RESEARCHREPORT
ENVIRONMENT

Title: Swine Manure Nutrient Fate and Pathogen Reduction for Midwestern Corn Production with Cover Crop Utilization **- NPB#15-095**

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Industry Summary
Recently the Midwestern US has seen a push has seen a movement to improve water quality for waters eventually reaching the Gulf of Mexico; this is in an effort to reduce the hypoxic zone. Cover crops show effectiveness at reducing nitrogen and phosphorus loads in waters leaving fields. One concern with cover crops is their impact on grain production following the kill of the over crop as they tend to tie nutrients into organic forms, which are not immediately plant available. This study looked to identify if manure would act differently than a commercial fertilizer (urea) when interacting with a cover crop (cereal rye).

This study found that cereal rye was effective at reducing total nitrogen and nitrate that leached from soil columns treated with both manure and urea, with no significant difference by fertilizer source. The cereal rye produced 20% more biomass when a surface application of urea was used instead of injected manure, however the cereal rye's nitrogen uptake per acre was similar and phosphorous uptake was higher when manure was applied. No differences were found in soil nutrient levels regardless of cover crop status or fertilizer source. In terms of corn production cereal rye inhibited yields with both urea and manure as the nutrient source. There was no significant difference by nutrient source in terms of corm yield, however manure produced nominally higher yields. Overall, during the 2015-2016 season, there was no significant differences in how the manure and urea interacted with the cover crop.

Keywords: *Manure, cover crop, cereal rye, nitrogen, phosphorus, microbial load*

Scientific Abstract
Cover crops are effective at reducing nitrogen and phosphorus loads in waters leaving agricultural fields. One concern with cover crops is the availability of nutrients to the cash crop because cover crops which scavenge nutrients tend to tie nutrients into organic forms, which are not immediately plant available Most studies have looked at how cover crops

interact commercial fertilizers in terms of performance, but limited data is available for how cover crops and manure interact and since manure tends to be higher in carbon it is more likely to have a slower transition from organic to plant available nutrient forms. This study found that a common cover crop, cereal rye was similarly effective at reducing nitrogen and nitrate in water drained from undisturbed soil columns treated with manure as it was from columns treated with urea. The cereal rye was also an effective scavenger of both nitrogen (~80 lb/acre) and phosphorous (~10 lb/acre). No significant differences were noted with the soil's nitrogen, phosphorous or organic carbon levels. Also, no significant differences were noted in chlorophyll meter readings or corn tissue nutrient levels. The cereal rye did not significantly influence corn yield in the soil columns, however yields were nominally lower (54, 56, 73 bushels/acre for cereal rye with manure, cereal rye with urea and manure without a cover crop, respectively).

Introduction
The ongoing issue of nutrient losses from agricultural systems is an issue that will need a dynamic solution to rectify. Fall applied fertilizers are more susceptible to loss compared with spring applied fertilizers (Randall and Vetsch, 2005). One method of reducing nutrient losses from fall application is by use of winter cover crops in place of a conventional, bare fallow method, which could leave field areas uncropped up to 8 months of the year. This period reduces carbon and soil organic matter stocks and leaves unused additions of inorganic nitrogen more vulnerable to losses (Drinkwater and Snapp, 2007). Tile drainage has been an important component in the Midwestern United States crop production, but it also increases surface water levels of nitrates (Keeney and Duluca, 1993). Cover crops increase the diversification of the ecosystem, reduce soil erosion, control weeds and pathogens, and fall growth and overwintering abilities can immobilize unused fertilizers which could otherwise be lost from the system (Snapp et al., 2005).

There have been a number of studies evaluating nutrient losses from fall applied swine manure. However environmental conditions, application methods, and soil types have strong influences on the amount of nutrients lost between fall application and spring/summer crop uptake. In general, the cover cropping system provides two pathways to reduce nutrient leaching, by reducing subsurface drainage volumes and by utilizing available nutrients. Typically, April-June are the months for greatest subsurface drainage, with almost 70% of all drainage occurring in this period (Helmers et al., 2005). Similarly, Randall and Vetsch (2005) found 71% of annual drainage occurs in this period and 75% of nitrate losses occurred. While field experiments indicate nominal differences in drainage volumes, they are often not significant. In lab scale studies, however up to 40% reduction in drainage are observed (Parkin et al., 2006).

In a recent cover cropping study, Lacey and Armstrong (2014) demonstrated that cover crops have potential to reduce nitrate leaching from fall-applied nitrogen from inorganic fertilizers. The combination of fall growth, a deep rooting system, a high carbon to nitrogen plant matter composition, and vigorous spring growth have been shown to reduce nitrate levels in the lower portions of the soil profile which are most susceptible to leaching loss (Lacey and Armstrong, 2014). For an overwintering crop, which has a high carbon to nitrogen ratio such as rye, its uptake of nitrate in the fall reduces leaching. Furthermore, when incorporated back into the soil in the spring, the crop slowly releases nitrogen through mineralization, leading to greater nitrogen availability for the following crop (Blesh and Drinkwater, 2014). Rye crops slow decomposition also better protects nitrogen loss due to wet spring conditions, which are commonly more prone to leaching (Lacey and

Armstrong, 2014). Strock et al. (2004) found a rye cover crop reduced drainage volumes by 11% and Ruffo et al. (2004) found rye uptake from 35-51 kg N ha^{-1} in Illinois.

Overall, rye should provide a viable and effective cover crop in this region.
With studies by N. Randall and Vetsch (2005) observing that up to 48% of fall-applied fertilizer nitrates can be lost and a reduction of only 14% of this by applying fertilizers in the spring, there is a great need to incorporate a growing cover crop into the cropping rotation, since simply changing fertilizer application timing is not enough. Although there is cost associated with seeding a cover crop in the fall, the benefits could significantly outweigh the costs, both financially and environmentally, by reducing nutrient losses to surface waters and providing an added source of fertilizer to the following year's crop via plant decomposition and mineralization at a time when crops need nutrients.

Stated objectives

Our *objective in this proposal* is to determine the relevant nitrogen forms in soil and water runoff at strategic time points in the manure-cover crop-cash crop cycle. In order to experimentally control the relevant parameters in this study, rectangular, undisturbed, soil columns will be collected. This setup will provide the ability to collect all water runoff, so the extent of nutrient leaching can be accurately obtained as well. In this study, we will specifically evaluate cereal rye, which has been previously recommended for use as a cover crop prior to corn in the Midwest. Three treatments will be considered; manure and no cover crop (Manure), manure with cover crop (CC+Manure), and cover crop without manure (CC+Urea). Nutrient forms and quantities will be determined for the manure, soil, and plant material as the cover crop grows and decomposes. Concurrently, environmental conditions, including precipitation events, critical phases of plant production, soil and air temperatures will be monitored. These approaches will allow us to achieve 3 specific objectives.

Specific Objective 1: Quantify amount of nutrients absorbed by plant biomass of cover crop and lost through leaching
Rationale: Past research shows cover crops have the capability of scavenging nutrients that may otherwise be lost to leaching due to their extensive rooting system. As well, cover crops reduce subsurface drainage volumes via evapotranspiration, which may reduce nutrient loss. By using soil column treatments with and without cover crops, and being able to collect all water, which leaches through the column, a direct comparison of the effects of cover cropping on nutrient losses to subsurface drainage will be achieved. Nutrient uptake by the cover crop will be evaluated by taking plant tissue samples.

Specific Objective 2: Identify the nutrient availability to and its impact on corn production
Rationale: After killing the cover crop, plant tissue samples will be taken to determine nutrient quantities in the biomass. As well, nitrogen uptake will be determined throughout the growth cycle of the corn. While direct measurements are not possible, a chlorophyll meter will indirectly give relative nitrogen content in the plant. At harvest, corn biomass will be determined, plant tissue samples will be analyzed for nutrients, and soil will be sampled and analyzed for nutrient levels.

Specific Objective 3: Identify the potential for pathogen reduction
Rationale: Water samples will be collected for nutrient analyses, as discussed in Objective 1. Utilizing these same water samples, microbial transport will be determined by detecting the

presence, and extent of presence, of indicator microorganisms. These results will be compared to the starting amount of indicator microorganisms, as determined by leachate from the columns before the application of manure plus the quantity of microorganisms contained in the applied manure.

Materials & Methods

Soil Column and Field Plots: The soil columns consist of an undisturbed soil monolith with a circular (20-inch diameter) exposed surface area and a depth of 20-24 inches. Initial soil column depth was originally proposed at 30 inches. Unfortunately, the site planted in cover crop and treated with manure had an unexpectedly high clay layer found between 20 and 24 inches below the surface. Because the clay has such slow infiltration rates, the decision was made that including a soil layer with high clay content would not reflect typical Midwestern conditions (with tile drainage). For this reason, all cores were stopped when the clay layer was reached. A 20-inch diameter vertical PVC pipe was used to hold the soil columns and powdered bentonite clay was placed along the edges to prevent preferential flow. The bottom of the soil column was placed on a sand and small pea gravel bed to encourage drainage. A PVC drain line from the bottom of the column was closed using a ball valve except when water samples were collected.

The decision was made to plant the cereal rye and apply manure to the field prior to collecting soil columns. The primary reason for this was to get an appropriate stand of cereal rye and a typical manure injection practice. The manure application is particularly difficult to replicate without field level equipment. Because we chose to plant cover crops and apply manure in the field prior to collecting soil columns, there was an opportunity to include small field plots with the soil columns for field production measures/verification. The field plots were set up for 8 rows of corn with the middle 4 rows used for a yield measurement. For the cereal rye treatment two replicates of 8 rows were planted. The field used for this study is on the University of Illinois Agricultural Engineering Farm. The field has been in a corn soybean rotation for at least the past 8 years. The field has also been tilled regularly. The decision was made to treat the columns and field in the same manor. As are noted below, there were a few times were field conditions limited access to the field, all work on the columns were similarly delayed.

Figure 1. The soil-coring machine used to extract 20-inch soil columns is shown on the left. It is attached to a skid steer with a post-hole digger hydraulic motor. On the right, a soil column in the PVC sleeve

Figure 2. The complete soil columns set upright on the left. The metal tubs below the PVC are filled with sand and small gravel to encourage quick and complete drainage from the column. On the right is a close up of the ball valve that drains from the bottom of the column.

	Cereal Rye 40 ft	No Cover 20 ft	Annual Ryegrass 20 ft
Swine Manure (Injected) 80 ft			
Urea Fertilizer (Surface Applied) 80 ft			
No Fertilizer 80 ft			

Figure 3. The layout of the field plots used in the experiment. Cover crops and corn were planted in rows with fertilizer applied perpendicular to the crop plantings.

Timeline: In early October 2015 cover crops were planted. Soil samples were taken in early November 2015, prior to manure application. The manure was injected in late November after soil temperatures dropped below 50 °F. A manure sample was pulled at the time of sampling and sent to a commercial lab for analysis. Soil columns were removed following manure application but prior to any precipitation. When manure results were returned, urea was applied to the cover crop non-manure treated columns and field plots to achieve the same nitrogen application rate. Unfortunately, December 2015 had high precipitation totals (~7.5 inches, 4.75 inches above normal) and it was not possible to apply the urea to the field until January 2016. In April 2016, an herbicide mixture of 2 oz/acre Sharpen, 16 oz/acre Outlook and 24 oz/acre Roundup was applied to the field plots and columns to kill the cereal rye. While cereal rye likely did not need such an aggressive herbicide program, other cover crop field plots like annual ryegrass (above) were more of a concern. The field used in this study has traditionally been tilled, so the decision was made to disk the cover crop into the soil one week after the herbicide mixture was applied. The columns were also turned to provide a similar treatment to running a disk through the field. Following this turning of soil, rain held up planting for approximately 10 days. Corn was planted in early May 2016. Spring starter fertilizer application was adjusted based on manure test results to ensure $200 kg/ha^{-1}$ (180 lb/acre) nitrogen was applied to all treatments. Corn was harvested the first week of October 2016 and final soil samples taken the following two weeks.

Soil sampling: For soil bulk density, undisturbed (2" diameter) soil cores were taken from 2 locations near where the columns would be collected (but outside the column to prevent destruction of the experimental soil column) and at three depths (0-6", 6-12", and 12-18"). Soil characterization was determined by collecting composite soil samples at 6-inch depth increments down to 18 inches from 3 locations close to the anticipated column collection locations. The soil samples were combined for one composite sample and were analyzed for nitrogen (N) using the Illinois Soil Nitrogen Test (ISNT), phosphorus (P) using the Bray P1 test, organic carbon (OC), and pH. Soil bulk density and nutrient characterization were again completed when the corn crop was harvested. Efforts were made to collect soil from similar areas of the field at the completion of the study and each column was destructed to provide a sample.

Manure application and sampling: Manure was collected from the University of Illinois Swine Research Center. The manure came primarily from grow-finish barns and was held in an outdoor storage. The manure was agitated to create a uniform material to be injected in the field and a small subsample sent off for characterization. The manure sample was analyzed for total Kjeldahl nitrogen (TKN), ammoniaical-nitrogen (NH_3-N), phosphorus (P), total solids (TS), potassium (K), pH, crude protein, crude fat, acid detergent fiber (ADF) and energy content. Manure was applied in hopes of achieving a nitrogen limiting rate. Approximately 7,500 gallons per acre were applied from the outdoor storage. Using the manure sample analysis, assuming 95% of NH_4-N and 35% of organic N were available to the corn the application yielded just over 100 lbs/acre N. This nutrient concentration was less than expected, however the manure storage had been partially pumped in August and fall rainfall was greater than average potentially leading to the lower N concentrations. When urea was applied to the field plot and columns in January an additional 60 lbs/acre of N was added to the manure applied treatments. The final 20 lbs/acre of N was added as starter N at planting.

Water Sampling: The water drained through the columns and was collected in PVC tubing under the columns. Samples were taken at the completion of a precipitation event and every 24 hours after until the columns stopped flowing. Typically, this included two samples per precipitation event. For nutrient analysis, the samples were frozen to maintain sample integrity, while pathogen sampling was started within 24 hours of the samples being collected. The collected jars of water were analyzed for total Kjeldahl nitrogen (TKN), nitrate (NO_3-N), phosphorus (P), and phosphate (PO_4).

In order to measure total coliform and *E. coli* in the water, one milliliter of each sample was taken and dispensed onto the center of the bottom film of the 3M Petrifilm *E. coli* / Coliform Count Plates and covered with the top film. This test used the AOAC® Official Methods when incubating the samples. The following day, the samples would be taken out and photographed individually and be counted for colonies of *E. coli* and total coliform.

Plant Sampling: Cover crop biomass was measured by taking three subsamples from each field plot. The decision was made to not send off samples from the columns because the sample size required for testing could remove a significant and potentially unequal quantity of nitrogen or phosphorus amongst columns. Samples of cover crop material were collected and dried for a dry matter measure. The samples were then shipped to a commercial lab and analyzed for total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO_3-N), phosphorus (P), potassium (K), and carbon (C). Similarly, the corn samples were collected from the field plots and the columns at the completion of the experiment. Measures were made of the whole stalk and the corn itself. These samples were also sent off for analysis. While nutrient availability is not being directly measured throughout the corn production phase, relative nitrogen availability can be measured. Chlorophyll meter readings are strongly correlated with nitrogen uptake into the plant. Chlorophyll meter readings and dates were recorded at key points in the corn growth cycle including vegetative stages (V6-early growth, V12-mid growth and high nitrogen demand phase, V16-late growth, and VT-tasseling) and reproductive stages (R1-silking and R-6 final stage).

Results

Growing Conditions:

Fall 2015 was a near ideal season for growing cover crops. The fall was warmer than average with average to above average rainfall totals. During this water collection period of the study, monthly rainfall was typically average or above average. During this water collection period of the study, monthly rainfall was typically average or above average. December 2015 had a very high precipitation total leading to the majority of the water collected from the soil columns. May 2016 had lower than average rainfall, but did have at least one rainfall event each week. As a result, no supplemental rainfall was supplied to the columns.

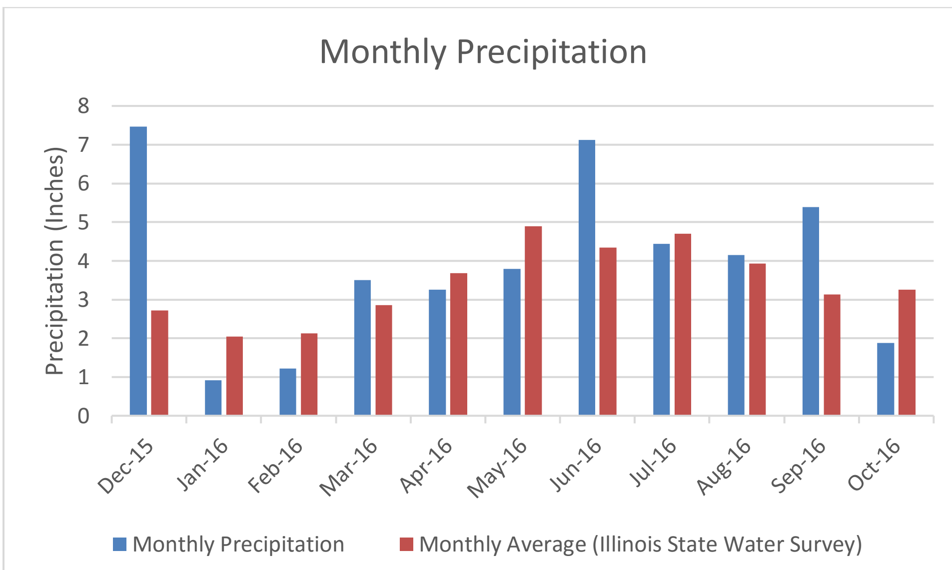


Figure 4: Monthly precipitation for the months when water could be collected from the soil columns. Final water collection actually occurred in May 2016.

Specific Objective 1: Quantify amount of nutrients absorbed by plant biomass of cover crop and lost through leaching

As was stated above, the cereal rye grew well in fall 2015. One of the concerns mentioned with cover crop utilization and manure application is the disturbance of soils during injection reducing cover crop yield. The injection system used in this study was not designed for minimal disturbance and as a result 20% more dry matter was available in the field plot with surface applied urea rather then injected manure (table 1). It is also apparent that fertilizer application did affect cereal rye growth as the field plot with no fertilizer had approximately half as much dry matter as the fertilized plots. While the manure application did influence biomass, the nitrogen uptake was not influenced. On a per acre basis both the manure and urea treatments took up the same mass of nitrogen even though biomass yields were different. This similarity nitrogen uptake has been reported in some extension publications but these investigators have not seen such findings in peer reviewed literature.

Certainly, this trend may suggest a need for further investigation. Additionally, the manure fertilizer treatment led to higher phosphorus uptake than either the urea or no fertilizer treatments.

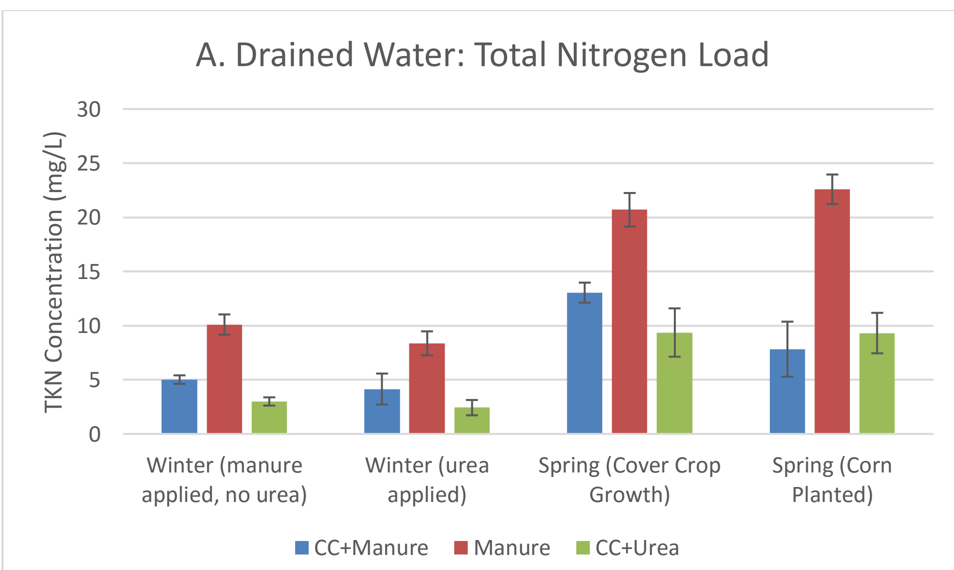
Table 1: Cereal rye biomass yield, nitrogen and phosphorus uptake with three fertilizer treatments with cereal rye cover for the fall 2015- spring 2016 growing season.

	Dry Matter	N Uptake	P Uptake
	tons/acre	lbs/acre	lbs/acre
CC+Manure	1.03	82.0	11.5
CC+Urea	1.21	82.6	9.9
CC+No Fertilizer	0.55	28.2	6.2

Water was also collected from the soil columns throughout the cover crop growing season. One concern with the water collection was the limited data after corn was planted. While rainfall totals were normal and even above average in June 2016, by late May drainage from the columns had ceased. The few water samples after corn planting are included in the figures (5 and 6) below rather than objective two due to the limited data available.

Similar to literature, both total nitrogen and nitrate levels were higher in spring then during the winter. Also, the manure treatment without cover crop had the highest concentrations for both total nitrogen and nitrate (Figure 5). Also, the manure treatment without cover crop had the highest concentrations for both total nitrogen and nitrate (Figure 5).
During the winter nitrate loads stay below 10 mg/L (an EPA limit for drinking water quality) for all three treatments. Both cover crop treatments kept nitrate levels near or below that same 10 mg/L limit in the spring, however the manure treatment without cover crop showed significantly higher nitrate and total nitrogen loads in the drained water.

Throughout the study, there were only a handful of total phosphorus and phosphate samples above the detection limit. With the limited number of samples and rarely samples from multiple treatments during the same precipitation event there are limited options for analysis. Some recent literature has indicated the importance evaluating phosphate in tile drainage however in the study no significant drained phosphorus was found.



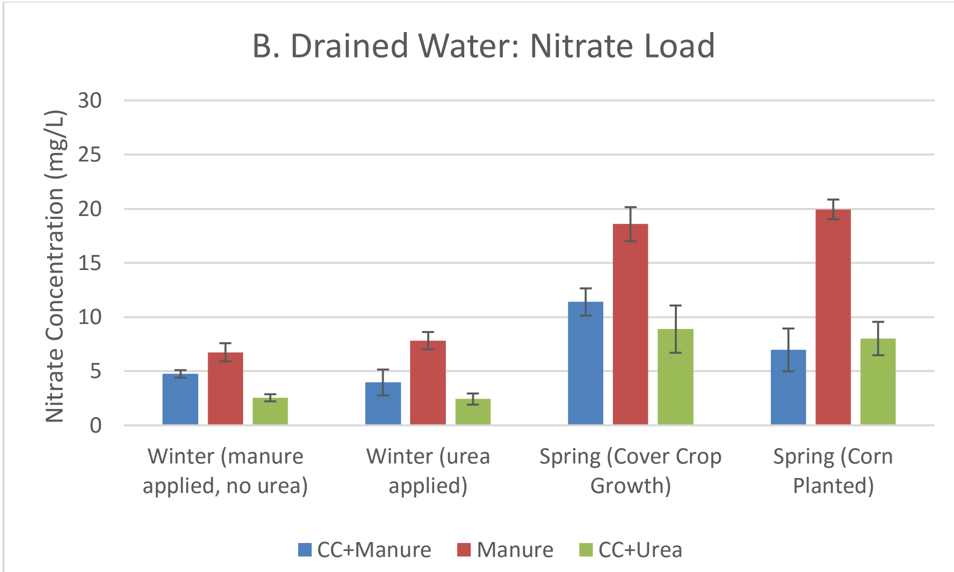


Figure 5: Concentrations of total nitrogen (A) and nitrate (B) in water samples drained from the soil columns for three treatments: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer. Error bars demonstrate one standard error.

The second way to evaluate nutrient leaching is to determine the total mass of the nutrient lost over the season. The mass of nitrogen lost from the columns were adjusted to reflect a lb/acre basis to make results applicable to field conditions. As was stated above, phosphorus measurements were limited and they are not included in this analysis. The highest loss of nitrate (20.7 lb/acre) and total nitrogen (22.3 lb/acre) came from the treatment of manure without cover crops. This loss was significantly greater than the other two treatments (Figure 6). The cover crop with manure treatment was nominally higher than the cover crop with urea treatment, however both cover crop treatments were approximately half of the total nitrogen and nitrate lost without a cereal rye cover over the monitoring period.

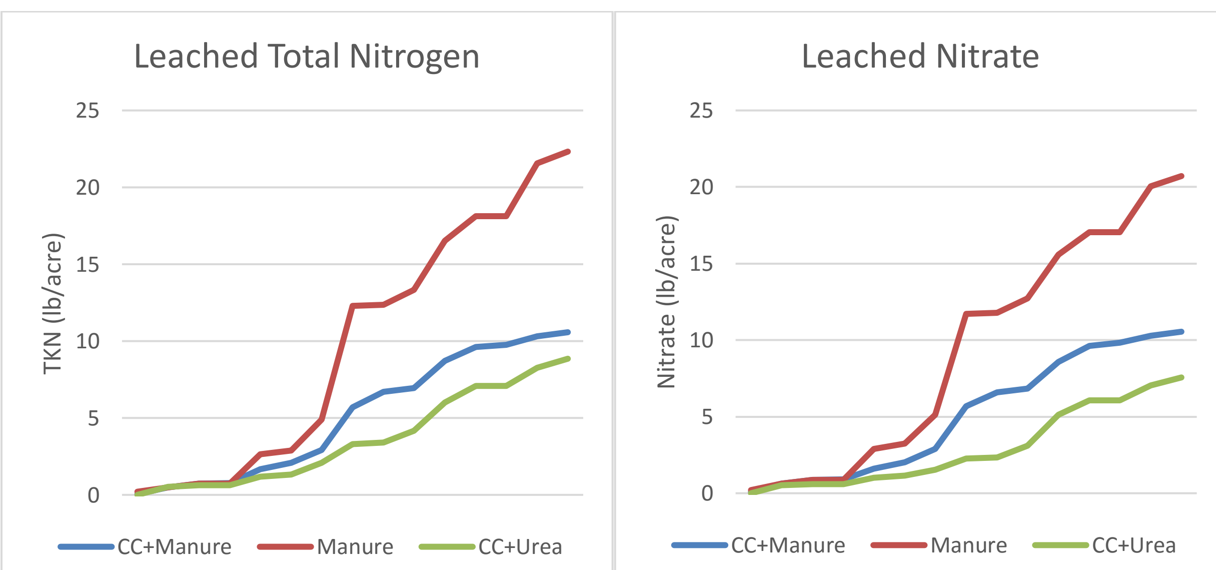


Figure 6 Cumulative total nitrogen and nitrate lost through leaching over the monitoring period for three treatments: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer.

Specific Objective 2: Identify the nutrient availability to and its impact on corn production

Soil samples were collected in the fall 2015 and 2016. There were high levels of variability in nutrient content amongst the samples, but bulk density measures were similar (Table 2). With the soils in this region being silty clay loam, this bulk density is appropriate and not considered compacted.

Table 2: Average soil bulk densities with (±SE) for three treatments: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer.

	Fall 2015 Bulk Density
	g/cm^3
CC+Manure	1.31 (±0.07)
Manure	1.32 (±0.01)
CC+Urea	1.35 (±0.03)

Overall nutrient levels in the soil were highest in the top 6 inches, lower between 6 and 12 inches and least between 12 and 18 inches of depth. Overall, the variability in soil samples did not lead to any significant differences found amongst treatments. On relationship to note was that nitrogen, phosphorous and carbon levels were higher in fall 2015 (at the beginning of the study) than fall of 2016 (figures 7, 8, and9). This trend was unexpected and may be related to field conditions during the previous growing season. The field has been in a soybean-corn rotation which may also have influenced these levels. In particular, the organic carbon levels, which are directly related to soil organic matter are an unexpected drop.

Soil nitrogen levels were nominally lower in the top twelve inches for the treatment manure without cover crops but higher in the 12-18 inch depth. Phosphorous readings at all depths appear higher in the treatment manure without cover crop. The P1 Bray reading is indicative of plant available phosphorous, which may be an indicator that cover crop is changing the form of phosphorous to a less readily available form. The baseline phosphorous levels measured where the columns for CC+Manure collected were quite high. The sample is being re-run, but it is a composite sample and may just reflect the in-field variability.

It is promising to note the field and soil columns in 2016, while not numerically similar followed similar tends in most conditions. In general, the nutrient levels in the columns at the end of the experiment were lower than field values. The columns did have a higher density of corn plants, particularly on a per volume of soil basis, which may have influenced nutrient removal rates.

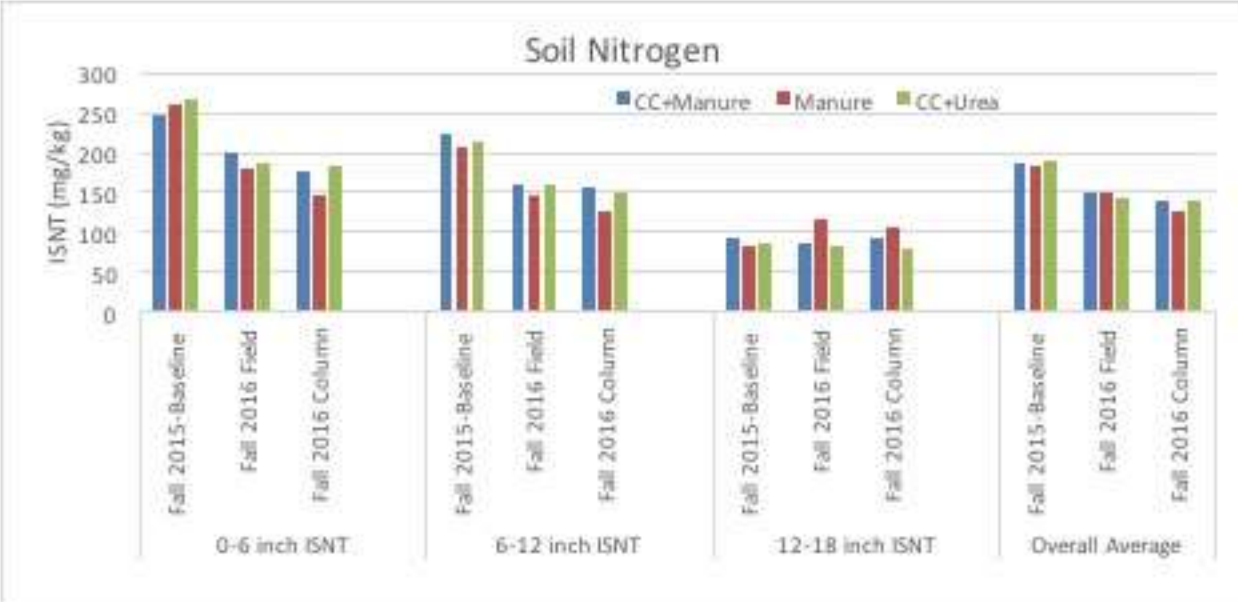


Figure 7: Soil nitrogen levels measured by the Illinois Soil Nitrogen Test (ISNT) in fall 2015 and fall 2016 from the field and columns at three depths and overall average over all 18 inches of depth for the three treatments: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer.

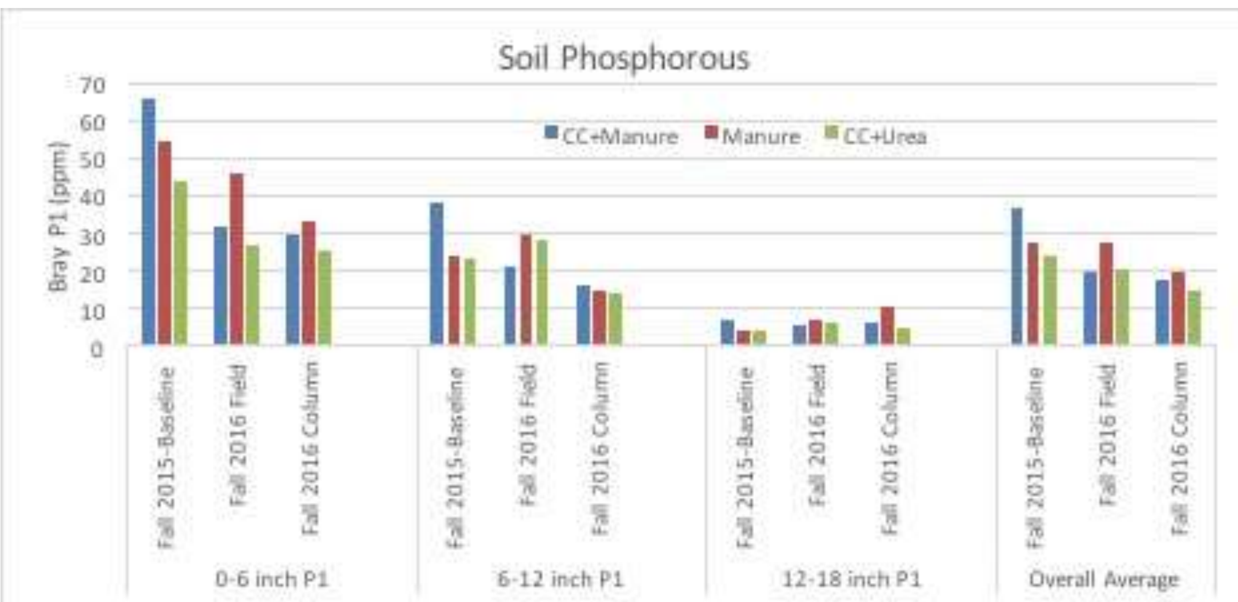


Figure 8: Soil phosphorous levels measured by the Bray P1 test for fall 2015 and fall 2016 from the field and columns at three depths and overall average over all 18 inches of depth for the three treatments: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer.

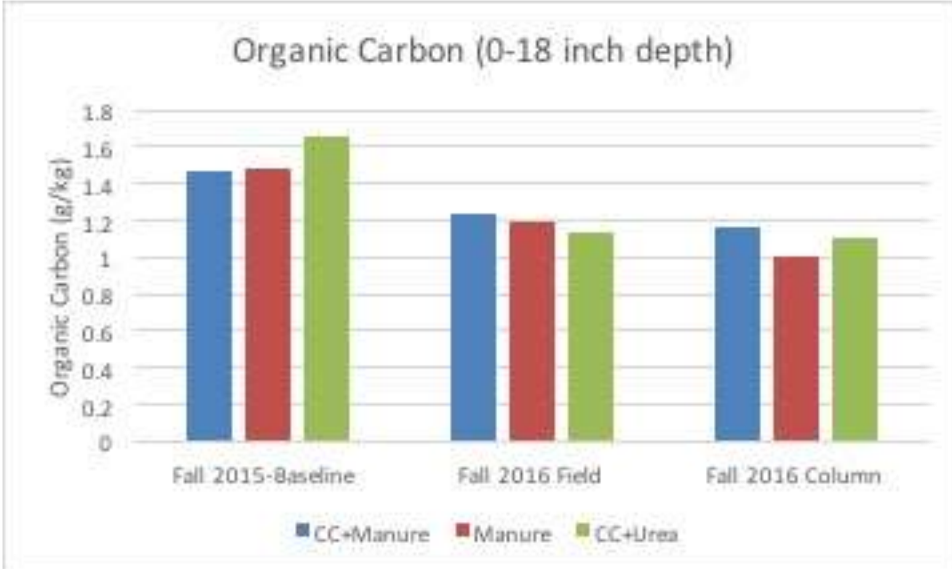


Figure 9: Soil organic carbon measured for fall 2015 and fall 2016 from the field and columns over all 18 inches of depth for the three treatments: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer.

During the growing season of the corn crop, chlorophyll readings were taken to try an identify any relative differences in nitrogen availability. Higher values shown in table 3 below are indicative of a healthier plant with more nitrogen available. Similar to the soil measures, the chlorophyll measure showed no significant difference between treatments. Nominally, the urea with cereal rye had the highest values early in the season and manure treatment without cover crop did have the highest value later in the season. The manure with cereal rye the lowest value throughout the growing season. This is a concern with the higher carbon levels in the combination of manure and cover crops potentially keeping nitrogen bound. A larger field sampling with more plants might be useful in trying to determine if this is potentially a significant difference and therefore a concern. While the columns did not show differences in chlorophyll readings, the field plot with no fertilizer was noticeably different when measured with the chlorophyll meter.

Table 3: Average chlorophyll readings of corn plants in the soil columns at 6 stages of growth (V6, V12, V18, VT, R1, and R6) by treatment: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer. Values shown are mean (± SE).

	V6	V12	V18	VT	R1	R6
CC+Manure	41.1 (±0.6)	44.4 (±0.3)	48.8 (±0.4)	50.4 (±0.3)	50.6 (±0.3)	49.3 (±0.3)
Manure	42.6 (±0.4)	44.6 (±0.5)	50.4 (±0.3)	51.9 (±0.3)	52.2 (±0.3)	50.1 (±0.2)
CC+Urea	43.0 (±0.6)	44.9 (±0.5)	50.5 (±0.4)	51.6 (±0.3)	51.6 (±0.4)	49.5 (±0.7)

Corn was harvested from the columns by hand and separated in a corn sample and biomass. Both were weighed, dried, reweighted and sent to a lab for plant tissue analysis. Yield for the corn was adjusted to reflect field yield at 14.5% moisture (table 4). No significant difference was found between treatments but the manure treatment without cereal rye was nominally greater. The yield in the columns was low compared to field values and was also quite variable. This is likely due to the environmental stressors (wind, sun, precipitation) to which these corn plants were exposed. There were no significant differences in plant tissue analysis from the lab, either.

Table 4: Average corn yield in the soil columns by treatment: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer. Values shown are mean (± SE).

Average Soil Column Corn Yield	
Treatment	bushel/acre
CC+Manure	54 (±10)
Manure	73 (±8)
CC+Urea	56 (±7)

Corn was harvested from the field using a 4 row combine. Additional plant samples were sent off for analysis from the outside four rows not used in the yield measurement. Because the field plot for cereal rye included 2 twenty foot widths, two yield measurement were made. With the plots, there were not enough replicates were available for a statistical analysis, but some trends can be noted. Similar to the columns, the plot with manure and no cover crop performed better that either fertilizer with cereal rye. Manure with cereal rye was slightly higher than urea with cereal rye, the same was true when annual ryegrass was used as a cover, however when no cover crop was planted the urea treatment performed better than the manure treatment. Also, it should be noted that the annual ryegrass did not show reduced yield compared to no cover crop. In the plots with no fertilizer, both no cover and annual ryegrass produced about 40 bushel per acre. The cereal rye plots produced less than 10 bushels per acre. This is likely indicative of the bound nutrients from the cereal rye impacting corn yield. The annual rye had less biomass and a lower carbon to nitrogen ratio, likely increasing the rate of decomposition (and therefore making the nutrients available sooner.

Table 5: Average corn yield in the field with three cover crops (cereal rye, annual ryegrass, and no cover) and three fertilizer treatments: manure, urea, and no fertilizer.

Field Plot Corn Yield		
Cover Crop	Treatment	bushel/acre
Cereal Rye 1	Manure	89.2
	Urea	73.3
	No Fertilizer	8.3
Cereal Rye 2	Manure	65.0
	Urea	49.4
	No Fertilizer	0.0
No Cover	Manure	128.8
	Urea	145.4
	No Fertilizer	41.8
Annual Rye	Manure	167.9
	Urea	143.5
	No Fertilizer	41.2

Specific Objective 3: Identify the potential for pathogen reduction

The result of measuring total coliform and *E. coli* were unexpected. Overall coliform counts were found in water samples throughout the sampling period, with lower counts found in the spring. However only a few *E. coli* colonies were identified in analyzing the plates and there was no trend with cover crop or fertilizer treatment. As a result, only total coliform results will be discussed Table 6 below shows the average coliform counts by treatment. Overall coliform counts were lowest in the manure treatment and highest in the cover crop with urea treatment. The expectation was that manure treated soil columns would have higher coliform counts due to the microbial activity in manure. While these values are nominally different, they are not significantly different. In looking for why the results reflect this unexpected trend; it should be noted that soil column was found to have a significant role. Figure 10 below shows the average coliform count by soil column. Columns 1, 7, and 9 typically had the lowest colony counts with soil column 12 regularly having the highest count. Since column 12 was a CC+Urea treatment, it makes sense that the treatment mean would also be higher.

Table 6: Average coliform count in water samples from the soil columns by treatment: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer. Values shown are mean (± SE).

	Coliform Count
CC+Manure	25.5 (±6.9)
Manure	15.5 (±5.0)
CC+Urea	27.8 (±6.7)

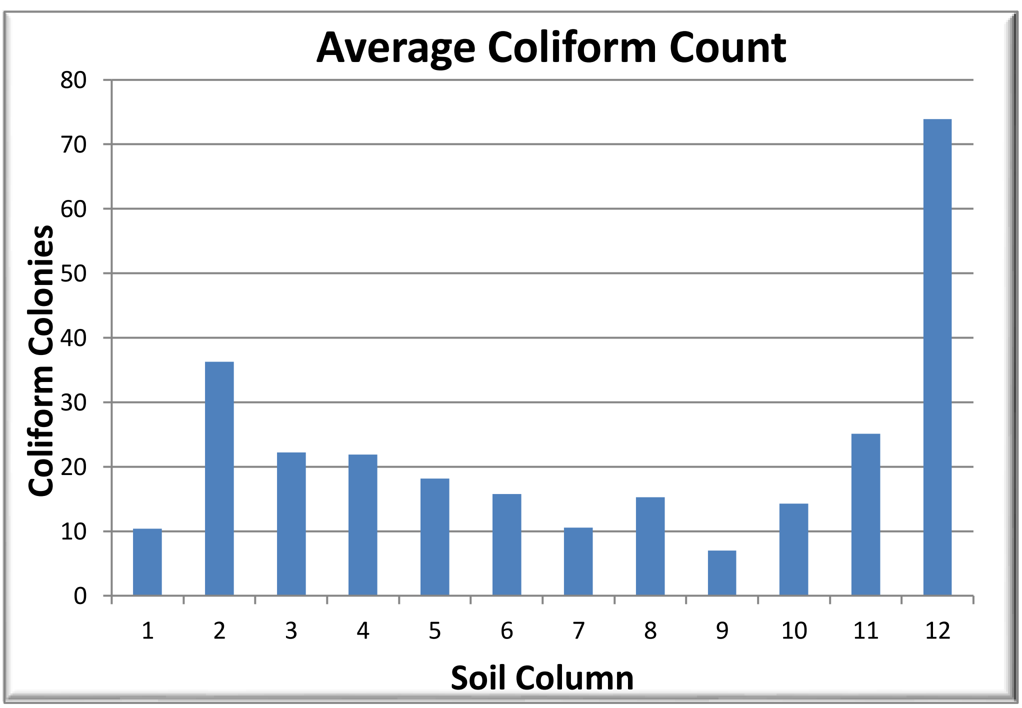


Figure 10: Average total coliform colony count by soil column over the monitoring period.

Discussion

Overall, the cereal rye performed as was expected. The cereal rye bound up nitrogen and phosphorus that was applied or was already available in the soil. While the manure injection did appear to disturb the soil and the cereal rye's root structure and therefore reduce biomass, it did not appear to reduce the amount of nutrients bound by the rye in this year. If the main goal of using a cover crop is to bind nutrients, this finding should be investigated further.

Additionally, the cereal rye was effective at reducing total nitrogen and nitrate in the water which drained from the columns. Neither phosphorous not phosphate was regularly found above detection limits in the water sampled, so comparisons between treatments is possible for these nutrient forms.

In terms of corn yield, a reduction was noted for both cereal rye with manure and cereal rye with urea. This would indicate that starter N applied at planting was not adequate for the nitrogen bound by the cover crop. Higher starter application or a sidedress application may be needed to overcome this issue. It was also interesting to observe that the second cover crop used on the field plot (annual ryegrass) did not show this same issue as cereal rye. The better characteristics for decomposition with the ryegrass appear to have eliminated this decline in corn yields. This may suggest that finding the right cover crop is critical to having nutrients cycle as desired.

One trend that may be worth further investigation would be collecting more samples with a chlorophyll meter in a field setting. The chlorophyll meter would provide relative nitrogen availability throughout the growing season, and while not significantly different the cover crop with manure treatment was always the lowest nominally. If this relationship could be be better described, it may assist in adjusting recommendations to ensure plant available nitrogen is applied as it is needed.

One of the unexpected results of the study was the very limited water collection which occurred after corn was planted. Two corn plants were stared in each column. On a surface area basis, this is not very different from field conditions, however there was essentially no drainage from the columns once the corn plants reached the V2 stage. The investigators believe that the limited depth of the columns may have influences this. The reduced volume of soil from which the roots could pull nutrients and water, may have reduced drainage earlier in the season than expected. This could certainly have skewed cumulative nutrient loss through leaching. Additionally, it was surprising to see the results of the coliform testing. The variability amongst columns was greater than expected and is indicative of the need for more replicates for further testing.

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