I. **Enhancing the Value of Swine Manure and Nutrient Availability with Application Timing and Cover Crops, NPB Project #08-013.**
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II. **Industry Summary:** The overall objective of this field study was to determine the effect of late summer and fall applications of liquid swine manure with and without an oat cover crop on the nitrate distribution in the soil profile, uptake of nitrogen (N) by the oat cover crop, corn yield and N utilization by corn. An experiment was conducted on a Webster clay loam soil at the Southern Research and Outreach Center at Waseca. Swine manure from a pit under a finishing barn was sweep-injected on August 8, September 2, October 1, October 31 and April 14 at a target available N rate of 120 lb N/A. The available N rate applied averaged 110 lb N/acre across the five application dates. An oat cover crop (ForagePlus) was established on August 8 and September 4 and harvested on October 20. The dry matter yield was 0.73 and 0.23 tons/acre while N uptake totaled 47 and 16 lb N/acre for the two planting dates, respectively. Soil samples taken to a 3-foot depth in early November indicated 88 to 90% of nitrate-N was located in the top foot of the profile from the 8/8, 9/2, and 10/1 manure application dates in this dry fall. The oat cover crop had removed 77 and 41% of the nitrate-N from the soil profile by 11/3 for the 8/8 and 9/4 cover crop planting dates. Soil samples taken to a 3-foot depth in mid-May and mid-June provided evidence of greater amounts of nitrate in the profile for the April application of manure compared to the fall application. However, more than 75% of the nitrate in the 3-foot profile was found in the top 2' for all application dates. Less than 15% was found in the 2-3' depth for the October and April manure application treatments while 18% and 25% were found for the September and August applications, respectively. Thus, only slight amounts of nitrate leached below the 2-foot depth in this dry year. Grain yields were not statistically different among the four manure application dates when the rate of manure N was not yield limiting. Yields ranged from 210 to 223 bu/A when the oat cover crop was absent. The zero-manure control plot yielded 158 bu/acre. The oat cover crop reduced corn yield for the August 8 and September 2 application by 71 bu/acre and 30 bu/acre respectively. Nitrogen uptake by the corn was reduced slightly by the August and September manure applications and substantially by the oat cover crop. Considering the dry conditions from

August 1-October 31, 2008, the results from this 1-year study indicate that producers could apply hog manure anytime between August 8 and April 14 the following spring without affecting grain yields. However, nitrate in the soil profile in June and N uptake by the corn plant was slightly greater for the manure applications made in October and April compared to those made in August or September. Corn yields were reduced significantly when an oat cover crop was planted in August and early September.

III. **Scientific Abstract:** Some swine producers are considering applying liquid hog manure in late summer (August) and then planting a cover crop to “stabilize” the manure-N in the upper soil profile rather than letting it be vulnerable to leaching losses. However, we are not aware of any data indicating this is a sound economical and environmental practice. Therefore, the overall objective of this field study was to determine the effect of late summer and fall applications of liquid swine manure with and without an oat cover crop on the nitrate distribution in the soil profile, uptake of nitrogen (N) by the oat cover crop, corn yield and N utilization by corn. An experiment was conducted on a Webster clay loam soil at the Southern Research and Outreach Center at Waseca. Fifteen treatments replicated four times were applied to plots measuring 50’ long x 10’ wide. Swine manure from a pit under a finishing barn was sweep-injected on August 8, September 2, October 1, October 31 and April 14 at rates ranging from 2815 to 4000 gal/A. The available N rate applied averaged 110 lb N/acre across the five application dates, and ranged from 79 to 144 lb N/acre. An oat cover crop (Forage Plus) was established on August 11 and September 4 and harvested on October 20.

The dry matter yield was 0.73 and 0.23 tons/acre while N uptake totaled 47 and 16 lb N/acre for the two dates, respectively. Soil samples taken to a 3-foot depth in early November indicated over 85% of the nitrate in the profile was found in the 0-1’ layer for the August, September and October 1 manure application treatments in this dry year. Samples taken in mid-June showed greater levels of nitrate in the 3-foot profile for the April application treatment compared to the fall manure treatments. However, there was very little evidence of leaching as 75% of the nitrate remained in the top two feet for all manure application dates. Nitrate found below the two-foot level ranged from 15% of the total in the profile for the April and October applications to 25% for the August application. Grain yields ranged from 210 to 223 bu/A and were not significantly different for the four N application dates when manure-N was applied at a non-yield-limiting rate and an oat cover crop was not grown. Oats planted as a cover crop on 8/11 or 9/4 reduced grain yields by 71 and 30 bu/A, respectively. Nitrogen uptake by the corn was slightly less for the August and September applications and was substantially reduced by the oat cover crop. With the exception of the oat cover crop, where the effect on corn yield and N uptake was the same in both years, corn production, N uptake, and soil nitrate were considerably different in 2009 (a dry year) compared to 2008 (a wet year). These 2009 results clearly showed that swine manure could be applied anytime from August 8 through April 15 without affecting corn grain production. However, total N uptake by the corn and nitrate-N in the soil profile were slightly greater for the April and October applications compared to September and August.

IV. **Introduction:** Swine manure has long been recognized as a valuable source of nutrients for corn production. Escalation of fertilizer N, P, and K prices in the last few years has brought a new level of value to swine manure. Moreover, many corn growers are obtaining greater yields with swine manure compared to fertilizer (also proven in our research during the 80's and 90's). These two factors have generated a keen interest in maximizing the nutrient value of manure among swine producers. However, due to manure storage limitations and/or time management of both the producer and the custom applicator, some swine producers desire to apply some of their manure in the summer after harvest of wheat, peas, or sweet corn. Cover crops such as oats or rye are being considered by some producers to stabilize N from the manure by using the cover crop to take up some nitrate and transpire water, minimizing nitrate loss from the soil profile if wet conditions occur. Currently, we are not aware of any research information which documents the availability of nutrients, primarily N, from these late summer hog manure applications or the role an oat cover crop could play in maximizing the value of manure N.

V. **Objectives:**

Thus, the objectives of this research are to:

1) determine corn yield, N uptake, N availability and nitrate distribution in the soil profile as affected by late summer and fall application of swine manure with and without an oat cover crop,
2) determine the value of fall manure applications with and without an oat cover crop compared to spring application of swine manure and urea fertilizer, and
3) provide valuable information to pork producers and corn growers on the value of swine manure as affected by time of application and a cover crop.

VI. **Materials and Methods:**

Following an experiment in 2007-08, we conducted a second-year study on a Webster clay loam at the University of Minnesota's Southern Research and Outreach Center following the harvest of wheat in early August, 2008. Each manure/cover crop/fertilizer N treatment was replicated four times in a randomized, complete-block design. Each plot measured 50' long by 10' (4-30" rows) wide. All experimental procedures and the date they were performed are reported in Table 1. Spring wheat, receiving 50 lb N/A as urea in April, was harvested for grain and the straw was baled and removed. The experimental site was then disked to incorporate the remaining stubble and any weed growth. Soil samples were taken to 6" to characterize soil pH, OM, P and K and in one-foot increments to 3' to characterize the nitrate content of the soil profile before applying any treatments. The pre-treatment samples indicated pH = 5.4, OM = 6.4%, Bray P_1 = 53 ppm, exchangeable K = 264 ppm, and nitrate-N = 5.8 ppm in the 0-1' layer and 40 lb/acre in the 0-3' layer.

Obtaining consistent liquid hog manure from a local pork producer's finishing system for each of the five application dates was a considerable challenge in the fall of 2008 due to manure management issues exercised by the producer. In the previous year, we collected enough hog manure prior to the September application for the September, October, and November application dates and stored it in a manure tanker truck. The tanker was not available in 2008; so we had to collect a fresh batch of manure for each application. As a result, the content was more variable than desired. The manure was obtained from an under-barn pit on August 8, September 2, October 1, and October 31 (Nov. 1 target date) and placed in a 600-gal. research plot manure applicator. The manure was thoroughly agitated and sweep-injected about 4-5" deep on 30" center spacings on the date of manure collection. A manure sample or two was taken during the application process frozen immediately, and sent via overnight delivery to the University of Wisconsin Soil and Forage Analysis Laboratory for dry matter (DM), total N, ammonium-N, total P_2O_5 and total K_2O analyses. The analyses and the amount of "available" N applied each date are shown in Table 2. Across the five application dates the DM averaged 5.1%, with a range from 2.7 to 7.8%. Total N, P_2O_5 and K_20 also varied considerably, ranging from 24.6 to 53.3 lb TN/1000 gal, from 9.3 to 17.1 lb P_2O_5/1000 gal, and from 18.9 to 37.0 lb K_2O/1000 gal. The target application rate of 3000 gal/A was adjusted to 4000 gal/A for the October 1 and October 31 applications based on physical observations of the manure. The spring-applied (April 14) treatment was much improved due to a better source of manure and because the manure was collected five days before application and stored in the 600-gal. applicator tank. A manure sample was taken during collection and was sent overnight for immediate analyses. The actual N analysis allowed us to calculate the manure application rate necessary to yield 120 lb available N/A --- our target N rate. The "available N" rates applied ranged from only 79 lb/A for the October 31 application to 144 lb/A for the October 1 application. Although this is a wide range, the following plant and soil data are quite good and with the exception of the October 31 treatment were not greatly affected. Seventy-four percent of the total N was NH_4-N

Forage Plus oats was planted at 1 bu/acre with a 10' drill on August 11 and September 4 on one of the targeted August and September manure treatments and on additional treatments that did not receive manure. The oat plots were clipped at a stubble height of 3 to 4" on Oct. 20. After collecting a sample for DM yield and total N analysis from each plot, the remainder of the harvested oats was removed from the plots and discarded. Weed control on the non-oat plots was accomplished with an application of Roundup herbicide on September 5.

Soil samples (two cores per plot) were taken in 1' increments directly in the manure bands to various depths to determine the extent to which the nitrate mineralized from the manure had leached down the soil profile. Samples were taken to 1' on September 2, to 2' on October 2, and to 3' on November 3, May 15, and June 15. All samples were dried at 125ºF, ground, and sent to a research analytical laboratory for soil nitrate and ammonium analyses.

Immediately after broadcast-applying urea to the 40, 80, 120, and 160 lb N/A treatments with a calibrated air-flow fertilizer research-plot applicator, the entire experimental area was disked on April 16 and then field cultivated on April 22. The oats sod tilled beautifully, no root masses were found, and an excellent seedbed was prepared. Corn (DeKalb 50-44) was planted at 35,000 seeds/acre in 30" rows on April 23. Pre-emergent broadcast application of Harness and Callisto kept early-season weeds under control, while Roundup Weather Max applied May 22 gave superb full-season weed control. Surface residue measurements were made on May 6 using the line-transect method to determine the effect of the oat cover crop. Surface residue accumulation was 29% and 21% for the oat cover crop plots established on 8/8/08 and 9/4/08, respectively, and 7% for the non-oat plots. Plant stands were determined on May 28 and thinned slightly to an uniform population on June 12.

In-season vegetative sensing measurements were taken at the V8 stage with GreenSeeker and Crop Circle instruments to determine NDVI and at the R1 stage with a SPAD chlorophyll meter to determine the leaf chlorophyll status – a surrogate for expressing N status. Stover yields were taken by cutting plants from 15’ of row #2 after removing the ears. The plants were chopped, weighed wet, dried, weighed dry, ground, and submitted for total N analyses. The remaining 79’ of row from the center two rows (1.5’ from each end of each row had been previously end-trimmed to eliminate border effects) was harvested with a research plot combine. Grain moisture and yield were determined before drying the grain for total N, starch, and oil analyses.

Air temperature and precipitation data were collected daily and compiled monthly from August, 2008 through October, 2009 (Table 3). The fall of 2008 was marked by normal temperatures and below-normal precipitation. For the August-October period, a total of 7.8” of rain occurred or 62% of normal. The 30-year normal for August-October is 12.6”. Moreover, air temps averaged from 0.2 degrees below normal to 2.3 degrees above normal. Soil temps at the 4” depth averaged 75.7, 66.0 50.7, and 38.6ºF for August, September, October, and November, respectively. These conditions were favorable for quick mineralization of the manure without much leaching of the nitrate in this poorly drained soil. The soils froze on Nov. 22, 2008 and remained frozen until March 18, 2009. In 2009, air temps were considerably cooler-than-normal from May-August, but warmed in September, resulting in growing degree units being 8% below normal for the season. Precipitation totaled 11.0” for the 5-month May-September growing season. This was 9.42” below normal, resulting in the second driest season in our 95-year record. Fortunately, water stress was minimal throughout the season due to the cool temps and the crop yields were excellent.

Table 1. Experimental procedures used in 2008 and 2009 to conduct this research.

Task	Date
Disk experimental area after wheat and straw harvest	Aug. 8, 2008
Inject first application of hog manure and obtain manure sample	Aug. 8
Plant Forage Plus oats with 10’ drill	Aug. 11
Take 0-6” soil samples to characterize soil pH, OM, P & K	Aug. 11
Take 0-3’ soil samples to characterize the nitrate content in the soil profile	Aug. 11
Take 0-1’ soil samples from the Aug. 8 manured plots and control plots	Sept. 2
Inject second application of manure and obtain manure samples	Sept. 2
Plant Forage Plus oats on 9/2 manure plots	Sept. 4
Broadcast-apply Roundup to all plots	Sept. 5
Inject third application of manure and obtain manure samples	Oct. 1
Take 0-2’ soil samples in 1-foot increments from the 8/8 and 9/2 manured and control plots.	Oct. 2
Harvest oat cover crop plots and remove all remaining oats from the plots	Oct. 20
Inject fourth application of manure and obtain manure samples	Oct. 31
Take 0-3’ soil samples in 1-foot increments from all manured and control plots	Nov. 3
Inject fifth application of manure and obtain manure samples	Apr. 14, 2009
Broadcast apply urea to N rate plots	Apr. 16
Disk entire experimental area	Apr. 16
Field cultivate entire experimental area	Apr. 22
Plant Dekalb 50-44 at 35,000 seeds/A in 30” rows	Apr. 23
Broadcast-apply Harness (1.5 pt/A) plus Callisto (5 oz/A)	Apr. 24
Take residue counts from cover crop plots	May 6
Take 0-3’ soil samples in 1-foot increments	May 15
Apply Roundup WeatherMax (24 oz)	May 22
Take plant stand counts	May 28
Thin plots to uniform plant stand	June 12
Take 0-3’ soil samples in 1-foot increments	June 15
Take GreenSeeker and CropCircle measurements at V8	June 26 & 29
Take leaf chlorophyll measurements at R1	July 28
Take stover yields from 15’ of row 2	Sept. 29
Combine harvest center two rows (79’ of row/plot)	Oct. 27

Table 2. Manure analyses for each of the manure application dates and "available" N applied in 2008-2009.

Application date	Dry matter	Total N	NH_4-N	Total P_2O_5	Total K_2O	Available[3/] N applied
	%	- - - - - - - - - - - - -	lb/1000 gal	- - - - - - - - - - - - -		lb N/acre
8/8/08	7.8	49.5	33.8	17.1	25.3	119
9/2/08	4.2	36.7	26.7	9.3	22.7	88
10/1/08	4.9	45.1	35.0	11.4	37.0	144
10/31/08	2.7	24.6	18.8	10.3	18.9	79
4/14/09	5.7	53.3	40.8	13.2	30.0	120

[1/] Assuming 80% of the total N is available. Manure applied at a rate of 3000, 3000, 4000, 4000, and 2815 gal/acre on 8/8, 9/2, 10/1, 10/31, and 4/14, respectively.

Table 3. Monthly air temperature averages and precipitation totals at Waseca during the period this study was conducted.

Month	Temperature		Precipitation	
	2008/09	Normal[1/]	2008/09	Normal[1/]
	- - - - - - - - °F	- - - - - - - -	- - - - - - - - inches	- - - - - - - -
August, 2008	68.3	68.9	2.18	4.58
Sept.,	62.5	60.2	1.44	3.19
Oct.,	47.9	47.7	1.94	2.56
Nov.,	33.7	31.4	2.25	2.32
March, 2009	30.8	30.3	1.77	2.49
April,	45.7	44.9	2.39	3.23
May,	58.0	58.3	1.90	3.96
June,	65.8	67.7	2.76	4.22
July,	66.1	71.2	1.53	4.47
Aug.,	66.4	68.9	3.33	4.58
Sept.,	64.1	60.2	1.48	3.19
Oct.,	42.0	47.7	7.05	2.50

[1/] Normal = 1971-2000 period.

VII. **Results:** Objectives 1 & 2. Because objectives 1 and 2 are co-mingled, these two objectives will be discussed simultaneously.

Soil nitrate

Soil samples taken to the 1-foot depth on Sept. 2 (26 days after the first manure application) showed very high levels of NO_3-N for both the non-oat cover crop plots and those where oats was planted (Table 4). This was due to rapid mineralization of the manure coupled with minimal uptake of nitrate by the slow-growing oats. Rainfall totaling 48% of normal resulted in delayed growth of the oats and virtually no leaching of nitrate out of the application zone. Soil NH_4-H concentrations were slightly greater than for the non-manured treatments, indicating some manure remained to be mineralized. These 2009 data are markedly different from the 2008 data where significant leaching occurred, emphasizing the influence of August rainfall on the fate of swine manure applied early in August.

Soil samples taken on October 2, 56 days after the 8/8 manure application and oat planting and 30 days after the 8/31 application and planting, showed all of the manure-N from both application dates had completely nitrified to nitrate-N (Table 4). More than 90% of the nitrate found in the manured plots (8/8 and 9/2 application) was found in the 0-1' layer with almost no leaching into the 1-2' layer (data not shown). Even though oat growth by early October was considerably less in 2009 than in 2008, considerably uptake of nitrate occurred for the plots where manure was applied and oats were planted on 8/8. Nitrate-N levels in the top 2' were reduced by 177 lb N/A for the 8/8 oat planting and only 35 lb N/A for the 9/4 planting. Planting an oat cover crop when manure was not applied resulted in NO_3-N levels being reduced from 62 lb/A without oats to only 14 and 34 lb/A when oats was planted on 8/8 and 9/4, respectively. Soil NH_4-N data indicated that all of the manure applied on 8/8 and 9/2 had mineralized by 10/2. September weather marked by slightly warmer-than-normal temps and rainfall 55% below normal had a profound influence on both mineralization of the manure and uptake of nitrate by the oat cover crop established in early August.

Soil samples were taken to a depth of 3' on 11/3 to determine the distribution of nitrate in the soil profile due to leaching and cover crop removal. Nitrate-N levels appeared to be related to the rate of available manure N applied with highest levels for the 10/1 application and lowest for the 9/2 application (Table 4). However, statistical analyses did not show a significant difference in the NO_3-N, NH_4-N, or TIN levels between the 8/8 and 9/2 application dates. Eighty-eight, 88, and 90% of the NO_3-N remained in the 0-1' layer for the 8/8, 9/2, and 10/1 application dates, respectively (Fig. 1). Ammonium-N for the 10/1 application (92 lb/A) was almost twice as high as for the 8/8 and 9/2 application dates (50 lb/A), indicating incomplete mineralization of the early October manure application (Fig. 1). Scavenging and uptake of NO_3-N by the oat cover crop was considerably greater for the 8/8 planting date compared with the 9/4 planting date. Compared to the 10/2 sampling date when approximately 63% and 12% of the NO_3-N had been removed from the 0-2' soil profile for the 8/8 and 9/4 oat planting date treatments, respectively, removal on the 11/3 sampling date totaled 77% and 41%, respectively. Furthermore, when manure was not applied, soil NO_3-N levels were reduced to only 14 and 20 lb/A by the 8/8 and 9/4 oat planting date treatments.

Soil samples taken to a 3-foot depth on 5/15 clearly showed: (1) substantial but not differing amounts of NO_3-N remained in the 0-3' profile for the 8/8, 9/2 and 10/1 application dates, (2) significantly less NO_3-N remained in the soil for the 10/31 application (likely due to the lower application rate), (3) considerable NH_4-N found for the 4/14 application date was still available for mineralization, and (4) considerable NO_3-N had been removed from the soil profile by the oat cover crop, especially when planted in early August. Nitrate distribution in the 3-foot soil profile for the treatments without oats showed 27%, 32%, 44%, 56%, and 68% of the NO_3-N in the top 0-1' layer for the 8/8, 9/2, 10/1, 10/31 and 4/14 application dates, respectively, and 24%, 21%, 11%, 11%, and 10% of the NO_3-N in the 2-3' layer for these same application dates, respectively. When the oat cover crop was planted on either 8/8 or 9/4, soil NO_3-N levels were much lower but 49 to 53% remained in the 0-1' layer while 15 to 16% was found in the 2-3' layer. The conclusion from these data is that more NO_3-N remains in the soil profile when oats were not planted but that a greater proportion remains or has moved into the 1-2' layer compared to the cover-crop plots (Fig. 2).

Soil samples taken to a 3-foot depth on 6/15 showed: (1) highest soil NO_3-N levels with the April manure application with relatively high nitrate levels for the 8/8 and 10/1 application dates (lowest NO_3-N levels occurred when the manure-N application rates were lower in the 9/2 and 10/31 application dates), (2) the scavenging effect of the oat cover crop was still very evident; and (3) manure-N from all application dates had completely nitrified to nitrate-N. Nitrate-N in the 3-foot profile was reduced to very low levels by the oat cover crop even when manure was applied, especially for the 8/8 planting date (Table 4 and Fig. 3). The significant “application date x oat cover crop” interaction for NO_3-N indicated substantially reduced levels of soil nitrate for the 8/8 cover crop planting than for the 9/4 planting. Nitrate distribution in this 3-foot soil profile for treatments without the oat cover crop showed 27%, 32%, 45%, 43%, and 54% of the NO_3-N in the 0-1' layer for the 8/8, 9/2, 10/1, 10/31, and 4/14 application dates, respectively, and 25%, 18% 14%, 14%, and 12% of the NO_3-N in the 2-3' layer for these same application dates. When the oat cover crop was planted on 8/8 or 9/4, soil NO_3-N levels were much lower but 46 to 49% remained in the surface foot while 16 to 20% was found in the 2-3' layer. Similar to the May 15 sampling, the primary conclusion from these data is that more NO_3-N remained in the soil profile when an oat cover crop was not grown, but that a greater proportion of the remaining nitrate has moved into the 1-2' and 2-3' layers compared to the cover-crop plots (Fig. 3).

<u>Oat cover crop production</u>

Oat cover crop DM yields were variable (CV = 20%), but they were significantly affected by planting date but not by manure application (Table 6). The 0.73 ton DM/acre yield for the 8/11 planting date was 3.1 times that of the 9/4 planting date. These DM yields were considerably less (60% lower) than the yields in 2008. Yield difference between the two years and between the two planting dates (August vs. September) can largely be explained by the differences in weather. The weather was warm and very wet in the fall of 2007, resulting in abundant oat growth especially when planted in early August. Adequate growth even occurred when planted on August 31. The very dry and moderate temps in the fall of 2008 contributed to slow germination and growth, especially in September. Based on these two years, planting of an oat cover crop should occur between the middle of August and Sept. 10 if optimum growth is to occur.

Total N in the forage DM was greater for the later planting (3.67% N) but was not affected by manure application. Total N uptake in the harvested forage was affected by both planting date and manure application. N uptake in oats planted 8/11 was almost three times as high (47 lb N/acre) as for the 9/4 date (16 lb N/acre). When manure was applied, N uptake was increased 10 lb/acre averaged across the two planting dates. The highly significant interaction between oat planting date and manure application for total N uptake is explained by significantly more N taken up from the manured plots by the oats when planted on 8/11 compared to the 9/4 planting date when N uptake was similar for the manured and un-manured treatments. The yields and N uptake data shown above are from the harvestable portion only and substantial N may have been removed by the oats but remains stored in the root system and stubble.

Corn production

Significant differences in grain yield were found among the 15 manure/cover crop/fertilizer treatments, but there was no significant yield difference among the four manure application dates (8/8, 9/2, 10/1, and 4/14) when no cover crop was planted (Table 7). Grain yields (@15.5% H_2O) ranged from a high of 223.2 bu/acre for the 10/1 application date to 201.9 for the 10/31 application date, while the LSD (0.10) was 14.7 bu/acre. The lower rate of available manure N applied on 10/31 compared to the other dates is likely the reason for the slightly lower yield for this treatment. For the UAN-fertilized treatments, grain yield was optimized between the 80 and 160-lb N rates, but the data do not allow us to be more specific. Yield from the zero-N control plot was 158 bu/A, indicating that soil N produced 71% of the maximum grain yield in this study.

When comparing the effects of early manure applications and the use of an oat cover crop, we saw a significant interaction between manure application date and oat cover crop for grain yield (Table 7). When manure was applied on 8/8 and oats planted 8/11, grain yields were reduced 71 bu/A as opposed to only a 30 bu/A reduction for the meager oat cover crop when planted on 9/4. The nitrate scavenging and sequestering effect was even greater when grown on the zero-N control plots. Grain yields from the control plots were reduced 72 and 54 bu/A when oats were planted on 8/11 and 9/4, respectively. These yield reductions were due to a deficiency in available N and not to a deficiency in soil water. Even though only 21 and 2 lb N/A were removed by the oat forage when planted 8/11 and 9/4, respectively, it is highly likely that considerably more N was immobilized in the oat root system and the short non-harvested stubble. Visible N deficiency symptoms in June on the cover crop plots suggest immobilization as a contributing factor.

Stover yields were not significantly different among the five manure application dates when a cover crop was not grown (Table 7). When the oat cover crop was grown, stover yields were reduced 0.86 T DM/A by the 8/11 oat planting but were not affected by the 9/4 planting.

Total DM yield (grain + stover) was greatest for the 8/8, 10/1, and 4/14 manure application dates (8.40 to 8.81 T DM/A) and least for the 9/2 and 10/31 dates (8.03 to 8.29 T DM/A), which received the lowest amounts of available manure N (Table 7). Thus, total DM produced was a function of available N rate and not time of application. The highly significant interaction between manure application date and oat cover crop was due to the cover crop reducing total DM by 2.53 T/A when the manure was applied and oats planted in early August compared to a reduction of only 0.69 T/A when applied and planted in early September.

Nitrogen concentrations in the stover were more variable than for the other parameters, but they did suggest a weak positive relationship to the rate of available manure N applied (Table 7). There was no trend with time of application (August vs. October vs. April). Stover N concentration was reduced more with the 8/11 cover crop planting than with the 9/4 planting.

Grain N concentration was not affected significantly by the four manure application dates (8/8, 9/2, 10/1, and 4/14) but was reduced slightly by the lower N rate applied on 10/31 (Table 7). The oat cover crop reduced grain N concentration substantially regardless of planting date.

Nitrogen removal in the harvested grain was not affected by the three manure application dates (8/8, 10/1, and 4/14) but was reduced about 15 to 28 lb/acre for the 9/2 and 10/31 application dates that received lesser rates of available manure N (Table 8). The significant manure application date x oat cover crop interaction was due to a 54 lb/A reduction when the oats was planted in early August compared to the 26 lb/A reduction when planted in early September. The lower rate of available manure N applied in September may also have been a factor in this smaller reduction.

Total N uptake/removal in the grain and stover was statistically greater for the 10/1 and 4/14 manure application dates compared to the 9/2 and 10/31 dates, which received small application rates of available manure (Table 8). However, there was not a statistical difference in total N uptake between the 8/8 and 4/14 application dates, which received equal amounts of available manure N. Thus, the nitrogen use efficiency (NUE) appeared to not be affected by time of application [fall (August) vs. spring (April)] in this dry year. These results were much different than the 2007-08 study that experienced much wetter conditions. Total N uptake by the corn was significantly reduced when using an oat cover crop, especially when the oats was planted in early August (66 lb N/A) compared to 31 lb N/A with the 9/4 planting.

Corn grain oil and starch content were variable and showed no consistent trends with manure application date or cover crop (Table 8).

Plant population ranged from 33,500 to 34,100 plants/acre, but population was not consistently or meaningfully affected by the treatments (Table 9).

Relative leaf chlorophyll (RLC) content at R1, a proven good surrogate for evaluating the N status of corn and its potential yield response to N, was not highly related to the time of manure application but was affected greatly by cover crop usage (Table 9). RLC did show a weak relationship to the amount of available manure N applied – much like total DM yield, grain N uptake, and total N uptake. The oat cover crop significantly lowered RLC, especially when planted in early August.

Normalized difference vegetative index (NDVI), an estimate of the total biomass at the V8 stage, was weakly related to the time of manure application (Table 9). In general, lowest NDVI's (smallest plants) were found for the August and September application dates, while greatest NDVI values were found for the 10/1 and 4/14 manure application dates. The oat cover crop significantly reduced NDVI regardless of planting date.

Objective 3

Because all of the analytical data were not available at the time of our winter meetings in December and January, we were only able to share some of our oat and corn yield and soil nitrate-N information from this 2008-9 study. This information was presented at five Winter Crops Day programs totaling over 200 producers, consultants, industry agronomists, and lenders. The greatly different fall '07 vs. fall '08 weather conditions and the effect they had on the results provided on excellent opportunity to compare the two years. It also allowed us to show the influence of non-controllable influences such as weather on the results obtained as a function of soil processes such as mineralization, immobilization, leaching and denitrification. The cover crop information has been eye-opening for many. The annual report for 2007-08 is presently found on the SROC website at
http://sroc.cfans.umn.edu/Research/Soilscience/SoilsResearchResults/2008/index.htm

The 2008-09 report will be placed on the SROC Web site later this spring. Copies of both the 2007-08 and 2008-09 reports will be sent to the Minnesota Pork Producers Association for their use and distribution.

Table 4. Soil nitrate-N (NO_3-N) ammonium-N (NH_4-N), and total inorganic N (TIN) in the soil profile in the fall as influenced by manure application date and cover crop planting date in 2008.

	Manure Applc'n	Oats Plant	Sampling Date and Depth								
			9/2 (0-1')			10/2 (0-2')			11/3 (0-3')		
Trt.	Date	Date	NO_3-N	NH_4-N	TIN	NO_3-N	NH_4-N	TIN	NO_3-N	NH_4-N	TIN
			- - - - - - - - - - - - - - - - - - - lb/acre - - - - - - - - - - - - - - - - - - -								
1	8/8/08	None	344	42	386	280	24	304	188	53	241
2	"	8/11	356	42	398	103	25	128	44	50	94
3	9/2/08	None				299	28	327	166	50	216
4	"	9/4				264	28	292	98	48	146
5	10/1/08	None							222	92	314
6	10/31/08	None									
7	4/14/09	None									
8	None	8/11	31	23	54	14	22	36	14	40	54
9	None	9/4				34	23	57	20	41	61
10	None	None	38	25	63	62	23	85	69	42	111
Stats for Randomized Block Design (all treatments)											
	P > F:		0.001	0.011	0.001	0.001	0.370	0.001	0.001	0.001	0.001
	LSD (0.10):		45	10	46	50	NS	51	54	15	61
	CV (%):		18.	24.	16.	27.	18.	24.	43.	23.	32.
Stats for Main Effects in Factorial Design (treatments 1-4)											
	Manure Application Date										
	8/8					191	25	216	116	51	167
	9/2					282	28	309	132	49	181
	P > F:					0.009	0.310	0.010	0.404	0.588	0.434
	Oat cover crop										
	No					290	26	315	177	51	228
	Yes					184	26	210	71	49	120
	P > F:					0.004	0.850	0.005	0.001	0.570	0.001
	Applc'n date x Oat cover crop interaction										
	P > F:					0.029	0.850	0.036	0.061	0.896	0.044
	CV (%):					23.	22.	22.	29.	15.	19.

Table 5. Soil nitrate-N (NO_3-N) ammonium-N (NH_4-N), and total inorganic N (TIN) in the soil profile in the spring as influenced by manure application date and cover crop planting date in 2008-2009.

	Manure	Oats	Urea	Sampling Date and Depth					
	Applc'n	Plant	N	5/15 (0-3')			6/15 (0-3')		
Trt.	Date	Date	rate	NO_3-N	NH_4-N	TIN	NO_3-N	NH_4-N	TIN
			lb N/A	lb N/acre					
1	8/8/08	None	--	170	51	221	150	34	184
2	"	8/11	--	45	61	106	49	38	87
3	9/2/08	None	--	166	47	213	120	40	160
4	"	9/4	--	85	56	141	86	42	128
5	10/1/08	None	--	153	53	206	159	38	197
6	10/31/08	None	--	107	55	162	129	43	172
7	4/14/09	None	--	139	100	239	171	38	209
8	None	8/11	0	30	48	78	37	33	70
9	None	9/4	0	40	48	88	49	39	88
10	None	None	0	79	52	131	78	36	114
11	None	None	40				119	36	155
12	None	None	80				158	45	203
13	None	None	120				148	40	188
14	None	None	160				170	40	210
Stats for Randomized Block Design (all treatments)									
P > F:				0.001	0.036	0.001	0.001	0.771	0.001
LSD (0.10):				47	24	65	24	NS	26
CV (%):				38.	35.	34.	18.	21.	14.
Stats for Main Effects in Factorial Design (treatments 1-4)									
Manure Application Date									
8/8				107	56	163	99	36	135
9/2				125	52	177	103	41	144
P > F:				0.320	0.322	0.497	0.734	0.382	0.377
Oat cover crop									
No				168	49	217	135	37	172
Yes				65	58	123	67	40	108
P > F:				0.001	0.038	0.001	0.001	0.553	0.001
Applc'n date x Oat cover crop interaction									
P > F:				0.244	0.950	0.315	0.015	0.818	0.008
CV (%):				30.	14.	24.	22.	27.	13.

Table 6. Oat cover crop dry matter yield, N concentration, and N uptake in oat forage on October 20, 2008.

Oat planting date	Manure application date	DM Yield	[N]	N Uptake
		ton/acre	%	lb N/acre
8/11	None	0.68	2.66	36
“	8/8	0.78	3.65	57
9/4	None	0.22	3.80	16
“	9/2	0.23	3.20	14
Stats for a RCB design				
P > F:		0.001	0.035	0.001
LSD (0.10):		0.12	0.63	8.4
CV (%):		20.	14.	21.
Statistical analysis of main effects in factorial design				
Oat Planting Date				
8/11		0.73	3.16	46.7
9/4		0.23	3.67	16.5
P > F:		0.001	0.064	0.001
Manure Application				
No		0.45	3.23	26.5
Yes		0.51	3.59	36.7
P > F:		0.275	0.171	0.012
Interaction				
Oat Planting Date x Manure Applc’n		0.388	0.028	0.012
CV (%):		20.	14.	21.

Table 7. Corn yields, grain moisture content, and N concentration as influenced by time of manure application and an oat cover crop at Waseca, MN in 2009.

	N management / Treatment				Grain	Grain	Stover	Grain & Stover	Stover	Grain
Trt	Source	Timing	Rate*	Cover Crop	H_2O	Yield	Yield	Yield	[N]	[N]
#			lb N/A		%	bu/A	- T DM/A -		%	%
1	Manure	8/8	120	No	27.1	210.9	3.41	8.40	0.383	1.22
2	Manure	8/8	120	Aug. seed	29.6	140.3	2.55	5.87	0.275	1.01
3	Manure	9/2	120	No	27.4	211.9	3.28	8.29	0.400	1.17
4	Manure	9/2	120	Sept. seed	29.3	182.1	3.29	7.60	0.315	1.05
5	Manure	10/1	120	No	27.5	223.2	3.52	8.81	0.498	1.24
7	Manure	10/31	120	No	27.3	201.9	3.25	8.03	0.313	1.09
8	Manure	4/14	120	No	27.0	219.0	3.48	8.66	0.458	1.24
9	None	8/8	0	Aug. seed	33.9	87.6	1.98	4.06	0.273	0.87
10	None	9/2	0	Sept. seed	31.1	104.2	2.54	5.00	0.233	0.91
11	None	--	0	No	28.7	158.1	3.07	6.81	0.275	0.95
12	Urea	4/16	40	No	27.6	207.5	3.59	8.50	0.395	1.12
13	Urea	4/16	80	No	27.3	210.5	3.52	8.50	0.415	1.21
14	Urea	4/16	120	No	27.0	214.1	3.54	8.60	0.450	1.24
15	Urea	4/16	160	No	27.1	222.2	3.36	8.62	0.528	1.25

* Target N rate, based on 80% of TN in manure.

Stats for RCB Design (All Treatments)						
P > F:	0.001	0.001	0.001	0.001	0.001	0.001
LSD (0.05):	1.4	17.7	0.33	0.60	0.104	0.09
LSD (0.10):	1.2	14.7	0.28	0.50	0.087	0.08
CV (%):	3.5	6.7	7.3	5.5	19.6	5.9

Statistical analysis of main effects in factorial design (trts 1 - 4).						
Application date						
8/8/2008	28.4	175.6	2.98	7.14	0.329	1.11
9/2/2008	28.4	197.0	3.28	7.95	0.358	1.11
P > *F*:	0.985	0.011	0.024	0.004	0.444	0.869
Oat cover crop						
No	27.3	211.4	3.34	8.34	0.391	1.19
Yes	29.5	161.2	2.92	6.74	0.295	1.03
P > *F*:	0.009	0.001	0.005	0.001	0.025	0.005
Interactions (P > F)						
Application date × oat cover crop	0.620	0.014	0.004	0.002	0.761	0.335
CV (%):	4.6	7.2	7.2	5.5	20.9	8.0

Table 8. Nitrogen removal in the grain, stover, and total dry matter (grain & stover) and grain oil and starch concentrations as influenced by time of manure application and an oat cover crop at Waseca in 2009.

	N management / Treatment				Nitrogen Removal			Grain	Grain
Trt	Source	Timing	Rate*	Cover Crop	Stover	Grain	G & S	Oil	Starch
#			lb N/A		- - lb N/acre - -			%	%
1	Manure	8/8	120	No	26.1	121.0	147.1	2.46	73.1
2	Manure	8/8	120	Aug. seed	14.6	66.9	81.5	2.25	73.5
3	Manure	9/2	120	No	26.2	116.4	142.6	2.25	74.1
4	Manure	9/2	120	Sept. seed	20.9	90.9	111.7	2.05	74.4
5	Manure	10/1	120	No	35.2	131.4	166.6	2.49	73.1
7	Manure	10/31	120	No	20.4	103.8	124.2	2.07	74.7
8	Manure	4/14	120	No	32.4	128.8	161.2	2.46	72.7
9	None	8/8	0	Aug. seed	10.6	36.1	46.7	2.01	75.6
10	None	9/2	0	Sept. seed	11.6	44.9	56.6	1.95	74.5
11	None	--	0	No	17.0	71.3	88.3	2.33	74.4
12	Urea	4/16	40	No	27.9	110.2	138.2	2.23	73.8
13	Urea	4/16	80	No	29.6	120.9	150.4	2.32	73.3
14	Urea	4/16	120	No	31.8	125.7	157.5	2.31	73.0
15	Urea	4/16	160	No	35.7	132.1	167.8	2.38	72.9

* Target N rate, based on 80% of TN in manure.

	Stover	Grain	G & S	Grain Oil	Grain Starch
Stats for RCB Design (All Treatments)					
P > F:	0.001	0.001	0.001	0.418	0.023
LSD (0.05):	7.5	14.9	18.1	NS	1.6
LSD (0.10):	6.2	12.4	15.1	NS	1.3
CV (%):	21.5	10.4	10.2	15.0	1.5
Statistical analysis of main effects in factorial design (trts 1 - 4)					
Application date					
8/8/2008	20.3	94.0	114.3	2.35	73.3
9/2/2008	23.5	103.6	127.2	2.15	74.3
P > *F*:	0.261	0.139	0.130	0.269	0.180
Oat cover crop					
No	26.1	118.7	144.8	2.36	73.6
Yes	17.7	78.9	96.6	2.15	73.9
P > *F*:	0.012	0.001	0.001	0.258	0.639
Interactions (P > F)					
Application date × oat cover crop	0.283	0.040	0.051	1.000	0.906
CV (%):	24.3	12.1	12.8	15.3	1.7

Table 9. Plant population, relative chlorophyll level, and NDVI (GreenSeeker and Crop Circle) as influenced by time of manure application and an oat cover crop at Waseca in 2009.

	N management / Treatment				Plant	Rel Chloro	GS red	CC Sensor
Trt	Source	Timing	Rate*	Cover Crop	Popl'n	at R1	V8	V8
#			lb N/A		p*10^3/A	%	NDVI	NDVI
1	Manure	8/8	120	No	34.0	96.2	0.793	0.714
2	Manure	8/8	120	Aug. seed	33.8	72.5	0.763	0.681
3	Manure	9/2	120	No	34.1	95.1	0.794	0.714
4	Manure	9/2	120	Sept. seed	33.9	87.4	0.785	0.693
5	Manure	10/1	120	No	33.9	97.6	0.803	0.727
7	Manure	10/31	120	No	33.9	93.2	0.802	0.719
8	Manure	4/14	120	No	33.7	96.5	0.808	0.724
9	None	8/8	0	Aug. seed	34.1	54.8	0.707	0.620
10	None	9/2	0	Sept. seed	34.0	61.8	0.761	0.672
11	None	--	0	No	33.9	81.4	0.777	0.698
12	Urea	4/16	40	No	33.8	95.6	0.792	0.720
13	Urea	4/16	80	No	33.5	97.3	0.794	0.719
14	Urea	4/16	120	No	33.9	97.6	0.790	0.710
15	Urea	4/16	160	No	33.8	98.0	0.781	0.709

* Target N rate, based on 80% of TN in manure

Stats for RCB Design (All Treatments)	Plant Popl'n	Rel Chloro at R1	GS red V8	CC Sensor V8
P > F:	0.769	0.001	0.001	0.001
LSD (0.05):	NS	5.3	0.015	0.013
LSD (0.10):	NS	4.4	0.012	0.011
CV (%):	1.2	4.3	1.3	1.3

Statistical analysis of main effects in factorial design (trts 1 - 4)	Plant Popl'n	Rel Chloro at R1	GS red V8	CC Sensor V8
Application date				
8/8/2008	33.9	84.3	0.778	0.697
9/2/2008	34.0	91.3	0.790	0.704
P > *F*:	0.590	0.014	0.540	0.252
Oat cover crop				
No	34.0	95.6	0.794	0.714
Yes	33.9	80.0	0.774	0.687
P > *F*:	0.440	0.001	0.003	0.001
Interactions (P > F)				
Application date × oat cover crop	0.951	0.006	0.641	0.235
CV (%):	1.2	5.2	1.3	1.5

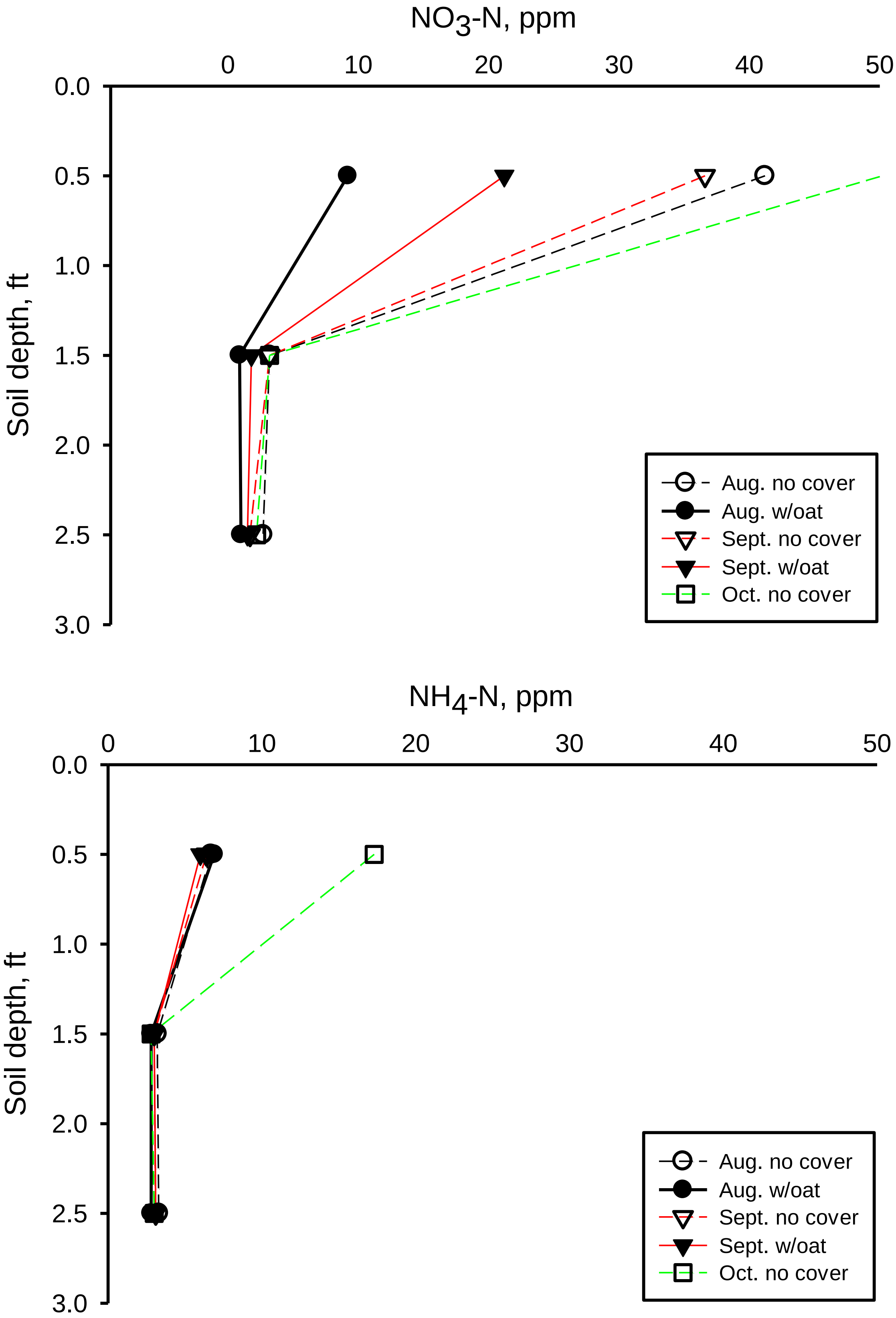

Fig. 1 Nitrate-N (NO_3-N) and ammonium-N (NH_4-N) in the 0-3' soil profile on Nov. 3, 2008 as influenced by time of hog manure application and presence of an oat cover crop.

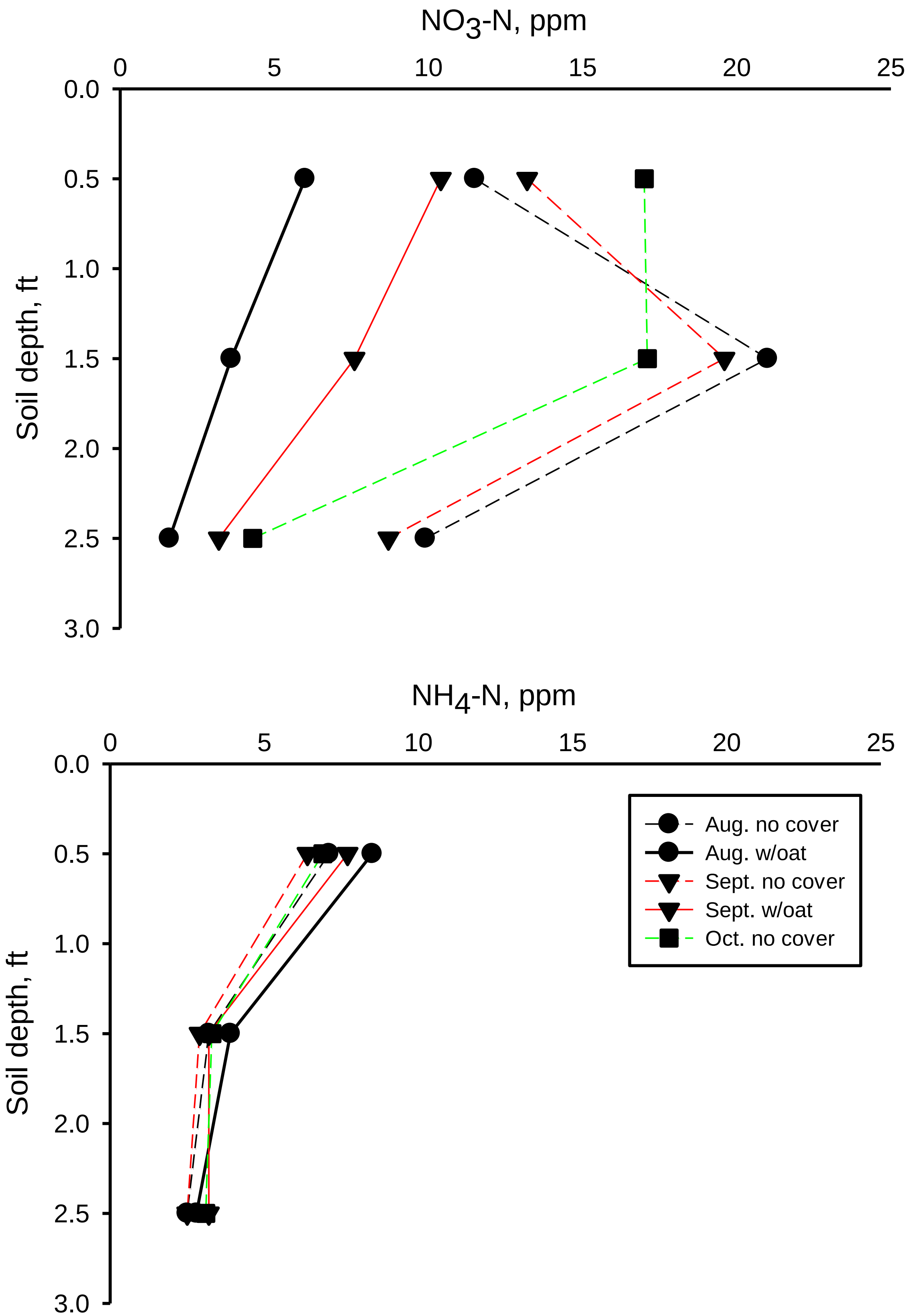

Fig. 2. Nitrate-N and NH_4-N in the 0-3' soil profile on May 15, 2009 as influenced by time of hog manure application and presence of an oat cover crop.

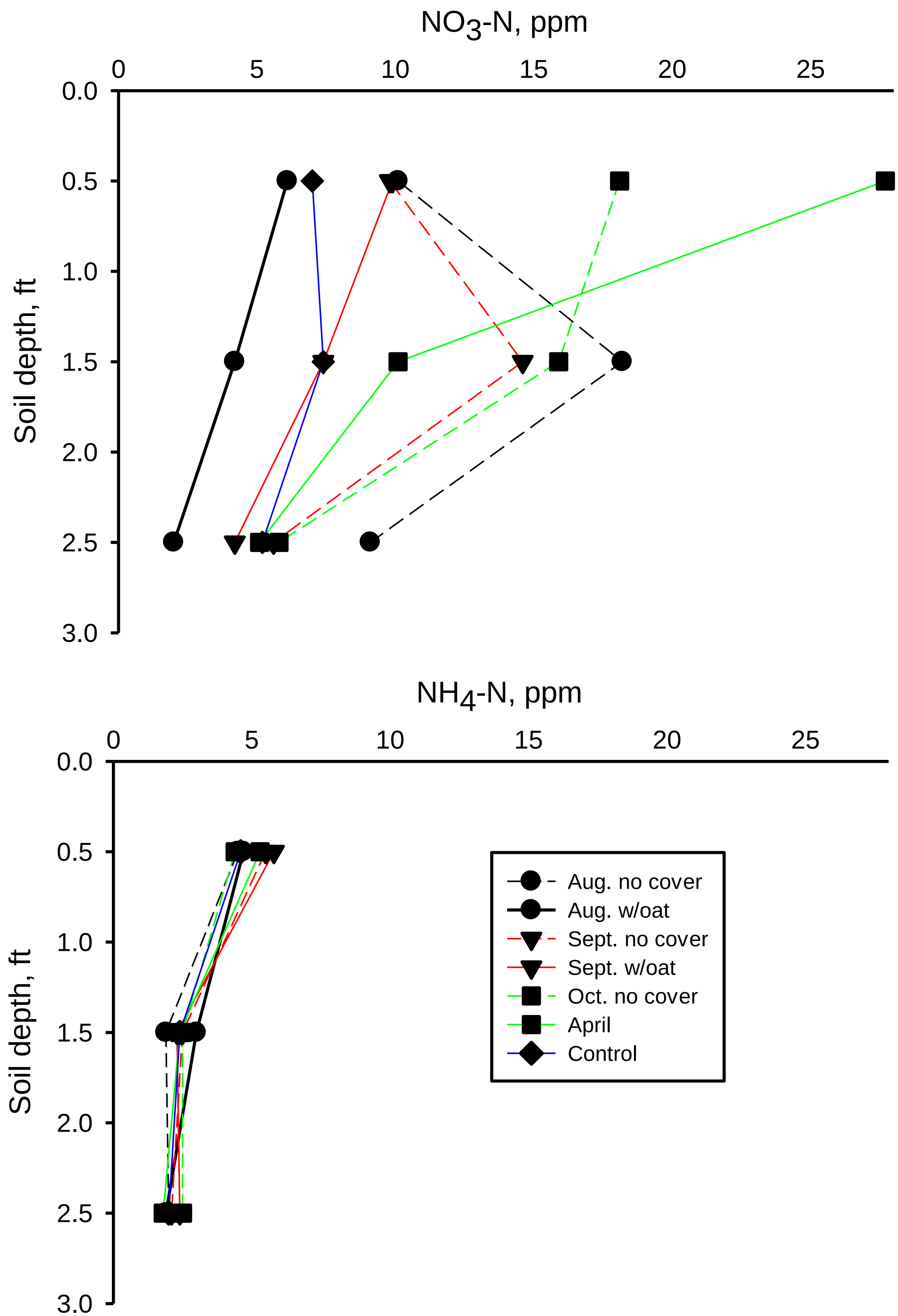

Fig. 3 Nitrate-N and NH_4-N in the 0-3' soil profile on June 15, 2009 as influenced by time of hog manure application and presence of an oat cover crop.

VIII. **Discussion:** A significant amount of discussion has occurred along with the data presented in section VII Results. Also, to a considerable degree, the results obtained in this dry and cool year, when conditions for N loss were minimal, were compared to those from the previous year – where a wet and warm fall had a pronounced influence on fall-applied hog manure. At the risk of becoming somewhat redundant, soil scientists and agronomists have long known the considerable influence that weather exerts on the behavior of nitrogen in agricultural production systems, regardless of N source. We know that fall-applied hog manure with around 75% of its N in the ammonium-N form is vulnerable to quick mineralization and nitrification of manure-N to nitrate-N under warmer conditions (August and September). Nitrate-N, which is mobile, is very susceptible to leaching if rainfall is abundant in the fall and following spring. Under cooler and drier conditions mineralization and denitrification are slower, resulting in the leaching potential being reduced greatly. We also knew that a grass cover crop such as oats had the potential to scavenge significant nitrate from the soil. What we did not know was the magnitude of the effect of the warm and wet conditions vs. dry and cooler conditions on the speed of mineralization and nitrification of manure-N to nitrate, the degree of nitrate leaching, the growth of an oat cover crop, the N sequestering capability of an oat cover crop as a function of planting date, and the effect of these interactive factors on corn production. The 2007-08 and 2008-09 seasons, in particular the fall manure application period, provided a superb opportunity to study and measure the magnitude of these effects.

In summary, the wet and warm fall of 2007 along with the warmer 2008 vs. the dry and cool fall of 2008 coupled with a cool and dry 2009 clearly demonstrated the magnitude of the effects on nitrate leaching, manure-N in the soil profile throughout the season, and nitrogen uptake by the corn and oats as a function of manure application date. Manure application in August and September resulted in greater leaching losses of N, less manure-N in the soil profile, and somewhat less N uptake in the corn compared to November and April applications when the fall was wet; whereas there were no leaching loss differences and only slight reductions in manure-N in the soil and N uptake by corn in the season marked with dry and cool conditions. Grain yield was not greatly affected by time of manure application in the wet year due to the high amount of mineralizable soil N at the site in 2008. This could be considered an anomaly. On the other hand, manure-N in the profile, oat growth, N uptake by the oats, and the depressing effect of oat growth on subsequent corn yields were clearly affected by the time of oat establishment, but they were not affected greatly by the amount of precipitation in the fall.

Based on the results from these two years, it can be concluded that August and September applications of manure clearly pose a greater environmental risk for leaching and N loss when fall conditions are wet but economical risk of lower yields may or may not occur, depending on mineralization of soil N later in the growing season. The oat cover crop consistently reduced the environmental loss of nitrate being leached from the rooting profile but significantly increased the risk of corn yield loss following both wet and dry fall seasons due to substantial amounts of N taken up by the oats and sequestered in the non-harvested short stubble and root systems. The immobilized N in the oats did not become available to the following corn crop in either year. This leads to the conclusion that an oat cover crop adds an additional, expensive risk to early fall-applied manure-N management. Based on these data, establishing an oat cover crop after August and early September manure applications is not considered a best management practice (BMP).

Acknowledgement

Grateful appreciation is extended to the National Pork Checkoff, who supported this project with funding.