RESEARCH REPORT

PUBLIC HEALTH/WORKER SAFETY

Title: Nutrient and Pathogen Losses to Subsurface Tile Drainage from Swine Manure - **NPB #02-095**

Investigator: Gyles W. Randall

Institution: University of Minnesota

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Abstract: A study was conducted to determine the effects of liquid swine manure and urea on the movement of N, P, and pathogens in the soil, into tile drainage, and on corn production. In November 2001, swine manure was spiked with *Salmonella anatum* and sweep-injected into chisel-plowed continuous corn at a rate of 5000 gal/A (310 lb "available" N/A). Urea was applied at a rate of 160 lb N/A in April 2002 and incorporated immediately. Corn production was generally not affected differently by the two sources of N. Grain yields were excellent, ranging from 180 to 186 bu/A. Although rainfall for the growing season was slightly below normal, an excessive amount (7.15") fell in June, resulting in abundant tile flow during a 45-day period. Significantly lower NO_3-N concentrations in the tile drainage water, in the 12" soil samples in early June, and in the 0-5' soil profile samples in late October for the manured plots compared with the plots receiving urea strongly suggest substantial loss of N from the fall-applied hog manure due to denitrification during the wet June period. Soil test P in the top 8" has been increased from 29 ppm Bray P_1 for the urea treatment to 140 ppm after nine consecutive annual manure applications to the manured plots. Soil tests in the 5-foot profile indicate no downward movement of P below 12" and high soil pH (7.8) and extremely low soil test P below 36". Losses of total P and ortho-P into tile drainage were minimal with detectable levels of total P occurring in 89% of the water samples and ortho-P in 47% of the samples. Concentrations of total P in the detects averaged $\leq$ 0.038 mg/L with ortho-P averaging $\leq$ 0.014 mg/L. Differences in P loss were negligible between the manure and urea treatments. *Salmonella anatum* was not found in any of the water samples, indicating that this organism either did not survive the winter or was retained in the upper layers of soil and not transported to drainage water. Numbers of fecal coliforms, male-specific phages, and somatic phages were similar in both urea-treated and manure-treated plots. This suggests these organisms did not survive over winter in the added manure and that levels seen during the six-week drainage period were probably background levels.

For more information contact:

National Pork Board, P.O. Box 9114, Des Moines, Iowa USA

800-456-7675, **Fax:** 515-223-2646, **E-Mail:** porkboard@porkboard.org, **Web:** http://www.porkboard.org/

Introduction: Land application of swine manure on tile-drained soils has become a focal point of controversy throughout major swine producing areas of the U.S. and a high priority issue among pork producers. Many in the environmental and policy communities have become concerned because the potential exists for nutrients [nitrogen (N) and phosphorus (P)] and pathogens to leach into subsurface tile water draining into surface waters. Many in the pork industry, especially those producers looking to site new facilities, are also faced with this concern.

Currently, little information exists describing the effect of land-applied swine manure on the enrichment of subsurface tile drainage water with N, P, and pathogens. Bacterial and nutrient levels in tile water discharge exceeded water quality standards in an Ontario watershed with 300 livestock farms. Limited studies in Iowa have measured N and P losses to drainage water from swine manure and have shown elevated levels of fecal bacteria in drainage from manured plots. High concentrations of ortho-P in tile drainage in New York studies were associated with dairy manure.

This report will describe the extent to which nitrate, P (total P and soluble P), and pathogens (fecal coliform and *Salmonella*) leached to tile drainage in clay loam soils from swine manure and urea fertilizer in southern Minnesota in 2002. The information should be helpful to pork producers, educators, the environmental community, and policy makers in making decisions important to the industry and society.

Objectives:

The immediate objectives are to:

1) determine the concentrations and losses of nitrate-N, soluble P, and total P in tile drainage as affected by land application of swine manure and urea for corn.
2) determine if liquid hog manure land-applied for corn has the potential to contaminate subsurface tile drainage water with pathogens and fecal indicators [Salmonella, fecal coliform bacteria, and coliphages (somatic and male-specific phages, as indicators of human and animal viruses)].
3) provide valuable information to pork producers on the movement or lack thereof of N, P, and potential human-health related pathogens through the soil to subsurface tile drainage water.

Materials and Methods: Tile drainage plots measuring 45' wide by 50' long were installed in 1975 on a Webster clay loam at Waseca. Each plot is surrounded with plastic sheeting to a 6-foot depth. For this study, the six most uniform plots were converted to three replications of swine manure vs. urea treatments; swine manure was applied to plots that had received various rates of dairy and swine manure from Nov. 1993 through Nov. 2000. Liquid swine manure (finishing barn) was experimentally contaminated with *Salmonella anatum* (prepared by Dr. Goyal's laboratory, Dept. of Veterinary Diagnostic Medicine) at a rate of 9×10^6 CFU/gallon of manure on Nov. 7, 2001 and thoroughly agitated prior to and during application. The manure was immediately sweep-injected into chisel plowed corn ground at a rate of 5000 gal/A. Manure analyses are shown in Table 1. Total N was 76% ammonium-N and 24% organic N. "Available" N was calculated based on the assumption that 80% of the total N in the swine manure was available in the first year after application (69.0 lb TN/1000 gal x 5000 gal/A = 345 lb TN/A x 0.80 = 276 lb "available" N/A) and 15% of the total N applied for the 2001 crop was available (226 lb TN/A x 0.15 = 34 lb "available" N/A) for a total of 310 lb "available" N/A. The hog manure application rate of 5000 gal/A and "available" N rate of 310 lb N/A was intentional because research conducted the previous 4 yr with an application rate of 3500 gal/A showed corn yields with manure to be either less than or equal to yields with the same rate of "available" N spring-applied as urea. On April 25, 2002 urea was broadcast-applied to three plots at a rate of 160 lb N/A before field cultivation. This nitrogen rate is the University of Minnesota N recommendation for continuous corn with an expected yield of 170 bu/A.

Table 1. Nutrient analyses and application rates of liquid hog manure applied in November, 2001 for the 2002 crop.

Dry Matter	Total Nitrogen	Ammonium-N	Organic N	Total P_2O_5	Total K_2O
%	- -	lb/1000 gal	- -		
11.4	69.0	52.4	16.6	33.5	35.5
	- -	lb/acre	- -		
	345	262	83	168	178

Corn (P36R11) was planted on April 26 at a population of 31000 plots/A. A soil insecticide (Force) was applied to control rootworms. Weeds were controlled with a combination of preemerge herbicide (Surpass) applied May 8, post-emergence herbicide (Accent Gold) applied June 7, and cultivation (June 14). Weed and insect control were excellent. Silage yields were taken at physiological maturity. Grain yields were taken on October 3 by combining four 45-foot rows per plot.

When tile lines were flowing, flow rates were measured daily and samples taken on a daily basis for the first week and then on a M-W-F basis thereafter for NO_3 analysis. Total-P, ortho-P and pathogen analyses were determined on samples taken on selected days when all tile lines were running. Nitrate and P analyses were conducted by the University's Research Analytical Lab and pathogen analyses by the Dept. of Veterinary Diagnostic Medicine.

Results:

Objective 1

Weather conditions during the 2002 growing season had a significant influence on the corn yield and N loss results in this study. Growing season (Apr.-Sept.) rainfall totaled 23.02" or 0.63" below normal. Conditions were dry in April, May, July and September. However, abundant rainfall in June (7.15", 2.93" above normal) and in August (6.08", 1.50" above normal) resulted in sufficient available water for excellent corn yields. Losses of N from the treatments occurred primarily in June when the soil profile was saturated for about 20 days.

Corn Production

All corn production parameters, except stover yield and grain moisture, were not significantly different ($P \leq 0.10$) between the urea and hog manure sources (Table 2). However, hog manure did result in greater stover N yield and lower grain moisture at harvest. These data indicate from a corn production perspective, there was generally no difference between spring-applied urea at 160 lb N/A and fall-applied liquid hog manure at 310 lb "available" N/A.

Table 2. Influence of nitrogen source on corn production and N utilization at Waseca in 2002.

N	Yield			Grain	N Concentration		R1 Leaf	Nitrogen Uptake		
Source	Grain	Stover	Silage	Moisture	Stover	Grain	Chlorophyll	Stover	Grain	Silage
	bu/A	- - T DM/A - -		%	- - - - - - % - - - - -		Rel. %	- - - - - - - - lb/A - - - - - -		
Urea	186	3.89	8.29	22.6	1.01	1.66	97.8	78	146	224
HM	180	4.39	8.63	21.6	0.91	1.65	100.0	80	140	220
Check[1]	65	2.36	3.90	23.4	0.59	1.32	62.4	28	41	69
	Treatment Statistical Analysis (Excludes Check Plots)									
P > F	0.632	0.058	0.274	0.074	0.295	0.478	0.289	0.861	0.609	0.284
C.V.(%)	7.7	3.7	3.3	1.6	9.6	0.9	1.9	10.7	8.3	1.7

[1/] The check plots (0 lb N/A) are not randomized within the replications and do not have the same plot history as the 6 main plots. Therefore, data from the check plots are not included in the statistical analysis.

Soil Nitrate, P, and K

Soil samples were taken from the 0 to12” layer of both the urea and manure plots on April 16, on May 15 at the VE stage, and on June 6 at the V4 stage, when a pre-sidedress nitrate test (PSNT) would have been taken. The data shown in Table 3 indicate significant nitrification of the swine manure by April 16 with some accumulation of NH_4-N remaining to be nitrified. By May 15, the manure appeared to be completely nitrified resulting in 25.0 ppm NO_3-N. Urea applied on April 25 had begun to nitrify (16.0 ppm NO_3-N), but significant NH_4 remained. On June 6, after receiving 2.49” of rain on June 1-4, NO_3-N concentrations were much lower for the manure-treated plots than for those plots receiving urea. Variability among the plots as shown by the SE’s was high, particularly for manure where two of the plots had NO_3-N concentrations <10 ppm. In addition, some NH_4-N still remained in the urea-treated plots. These data indicate the distinct possibility of much greater denitrification in the manure plots during this short wet period when soils became saturated. If the loss was dominated by leaching, one would have expected NO_3-N concentrations to be reduced in the urea-treated plots as well.

Table 3. Soil NO_3-N and NH_4-N in the 0-1’ layer early in the growing season as influenced by swine manure and urea.

Sample date	N Source	NO_3-N Avg.	NO_3-N SE	NH_4-N Avg.	NH_4-N SE
		- - - - - - -	- - - - - - - - ppm	- - - - - - - -	- - - - - - -
April 16	Urea	1.4	0.3	12.3	2.5
	Manure	14.2	2.7	17.3	3.9
May 15	Urea	16.9	2.8	23.3	3.8
	Manure	25.0	2.5	11.8	0.7
June 6	Urea	25.8	9.8	15.6	1.3
	Manure	16.0	6.7	11.0	1.1

Soil samples were collected from the plow layer (0 - 8 inch depth) in June 2002 to measure the influence of hog manure vs. urea on soil fertility. Phosphorus and potassium contained in the dairy and hog manure applied for corn grown in 1994 through 2001 totaled 971 lb P_20_5/A and 1755 lb K_20/A. The hog manure applied for the 2002 crop contained 168 lb P_20_5 /A and 178 lb K_20/A (Table 1). In addition, commercial fertilizer applied to all plots in 1994, 1998, and 2000 totaled 338 lb P_20_5 /A and 500 lb K_20/A. Soil test P (STP) and K (STK) shown in Table 4 reflect these application rates. During the 9-year period, STP and STK were increased 1 ppm by application rates of 8.7 lb P_20_5 /A and 12.4 lb K_20/A as manure.

Table 4. Influence of nitrogen source on soil pH and soil test P and K (0-8 inch depth) in June 2002 after 9 years of manure application.

Nitrogen Source	Bray P_1	Exchangeable K
	- - - - - - - - - ppm	- - - - - - - - -
Urea	29	152
Hog Manure	140	294

Soil samples were taken in one-foot increments to a 5-foot depth on October 21, 2002 and analyzed for pH, extractable P, K, and residual NO_3-N. The data shown in Table 5 indicate the vast majority of P added as manure and fertilizer remains in the top 12”. Soil test P at deeper depths was very low. Moreover, the soil profile becomes calcareous at about 30” and is highly calcareous below 36”. The Olsen P test was also used on the high-pH samples and gave STP values of 1 ppm. These data confirm the lack of extractable P at depths below two feet even though more than 1400 lb P_2O_5/A has been applied in the last 9 years.

Table 5. Soil pH, Bray P_1 extractable P, exchangeable K, and nitrate-N in the 0-5’ soil profile on October 21, 2002 as influenced by swine manure and urea.

	N Source							
	Urea				Swine manure			
Depth	pH	P	K	NO_3-N	pH	P	K	NO_3-N
feet		- - - - - - -- ppm - - - - - - - -				- - - - - - - - - ppm - - - - - - - - -		
0-1	6.0	25	147	3.0	6.2	111	233	3.6
1-2	6.7	4	140	2.3	6.7	6	144	2.1
2-3	7.2	1	153	3.4	7.2	2	150	2.2
3-4	7.7	1	129	5.0	7.8	2	144	2.6
4-5	7.8	1	138	5.4	7.8	1	148	3.4
0-5’ Total (lb/A)	-	-	-	76	-	-	-	56

Soil samples taken after harvest in October indicate relatively low amounts of residual soil nitrate in the 0 to 5’ profile, but slightly more for urea (76 lb/A) compared to hog manure (56 lb/A) (Table 5). Nitrate-N amounts were quite similar in the top two feet for the two N sources, but greater amounts were found for the urea-treated plots below two feet. From a simple N balance perspective, the low amount of residual soil nitrate found in the manured plots is surprising, considering “available” N application was 150 lb/A greater than in the urea plots. Moreover, plant uptake of N was almost identical for the two N sources. Perhaps the low residual soil nitrate in the manured plots is related to the “loss” of N suggested by soil samples taken in early June (Table 3). These post-harvest data strongly suggest and perhaps confirm substantial denitrification and/or leaching of N during the growing season in the manured plots.

Nutrient Losses in Tile Drainage

Precipitation distribution during the spring of 2002 had a direct effect on tile drainage flow. Precipitation during April totaled 2.84” or 0.39” below normal while May rainfall (1.71”) was 2.25” below normal. Soils became saturated in June with 7.15” of rain. Rainfall was heaviest between June 3 and 15 (3.77”) and June 22-30 (2.85”). Tile flow began on April 13 and flowed for a total of 45 days: 8 in April, 4 in May, 28 in June, and 5 in July. The most significant drainage events occurred from June 3-15 and June 22-30. Ninety percent of the 2002 drainage occurred in June (Table 6). Drainage during April, May, and July was highly variable due to the dry conditions and extremely low flow rates. For the season, total drainage was not considered to be different between the two N sources.

Flow-weighted NO_3-N concentrations shown in Table 6 indicate consistently higher NO_3-N levels for the urea treatments compared to hog manure. Treatment differences in April, May and July are difficult to assess due to very low flow, but the June and annual total data provide solid evidence that NO_3-N concentrations for the manure plots were 35% lower than for the urea plots. At least two possible reasons exist for the difference in NO_3-N concentration between the two N sources. First, in the previous year (2001), flow-weighted NO_3-N concentrations in December were greater for urea (17.6 mg/L) compared with hog manure (12.4 mg/L). Similarly, residual soil nitrate in late October was greater for urea (173 lb/A) compared with swine manure (67 lb/A). A 40 bu/A corn yield reduction in the manured treatment provided additional evidence that substantial loss of manure-N had occurred during the growing season;

probably due to denitrification because NO_3-N losses in tile drainage water for 2001 were not different between the two N sources. Perhaps these differences simply carried over into 2002. Second, soil nitrate data found in Tables 3 and 6 along with excessive June precipitation again suggest likely conditions for denitrification of fall-applied hog manure after the manure-N has nitrified. Thus, the nitrate concentrations found in the tile drainage and soil profile in 2002 most probably reflect a combination of precipitation-driven denitrification losses in 2002 coupled with carryover effects from 2001. The primary difference between the two years is "available" N in 2002 was sufficient to meet N demand by the crop and, thus, prevent corn yield loss.

Nitrate-N lost in the tile drainage was small and was only 4 lb/A less (26%) for the manured plots (11.6 lb/A) compared with the urea plots (15.6 lb/A) (Table 6). Loss of NO_3-N in the drainage water was the equivalent of 9.8% of the urea-N applied and 3.7% of the "available" manure-N for 2002. Eighty nine percent of the annual nitrate loss occurred in June.

Table 6. Influence of nitrogen source on tile flow, flow weighted NO_3-N concentration, and NO_3-N loss in 2002.

	Tile Flow		Flow-weighted NO_3-N Conc.		NO_3-N Lost	
Month	Urea	Hog Manure	Urea	Hog Manure	Urea	Hog Manure
	- - - - - - - - Acre-In - - - - - - -		- - - - - - - - - mg/L - - - - - - - - -		- - - - - - - - - lb/A - - - - - - - -	
April	0.10	0.23	21.4	12.3	0.5	0.9
May	0.02	0.12	26.3	18.1	0.1	0.5
June	3.10	3.06	21.5	13.7	14.5	9.7
July	0.10	0.13	19.1	14.1	0.5	0.5
Total	3.32	3.54	21.5	13.9	15.6	11.6

Tile water samples were collected 6 times when water was flowing from all plots and were analyzed for ortho-P and total P. Ortho-P concentrations were at or above detection limits (0.01 mg/L) in ≤ 50% of the water samples and were not different between the urea and manure-treated plots (Table 7). Detectable levels of ortho-P were not different between the N sources and averaged 0.014 mg/L for the manured plots and 0.010 mg/L for the urea plots. Ortho-P never exceeded 0.03 mg/L in the 18 water samples. Total P was detected in 89% of the water samples from both the manured and urea-treated plots. Total P concentration ranged from 0.02 to 0.11 mg/L in the 16 samples from the manured plots and from 0.02 to 0.06mg/L in the 16 samples from the urea plots. Average total P concentration across water samples with detectable levels was 0.038 mg/L for the manure treatment and 0.030 mg/L for the urea treatment.

Table 7. Ortho-phosphorus and total phosphorus detects and concentrations in tile water samples in 2002.

	Ortho-Phosphorus		Total Phosphorus	
	Manure	Urea	Manure	Urea
Number of samples analyzed	18	18	18	18
Number of detects†	9	8	16	16
% of samples with detects	50	44	89	89
Conc. range of detects (mg/L)	0.01-0.03	0.01-0.01	0.02-0.11	0.02-0.06
Avg. Conc. of detects (mg/L)	0.014	0.010	0.038	0.030

† Detection level is 0.01 mg/L for ortho-P and 0.02 mg/L for total P.

Objective 2

Pathogen Losses in Tile Drainage

No *Salmonella anatum* was isolated from any of the water samples (Table 8). The numbers of fecal coliforms in water samples from control (urea treated) and manure-treated plots were similar over the six-week period (Table 8). No fecal coliforms were isolated from samples obtained at the three and six-week samplings. At five weeks, only one control plot and one test plot were positive for fecal coliforms.

F^+RNA (male specific) coliphages were detected in nearly all water samples except from a urea plot at week 2, another urea plot at week 3, and a manure plot at week 3 (data not shown). The average number of male-specific phages was higher at week 1 in both urea and manure plots and thereafter, the numbers declined and were similar in manure and urea treated plots. The numbers of somatic coliphages were lower in general than those of F^+RNA (Table 8), with seven samples being negative. These phage negative samples were found to have lower numbers of fecal bacteria. In general, the number of male-specific and somatic coliphages was relatively higher than those of bacterial indicators in all plots. The numbers of both phages and fecal coliforms were higher during the first two weeks of sampling than in subsequent samplings.

Table 8. *Salmonella*, fecal coliforms and coliphages in tile water samples as influenced by swine manure and urea.

Organism	Treatment	Mean (Standard Deviation)					
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Salmonella	Urea	0	0	0	0	0	0
	Manure	0	0	0	0	0	0
Fecal coliforms	Urea	37 (62.9)	45 (71.7)	0	9 (10.9)	<1 (0.5)	0
	Manure	4 (2.3)	31 (15.0)	0	8 (6.8)	<1 (0.5)	0
F^+RNA coliphages	Urea	43 (27.3)	12 (11.2)	1 (1)	4 (2.8)	14 (6.5)	8 (4.7)
	Manure	33 (14.4)	11 (12.6)	4 (3.5)	5 (3.7)	20 (18.0)	9 (6.5)
Somatic coliphages	Urea	18 (12.5)	22 (8.1)	2 (2.5)	<1 (0.5)	3 (2.5)	11 (6.0)
	Manure	6 (10.1)	27 (18.7)	22 (36.3)	5 (8.0)	3 (3.2)	8 (5.5)

Objective 3

The information reported above and summarized in the following "Discussion" section meets this objective.

Discussion: The results obtained in 2002 indicates the marked effect that periods of excessive June precipitation can have on the performance of fall-applied hog manure and spring-applied urea. Corn production was not affected differently by the two N sources. But NO_3-N concentrations in the tile drainage water, in the 0-12" soil samples in early June, and in the 0 to 5' soil profile after harvest were markedly greater for the urea-treated plots compared with the manured plots even though the applied "available" N rate was 150 lb/A greater for the manured plots. These data strongly suggest substantial denitrification losses of the N from the fall-applied hog manure during the wet June period. Denitrification may have been catalyzed in the manure treatments because of the significant amount of carbon from the manure and corn residue. We can not suggest, however, that similar results would have been obtained if the manure had been sweep-injected into soybean ground. Corn production was not hampered due to the high rate of manure-N (310 lb "available" N/A).

Losses of ortho-P and total P into the tile drainage system were minimal and did not appear to be influenced greatly by source of N. Ortho-P and total P were detected in 47 and 89% of the water samples, respectively, with no difference between the manure and urea treatments. Concentrations of ortho-P and total P in the "detect" samples averaged ≤ 0.014 mg/L and ≤ 0.038 mg/L, respectively. *Salmonella anatum* was not found in any of the drainage water samples. Fecal califorms were found in the drainage water in 4 of 6 samplings with no consistent difference between the manured plots and the urea plots. Male-specific coliphages and somatic coliphages were found in the drainage water in all six samplings with greater numbers in the first two samplings (early June with higher flow rates). Differences in phage numbers between the manured and urea treatments were not apparent. Since fecal coliforms and coliphages were found in the subsurface drainage water from both manure and urea-treated plots, it is difficult to conclude from this 1-year study whether the application of swine manure on tile-drained land leads to contamination of subsurface water or not.

Lay Interpretation: Land application of swine manure on tile-drained soils has become a controversial issue in some swine producing areas because of uncertainties regarding the leaching of nitrates, phosphorus, and pathogens through the soil and into tile drainage water. A study was started on a set of tile drainage plots at Waseca, MN in November 2001 when liquid swine manure spiked with *Salmonella anatum* was sweep-injected into three plots at a rate of 5000 gal./acre. Urea was applied to three additional plots in April 2002. Corn was grown and samples of soil and tile water were taken during the year. Corn grain yields were excellent and were not different between the manure and urea N sources. Nitrate-N levels in the tile water and in the soil samples during and at the end of the season were lower for the manure treatment compared with urea even though 150 lb per acre more "available" N had been applied in the manure treatment. These findings suggest denitrification losses of N from the fall-applied manure may have been substantial in June when excess precipitation (7.15") occurred and soils became saturated. Soil test phosphorus (P) analysis showed no detectable movement of P from the manure down through the soil profile. Detectable levels of total P were found in 89% of the water samples, whereas only 47% of the samples contained detectable levels of soluble P. Losses of soluble and total P were very small and did not appear to be different for manure vs. urea. *Salmonella anatum* was not found in any of the water samples, indicating either the organism did not survive the winter or it was retained in the upper soil profile and not transported to tile drainage water. Numbers of fecal coliforms were similar for both manure and urea treated plots. This suggests these organisms did not survive over winter in the added manure and that levels found during the six-week drainage period were probably background levels. For further information contact Dr. Gyles Randall at (507) 837-5616 or grandall@soils.umn.edu.