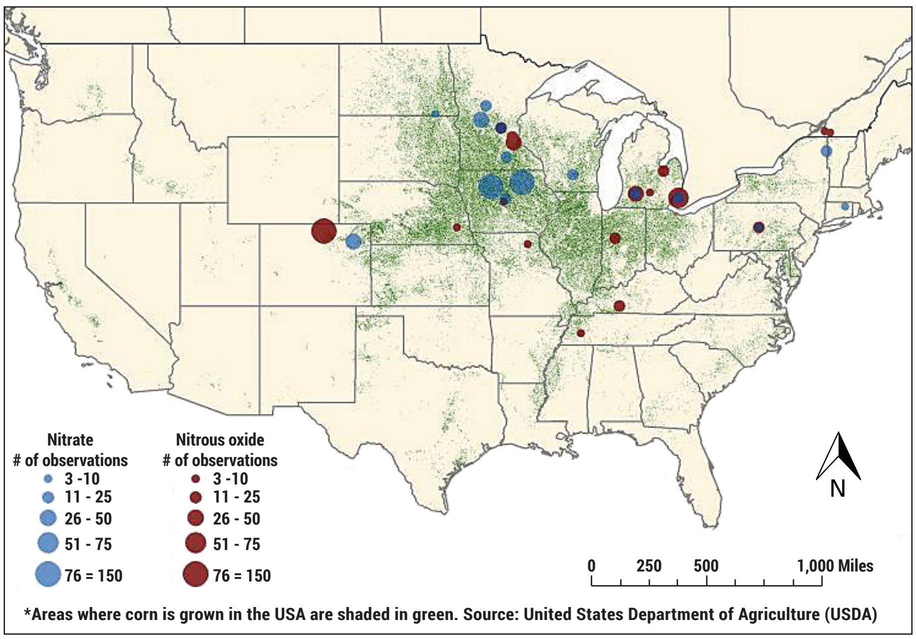
Table 1. Mitigation of N_2O emissions and NO_3^- leaching through 4R nutrient management and influence of climate and soil factors.

	Management change	N_2O emissions	NO_3^- leaching
Fertilizer management			
Rate	Reducing 180 kg N/ha by 10 kg N/ha	-4%	-3%
Timing	Side-dressing	-20 to -39%	No response[1]
Place	Broadcast	-25%	Limited data
Source	Nitrification inhibitor	-31%	No response[1]
Soil factors			
Soil carbon content	Increase in soil carbon content by 1%	+24%	-31%
Climatic factors			
July temperature	Increase by 1°C	+18%	No response[1]
Annual precipitation	Increase by 100 mm	No response[1]	+27%
Irrigation	Application of 200 mm	No response[1]	+27%

[1] The lack of effect may be due to limited data. Experiments were often not set up to test these treatments, and when combining across studies, the differences due to location and year can mask effects of the management differences.



Geographic distribution of agricultural N loss dataset. Eagle et al. 2017.
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tilizer N may be lost from the plant-soil system. Therefore, the effectiveness of different fertilizer management practices to combat N losses likely depends on site-specific conditions.

In 2017, Eagle et al. published a study examining the impact of 4R management, climate, and soil factors on two loss pathways: N_2O emissions and NO_3^- leaching. The authors asked the following research questions:

1. How do fertilizer N source, rate, timing, and placement affect N_2O emissions and NO_3^- leaching?
2. How do such fertilizer management effects compare to and depend on climate and soil factors?
3. Do N_2O emissions and NO_3^- leaching respond similarly to management, climate, and soil conditions?

The authors focused their research on North American corn systems, which produce 37% of the world's supply, and in the USA demand 40% of all N fertilizer consumed. These researchers conducted a systematic review and identified 237 articles that studied fertilizer N management in corn production in North America. Of these, a total of 51 field studies met the following criteria: corn yields were reported, N_2O and/or NO_3^- losses were measured over at least 55 days in the growing season, and at least one of the 4Rs (source, rate, time, place) for N fertilizer management was compared between treatments. They built the final database from studies conducted in the USA and Canada, including 417 observations of N_2O losses (27 studies at 19 locations) and 388 observations for NO_3^- leaching (25 studies at 16 locations). One of these studies, with 16 observations, reported both types of N loss. The articles, and in some cases the field researchers themselves, also contributed other data, including irrigation, tillage, cover crop, 4R management, N uptake, residual soil N, inhibitors, soil texture, drainage classes, surface soil organic carbon, long-term average precipitation, and July temperature, as well as annual precipitation for each study.

Using the database, Eagle et al. (2017) tested the effects of 4R management and environmental factors on N losses. First, they modeled the relationship of N rate and N losses for different site-year combinations using linear and non-linear regressions. Secondly, they used a standard meta-analysis approach to make paired comparisons to determine the effect on N losses from alternative N fertilizer timings, sources, and placements. Finally, they evaluated the entire dataset with a multi-level regression model that could determine the influence of 4R management and environmental factors. This third analysis handled complex data when paired comparisons were not available and could compare

Interactive Chart
Explore the modeled effect of 4R N management on N_2O emissions

TAKE IT TO THE FIELD

Optimizing rate, source, timing, and placement of N fertilizer reduces N_2O emissions. Climate and soil factors affect N_2O emissions and nitrate leaching losses, but sometimes in contrasting ways.

across sites and years that had different management, soil, or weather conditions.

How Do 4R Nutrient Management, Soil, and Climatic Factors Affect Nitrogen Losses?

Nitrous oxide emissions were influenced by 4R N management, including rate, timing, source, and placement. Specifically, N_2O emissions declined due to a reduction in N rate, the application of nitrification inhibitors, side-dressing fertilizer when the crop was growing compared to when all was applied pre-plant, or when N was broadcast rather then banded (**Table 1**). For example, a nitrification inhibitor, broadcast placement, or a side-dress application at least three weeks after planting reduced emissions by a similar magnitude as reducing N rate by 100 kg N/ha. Climate and soil factors also affected N_2O emissions. Specifically, N_2O fluxes tended to increase with higher soil carbon and higher July temperatures. The effect of climate was also comparable to a large reduction in fertilizer rate, where a 1°C increase in July temperature had an equivalent effect on increased N_2O emissions as applying 100 kg N/ha more fertilizer.

In comparison, NO_3^- leaching responded significantly to N rate, but not to source, placement, or timing (**Table 1**). There was some evidence that leaching losses were lower with banded urea and greater with aqueous ammonia, but these data came from single studies. Nitrate leaching increased with precipitation and decreased with soil carbon content, but did not respond to nitrification inhibitors or timing. However, with most studies designed to test management other than the 4Rs, the lack of response may be largely a result of limited data. An increase in precipitation by 100 mm/yr enhanced NO_3^- leaching by a similar magnitude as increasing fertilizer N rate by 100 kg N/ha.

Do We Need to Consider Management Effects on Multiple Loss Pathways?

In general, Eagle et al. (2017) found that practices that reduced N_2O emissions also reduced NO_3^- leaching or had a limited effect. However, a particular management strategy that reduces N_2O emissions may not be effective at reducing NO_3^- leaching, and vice versa. For instance, although both N_2O emissions and NO_3^- leaching increased with N rate, the nature of the relationship was not the same. For N_2O emissions, the relationship was exponential; whereas, for NO_3^- leaching, the relationship was linear. Nitrous oxide emissions were also more dependent on source and timing than were NO_3^- leaching losses.

Climate and soil conditions, on the other hand, could sometimes have contrasting effects on N_2O emissions and NO_3^- leaching. Soil carbon content, for example, was positively correlated with N_2O emissions, but negatively correlated with NO_3^- leaching.

The findings of Eagle et al. (2017) provide valuable insight into mitigating N losses through 4R practices. One important take-away from the article is that simultaneously assessing multiple loss pathways is necessary when tailoring N management to specific soil and climatic conditions. Yet, weighing the potential trade-offs among management decisions is challenged by the lack of scientific studies that measure N losses through more than one pathway. Additionally, N_2O and NO_3^- leaching are not the only two loss pathways, and other losses, such as ammonia volatilization, should also be considered, especially if broadcasting urea without a urease inhibitor. (In fact, lower N_2O losses from broadcast fertilizer could happen if a large portion of the N fertilizer volatilized as ammonia soon after application.) And so, as we continue to conduct the research to fill these knowledge gaps (see http://research.ipni.net/project/IPNI-2017-USA-4RF01), crop advisers must utilize their knowledge to select practices that minimize N losses through the pathways important to their particular systems or site-specific conditions. **BC**

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