Soils & Greenhouse Gas (GHG) Mitigation

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Understanding greenhouse gas benefits of soil health practices in New York State

In-depth summary of opportunities for New York farmers to reduce GHG emissions while improving soil health

WHY SOIL HEALTH IS IMPORTANT

Improving soil health has many agricultural and environmental benefits, including improved yields, increased resistance to drought and flooding, improved water quality, and reduced ***greenhouse gas (GHG)*** emission to the atmosphere (Wolfe et al. 2019, Paustian et al. 2016).

TWO SOIL HEALTH PATHWAYS THAT ADDRESS CLIMATE CHANGE

This fact sheet covers two critical pathways that improve soil health, increase profitability and reduce greenhouse gas emissions.

1. **GHG OFFENSE: Soil carbon management**
   Increasing the amount of carbon (C) stored in soils (soil carbon, very closely related to soil organic matter) is beneficial for soil health for many reasons, including improved water infiltration, improved water retention, reduced erosion, improved tilth, and improved biological activity.
2. **GHG DEFENSE: Nitrogen management**
   Nitrogen (N) fertilizer is critical for crop production but applying too much at the wrong time can reduce profitability and increase water pollution, air pollution, and GHG emissions.

This Information Sheet focuses on how farms can reduce GHG emissions using soil health best management practices (BMPs).

CONTEXT FOR MANAGING SOIL HEALTH FOR GHG EMISSIONS

Reducing GHG emissions is important to reducing the extent and impacts of climate change. Improving soil C and N management provides cost-effective GHG mitigation opportunities.

The three most important agricultural GHGs are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). All three are released through soil processes. These different GHGs have different potencies (called global warming potential, **GWP**) to cause climate change.

Different greenhouse gases have different Global Warming Potentials (GWP) – Two factors contribute to the global warming potential: (1) the strength of a greenhouse gas, and (2) its lifetime in the atmosphere. These GWP values are calculated for either 20 years or 100 years, representing the average GWP value over those time periods. The unit of GWP is a ***"carbon dioxide equivalent" or CO_2e,*** because the other gases are compared to CO_2. Therefore, over 100 years, the GWP of CO_2 is 1. Methane over 100 years has a GWP value of 34 because it is 34 times more potent than CO_2. Nitrous oxide over 100 years has a GWP value of 298. To convert tons of methane to CO_2e, multiply by 34. To convert tons nitrous oxide to CO_2e multiply by 298. In summary, CH_4 and N_2O are far more potent than CO_2 as greenhouse gases.

Global Warming Potential (GWP) of GHG relevant to agriculture

GHG	**GWP** (20 year time scale)	**GWP** (100 year time scale)	**Source**
Carbon Dioxide (CO_2)	1	1	IPCC. AR5. 2014
Methane (CH_4)	86	34	IPCC. AR5. 2014
Nitrous Oxide (N_2O)	268	298	IPCC. AR5. 2014

Microbes in wet soils (such as Muck soils) can create CH_4; however most soils in NYS are well drained and generally do not release CH4 so we are not considering soil methane emissions here. However, given the potency of nitrous oxide as a greenhouse gas, small amounts of nitrous oxide add up quickly from fields. For example, 61% of GHG emissions from corn production are from N_2O field emission combined with emissions from the energy intensive production of synthetic N fertilizer (Wightman et al. 2015). Like CH_4 and CO_2, N_2O is a gas produced naturally by soil microbes. Much more N_2O is produced when there is abundant N in the soil, such as after application of manure or synthetic N fertilizer.

The two most effective strategies for reducing GHG from soil processes are listed below. The remainder of this Information sheet will detail how Best Management Practices (BMPs) can reduce GHG emissions.

(1) Improving N fertilizer management is one of the most effective GHG reduction strategies that farmers can adopt (Woodbury 2018, Sela et al. 2018). This information sheet explains how good management of N fertilizers can reduce N_2O emissions from crops.
(2) As plants grow, they remove CO_2 from the atmosphere and store it as carbon in the shoots, roots, and soil. As dead plant material is eaten by soil organisms, most of the carbon is released back to the atmosphere as CO_2. Soil carbon can be increased by (1) increasing carbon inputs to soil, (2) reducing the rate of soil carbon emission to the atmosphere.

GOAL

This Information Sheet is intended to help technicians and educators work with landowners to help them better understand and navigate methods for reducing GHG emissions from soil through soil carbon and N management. Remember, these are living and breathing systems and these practices are selected for their likelihood of mitigating emissions while also addressing other social or economic considerations.

OFFENSE: SUMMARY OF POTENTIAL CO_2 MITIGATION PRACTICES

Strategy	Opportunities	Challenges
Reduce tillage.	Increases soil carbon and soil health when practiced over many years.	Soil carbon can be lost quickly if tillage is later increased making it difficult to qualify as 'permanent' mitigation of GHG.
Add crop residues.	Increases soil carbon, especially combined with reduced tillage. Improves soil health, including tilth.	Excess residues on the soil surface can keep soil too cool and wet in spring, and can interfere with planting or early crop growth.
Add manure, compost, or biochar.	Increases soil carbon, especially combined with reduced tillage. Improves soil health, including tilth.	Transporting these materials from off the farm can be difficult and costly. Biochar (via pyrolysis) may offer significant potential, but public-private demonstration projects need to be implemented to determine feasibility and value on a large scale.
Add cover crops or double crops.	Having crops cover the soil and build additional root systems for more of the year increases soil health and soil carbon.	Cover crops require time and money to manage. Double crops increase total yield, but may reduce yields of the primary crop.
Convert land from annual to perennial crops.	Perennial crops, pasture, and tree root systems sequester soil carbon, use nutrients more efficiently, reduce erosion, and reduce GHG emissions.	It may be difficult to find appropriate on-farm use or markets for some perennial crops.

DEFENSE: SUMMARY OF POTENTIAL N_2O MITIGATION PRACTICES

Strategy	Opportunities	Challenges
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, crop rotations and other soil amendment. The CNMP must be kept up to date with changes in livestock numbers, cropping systems, management practices (e.g. manure management & 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 urea and anhydrous 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 time.	Applying most N fertilizer as side-dress reduces N_2O and increases yield.	Fertilizer requirements vary yearly; use of an adaptive in-season N rate helps manage variability.
Optimize N fertilizer rate.	Using appropriate source, placement, and timing, and rate, all reduce the total rate, reducing N losses including N_2O.	Fertilizer requirements vary yearly; use of an adaptive in-season N rate and timing can help manage this variability.
Reduce use of synthetic N fertilizer.	Synthetic N production requires lots of energy and emits GHGs; reducing its use reduces upstream GHG emissions.	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, 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 termination of cover crops, including interactions with tillage practices.

OFFENSE AND DEFENSE – TWO MAJOR PATHWAYS FOR SOILS TO ASSIST CLIMATE.

The following pages describe a range of opportunities for farmers to reduce GHG emissions. We have divided them into two general pathways: carbon sequestration (offense) and nitrous oxide reductions (defense). To note, these processes interact and holistic thinking about a particular farm site, system, and current practices will inform next steps to advance GHG mitigation.

OFFENSE – Improving soil Carbon

Adequate soil organic carbon is important for soil health (the capacity of a soil to function), and has a direct impact on crop production and an indirect impact on water quality. Unhealthy soils with less soil carbon are more likely to erode and have a higher potential for runoff during storm events. Soil erosion can carry sediments, nutrients and pesticides to surface water bodies degrading water quality. Healthy soils are able to absorb and supply water, retain nutrients, suppress pests and weeds, and produce high crop yields.

Soil carbon (closely related to soil organic matter) is beneficial for soil health for many reasons.

- Improved water infiltration reducing flooding/swamping (co-benefit).
- Improved water retention (adaptation to climate change).
- Reduced erosion (co-benefit).
- Improved tilth (co-benefit).
- Improved biological activity (co-benefit).
- Improved crop health and yield (profitability).
- Improved resistance to drought and flooding (adaptation to climate change).
- Improved water quality.
- Reduced CO_2 in the atmosphere (reducing emissions that contribute to climate change)

There is significant opportunity to store carbon in soil for many years or decades especially with perennial vegetation such as forests and permanent hay or pastureland. However, soil carbon can be lost quickly with tillage and GHG mitigation benefits are quickly lost if a long-term sod is plowed or disturbed. It takes decades to build up (sequester) soil carbon but only up to a few years to lose it due to tillage (Woodbury et al. 2007).

The highest potential for carbon sequestration on agricultural land comes from planting trees on non-forest lands (afforestation), because carbon accumulates both in the soil and even more in the trees (Fahey et al. 2010). However, substantial increases in soil carbon also occur when annual cropland is converted to perennial crops or permanent pasture. Below we discuss this and other practical approaches including adding crop resides, manure, or compost, and reducing tillage.

In sum, improved soil health increases yield and profitability, reduces erosion and water contamination, and sequesters carbon thus assisting in mitigating climate change.

CHALLENGES: C:N RELATIONSHIPS IN SOIL

Because N_2O is 298 times more potent than CO_2, managing soil N is important in reducing GHG emissions from a field. No-till and cover cropping systems, especially those that fix N, increase soil N, and can in some cases increase N_2O, especially between crops (after cover crops or crops have been killed but before the next crop is actively growing). In such situations, these systems may not mitigate GHG emissions, but may still be beneficial to farm productivity and soil carbon. Simply put, the N emissions from soil can sometimes negate the benefits of carbon sequestration for total GHG emissions. However, the other carbon benefits that increase yield and reduce erosion are valuable and important factors for farm sustainability.

DEFENSE– Reducing N emissions from soil

Nitrogen fertilizer is critical for crop production but applying too much at the wrong time reduces profitability and increases water pollution, air pollution, and greenhouse gas (GHG) emissions. A fraction of the N in fertilizer or manure is lost from soils in the form of N_2O gas, a much more potent greenhouse gas than carbon dioxide. Farmers often apply extra N as 'insurance' to ensure highest yield, but this practice may reduce profits and cause unnecessary water pollution and GHG emissions. Nitrogen fertilizer using the 4 Rs (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 (Woodbury 2018, Sela et al. 2018).

Nitrous oxide, a potent GHG, is produced as part of the N cycle in soils. Nitrogen occurs in several chemical forms in the soil. The form most readily taken up by crops is nitrate (NO_3^-). Nitrate can also be changed to other chemical forms by a process called denitrification. Depending on the soil properties, water saturation, oxygen levels, and the microbial populations, nitrate can change into many forms, for example, nitrate (NO_3^-) can become nitrite (NO_2^-) which can become nitric oxide (NO), which can become **nitrous oxide (N_2O),** which can become dinitrogen gas (N_2). This process of denitrification can release gases into the air and when the N is released as N_2O, it impacts climate. However, nitrate also moves easily with water, so during heavy rainfall with saturated soils, nitrate can be leached, creating the potential for pollution of ground water and surface water. Coarse-textured soils lose N mostly by leaching while fine-textured soils lose N mostly by denitrification and volatilization to the atmosphere.

The goal of crop N 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 N removed from the field in the harvested crop divided by the amount of fertilizer N applied. Improving N use efficiency reduces the amount of pollution caused for the amount of crop produced.

Improving fertilizer management (right source, rate, time, and place) for increased crop N use efficiency is beneficial because it:

- Decreases water pollution (co-benefit),
- Decreases air pollution (co-benefit),
- Decreases GHG emissions (co-benefit),
- Increases profitability because less synthetic fertilizer N is purchased which reduces costs and increases profits.

In sum, improving N-use efficiency saves money, protects water resources, and reduces GHG emissions.

SOIL OFFENSE – Sequestering CARBON: Key concepts and mitigation opportunities

- ***Reducing tillage increases soil carbon.***
- ***Adding cover crops (or double crops) increases soil carbon.***
- ***Adding crop residues to soil increases soil carbon.***
- ***Adding organic matter (manure/compost/biochar) to soil increases soil carbon.***
- ***Replacing annual crops with perennial crops can greatly increase soil carbon.***

MITIGATION OPPORTUNITY 1: REDUCING TILLAGE INCREASES SOIL CARBON

Reducing tillage, particularly no-till, can increase soil carbon by developing soil aggregate structure and slowing decomposition of soil organic matter. Reduced tillage can also improve soil health, including reducing erosion, improving tilth, and improving water holding capacity. All of these changes can improve crop performance, including resiliency during adverse weather conditions. Improved water holding capacity can improve crop growth during droughts, and improved aggregate structure can improve soil drainage, reducing waterlogging and erosion during extreme rainfall events.

However, these benefits require some time to build up, and may not occur for several years after the cessation or reduction in tillage. In fact, waterlogged soils can temporarily increase N_2O emissions following eliminating tillage (Six et al. 2004). Additionally, soil carbon can be lost very quickly if tillage is later increased, so it cannot be viewed as a 'permanent' mitigation of GHG emissions. Remaining knowledge gaps about effects of tillage on soil carbon include (1) whether the observed increases in soil carbon in the topsoil differ from those deeper in the profile and (2) whether erosion has been adequately accounted for in many field studies (Tonitto et al. 2016).

Strategy	Opportunity	Challenges
Reduce tillage.	Increases soil carbon and soil health when practiced over many years.	Soil carbon can be lost quickly if tillage is later increased making it difficult to qualify as 'permanent' mitigation of GHG.

MITIGATION OPPORTUNITY 2: ADDING COVER CROPS INCREASES SOIL CARBON

Having living plant root systems in the soil throughout more of the year increases soil health and soil carbon. Similar to adding crop residues, these benefits will be even greater when combined with reduced tillage. Intact root systems reduce erosion by holding the soil in place and preventing loss of carbon. However, cover crops require time, money, and careful management to avoid interfering with planting time in spring for the primary crop. Double cropping has the benefit of producing two marketable products, and many farmers in New York State include crops such as winter wheat in their crop rotations. Double crops increase total yield, but may reduce yields of the primary crop, which may limit their benefits. With ongoing climate warming that is occurring, there will be increased opportunities for double cropping throughout New York State.

Strategy	Opportunity	Challenges
Add cover crops or double crops.	Having crops cover the soil and build additional root systems for more of the year increases soil health and soil carbon.	Cover crops require time and money to manage. Double crops increases total yield, but may reduce yield of the primary crop.

MITIGATION OPPORTUNITY 3: ADDING CROP RESIDUE TO SOIL INCREASES SOIL CARBON

Adding crop residues or other organic matter to soils increases soil carbon and soil health. Such benefits will be even greater when combined with reduced tillage, which can decrease the rate at which residues decompose (see previous section). However, excess residues on the soil surface can keep soil too cool and wet in spring, and can interfere with early crop growth. Additionally, there may be other competing uses for residues, such as animal fodder, bedding, etc. Therefore, on many farms, especially those with livestock, there may be limited opportunities to return residues to soil. However, on livestock farms there is the opportunity to return manure and soiled bedding to soil, as discussed below (see Mitigation Opportunity 4).

Strategy	Opportunity	Challenges
Add crop residues.	Increases soil carbon, especially combined with reduced tillage. Improves soil health, including tilth.	Excess residues on the soil surface can keep soil too cool and wet in spring, and can interfere with planting or early crop growth.

MITIGATION OPPORTUNITY 4: ADDING MANURE, COMPOST, OR BIOCHAR TO SOIL INCREASES SOIL CARBON

Adding organic matter such as manure, compost produced from plant material or manure, residues from food processing, or biochar to soil increases soil carbon (especially combined with reduced tillage). As discussed above for other sources of organic matter, these sources can also improve soil health, including reducing erosion, improving tilth, and improving water holding capacity, which helps reduce the impacts of both drought and extreme rainfall events. When organic matter is available on the farm, it may already be returned to the soil, or it may be practical to do so, rather than disposal by other methods, such as burning. However, bringing organic matter from outside the farm can be time consuming and expensive unless a disposal (tipping) fee is paid to the farmer. Furthermore, some materials require processing, such as making compost, which adds to the time and cost required for management. In particular, for biochar, there is currently little commercial experience or conversion facilities available to produce it within New York State. However, biochar remains in the soil longer than other forms of soil carbon, so there is research investigating whether it is possible to develop commercially viable systems for producing biochar for soils.

Strategy	Opportunity	Challenges
Add manure, compost, or biochar.	Increases soil carbon, especially combined with reduced tillage. Improves soil health, including tilth.	Transporting these materials from off the farm can be difficult and costly. The use of biochar produced through pyrolysis may offer significant potential, but public-private sector demonstration projects need to be implemented in multiple waste stream settings (crop residues, manure, food waste and yard waste) to fully determine feasibility and value on a large scale.

MITIGATION OPPORTUNITY 5: REPLACING ANNUAL CROPS WITH PERENNIAL CROPS CAN GREATLY INCREASE SOIL CARBON

The highest potential for carbon sequestration on agricultural land comes from afforestation because large amounts of carbon can be sequestered in trees and soil. Substantial increases in soil carbon also occur when annual cropland is converted to perennial crops or permanent pasture. Perennial crops, pasture, and tree root systems sequester soil carbon, use nutrients more efficiently, and reduce erosion from extreme rainfall events. Compared to annual cropping with conventional tillage, up to 25% more carbon may be stored in the topsoil under perennial vegetation, whether it is pasture, hay, forest etc. (Wightman et al. 2015, Woodbury et al. 2007). Because the carbon in plants comes from CO_2 in the air, this increased soil carbon sequestration mitigates greenhouse gas accumulation in the atmosphere.

Annual crops may be more vulnerable to extreme weather events than perennials. In place of some annual crops, livestock farmers may wish to explore opportunities for using perennial crops including improved pasture, hay, and forage systems, and different methods of processing and storing harvested materials, including haylage and other silage. However, annual crops provide many important benefits as livestock feed and as marketable products, and on many farms, there may be limited opportunities to replace them with perennial crops without a change in the cropping system or farming system.

Strategy	Opportunity	Challenges
Convert land from annual to perennial crops.	Perennial crops, pasture, and tree root systems sequester soil carbon, use nutrients more efficiently, reduce erosion, and reduce GHG emissions.	It may be difficult to find appropriate substitutes for many annual crops and to find markets for some perennial crops.

SOIL DEFENSE – REDUCING N_2O Emission: Key concepts and mitigation opportunities by reducing nitrous oxide emissions from fertilizer and manure nitrogen

1) ***Use the 4 Rs of fertilizer management to reduce N_2O emissions.***
2) ***Reduce the use of synthetic N 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 N 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, Woodbury 2018). These 4 Rs should be used all together in a comprehensive plan appropriate for the cropping system, and accounting for all sources of N 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 N formulations may 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 N fertilizer application do not include applying fertilizer in the fall for a spring crop, because most of the N 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, N 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 N 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 N, including all fertilizers, manure, crop residues, cover crops, and any other source of N applied to crop fields. Farmers commonly do not adequately account for these other sources of N, and therefore over-apply synthetic N fertilizer.

Strategy	Opportunity	Challenges
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 urea and anhydrous 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 time.	Applying most N fertilizer as side-dress reduces N_2O and increases yield.	Fertilizer requirements vary yearly; use of an adaptive in-season N rate helps manage variability.
Optimize N fertilizer rate.	Using appropriate source, placement, and timing reduces the total required rate, reducing N losses including N_2O.	Fertilizer requirements vary yearly; use of an adaptive in-season N rate and timing can help manage this variability.

MITIGATION OPPORTUNITY 2: REDUCE USE OF SYNTHETIC NITROGEN FERTILIZER

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

Strategy	Opportunity	Challenges
Reduce use of synthetic N fertilizer.	Synthetic N production requires lots of energy and emits GHGs; reducing its use reduces upstream GHG emissions.	Synthetic N fertilizer is valuable and useful as part of a comprehensive nutrient plan.

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 N 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.

Strategy	Opportunity	Challenges
Appropriate Manure Management	Develop a ***comprehensive nutrient management plan*** (CNMP, see below) to help prevent erosion, water contamination, air contamination, and GHG emissions.	It can be challenging to account for nutrients from application of manure. Consider the 4 R's above and keep the CNMP up to date (livestock numbers, cropping systems, manure management & livestock feed).

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 N 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 N 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.

Strategy	Opportunity	Challenges
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.

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. 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 N available from the cover crop for the main crop, especially for leguminous cover crops, in order to improve N use efficiency and reduce potential for N_2O emissions. While cover crops are beneficial, they require time and money to manage, and if managed poorly, can interfere with management of the main crop.

Strategy	Opportunity	Challenges
Use a winter cover crop for annual crops.	Cover crops reduce nitrate in soil, reduce erosion, N leaching, and N_2O emission, N availability from cover crop for subsequent crop must be accounted for.	Cost and logistics may be challenging for both planting and termination of cover crops.

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 N benefits from practices and therefore apply excessive N fertilizer that reduces profits and supplies excess N 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.

Strategy	Opportunity	Challenges
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, crop rotations and other soil amendment. The CNMP must be kept up to date with changes in livestock numbers, cropping systems, management practices (e.g. manure management & livestock feed).

PROFITABLE OPPORTUNITIES TO REDUCE N_2O BY FIELD MANAGEMENT

Opportunity #1: Applying manure or synthetic N 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 N to the soil. Using these practices and accounting for their contribution to crop N needs can further reduce the need for synthetic N fertilizers, reduce N_2O emissions, and increase profitability. In some cases, payments may be available to help pay for implementation.

VOCABULARY

Afforestation: Planting trees on land that hasn’t been forested for at least 50 years (does not include tree growth after tree harvest of forest land). Re-growing trees after harvest in forest land is called reforestation.

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

Biochar: A solid dark-colored charcoal-like material produced by means of pyrolysis (a thermochemical process in a low oxygen environment).

Carbon Sequestration: The storage of carbon in a biological or geological sink (also called a reservoir or pool). Biological sinks include soil, trees, wetlands, and the ocean. There are many ways to sequester carbon. For carbon sequestration to have a meaningful impact on the atmosphere it is necessary to ensure that the carbon remains sequestered and is not released back into the atmosphere.

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 across farmstead facilities and fields related to soil erosion, livestock manure and recycling of organic by-products.

Cover Crop: Growing a crop of grass, small grain, and/or legumes primarily for seasonal protection and soil improvement.

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

Double Crop: Growing and harvesting two different crops in the same field during the same, often extended, growing period. Double crops serve a similar role for soil function as cover crops, but are harvested for further use.

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).

Haylage: Silage made from grass that has been partially dried.

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 under 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), minimizing GHG potency (e.g. flare methane to reduce its GWP), or sequestering GHG (e.g. photosynthetic capture & storage of atmospheric CO_2 in long-lived wood products).

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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