NebGuide

Nebraska Extension

Research-Based Information That You Can Use

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Crop Management to Reduce Soil Nitrous Oxide Emissions in Nebraska

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The direct soil emission of the greenhouse gas nitrous oxide (N_2O) associated with crop production is a major concern for future climate. This NebGuide addresses soil and crop management practices for reduced soil N_2O emission such as fertilizer-N use and additives, managing anaerobic soil conditions, crop rotations, tillage, crop residue harvest, cover crops and manure use. These practices often have multiple benefits and low or no cost.

Increased concentrations of atmospheric greenhouse gases have contributed to global climate changes. On average, warming in Nebraska during the past 30 years has been 0.3° F per decade. Nebraska has experienced increased frequency of exceptionally wet springs and droughty summers. Expectations for 2050 compared with State averages include a doubling of days annually with >95° F temperature, 50% less extremely cold days, 20–25% more growing degree days per year, and wetter winters and springs but drier summers.

Nebraska agriculture is likely to be most challenged by the more frequent occurrence of extreme weather events. Responses to extreme weather events have been primarily damage recovery, purchase of additional insurance, and some changes in farming practices for more resilience to extreme events. Adaptation to more frequent occurrence of extreme weather events is important for the here-and-now, but long-term and global concerns needs to include reduced greenhouse gas emissions. The trend to more frequent extreme weather events may not be reversed within our lifetimes, but actions taken now in agriculture and other sectors can contribute to slowing the rate and eventual amount of global change by overall reductions in greenhouse emission and increased carbon (C) sequestration.

The major greenhouse gases are CO_2, methane (CH_4) and nitrous oxide (N_2O). These differ greatly in the amount of emission but also in their global warming effect per ton of emission. One ton of CH_4 is equivalent to about 23 tons of CO_2 (CO_2eq). Each ton of N_2O emission is equivalent to about 300 tons of CO_2eq. Annual CO_2eq emission for the US is estimated to be 72.5% from CO_2, 13.8% from CH_4, and 6.2% from N_2O. Water vapor also has a CO_2eq effect, but the water vapor effect alone is short-lived and does not control air temperature. Rather, atmospheric water vapor increases with increased temperature and magnifies greenhouse gas effects. Much of CO_2eq emission occurs naturally

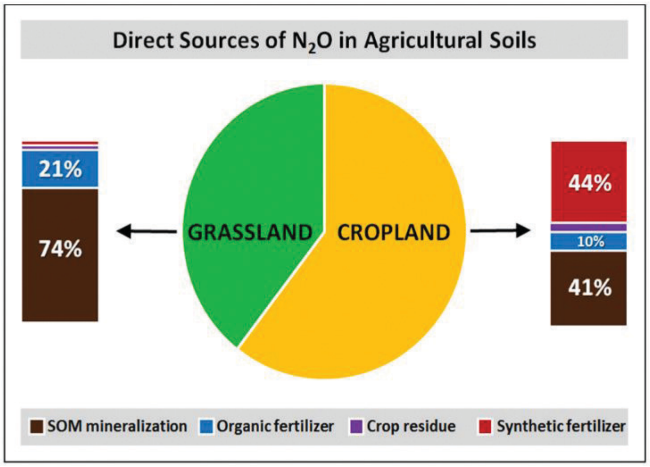

Figure 1. Agricultural sources of direct N_2O emissions.

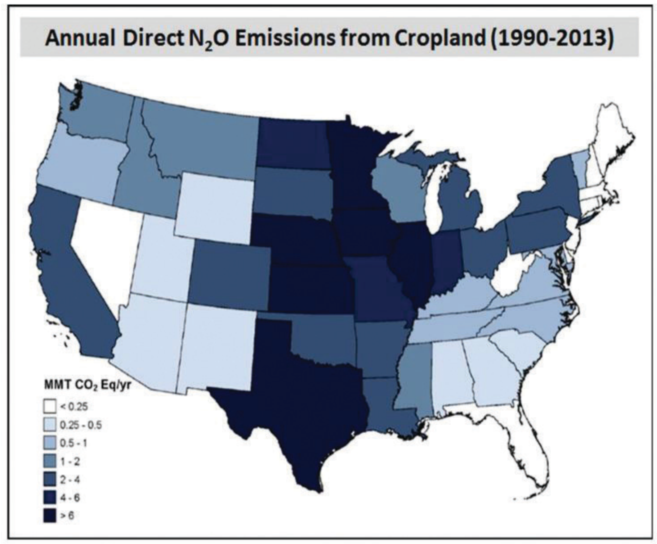

Figure 2. Direct N_2O emissions from U.S. cropland, 1990–2013.

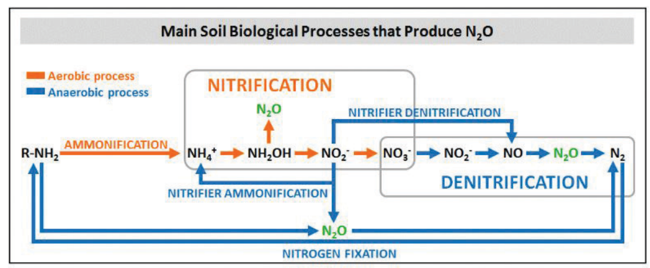

Figure 3. Primary soil biological processes that produce N_2O. R-NH_2 = organic N; NH_4^+ = ammonium; NH_2OH = hydroxylamine; NO_2^- = nitrite; NO_3^- = nitrate; NO = nitric oxide; N_2 = dinitrogen gas.

and, because these natural emissions have changed little historically, increases in atmospheric CO_2eq are attributed to human activity.

The emission of CO_2eq associated with agriculture is estimated to account for 8.4% of total US emission with 5.1% of total emission attributed to soil management. Methane tends to be absorbed rather than emitted from well-drained agricultural lands, and the net effect is near zero for upland production systems. Most of the greenhouse gas (CO_2eq) emission associated with cropland and soil management in Nebraska is soil emission of N_2O. Cropland related emission of agricultural N_2O includes direct soil-to-atmosphere emissions and indirect N_2O emissions resulting from N losses to leaching, runoff, and volatilization that can convert to N_2O in a receiving ecosystem. Therefore, any reduction in N losses will directly or indirectly curb N_2O emissions. This article, however, focuses on direct soil N_2O emission from cropland of Nebraska.

Nitrous oxide: sources and how soils affect emissions

Nationally, N_2O emission from cropland is 50% more than from grassland due to fertilizer-N use, with the mineralization of soil organic N and biological N fixation being other major sources (Figure 1). Croplands in Nebraska, along with other Corn Belt states and Texas, emit large amounts of N_2O annually (Figure 2). The emission of N_2O from agricultural land depends on the amount of inorganic N (mostly ammonium and nitrate) in the soil profile, the soil water-filled pore space (WFPS), microbial activity, climate, and management.

The microbial generation of N_2O from inorganic soil N primarily occurs during: (1) the aerobic process of nitrification, where ammonium is converted to nitrate; and, (2) the anaerobic process of denitrification, where nitrate is converted to non-reactive dinitrogen gas (N_2) (Figure 3). Wetter soils have higher WFPS and less available oxygen than drier soils with lower WFPS. Nitrification tends to be the more important process for generating N_2O for WFPS <60%, and denitrification dominates when WFPS >60%. Emission of N_2O due to denitrification increases rapidly as WFPS increases above 70% and may be twice as much at 80% compared with 60% WFPS, especially if associated with warm soil (Figure 4). Emission of N_2O is most associated with nitrification for semi-arid production areas such as in western Nebraska and with denitrification for humid production areas as for the Corn Belt.

Emission of N_2O is affected by soil drainage and may be twice as much for somewhat poorly drained and three times as much for poorly drained compared with well-drained soils (see county soil survey reports or NRCS Web-Soil Survey). A global analysis of research results indicated that emission of N_2O increases as soil clay content increases

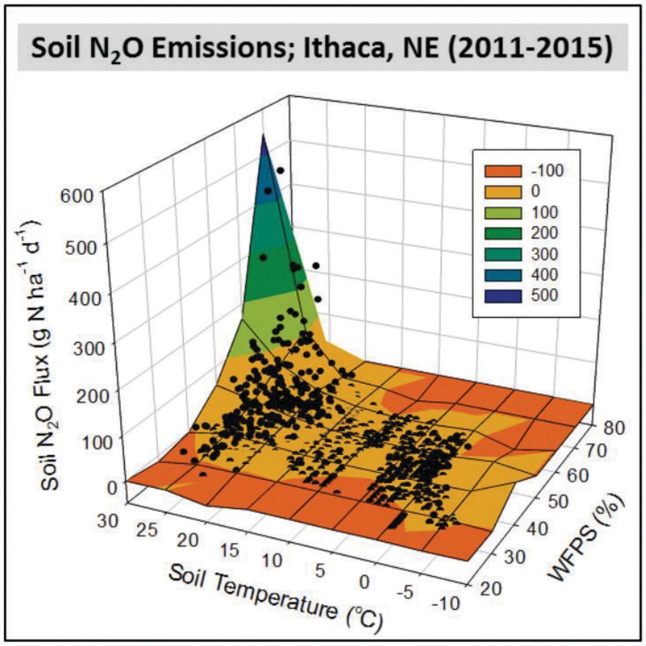

Figure 4. Daily soil N_2O emissions from an irrigated continuous corn site in Ithaca, NE (2011–2015). Urea-N was applied at 180 lbs/ac. The 5-yr average grain yield was 180 ± 8 bu/ac. Soils were Tomek and Filbert silt loams. Soil emissions were measured weekly during the growing season, and monthly during the non-growing season for a total of 1,573 measurements over 100 sampling dates.

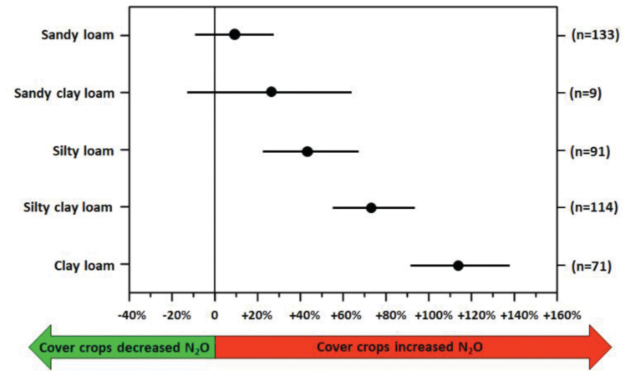

Figure 5. Cover crops increase N_2O emissions as soil clay content increases (average ± 95% confidence intervals). Points or error bars crossing "0" indicate no cover crop effect. Numbers (n) in parentheses indicate the number of comparisons.

and sand content decreases (Figure 5). Emission may be 25 and 35% more for soils of hydrologic class C (low percolation rate) and D (high clay and very low percolation rate) compared with B (moderate percolation rate) and relatively low for A (high percolation rate).

Nitrogen application practices

Nitrogen rate is the major determinant of N_2O emission for most cropland of Nebraska together with the average quantity and duration of the inorganic N present in the soil (Figure 3). The N rate effect increases as the rate exceeds the economically optimal N rate (EONR). The amount of residual soil nitrate-N during fall to spring is also important to N_2O emission. Crop N uptake and fertilizer N recovery efficiency, however, are less related to N_2O emission than N rate and residual nitrate-N. Therefore, N management to avoid applying N in excess of EONR is especially important to reduce N_2O emission. Emission of N_2O is further increased by the interaction of increased inorganic N supply with >60% WFPS.

Avoid excessive N application. The overall crop response to applied fertilizer-N is curvilinear, where increasing N rates cause net returns to fertilizer-N and yield to rise to maximums with potential for decreased profit and yield at excessively high N rates. The profit gains with additional increments of fertilizer-N applied decrease and reach zero as the EONR is reached. Available information indicates that, on average, fertilizer-N application to corn in Nebraska is near the average EONR but >30% of the fields have an excessively high N application rate, often with high post-harvest residual soil nitrate-N. The generation of N_2O-N is on average about 1.0 ± 0.3% of fertilizer-N applied but higher for N applied in excess of EONR. Therefore, reducing an excessive fertilizer-N application rate by 50 lb/ac is expected on average to reduce emission of N_2O-N by 0.5 lb/ac, N_2O by about 0.79 lb/ac, and CO_2eq by about 235 lb/ac. In addition, as fertilizer-N manufacture and transport may produce an average 2.8 lb CO_2eq per lb of fertilizer-N (less with anhydrous ammonia and more with urea ammonium nitrate), the 50 lb/ac reduction in N rate reduces CO_2eq by another 140 lb/ac for a total of 375 lb CO_2eq /ac. The 375 lb CO_2eq /ac is the direct equivalent to burning 19 gal/ac of regular gasoline which produces about 20 lb CO_2 /gal, not accounting for CO_2eq emitted due to production and delivery of the gasoline. Reducing the net N balance after harvest by 10 lb/ac is expected to give a further 7% average reduction in N_2O emission. Therefore, avoiding fertilizer-N application in excess of the EONR is a cost-saving means of reducing N_2O and CO_2eq emission with the added benefits of reduced N losses to leaching, denitrification, runoff, and volatilization.

Application at less than EONR. Another N rate option to reduce CO_2eq emission with a cost would be to apply N at less than EONR at a rate that results in 5% less net returns to fertilizer N use. For irrigated high-yield corn in Nebraska, this was estimated to reduce the fertilizer-N rate by 51 lb/ac for corn after corn and 40 lb/ac for corn after soybean when the value of a bushel of grain was equal to the cost of 8 lb of fertilizer-N use. The mean reductions in yield and profit due to fertilizer-N use were 9.1 bu/ac and \$11.75/ac for corn after corn, and 6 bu/ac and \$8.41/ac for corn after soybean. The reduced CO_2eq emission of N_2O plus CO_2eq associated with fertilizer-N production and transportation was estimated to total 383 lb/ac for corn after corn and 301 lb/ac for corn after soybean. The resulting cost per ton of reduced CO_2eq emission due to applying fertilizer-N at less than EONR was \$61.26 for corn after corn and \$55.89 for corn after soybean. This again does not account for additional reductions in CO_2eq emission associated with low N balance after harvest and the other environmental benefits associated with reduced N losses, such as to leaching of nitrate beyond the root zone. For comparison, the cost of CO_2 capture, transport and very long-term storage such as from coal-burning plants is estimated at >\$55 to <\$200/t.

In-season and variable rate N application. The importance of avoiding N rates in excess of the EONR and of delayed fertilizer-N application for reduced N_2O and CO_2eq emission has been mentioned above. Unfortunately, the EONR varies unpredictably by year. Application of much of the fertilizer-N in-season at a time of rapid crop N uptake means that the EONR for that crop can be better estimated and that much of this applied N will be taken up within a short time by the crop and soil microbes as ammonium. The remaining N will have a relatively short residence time as inorganic N in the soil giving little opportunity for N_2O emission.

Remote sensing of crop canopy reflectance can be used to estimate crop need for in-season N application to approach EONR across the field and to minimize residual nitrate-N. The in-season N application rate may be uniform for the field or at site-specific rates determined from variation in crop canopy reflectance to apply more fertilizer-N where the need is high and less N when the need is small. The reduction of direct soil N_2O emission with in-season application occurs inconsistently (Figure 6) but N loss that contributes to indirect N_2O emission is often reduced with in-season application.

Inhibitors and specialty fertilizer-N products. Use of slow or controlled release N-fertilizers or effective nitrification inhibitors can be effective in reducing N_2O emission if well-targeted and timed to minimize soil nitrate-N when the potential anaerobic conditions (i.e. high WFPS and water-logging) is high (Figure 6).

Anaerobic conditions occur most frequently for soils with moderately poor or poor drainage and for soils with hydrologic class of C or D. In Nebraska, the occurrence of such anaerobic conditions is most common between May 1 and June 15—therefore, treating N-fertilizer with a nitrification inhibitor for spring application to soils with poor drainage has a relatively high chance of reducing N_2O emission as well as fertilizer-N loss to denitrification. These N savings may allow a no- or low-cost means to reducing N_2O emission due to the need for less N application. The inhibitor effectiveness is greatly reduced by 2–4 weeks after application, depending on soil water and temperature.

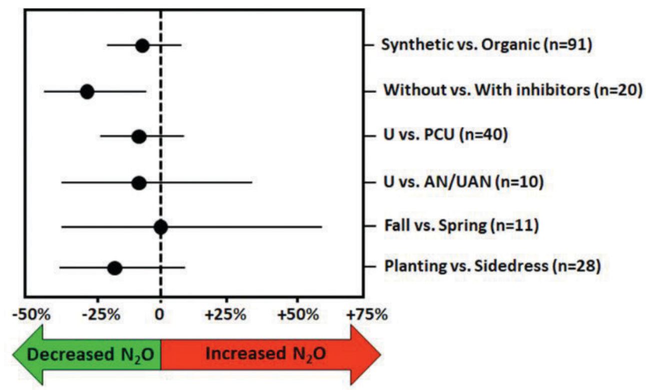

Figure 6. Effect of fertilizer management practices on N_2O emissions (average ± 95% confidence intervals). Points or error bars crossing "0" indicate no treatment effect. Numbers (n) in parentheses indicate the number of comparisons. Abbreviations: U, urea; PCU, polymer coated urea; AN, ammonium nitrate; UAN, urea ammonium nitrate. The comparison is of the second factor compared with the first in the pairs, e.g. N_20 is less "with inhibitors" compared to "without."

Other N management practices. Direct N_2O emission tends to be less with (Figure 6):

- Application of manure-N than with fertilizer-N;
- Ammonium nitrate or urea ammonium nitrate compared with urea; and
- Sidedress N application compared with N application at planting

On average, fall compared with spring application did not affect N_2O emission.

The physical placement of fertilizer can affect N_2O emissions depending on fertilizer type, soil, and climate. Injection of anhydrous ammonia at shallower compared with deeper depths was found to reduce N_2O emission for clayey soils and increase emission for sandy soil with no effect on emission for a silt loam. The greater emission for clayey soil, especially if poorly drained, with deeper placement may be due to high WFPS and increased denitrification. The emission of N_2O in sandy and well-drained soils may be most associated with nitrification which may occur earlier with shallow compared with deep placement. The

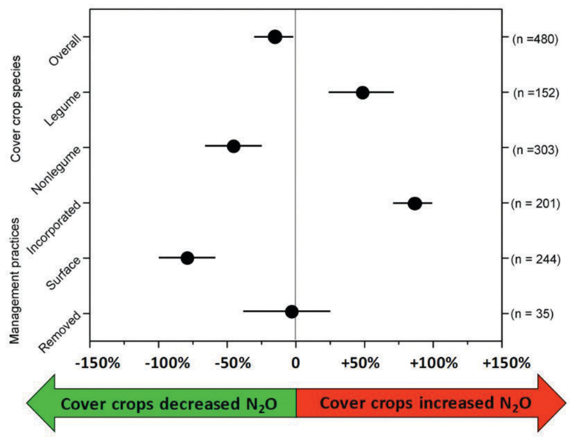

Figure 7. Cover crop effect on soil N_2O emissions compared to no cover crop use (average ± 95% confidence intervals). Points or error bars crossing "0" indicates no cover crop effect. Numbers (n) in parentheses indicate the number of comparisons.

effect of fertilizer placement depth on N_2O emissions can also be affected by N fertilizer type, the actual application depth, climate and weather conditions, drainage class, and soil organic carbon content.

Cover crops and crop residue harvest

In Nebraska, cover crop effects on annual N_2O emission have been near neutral with variable year-to-year and field-to-field effects. With irrigated no-till continuous corn in south-central NE, the average annual N_2O emission over seven years was

- 32% (1.1 lb N_2O/ac/yr) less N_2O emission when 56% of the corn stover was baled compared to no removal; this was with no cover crop planted or manure applied,
- 13% (0.3 lb N_2O/ac/yr) more N_2O emission with a winter rye cover crop compared to no cover crop when stover was baled, and
- 42% (1.0 lb N_2O/ac/yr) less N_2O emission when 11 t/ac every two years of maure was applied compared with no manure applicaion when stover was baled.

In contrast, N_2O emissions were decreased by about 29% and 0.9 lb/ac/yr with a winter rye cover crop for rainfed no-till corn in eastern NE. The effect of grazing crop residue on N_2O emission has not be determined.

A global review of research results for cover crop effects on N_2O emssion (Figure 7) indicated that cover crops tended to decrease N_2O emissions overall due to uptake of residual N and storage in cover crop biomass with more decrease with more cover crop biomass yield and N-uptake. Some of this benefit may be lost when additional fertilizer-N is needed to compensate for the N tie-up. Cover crop type and biomass management were important to annual N_2O emission which was on average

- increased with leguminous cover crops
- decreased with non-leguminous cover crops
- increased with the incorporation of cover crop biomass
- decreased with leaving the cover crop biomass on the soil surface, and
- unaffected when the cover crop biomass was removed.

Early versus late termination of cover crops did not affect the N_2O emission rate in Nebraska studies.

In a regional analysis across the U.S. Corn Belt, the harvest of some stover decreased N_2O emission by 7%, likely due to reduced energy availability for microbes, but results were highly variable from year-to-year and from site-to-site. For irrigated no-till continuous corn systems in Nebraska, stover removal decreased N_2O emissions by 23% in eastern Nebraska and by 32% in south-central Nebraska.

Other practices

Tillage has had an inconsistent effect on N_2O emission with a tendency for more emission with no and reduced tillage than with more aggressive tillage for higher clay (hydrologic class C and D) soils. For loamy and sandy soil, there may be some decrease in N_2O emission with no-till and reduced tillage compared with more aggressive tillage but the tillage effects have been inconsistent.

Rotation with legumes is a means to greatly reduce N_2O emission, largely because of less fertilizer N applied and more depletion of nitrate-N. As a result, the average annual emissions in diverse rotations that include legumes tend to be significantly lower than for continuous corn. The N_2O emissions were 59% less for the corn-soybean rotation than with continuous corn in eastern Nebraska and 18% less for a more diverse four-year rotation compared with the corn-soybean rotation at Brookings SD. In both studies, grain yields increased with greater rotation complexity giving financial compensation for the inclusion of some less profitable crops in the rotation and thereby achieving decreased N_2O emissions at low cost.

Crediting manure-N for less fertilizer-N application can reduce N_2O emissions as found for the above-mentioned 12% reduction with manure application in south-central NE and in Figure 6. However, the effect of manure has been inconsistent with cases of decreased, increased and no effect on N_2O emission. Soil N_2O emissions may be greater with slurries and liquids compared with solid manures, composts, or crop residues. Injecting slurries into soils tends to increase N_2O emissions compared to surface broadcast application.

Irrigation can increase N_2O emission when the WFPS is much increased compared with unirrigated conditions but not if WPFS with irrigation is similar to that with rainfed management. However, nitrate leaching may be more with irrigation and contribute to indirect N_2O emission from downstream ecosystems. Much more N_2O emission is expected with furrow irrigation than with drip or sprinkler irrigation due to the large amounts of water applied per event with furrow irrigation causing greatly increased WFPS for a few days, even though the furrow irrigation events may be relatively infrequent.

Summary

The direct soil emission of N_2O associated with crop production is a major concern. The amount of N_2O emitted is closely associated with fertilizer-N rate and with residual soil nitrate-N. Soil aeration is a major determinant of N_2O emission with more emission associated with less aeration and more WFPS. Practices for reduction of soil N_2O emission include

- avoid excessive N application
- application of N at less than EONR
- in-season and variable rate N application
- full crediting manure N
- timely use of nitrification inhibitors and specialty fertilizer-N products for soils prone to water logging
- injection of anhydrous ammonia at shallower compared with deeper depths for clayey soil and with other N application practices
- some baled harvest of crop residue
- double cropping with non-leguminous, unincorporated cover crops
- rotation of corn with legumes and other crops requiring less fertilizer-N
- avoid over-irrigation.

Some of these practices have little or no cost and have additional benefits such as reduced leaching of nitrate beyond the rooting zone.

Acknowledgement: The research results of many studies and people were considered and interpreted for this publication but the hyperlinks to references are limited to mostly major review and synthesis works.

This publication has been peer reviewed.
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