Measuring Nitrous Oxide Emissions from agriculture

by Tracy Hmielowski

Photo by Andrew VanderZaag.
Carbon dioxide (CO₂) emissions are usually the first thing to come to mind when talking about greenhouse gases, but there is a suite of greenhouse gases of concern. One of these is nitrous oxide (N₂O). Nitrous oxide occurs naturally in the atmosphere, but levels are increasing due to human activity. This increase is concerning as N₂O has more than 300 times the warming potential of CO₂ and can remain in the atmosphere for over 100 years. The greatest sources of N₂O from human activity include agriculture and fossil fuel combustion. Agricultural systems contribute N₂O through fertilizer application, the breakdown of crop residue, and animal waste. Nitrous oxide is a by-product of soil microbial processes, and the production of N₂O depends upon soil characteristics, weather, carbon sources, and other environmental factors. Because these factors can vary from site to site, it is challenging to develop broad strategies to reduce N₂O emissions.

Recent articles in the Journal of Environmental Quality (JEQ) and Soil Science Society of America Journal (SSSAJ) report on different aspects of N₂O emissions. From improving methods to measure N₂O flux to evaluating the impact of seasonal cycles, fertilizer inputs, and cover crops on emissions, these articles point out the need to have accurate measures of N₂O emissions and an understanding of how management actions and environmental variables can influence N₂O flux.

Soil Oxygen Dynamics

The primary pathways for production of N₂O in soils are denitrification and nitrifier-denitrification. These biological pathways are influenced by soil properties, including oxygen availability. “When there is nitrogen available as a substrate for microbial metabolism, rates of N₂O production from these pathways generally increase as soil oxygen concentrations decrease,” says Jen Owens, a recent Ph.D. graduate of Lincoln University in New Zealand and co-author of the new SSSAJ article, “Nitrous Oxide Fluxes and Soil Oxygen Dynamics of Soil Treated with Cow Urine” (as of this writing, its’ in the First Look section of the SSSAJ site but will be available soon at http://dx.doi.org/doi:10.2136/sssaj2016.09.0277).

Despite N₂O being a potent greenhouse gas, there is relatively little data exploring how soil physical properties impact soil oxygen concentration and subsequently influence N₂O emissions. Laboratory work has demonstrated that relative soil gas diffusivity explained N₂O emissions (see Balaine et al. 2013 at http://dx.doi.org/doi:10.2136/sssaj2013.04.0141). Owens explains, “Relative soil gas diffusivity is a physical variable that describes the rate of gas diffusion in soil relative to that of free air. It gives an indication of how easily oxygen moves into and through the soil by telling us how much of the pore space is available for diffusion of gas.” Wanting to determine how well soil moisture, soil oxygen content, and soil gas diffusivity explained N₂O emissions, Owens and colleagues conducted a field study.

The study took place in 2014 in an ungrazed perennial ryegrass pasture at Lincoln University. The experimental site is poorly drained, which Owens points out is an important detail because “soil oxygen concentrations are more prone to decreasing when soil moisture increases in poorly drained soils, which encourages greater rates of N₂O production.” The authors compared soil with a simulated urine patch, using urine collected from cows off site, to soil without urine inputs.

Soil in the simulated urine patches were reported to have daily fluxes of N₂O that were 16 times greater than non-urine soils. In these patches, Owens and colleagues observed an immediate increase in N₂O emissions after urine was applied and also measured greater emissions when flooding occurred. This demonstrated how, in a poorly drained site, urine patches provide a source of nitrogen that is readily converted to N₂O when soil oxygen concentration drops.

The results also support the hypothesis that soil oxygen and soil gas diffusivity would be correlated with N₂O emissions. Relative diffusivity of oxygen decreases as soil water content increases, and fluxes of N₂O increase as relative diffusivity of oxygen decline. “I think a significant outcome of this study is showing that the relationship between N₂O emission and relative gas diffusivity is as good, or better, than the relationship between N₂O emissions and water-filled pore space,” Owens says. Being able to explain the drivers of N₂O emissions in the field will improve the ability of researchers to monitor conditions and the effectiveness of mitigation strategies.

The graph shows the daily average nitrous oxide (N₂O) fluxes and the daily average relative soil gas diffusivity (Dᵢ/Dₒ) from the urine treatment for each day of the experiment. According to the results from Balaine et al. (2013), the Dᵢ/Dₒ value of ~0.006, marked with the red dashed line, is where N₂O emissions are expected to reach a maximum. As shown in the graph, as Dᵢ/Dₒ falls below 0.006, there is an increase in N₂O fluxes, with N₂O fluxes and Dᵢ/Dₒ dynamics mirrored about a Dᵢ/Dₒ value of 0.006.
Timing and Type of Manure Applications

Manure applied to agricultural fields as fertilizer is another source of N$_2$O emissions. Farmers have some control over fertilizer applications, including the timing and type of manure applied. Understanding how these options influence emissions could lead farmers to change their management practices to reduce one source of greenhouse gas.

In the temperate zone, fertilizer applied in the fall sits through the winter and is present during the spring thaw conditions, which favor N$_2$O emissions. However, N$_2$O is not the only pathway for nitrogen loss from agricultural fields. “Perhaps there are these trade-offs between trying to reduce nitrous oxide emissions and potentially ending up increasing nitrate leaching,” says Andrew VanderZaag, a researcher with Agriculture and Agri-Food Canada. Nitrate (NO$_3$) can leach into waterways and cause eutrophication or provide an indirect pathway for N$_2$O emissions.

Farmers may also have access to different types of manure. For example, some farmers apply raw manure while others use digested manure from biodigesters. Manure biodigesters reduce methane emissions and produce energy, having environmental and monetary benefits for farmers. However, digested manure has less carbon and more mineral nitrogen, and it is unclear if this change also alters nitrogen loss.

To determine how timing and type of manure would impact nitrogen loss throughout the year, VanderZaag and colleagues measured N$_2$O emissions and NO$_3$ leaching. The results of this study were published in JEQ in an article titled, “Field Nitrogen Losses Induced by Application Timing of Digestate from Dairy Manure Biogas Production” (http://dx.doi.org/doi:10.2134/jeq2016.04.0148).

The experiment ran from the fall of 2011 through the spring of 2014 in an experimental field where tile drainage is collected from individual plots, providing detailed data on NO$_3$ leaching. Nitrous oxide emissions were measured using soil respiration chambers. By collecting data throughout the year, the authors were able to compare growing and non-growing season patterns and look at how spring thaw events impacted nitrogen loss. They report that N$_2$O emissions were similar for fall and spring applications, but the timing of N$_2$O loss was different. When manure was applied in the fall, peak N$_2$O flux occurred during the spring thaw. When manure was applied in spring, peak N$_2$O flux occurred during tillage and planting. “There might be a tendency to just look at the emissions during the growing season, but as we saw here, emissions could just be shifting from one time of the year to another,” notes VanderZaag, making it important to do year-round monitoring when comparing mitigation strategies.

The data for NO$_3$ leaching provided an explanation for the difference in total N loss. There was greater NO$_3$ leaching from the fall application plots. This was observed over the winter and early spring and was more pronounced in the wet year of the study. When considering management implications of farmer choices, VanderZaag says, “The spring application certainly looks like a better management practice, if at all possible.”

Cover Crops

The use of cover crops to reduce soil erosion and improve soil quality is a growing practice. Research scientist Xiying Hao and postdoctoral researcher Ben Thomas, both with Agriculture and Agri-Food Canada in Lethbridge, Alberta, set out to determine how cover crops might affect N$_2$O emissions. In their article published in the January–February 2017 issue of SSSAJ, titled, “Non-Legume Cover Crops Can Increase Non-Growing Season Nitrous Oxide Emissions,” (http://dx.doi.org/doi:10.2136/sssaj2016.08.0269) they compare N$_2$O emissions of two cover crops.

When considering the impacts of cover crops, the authors point out how winter conditions in this region are
unique. Minimal snow accumulation combined with warm chinook wind events result in a soil surface that is exposed to freeze-thaw cycles throughout the non-growing season. Nitrous oxide emissions can increase during these thaw events, making it important to determine if, and how, cover crops alter emissions during the non-growing season.

The authors conducted a two-year study to quantify how cover crops impact \( \text{N}_2\text{O} \) emissions, soil \( \text{NO}_3^- \), and water-extractable organic carbon (WEOC). Two cover crops, fall rye (fibrous roots, survives the winter) and oilseed radish (large taproot, winter-kills), were used as well as control plots without cover crops. Nitrate was measured given that it is a substrate for denitrification, and WEOC was measured as a proxy for carbon that is available for microbes. Increased levels of soil \( \text{NO}_3^- \) or WEOC associated with cover crops could provide a pathway for increased \( \text{N}_2\text{O} \) emissions.

In general, \( \text{N}_2\text{O} \) emissions corresponded with thawing events in the non-growing season, and winter emissions were greater than spring and fall. The greatest non-growing season \( \text{N}_2\text{O} \) fluctuation recorded was associated with a thaw event where soil surface temps rose by 7.7 °C in 13 days.

In the first year of the study, 2013–2014, there were no significant differences among treatments. In the second year, 2014–2015, there was a significant difference in emissions between the two cover crops. Oilseed radish had greater \( \text{N}_2\text{O} \) emissions compared with fall rye. The authors also report that cover crops had greater \( \text{N}_2\text{O} \) emissions than non-cover crop control plots.

There were also differences in \( \text{NO}_3^- \) and WEOC associated with cover crops. Oilseed radish treatments had greater soil \( \text{NO}_3^- \) than fall rye, and fall rye treatments had greater levels of WEOC than oilseed radish. The interactions among weather conditions, carbon and nitrogen availability, microbial activity, and \( \text{N}_2\text{O} \) production are complex, and the authors state in the paper that “there was an apparent alternating relationship between WEOC limitation and \( \text{NO}_3^- \) limitation controlling the over-winter \( \text{N}_2\text{O} \) fluxes.” Over the course of this study, the availability of \( \text{NO}_3^- \) appeared more limiting on \( \text{N}_2\text{O} \) emissions than WEOC.

Thomas points out that while the cover crop treatments had greater emissions, the N loss was relatively small, and that the benefits of cover crops may outweigh this negative aspect. In this region, the use of cover crops will need to take into account site-specific practices and goals of individual farmers and fields.

Dig Deeper
- Nitrous Oxide Fluxes and Soil Oxygen Dynamics of Soil Treated with Cow Urine: Will be available soon at http://dx.doi.org/doi:10.2136/ssaaj2016.09.0277
- Field Nitrogen Losses Induced by Application Timing of Digestate from Dairy Manure Biogas Production: http://dx.doi.org/doi:10.2134/jeq2016.04.0148
- Non-Legume Cover Crops Can Increase Non-Growing Season Nitrous Oxide Emissions: http://dx.doi.org/doi:10.2136/ssaaj2016.08.0269

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