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Nitrogen Fertilizer Management & Greenhouse Gas Mitigation Opportunities

Information Sheet #5

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Information Sheet #5 – OVERVIEW

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FAST FACTS

- **Impacts**: Nitrogen fertilizer is critical for crop production but applying too much at importune time reduces profitability and increases water pollution, air pollution, and greenhouse gas (GHG) emissions.
- **An imperative to act:** A fraction of the nitrogen in fertilizer or manure is lost from soils in the form of nitrous oxide gas, a much more potent greenhouse gas than carbon dioxide.
- **A concern for implementation:** Farmers often apply extra nitrogen as 'insurance' to ensure highest yield, but this practice reduces profits and causes unnecessary water pollution and GHG emissions.
- **An opportunity for proactive change:** Applying nitrogen fertilizer using the right source, right rate, right time, and right place increases crop yield and profitability. These management practices can also greatly reduce greenhouse gas emissions while improving profitability.

The three most important agricultural greenhouse gases (GHGs) are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (see Information Sheet #1). Nitrous oxide is 298 times more potent than carbon dioxide and is a very important GHG emitted from field crops. For example, 61% of GHG emissions from corn production are from N_2O and production of nitrogen (N) fertilizer (Wightman and Woodbury 2015). Nitrous oxide is a gas produced naturally by soil microbes. Much more N_2O is produced when there is abundant nitrogen in the soil, such as after application of manure or synthetic nitrogen fertilizer. Improving nitrogen fertilizer management is one of the most effective GHG reduction strategies that farmers can adopt (Snyder et al. 2009). This information sheet explains how good management of nitrogen fertilizers can reduce N_2O emissions from crops.

ENVIRONMENTAL CONCERNS

Society expects agriculture to produce food in a manner that maintains environmental quality. Manure and nitrogen fertilizer management is very important for soil, water, and air quality. Agricultural practices affect nutrient cycling. For example, some practices can cause nutrient leaching to nearby streams and groundwater, and volatilization to the atmosphere. For more information about such impacts other than GHG emissions, see AEM Information Sheet on Nutrient Management.

SUMMARY OF REGULATION OF GHG EMISSIONS

While there are regulations on GHG emissions from the electric sector, there are no regulations of GHG emissions from agriculture. However, for confined animal feeding operations (CAFOs), there are regulations about nutrient management (see Information Sheet #1, Information Sheet #2, and AEM Information Sheet on Nutrient Management).

GOAL

This Information Sheet is intended to help educators and technicians assist farms in navigating voluntary methods for reducing GHG emissions from nitrogen fertilizer management.

SUMMARY OF POTENTIAL GHG MITIGATION PRACTICES

Description of BMP	**Opportunities**	**Considerations**
Develop a comprehensive nutrient management plan (CNMP).	A **comprehensive nutrient management plan** (CNMP) can help prevent erosion, water contamination, air contamination, and GHG emissions.	It can be challenging to account for nutrients from prior application of manure, residues, compost, cover crops, and crop rotations and any other soil amendment. The CNMP must also be kept up to date with changes in livestock numbers, cropping systems, and management practices, including manure management and livestock feed.
Optimize N fertilizer source.	Using the appropriate chemical form and formulation increases crop N use efficiency and reduces losses.	Cost, availability, and logistics limit practical choices of fertilizer source. Coatings or inhibitors are expensive and not always effective.
Optimize N fertilizer placement.	Incorporating fertilizer into soil can reduce losses due to volatilization, particularly of ammonia.	Placing fertilizer at depth or in bands can in some cases increase N_2O losses, particularly if timing, source, and rate are not optimal.
Optimize N fertilizer timing.	Applying most N fertilizer as a side-dressing reduces N_2O and increases yield.	Fertilizer requirements vary among years but use of an adaptive in-season N rate helps manage this variability.
Optimize N fertilizer rate.	Using appropriate source, placement, and timing reduces the total rate, reducing N losses including N_2O.	Fertilizer requirements vary among years, but use of an adaptive in-season N rate and timing can help manage this variability.
Reduce use of synthetic N fertilizer.	Creating synthetic nitrogen fertilizer requires lots of energy and emits GHGs, so reducing its use reduces GHG emissions upstream of your farm.	Synthetic N fertilizer is valuable and useful as part of a comprehensive nutrient plan.
Use appropriate crop rotations.	Crop rotations can increase yields and profitability, and if legumes are included, reduce N fertilizer requirements.	Farm management and marketing may limit the choices of profitable and appropriate crop rotations.
Use a winter cover crop for annual crops.	Cover crops reduce nitrate in soil and reduce erosion, N leaching, and N_2O emission, but must account for N availability from cover crop for subsequent crop.	Cost and logistics may be challenging for both planting and plow-down of cover crops.

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Information Sheet #5 – IN DEPTH

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Target Audience: Educators and technicians helping farmers manage nitrogen fertilizer
Target Greenhouse Gases (GHG): Nitrous oxide (N_2O)
Background Questions By Educator To Help In Farmer Planning

- Do you keep records of nutrient applications to fields?
- Do you use manure? If yes:
  - How many animal units do you have?
  - How is manure stored? (see Information Sheet #2)
  - How is nitrogen application rate determined?
  - How often do you test for nutrient content?
- What crops do you grow, in what rotations?
- What is the timing of synthetic and manure N application?
  - Are you experiencing any issues with your management practice?
- What are your near and long term nutrient management goals?
- Are you interested in exploring GHG mitigation options?
- Do you have a comprehensive nutrient management plan?

BACKGROUND: The Nitrogen Cycle in Crop Fields

Nitrous oxide, a GHG, is produced as part of the nitrogen cycle in soils. Nitrogen occurs in several chemical forms in the soil. The form most readily taken up by crops is nitrate (NO_3^-). However, nitrate also moves easily with water, so during heavy rainfall and highly saturated soils, nitrate can be leached, creating the potential for pollution of ground water and surface water. Nitrate can also be lost by **denitrification,** producing several gases that can be emitted from soil. Coarse-textured soils lose nitrogen mostly by leaching while fine-textured soils lose nitrogen mostly by denitrification and volatilization to the atmosphere (Figure 1).

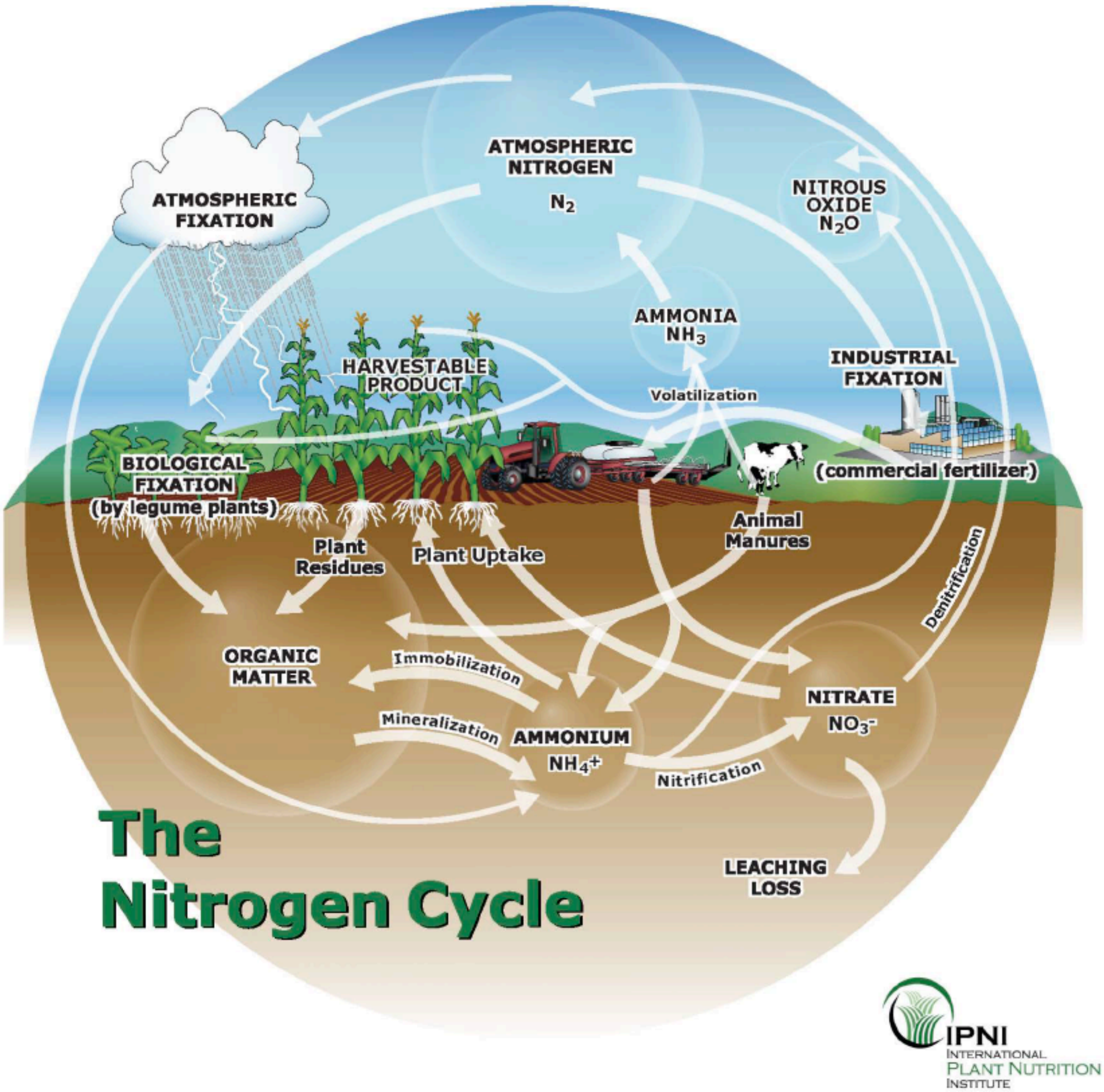

Figure 1. Movement and transformation of agricultural nitrogen. Used by permission: IPNI – international Plant Nutrition Institute, http://www.ipni.net/article/IPNI-3326

The goal of crop nitrogen management is to provide adequate nutrition to the crop while minimizing losses to the environment that can cause water pollution, air pollution, and climate change. Nitrogen use efficiency is defined as ratio of the amount of fertilizer N removed from the field in the harvested crop versus the amount of fertilizer N applied. Improving nitrogen use efficiency reduces the amount of pollution caused for the amount of crop produced. Improving the 4 Rs of fertilizer management (right source, rate, time, and place) results in increased crop nitrogen use efficiency as well as decreased potential for water pollution, air pollution, and GHG emissions. Additionally, less synthetic fertilizer N is purchased which reduces costs and increases profits, and also reduces the substantial GHG emissions at the fertilizer factory.

OPPORTUNITIES for reducing GHG emissions from fertilizer and manure

1) Use the 4 Rs of fertilizer management to reduce N_2O emissions.
2) Reduce the use of synthetic nitrogen fertilizer to reduce GHG emissions.
3) Use appropriate manure management practices to reduce GHG emissions.
4) Use appropriate crop rotations to reduce N_2O emissions.
5) Use cover crops to reduce N_2O emissions.
6) Develop and use a comprehensive nutrient management plan.

MITIGATION OPPORTUNITY 1: Use the 4 Rs of fertilizer management

Applying nitrogen fertilizer from the Right source at the Right rate, Right time, and Right place increases crop yield and profitability, while also greatly reducing GHG emissions (Snyder et al. 2009). These 4 Rs should be used all together in a comprehensive plan appropriate for the cropping system, and accounting for all sources of nitrogen input to crop fields.

Optimize N fertilizer source: Using the appropriate chemical form and formulation can help increase crop N use efficiency and reduce losses to the environment that can cause water, air, and soil pollution as well as GHG emissions. In particular, replacing anhydrous ammonia with other nitrogen formulations can reduce emissions substantially (Eagle & Olander 2012). In some situations, fertilizers with coatings or inhibitors to delay availability are useful, but they are expensive and the results have been inconsistent in moist climate zones such as the Northeast USA.

Optimize N fertilizer placement: Incorporating fertilizer into soil reduces losses due to volatilization, particularly of ammonia. This is important both for ammonia-containing fertilizers and for manure, which also contains ammonia, because ammonia is very volatile and large amounts can be lost in a short time. However, placing fertilizer at depth or in bands can in some cases increase N_2O losses, particularly if timing, source, and rate are not optimal, so care should be taken to optimize these other factors (Maharjan & Venterea 2013).

Optimize N fertilizer timing: Best management practices for nitrogen fertilizer application do not include applying fertilizer in the fall for a spring crop, because most of the nitrogen can be lost during winter and early spring due to rainfall and leaching through the soil profile and loss of gases including N_2O. Instead, nitrogen fertilizer should be applied as close to the time of maximum growth of the crop as possible. For crops such as corn, applying appropriate starter N at planting and side-dressing the remainder of the season reduces N losses including N_2O while improving yield and improving profitability, as has been demonstrated using the Adapt-N tool on corn trials on farmer's fields in New York (Sela et al. 2016).

Optimize N fertilizer rate: Using appropriate source, placement, and timing can all help to reduce the total rate applied, while assuring that more of the N is available as needed for uptake by the crop. After these other factors have been addressed, it is also important only to apply the minimum required N rate to obtain a good crop yield. This is important, because many farmers apply extra nitrogen as 'insurance' to ensure that the highest possible yield can be obtained, but this practice reduces profits and causes unnecessary water pollution and GHG emissions. Fertilizer requirements vary among years due to weather and management. Use of an adaptive in-season N rate and timing can help manage this variability, as has been demonstrated using the Adapt-N tool for corn on trials on farmer's fields in New York (Sela et al. 2016). Using this tool, field trials for corn demonstrated that N rate could be reduced an average of 48 lb/ac while maintaining yields and increasing profits (Sela et al. 2016).

In addition to rate reductions discussed above, it is critically important to properly account for all sources of nitrogen, including all fertilizers, manure, crop residues, cover crops, and any other source of nitrogen applied to crop fields. Farmers commonly do not adequately account for these other sources of nitrogen, and therefore over-apply synthetic nitrogen fertilizer.

MITIGATION OPPORTUNITY 2: Reduce the use of synthetic nitrogen fertilizer

Creating synthetic nitrogen fertilizer requires a lot of energy and emits a lot of fossil fuel based GHGs, so reducing its use reduces GHG emissions upstream of your farm in addition to reducing emissions from the crop field as discussed above. Use of synthetic nitrogen fertilizer can be reduced as discussed above by optimizing the 4 Rs of fertilizer use, using other available sources of nitrogen such as manure, crop residues, and cover crops, and developing and using a comprehensive nutrient management plan as discussed below.

MITIGATION OPPORTUNITY 3: Use appropriate manure management

Manure should be managed as part of a comprehensive nutrient management plan (see section below), to assure that it is used appropriately. Manure should be managed for the 4 Rs as discussed above, including rapid incorporation into the soil to avoid loss of ammonia, and rates of manure should not exceed the nutrient requirements of the crop. Manure should be tested for nitrogen content as well as other nutrients such as phosphorus so that an appropriate application rate can be selected to meet crop needs, and reduce the amount of N_2O emission from crop fields.

In addition to N_2O emission from crop fields, there can also be substantial emissions of methane and some emission of N_2O from manure storage and handling. For more information on managing manure storage, see Information Sheet #2.

MITIGATION OPPORTUNITY 4: Use appropriate crop rotations

Using appropriate rotations can increase yields and profitability, and if N-fixing legumes are included, reduce N fertilizer requirements. For example, soybean and alfalfa can provide considerable nitrogen to a following corn crop, and yields of corn in rotation with legumes are generally higher than continuous corn. As discussed above (see 4 Rs), appropriate “N credit” should be given to prior crops, and residues should be managed to provide nitrogen to the following crop as close as possible to the time of maximum crop growth. Of course, the farming system, cropping system, management of livestock and their feed needs as well as markets will limit the choices of profitable and appropriate crop rotations.

MITIGATION OPPORTUNITY 5: Use cover crops

Using cover crops such as annual rye when crops are not growing reduces nitrate in soil, reduces erosion, N leaching, and can reduce N_2O emission with proper management. Cover crops can also add carbon to the soil, especially with reduced tillage or no-till (see Information Sheet #6). In terms of management, it is important to manage the cover crop in spring to assure timely planting of the main crop. Furthermore, it is important to account for the nitrogen available from the cover crop for the main crop, especially for leguminous cover crops. While cover crops are beneficial, they require time and money to manage, and if managed poorly, can interfere with management of the main crop.

MITIGATION OPPORTUNITY 6: Develop and use a comprehensive nutrient management plan

A comprehensive nutrient management plan (CNMP) can help prevent erosion, water contamination, air contamination, and GHG emissions. On livestock farms, it can also assure appropriate management and use of manure to supply nutrients to crops without exceeding crop needs. It can be challenging to properly account for nutrients from practices related to manure, residues, compost, cover crops, and crop rotations and any other soil amendment. However, N-accounting is important because farmers often do not adequately credit the nitrogen benefits from practices and therefore apply excessive nitrogen fertilizer that reduces profits and supplies excess nitrogen that can cause water pollution or GHG emissions.

Another challenge is that the CNMP must be kept up to date with changes in the farm such as livestock numbers, cropping systems, and management practices, including manure management and livestock feed production and use. CNMPs are required for livestock farms above a certain size, but are recommended as a best management practice for all farms.

PROFITABLE OPPORTUNITIES TO REDUCE N_2O by field management

Opportunity #1: Applying manure or synthetic nitrogen fertilizer using the right source, rate, time, and place (the 4 Rs) increases crop yield and profitability. These same management practices can also reduce N_2O emission, reducing a very important source of GHG from agriculture while saving money.

Opportunity #2: Using appropriate crop rotations can increase yields and decrease GHG emissions.

Opportunity #3: Recommended crop management practices such as crop rotations, cover crops, and appropriate use of manure and organic residues and compost can contribute carbon and nitrogen to the soil. Using these practices and accounting for their contribution to crop nitrogen needs can further reduce the need for synthetic nitrogen fertilizers, reduce N_2O emissions, and increase profitability. In some cases, payments may be available to help pay for implementation.

RESOURCES AND TOOLS

- For assessment of the potential for various agricultural management practices to reduce GHG emissions from US agriculture see Eagle and Olander (2012).
- To learn more about appropriate management of nutrients on New York State Farms, including fertilizer, manure, and CNMPs, see the Nutrient Management Spear Program (http://nmsp.cals.cornell.edu/)
- To learn more about the Adapt-N tool for nitrogen fertilizer management on corn fields see Sela et al. (2016) and the commercial Adapt-N web site (http://www.adapt-n.com/).

To learn more about opportunities to reduce GHG emissions, see other information sheets in this series:

Tier II Worksheets	Identifying Farm & Forest GHG Opportunities

Information Sheet	**Topic**
IS#1	Intro to Farm & Forest GHG
IS#2	Dairy Manure Storage
IS#3	Planning for Quantitative Methane Capture and Destruction from Liquid Dairy Manure Storage
IS#4	Energy Efficiency
IS#5	Nitrogen Fertilizer Management
IS#6	Soil Carbon Management
IS#7	Forest Management
AEM Technical Tools	Water Quality BMPs http://www.nys-soilandwater.org/aem/techtools.html

VOCABULARY

Anhydrous Ammonia: A widely used but highly explosive form of nitrogen fertilizer composed of one part nitrogen and three parts hydrogen (NH_3) where anhydrous refers to 'without water'.

Comprehensive Nutrient Management Plans (CNMPs): Conservation plans unique to livestock operations. These plans document practices and strategies adopted by livestock operations to address natural resource concerns related to soil erosion, livestock manure and disposal of organic by-products.

Denitrification: The loss or removal of nitrogen or nitrogen compounds; specifically, reduction of nitrates or nitrites commonly by bacteria in soil that usually results in the volatilization of nitrogen gases into the air.

Greenhouse Gas (GHG): Any gas that causes atmospheric warming by absorbing infrared radiation in the atmosphere (common greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs), ozone (O_3), perfluorinated carbons (PFCs) and hydrofluorocarbons (HFCs).

Nitrogen (N): an element essential to plant and animal growth. Nitrogen is found in many forms on the farm, including nitrate, ammonia, nitrous oxide (N_2O), and other N-species.

Nitrous oxide (N_2O): A potent greenhouse gas that has a global warming potential (GWP) of 298 on 100-year time scale (meaning that it is 298 times more potent than CO_2 as a GHG). It is produced in when N is present in wet agricultural fields or more aerobic manure storage systems (and inhibited in anaerobic conditions).

Mitigation: In general terms mitigation refers to the elimination or reduction of the severity of exposure to risks, or minimization of the potential impact of a threat or risk. Mitigation in the context of Climate Change refers to efforts that reduce the amount of greenhouse gases (GHG) in the atmosphere by reducing emissions (e.g. Increased energy efficiency, See IS#4), minimizing GHG potency (e.g. flare methane to reduce its GWP, See IS#2), or sequestering GHG (e.g. photosynthetic capture and storage of atmospheric CO2 in long-lived wood products, See IS#7).

Weather versus Climate: Weather describes atmospheric conditions for a specific place and time (often short-term, like a day), while climate is the average of those weather conditions over long periods of time.

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