FERTILIZER-DERIVED NITROGEN FATE IN MINNESOTA CORN WITH RYE AND KURA CLOVER COVER CROPS

Jacob E. Kastenbauer, Fabián G. Fernández, Vasudha Sharma, Rodney T. Venterea, Jared A. Spackman
University of Minnesota - St. Paul, Minnesota
kaste178@umn.edu
763-447-5805

ABSTRACT

While ideally all fertilizer nitrogen (N) is utilized by crops, much can be lost to the environment as nitrate (NO_3), nitrous oxide (N_2O), or ammonia (NH_3). To enhance agronomic systems and mitigate environmental N loss, best management practices can be utilized. Here, urea was applied to continuous corn at 250 kg N/ha or a 0 kg N/ha control, and with select cover crops (no cover, winter rye, kura clover) to assess practices that may result in optimal fertilizer N utilization. Rye and no cover crop treatments showed significantly greater yield compared to both fertilized and unfertilized kura clover treatments, suggesting kura clover competes with corn for N availability. Volatilization of NH_3 was even across rate and cover crop treatments, though these losses only accounted for a small fraction of total N applied. Greater NO_3 leaching was shown with increased N rates for no cover crop and rye treatments, though this effect was smaller for kura clover, likely due to continuous deposition of kura biomass. Greater N_2O emissions were observed with increased fertilizer rates across all cover crop treatments, with the greatest emissions coming from kura clover, likely due to strong microbial interactions. Analysis of isotopic N dispersion shows that kura clover increased the loss of fertilizer-derived N_2O relative to rye and no cover treatments. Meanwhile, rye treatments showed greater fertilizer-derived NO_3 losses relative to kura clover. There was no difference in fertilizer-derived NH_3 across cover crop treatments. In total, only 1.38, 4.00, and 2.87 percent of applied fertilizer N was lost from the system in kura, rye and no cover treatments, respectively, suggesting an idealized nutrient management system. Further isotopic analysis of corn, cover crop, and soil N pools will help determine where fertilizer-derived N disperses in a given growing season.

INTRODUCTION

As the global demand for food and commodity goods increases, so does the demand for N to enhance crop production. While fertilizer-derived N is ideally utilized by crops, much can remain in the soil or be lost to the environment in various forms such as NO_3, N_2O, and NH_3. The loss of N from soil into the environment can cause substantial economic and environmental harm as it reduces crop yield for producers, amplifies the effects of global climate change, diminishes air and water quality, and disrupts natural ecosystem processes (Kumar et al., 2018; Stark & Richards, 2008). Economically optimum N rates (EONR) have been utilized to optimize crop uptake of fertilizer N with less loss of N to the environment and minimal economic loss to crop producers (Rubin et al, 2016). By investigating optimum fertilizer N input rates producers may profit from fewer agricultural inputs while still yielding crops that satisfy consumer driven markets.

The use of cover crops has also obtained increased interest in central Minnesota as they may be useful tools in combating the water and N loss common in this area. Substantial research has been done with N scavengers, such as winter rye, and N fixers, such as kura clover to determine their potential to enhance soil health (Krueger et al., 2011; Logsdon et al., 2002; Sainju and Singh, 1997) and influence soil biogeochemistry (Alexander et al., 2019; Peterson et al., 2002). However, relatively little is known about their potential to mitigate NO_3 leaching, N_2O emissions, or NH_3 volatilization (McCracken et al., 1994; Ochsner et al., 2010), or about best nitrogen management practices when these crops are growing in combination with corn specifically (Krueger et al., 2011; Pedersen and Albrecht, 2009).

To best assess the utilization or loss of N, stable isotopes can be used to trace the movement of N in crop-soil systems. Crops commonly grown in Minnesota, such as corn, may take up naturally occurring N (^{14}N) or anthropogenically introduced isotopes of N (^{15}N) throughout the growing season. With the introduction of ^{15}N enriched fertilizers, plants may incorporate this N isotope into their biomass, thereby allowing for the detection of fertilizer-derived N in field crops. Similarly, this technique can show where in soil, water, and gas fractions fertilizer-derived ^{15}N is, and in what chemical form. While isotopically labelled fertilizers have been utilized in agricultural soils before (Tran and Giroux,1998; Walter and Malzer, 1990; Lacey et al., 2022), much remains unknown about how ^{15}N fertilizers respond in central Minnesota sandy soils with additional cover crop by N rate combinations. Overall, this study aims to leverage a ^{15}N isotopic tracing approach to better determine fertilizer-derived N loss pathways in corn to address sustainable use of fertilizers and cover crop systems in sandy soil of central Minnesota, thereby allowing for greater economic returns for producers while limiting N outputs to the local environment.

MATERIALS AND METHODS

This study was conducted starting in the spring of 2023 at the Rosholt Research Farm (Westport, MN) as part of an ongoing study. Plots of continuous corn have been in place for several years, utilizing a winter-annul rye cover crop, continuous kura clover living mulch, or no additional crop as a control since 2016. Urea fertilizer with a urease inhibitor was applied as a four-way split application administer incrementally using 90-270 lbs N/ac, with no fertilizer addition as a control. Upon application, fertilizer was incorporated into the soil with a small amount of irrigation. Treatments were replicated four times in a randomized complete block design. To trace the utilization of fertilizer N by crops or loss from the soil, a ^{15}N isotopic enrichment was utilized for a subset of plots. Microplots were established in unfertilized control plots along with 225 lbs N/ac treatment blocks which were applied with 5 atom % ^{15}N urea.

Agronomic and environmental responses were obtained for each cover crop by N rate treatment. Agronomic responses were assessed as corn grain yield. Environmental responses were assessed for NO_3, N_2O, and NH_3. Pre-established lysimeters were utilized at this site to examine the loss of N from the soil as NO_3. Installed approximately 48 inches below the soil surface and below the crop rooting zone, the lysimeters were used to collect soil water samples for NO_3 analysis and combined with water model data to obtain flow-weighted NO_3 load responses per treatment. Water samples were collected once per week and analyzed for NO_3 concentration beginning with ground thaw in April and lasting until freeze around November each year. Ammonia volatilization and nitrous oxide emissions were also measured throughout the growing season. Nitrous oxide emissions were measured two to three times a week using static chambers and a portable gas analyzer. Ammonia volatilization was measured by utilizing exchangeable acid traps 1, 4, 7, 14, and 21 days after planting and fertilizer application events. Data was analyzed with a mixed effect linear regression model using Rstudio.

RESULTS AND DISCUSSION

Preliminary results suggest that corn grain yield follows a positive relationship with fertilizer N rate. It is well known that increasing N rate to an optimum level can increase grain yield and enhance crop performance. This was observed in all cover crop treatments, with the EONR rate of 225 lb N/ac resulting in substantially higher yields compared to a 0 lbs N/ac control. At the EONR rate there were significant differences in yield between kura clover (193 bu/ac) and both rye (262 bu/ac) and no cover crop (255 bu/ac) treatments, with kura clover decreasing grain yield relative to the other treatments. This is likely due to the living mulch competing for water and bioavailable N within the growing season, thereby limiting corn to obtain essential resources needed to enhance crop performance. There was no significant difference in yield between unfertilized cover crop treatments, suggesting additional plant tissue or biological nitrogen fixation was not sufficient in supplementing crop growth (Figure 1).

From spring to fall of 2023 NO_3 was the greatest source of N loss from the soil system. Nitrate leaching load strongly correlated with water inputs into the soil system, with large precipitation and irrigation events allowing for the movement of soluble NO_3 through the soil. These losses increased with N rate, possibly due to rapid nitrification of the inorganic fertilizer upon application. Among unfertilized plots there was no difference in cumulative NO_3 leaching load between rye and no cover crop treatments. However, unfertilized kura clover showed increased leaching likely due to a small amount of biological nitrogen fixation and routine plant tissue deposition. In fertilized plots the no cover control showed the greatest leaching (122 lbs N/ac) followed by rye (90 lbs N/ac) and kura clover treatments (56 lbs N/ac). This is likely due to cover crop biomass utilizing available soil water and N that would otherwise leach from the system, especially in spring when little to no corn biomass is present (Figure 2).

Throughout the growing season both environmental gas fractions, N_2O and NH_3 remained relatively low. Nitrous oxide emissions responded to N rate, with greater fertilizer inputs resulting in increased N_2O production, likely driven by greater rates of denitrification. Among unfertilized cover crop treatments there was no difference in cumulative season-long N_2O emissions, suggesting that any additional bioavailable N from crop tissues or biological nitrogen fixation was negligible in denitrification processes. In fertilized cover crop treatments kura clover showed greater cumulative N_2O emissions (0.43 lbs N/ac) compared to rye (0.20 lbs N/ac) and no cover crop (0.21 lbs N/ac). As kura clover biomass increased with fertilizer N, the additional biomass likely provided substantially greater plant tissue that became redeposited to the soil, spurring denitrification particularly in the second half of the growing season when the crop may have been outcompeted by corn (Figure 3). Similar to N_2O, cumulative season-long loss of NH_3 was relatively low (0.82 – 0.96 lbs N/ac). There were no significant differences in NH_3 volatilization between any cover crop or N rate treatments. As this study utilizes best management practices that are intended to minimize volatilization, small losses of NH_3 are to be expected (Table 1).

The use of ^{15}N allowed for the tracing of fertilizer-derived nitrogen (FDN) into distinct environmental fractions. No cover crop plots showed no difference in fertilizer-derived nitrate ($FDNO_3$-N) compared to kura clover or rye treatments, however kura clover was significantly lower in $FDNO_3$-N compared to rye likely due to the clover's ability to take up additional FDN throughout the growing season. Kura clover also showed a difference in fertilizer-derived nitrous oxide (FDN_2O-N) compared to other cover crop systems with greater FDN_2O-N than both rye and no cover. As the clover likely incorporated ^{15}N into its biomass, subsequent tissue deposition may have been a viable source of N for denitrification processes. No differences in fertilizer-derived ammonia ($FDNH_3$-N) were observed between cover crop systems, likely due to idealized application systems (Table 1). Total season-long losses as FDN were mostly in the form of NO_3, followed by small amounts of NH_3 and NO_3, representing 1.38, 4.00, and 2.87% of total applied N in kura, rye, and no cover treatments respectively. This suggests that in corn production systems that utilize best management practices, there is a high potential to minimize FDN losses, a key strategy for enhancing environmentally responsible agriculture.

Figure 1. Corn grain yield response to cover crop and N fertilizer rate

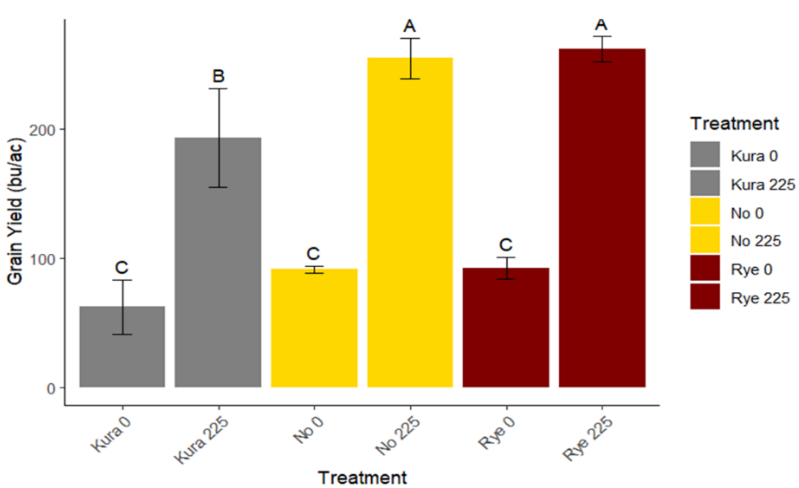

Figure 2. Cumulative soil nitrate leaching load by N rate and cover crop treatments

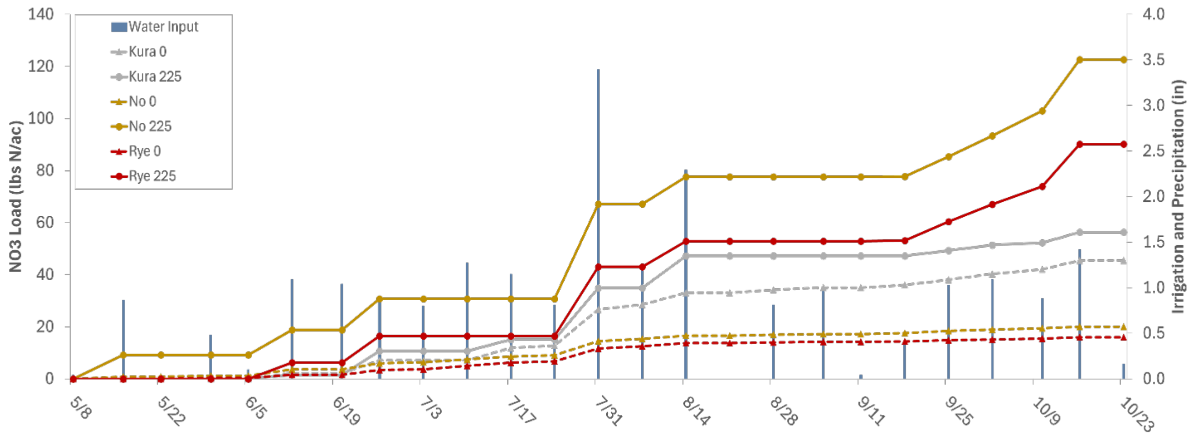

Figure 3. Cumulative soil nitrous oxide emissions by N rate and cover crop treatments

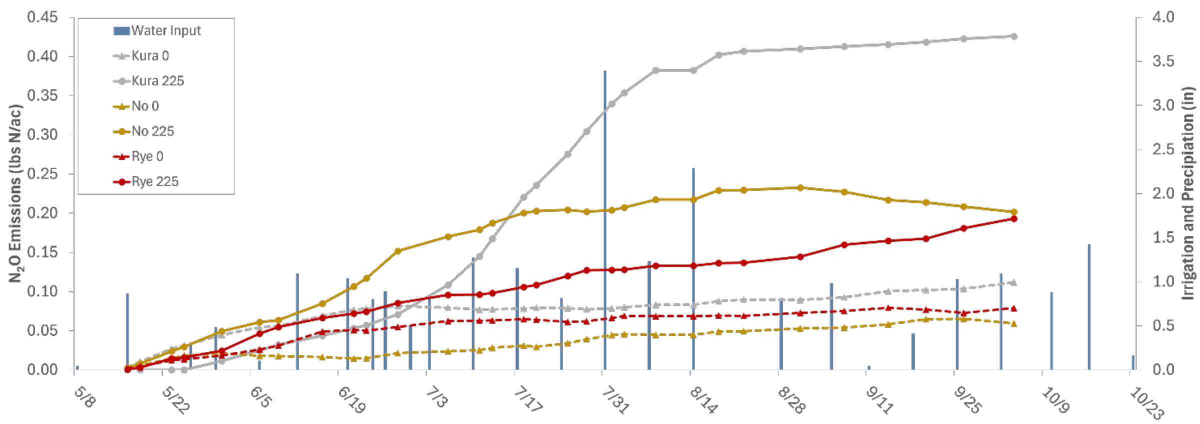

Table 1. Season long N losses and 15N fertilizer-derived nitrogen (FDN) losses in nitrate, ammonia, and nitrous oxide fractions.

Treatment	NO_3-N	$FDNO_3$-N	NH_3-N	$FDNH_3$-N	N_2O-N	FDN_2O-N	Total FDN Loss
		- - - -		lbs N / ac	- - - -		
No	122.09a	5.74ab	0.82a	0.02a	0.21b	0.01b	5.76ab
Rye	89.82b	8.00a	0.96a	0.02a	0.20b	0.01b	8.03a
Kura	55.54c	2.72b	0.93a	0.02a	0.43a	0.02a	2.76b

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