Relationships of Nitrous Oxide Emissions to Fertilizer Nitrogen Recovery Efficiencies in Rain-fed Corn Systems: Research Foundation Building

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Introduction

Despite many years of research on nitrous oxide (N_2O) emission from corn experiments with various N management treatments applied, little is known about the relationships between N_2O loss and plant nitrogen recovery efficiency (NRE). Our review publication (Omonode et al., 2017) provided a summary of the known relationships with existing North American data, but in most cases N_2O and NRE data are seldom collected and/or reported from the same experiments. Thus, although it is commonly assumed that higher NRE following environmentally-beneficial N fertilizer management practices will lead to lower N_2O emissions, too little evidence exists for this assumption across the range of corn/N management tracks. The overall aim of this project was to provide more concrete field research data to either support or reject this hypothesis. Our specific objective was to determine the relationships between seasonal N_2O emissions, whole-plant nitrogen (N) uptake, and NRE in rainfed corn under different tillage and nitrogen (N) fertilizer management systems. This report will focus on our resulting N_2O and NRE field data, and the relationships between these variables under different corn management systems.

Materials and Methods

Three separate corn-focused experiments were conducted in 2015 and 2016. Experiments #1 and 2 were conducted on high OM (~4%) prairie soils at the Purdue Agricultural Center for Research and Education (ACRE) near West Lafayette, IN. Experiment #3 was conducted on lower OM sandy soils (~2%) at Purdue Pinney Agricultural Center (PPAC) near Wanatah, IN. All experiments involved a minimum of 3 replications for each treatment.

Experiment #1 compared corn management by ecological intensification (EI), where treatments consisted of increased plant population (92,000 plants ha^{-1}) managed at three N rates (0, 180, 250 kg N with and without a nitrification inhibitor), and typical farmers' practice (FP) that consisted of 75,000 plants ha^{-1} managed at 0, 110, 180 kg N ha^{-1}.

Experiment #2 consisted of long-term (no-till, NT; strip, ST; chisel plow, CP; and moldboard plow, MP) where UAN was applied at recommended rate, with and without the nitrification inhibitor Instinct (I)-a newly reformulated nitrapyrin-, contrasted with a zero-N control area in each tillage plot.

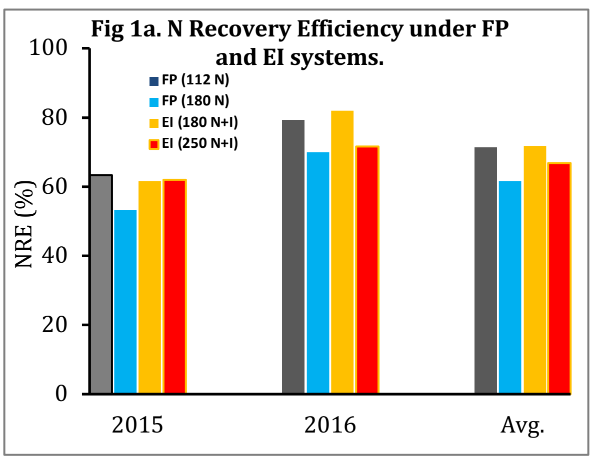
Experiment #3 involved N rate and timing treatments consisting of N rates that were either applied as single-time early sidedress at V4-6 corn growth stage, or intentionally split-applied with both early and late-vegetative (V10-12) applications. In 2015, treatments for PPAC consisted of 0, 160, 200, and 245 kg ha^{-1} single sidedress, and 160 kg early (E) + 45 kg late (L) plus 200 kg (E) + 45kg (L) to give a total of 200 and 245 kg ha^{-1} (designated 200S and 245S). In 2016, treatments consisted of 0, 112, 160, 200, and 245 kg ha^{-1} single early sidedress and 112E+45L (160S), 160E+45L(200S) and 200E+45L (245S) as the late-split N treatments. More details about the methodology and corn NRE results of this experiment are available in Mueller et al. (2017). Although the entire field experiment involved four hybrids, our greenhouse gas measurements only occurred in one of the four hybrids (P1498).

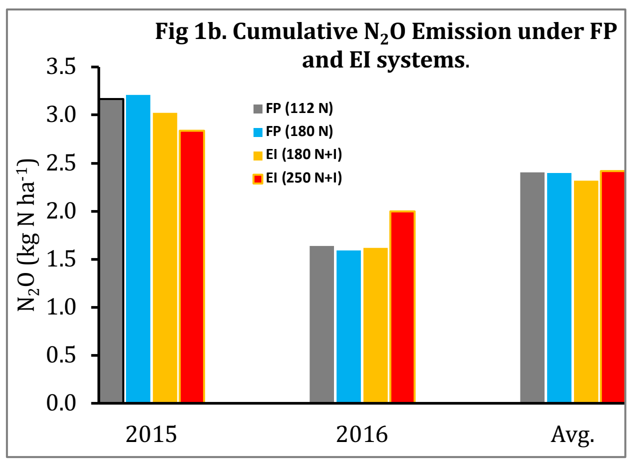
For all experiments, N_2O emissions were measured two times a week for 6-8 weeks following early sidedress UAN application, and weekly thereafter till corn maturity. Cumulative seasonal N_2O emissions were calculated by linear interpolation of daily N_2O between measurement dates and for the growing season. At maturity, corn was harvested (grain and above-ground stover), grain and stover N concentrations and uptake were determined, and each plot's NRE was calculated. From these data, the relationships between N_2O and NRE and/or NUE were evaluated using linear regression models.

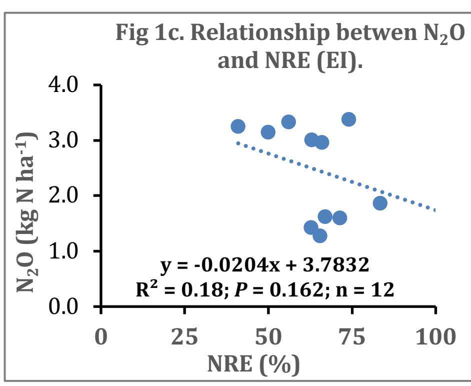
Results and Discussion

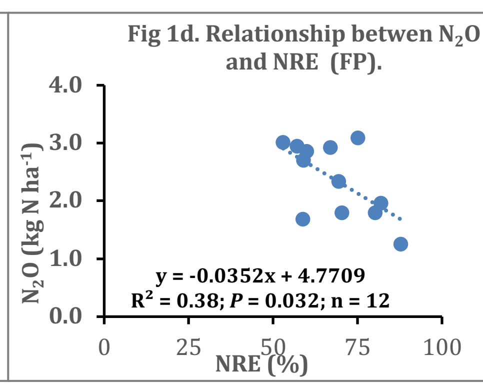
<u>Expt. #1: Management by ecological intensification and farmer practices:</u>

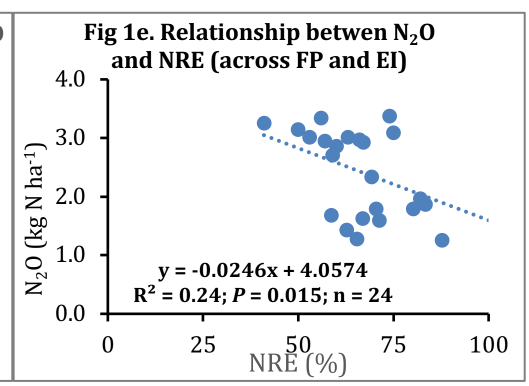
Grain yield, NRE and N_2O loss varied by corn management practice and year of application. Across years, grain yield was significantly greatest for EI (250N+I) but NRE and cumulative N_2O losses (Fig. 1a, b) were similar among practices (excluding 0N). Remarkably, the EI practices were able to maintain NRE despite lower overall N rates than those in FP. On average, seasonal N_2O emission was not higher for EI (2.19 kg N ha^{-1}) compared to FP (2.12 kg N ha^{-1}) despite the higher N rates in EI. Overall, negative linear relationships existed between N_2O and NRE, regardless of management practice (Fig. 1c-e). Cumulative N_2O loss decreased by 20 g N ha^{-1} (but not significantly) under EI, by 35 g N ha^{-1} under FP, and by 25 g N ha^{-1} across practices, for every percentage point increase of NRE (Fig. 1c-e).











Expt. #2: Long-term tillage systems:

Nitrous oxide emission and its relationships to NRE under long term tillage systems are shown in Figures 2 and 3. Overall, NRE and N_2O emission intensity varied by year and tillage system (Fig 2a and b). Nitrogen recovery efficiency was significantly greatest for ST (58.5%) and smallest for CP (45.2%) in 2015 but was similar among tillage systems in 2016 (Fig 2a). In contrast, cumulative N_2O was not significantly different between years or across tillage systems in either 2015 or 2016 (Fig 2b).

Significant negative linear relationships existed between N_2O and NRE under NT and ST systems (Fig. 3 a,b), similar to the negative relationships observed in the FP and EI management systems in Experiment #1. On average, N_2O decreased by 17 and 13 g N ha^{-1}, respectively, under ST and NT for every percentage increase of NRE. However, the same relationships were not significant for CP- and MP-based conventional tillage systems (Fig. 3 c-d).

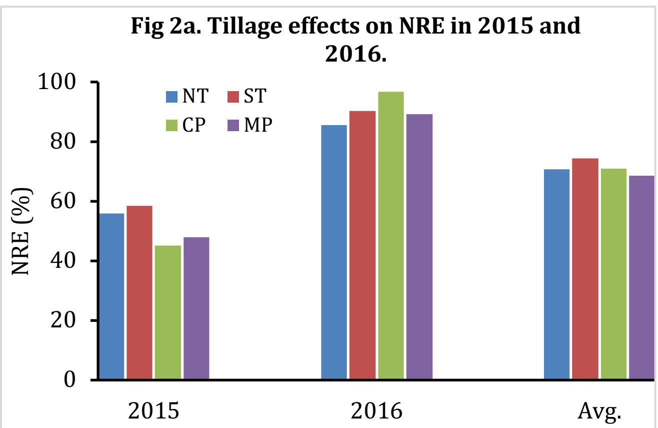


Fig 2a. Tillage effects on NRE in 2015 and 2016.

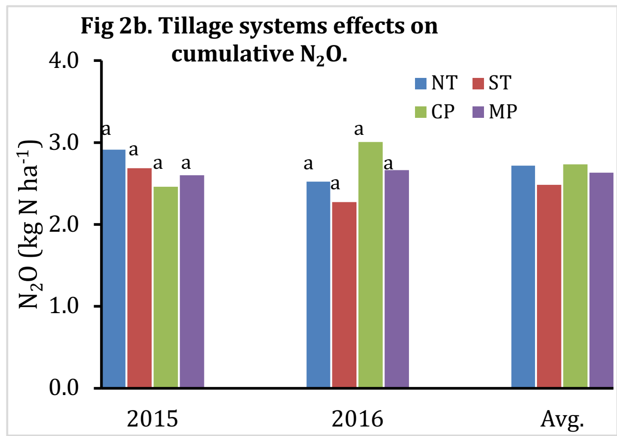


Fig 2b. Tillage systems effects on cumulative N_2O.

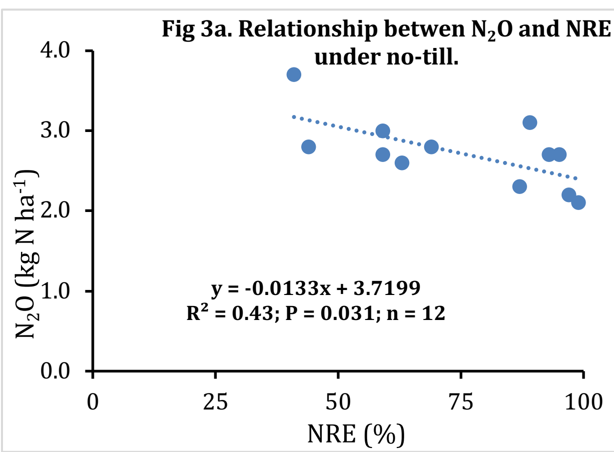


Fig 3a. Relationship betwen N_2O and NRE under no-till.

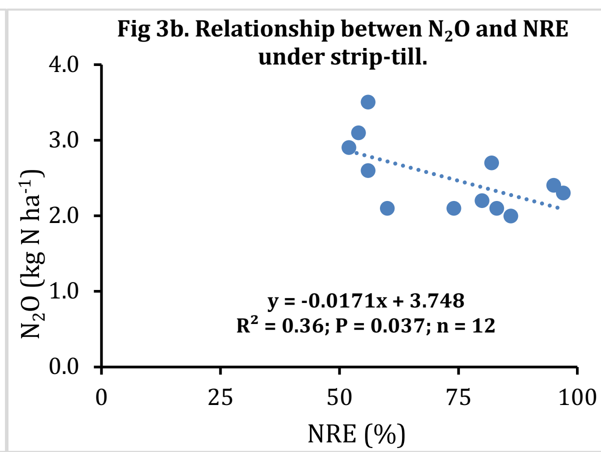


Fig 3b. Relationship betwen N_2O and NRE under strip-till.

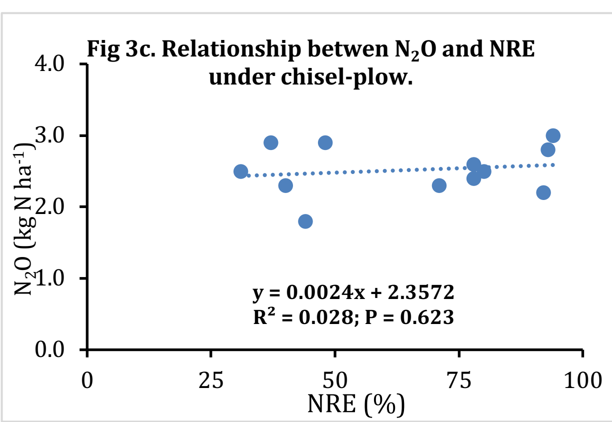


Fig 3c. Relationship betwen N_2O and NRE under chisel-plow.

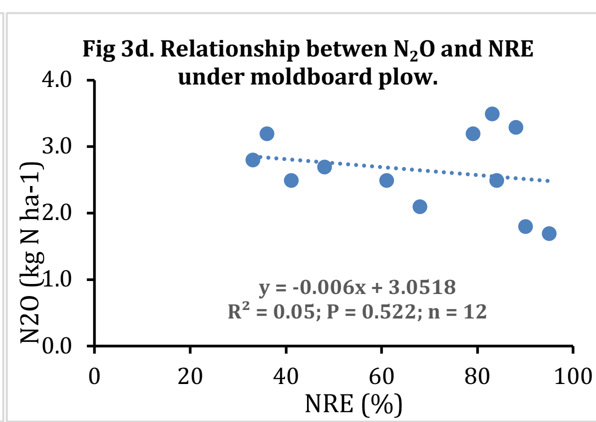


Fig 3d. Relationship betwen N_2O and NRE under moldboard plow.

Experiment #3: Single early sidedress and supplemental late-vegetative N applications:

For this location, N_2O losses were relatively low and inconsistent in both 2015 and 2016 (Fig. 4a). In 2015, seasonal cumulative N_2O loss was significantly affected by timing of N application ($P = 0.009$) and N_2O loss was greater for 245 and 245S relative to other N rates (Fig. 4b). Similarly, cumulative N_2O for 2016 was greatest under 245S compared especially to lower N rates applications (Fig. 4c). Overall, intentionally late-vegetative N application did not reduce N_2O compared to a single early sidedress. On the contrary, late-vegetative N application tended to increase N_2O emissions in 2016 by up to 35% for the 160 kg N ha^{-1}, and ~17% under the 245 kg N ha^{-1} rate.

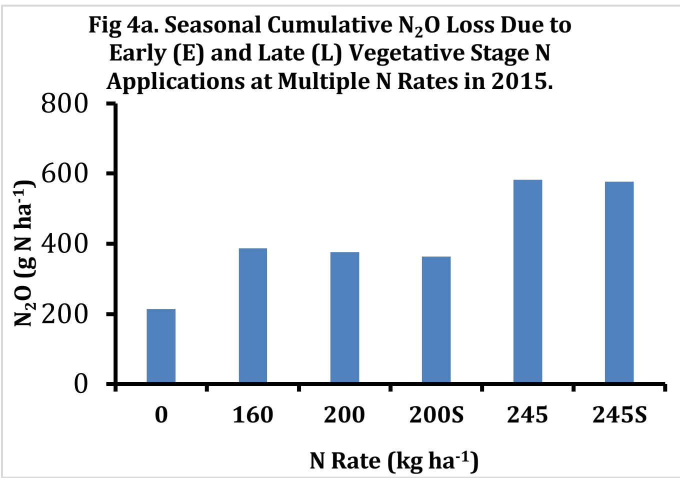


Fig 4a. Seasonal Cumulative N_2O Loss Due to Early (E) and Late (L) Vegetative Stage N Applications at Multiple N Rates in 2015.

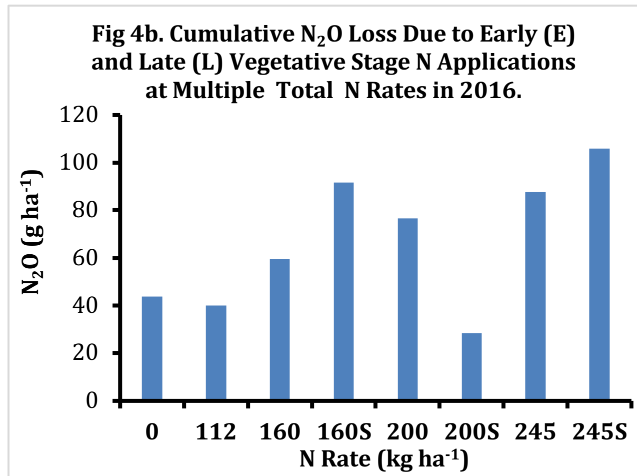


Fig 4b. Cumulative N_2O Loss Due to Early (E) and Late (L) Vegetative Stage N Applications at Multiple Total N Rates in 2016.

The relationships between cumulative N_2O and NRE varied by treatment, and year of application (Fig. 5). Overall, relatively weak (non-significant) but negative linear relationships existed between N_2O and NRE such that N_2O decreased by ~10 g ha^{-1} for every percentage point increase of NRE in 2015 at PPAC (Fig. 5a; negligible decrease in 2016, Fig. 5b).

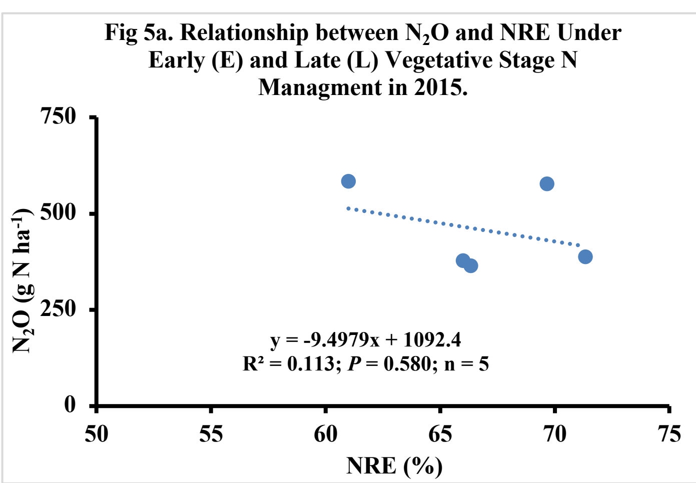


Fig 5a. Relationship between N_2O and NRE Under Early (E) and Late (L) Vegetative Stage N Managment in 2015.

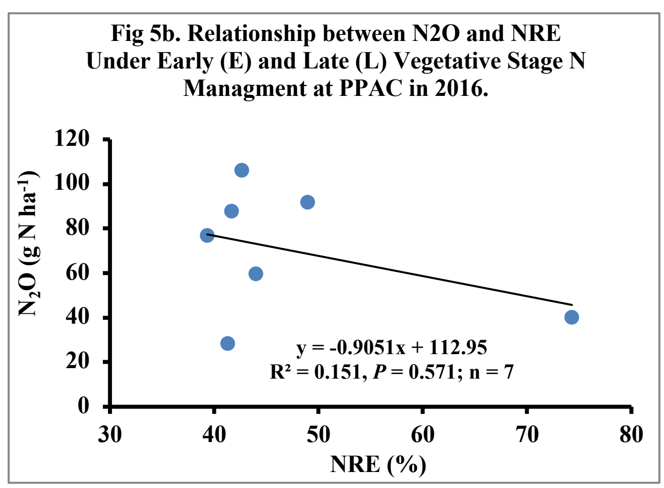


Fig 5b. Relationship between N2O and NRE Under Early (E) and Late (L) Vegetative Stage N Managment at PPAC in 2016.

Tentative Conclusions

Our two-year data suggested that functional, negative linear relationships existed between N_2O emission and NRE for Indiana corn production at high yield levels under a wide range of N management and tillage systems. Our N fertilizer management contrasts involved altering rates, timing, and presence of nitrification inhibitors. Our corn management contrasts involved multiple tillage systems and two plant densities. The majority of the data supported the hypothesis that N_2O would decrease with an increase of NRE following optimized N fertilizer applications to corn. Our models showed that area-scaled, cumulative N_2O losses during the growing season were reduced by up to 35 g N ha^{-1} for every percent increase of NRE by corn in that season. However, both the slope and strength of the relationships (r^2) varied significantly due to year-to-year variability of N_2O and NRE, insufficient data points employed in the models, and perhaps because the relative timings of peak N_2O emissions and peak corn plant N uptake did not coincide sufficiently (even with sidedress N timing). This research made a strong contribution to the understanding of N_2O relationships with N fertilizer efficiencies in a rainfed production environment. However, research foundation building concerning these relationships should continue across an even wider spectrum of environments and 4R N management choices for modern corn production.

Outreach Activities:

Numerous presentations based on this research were made throughout the 3-year period. Some of these presentations were made to American Society of Agronomy Meetings, but several more were made to CCA Training Events in various Corn Belt states and Industry Sponsored Workshops (including the 4R Nutrient Stewardship Workshops).

Abstracts of posters or oral talks presented at professional meetings include the following:

1. Omonode Rex A., and Tony J. Vyn. 2016. Effects of ecological intensification and late-split N timing on the relationship between nitrous oxide emission and nitrogen recovery efficiency in corn. Abstract 47-19; ASA-SSSA-CSSA International Annual Meeting, Phoenix, AZ. Nov 6-9, 2016. https://scisoc.confex.com/crops/2016am/webprogram/Paper101816.html

2. Vyn, Tony and Rex Omonode. 2016. Relationship between nitrous oxide emission and nitrogen uptake and use efficiency in corn cropping systems. Presentation at the International Plant Nutrient Institute and Fertilizers Canada's North American 4R Nutrient Stewardship Researchers Meeting, Remington Room, Hyatt Regency, Phoenix, AZ. November 6, 2016.

3. Omonode, Rex A., and Tony J. Vyn. 2015. Integrated nitrogen rate and nitrification inhibitor application effects on nitrogen use efficiency and nitrous oxide emission in rainfed corn. Abstract 183-3; ASA-SSSA-CSSA International Annual Meeting, Minneapolis, MN. Nov 15-19, 2015. https://scisoc.confex.com/scisoc/2015am/webprogram/Paper93932.html

4. Omonode, Rex A., Douglas Smith, and Tony J. Vyn. 2015. Trace gas fluxes, global warming potential and greenhouse gas intensity related to tillage and nitrogen application with and without nitrapyrin in rainfed corn. Abstract 79-1; ASA-SSSA-CSSA International Annual Meeting, Minneapolis, MN. Nov 15-19, 2015. https://scisoc.confex.com/scisoc/2015am/webprogram/Paper94328.html

5. Omonode, R.A., Cliff Johnston, and Tony J. Vyn. 2014. Nitrification kinetics and nitrous oxide emissions in long-term tillage systems following co-application of urea-ammonium-nitrate and Nitrapyrin. ASA Abstract # 257-6: ASA, CSSA, SSSA Annual Meetings. Long Beach, CA. Nov. 2-5 2014. https://scisoc.confex.com/scisoc/2014am/webprogram/Paper89190.html

Submitted Publications:
In 2017, we submitted two relevant publications about this research to refereed journals and these are under review and revision. These are described below. More publications are planned when funding is available.

Omonode, R.A, and T.J. Vyn*. 2017. Tillage and Nitrogen Source Impacts on Relationships Between Nitrous Oxide Emission and Nitrogen Recovery Efficiency in Corn. Submitted to J. Environ. Quality (9-21-2017).

Omonode, R.A., D.R. Smith and T.J. Vyn*. 2017. Nitrapyrin Application Reduced Nitrous Oxide Emissions from Urea-Ammonium Nitrate in Multi-Year On-Farm Corn Trials. Submitted to Agron. J. (08-05-2017)

Published References Cited in Final Report:

Mueller, S.M.*, J. Camberato, C. Messina, J. Shanahan, H. Zhang and T.J. Vyn*. 2017. Late-split N applications increased maize plant N recovery but not yield under moderate to high N rates. Agron. J. 109: 2689-2699 doi:10.2134/agronj2017.05.0282

Omonode, R.A., A. D. Halvorson, B. Gagnon, and T.J. Vyn*. 2017. Achieving lower nitrogen balance and higher nitrogen recovery efficiency reduces nitrous oxide emissions in North America's maize cropping systems. Frontiers in Plant Science 8:1080. doi: 10.3389/fpls.2017.01080