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RESEARCH REPORT

Managing Nitrous Oxide Emissions in Agricultural Fields

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Agriculture is a major contributor to atmospheric nitrous oxide (N_2O) (Smith et al., 2014; Tian et al., 2015). Unfortunately, nitrous oxide destroys stratospheric ozone (O_3) which protects us from ultraviolet radiation (Cicerone, 1989) and it increases ground level O_3, which is an air pollutant threatening human health and food production. Nitrous oxide is also 298 times more potent than an equivalent amount of carbon dioxide (CO_2) in terms of trapping and absorbing reflected solar radiation (Forster et al., 2007). Basic chemistry and physics assure us that increased levels of N_2O in the atmosphere are not good.

N_2O and Atmospheric O_3 Destruction

$$N_2O \xrightarrow{hv} N_2 + {*O}$$
$$N_2O + {*O} \rightarrow 2NO$$
$$NO + O_3 \rightarrow NO_2 + O_2$$

'hv' = ultraviolet radiation and *O represents reactive oxygen.

Nitrous oxide contributions to global warming or increased skin cancer rates are long-term concerns. An immediate issue for agriculture is that every pound of nitrous oxide going into the atmosphere contains more than six-tenths of a pound of nitrogen (N) that isn't going into plants. That's potential nitrogen fertilizer expense coming straight out of someone's wallet.

What can you do? There aren't many ways of working with nitrogen in agriculture that won't produce some nitrous oxide. This article will introduce a few ideas about what nitrous oxide is, where it comes from, and how best management practices affect its production; possibly keeping more nitrogen in the soil or making sure its loss is least harmful.

What is nitrous oxide? It's also called 'laughing gas,' the same gas a dentist or surgeon uses to make procedures pain-free. Nitrous oxide contains two nitrogen molecules linked to a molecule of oxygen. It's very soluble in water (6 parts N_2O dissolve in 10 parts water at room temperature) (Tiedje, 1994) and there are normally about 330 parts per billion nitrous oxide in the atmosphere. Nitrous oxide can persist there for over 100 years before being decomposed. So it has long term effects if it's released.

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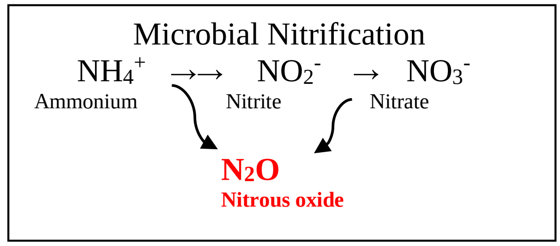
Microbial Denitrification

NO_3^- (Nitrate) → NO_2^- (Nitrite) → NO (Nitric Oxide) → **N_2O** (Nitrous Oxide) → N_2 (Dinitrogen)



Where does nitrous oxide come from? In addition to combustion by power plants, cars, and farm equipment (about 26% of global sources), nitrous oxide is naturally produced in fires (4.5%), forests (49-51%), grasslands (1%), and croplands (5%). The natural sources have biological and non biological parts. 1) Nitrous oxide is one of the gas products of **denitrification**, a process in which microscopic bacteria and fungi convert nitrate (NO_3^-) step-wise to dinitrogen gas (N_2) in wet conditions. 2) Nitrous oxide is one of the by-products of **nitrification**, in which bacteria and fungi convert ammonium (NH_4^+) step-wise into nitrate (NO_3^-) in aerated conditions. 3) Nitrous oxide is one of the products of **chemodenitrification**, a non biological process, in which nitrate or nitrite react with metals like iron (Fe) or manganese (Mn) in soil – usually acidic soil.

None of these processes forming nitrous oxide are completely avoidable (at least not for long). But they can be managed to minimize nitrous oxide loss. Here are four common agricultural management practices that affect nitrous oxide release:

1. Fertility management
2. pH management
3. Soil organic matter (SOM) management
4. Cover crop management

Fertility. Practicing the four R's of fertility (right rate, right time, right location, right formulation) is not only good management, but it can reduce nitrous oxide production (find out more at http://www.nutrientstewardship.com/4rs/).

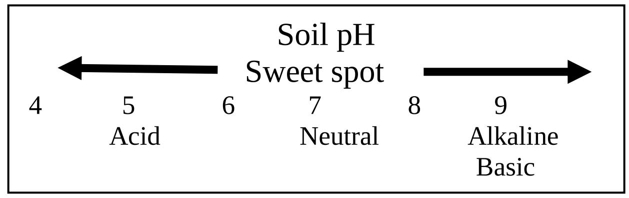
Applying more nitrogen than a crop needs does more than waste money. The surplus nitrogen left in soil can produce nitrous oxide biologically (through nitrification and denitrification) and abiologically (chemodenitrification). Nitrous oxide losses often increase at higher fertilizer rates.

Denitrification rates are highest after rain or irrigation, especially in saturated soils. Timing N fertilization to avoid typically wet seasons conserves nitrogen because it decreases the potential for denitrification. Fertilization timed when there are actively growing plants (e.g. cover crops) to compete with soil microbes for nitrogen also helps decrease nitrous oxide loss. Sidedressing or topdressing N fertilizer 3 to 4 weeks after planting a crop is a strategy that may reduce N loss by avoiding typically wet spring weather and placing the N in soil just before most crop plants enter a rapid growth phase.

The right location for fertilizer nitrogen is where plant roots can best compete for it against microbes. Plants compete with soil microbes for soil nitrogen, whether that nitrogen is nitrate or ammonium. Banding or sidedressing N fertilizer near the crop row can improve N utilization efficiency by the crop and reduce N losses.Such pratices can reduce N needs by 20 to 30% compared to pre-plant broadcast applications, especially on poorly drained soils.

Nitrate can leach and denitrify quickly. There are no useful commercial inhibitors of denitrification. Ammonium can be nitrified quickly, but it can also be formulated in slow release forms and forms with nitrification or urease inhibitors (like nitrapyrin or NBPT) that can reduce the amount of nitrate-nitrogen entering the soil at any given time. These inhibitors have a positive effect on reducing nitrous oxide loss (Liu et al., 2006).

Liming. Maintaining soil pH at the optimum range by adding lime might actually help plants use N more efficiently, result in less N being added, and reduce nitrous oxide loss. Most crop plants thrive in neutral to slightly acid soils, but most soils in Kentucky are more acid (have a lower pH) than recommended for maximum yield. Liming raises the pH so plants compete better for soil N. Liming also affects nitrous oxide emissions in four ways: 1) Fungi that denitrify produce mostly nitrous oxide, but most fungi don't do well in neutral or alkaline soils. 2) When bacteria denitrify they produce more nitrous oxide as a fraction of gas lost in acid soils. You may still lose nitrogen as a gas from neutral soils, but you tend to lose more of it as dinitrogen gas (N_2), which is harmless to the environment. The downside is that liming a soil can increase overall denitrification rates and the potential for nitrous oxide production – which means better management for denitrification losses is needed. 3) Chemodenitrification rates are typically higher in acid conditions. 4) Neutral to basic pH is optimal for nitrification and if the nitrifying bacteria grow optimally they produce less nitrous oxide as a byproduct.



Soil Organic Matter (SOM). One of the single most important attributes of any sustainable, fertile soil (after water) is the amount of soil organic matter and the depth in soil to which it is found. Organic-poor soils produce more nitrous oxide than organic-rich soils if the same amount of nitrogen is added. Why? When soil bacteria and fungi denitrify, they consume carbon (C) from the soil organic matter to provide them with energy. The more carbon that is readily available, the farther along the denitrification pathway they proceed. With enough SOM the final product will be mostly harmless dinitrogen gas (N_2) rather than harmful nitrous oxide. However, that mostly applies to soils that have > 90% water filled pores (wet soils). In drier soils, crop residues with a low C:N ratio (legime residue, for example) can stimulate nitrous oxide production, probably because the residue breaks down quicker and puts more N into the soil environment (Chen et al., 2013).

The benefits of adding organic matter for soil physical properties and biological activity almost certainly outweigh the potential detriment of increased nitrous oxide production. But what about trying to maintain greater amounts of SOM by no-tillage or reduced tillage? Results are mixed. There are reports that no-tillage both increases (Liu et al., 2006) and decreases (Elmi et al., 2009; Deng et al., 2015) nitrous oxide emissions relative to plow tillage. This means that with respect to tillage, the soil type, field location, management, and sampling season all influence how much nitrous oxide a soil produces (Kessel et al., 2013). Future research needs to examine this question.

Live Roots: Keep live roots around at all times. Actively growing cover crops are great for this. In addition to reducing soil erosion, live roots:

1. Compete with soil microbes for ammonium and nitrate.
2. Keep the soil drier because of transpiration, and drier soils produce less nitrous oxide than wetter soils (Chen et al., 2013).
3. Pump carbon into the soil. Soil microbes can use that carbon to transform nitrate all the way to dinitrogen gas. Even if the plant roots are dead and decaying, the carbon they add into the soil will still help to turn residual nitrate into dinitrogen rather than nitrous oxide, or help trap the nitrogen in SOM.

How do we make progress managing nitrous oxide emmisions from agriculture?

Managing nitrous oxide is a local and regional problem. We need systematic and methodical research to know which management practices are best in agriculture locally and how to apply them. Regionally, we have to greatly improve our understanding of how spatial variability of vegetation and soil characteristics in agricultural landscapes affect nitrous oxide loss. We have to quantitatively investigate the consequences of historic and current management practices and explore the consequences of new or innovative agricultural management practices. We need to better understand the potential impacts of dynamic changes in multiple, interacting environmental factors (such as population growth, climate variablity/change, land use change), which, together with agricultural management practices, can influence nitrous oxide loss.

Accomplishing these goals is a team approach. It requires developing interdisciplinary research including soil and crop sciences, agrometerology, agronomy, atmospheric science, engineering, land use science, etc. and multidisciplinary research groups made of field scientists, climate and land system modelers, computer scientists, and engineering scientists, etc. - the expertise you expect from a land grant university.

Having identified current best managment practices in agriculture, we need to apply them effectively and practically through collaboration with cooperative extension. Communication between researchers, producers, and local policy makers is central to effective best agricultural management practices. Good science is unbiased, and good communication of the science lets policy-makers understand the research to make policies accordingly, while enabling producers to make informed management decisions.

There are no permanent best management solutions. We need to constantly examine the interactions and feedbacks between the land, atmosphere, and management. We need to periodically assess key indicators (crop production, nitrous oxide emission, SOM, etc.) that are influenced by current ‘prescribed’ best management practices. We may need to regularly amend the best management practices for a rapidly changing environment, particularly at regional and local scales.

Agriculture affects nitrous oxide loss from soil in positive and negative ways. Best management practices for fertility, liming, soil amendments, tillage, and plants can help gain the most mileage out of soil N, while minimizing nitrous oxide loss. Better nitrogen use efficiency and making a positive global difference at the same time. That’s not a bad tradeoff.

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