SWINE MANURE APPLICATION TIMING: RESULTS OF EXPERIMENTS IN SOUTHERN MINNESOTA

Jose A. Hernandez, Jeffrey A. Vetsch, and Leslie A. Everett

Purpose: This publication describes the results of 12 site-years of research on-farm and on-station in Southern Minnesota. The goal of the experiments was to determine the best time to apply liquid swine manure to corn to maximize crop yields and minimize nitrogen (N) losses.

INTRODUCTION

Most producers in the upper Midwest apply manure in the fall because of the limited period for tillage, nutrient application, and planting in the spring. However, N from manure with a high composition of ammonium N is susceptible to losses under the same conditions that cause N losses from fall-applied inorganic fertilizers. Application of ammonium N at soil temperatures above 50 degrees F can lead to nitrification (conversion of ammonium N to nitrate) and subsequent loss of nitrate by leaching or denitrification.

Photo: J. Hernandez, UMN-Extension

Previous research from the University of Minnesota Southern Research and Outreach Center (SROC) at Waseca showed that liquid dairy and hog manures injected in April produced yields 5% higher than manures injected in September and October. The study included seven site-years over a three year period in Southern Minnesota. (Randall, G.W., et al. 1999. J.Prod. Agric. 12:317-323).

A 2006 Cornell University study (van Es, H.M., et al. 2006. J. Environ. Qual. 35:670-679) showed when applying dairy manure to corn, nitrate losses due to leaching were significantly greater when manure was applied in the early fall, especially in sandy soils. In contrast, early spring application showed the lowest nitrate losses during the three year study period for the two soils (loamy sand and clay loam).

In order to determine the optimum time for swine manure application, the following experiments were carried out at SROC and on farm fields in southern Minnesota. Corn yield response and nitrate movement were measured over a range of fall swine manure application dates.

EXPERIMENTAL PROCEDURES

Small-Plot Studies

Three small-plot trials were performed in 2007-2008, 2008-2009 and 2010-2011 at the SROC on a clay loam soil. The effects of manure application timing on corn production and nitrate and ammonium nitrogen content in the soil were compared in these trials. Swine finishing manure, provided by a local hog producer, was sweep-injected. Target dates for the manure applications were 1 August, 1 September, 1 October, and 15 April, but actual dates depended on soil conditions. Available manure-N averaged 150 lb/acre across the four application times for the 2007-2008 trial, but varied widely for the 2008-2009 trial due to an inconsistent manure supply. (See UM Extension publications “Manure Management in Minnesota” and “Nitrogen Availability from Liquid Swine and Dairy Manure: Results of On-Farm Trials in Minnesota” for determination of N availability from manure.) Urea was broadcast in the spring using a calibrated air-flow fertilizer research-plot applicator. Each manure/fertilizer nitrogen treatment was replicated four times in the first two trials and three times in the third in a randomized complete-block design. Plot dimensions were 50 feet long by 10 feet wide in the first two trials, and 80 feet by 15 feet in the third, with four and six 30-inch rows respectively. The fields were tilled and managed using procedures typical of south central Minnesota. Treatments, manure application dates, and available N applied are listed in Table 1.

Table 1. Swine liquid manure (SLM) and fertilizer application timing, and applied nitrogen rates for the small-plot trials.

Source	Manure Application Timing			Rate† lb N/A		
	2008	2009	2011	2008	2009‡	2011
SLM	02-Aug-07	8-Aug-08		150	120	
SLM	01-Sep-07	2-Sep-08	30-Sep-10	150	90	120
SLM	12-Oct-07	1-Oct-08	14-Oct-10	150	145	120
SLM	01-Nov-07	31-Oct-08	1-Nov-10	150	80	120
SLM	17-Apr-08	14-Apr-09		150	150	
None	None	None		0	0	0
Urea	30-Apr-08	17-Apr-09	6-May-11	40	40	120
Urea	30-Apr-08	17-Apr-09		80	80	
Urea	30-Apr-08	17-Apr-09		120	120	
Urea	30-Apr-08	17-Apr-09		160	160	

† N rate, based on 80% of total N in manure.

‡ Available manure nitrogen varied due to inconsistent manure supply.

Soil samples were taken in 1-foot depth increments directly in the manure bands to determine the extent to which the nitrate mineralized from the manure had leached down into the soil profile. Samples were taken to one foot in September, to two feet in October, and to three feet in November, May, and June. Sampling dates are shown in Table 2.

Table 2. Soil sampling dates for three small-plot experiments.

2007-2008 Trial	2008-2009 Trial	2010-2011 Trial
31-Aug-07	2-Sep-08	30-Sep-10
12-Oct-07	2-Oct-08	18-Nov-10
9-Nov-07	3-Nov-08	6-Jun-11
15-May-08	15-May-09	
16-Jun-08	15-Jun-09	


Photo: J. Hernandez, UMN-Extension

Field-Size Strip Studies

Nine on-farm strip trials of corn response to timing of manure were carried out, three in 2009-2010 and six in 2010-2011. Sites without a recent manure history were chosen by the farmer or their crop advisor. All sites were corn after soybean. Swine finishing manure from the host farm or a local hog producer was sweep-injected. The target available nitrogen rate was 120 lb/acre. All sites contained soil types that represented typical drained soils derived from loamy glacial tills or glacial moraines in the flat landscapes of South Central Minnesota.

Participant farmers managed their fields according to their typical practices except for nitrogen applications. Nitrogen was applied as manure or fertilizer to long strips across each field. Strip width was dependent upon the width of the manure applicator and combine header. Strip lengths varied between 300 and 850 feet. Fertilizer treatments were applied either in the fall in the form of injected anhydrous ammonia or in the spring as broadcast urea. Each manure/fertilizer nitrogen treatment was replicated three times in a randomized complete-block design.

Initially the target dates for the manure applications were August 1, September 1, October 1, and November 1. The August manure application was not possible due to the lack of available harvested fields in August. The other applications were applied at the farmers' availability. Table 3 shows the actual application dates for the manure and fertilizer treatments. October 2010 was extremely wet and farmers were not able to apply manure.

Table 3. Manure and fertilizer application timing for the 2010 and 2011 on-farm trials.

Trials by Year	Manure Application Dates (Fall)			Fertilizer Application Dates
2010	September	October	November	
1	2-3	31		15-Apr-10
2	9		2-5	20-Apr-10
3	10		2-5	3-Nov-09
2011	September	October	November	
4	13-15	15	9	12-Nov-10
5	15-17	11	15	6-Nov-10
6	17	21-23	15-18	3-Nov-10
7	16	15	10	4-Nov-10
8	9	11	11-13	10-Nov-10
9	14	11-13	12	7-Nov-10

Table 4. Location, major soils and planting and harvest dates for the on-farm trials.

Trial Number	County	Major Soil Series	Planting Date	Harvest Date
1	Nicollet	Dickinson Loam	26-Apr-10	12-Nov-10
2	Blue Earth	Cordova Clay Loam	20-Apr-10	18-Oct-10
3	Nicollet	Delft Clay Loam Le Sueur Clay Loam	18-Apr-10	27-Oct-10
4	Watonwan	Le Sueur-Lester Complex	30-Apr-11	19-Oct-11
5	Sibley	Dickinson Loam	18-Apr-11	25-Oct-11
6	Blue Earth	Nicollet Clay Loam Le Sueur Clay Loam	18-Apr-11	29-Oct-11
7	Watonwan	Marna Silty Clay Loam Kamrar Silty Clay	20-Apr-11	19-Oct-11
8	Blue Earth	Webster Silty Clay Loam Canisteo Silty Clay Loam Clarion Loam	18-Apr-11	29-Oct-11
9	Nicollet	Nicollet Clay Loam Harps Clay Loam	3-May-11	26-Oct-11

RESULTS

Small-Plot Studies

Corn yields (Tables 5-7) were excellent in all three trials/years. Yields ranged from 190 to 226 bu/acre in the fertilized (manure and urea) treatments. All fertilized treatments yielded significantly more than the control (zero N) treatment. However, no significant differences were found among the fertilized treatments within a given trial/year. The lack of yield differences among manure application timings (late summer to early spring) can be explained by the data. Control plot yields ranged from 158 to179 bu/acre. These high control plot yields suggest significant soil N contributions in these trials. All three sites were corn following small grain. It’s likely a combination of carryover nitrogen from the small grain crop and mineralization of N from the organic matter in these high organic matter soils provided much of the N the crop needed. This hypothesis is also supported by the fact that in two of the three trials 40 lb N/acre as urea was enough N to maximize corn yield. In the absence of yield differences, we will look at the distribution of N in the soil profile at different times during the growing season to help explain the effect of manure application timing.

Table 5. Corn yields for the small-plot experiment harvested in 2008.

N management / Treatment			Grain Yield	Tukey HSD Group‡
Source	Timing	Rate†		
		lb N/A	bu/A	
SLM	02-Aug-07	150	207	ab
SLM	01-Sep-07	150	213	ab
SLM	12-Oct-07	150	223	a
SLM	01-Nov-07	150	213	ab
SLM	17-Apr-08	150	223	a
None	30-Apr-08	0	179	b
Urea	30-Apr-08	40	223	a
Urea	30-Apr-08	80	217	a
Urea	30-Apr-08	120	226	a
Urea	30-Apr-08	160	223	a

† Nitrogen rate, based on 80% of total nitrogen in manure.

‡ Letters indicate statistical significance ($P < 0.1$). Values with the same letter are not statistically different from each other.

Table 6. Corn yields for the small plot experiment harvested in 2009.

N management / Treatment			Grain Yield	Tukey HSD Group‡
Source	Timing	Rate†		
		lb N/A	bu/A	
SLM	8-Aug-08	120	211	a
SLM	2-Sep-08	90	212	a
SLM	1-Oct-08	145	223	a
SLM	31-Oct-08	80	202	a
SLM	14-Apr-09	150	219	a
None	None	0	158	b
Urea	17-Apr-09	40	208	a
Urea	17-Apr-09	80	210	a
Urea	17-Apr-09	120	214	a
Urea	17-Apr-09	160	222	a

† Nitrogen rate, based on 80% of total nitrogen in manure.

‡ Letters indicate statistical significance ($P < 0.1$). Values with the same letter are not statistically different from each other.

Table 7. Corn yields for the small plot experiment harvested in 2011.

N management / Treatment			Grain Yield‡
Source	Timing	Rate†	
		lb N/A	bu/A
SLM	30-Sep-10	120	190
SLM	14-Oct-10	120	199
SLM	1-Nov-10	120	198
Urea	6-May-11	120	205
None		0	167

† Nitrogen rate, based on 80% of total nitrogen in manure.

‡ Treatments significant at $P<0.06$. Only the check was significantly different from others.

Soil Nitrate and Ammonium

Data in Figures 1 – 6 indicate that in all three manure application years, by November, ammonium N from manure applications in August and September had been converted to nitrate. Some of that nitrate, depending on the year, had leached further down in the profile or been lost to denitrification. A larger proportion of ammonium N from the October application was still present in the top one foot of the profile. In the third year there were 17 days between a November manure application and November sampling, so November was added to the graph of that year. It shows that manure ammonium remaining from the October application was less than half of that from the November application. By June of the following year (crop year), ammonium N had been mostly converted to nitrate in all treatments except spring applied manure.

Total nitrate and ammonium N remaining in the soil profile in June of the cropping year are shown in Tables 8 and 9. In the 2007-2008 trial, a significant contrast between the August and September applications compared with the later manure applications showed greater total nitrate in the soil profile from the later manure applications. A contrast between the August, September and October applications compared with November and April was also significant. These data suggest that the later applications had lost less N from the soil profile by June of 2008. The effect was less obvious in the 2008-2009 trial. Data from an additional trial are being collected and will be entered into this publication when available.

All of these N processes are controlled by soil type and rainfall patterns (Appendix 1 and 2). But in general the earlier fall applications of manure increase the risk for more rapid conversion of ammonium N to nitrate and subsequent leaching losses, since there is no significant crop present for nitrogen uptake before June.

Table 8. Soil nitrate and ammonium in the soil profile (0-3') on June 16, 2008 as influenced by manure/fertilizer application date.

N management / Treatment			NO_3-N‡	NH_4-N
Source	Timing	Rate†		
			- - - - - - lb N/A - - - - - -	
SLM	02-Aug-07	150	104 c	33
SLM	01-Sep-07	150	123 c	37
SLM	12-Oct-07	150	161 bc	38
SLM	01-Nov-07	150	187 bc	42
SLM	17-Apr-08	150	194 bc	40
None	30-Apr-08	0	87 c	38
Urea	30-Apr-08	40	134 c	38
Urea	30-Apr-08	80	185 bc	40
Urea	30-Apr-08	120	243 b	45
Urea	30-Apr-08	160	357 a	47

† Nitrogen rate, based on 80% of total N in manure.
‡ Letters indicate statistical significance ($P < 0.05$) Tukey HSD.
Values with the same letter are not statistically different from each other.

Table 9. Soil nitrate and ammonium in the soil profile (0-3') in June 15, 2009 as influenced by manure/fertilizer application date.

N management / Treatment			NO_3-N‡	NH_4-N
Source	Timing	Rate†		
			- - - - - - lb N/A - - - - - -	
SLM	8-Aug-08	120	150 a	34
SLM	2-Sep-08	90	120 ab	40
SLM	1-Oct-08	145	159 a	38
SLM	31-Oct-08	80	129 ab	43
SLM	14-Apr-09	150	171 a	38
None	None	0	78 b	36
Urea	17-Apr-09	40	119 ab	36
Urea	17-Apr-09	80	158 a	45
Urea	17-Apr-09	120	148 a	40
Urea	17-Apr-09	160	170 a	40

† Nitrogen rate, based on 80% of total N in manure.
‡ Letters indicate statistical significance ($P < 0.05$) Tukey HSD.
Values with the same letter are not statistically different from each other.

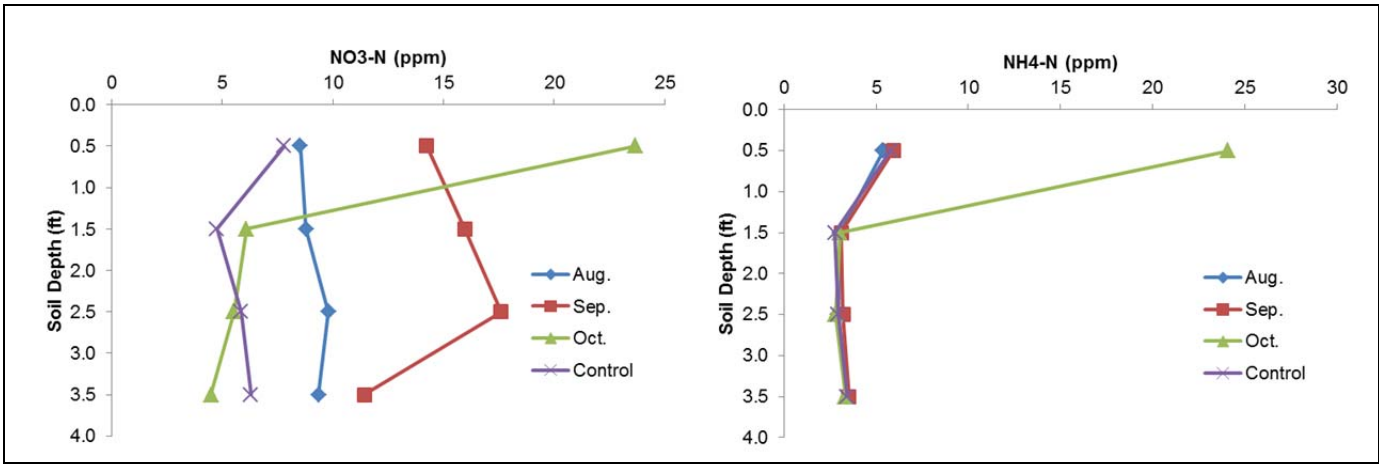

Fig. 1. Nitrate-N (NO_3-N) and ammonium-N (NH_4-N) in the 0-3' soil profile on November 7, 2007 as influenced by time of hog manure application.

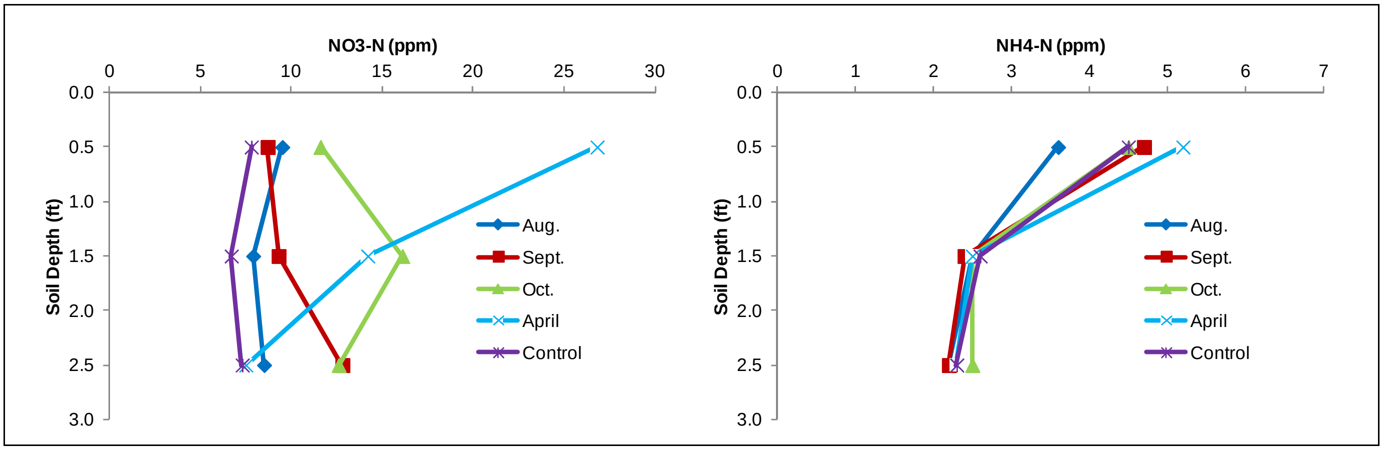

Fig. 2. Nitrate-N (NO_3-N) and ammonium-N (NH_4-N) in the 0-3' soil profile on June 16, 2008 as influenced by time of hog manure application.

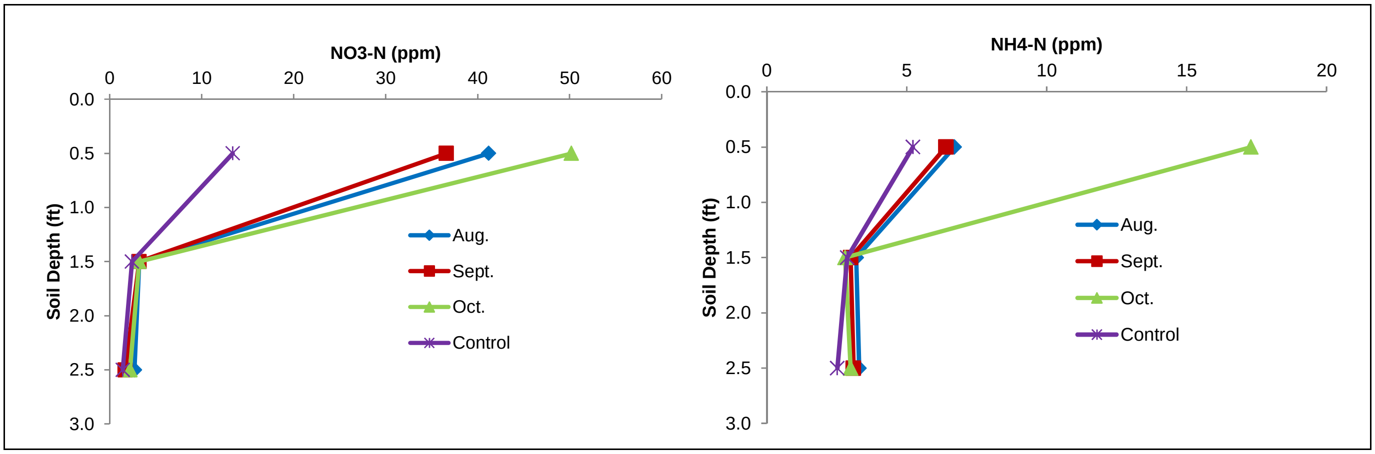

Fig. 3. Nitrate-N (NO_3-N) and ammonium-N (NH_4-N) in the 0-3' soil profile on November 8, 2008 as influenced by time of hog manure application.

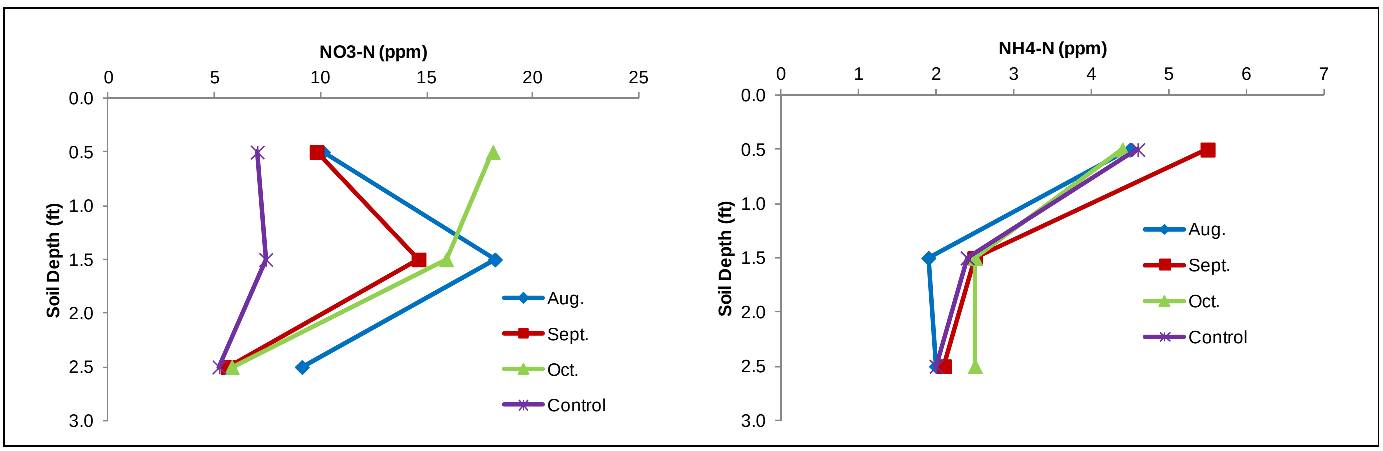

Fig. 4. Nitrate-N (NO_3-N) and ammonium-N (NH_4-N) in the 0-3' soil profile on June 15, 2009 as influenced by time of hog manure application.

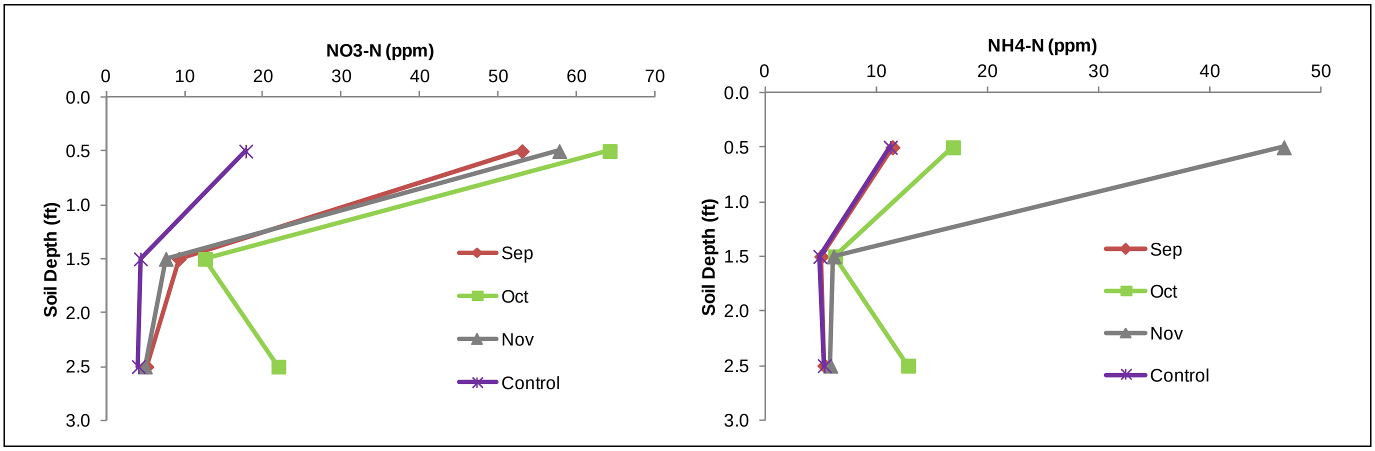

Fig. 5. Nitrate-N (NO_3-N) and ammonium-N (NH_4-N) in the 0-3' soil profile on November 18, 2010 as influenced by time of hog manure application.

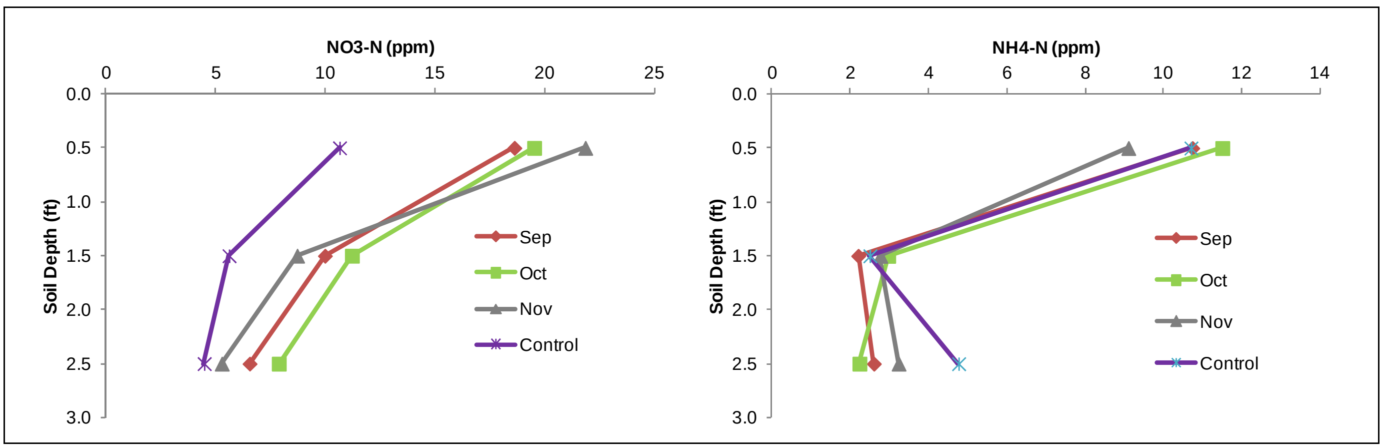

Fig. 6. Nitrate-N (NO_3-N) and ammonium-N (NH_4-N) in the 0-3' soil profile on June 6, 2011 as influenced by time of hog manure application.

Field-Size Strip Studies

Results of the two years of on-farm trials are shown in Tables 10 and 11. An analysis of variance for each year separately indicated no significant site by treatment interaction in either year. Treatments were not significantly different ($P<0.05$) in the first year trials. For the second year, 2011, treatments were significant. The September manure application showed a significantly lower corn yield compared to the two other manure application times and the fertilizer application, when using a pre-planned contrast in the analysis. With the Tukey HSD for unplanned comparisons some individual sites showed significant differences among treatments.

In order to combine the two years of data for analysis, it was necessary to average the October and November manure application yield data in each replication of the second year sites to form one treatment. The number of treatments in the second year then matched the number of treatments (three) in the first year, i.e. “early manure”, “late manure”, and “late urea”. This is appropriate because the late treatment in the first year was at the end of October or beginning of November, while the corresponding treatments in the second year were mid-October and mid-November. The nine-site analysis of variance of corn yields was significant for treatments and insignificant for the treatment by site interaction. The contrast of early with late manure application showed that the yields from the September (early) manure application were significantly lower than yields from the late (October-November average) application and lower than from the late urea application (Table 12) The contrast of yields from late manure application compared to late urea was also significant at $P<0.05$ (pooled error term), but not with the more conservative Tukey HSD comparison at $P<0.05$. The combined analysis clearly shows a significant loss in yield when manure was applied in September relative to later months.

Table 10. Corn yields for the field-size strip trials harvested in 2010.

Trial	Source†	Manure Application Timing		Grain Yield	Tukey HSD
		Month	Day	bu/A	Group‡
1	SLM	September	2-3	187	a
	SLM	October	31	186	a
	Urea	April	15	195	a
2	SLM	September	9	201	a
	SLM	November	2-5	215	a
	Urea	April	10	207	a
3	SLM	September	10	189	a
	SLM	November	2-5	197	a
	AA	November	3	203	a

† SLM: Swine Liquid Manure, AA: Anhydrous Ammonia

‡ Letters indicate statistical significance ($P < 0.1$). Values with the same letter are not statistically different from each other.

Table 11. Corn yields for the field-size strip trials harvested in 2011.

Trial	Source†	Manure Application Timing		Grain Yield	Tukey HSD Group‡
		Month	Day	bu/A	
4	SLM	September	13-15	186	a
	SLM	October	15	197	a
	SLM	November	9	199	a
	AA	November	12	203	a
5	SLM	September	15-17	178	b
	SLM	October	11	201	a
	SLM	November	15	196	a
	AA	November	6	198	a
6	SLM	September	17	196	a
	SLM	October	21-23	199	a
	SLM	November	15-18	205	a
	AA	November	3	211	a
7	SLM	September	16	195	a
	SLM	October	15	206	a
	SLM	November	10	203	a
	AA	November	4	205	a
8	SLM	September	9	188	b
	SLM	October	11	196	b
	SLM	November	11-13	201	b
	AA	November	10	222	a
9	SLM	September	14	191	a
	SLM	October	11-13	198	a
	SLM	November	12	195	a
	AA	November	7	195	a

† SLM: Swine Liquid Manure, AA: Anhydrous Ammonia

‡ Superscript letters indicate statistical significance ($P < 0.1$). Values with the same letter are not statistically different from each other.

Table 12. Corn yields for three treatments averaged across nine trials in 2010 and 2011.

Treatment	Month(s)	Grain Yield	Tukey HSD Group†
		bu/A	
Early manure	September	190	a
Late manure	October &/or November	200	b
Late urea	November or April	205	b

† Letters indicate statistical significance ($P < 0.05$). Values with the same letter are not statistically different from each other.

CONCLUSIONS:

The small-plot experiment station results indicate that N from fall applied swine manure, which has a high proportion of N in the inorganic, ammonium form, is rapidly converted to nitrate. The earlier the application, the higher the proportion of ammonium that is converted and available for leaching. The total N remaining in the top three feet of the soil profile by June of the cropping year was less for the earlier manure applications than for the later applications in 2008 but not as clear in 2009.

In the on-farm strip trials over two years the contrast of early compared with late manure applications showed that the yields from the September (early) manure application were significantly lower than yields from the later (October-November average) application and lower than from the late urea application. The combined analysis clearly shows a significant loss in yield when manure was applied in September relative to later months.

All of these nitrogen processes are controlled by soil type and rainfall patterns. But in general early application of manure increases the risk for leaching and denitrification losses, since there is no crop present for nitrogen uptake. Liquid swine manure, with a high inorganic N content, should be managed much like inorganic fertilizer N sources with either late fall or spring application to delay conversion of ammonium to nitrate and subsequent loss by leaching and denitrification.

RESOURCES FOR ADDITIONAL INFORMATION:

- Manure Management in Minnesota. UMN – Extension Publication WW-03553.
- Nitrogen Availability from Liquid Swine and Dairy Manure: Results of On-Farm Trials in Minnesota. UMN – Extension Publication 08583.

AUTHORS:

Jose A. Hernandez, Extension Educator, Soil Scientist, University of Minnesota - Extension
Jeffrey A. Vetsch, Assistant Scientist, University of Minnesota Southern Research and Outreach Center
Leslie A. Everett, Education Coordinator, Agronomist, University of Minnesota - Water Resources Center

ACKNOWLEDGMENTS:

Funding for this study was provided by Minnesota Pollution Control Agency, Section 319 Nonpoint Source (NPS) Management Program from E.P.A.

Appendix 1: Monthly air temperature by season and year.

Season	Month	Temperature			
		2008/2009	2009/2010	2010/2011	Normal*
		- - - - - - - - - - - - -	°F	- - - - - - - - - - - - -	
Previous Fall	August	68.3	66.4	73.0	68.9
	September	62.5	64.1	58.9	60.2
	October	47.9	42.0	51.0	47.7
	November	33.7	41.2	33.2	31.4
Growing Season	March	30.8	35.2	26.9	30.3
	April	45.7	53.7	43.8	44.9
	May	58.0	59.2	57.0	58.3
	June	65.8	67.0	68.6	67.7
	July	66.1	72.5	76.3	71.2
	August	66.4	73.0	70.0	68.9
	September	64.1	58.9	59.6	60.2
	October	42.0	51.0	51.3	47.7

*Normal: Based on 1971-2000 average for air temperature and precipitation.

Appendix 2: Monthly precipitation by season and year.

Season	Month	Precipitation			
		2008/2009	2009/2010	2010/2011	Normal*
		- - - - - - - - - - - - Inches - - - - - - - - - - - -			
Previous Fall	August	2.18	3.33	2.43	4.58
	September	1.44	1.48	12.66	3.19
	October	1.94	7.05	1.02	2.56
	November	2.25	0.91	2.46	2.32
Growing Season	March	1.77	1.45	2.16	2.49
	April	2.39	1.60	4.46	3.23
	May	1.90	3.27	4.67	3.96
	June	2.76	9.64	5.19	4.22
	July	1.53	6.61	7.21	4.47
	August	3.33	2.43	0.92	4.58
	September	1.48	12.66	0.86	3.19
	October	7.05	1.02	0.44	2.50

*Normal: Based on 1971-2000 average for air temperature and precipitation.