Nitrous Oxide Emission from Crop Fields

Introduction

Gases that trap heat in the atmosphere are called greenhouse gases (GHGs). According to 2013 estimates from the Environmental Protection Agency (EPA), agriculture generates 9% of the US GHG emissions. The main GHGs of concern for agriculture are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). For comparison purposes, GHGs are characterized by their "global warming potential" (GWP), a measure of how much heat each gas can trap over a 100 year period relative to CO_2. The GWP of CO_2 is set at 1 versus 24 for CH_4 and 298 for N_2O making N_2O a gas of interest for agriculture. Nitrous oxide emission is primarily driven by soil management practices and represents an estimated 44% (GWP basis) of the total agriculture-related GHG emissions. This fact sheet describes factors that influence N_2O emissions from field management practices that can reduce N_2O emissions.

N_2O Pathways / Processes

Managing nitrogen (N) for optimal crop production and minimal environmental impact is a real challenge. Manure or inorganic N fertilizer application, decomposition of crop residues or soil organic matter, N fixation, and N deposition from the air are potential N sources in the soil. Each year, a portion of these N sources convert to plant available N (primarily nitrate) through mineralization and nitrification. Nitrate-N is taken up by plants or soil microbes but it can also be lost from the root zone primarily through leaching or denitrification. Denitrification occurs when soils are saturated (anaerobic, oxygen-poor). Anaerobic microbes convert nitrate to nitrite (NO_2^-), nitric oxide (NO), N_2O, and, finally, to dinitrogen gas (N_2) (Figure 1). In each step, gases can escape to the atmosphere.

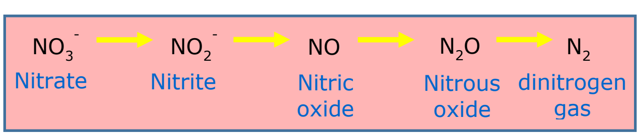

Figure 1. Denitrification, a natural process, is the primary cause of nitrous oxide emissions from crop fields.

Factors Affecting Level of N_2O Emission

The key drivers for denitrification are (1) initial nitrate level when the anaerobic conditions occur, (2) soil moisture, (3) soil temperature, (4) soil organic matter, and (5) soil pH.

Initial Nitrate Level: Nitrous oxide can only be formed if nitrate is present when conditions are favorable for denitrification to occur. Management decisions or weather patterns that result in an excess of soil nitrate during the growing season, or an accumulation of soil nitrate outside of the growing season, increase the risk of N_2O emissions.

Soil Moisture: When soils are saturated with water for 36 hours or more, denitrification can occur. Practices that increase the degree of soil saturation, such as compaction, are likely to increase N_2O emissions, while practices that decrease saturation, such as subsurface drainage, will reduce emissions.

Soil Temperature: Nitrous oxide emissions increase with temperatures above 41°F (reflecting higher microbial activity) up to a soil temperature of 104°F. At temperatures higher than 104°F, microbial activity decreases and emissions are reduced as well.

Soil Organic Matter: Generally, N_2O emissions are higher in soils with elevated organic matter levels, reflecting greater capacity to mineralize N and more available C for microbial activity as soil organic matter increases.

Soil pH: In general, N_2O emissions are lower in acidic soils than in neutral or alkaline soils. This is because microbes involved in the denitrification processes are most abundant and active in soil with a pH between 7 and 8.

Agronomic Management Practices

Source, Time, Rate, Application Method:
Because N_2O emissions are driven by the amount of nitrate present when denitrification conditions occur, manure and fertilizers play an important role in vulnerability to N_2O loss.

Nitrous oxide emissions are lower when N fertilizer is sidedressed rather than broadcast at planting. This is because with sidedressing, fertilizer application is made at the time when plant growth and root systems have developed enough to support rapid nitrate uptake, and because growing conditions tend to be better (reduced risk of saturated soils). In general, for any source, greater N_2O loss can be expected when rates exceed crop needs.

Manure injection and incorporation reduce ammonia loss to the air, increasing the amount of available N per unit of manure applied. This could lead to greater N_2O emission if application rates are not reduced to reflect the higher N value of the injected/incorporated manure. More research is needed to evaluate if injection or subsurface banding of manure enhances N_2O emission over tillage-based incorporation.

Tillage, Crop Residue and Rotation:
Tillage systems (no-till versus conventional) influence both nitrate formation and conditions in which denitrification can occur. Tilling of high N residue (for example a terminated hay stand), followed by saturated conditions, can result in higher N_2O emissions than when the soil is left undisturbed. This is because tillage-incorporation of plant residues with a high N content (low carbon (C) to N ratio) can speed up mineralization of the plant residues and thus increase nitrate levels in the soil beyond what would be seen if the residue was left on the surface.

Perennial legumes such as alfalfa contain more N than perennial grasses. When an alfalfa stand is terminated (rotation to a row crop like corn), the decomposition of the legume residues will generate nitrate in the weeks and months after termination and hence increase the risk of N_2O emissions.

Due to the presence of extensive root systems and rapid N uptake by the roots, soil nitrate levels in alfalfa/grass fields are typically lower than in corn fields. This also means that the risk of N_2O emission is much lower when a field is in hay.

Management to Mitigate N_2O Losses
The most effective way to reduce on-farm N_2O emission is to retain N in ammonium or organic N form when there are no plants that can activity take up nitrate. In addition, it is important to try to manage nitrate during the growing season at levels that do not exceed crop needs. Options are farm specific but some suggested practices include:

- Avoid over-application of inorganic fertilizer or manure and consider precision agriculture technologies such as yield zone mapping and crop sensing to support variable rate application.
- Use overwintering cover crops or double crops to capture end-of-season nitrate.
- Improve drainage to reduce the risk of saturation of soils.
- Apply N as close to crop N uptake through split applications (starter plus sidedressing for corn), or use enhanced efficiency fertilizers.

Concluding Remarks
Nitrous oxide emission can only occur if nitrate is present when conditions favorable for denitrification occur. Practices that retain N in ammonium or organic N form when crops cannot take up the N and/or avoid over-application of N, along with reducing the risk of soil saturation (such as tile drainage) are effective in reducing N_2O emissions from agricultural fields.

Additional Resources
- United State Environmental Protection Agency (EPA). Agricultural sector emissions. Sources of greenhouse gas emissions: www3.epa.gov/climatechange/ghgemissions/sources/agriculture.html
- Climate Change and Agriculture Fact Sheet Series. Michigan State University Extension Bulletin E3152: lter.kbs.msu.edu/wp-content/uploads/2014/12/Nitrogen-fertilizer_climate-fact-sheet_FINAL.pdf

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For more information

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