RESEARCHREPORT
ENVIRONMENT

Title: Impact of Liquid Swine Manure Application on Surface and Ground Water Quality – **NPB# 98-244**

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I. Abstract

Field experiments were conducted to determine the effect of liquid swine manure application on crop yields and surface and groundwater quality by using a recommended rate of 168 kg-available N/ha (150 lb-N/ac), based on a yield goal of 9.8 Mg/ha (155 bu/ac), in a corn-soybean rotation, compared to a double application rate of 336 kg-available N/ha (300 lb-N/ac). In addition, long-term effects of late winter broadcast, and spring and fall inject methods of liquid swine manure application on nitrogen, phosphorus, and bacteria concentrations in surface runoff and shallow groundwater were also studied..

The results of this study showed that in 1997, winter broadcast and spring inject treatments for manure applications yielded significantly higher flow weighted average NO_3-N concentrations in subsurface drainage water at the 336 kg-N/ha rate than at the 168 kg-N/ha, while the fall manure application treatments showed no significant differences between NO_3-N concentrations in tile water. The fall slot inject plots yielded statistically similar NO_3-N concentrations in tile water at both application rates. These NO_3-N concentrations in drain water did not differ significantly from those produced by the commercial UAN treatment and are slightly lower than those produced by the standard fall manure inject treatments. The fall manure inject at a rate of 336 kg-N/ha treatment actually resulted in lower NO_3-N concentrations than the fall manure inject at a rate of 168 kg-N/ha. No significant differences in PO_4-P concentrations in subsurface drainage were found between treatments in 1997. Because phosphorus is relatively insoluble, it is not surprising that manure treatment did not significantly impact PO_4-P levels in subsurface drainage. In 1998, NO_3-N concentrations in subsurface drainage from manure plots were generally higher than the previous year. Total N mass losses followed the same pattern as average flow weighted NO_3-N concentrations during 1998. Double N rate treatment values generally exceeded the corresponding single N rate treatment value. The winter manure broadcast 336 kg-N/ha treatment yielded the highest N losses, while the fall and spring manure inject 168 kg-N/ha treatments yielded the lowest N losses.

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II. Introduction

Appropriate manure application rates, timing, and methods are necessary to maximize nutrient utilization by plants from manure, while minimizing water resource pollution potential. Potential pollutants, which may emanate from improperly handled manure, include nutrients and bacteria. This study focuses on the movement of these pollutants to receiving surface and ground waters. Specifically, the impacts of different manure management regimes on nitrate - nitrogen (NO_3-N), phosphorus (P), fecal coliform, fecal streptococcus, and E.coli concentrations in surface runoff and subsurface tile flow are examined. This report also includes the results of a soil column study where movement of bacteria through undisturbed soil columns was monitored in response to manure application under two different temperature conditions. Due to atypically dry field conditions during the 2000 crop growing season, no new water quality data are included in this progress report.

III. Objectives

The overall objective of this project is to identify the optimum swine manure application rate, timing, and method, in order to minimize the nutrient and bacterial pollution potential on surface and ground water quality, while maintaining crop yields. Secondary objectives are:

1. To determine the effect of liquid swine manure application on surface and groundwater quality, using a recommended rate of 168 kg-available N/ha (150 lb-N/ac), based on a yield goal of 9.8 Mg/ha (155 bu/ac), in a corn-soybean rotation, compared to a double application rate of 336 kg-available N/ha (300 lb-N/ac).
2. To study the long-term effects of late winter broadcast, and spring and fall inject methods of liquid swine manure application on nitrogen, phosphorus, and bacteria concentrations in surface runoff and shallow groundwater.
3. To provide input in the development of recommended management practices to reduce the water contamination potential from manure applications and to enhance the use of swine manure as an alternative to use of inorganic fertilizers for Iowa's agriculture.
4. To develop an improved applicator for uniform and accurate application of swine manure (injection/incorporation) with no adverse effects on crop yields and test its use for water quality enhancement.

IV. Procedures and Results (Progress towards meeting objectives)

A) Objectives 1,2,3

A field study was initiated in 1996, with a funding from Iowa Commodity Groups (ICPA, ISPA, IPPA). A soil column study, designed to further investigate the relationship between swine manure application and bacterial leaching in the subsurface, was launched in November of 1999.

Field Study

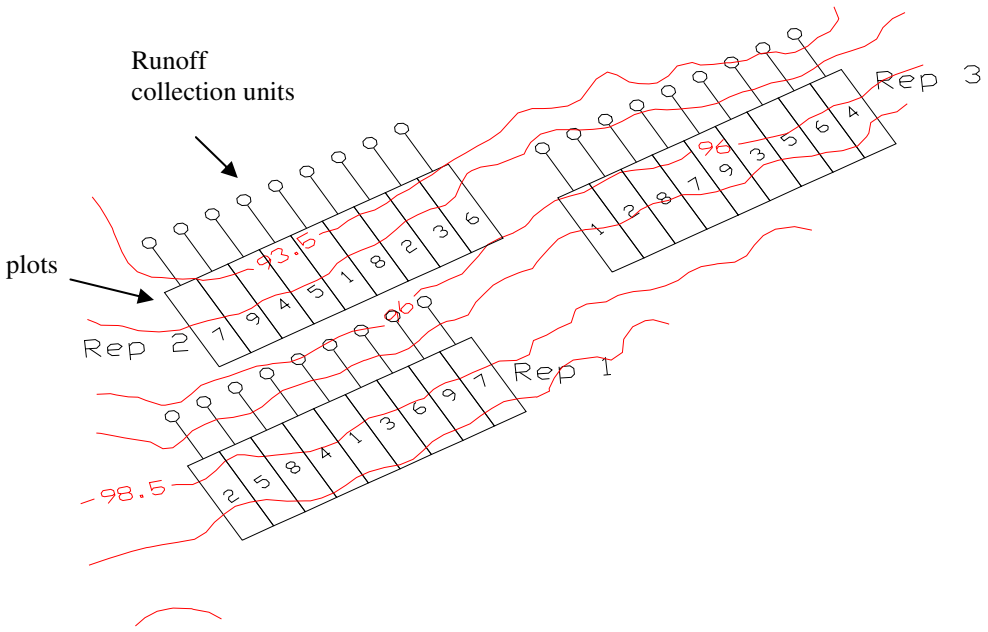
Preliminary and background water quality data were collected in 1996. Data collection continued through 1998 and is scheduled through the 2001 crop growing season, with expected additional funding from the National Pork Producers Council and the State of Iowa. The experimental site is located at the Iowa State University Agronomy and

Agricultural Engineering Research Center near Ames, Iowa. The site is on a Clarion Loam soil with 1 to 4 % slope. The area receives an annual average of 82.5 cm (32.5 in) of precipitation, with about 55.0 cm (21.7 in) occurring during the spring and summer months.

The study site has been divided into three experimental blocks each having nine treatment plots (Table 1), resulting in 27 individual plots in a randomized block design (Figure 1). For each replication, eight of the plots were designated for manure treatments, while one plot was designated as a control plot where a commercial nitrogen treatment of liquid urea ammonium nitrate (UAN) was applied. This experimental design was chosen to provide the basis for comparison between manure and the alternative commercial fertilizer.

Table 1. Experimental treatments.

Treatment ID Number	Abbreviation	Application Timing	Application Method	Application Rate Kg-N/ha (lb-N/ac)
1	CTL	Spring (UAN)	Incorporate	168 (150)
2	FI1X	Fall	Inject	168 (150)
3	FI2X	Fall	Inject	336 (300)
4	FN1X	Fall	Slot Inject	168 (150)
5	FN2X	Fall	Slot Inject	336 (300)
6	WB1X	Late Winter	Broadcast	168 (150)
7	WB2X	Late Winter	Broadcast	336 (300)
8	SI1X	Spring	Inject	168 (150)
9	SI2X	Spring	Inject	336 (300)



Prior to application, manure from the Iowa State University Swine Nutrition Farm near Ames, Iowa was analyzed for nutrient contents (N,P,K), to determine the application volumes necessary to achieve the desired N-application rates. Table 2 gives the nutrient levels in swine manure spring injected in 1999.

Table 2. Laboratory analysis of manure spring injected in 1999.

	Moisture	solids	Nitrogen TKN	Ammonia NH_3-N	Phosphorus P_2O_5	Potash K_2O
ID	**%**	**%**	%	mg/l	%	%
Pre apply 1	92.1	7.9	0.46	2205	0.39	0.13
Pre apply 2	92.1	7.9	0.48	2300	0.39	0.13
Pre apply 3	91.8	8.2	0.49	3249	0.39	0.13
Average	92.0	8.0	0.48	2585	0.39	0.13
Rep 1 – 168	90.0	10.0	0.51	2358	0.37	0.14
Rep 2 – 168	90.6	9.4	0.35	2275	0.44	0.14
Rep 3 – 168	90.1	9.9	0.5	2249	0.42	0.14
Rep 1 – 336	90.7	9.3	0.49	2266	0.44	0.14
Rep 2 – 336	93.8	6.2	0.50	1928	0.40	0.14
Rep 3 – 336	90.4	9.6	0.49	2358	0.40	0.14
Average	90.9	9.1	0.47	2239	0.41	0.14

Late winter broadcast treatments occurred in late February 1997, early April 1998, late March 1999, and April 2000. Spring inject treatments occurred in late May 1997, early April 1998, late March 1999, and May 2000. Fall inject treatments occurred in November 1997 and 1998, and late October 1999, and November 2000. The commercial UAN treatment occurs at the time of planting each year. The criteria used in calculating manure application rates are given in Table 3.

Table 3. Manure application rate calculation criteria.

Corn yield goals (Mg/ha)	9.8
Soybean yield goals(Mg/ha)	2.7
Nitrogen credit from soybeans (g-N/kg soybeans)	16.7
Nitrogen required for corn (g-N/kg corn)	21.8
Nitrogen volatilization loss (surface broadcast) (%)	30
Nitrogen volatilization loss (subsurface injection) (%)	5
First year nitrogen availability (%)	75

Experimental Plot Design

Each experimental plot was selected to be 7.5 meters wide, to accommodate an annual rotation of 5 rows of corn in half the plot and 5 rows of beans in the other half, and 22.5 meters long. Each plot is equipped with both subsurface flow and surface runoff collection systems. Collection systems are gravity fed to the end of each plot. All plots are surrounded by earthen berms, to avoid overland flow and subsequent cross contamination between plots. Figure 2 shows a schematic of the experimental plot.

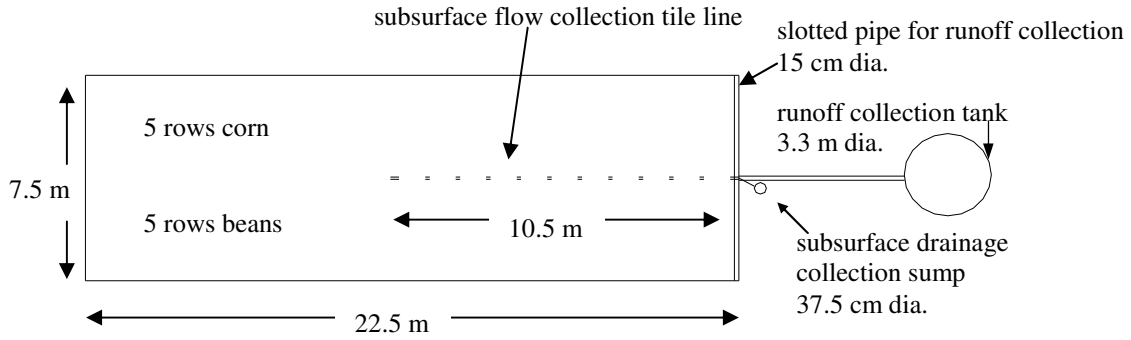


Figure 2. Aerial schematic of experimental plot.

Surface runoff is collected from the plots through 15 cm slotted PVC pipes installed at the down slope end of each plot. Runoff is then carried from the collection pipe into a 15 cm solid PVC transmission pipe, which drains runoff water into a 0.67 x 3.33 meter circular storage tank until water samples are collected for nutrient and bacteria analysis. These tanks are covered with domed tarps to preclude direct precipitation, wind blown particles, small animals, and other contaminants. Immediately following a runoff event, the contents of each tank are stirred to ensure representative sampling, and samples are collected for nutrient and bacterial analysis. Nutrient samples are collected in 500 ml plastic sample bottles and bacteria samples are taken in sterile plastic bags. The tanks are then pumped dry in preparation for the next event. Runoff is quantified during pumping.

Subsurface flow is collected through corrugated plastic subsurface tile lines, which were installed at a 1.2 m depth, and 10.5 m in length into the field (Figure 2). They are positioned in the middle of each plot and perpendicular to the contour. Each tile line drains into a vertical 37.5 cm diameter PVC collection sump at the end of each plot. The collection system dimensions were designed to yield a representative sample at a manageable flow volume. Electric sump pumps, which operate automatically on a float mechanism to pump subsurface flow from each plot through an orifice tube, were installed in each collection sump in August of 1997. Orifice plates divert 0.2 percent of the total tile flow into 3.78 liter glass sampling bottles. Thus, samples are composited over the period of flow, and total subsurface flow from each plot can be calculated using the volume of diverted flow in the sampling jar. The composite samples are collected in 250 ml plastic sample bottles for nutrient analysis and quantified weekly during the flow season. Because samples collected for bacterial analysis must be less than 24 hours old, bacteria samples are not time composited, but are pumped directly from the sump into sterile plastic bags and analyzed within 24 hours. All samples are stored at 4 ^{o}C until they are analyzed.

Nutrient samples are analyzed according to EPA Methods 353.2, 365.2, and 365.4 for nitrate-nitrogen, phosphate-phosphorus, and total-phosphorus, respectively. Bacterial analysis is done according to Standard Methods for the Examination of Water and Wastewater, 18th edition. The membrane filtration technique is used, with m-FC agar

for fecal coliforms, m-*Enterococcus* agar for fecal streptococcus, and m-ColiBlue for E. Coli.

Soil Column Study

Eighteen soil columns were collected from the Iowa State University Agronomy and Agricultural Engineering Research center near Ames, IA in order to accommodate three replications of four manure treatments and two control treatments. Soil column treatments are listed in Table 4. The soil was a Clarion loam in annual corn and soybean rotation. Soil columns were extracted in late fall, after the 1999 soybean harvest, using a Giddings probe and an 8-inch bit adapter. The 12-inch columns were extracted in 15-inch sections of sterilized galvanized tubing that had been sharpened on the down - facing edge. In order to detect compaction, the vertical distance between the top edge of the column and the inside soil surface was measured and compared to the vertical distance between the top edge of the column and the outside soil surface, prior to extraction of each soil column. No compaction was detected.

Table 4. Experimental Treatments.

Spring Control	Not amended
Fall Control	Not amended
Spring Inject 1X	Manure application rate 150lb-N/ac (168kg-N/ha)
Spring Inject 2X	Manure application rate 300lb-N/ac (336kg-N/ha)
Fall Inject 1X	Manure application rate 150lb-N/ac (168kg-N/ha)
Fall Inject 2X	Manure application rate 300lb-N/ac (336kg-N/ha)

The soil columns were transported to a growth chamber, simulating the soil temperature at the 4-inch depth during the typical periods of fall and spring manure application. Autoclaved screen was installed on the bottom of each column in order to prevent soil loss. The columns were then arranged in a random block design in a leachate collection apparatus consisting of 10-inch autoclaved funnels and a guide table that prevented the columns from deviating from the vertical position. They were saturated with 5000ml of water and allowed to drain for four days. After this period, manure was incorporated to the 4-inch depth. The manure was obtained from a finishing unit at Bilsland Memorial swine farm near Luther, IA and was less than 7 days aged. Bacterial analysis revealed a fecal coliform density of 2,000,000 cfu/100ml.

The Spring soil columns remained under May conditions in the growth chamber following manure application. The growth chamber temperature was set to reflect the average daily minimum and maximum soil temperature fluctuations at the 4-inch depth, using a ten-year average from data collected at the experimental site from which the columns were extracted. The temperature regime is illustrated in Figure 3.

mperature (F)

mperature (C)

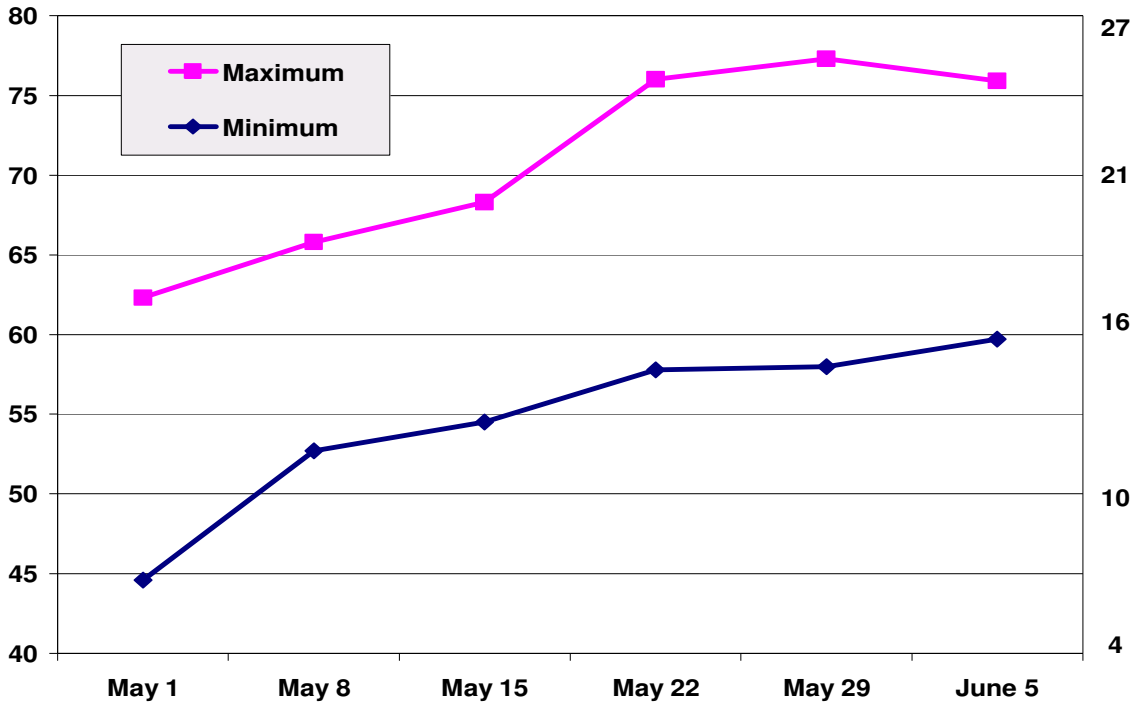


Figure 3. Average daily soil temperature at the 4-inch depth, Ames IA, 1990-1999.

Soil temperature was chosen over air temperature for the growth chamber program because of the semi-exposed condition of the soil columns, which is in contrast to the less exposed condition of a similar soil profile in situ. Buffering of air temperature fluctuations, which significantly affects soil temperature at depth, was built in to the growth chamber temperature program by setting the growth chamber air temperature equal to the average daily soil temperature at the four-inch depth. In the growth chamber, the average daily minimum soil temperature occurred during 12 hours of darkness and was followed by 12 hours of the average daily maximum soil temperature during 12 hours of light.

Six days after manure application, the first of four ponding events took place. Water was ponded to a depth of 2.1 inches (5.3 cm / 1700ml), which is a typical weekly rainfall amount for this time of year. Weekly rainfall depths were based on weekly rainfall data and ponded in a single event in order to produce the effects of macropore flow and yield enough leachate to perform bacterial analyses. The leachate was collected in sterile plastic sample bottles and analyzed for fecal coliform, E. coli, and enterococci using Standard Methods 9222D, 9222G, and 9230C, respectively. This process was repeated for the second, third, and fourth ponding events. Ponding depth for these events was 1.5in (3.7cm / 1200ml), 1.3in (3.4cm / 1100ml), and 1.3in (3.4cm / 1100ml), respectively. Outflow was quantified in order to provide data necessary to complete water budgets on each column, and confirm uniform moisture contents. Average outflows between treatments were similar. A mass evaluation was performed on three representative soil columns. Prior to each ponding event, these columns were weighed. The mass of outflow was monitored using volumetric analysis of leachate samples. The mass data will be used in conjunction with moisture analysis of the

columns after the completion of the study in order to model the water budget for each column. Mass data are given in Table 5.

Table 5. Mass balance for three representative Fall soil columns.

	Fall control replicate 2 Mass (kg)	Fall 2X replicate 1 Mass (kg)	Fall 2X replicate 2 Mass (kg)
Prior to Event 1	17.91	19.01	17.90
Add	1.70	1.70	1.70
Drain	0.82	0.78	0.79
Evapotranspiration	0.67	0.77	0.64
Prior to Event 2	18.12	19.16	18.17
Add	1.20	1.20	1.20
Drain	0.43	0.42	0.55
Evapotranspiration	0.71	1.00	0.83
Prior to Event 3	18.18	18.94	17.99
Add	1.10	1.10	1.10
Drain	0.43	0.12	0.30
Evapotranspiration	1.06	1.62	0.71
Prior to Event 4	17.8	18.3	18.08
Add	1.10	1.10	1.10
Drain	0.36	0.10	0.13

Six days after manure application, Fall columns were sealed and transported to a freezer, where they remained for 7 weeks, to simulate over-winter conditions of below freezing temperatures and snow cover, and to produce the cell changes associated with freezing and thawing. After this period, they were transported to a growth chamber simulating the same time period as the Spring columns. According to field data, this is the period during which bacterial leaching occurs on Fall manured plots as well as Spring manured plots. Ponding events on the Fall soil columns began two days after transport to the growth chamber. The depth and timing of Fall column ponding events were the same as the depth and timing of Spring column ponding events.

B) Objective 4

Construction of the improved applicator is complete and this objective of this study was accomplished in 1995 and 1996. A brief description of the process is outlined below. In October of 1995, the research team began the task of designing a new manure applicator. The main goal of the applicator design was the ability to accurately determine the application rate and volume of manure applied to the injected plots.

The main components of the applicator are two cast iron progressing cavity pumps (Roper 71228) with hard chrome plated alloy internals. The progressing cavity pumps are ideal for handling materials, which are often considered unpumpable, like manure containing solids. These pumps can handle particle sizes up to 0.8 inches and are PTO driven. Running at 700 rpm, each pump puts out 180 gpm. Due to the high cost of each pump, only two pumps were used in the final design. Each pump is used to supply manure to one knife at a time. For plot application, the middle two knives are fed by the two pumps for applying the first half of the volume for the predetermined application rate. Each shank with the knives can be raised and lowered using hydraulic cylinders (8" stroke, 3" bore, 2500 psi) driven by the tractor hydraulic system. While the two middle shanks are in the ground, the outer two shanks are in a raised position.

After applying the manure using the middle shanks, the outer two shanks are used to apply the second half of the manure during a second pass. This order of operation reduces the possibility of tractor tire slippage due to the wet-manured condition. Shutoff values are located between the pump and each shank to ensure that each pump is only supplying manure to one shank at a time. The pumps supply the manure to the shutoff values using non-collapsible hose and PVC tubing. Flexible/collapsible hose is used between the shutoff values and the application tubing behind each shank.

The pumps were mounted on a steel chassis with a dual walking tandem adjustable wheel base. The frame for this chassis was constructed with 4" square steel tubing. Each axle is rated for a 12,000 lb load. The wheels straddle three 30" rows or have a 90" center to center spacing. The pumps are fed with liquid manure from a 925 gallon polyethylene tank, 65" in diameter and 76" long. A 5 HP trash pump, that can handle up to 1 1/8" solids, is used to recirculate the manure within the tank itself. Two-inch solid hose is used for recirculating. Due to late funding of the project, the applicator was not ready for the fall manure application. The manure applicator was fully functional and tested by the middle of March, 1996. The applicator has been used since to apply the swine manure on all plots for this project.

Calibration of swine manure applicator

The applicator was calibrated on March 27, 1996 and each year thereafter prior to manure application. Water was used as the calibrating fluid. Pumps were calibrated one at a time. However, both pumps ran simultaneously. The water from the pump was recirculated back to the tank. Once the tractor was up to steady engine speed, the flow meter and stopwatch readings were simultaneously recorded. Outflow was collected in a 500 gallon tank. Once this tank was near full, final flow meter and stopwatch readings were taken and then the tractor was slowed and the pumps shut off. The outflow was pumped back into the applicator tank and the process was repeated for different engine speeds. Engine speeds of 1000, 1500, 1800, and 2150 (PTO speed) rpm were tested. Calibration was performed by the same process on the second pump. Readings from the liquid swine manure levels in the tank before and after applications are used to confirm the accuracy of the calibration. To date the agreement has been very good.

V. Status of Project in Regards to Stated Timeline

The project is progressing on schedule. The timeline given in Table 6 was established for the completion of the project. This timeline is applicable through the projected completion date November 1, 2001. By project completion, six seasons of water quality data will be collected. Due to dry field conditions this year, no water quality data have been generated in the field since the last progress report was submitted.

Table 6. Project timeline.

June – September	Water quality data collection: water sampling and analysis
November	Manure application on fall inject plots (standard and new slot)
February	Manure application on late winter broadcast plots
May	Manure application on spring inject plots
May	Seeding of all plots
May	UAN application on commercial fertilizer plots

VI. Modifications of the Project from Original Proposal

The proposed method used in collecting runoff samples for bacteria analysis will no longer be used. Small animal activity in and around the sampling units has caused fecal bacterial contamination of the original sampling units. A new sampling unit is in the design phase.

The tarps used to seal the runoff collection units from direct precipitation and wind blown contaminants have suffered wind damage. They will be replaced with flat tin roofing covers in time for the 2000 crop growing season.

VII. Results

Field Study

A) Nitrate-N and phosphate-P losses with subsurface drain water

Because much of the 1996 data were collected during the construction phase of the experimental plots, 1996 data are not presented in this section. The 1999 nutrient data are still being analyzed in the lab and are yet available. The 1997 monitoring period was typical for the region in terms of hydrology, with a total precipitation of 42.9 cm (16.9 in), two runoff events, and total tile flow of 4.1 cm (1.61 in). Periodic tile flow and rainfall data are given in Figures 4, 5, and 6. Total tile flow was 42.8 cm (16.9 in) during 1998, and 36.2 cm (14.3 in) during 1999.

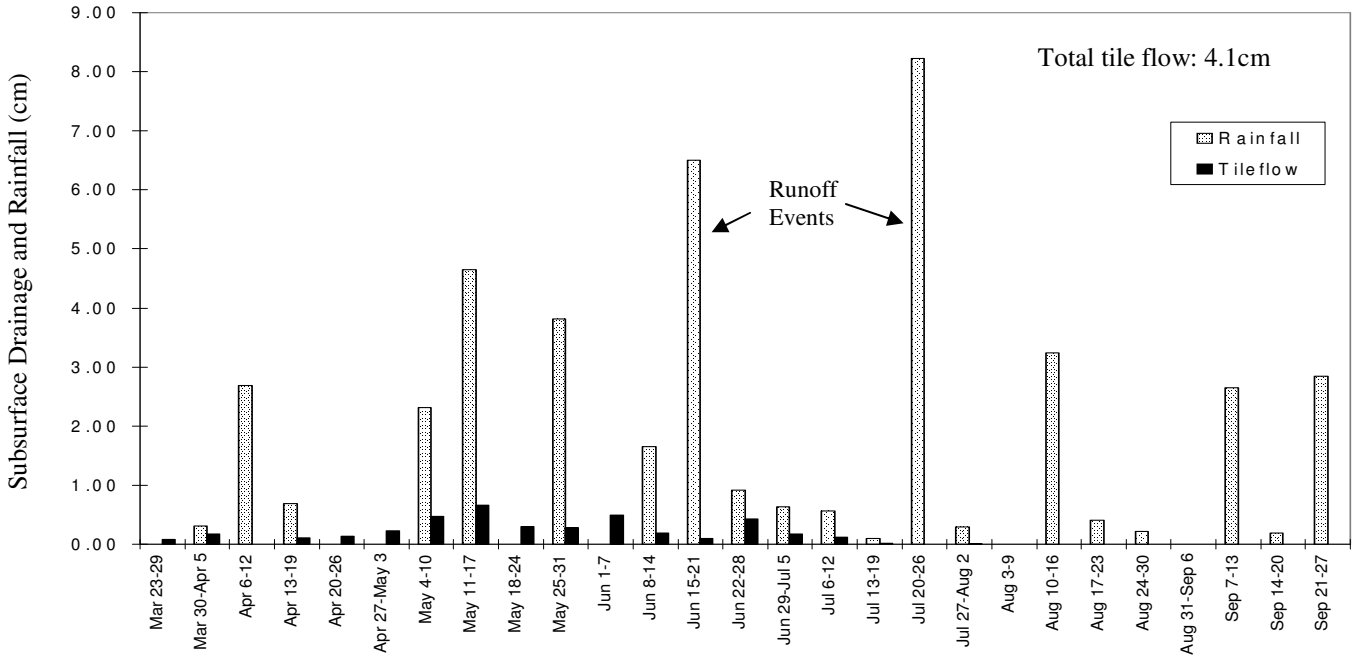


Figure 4. Periodic subsurface drain flow and precipitation for the growing season of 1997.

Subsurface Drainage (cm)

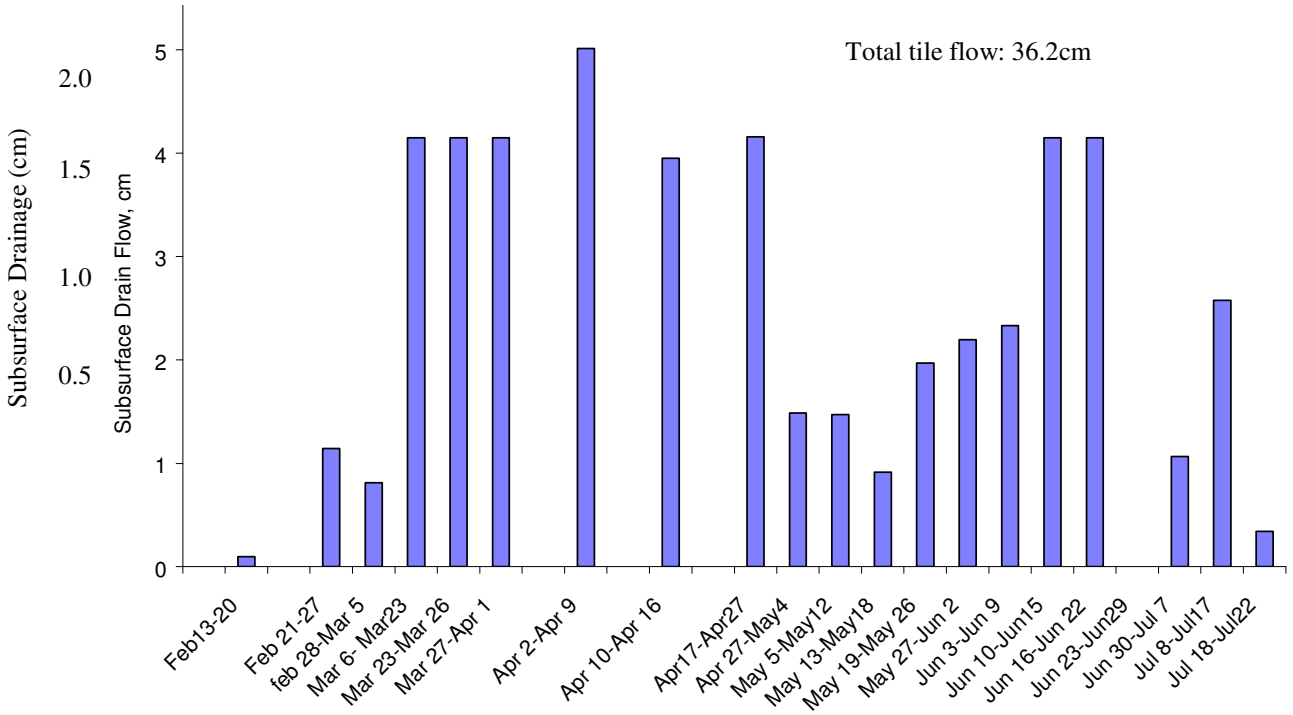


Figure 5. Periodic subsurface drain flow during the growing season of 1998.

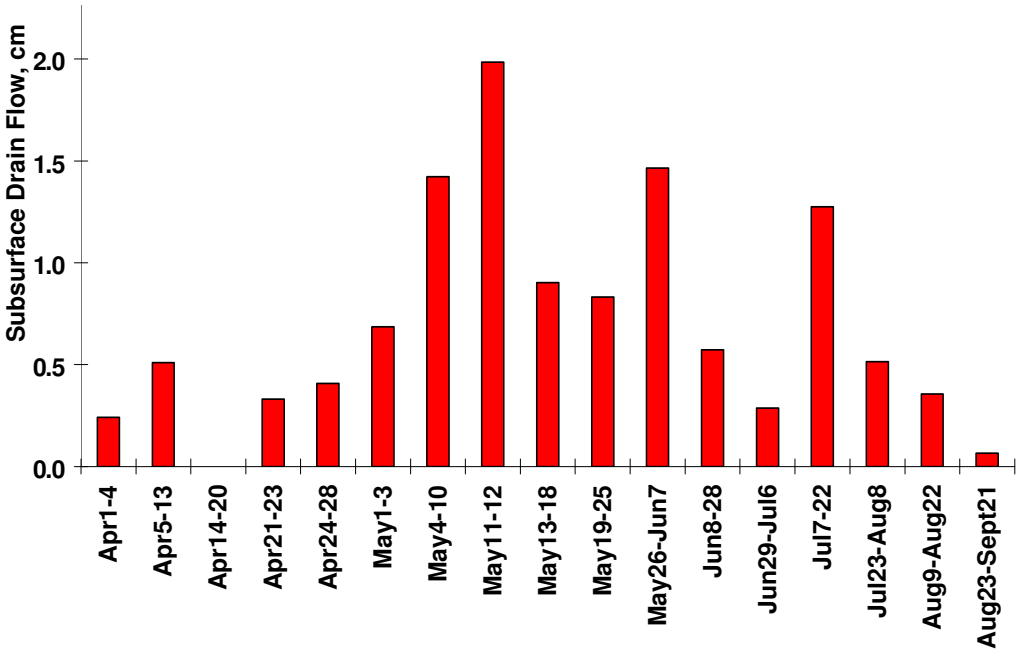


Figure 6. Periodic subsurface drain flow during the growing season of 1999.

For 1997, winter broadcast and spring inject treatments for manure applications yielded significantly higher flow weighted average NO_3-N concentrations in subsurface drainage at the 336 kg-N/ha rate than at the 168 kg-N/ha, while the fall manure application treatments showed no significant differences between NO_3-N concentrations in tile water (Table 7). The fall slot inject plots yielded statistically similar NO_3-N

concentrations in tile water at both application rates. These NO_3-N concentrations in drain water did not differ significantly from those produced by the commercial UAN treatment and are slightly lower than those produced by the standard fall manure inject treatments. The fall manure inject at a rate of 336 kg-N/ha treatment actually resulted in lower NO_3-N concentrations than the fall manure inject at a rate of 168 kg-N/ha. No significant differences in PO_4-P concentrations in subsurface drainage were found between treatments in 1997 (Table 7). Because phosphorus is relatively insoluble, it is not surprising that manure treatment did not significantly impact PO_4-P levels in subsurface drainage.

In 1998, NO_3-N concentrations in subsurface drainage from manure plots were generally higher than the previous year. Total N mass losses followed the same pattern as average flow weighted NO_3-N concentrations during 1998. Double N rate treatment values generally exceeded the corresponding single N rate treatment value (Figure 7). The winter manure broadcast 336 kg-N/ha treatment yielded the highest N losses, while the fall and spring manure inject 168 kg-N/ha treatments yielded the lowest N losses (Table 7).

Table 7. Average (flow weighted) nutrient concentrations in subsurface drainage in 1997 and 1998.

Treatment	1997		1998	
	NO_3-N +NO_2-N mg/l	PO_4-P µg/l	NO_3-N +NO_2-N mg/l	PO_4-P µg/l
Spring UAN, 168kg-N/ha	7.4	40.35	6.3	
Fall Inject, 168kg-N/ha	9.8	28.80	15.2	not
Fall Inject 336kg-N/ha	7.9	20.53	14.2	
Fall Slot Inject, 168kg-N/ha	7.3	20.17	9.7	available
Fall Slot Inject 336kg-N/ha	6.9	30.75	21.9	
Winter Broadcast 168kg-N/ha	7.8	19.95	11.9	as
Winter Broadcast 336kg-N/ha	9.8	24.26	23.4	
Spring Inject 136kg-N/ha	9.0	31.62	9.1	yet
Spring Inject 336kg-N/ha	11.9	20.86	15.1	

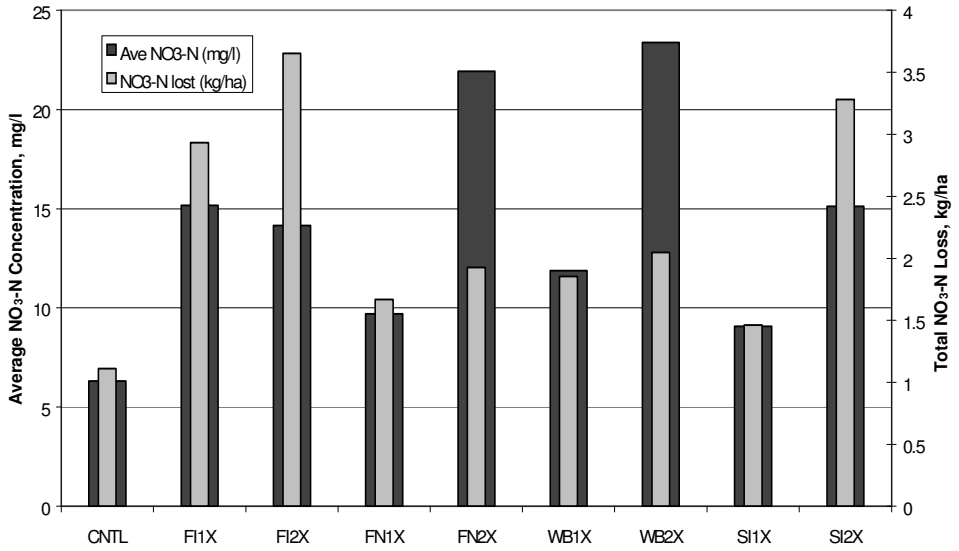


Figure 7. Total NO_3-N loss and average NO_3-N concentrations for 1998.

B) Bacterial leaching with subsurface drain water

Fecal bacterial densities differed significantly between treatments in 1997 and 1998, although trends are not clear (Tables 8,9). For instance, the commercial UAN treatment had the lowest concentration of fecal streptococcus, but not for fecal coliform. One possible explanation for this is that the two species have different growth requirements. Factors, such as pH, moisture, temperature, texture, nutrients, and macropores, which influence their growth and movement may vary spatially between or within plots. Trends in 1999 bacterial densities are also unclear at the annual level (Table 10), although monthly data show spikes in some treatments (Figure 8). On the average, for every manure application method, the 336 kg-N/ha treatment resulted in higher bacterial counts in tile water in comparison with the 168 kg-N/ha rate for the same method of manure application.

Table 8. Average bacterial densities in subsurface flow for 1997.

Treatment	Fecal coliform CFU/100ml	Fecal streptococcus CFU/100ml	E.Coli CFU/100ml
Spring UAN, 168kg-N/ha	8.6	4.0	0.1
Fall Inject, 168kg-N/ha	4.0	3.0	0.3
Fall Inject 336kg-N/ha	3.8	7.5	1.3
Fall Slot Inject, 168kg-N/ha	11.4	8.4	0.2
Fall Slot Inject 336kg-N/ha	2.6	6.4	0.5
Winter Broadcast 168kg-N/ha	4.6	3.7	3.6
Winter Broadcast 336kg-N/ha	4.8	4.4	0.5
Spring Inject 136kg-N/ha	90.2	5.8	5.5
Spring Inject 336kg-N/ha	25.9	3.4	0.8

Table 9. Average bacterial densities in subsurface flow for 1998.

Treatment	Fecal coliform CFU/100ml	Fecal streptococcus CFU/100ml	E.Coli CFU/100ml
Spring UAN, 168kg-N/ha	3.0	20.9	0.4
Fall Inject, 168kg-N/ha	0.1	8.6	0.2
Fall Inject 336kg-N/ha	0.1	10.2	0.1
Fall Slot Inject, 168kg-N/ha	0.3	40.5	3.8
Fall Slot Inject 336kg-N/ha	1.9	14.7	13.3
Winter Broadcast 168kg-N/ha	3.9	20.3	0.6
Winter Broadcast 336kg-N/ha	13.2	87.2	1.8
Spring Inject 136kg-N/ha	0.8	16.9	0.4
Spring Inject 336kg-N/ha	5.3	44.8	7.7

Table 10. Average bacterial densities in subsurface flow for 1999.

Treatment	Fecal coliform CFU/100ml	Fecal streptococcus CFU/100ml	E. Coli CFU/100ml
Spring UAN, 168kg-N/ha	6.6	34.0	0.5
Fall Inject, 168kg-N/ha	1.5	24.6	0.4
Fall Inject 336kg-N/ha	3.5	25.7	0.5
Fall Slot Inject, 168kg-N/ha	24.8	24.6	0.6
Fall Slot Inject 336kg-N/ha	9.0	103.4	1.4
Winter Broadcast 168kg-N/ha	6.5	62.3	1.6
Winter Broadcast 336kg-N/ha	6.0	130.2	9.5
Spring Inject, 168kg-N/ha	17.9	28.0	4.4
Spring Inject 336kg-N/ha	0.6	62.5	1.3

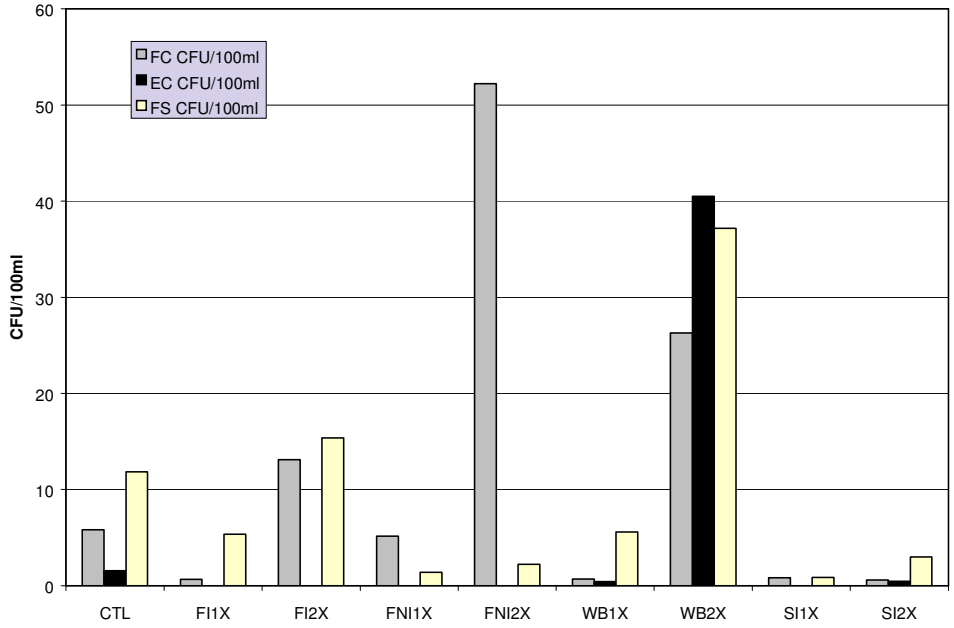


Figure 8. Bacterial densities in subsurface drainage on April 13, 1999.

C) Nutrient and bacterial losses with runoff water

Nutrient and bacterial losses with runoff water were significantly higher in winter manure broadcast plots than the fall manure inject plots (Table 11). Other manure application treatments were statistically similar. Phosphorus concentrations in surface runoff did not differ significantly between treatments (Table 11).

Table 11. Average nutrient concentrations in surface runoff in 1997.

Treatment	NO_3-N +NO_2-N mg/l	Total P mg/l
Spring UAN, 168kg-N/ha	2.6	2.1
Fall Inject, 168kg-N/ha	1.6	0.9
Fall Inject 336kg-N/ha	1.8	2.1
Fall Slot Inject, 168kg-N/ha	2.2	3.0
Fall Slot Inject 336kg-N/ha	2.3	1.6
Winter Broadcast 168kg-N/ha	2.9	2.5
Winter Broadcast 336kg-N/ha	3.2	1.2
Spring Inject 136kg-N/ha	1.6	1.6
Spring Inject 336kg-N/ha	2.5	1.7

Bacterial densities in surface runoff for 1997 and 1998 were highly variable and not significantly different between treatments (Table 12). Factors such as small animal activity near the runoff collection systems may have influenced bacterial densities. Because of this high variability in the data, bacteria analyses were discontinued in 1999.

Table 12. Average bacterial densities in surface runoff for 1997 and 1998.

Treatment	1997		1998	
	Fecal coliform CFU/100ml	Fecal streptococcus CFU/100ml	Fecal coliform CFU/100ml	Fecal streptococcus CFU/100ml
Spring UAN, 168kg-N/ha	19,233	47,500	7320	89,067
Fall Inject, 168kg-N/ha	4650	41,167	24,407	158,333
Fall Inject 336kg-N/ha	8625	49,917	3817	28,435
Fall Slot Inject, 168kg-N/ha	181,250	203,750	4340	59,233
Fall Slot Inject 336kg-N/ha	34,000	104,900	4820	211,867
Winter Broadcast 168kg-N/ha	15,200	39,025	11,000	48,933
Winter Broadcast 336kg-N/ha	10,950	29,083	12,500	76,067
Spring Inject 136kg-N/ha	4367	44,333	5240	32,200
Spring Inject 336kg-N/ha	11,650	28,500	14,514	54,267

For the year 2000, manure application will remain the same for each plot during the growing season as has been for the past 4 years. It is expected that accumulation effects may cause water quality trends between treatments to become more defined in the future.

Soil Column Study

Bacterial densities in soil column leachate from ponding events one through four are given in Figures 9-12 and Tables 13-20. In general, the double rate manure treatment resulted in slightly higher bacterial densities in soil column leachate. The Fall columns yielded similar bacterial densities as the Spring columns for event one, and slightly lower bacterial densities for events two, three and four. Fall bacteria may have survived the freeze-thaw cycle and over-winter conditions in a weakened state and have experienced more rapid die-off than the Spring columns.

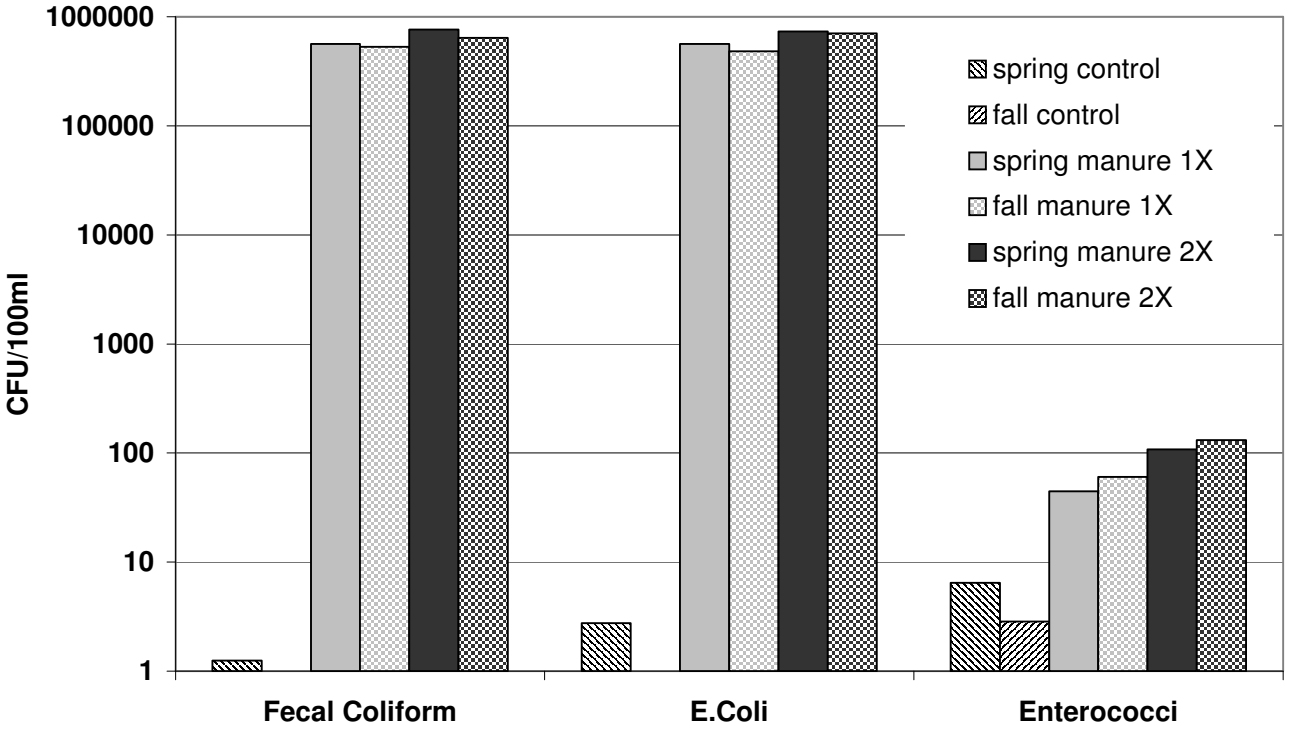


Figure 9. Bacterial densities in soil column leachate from event 1.

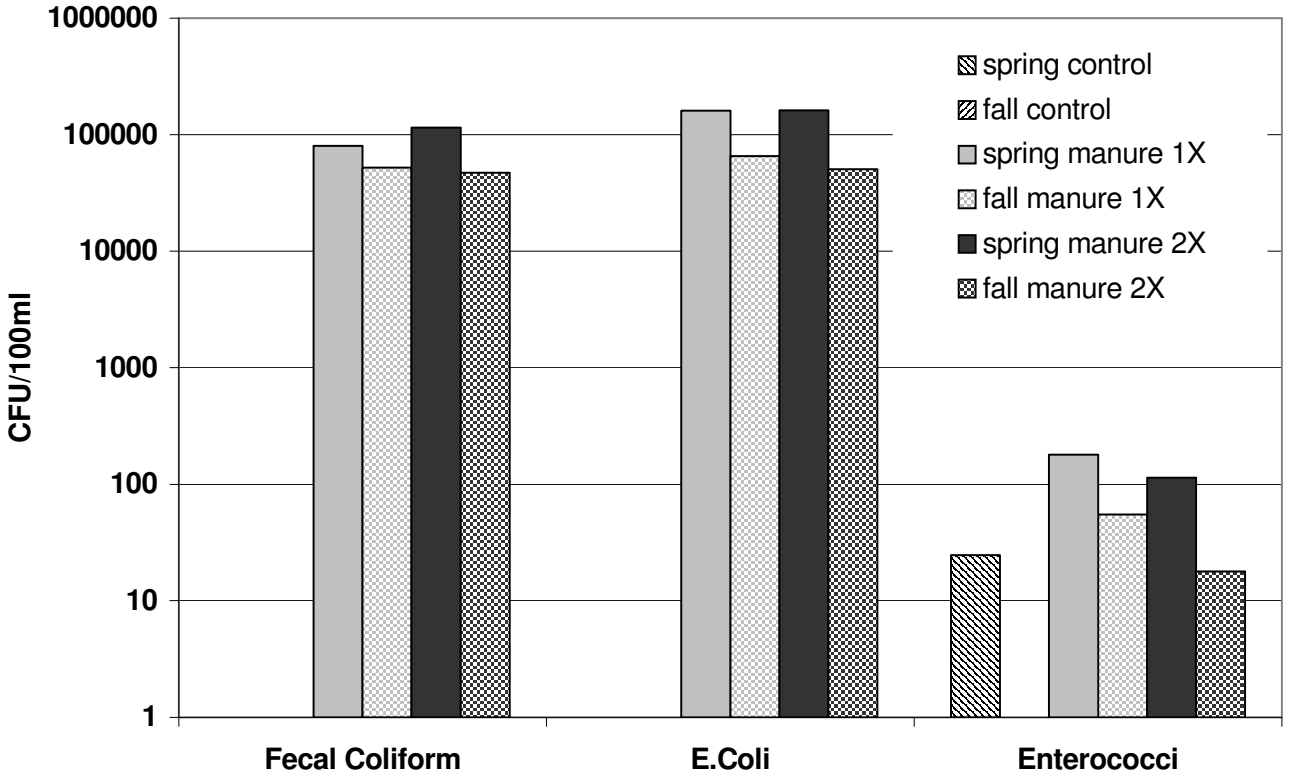


Figure 10. Bacterial densities in soil column leachate from event 2.

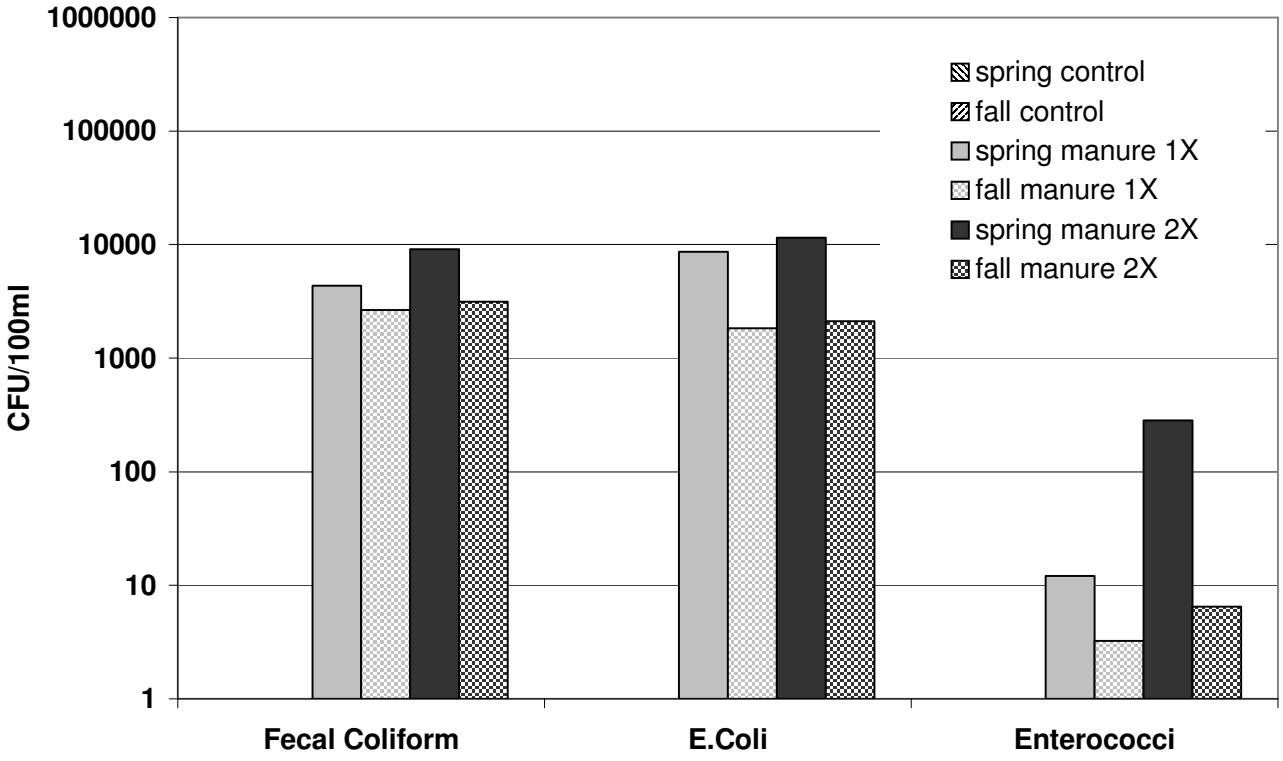


Figure 11. Bacterial densities in soil column leachate from event 3.

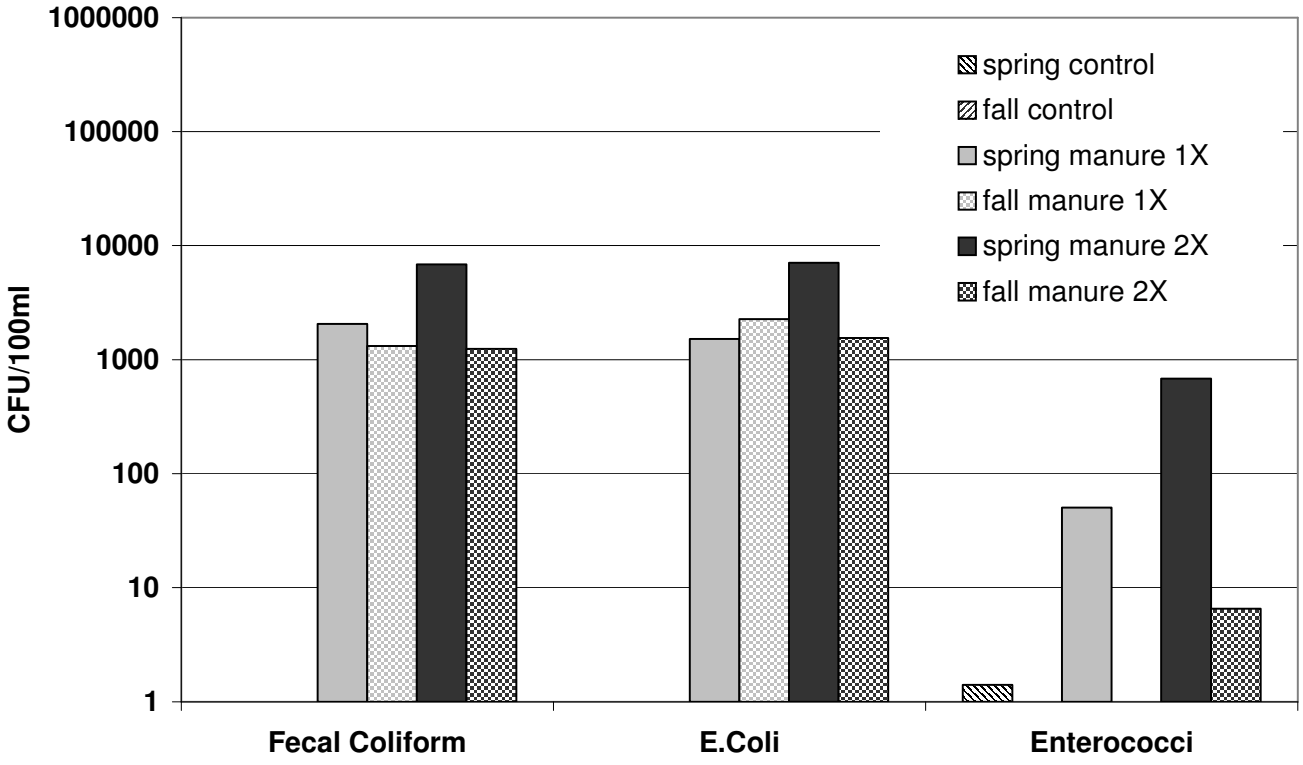


Figure 12. Bacterial densities in Spring soil column leachate from event 4.

Table 13. Bacterial densities in Spring soil column leachate for event 1.

Event 1 Column	Fecal Coliform (CFU/100ml)	E.coli (CFU/100ml)	Enterococci (CFU/100ml)	Volume (ml)
Spring control 1	<1	<1	<10	300
Spring control 1	<1	<1	2	300
Spring control 2	<10	<10	1	400
Spring control 2	8	10	<1	300
Spring control 3	<1	<1	5	300
Spring control 3	<1	<1	31	300
Spring 1X 1	580,000	640,000	32	300
Spring 1X 1	600,000	610,000	48	300
Spring 1X 2	530,000	500,000	30	250
Spring 1X 2	520,000	570,000	24	300
Spring 1X 3	550,000	570,000	66	400
Spring 1X 3	590,000	460,000	58	300
Spring 2X 1	1,000,000	960,000	52	300
Spring 2X 1	1,000,000	990,000	70	300
Spring 2X 2	990,000	1,000,000	150	350
Spring 2X 2	700,000	680,000	86	300
Spring 2X 3	510,000	420,000	152	450
Spring 2X 3	460,000	440,000	110	300

Table 14. Bacterial densities in Spring soil column leachate for event 2.

Event 2 Column	Fecal Coliform (CFU/100ml)	E.coli (CFU/100ml)	Enterococci (CFU/100ml)	Volume (ml)
Spring control 1	<1	<1	83	325
Spring control 2	<1	<1	<2	330
Spring control 3	<1	<1	<10	440
Spring 1X 1	98,000	190,000	440	301
Spring 1X 2	85,000	210,000	100	480
Spring 1X 3	57,000	62,000	55	325
Spring 2X 1	220,000	240,000	150	500
Spring 2X 2	77,000	170,000	160	420
Spring 2X 3	22,000	57,000	20	400

*Leachate samples from Spring columns were divided by time of collection for event 1 in order to detect bacterial changes between first and final flushes within the event. None were detected and samples were composited for the remaining events.

Table 15. Bacterial densities in Spring soil column leachate for event 3.

Event 3 Column	Fecal Coliform (CFU/100ml)	E.coli (CFU/100ml)	Enterococci (CFU/100ml)	Volume (ml)
Spring control 1	<2	<2	2	198
Spring control 2	<1	<1	<1	320
Spring control 3	<1	<1	<1	520
Spring 1X 1	1000	3000	<10	395
Spring 1X 2	6300	9900	27	475
Spring 1X 3	6400	17,000	<10	195
Spring 2X 1	2700	2700	650	500
Spring 2X 2	21,000	25,000	110	415
Spring 2X 3	5500	9100	50	480

Table 16. Bacterial densities in Spring soil column leachate for event 4.

Event 4 Column	Fecal Coliform (CFU/100ml)	E.coli (CFU/100ml)	Enterococci (CFU/100ml)	Volume (ml)
Spring control 1	<2	<2	7	180
Spring control 2	<1	<1	<1	280
Spring control 3	<1	<1	<1	440
Spring 1X 1	1300	1000	<10	170
Spring 1X 2	2500	1800	82	350
Spring 1X 3	1500	1300	<10	50
Spring 2X 1	2000	1900	80	360
Spring 2X 2	5200	5000	3400	140
Spring 2X 3	15,000	16,000	<10	240

Table 17. Bacterial densities in Fall soil column leachate for event 1.

Event 1 Column	Fecal Coliform (CFU/100ml)	E.coli (CFU/100ml)	Enterococci (CFU/100ml)	Volume (ml)
Fall control 1	<3	<3	<3	980
Fall control 2	<1	<1	<1	820
Fall control 3	<1	<1	10	720
Fall 1X 1**	4,800,000	3,700,000	1200	780
Fall 1X 2	690,000	650,000	60	740
Fall 1X 3	430,000	370,000	70	680
Fall 2X 1	890,000	900,000	310	780
Fall 2X 2	650,000	900,000	73	790
Fall 2X 3	420,000	360,000	30	920

Table 18. Bacterial densities in Fall soil column leachate for event 2.

Event 2 Column	Fecal Coliform (CFU/100ml)	E.coli (CFU/100ml)	Enterococci (CFU/100ml)	Volume (ml)
Fall control 1	<1	<1	<1	500
Fall control 2	<1	<1	<1	430
Fall control 3	<1	<1	<1	310
Fall 1X 1**	340,000	350,000	91	460
Fall 1X 2	32,000	45,000	<10	440
Fall 1X 3	110,000	130,000	80	300
Fall 2X 1	71,000	87,000	20	420
Fall 2X 2	34,000	35,000	30	550
Fall 2X 3	41,000	35,000	<10	430

Table 19. Bacterial densities in Fall soil column leachate for event 3.

Event 3 Column	Fecal Coliform (CFU/100ml)	E.coli (CFU/100ml)	Enterococci (CFU/100ml)	Volume (ml)
Fall control 1	<1	<1	<1	500
Fall control 2	<3	<3	<3	425
Fall control 3	<3	<3	<3	350
Fall 1X 1**	24,000	11,000	<10	320
Fall 1X 2	2300	1800	<10	335
Fall 1X 3	3400	1900	10	160
Fall 2X 1	5400	3900	20	120
Fall 2X 2	2000	2100	10	300
Fall 2X 3	3300	1600	<10	410

Table 20. Bacterial densities in Fall soil column leachate for event 4.

Event 4 Column	Fecal Coliform (CFU/100ml)	E.coli (CFU/100ml)	Enterococci (CFU/100ml)	Volume (ml)
Fall control 1	<1	<1	<1	480
Fall control 2	<3	<3	<3	360
Fall control 3	<3	<3	<3	300
Fall 1X 1**	7500	7100	<10	320
Fall 1X 2	870	1700	<10	260
Fall 1X 3	2300	3500	<10	120
Fall 2X 1	730	1400	10	100
Fall 2X 2	1600	1900	10	125
Fall 2X 3	1300	1300	<10	120

**suspected outlier

It is expected that fecal coliform densities follow a similar pattern to E. coli densities, since E. coli is a subset of fecal coliforms. Enterococci are unrelated enteric organisms however, with a higher degree of survivability in the soil. This may explain the different pattern of enterococci levels over time and background levels of enterococci in control columns, which received no manure application. Wildlife activity or general farm operations could have caused bacterial contamination of control columns prior to extraction. The effects of this type of contamination would be most visible and most persistent in enterococci densities.

Clear differences in bacterial densities were identified between treatments during the second, third, and fourth irrigation events following manure application. Spring application of swine manure resulted in higher bacterial densities in subsurface drainage than fall application during the 5-week period following spring manure application. Specifically, the spring 336 kg-N/ha treatment yielded higher bacterial densities than other treatments during all but the first irrigation event. This suggests that manure applied to the field at a rate of 336 kg-N/ha during the spring may contribute significantly more bacterial contamination to ground water and tile drainage than fall and spring 168 kg-N/ha manure applications and fall 336 kg-N/ha applications. Although few significant differences were detected between application rates, the columns that received 336 kg-N/ha swine manure almost always yielded higher bacterial densities in leachate than the columns that received 168 kg-N/ha swine manure during the same season. Additionally, an interaction between the application rate and timing was observed, suggesting that an increase in application rate is more likely to cause greater bacterial contamination in subsurface drainage for spring application than for fall application.