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Abstract

The widespread practice of applying nitrogen fertilizer to corn monoculture provides the farmer with a dilemma: apply too little fertilizer and lose yield, or apply too much and spend excess money while contributing to significant environmental problems? This study sought to explore this dilemma by comparing the effects of varying nitrogen fertilizer levels and application methods. Soil characteristics (moisture, bulk density, and organic matter content), nutrient properties (NO_3, NH_4, and PO_4 concentrations), macroinvetebrate communities, cornstalk nitrate concentrations, and economic return data were collected from cornfields having undergone four fertilizer treatments (0 N, 30 lbs/acre applied by side-dressing or injection into the soil, and 54 lbs/acre applied by both side-dressing and dribbling on the soil surface). Soil moisture and organic content were significantly lower in the dribbled section, and corn moisture also varied significantly. Cornstalk nitrate increased with higher application levels but was deficient for the dribble-fertilized sample. Economic returns showed a general increase with increased nitrogen fertilizer application and supported the idea that side-dressing is a more cost-effective and efficient method of applying nitrogen than conventional dribbling.

Introduction

The production of corn is central to the landscape and economy of a large portion of the Midwestern United States, including Minnesota. 26 million hectares in only five states of this region is occupied by the agroecosystem of alternating corn and soybeans (Russel et al 2009). The manipulation of soil nutrient levels through the application of nitrogen fertilizer has correlated positively with increased corn yield, plant maturation rate, and soil organic carbon levels (Seungdo et al 2008, Zhang et al. 2008). This technology has allowed for a production boom, and corn is currently fertilized on 97-100% of Midwestern farms. On average, fertilizer is applied at a rate of 135 kg N per hectare per year (Russel et al 2009). While this practice is very helpful in terms of increasing yield, it also has significant financial and environmental costs. Excess fertilizer can run off of agricultural lands and pollute nearby soil and waterways, disrupting the functioning of local ecosystems (Seungdo et al 2008). Concentrations of soil nitrate increase with higher levels of fertilization, nitrate which can then leach through the soil and into waterways, causing eutrophication and hypoxia (Xingping et al 2004). Soil testing is often used to determine necessary rates of fertilizer, lots of energy has gone into trying to determine the minimum economically viable level of N fertilizer to apply in order to maximize yields without creating nitrogen pollution (Yu-Kui et al. 2009, Kachanoski 2009).

The nutritional quality of corn is also a concern directly affected by the level of nitrate fertilizer applied to it. As one might expect, concentrations of nitrogen in above-ground plant tissue tends to increase with higher levels of N application (Xingping et al. 2004). Corn silage with high nitrate levels can be toxic to animals (Heininger et al.). Consequently, it is imperative to determine an optimal level of nitrate fertilizer application that maximizes economic returns and results in a healthy plant nitrate content (Seungdo et al. 2008).

Conflict also exists as to how nitrogen fertilizer should be applied. While its common practice to fertilize in the fall after harvest, much of the nitrogen applied in this manner is lost via runoff before the next growing season comes around. This results in both negative economic impacts on the farmer (who spends too much on fertilizer), and the environment (Dave Legvold, personal communication, 2010). Additionally, many farmers apply nitrogen fertilizer by dribbling it on the soil surface; however, a study by

Blackmer et al. concluded that side-dressing (injecting the nitrogen into the soil directly at the base of the plant) is a more efficient means of applying fertilizer (1998).

This study will examine a section of farmland owned by St Olaf College in Northfield, MN that is currently being cultivated by David Legvold, an environmentally-conscious local farmer, as a four-year corn-on-corn project (rather than the typical corn-on-soybean annual rotation). The field is part of a carbon offset credit system and is annually planted with corn and strip tilled in order to maximize carbon sequestration (David Legvold, personal communication, 2010). Soil nitrate, ammonium, and phosphorus concentrations as well as soil moisture, organic matter, bulk density, and macroinvertebrate biomass and diversity will be compared between fields fertilized with 4 different treatments of liquid ammonium nitrate fertilizer, 3 side-dressed and 1 dribbled. Additionally, cornstalk nitrate concentration, C:N ratio, crop yields, and economic returns will be compared between these four fields and one more that received an excessive rate of nitrogen application. The hypotheses guiding this research are 1) That soil characteristics will vary between fertilizer treatments, 2) that more intensive fertilizer regimes will correspond with higher soil nutrient levels, 3) that yield and economic returns will be greater for higher rates of fertilizer application, and 4) that side-dressing will be a more economically profitably fertilization method than dribbling.

Methods

Study site: I conducted this study on an agricultural field farmed by David Legvold and owned by St. Olaf College in Northfield, Minnesota. The field is currently in its second year of corn production as part of a carbon offset program run by the college. Phosphorus and potassium were applied to the field after harvest in the fall of 2009, and dry urea was applied prior to planting. Dave applied varying treatments of nitrogen fertilizer in the form of liquid 28% ammonium nitrate when the corn was 1' tall. A recommended N amount was determined using the online Iowa State N Calculator, which takes into account fertilizer price, grain selling price, and crop history. For Dave's fields, the recommended rate was 54 lbs N/acre. Three conservative treatment levels (0 N, 30 lbs/acre, and 54 lbs/acre) were applied via the side-dressing method of application, wherein the fertilizer is injected directly into the soil at the base of the plant, and one section was fertilized at the recommended 54 lbs/acre rate but via the dribbled method (the fertilizer is released on the surface of the ground). Another field was fertilized by side-dressing at a liberal rate of 79.8 lbs/acre, but is only included in the stalk nitrate, corn moisture, yield, and economic returns segments of this study (David Legvold, personal communication, 2010).

Soil collection and analysis: I collected soil samples from the field in October 2010, prior to harvest. I selected 2 random points per treatment section and took samples to analyze for soil moisture, percent organic matter, and bulk density in addition to nutrient analysis. Moisture was determined by weighing the soils before and after a period of 24 hours in a drying oven; the water weight was then divided by the dry soil weight to obtain percent moisture for each sample. I determined bulk density by dividing the dry soil weight by the volume of the soil core. To discern organic matter content, dried and sieved samples were placed in a muffle furnace at 500 C for four hours. The percent organic matter was calculated by dividing the difference in weight after the muffle furnace by the original dry mass.

Analysis of soil nitrate content was conducted using a KCl extraction and Lachat. I determined soil phosphates by combining 2-g soil samples will 17 ml of 10% Mehlich 2 solution. 22 mL Millipore water was combined with 1 mL of each filtrate, and 1 mL of Phosphate 1 Reagent and 1 mL of Phosphate 2 Reagent was added to that and inverted to mix. The absorbance of these solutions was measured using a spectrophotometer (Mitchell 2009). I conducted a flourometric ammonium analysis as outlined by Schmidt and Kendit (2010).

Macroinvertebrates: To examine the macroinvertebrate community, I removed the top 12 cm of soil in a .25 x .25 m quadrat at each of previously determined random points. I examined the soil for invertebrates, preserved those found in ethanol, and dried them at 105 C to obtain a dry biomass (Mitchell 2009).

Stalk nitrate analysis: Before taking stalk samples for nitrate analysis, I verified that the corn had reached physiological maturity by peeling examining the end of several corn kernels for a thin black layer of tissue (David Legvold, personal communication, 2010). Then I collected 6 8" stalk segments (around 1' from the ground) per treatment field. The stalk segments were shipped to MN Valley Testing Laboratory for analysis.

Corn moisture: I collected 3 ears of corn per treatment, removed the kernels, and tested their moisture content using a corn moisture tester provided by Dave.

Yield and economic returns: The corn was harvested on November 4, 2010. One combine sweep per treatment (8 rows) resulted in a standard 30 x 1114 ft section of each field being collected and yield data obtained with a weigh wagon. Mike Ludwig from MONSANTO (the company that provided the seed for this experiment) provided data on grain selling price, drying charge, and gross returns. Dave Legvold provided data on input costs that were used to calculate economic returns.

Statistical analyses: Soil moisture, bulk density, organic matter, corn moisture, and earthworm biomass between treatments were compared using a one-way ANOVA test of variance. A one-way ANOVA was also used to compare the mean concentrations of soil NO_3-N, NH_4-N, and PO_4-P. All statistical analyses were conducted using R statistical software.

Results

Fertilizer treatment had a significant effect on soil moisture, as illustrated in Figure 1 ($p = 4.4 \times 10^{-14}$). The soil that was fertilized by dribbling as opposed to injecting had significantly lower mean percent soil moisture. Differences between soil bulk density under different fertilizer treatments was insignificant (Figure 2, $p = .107$). There was a significant difference between mean soil organic matter between treatments ($p = 2.01 \times 10^{-11}$). As illustrated in Figure 3, the field that was fertilized by dribbling had a significantly lower percentage of soil organic matter than did the other three experimental plots.

Both soil nitrate nitrogen and soil ammonium nitrogen varied insignificantly between treatments (Figure 4, $p = .28$ and $p = .60$, respectively). Overall, more nitrogen was available in the form of ammonium than nitrate, and ammonium did show a gradual trend towards a higher available soil nitrogen with increased fertilization for the injection-fertilized fields. The dribbled field had the lowest soil N concentration for both ammonium and nitrate. Soil phosphorus did not vary significantly between treatments, as seen in Figure 5 ($p = .22$).

Mean corn kernel moisture did vary significantly between treatments (Figure 6, $p = .03$). The section injected with 54 lbs/acre had higher kernel moisture than the other treatments, most notably the 30 lbs/acre injection. However, there is no clear pattern for this variation.

Cornstalk nitrate concentration by fertilizer treatment is summarized in Table 1. The unfertilized plot had a cornstalk nitrate concentration of 107 parts per million, which is considered deficient by MN Valley Testing Laboratories and indicates that the farmer probably lost yield by not applying enough fertilizer. The plots that were injected with 30 and 54 lbs/acre both fell in the optimum range of 700-2000 ppm, which concentrations of 715 and 1800, respectively. The extra plot that was fertilized with 79.8 lbs/acre had a concentration of 2600, which is considered excessive. Interestingly, the plot that received 54 lbs/acre of fertilizer by the dribbling method had a deficient cornstalk nitrate concentration of only 242 ppm.

All the macroinvertebrates found and collected throughout this study were earthworms, meaning diversity did not vary between treatments. Earthworm dry biomass also did not vary significantly between treatments (Figure 7, $p = .20$).

Net returns per acre are summarized in Table 2. Economic returns varied from $1,359.52/acre (0 nitrogen) to $1,499.15/acre (79.8 lbs N/acre). The 54 lbs/acre dribbled plot had a lower rate of economic returns than the 54 lbs/acre injection fertilized plot by $29.31/acre.

Discussion

While soil characteristics did not vary considerably between areas fertilized with different amounts of injected nitrogen, the application of N by surface dribbling rather than side-dressing correlated with a significantly lower percentage of both soil moisture and soil organic matter. This was similar to the results of Coulter et al., who found that soil organic matter content varies more with cropping system than fertilizer level (2009). It is likely that the low SOM and moisture of the dribbled field are related, since increased soil moisture has been found to positively influence decomposition and, consequently, the abundance of soil organic matter (Orchard and Cook, 1983). The relationship between organic matter and fertilization method could be due to the increased efficiency of plant nitrogen uptake in injected fields: by applying nitrogen directly into the soil, N losses could be minimized and the overall productivity of the soil community increased.

The lack of significant correlation between soil nitrogen and fertilizer treatment is surprising given the findings of Xingping and others, who concluded that concentrations of soil nitrate increase with higher levels of fertilizer application (2004). One potential explanation for this is the relatively "slippery" nature of nitrogen; when sampling late in the season, it is likely that much of the applied nitrogen that wasn't taken up by the plants had already been washed away in runoff (Blackmer et al. 1989). Beauchamp suggests that residual N decreases throughout the season in a curvilinear manner, and by harvest time would not vary significantly between fields with different fertilization histories (1987).

The higher concentrations of both NH4-N and NO3-N in fields side-dressed with 54 lbs/acre relative to those dribbled with the same amount is supportive of the theory that side-dressing is a more efficient means of delivering N to the crop (Steinhardt et al. 2002). Precise and direct N application can do a lot both to increase yield and to minimize N losses through leeching and denitrificaiton (Blackmer et al. 1989). The greater availability of N in the form of NH4 speaks to the plants' need for N in nitrate form in order to uptake it; because NO3 was in relatively low concentration throughout the soil, we can theorize that at the time of sampling, the plants had already taken up the majority of available N in the soil.

Because the amount of pre-planting phosphorus applied was the same across all fields, it is unsurprising that soil P concentrations did not vary significantly between sample plots (Dave Legvold, personal communication, 2010).

Typically, corn kernels have to be at 15% moisture or less before they can be safely stored. Therefore, it is to the farmer's advantage to wait to harvest the corn until it is at a sufficiently low moisture level to minimize drying charges (Mike Ludwig, personal communication, 2010). Although this study found a significant difference in mean kernel moisture between treatments, no discernable trend occurred and a relationship between N fertilizer treatment and corn kernel moisture cannot be concluded. Corn moisture must be dependent on other factors, such as the local soil characteristics of the field or inter-plant variation.

The increase in cornstalk nitrate concentration with increased N fertilizer applied is consistent with the results described in the literature (Balkcom et al. 2003, Xingping et al. 2004). Minnesota Valley Testing Laboratories have identified the optimal range of cornstalk nitrate to be between 700 and 2000 parts per million. Under 700 ppm suggests that yield was lost due to insufficient nitrogen application, and over 2000 ppm is indicative of excess nitrate losses to water sources as runoff (Balkcom et al. 2003). Excess nitrogen application is detrimental both from an economic standpoint, as fertilizer costs money, and from an environmental standpoint, since agricultural runoff is a common source of water pollution (Broussard and Turner 2009). Again, the lower cornstalk nitrate of the dribbled versus injected fields (242 ppm and 1800 ppm, respectively) suggests that dribbling is a less efficient means of delivering fertilizer to corn plants. The extra field that was fertilized with a high rate of 79.8 lbs/acre via side-dressing had the only "excessive" cornstalk nitrate concentration (2600 ppm), indicating that this field may have contributed to the contamination of nearby water sources through runoff. Another factor not taken into account here is early-season rainfall, which has been found to have a significant impact on both soil N concentration and cornstalk nitrate concentration (Balkcom et al. 2003).

Traditionally, N fertilization rate is determined by the "economic optimum rate" (EOR), which takes into account fertilizer price, crop history, and predicted grain selling price to determine an N rate that maximizes returns to the farmer (Kyveryga et al. 2007). This is the technique utilized by the Iowa State Nitrogen Calculator, which is was Dave's method for calculating a "standard" N rate. However, Kachanoski et al. found that the rate of yield response to increased fertilization decreased progressively with higher application rates (2009). The environmental concerns surrounding nitrogen fertilizer are causing farmers to question the ultimate value of traditional EORs. Kyveryga et al. suggest that alternative benchmarks for calculating optimum N are necessary in order to maximize N efficiency despite variability in crop yield (2007). Although this research indicates that a high nitrogen rate is preferable economically, it focuses on relatively low N systems and doesn't directly account for environmental conditions in factoring economic returns. Taking environmental externalities into account would further lower the optimal rate of N application and should be included in the restructuring of the EOR concept. Additionally, this research underlines the idea that side-dressing instead of dribbling as a mode of fertilizer application is an important measure, both in terms of conservation and economics.

Acknowledgements

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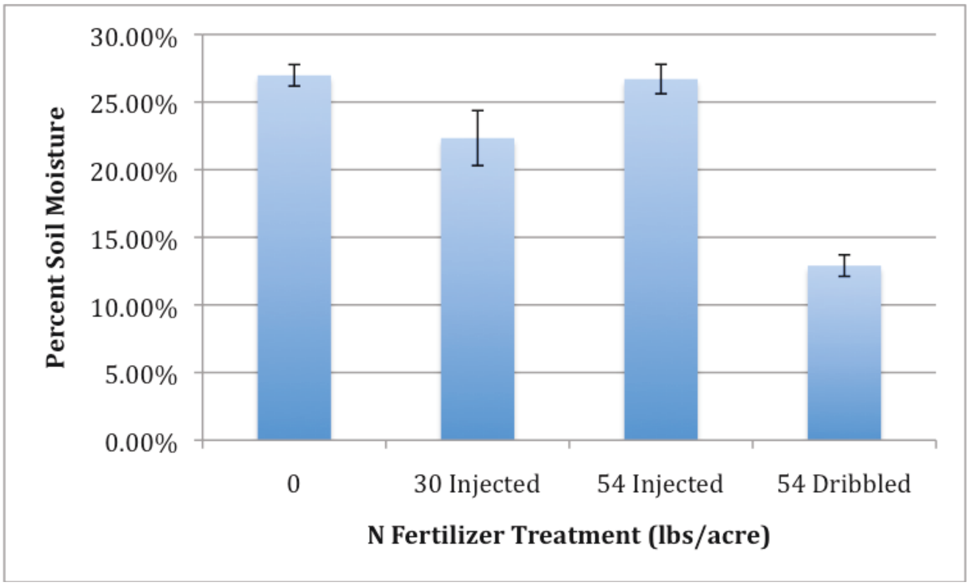

Figure 1. Comparison of mean soil moisture percentages between N fertilizer treatments southeastern MN cornfield. $P^* = 4.4 \times 10^{-14}$.

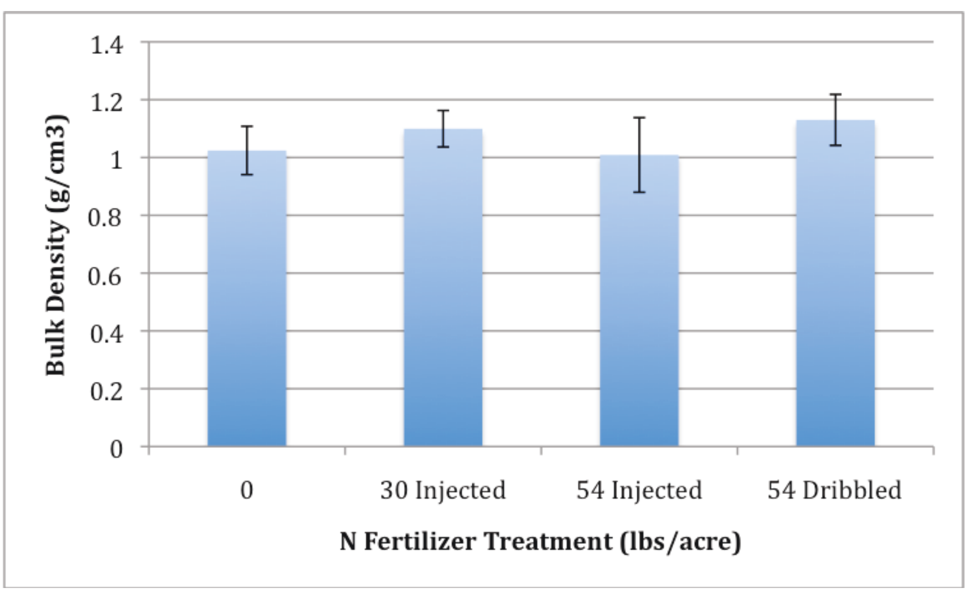

Figure 2. Comparison of mean soil bulk densities between N fertilizer treatments in southeastern MN cornfield. P = .107.

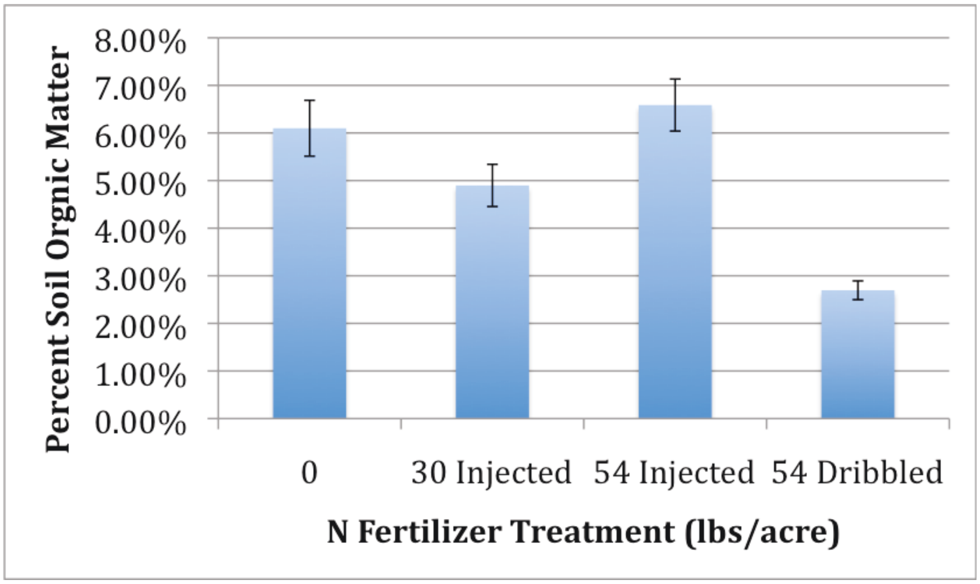

Figure 3. Mean percent soil organic material between N fertilizer treatments in cornfield of southeastern MN. P*=2.01 x 10^{-11}.

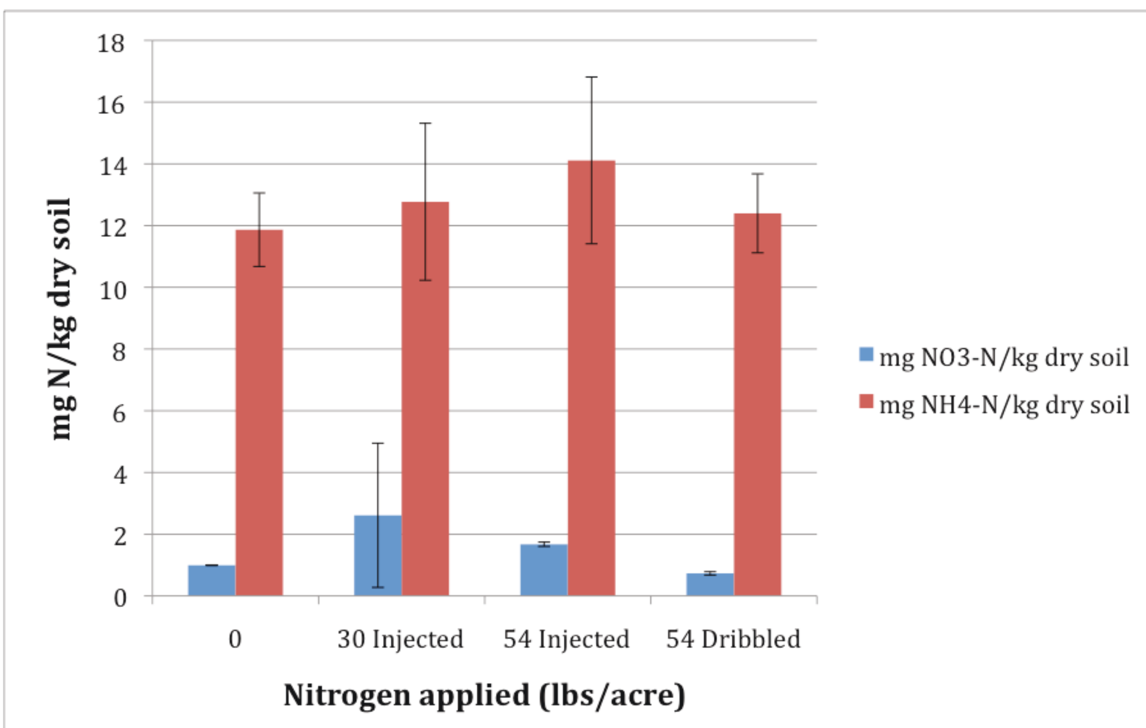

Figure 4. Comparison of mean N availability by form and fertilizer treatment in asoutheastern MN cornfield. P = .28 for NO3-N and p = .60 for NH4 N.

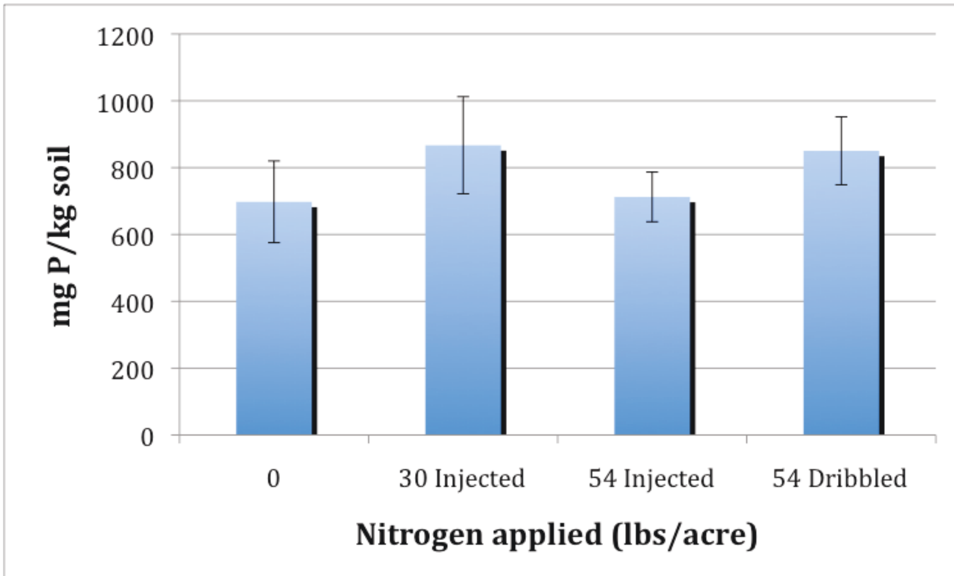

Figure 5. Available soil PO4-P by fertilizer treatment in southeastern MN cornfield. P = .22.

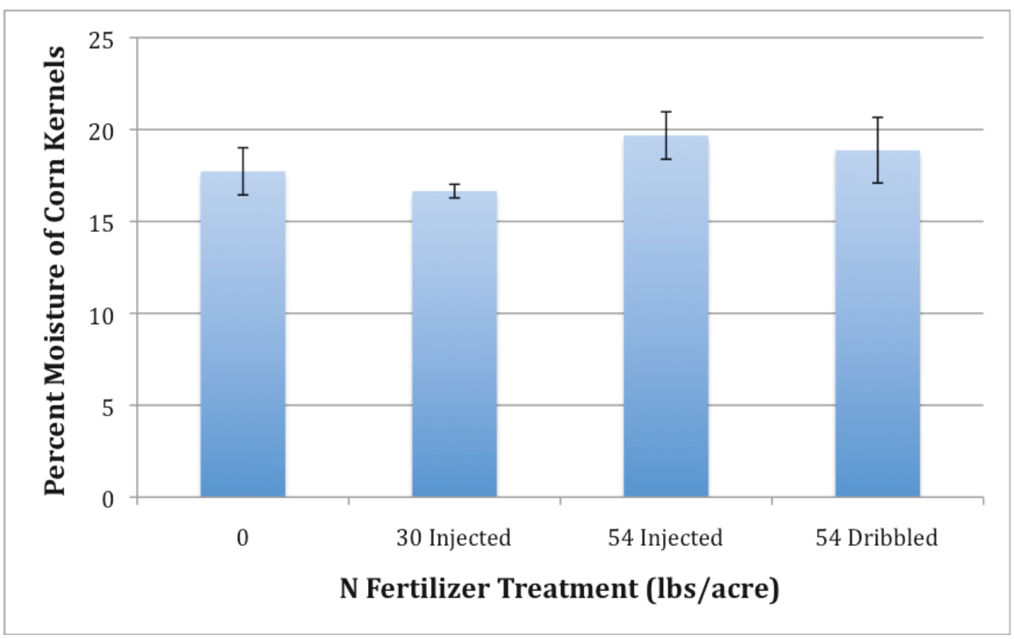

Figure 6. A comparison of mean percent moisture of corn kernels between varying N fertilizer treatments on a cornfield in southeastern MN. P* = .03.

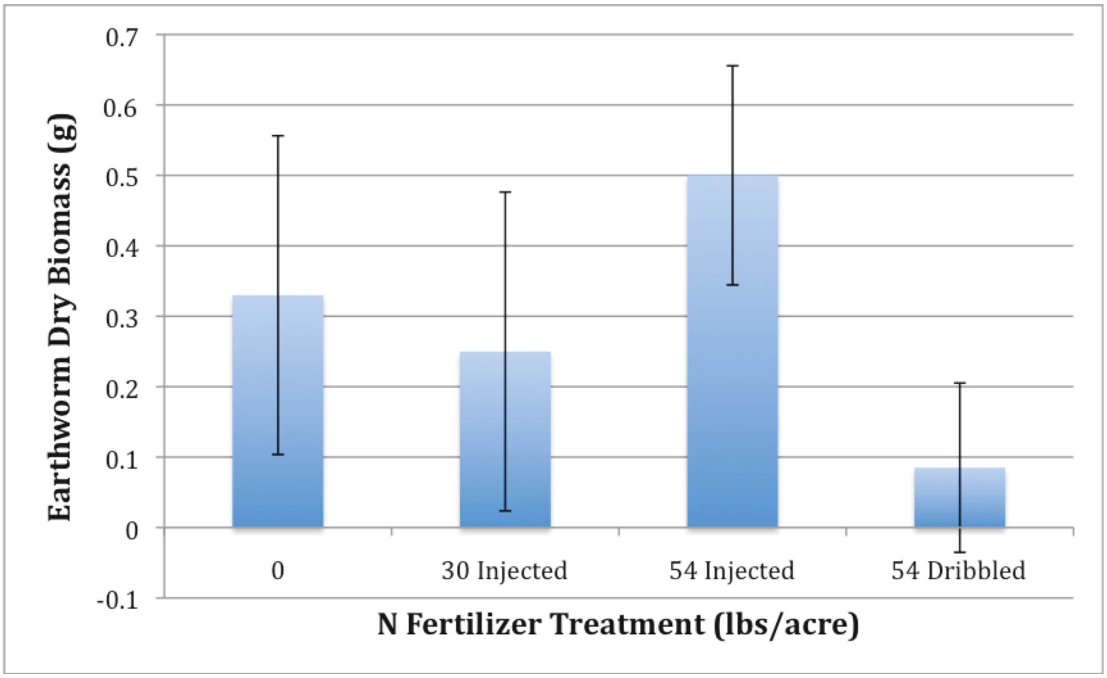

Figure 7. A comparison of the dry biomass of invertebrates (all earthworms) from .25 m x .25 m x 1' deep soil plots in southeastern MN cornfields having undergone four different nitrogen fertilizer treatments. P = .20.

Table 1. Summary of cornstalk nitrate concentrations in parts per million by N fertilizer treatment. Cornstalk nitrate of 0-700 is considered deficient; 700-2000 is optimal, and 2000+ is considered excessive.

Nitrogen Applied (lbs/acre)	Application Method	Cornstalk Nitrate (ppm)	Interpretation
0	Injected	107	Deficient
30	Injected	715	Optimum
54	Injected	1800	Optimum
54	Dribbled	242	Deficient
79.8	Injected	2600	Excessive

Table 2. Net returns per acre on corn fertilized with different treatments of 28% ammonium nitrate liquid fertilizer. Cost of fertilizer and drying charge were subtracted from gross returns based on yield and $5.50/bushel selling price to obtain net returns data.

Nitrogen Applied (lbs/acre)	Application Method	Net Returns per acre
0	Injection	$1,359.52
30	Injection	$1,462.18
54	Injection	$1,446.43
54	Dribbled	$1,417.12
79.8	Injection	$1,499.15