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Climate Change and Soil Management in Field Crops

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Variable weather presents no new challenge to Michigan farmers. In recent years, farmers have faced increased frequency of extreme weather events, including intense rainfall, unprecedented temperatures and drought. Climate change is at our doorstep but fortunately, field crop agriculture has the potential to become a part of the solution to help mitigate climate change. Farming practices have been identified as both sources and sinks for greenhouse gases and thus can provide partial solutions to excess greenhouse gas emissions. Agriculture and forestry account for 31 percent of global greenhouse gas (GHG) emissions (IPCC, 2007).

> As climate variability increases, the risk factors associated with cropping and soil management strategies become more prominent.

Carbon dioxide (CO_2), methane and nitrous oxide (N_2O) are all greenhouse gases influenced by agricultural practices. This bulletin will focus on ways to manage soil, presenting recent findings and tested practices that reduce losses of two of those gases: carbon dioxide and nitrous oxide. As one of the most influential of the GHGs, nitrous oxide deserves particular attention. One molecule of nitrous oxide has an atmospheric lifetime of 114 years and more than 300 times the global warming potential as carbon dioxide (Doll & Baranski, 2011).

Management practices that conserve soil organic matter and nitrogen (N) fertilizer generally also reduce losses of carbon dioxide and nitrous oxide. Reducing fertilizer costs while reducing GHGs presents a win-win proposition. Growers universally recognize the value of soil organic matter to high crop yields. However, few growers understand that incremental gains in soil organic matter may also reduce emissions of the GHG carbon dioxide. Management of soil nitrogen and carbon lies at the foundation of reducing the GHG "footprint" of agriculture.

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The risks imposed by variable weather create the necessity to learn about soil management. A healthy, functioning soil eases the management of drought and flood risk in field crop production. Although the weather is difficult to predict, recent weather history seems to indicate that in the coming decades, Michigan agricultural producers will face increasingly variable weather patterns. Climate change, propelled by global warming, will add to the current uncertainty in predicting rainfall and temperature. Now, more than ever, farmers need to consider and account for crop and soil management practices that influence GHG emissions, and know the practices that can help them cope with greater weather variability (Nicholls & Alexander, 2007).

Farmers have always needed to account for timing, frequency and duration of drought and precipitation when planting, fertilizing or managing their crop. If future climate scenarios bring earlier and warmer spring temperatures, increased variability of both winter and growing season precipitation, large temperature fluctuations and more protracted growing seasons, then conservation-based management strategies may become even more important than they are today.

In this bulletin, we will present documented methods to manage soils for conservation of nitrogen and carbon. A healthy, highly productive soil that can help buffer crop yield during times of variable climate will save on input costs and reduce GHG emissions.

Nitrogen management

If you understand the environmental factors influencing the nitrogen cycle, you'll know how to manage nitrogen losses, including nitrous oxide. Remember: soil biology regulates the nitrogen cycle. Many environmental factors such as mineralization, nitrification and denitrification influence soil biological processes (see text box). These factors regulate availability of nitrogen for crop uptake, and nitrogen loss pathways such as leaching and gas emissions of nitrogen gas (N_2) and nitrous oxide.

Nitrogen management and GHG emissions

Optimizing nitrogen management involves the 4 Rs: right source, right time, right amount and right placement (adapted from Roberts, 2007). Michigan nitrogen recommendations for field crops follow the 4R approach. Detailed information on recommendations is presented in the *Extension bulletin Nutrient Recommendations for Field Crops in Michigan (E2904)* (Warncke & Dahl, 2009). In the following sections, we focus on the management principles and practices that conserve nitrogen and reduce greenhouse gas emissions.

Nitrogen mineralization, nitrification and denitrification processes regulate nitrogen availability to crops and soil nitrogen losses in the form of NO_3 (nitrate) leaching and N_2O (nitrous oxide) emissions. These biological processes are influenced by environmental factors including:

- Temperature.
- Precipitation.
- Soil properties such as texture, pH, inorganic nitrogen content, moisture status and abundance of microbial communities.

Management factors interact with the environment at a given field site. These include:

- Fertilizer source, rate, placement and timing.
- Tillage system.
- Organic amendments in the form of manure, crop residues and rotation sequence.

(IFA/FAO, 2001; Eichner, 1990)

Right Source. When accounting for differences among climate, soil physical properties and rate of application, N_2O emission differences between nitrogen sources following application are negligible and no individual fertilizer type will generally contribute greater amounts of N_2O than another (Stehfest & Bouwman, 2006). Scientists agree that N_2O emission factors for various nitrogen sources such as urea, ammonium nitrate and ammonium sulfate depend on site conditions immediately following fertilization (Harrison & Webb, 2001). However, N_2O emissions vary with the manufacturing process and distribution of various fertilizers to the grower. Therefore, your purchasing decision does have an impact. Due to Global Warming Potential (GWP) differences from N_2O emissions associated with production and distribution of nitrogen fertilizer sources, agricultural producers may indirectly have a substantial influence on N_2O emissions simply by their choice of nitrogen source, where ammonium nitrate has the largest associated generation of modern GHG emissions (Table 1) (Wang, 2007). Ammonium nitrate comprises less than 4 percent of North American total fertilizer N with urea (40 percent), anhydrous ammonia (26 percent) and urea-ammonium nitrate (21 percent) having much larger usage rates.

Table 1. Energy use and GHG emissions associated with the production and distribution of nitrogen fertilizer (Table adapted from Snyder, Bruulsema, Jensen, & Fixen, 2009).

	Ammonia	Urea	Ammonium nitrate
	(per kg of N)		
Energy use (MJ)	45	53	65
CH_4 emission (g)	2.5	3.7	4.2
N_2O emission (g)	0.02	0.03	19.7
CO_2 emission (kg)	2.6	3.1	3.8
GWP (kg CO_2 equiv.)	2.6	3.2	9.7

Right Time. Managing nitrogen application to minimize N_2O emissions requires attention to matching supply and demand. Timing of nitrogen fertilizer application should occur in synchrony with peak crop demand. Spring application or split applications of fertilizer are two methods that help ensure nitrogen is available when a summer crop such as corn needs nitrogen most. Recommended timing of nitrogen placement depends in large part upon paying attention to local climate patterns rather than following standardized practices.
Under high rainfall conditions, using multiple split applications is a particularly important strategy to conserve nitrogen by minimizing the size of the soil inorganic nitrogen pool at any point in time, reducing the potential for gaseous and leaching losses. Research shows that split applications of fertilizer can reduce N_2O emissions without sacrificing crop yield. Spring applications have a lower impact on greenhouse gases and are more effective than autumn-applied fertilizer (Matson, Naylor, & Ortiz-Monasterio, 1998; Hultgreen & Leduc, 2003). Not as effective as spring applications, fall applications of nitrogen fertilizer typically often lead to lower corn yields (see Tri-State fertilizer recommendations at **http://ohioline.osu.edu/e2567/**). (Vitosh, Johnson, & Mengel, n.d.). Therefore, we don't recommend fall applications of nitrogen fertilizer for Michigan farmers.

Right Amount. Due to yearly changes in growing conditions and differences in yield potential that vary with site and weather, producers may find matching N rate and crop N demand a difficult task. Nitrogen applications in excess of crop demand will generally reduce N use efficiency due to either enhanced GHG emissions or increases in leaching or denitrification from excessively high post-harvest soil residual nitrate levels. Synchronizing nitrogen supply with crop demand is a key, yet problematic, management goal. Reductions in nitrogen fertilizer rate below recommended levels risk yield reduction, while at the same time excess nitrogen supply can be associated with spikes in nitrous oxide losses (McSwiney, Snapp, & Gentry, 2010).

To minimize GHG contributions, agricultural producers may want to modify nitrogen fertility rates to match but not exceed crop and soil nutrient uptake capacities. Research shows that N_2O emissions remain static when producers apply nitrogen at or below crop needs, but emissions substantially increase once nitrogen application rates increase beyond crop and soil uptake capabilities (Bouwman, Boumans, & Batjes, 2002; Grant, Pattey, Goddard, Kryzanowski, & Puurveen, 2006). Even without the addition of nitrogen fertilizers, modest background levels of N_2O emission can naturally occur from the N mineralization of soil organic matter (Del Grosso et al., 2006). Inherently well-drained soils or those that are hydrologically modified through tile drainage are generally associated with moderate N_2O emissions compared to sites with clay-textured soils or poor drainage (Liu, Mosier, Halvorson, & Zhang, 2006).

Right Placement. Nitrogen placement or depth may have an effect on overall N_2O emissions. Field studies have documented enhanced GHG emission levels with deep-banded nitrogen placement in the soil profile regardless of source. Anhydrous ammonia had greater N_2O emission rates placed 12 inches deep into the soil as compared to 4 or 8 inches deep, and ammonium nitrate had greater N_2O emissions placed at a 4-inch depth as opposed to a 1-inch depth (Drury et al., 2006; Breitenbeck & Bremner, 1986). Urea band applied below the seed row reduced N_2O emissions compared to urea broadcast across the soil surface (Hultgreen & Leduc, 2003). While surface fertilizer applications may save time, subsurface fertilizer placement that is not deep banded may reduce N_2O emissions and improve the nitrogen use efficiency of the plant.

Newer technologies including controlled- and slow-release fertilizers may offer additional options concerning application timing. These products tend to either inhibit N transformations, require microbial decomposition or are coated with semi-permeable polymers to allow a controlled dissolution of fertilizer at a lower rate than conventional water-soluble fertilizers. The effects of these products on overall N_2O emissions are not well defined, and studies show conflicting results. Studies on nitrapyrin in corn show delay of nitrification in the soil and reduction of N_2O emissions outside of the main growing season. Overall N_2O loss was not reduced (Parkin & Hatfield, 2010). Studies have suggested these products may delay initial GHG emissions soon after application but emissions continue for a longer period, while other studies have demonstrated overall reduced N_2O emissions (Delgado & Mosier, 1996; Shoji, Delgado, Mosier, & Miura, 2001). Whether you prefer soluble or controlled-release fertilizers, time your nitrogen release to coincide with high crop demand for nitrogen.

Integrated management of nitrogen and carbon

Highly variable rainfall throughout the growing season affects crop growth and nitrogen demand from year to year. An integrated approach that manages nitrogen and carbon in combination provides insurance against loss of nitrogen to the environment. Various sources of carbon can promote soil biology and the assimilation of nitrogen into organic matter. Carbon sources include crop residues, manure or winter cover crops (Snapp & Grandy, 2011). Winter wheat and cereal rye both effectively capture any residual nitrogen from excess fertilizer applied (Strock, Porter, & Russelle, 2004). A recent study found that when researchers applied excessive nitrogen rates to a growing corn crop, planting a cereal rye cover crop in late fall after crop harvest effectively temporarily captured and immobilized nitrogen in the spring, dramatically reducing nitrous oxide losses to background levels (Figure 1). The cover crop provided a source of carbon that helped to function in the capture and re-release of nitrogen fertilizer when N was needed most, in early spring. This method transforms inorganic nitrogen fertilizer into a slow-release fertilizer (McSwiney et al., 2010).

In well-drained Michigan soils, a rye or winter wheat cover crop has shown particular promise when combined with manure nitrogen as part of high production corn and potato systems (Snapp, Nyiraneza, Otto, & Kirk, 2003). However, performance on specific sites such as clay-textured soils may pose problems to accurately predict nitrogen release from organic amendments. As with any new practice, experiment with a small portion of a field before adopting on a larger scale.

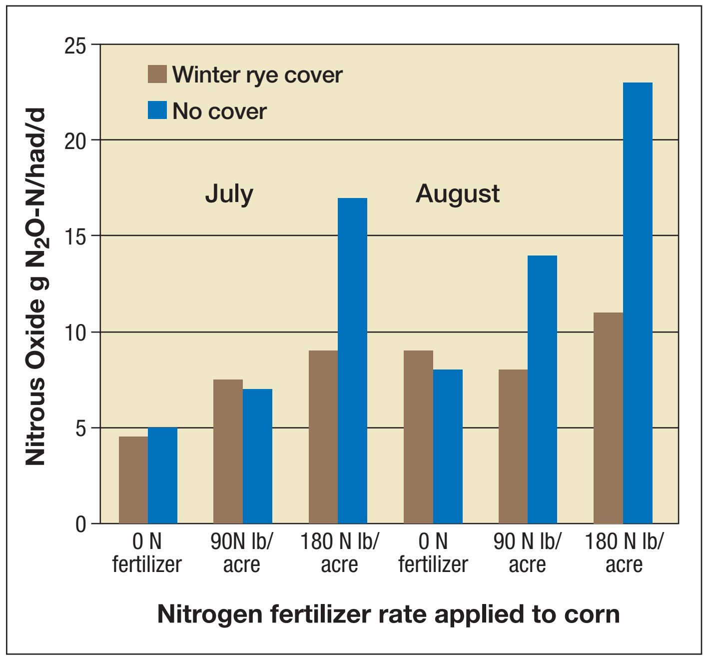

Figure 1. Nitrous oxide losses from conventionally managed corn at a southwestern Michigan site where broadcast ammonium-nitrate fertilizer was sidedressed at rates of 0, 90, and 180 lb N per acre to V6 corn. Corn grown at N application rates in excess of crop needs (in this case 180 lb. N/A) without winter cover crops had almost double the nitrous oxide losses in August as compared to corn grown with a winter cover crop (McSwiney et al., 2010). Where nitrogen was applied at rates beyond the needs of the plant, incorporating winter cover crop residues appeared to immobilize and retain excess nitrogen, decreasing the losses of nitrous oxide to the atmosphere.

Tillage and greenhouse gas emissions

Simply switching from a conventional tillage system to conservation tillage may not reduce GHG emissions (Snyder et al., 2009). Studies have documented reduced GHG emissions under conservation tillage practices as compared to intense tillage systems but individual results may depend upon nitrogen source and application method (Venterea, Burger, & Spokas, 2005; Halvorson, Del Grosso, & Reule, 2008). For example, researchers have noticed elevated GHG emissions under conservation tillage with broadcast urea applied post-emergence, but this was not the case with pre-plant injected anhydrous ammonia or pre-plant broadcast urea-ammonium nitrate (Venterea et al., 2005).

Recent studies have reported that adoption of conservation tillage does not always produce direct benefits involving nitrous oxide reduction and carbon dioxide production. Results will depend on climate and physical soil properties (i.e., soil water, residual nitrate), and the time frame under consideration. Some benefits take time to accrue, such as assimilation of nitrogen and carbon through building soil organic matter (Six et al., 2004; Lee, Six, King, Van Kessel, & Rolston, 2006). Humid regions tend to have greater capabilities to sequester soil carbon and decrease N_2O fluxes, often resulting in a net negative GWP for conservation versus conventional tillage systems. Drier environments may have generated higher CO_2 and N_2O emissions, given a lower overall ability to store carbon (C) and N in the soil.

Soils have a finite capacity to store soil organic carbon. Once soil carbon has accumulated to the maximum level for that environment, the potential to further mitigate the GWP of soils may be minimal.

Carbon management and GHG emissions

The well-known principles associated with building soil organic matter involve either increasing carbon inputs or reducing carbon outputs, as carbon is the key ingredient in soil organic matter. The primary sources of carbon inputs include crop residues, manure and extended presence of deep-rooted plants from a forage rotation or cover crop. Reducing the intensity and frequency of tillage usually reduces carbon outputs. Soil management practices that integrate reduced reliance on nitrogen fertilizer through the application of soil amendments such as livestock manure and that enhance soil conservation through planting winter cover crops also support gains in soil organic matter. Many producers practice reduced tillage systems such as strip tillage and no-till. These systems have proven particularly effective for soybean production on well-drained sites. Find more detailed information on advanced soil organic matter management for Michigan field crop production in the Extension bulletin *Advanced Soil Organic Matter Management (E3137)* (Snapp & Grandy, 2011).

Conclusions

As the global climate continues to evolve, agricultural producers and researchers will need to address changing growing conditions and the demands for increased food production. A primary component of this change may not involve altering total fertilizer applications but rather applying and placing fertilizer in a more timely manner, which may differ each year. Investment in practices such as conservation tillage and cover crops may become even more important to build soil productivity and mitigate nitrogen loss. Increased risk may accompany climate change through increased investment risk (inputs), increased rates of crop failure, or economic and environmental losses. Growers may need to closely examine every input to determine whether the greater chance of downside risk associated with higher investment may lead to operating at a level other than the maximum rate of economic return.

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