# Bacteria in agricultural drainage as affected by manure management

by

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# INTRODUCTION

For many years, manure was considered a waste and not managed properly as a nutrient source. With adequate land resources, proper application volumes, and knowledge of manure management, this 'waste' product can benefit producers in crop production. Inadequate knowledge and land constraints have the potential to cause serious environmental degradation, particularly to water resources.

In Iowa, the economic benefits of hog production cannot be doubted. The Iowa Agricultural Statistics Report (1996) states that in 1995 the Iowa hog industry generated 14.4 million dollars, almost one-fourth of the national total. Each year, as the industry grows and becomes more concentrated, more land is utilized for animal production. In the U.S. in 1995, there were 43 farms with more than 10,000 sows (Freese, 1995). In 1997, there were 54 farms with more than 10,000 sows (Freese, 1997). In light of this expansive growth, of large hog operations one must consider not only the economic positive impacts, but also possible negative environmental implications that surround this industry.

It is widely known that agriculture is the primary contributor to nonpoint source pollution (NPS). Therefore, understanding the developing swine industry, and how nutrients and pathogenic bacteria pose potential threats to surface and ground water, has become essential. The purpose of the research addressed in this thesis is to determine the potential effects of rate, timing, and method of manure applications with respect to their impact on surface and ground water quality.

## Thesis Organization

Information in this thesis was organized into five chapters with a general introduction and literature review followed by the results of two studies, in the form of journal papers, and then general

conclusions. Chapters 1 and 2 include a general introduction and literature review respectively. Chapter 3 discusses manure management effects of bacteria transport with agricultural drainage from field plots. It consists of an abstract, introduction, materials and methods, results and discussion, and a list of references. Chapter 4 discusses bacteria and nutrient transport to tile lines shortly after large applications of liquid swine manure to the soil surface in lysimeters. The format of the fourth chapter is the same as Chapter 3. Chapter 5 is a general conclusion chapter. Directly following Chapter 5 is the Appendices of data The references for the general introduction and literature review are located at the end of the thesis.

## LITERATURE REVIEW

Currently, in the Midwest, increasing concentration of livestock production units has become an environmental concern. This concern stems from the need for sound use of the manure produced from these units, or handling of this manure that minimizes the potential environmental degradation. The application of manure on cropland is a practice that has been used for centuries. Crops can utilize the nutrients, primarily nitrogen (N), phosphorus (P), and potassium (K) from the manure, and producers can utilize crop-land for manure disposal. The amount of nutrients in excreted manure depends on the type of feed, species in production, animal size and medication, in addition to many other factors. Environmental degradation is possible from off-site contaminant transport of nutrients, sediments, and bacteria. Constituents in manure, nutrients and pathogenic bacteria such as fecal coliform (FC) and fecal *Streptococcus* (FS), pose threats to both subsurface drainage and surface runoff water quality. These potential contaminants may travel from land receiving manure, in surface runoff and subsurface drainage, to surface recreational waters or even groundwater, both of which may also be a drinking water source.

The degree to which agricultural drainage water becomes contaminated depends on many varying field factors. Cropping system, rainfall events, soil conditions, and management of manure applied, are all factors that must be considered. Cropping system is important due to the fact that some plants take up nutrients better than others. Cropping system is also important in how water is retained. Surface runoff is generally more likely in row crops than in forage cropping systems. Tillage is also important in determining water quality. The use of conservation tillage practices can increase the soil's ability to infiltrate and retain water, thus reducing surface runoff and contamination of surface waters, although the amount of water leaching through the root zone may increase due to the higher infiltration. Nutrients, primarily P, can attach themselves to soil particles and are more likely to be lost with sediment in surface runoff, thus not typically posing a threat due to leaching. Rainfall timing, amounts, and intensities will dictate the losses to surface runoff and subsurface drainage. Soil

conditions and types must be considered relative to potential infiltration and surface sealing, both of which influence contaminant transport with surface and subsurface drainage. Rate of manure application is an important consideration for the crop and the environment. Rate of application will depend upon crop requirements, soil nutrient levels and levels of nutrients in manure. Considering all of this, if a farmer does not consider the level of nutrients in manure, an over-application can occur, increasing the potential for contamination of water resources.

Threats to subsurface water from manure application deal primarily, but are not limited to N and bacteria. Nitrogen in the form of nitrate-nitrogen ($NO_3$-N) poses the largest threat, due to the potential for leaching. Threats to human health can range from methemoglobinemia, caused by excessive $NO_3$-N in drinking water, to gastrointestinal disease from consumption of water contaminated with pathogenic bacteria. Spalding and Exner (1993) state that consumption of water, contaminated by $NO_3$-N, may be linked to hypertension, birth defects, cancers, and infant mortality. This potential toxicity of $NO_3$-N is the reason for the maximum contaminant level (MCL) of 10 mg/L $NO_3$-N for drinking water. Current governmental standards of maximum allowable limits for FC bacteria within varying categories of water are: Public water supply (prior to primary treatment) 2000/100 mL, recreational waters (limited contact) 200/100 mL and irrigation water 1000/100 mL. Finished drinking water is expected to have zero bacterial contamination.

The potential for disease transmission is a major bacteriological problem, when considering manure application to soil. Within manure, groups of pathogenic groups of bacteria exist, namely FC and FS. These bacterial indicator species have been used to monitor the contamination of surface and ground water resources. An indicator organism is one that is present in only given situations. The indicator population of bacteria that is sampled for most frequently is FC. FC populations are only seen in the feces of warm-blooded animals and are not present in the normal soil microflora. A sub-population of FC is *Escherichia. coli* (EC). This organism would also indicate fecal contamination, but not as broadly as FC quantification. Questions exist about FS populations and why that group is

not included in governmental standards. Geldreich and Kenner (1970) discussed the potential for FS to be native to soil, vegetation, as well as insects, thus making it a less reliable indicator organism; nevertheless, it is present in animal feces. These authors also state that risks for potential human infection increase significantly when exposed by contact to concentrations of FC higher than 200/100ml in recreational waters. A review of the past research dealing with nutrient and bacterial transport with water follows.

The use of soil columns is one scientific method used to determine the potential for bacterial leaching that attempts to emulate field studies on a smaller scale with less natural interaction and more experimental control, in addition eliminating the potential environmental degradation of field studies. Columns can be useful for obtaining a better understanding of basic scientific factors, which then may be applied to field-scale studies. The following studies discuss the importance of soil type in retaining bacteria in the soil matrix, as well as potential management strategies for maintaining the water quality of water draining from the root zone. Smith et al. (1985) and Gannon et al. (1991) concluded that bacteria applied to the surface of the column travel down with water from irrigation or rainfall. Smith et al. (1985) state, that although removal varied by bacterial species type, the soil matrix is effective in mechanically filtering bacteria from the water travelling through the soil. Tan et al. (1992) concluded that bacteria traveled faster in coarser textured soils than in finer soil types. Smith et al. (1985) and Gannon et al. (1991) also concluded that macropore or preferential flow poses a major threat to the overall quality of the effluent discharged from columns of soil. In addition, Smith et al. (1985) states that even minimal disturbance of the surface of a soil column aids in retaining bacteria in the soil column matrix. The effects of this disturbance of the soil surface may be linked to a shearing of macropores, thus preventing rapid transport and contamination, namely with nutrients and bacteria, of the subsurface waters.

Similar to column studies, a lysimeter study attempts to emulate field environmental conditions. Lysimeters are blocks of soil encased in impermeable containers that control over-all

water percolating through the soil profile, not allowing water loss by transverse movement, thus allowing for total accounting of water entering the lysimeter. In a study conducted by Bergstrom and Johansson (1991), using monolith lysimeters with commercial fertilizer as the source for N, it was determined that coarser soils had higher $NO_3$-N leaching losses than did the finer soils. It was also noted that higher levels of precipitation produced higher concentrations of $NO_3$-N.

With an understanding of some of the basic principles obtained from 'simulated' studies (i.e. columns and lysimeters), a detailed look at field-scale research should then be done to obtain information about the potential environmental effects of the application of manure on the quality of surface and subsurface agricultural drainage.

The high nutrient and bacterial contents of manure may create potential environmental problems when it is improperly applied to the soil. Nutrients and bacteria may be carried in surface runoff, contaminating recreational waters, as well as surface sources of drinking water. Hynes (1971) research found that high nutrient overloading of N and P in surface water ultimately leads to eutrophication of lakes and streams. Fish kills, contamination of livestock drinking water, and poor water aesthetics may also result from improper manure application. Studies by Dunigan and Dick (1980), Faust (1982), Crane et al. (1983), Patni et al. (1985), and Baxter-Porter and Gilliland (1988) address the potential contamination of surface waters from manure application. Patni et al. (1985) states that bacterial quality, measured by FC, FS, and total coliform (TC) counts in drainage from manure treated plots had much higher levels of contamination in surface runoff than from non-manured plots. This same study indicates that only under excessive runoff events were governmental standards exceeded for recreation or public water supply prior to primary treatment. Patni et al. (1985) mentions that manure stored for long periods of time had much lower concentrations of indicator bacteria than relatively fresh manure. Similarly, Faust (1982) and Baxter-Porter and Gilliland (1988) state that surface runoff from grazed areas produces higher levels of bacterial contamination than ungrazed areas. It is logical that increased manure levels create the potential for

increased surface water contamination. Faust also mentions that indicator bacteria concentrations in soil water decrease as the depth of the soil increases. This same study indicates that cornfield and forest soils have lower bacterial densities in surface runoff than pasture soil where animal grazing has occurred. In another study, Dunigan and Dick (1980) report higher surface runoff losses of FC, N, and P from surface-applied sewage sludge than incorporated sewage sludge. This same study also indicates that the number of FC in the soil decreased rapidly after the soil became drier. Dunigan and Dick also mention that application method has an effect on ammonia ($NH_3$) losses. These researchers found that surface-applied sewage sludge had higher nutrient losses associated with surface runoff than incorporated sewage sludge. Similarly, Hensler et al. (1969) found increased losses of N, P, and K in runoff for winter-applied broadcast manure than spring knife-applied manure. In a study by Hawkins et al. (1994), evaluation was made to determine the effectiveness of overland flow, on slopes of 5 and 11 percent, for treatment, or removal of nutrients, in swine lagoon effluent. These researchers found that the overland flow treatment, when dry conditions prevail, is an effective method for reducing levels of nutrients in surface-applied wastes, excluding $NO_3$-N. In this case, however, it appears that the $NO_3$-N leaching may pose a threat to subsurface waters.

Several studies have been conducted to determine potential threats of manure application on subsurface water quality (Evans and Owens, 1972; Smith , 1972; Baker et al., 1975; Brown et al., 1979; Patni et al., 1984; Evans et al., 1984; Fleming and Bradshaw, 1992; Dean and Foran, 1992). P is rarely thought of as a threat to the quality of subsurface water, due to its adsorption to soil particles. However, Breeuwsma et al. (1995) found P contamination in groundwater, believed to be from manure application. It should be noted that the initial levels of P in the soil were above the saturation level. Evans et al. (1984) and Fleming and Bradshaw (1992) indicate that following manure application, levels of $NO_3$-N contamination increased in subsurface drainage. Evans et al. (1984) also note that over-application of manure; that is to say, more nutrients than plants require for optimum growth, is a measure that contributes highly to the contamination of subsurface waters by nutrients.

Their study involved application rates of 325, 650, and 1300 kg N/ha/yr. These application rates represent 1, 2, and 4 times the recommended rate of N application for Coastal Bermudagrass. The research indicates that an application rate of 400 kg N/ha/yr, approximately 1.25 times the recommended rate, will still maintain subsurface soil-water quality within the 10 mg/L standard. These same researchers also indicate that periods of high precipitation, following application, were more likely to cause subsurface water contamination than periods of relatively low precipitation.

In a similar study, Phillips et al. (1981), determined the effect of rate and timing of manure application on groundwater quality. In this study, liquid dairy manure was applied at three rates, 224, 560, and 897 kg N/ha/yr. Timing was also a factor with winter, spring, fall, and split spring/fall applications used. This study also utilized an 134 kg/ha/yr spring treatment of inorganic N as well as a 0 kg/ha/yr treatment, as a control, for comparison reasons. The research determined, by collecting samples from a 0.7 m-deep perforated tile, that rate of application had a larger effect on groundwater quality than timing. Flemming and Bradshaw (1984) observed the effect of three manure application methods to the soil: injected, broadcast, and broadcast with incorporation. Their research indicated that liquid dairy manure when broadcast followed by incorporation is the best management strategy for preserving groundwater quality. This may be due to the shearing of macropores at the soil surface. A Canadian study by Patni et al. (1984) mentioned that the potential for bacterial contamination increased with coarse textured soils. Gerba et al. (1975) found similar results, indicating that bacteria maybe filtered or adsorbed better by clay particles. Contrary to the study by Patni et al., Smith et al. (1972) state the microbiological quality of the subsurface drainage is influenced very little by the use of bacterial contaminated irrigation water. This study showed no increase in FC densities after irrigation with water containing 33,000 FC/100ml. However, studies by Evans and Owens (1972) and Dean and Foran (1992) described very different results. Evans and Owens (1972) research shows a 30- to 900-fold increase in fecal bacteria concentrations of subsurface drainage 2 h after application of swine manure. Dean and Foran (1992) found similar results when comparing various cropping

regimes and management practices. In their study, 12 applications of liquid waste were made under a variety of field conditions on a total of five soils in Ontario, Canada. Eleven of the applications used the irrigation method, while the remaining application was a broadcast application. Eight of the 12 applications resulted in subsurface water quality degradation within 20 min to 6 h following manure application. For the two events that did not result in water quality degradation, no tile flow was recorded following application. For one other application for which no significant contamination was evident, the soil had just been tilled prior to application. This may have impeded movement of manure, by shearing the macropores in the soil surface. Although some understanding of the potential for contamination exists from a nutrient and bacteriological standpoint; a better understanding of the soil-water-manure relationship on contaminant fate and transport needs to be achieved.

From a nutrient standpoint, research has been conducted in order to obtain information about minimizing losses. It is well known that incorporation or injecting manure into the soil can minimize nutrient losses due $NH_3$ volatilization (Hensler et al., 1969; Fleming and Bradshaw, 1992; and Dunigan and Dick 1980). This practice also minimizes potential odor problems. While injection minimizes losses due to volatilization, it may promote increased nutrient losses to subsurface drainage (Dunigan and Dick, 1980 and Fleming and Bradshaw, 1992).

A complete understanding of the factors affecting the survival of microorganisms may not be as attainable, as microorganisms are dynamic living creatures. The main factors influencing bacterial survival in the soil environment are moisture content, temperature, pH, sunlight, organic matter, and competition of other microflora (Romero, 1970; Gerba et al., 1975; and Crane et al., 1983). These factors deal with basic microbiological principles; the requirement of nutrients and water for survival, and reasonable pH and temperature to provide a hospitable climate. Sunlight and competition can present negative interactions for microbial communities. In a study by Bell (1976), FC populations in soil were completely destroyed by 10 h of bright sunlight. Bell also states there was no decrease in population in the absence of bright sunlight (i.e. cool, damp, and overcast conditions). Van Donsel et

al. (1967) found similar results, showing 90% reductions in FC populations in soil in 3.3 days in the summer and the same reduction to FS populations in 2.7 days also in the summer. Variations in these die-off rates and a better understanding of the soil-water-bacteria relationships may help provide some explanation to the variability seen in the field experiments when dealing with bacteria. Another explanation can be offered by the research completed by Van Donsel et al. (1967) in which the possibility for populations of bacteria to increase from applied manure shortly after application was considered. This observation was made for non-fecal bacteria after a short rainstorm and this could be due to the nutrient levels in the soil matrix and the added water available from the rain.

It can be observed from the research discussed, that the timing, rate, and method of application of manure to the soil can have definite impacts on the quality of surface and subsurface drainage. Consequently, since Iowa is the largest swine producing state in the nation, and so few studies have been conducted in Iowa, it is appropriate that a study be done to examine the effects of swine manure application on the quality of surface and subsurface drainage from cropland to which manure has been applied.

# MANURE MANAGEMENT EFFECTSOF BACTERIA IN AGRICULURAL DRAINAGE

A paper to be submitted to Transactions of the ASAE

## ABSTRACT

There is an increasing concern in rural areas of the Midwest regarding sound use of animal manure from swine production units. In an ongoing total water quality project, the effect of timing, rate, and method of manure application in a corn/soybean rotation is being studied to determine appropriate management practices. Surface and subsurface drainage from experimental plots are being monitored for bacterial (fecal coliforms, fecal *Streptococcus*, and *E. coli*) and nutrient contents. There are three replications of nine treatments related to timing, rate, and method of application of manure, one of which is a no-manure fertilizer-only treatment. In addition, crop nutrient uptake, crop yield, and drainage volumes are being determined as a part of a comparnion study. Bacterial measurements of water from shallow subsurface drainage and surface runoff throughout the year under natural precipitation conditions show some contamination for all plots, but to a higher degree in manured plots.

## INTRODUCTION

Currently, in the Midwest, increasing concentration of livestock production units has become an environmental concern. This concern stems from the need for the sound use of the manure that is produced from these units, or in other words handling of this manure in a manner that does not degrade the environment. Environmental degradation can be manifested in many ways in terms of off-site impacts of the nutrients; nitrogen (N), phosphorus (P), sediments, and bacteria. This paper will focus on potential bacterial contamination, a major public health concern, of both subsurface

drainage water and surface runoff. Within manure, pathogenic groups of organisms exist, namely fecal coliform (FC) and fecal streptococcus (FS). These pathogens can travel from soil applied manure, in surface runoff and subsurface drainage ultimately to recreational surface waters, which may be used both as a source for drinking water and recreation. Current governmental standards of maximum allowable limits for FC bacteria within varying categories of water are: Public water supply (prior to primary treatment) 2000/100 mL, recreational waters (limited contact) 200/100 mL and irrigation 1000/100 mL. Finished drinking water is expected to have zero bacterial contamination.

The application of manure on cropland is a practice that has been used for centuries. Crops can utilize nutrients from the manure and the producer can utilize land for manure disposal, although in a "sustainable system" the concept is of utilization and not disposal. Past research on bacterial transport with water has been performed. In a field study observing the bacterial quality of subsurface drainage from land receiving irrigation water, filtration through the soil medium was seen to decrease fecal bacterial populations greatly (Smith et al., 1985). Column studies found that transport of bacteria with leaching water varies with species type, but generally, all species were filtered out to some degree by the soil in the columns (Gannon et al., 1991). Smith et al. (1985) and Gannon et al. (1992) concluded that macropore flow or preferential flow pose a major threat to the overall quality of the effluent discharged from columns. Tan et al. (1992) concluded that bacteria traveled faster in coarser textured soils than in finer soil types. In an additional study observing bacterial quality of field tile drainage water, Patni et al. (1984) found little difference in the bacterial quality of subsurface drainage from manured and non-manured fields. Contrasting these results, Owens and Evans (1972) found an increase of 30-900 fold in the populations of FC in water in tile lines within 2 h of application of pig slurry.

Bacterial contamination of surface runoff was found to occur in greater degrees from manured plots during wetter periods of the season than during drier periods (Patni et al., 1985). In another study on agricultural land, comparing grazed and ungrazed areas, the grazed area was seen to

have higher bacterial concentrations in runoff than the ungrazed area (Faust, 1982 and Baxter-Porter and Gilliland, 1988). Dunigan and Dick (1980) reported higher surface runoff losses of FC from surface-applied sewage sludge than incorporated sewage sludge. Realizing that the potential for contamination exists, a better understanding of the soil-water-bacterial relationships needs to be achieved.

The main factors affecting the survival of microorganisms in soil are moisture content, temperature, pH, sunlight, organic matter, and competition of microflora (Gerba et al., 1975). These factors deal with basic microbial principles, the requirement of nutrients and water for survival, and reasonable pH and temperature to provide a hospitable climate. Sunlight and competition can present negative interactions on the microbial communities. Solar radiation plays a key role in the survival rates of bacteria in the soil. Bell (1976) using an alfalfa cropping regime irrigated with municipal sewage, found 10 h of bright sunlight completely destroyed the population of FC. Similar reductions were observed in a study utilizing soil pots; populations of FC and FS were reduced by 90% in 3.3 days in the summer and in 13.4 days in the autumn (Van Donsel et al., 1967). Table 1 gives a broader listing of factors affecting survival (Crane et al., 1983). Similarly, Table 2 summarizes factors affecting movement of bacteria over and through soil (Crane et al., 1983). The study reported here began in the late winter/spring of 1996 with the purpose of the study is to examine the effects of timing, rate, and method of application of liquid swine manure on the quality of shallow subsurface drainage and surface runoff.

## MATERIALS AND METHODS

This study is being conducted at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames, Iowa, and consists of three replications of nine treatments involving application at the recommended rate (1X) and at the double rate (2X), timing and method of

application (Table 3). There are two fall inject treatments, one fall application is with a conventional injection shank, while the other is with a newly developed shank that attempts to minimize surface disturbance. The soil in the area is primarily a Clarion loam with 2-4% slope. Each plot is 7.6 m (25 ft) by 22.9 m (75 ft) long, grown in a corn-soybean rotation, consisting of five rows corn and soybeans 0.76 m (30 in) wide each of, rotated yearly. Figure 1 shows the complete site layout.

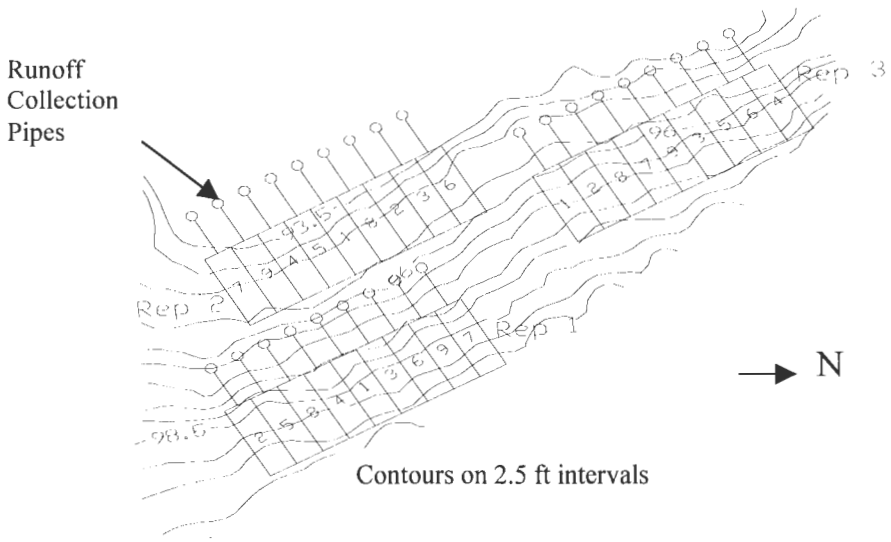


Figure 1. Site layout

All the plots are set up to collect surface runoff and subsurface drainage. The surface runoff, from the whole plot, is collected and transported by pipes into large circular stock tanks, allowing for measurements of the amount of runoff and as well as providing for water quality sampling. A view of an individual plot layout and plot dimensions can be observed in Figure 2. After ample mixing to homogenize the collected surface runoff water, the tanks are pumped out using a standard trash pump and samples are taken after ample pumping to ensure no cross contamination from the previous sample. The runoff volumes are determined by measuring the depth of water within the stock tank

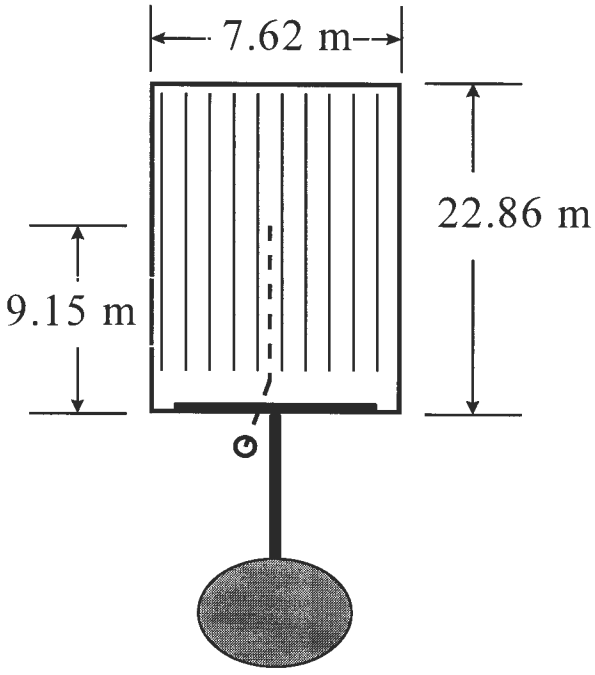


Figure 2. Plot Layout

Table 1. Factors affecting the survival of enteric bacteria in soil

| |
|---|
| Physiochemical Characteristics of Soil |
| a) pH |
| b) porosity |
| c) organic matter |
| d) texture |
| e) temperature |
| f) moisture |
| g) adsorption/ filtration |
| I) nutrients |
| Atmospheric Conditions |
| a) sunlight |
| b) moisture |
| c) temperature |
| Biological Interactions |
| a) competition |
| b) antibiotics |
| c) toxic substances |
| Application Methods |
| a) technique |
| b) frequency |
| c) organism density in waste material |

Table 2. Factors affecting movement of bacteria through soil

Soil Physical Characteristics
- a) texture
- b) particle size
- c) clay type and content
- d) organic matter content
- e) pH
- f) cation exchange capacity
- g) pore size distribution

Soil Environmental and Chemical Factors
- a) temperature
- b) moisture content
- c) chemical make-up of the soil solution
- d) bacterial density
- e) nature of organic matter in waste effluent solution

Table 3. Manure application treatments

| Treatment | Timing | Method | N rate | N (lb./acre) |
|---|---|---|---|---|
| 1 | control* | broadcast | 1X+ | 150 |
| 2 | fall | inject | 1X | 150 |
| 3 | fall | inject | 2X | 300 |
| 4 | fall | inject | 1X | 150 |
| 5 | fall | inject | 2X | 300 |
| 6 | late-winter | broadcast | 1X | 150 |
| 7 | late-winter | broadcast | 2X | 300 |
| 8 | spring | inject | 1X | 150 |
| 9 | spring | inject | 2X | 300 |

- *N applied to control was inorganic fertilizer in the form of 28% urea-ammonium nitrate solution +1X equals the recommended rate for corn following soybeans (as "available" N); 2X twice the recommended rate

and knowing the tank dimensions. The subsurface drainage water is collected by 7.5-cm diameter perforated plastic drainage tubes, 9.15 m long, placed at the center of each plot at a depth of 1.2 m. Each tube empties into a vertical 38-cm diameter PVC sump. All plots are surrounded by earthen berms, to avoid any cross contamination from surface runoff. Manure is either obtained from the Iowa State University Swine Nutrition Farm near Ames, Iowa or Swine Breeding Research Unit near Madrid, Iowa. Manure samples are taken and analyzed for N content, to determine appropriate treatment rate application volumes. Subsurface drainage samples are taken weekly, starting with flow in the spring or summer and continuing until flow stops, usually through mid-fall. A submersible electric pump is used to gather samples from each sump. To ensure consistency, samples are taken once the water level within the sump is below the subsurface inlet. An in-line flow meter quantifies the amount of water pumped. The water samples are collected in sterile plastic bags and analyzed within 24 h (if not analyzed immediately, samples are stored at 4°C but not for more than 24 h). Analysis for FC, *E. coli* (EC), and FS are done according to Standard Methods for the Examination of Water and Wastewater, 18th edition. Enumeration of FC, EC, and FS are done using membrane filtration techniques, plating, on m-FC agar for FC, m-coli blue for EC, and m-*Enterococcus* agar for FS. All bacterial densities are recorded in terms of colony forming units (CFU) per100 ml. Additional samples are taken to monitor plant nutrient uptake and to quantify nutrient levels in surface and subsurface waters in a companion study. Statistical analyse were completed using SAS, which showed no significant difference among the treatments in surface and subsurface drainage

## RESULTS AND DISCUSSION

Bacterial measurements from the summer of 1996 includes only five of the nine scheduled treatments: control, late winter broadcast at the recommended N rate and at the double rate, and spring inject at the recommended N rate and the double rate. These treatments were implemented prior to the summer of 1996. Timing of the start of this project did not allow fall applications to be

made in 1995. Installation of the surface runoff collection system was weather delayed, therefore the results for 1996 only describe subsurface drainage. However, qualitative observations indicated there was little surface runoff in 1996. Results of rainfall/flow, FC, and FS for 1996 are summarized in Figures 2-4, respectively. The 1996 tile flow and rainfall data are shown in Figure 2. The tile flow peaked directly following a peak rainfall week. It would also follow that when rainfall was low, tileflow was also low.

The FC data in Figure 3 show the 2X late winter broadcast treatment had high counts early in the summer and the 2X spring inject treatment had high counts later in the summer. It should be mentioned that the soil received the broadcast treatment prior to the installation of subsurface drainage. Considering this, the broadcast treated soil was then used to backfill after installation of the subsurface drainage tube, increasing the likelihood of contaminants being observed the first year due to leaching. The level of contamination for the most part was relatively low when considering the primary contact standard for recreation, which is 200 FC/100 mL. The FS data, in Figure 4, shows even more variability, with the 1X inject treatment showing a peak early in the summer, followed by a peak for the 2X winter broadcast treatment a week later. These counts proved higher than FC densities, but followed a similar trend, high bacterial densities usually followed periods of heavy rainfall. Following the early part of the season, relatively low levels of both FS and FC were measured. It might be inferred from these data that after ample flushing of the system, microbial contamination of subsurface drainage waters is limited.

Data for 1997 are summarized in Figures 5-11. Tile flow and rainfall data for 1997 are presented in Figure 5, and are similar to the 1996 data, showing that the tile flow peak lags behind the rainfall event, due to the time it takes for infiltration and water movement through the soil profile. For the most part, bacterial densities were low in subsurface drainage samples. Figure 6 shows populations of FC in subsurface drainage for 1997. FC counts increased following the June runoff event. A count of 967 CFU/100 ml was observed in subsurface drainage following the June 21

surface runoff event for the spring 1X inject; the primary contact standard is 200 FC/100 ml for surface waters. FS (Figure 7) and EC (Figure 8) densities also peaked in the subsurface drainage following the June 21 runoff event. These elevated densities could possibly be explained by macropore flow that was generated from the surface runoff event. Elevated bacterial densities were also seen in subsurface flow immediately following the July 24 runoff event. These numbers are not included in the graphs because so few of the plots had subsurface flow, thereby failing to generate replications. This data can be seen in Appendix A. These elevated numbers can be possibly explained by macropore flow from the surface ponding of the runoff event.

Bacterial densities in surface runoff for the two rainfall-runoff events that occurred in 1997 were highly variable. No clear trends were seen with respect to treatment (Figures 9 and 10). In general, densities were higher for the July 25 event than for the June 21 event. This could be explained by the more intense event seen on July 25. Runoff volumes for these two events are outlined on Figure 11. It should be mentioned that in most cases, the manured plot varied little from the control plots for surface water samples. For the most part, this would tend to agree with results from Patni et al. (1984), which indicate that during periods of high flow (precipitation), high bacterial densities follow. Also, Evans and Owens (1972) state that bacterial contamination returned to normal levels within 24 h after a heavy rain.

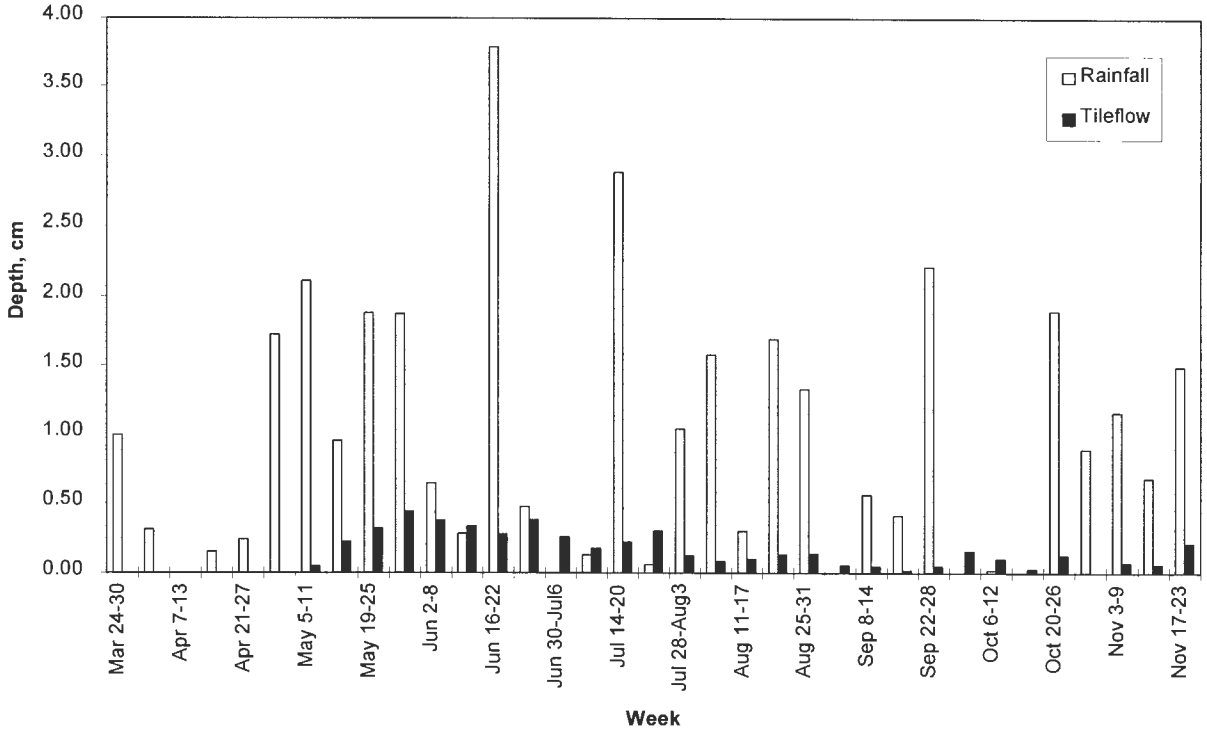


Figure 2. Weekly total rainfall and tile flow in 1996

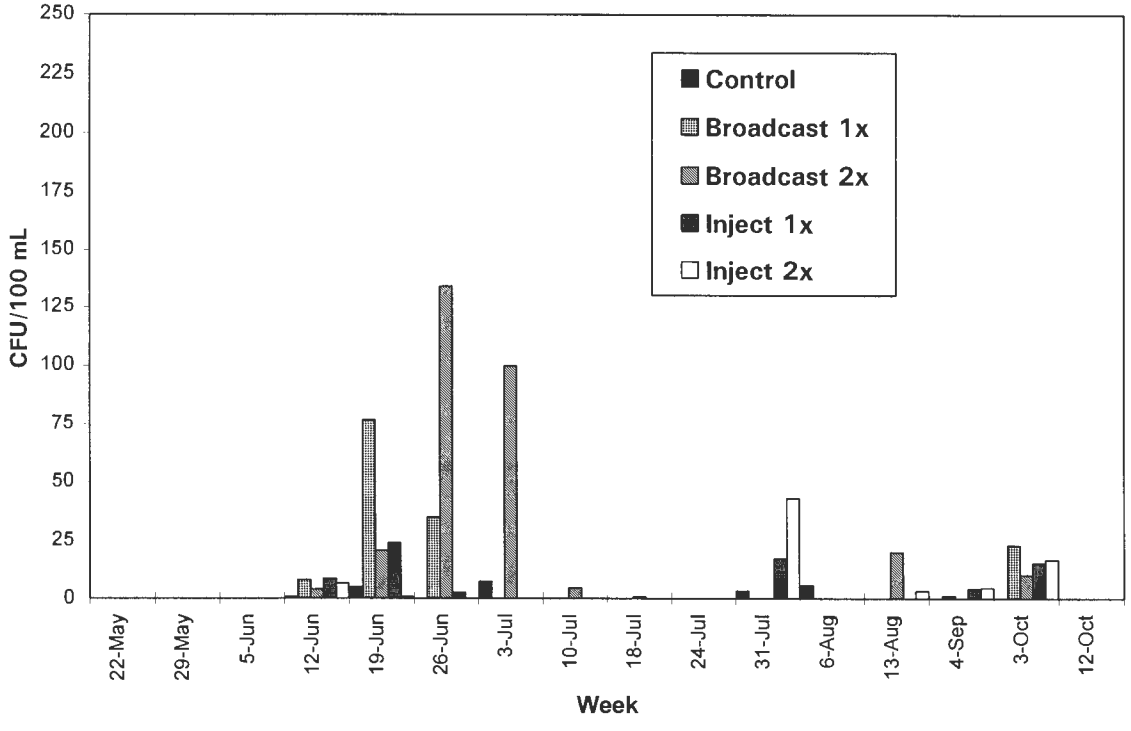


Figure 3. Average FC counts in subsurface flow in 1996

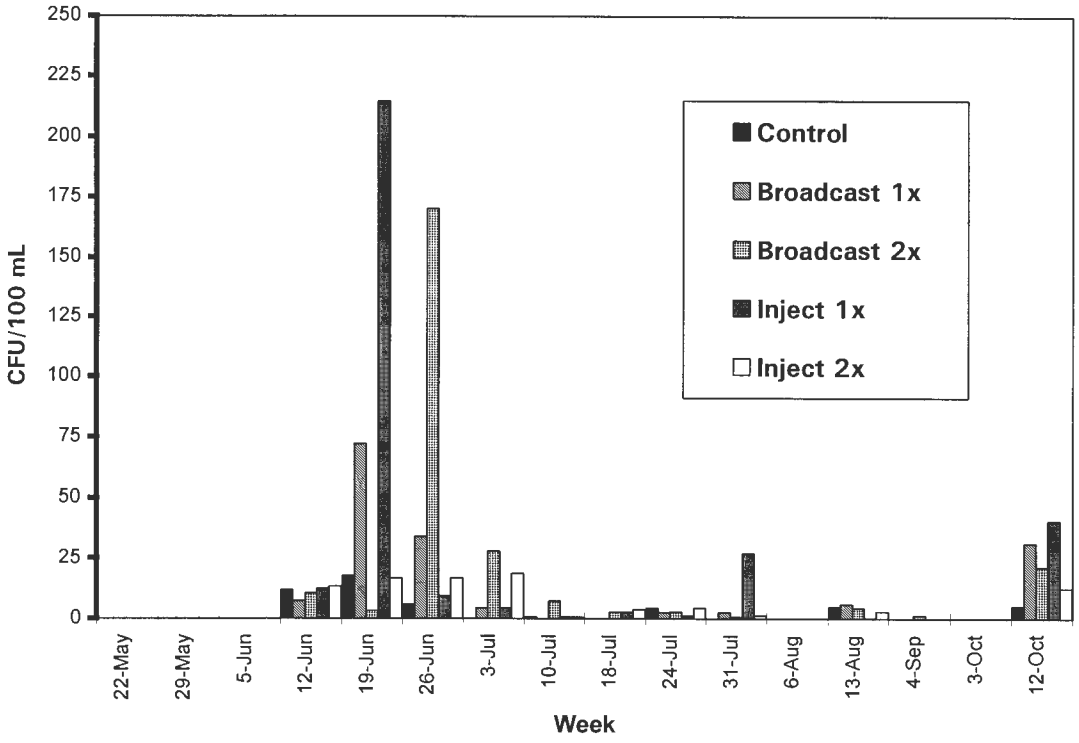


Figure 4. Average FS counts in subsurface flow in 1996

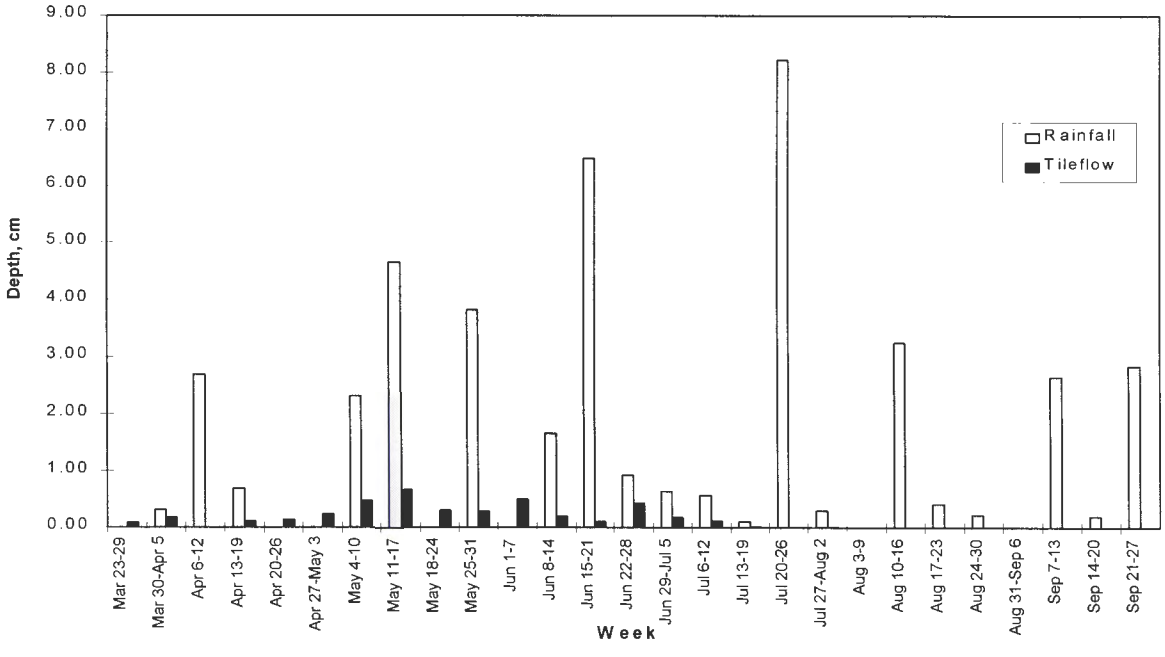


Figure 5. Weekly total rainfall and tileflow in 1997

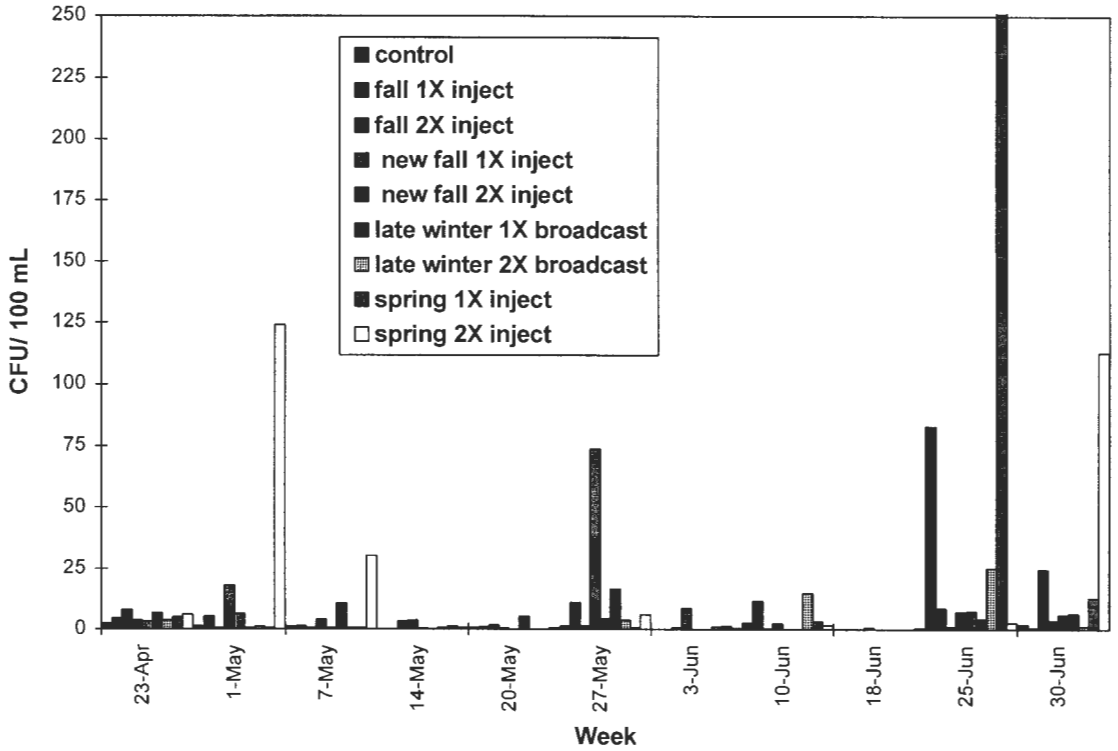


Figure 6. Average FC densities in subsurface flow in 1997

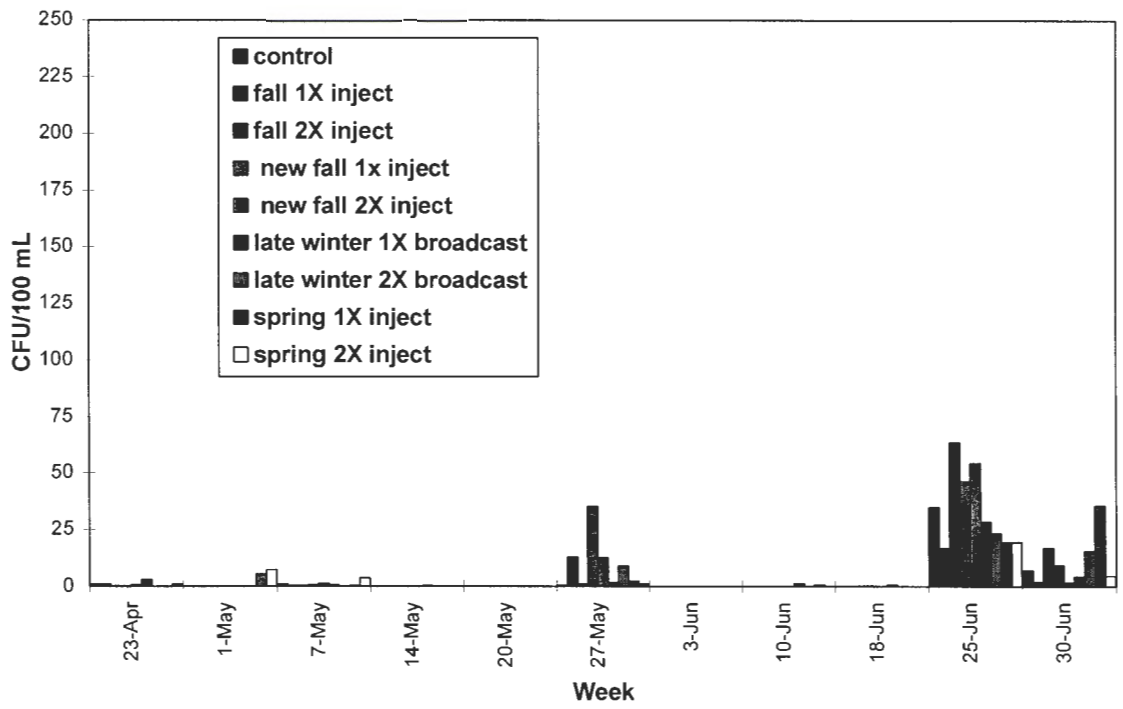


Figure 7. Average FS counts in subsurface flow in 1997

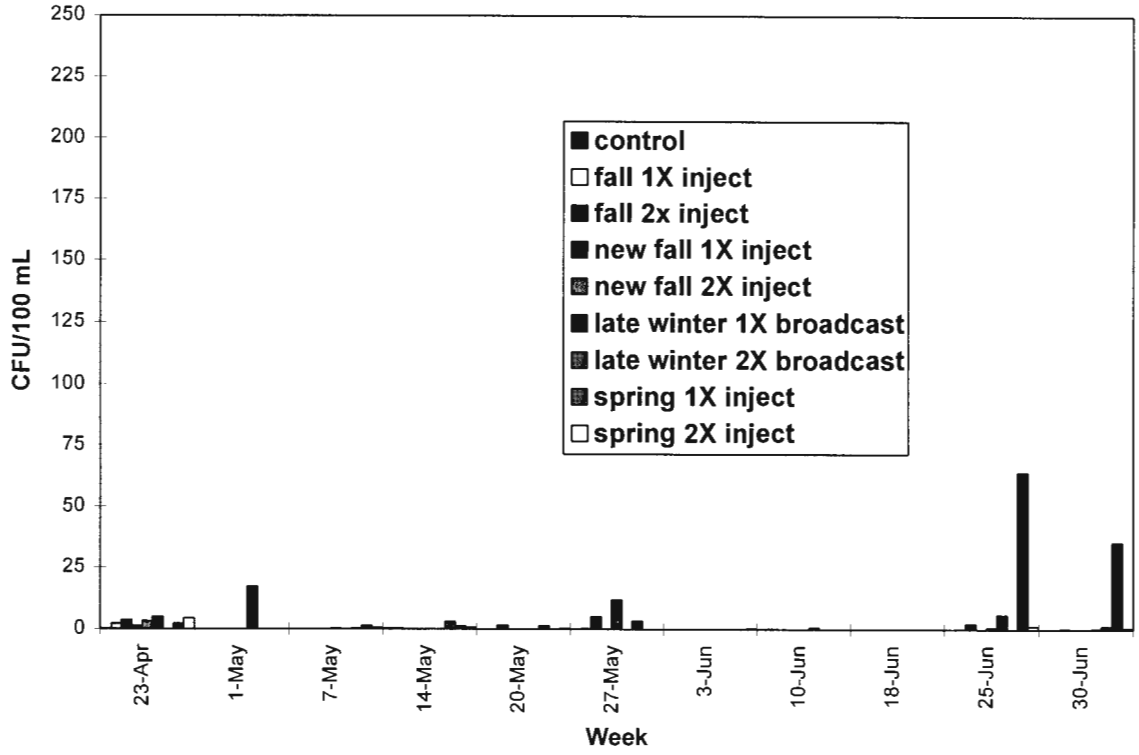


Figure 8. Average EC counts in subsurface flow in 1997

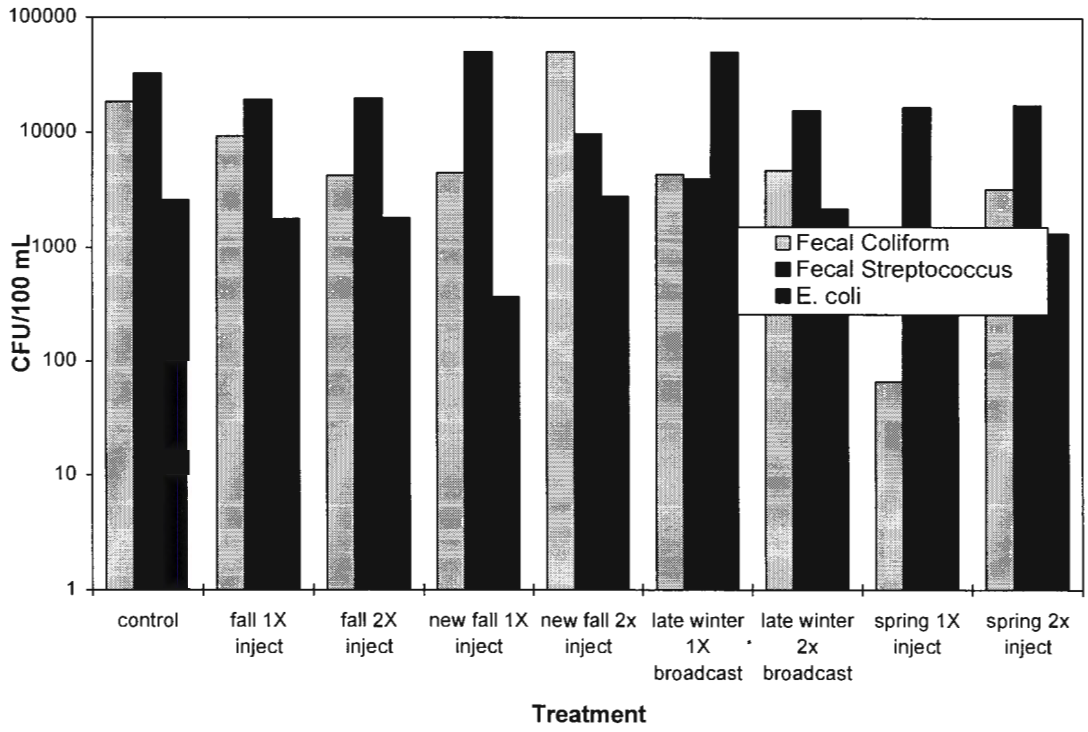


Figure 9. Average fecal bacterial counts in runoff water from June 21, 1997 event

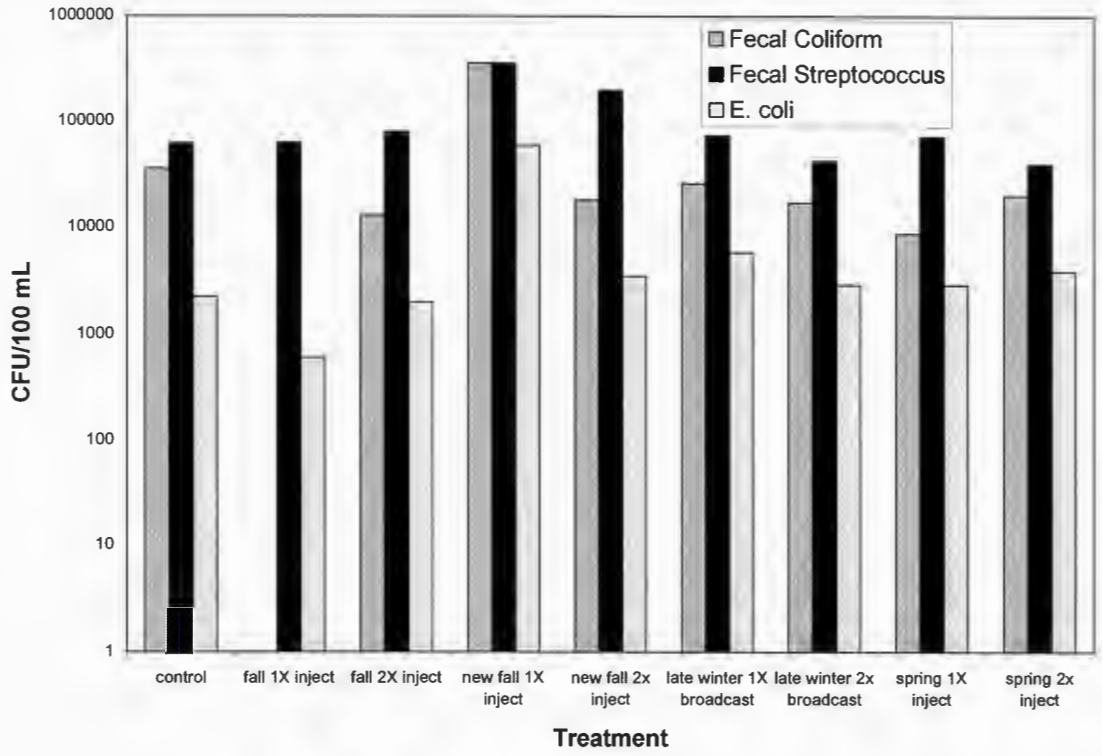


Figure 10. Average fecal bacterial concentrations in runoff water from July 24, 1997 event

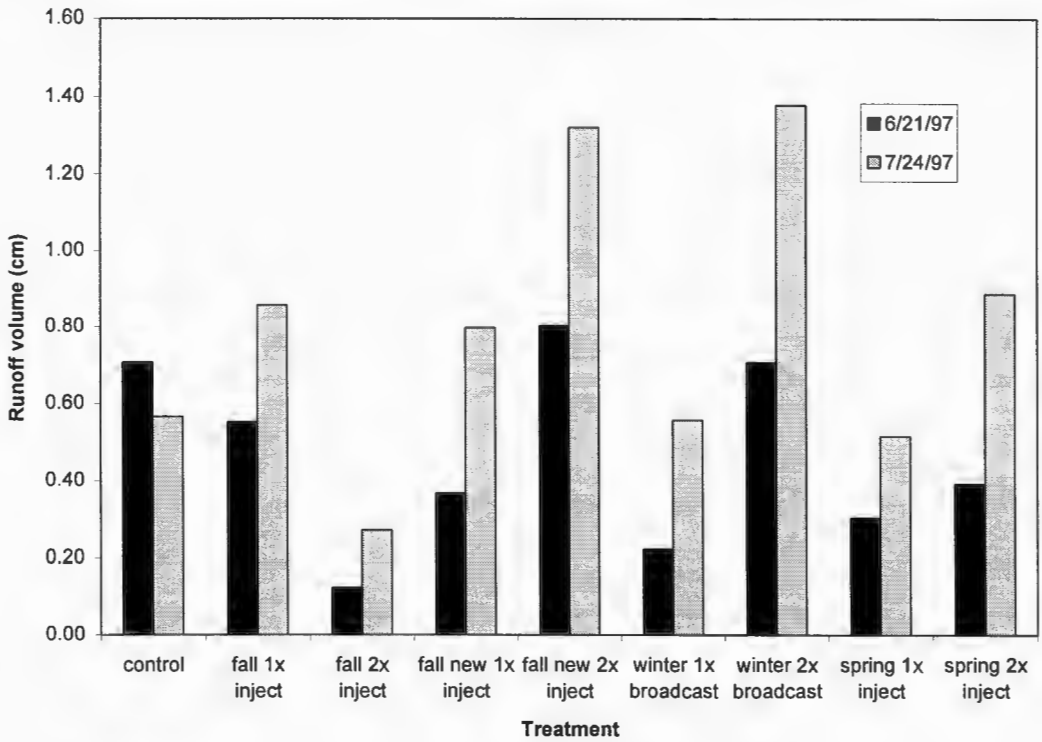


Figure 11. Average surface runoff volumes for June 21 and July 24, 1997 events

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# BACTERIA AND NUTRIENT TRANSPORT TO TILE LINES SHORTLY AFTER APPLICATION OF LARGE VOLUMES OF LIQUID SWINE MANURE

A paper to be submitted to Transactions of the ASAE

M. J. Cook and J. L. Baker

## ABSTRACT

The rapid growth of the livestock production industry has introduced some concerns about potential water quality problems from land application of manure. A study was conducted using 14 lysimeters to observe the transport of bacteria and nutrients with subsurface drainage water as a function of liquid swine manure application rate. Lagoon effluent was surface-applied to no-till soil in lysimeters at rates of 2.8 and 8.3 cm. At the lower rate, additional management strategies or treatments were used, consisting of tilled and air-pressurized lysimeters. The subsurface drainage water was analyzed for flow volume, pathogenic bacteria, and nutrient concentrations. The results indicate that the higher rate of application produced higher levels of nutrient and bacterial contamination within 1 h after application as well as throughout the 21-day study period. At the lower rate, there was less bacteria and nutrient transport, and no-till lysimeters were seen, somewhat, to have higher levels of contamination earlier in the study than did tilled or air-pressurized lysimeters. The use of tillage as a management strategy appeared to retain the lagoon effluent to the highest degree; some potential was seen for reduction of contamination in the subsurface drainage from air pressurization.

## INTRODUCTION

Currently, in many regions in the United States, the rapid increase and concentration of livestock production units have produced some water quality concerns. These concerns may exist even when proper use of the manure produced from these units is made on cropland. The idea is to

handle this manure in a manner that does not degrade the environment. Environmental degradation can be manifested in many ways in terms of off-site impacts of nutrients, sediments, and bacteria. This paper will focus on the potential bacterial and nutrient contamination of subsurface agricultural drainage. Bacteria and excess levels of nutrients in drinking water have potential to cause disease in humans. The disease can range from gastrointestinal problems from bacteria to methemoglobinemia from excess nitrate-nitrogen ($NO_3$-N).

These primary contaminants can travel from soil-applied manure in subsurface drainage ultimately to surface recreational waters, which are potential drinking water sources as well as recreational waters. The current governmental standard for maximum allowable limits of $NO_3$-N in drinking water is 10 mg/L. Elevated phosphorus (P) levels can cause eutrophication in surface waters such as lakes. The governmental standards for maximum allowable limits for fecal coliform bacteria (FC) within varying categories of water are: public water supply (prior to primary treatment) 2000/100 mL, recreational waters 200/100 mL and irrigation water 1000/100 mL. Finished drinking water is expected to have zero bacterial contamination.

The application of livestock manure to cropland is a practice that has been used for centuries. Crops can utilize nutrients from manure and the producer can utilize land for disposal, although in a "sustainable system" the concept is manure utilization and not waste disposal. Past research on contaminant transport with water has been performed. In a field study of bacterial quality of subsurface drainage from land receiving irrigation water, filtration through the soil matrix was seen to decrease FC populations greatly (Smith et al., 1972). Column studies found that transport of bacteria with leaching water varies with bacterial species type, but generally all species were filtered out to some degree by the soil columns (Gannon et al., 1991). In an additional study of bacterial quality of subsurface drainage water, Patni et al., (1984) found little difference in the bacterial quality of subsurface drainage from manured and non-manured fields. Contrasting these results, Owens and Evans (1972) found an increase of 30-900 fold in the populations of FC in water in tile lines within 2

h of application of pig slurry. Dean and Foran (1992) found similar results when comparing various cropping regimes and management practices. This study involved 12 applications of liquid waste under a variety of field conditions on a total of five soils. Eight of the 12 applications resulted in subsurface water quality degradation within 20 min to 6 h following manure application. For two of the applications that did not result in water quality degradation, no subsurface flow was recorded following application. For the remaining application that had no significant contamination, the soil had been tilled prior to manure application. This may have impeded the movement of manure by shearing the macropores or preferential flow paths at the soil surface.

From a nutrient perspective, research by Hawkins et al. (1994) evaluated the effectiveness of overland flow for treatment of swine lagoon effluent. The researchers found that when dry conditions prevail, overland treatment is an effective method for reducing levels of nutrients in surface-applied wastes, with the exception of $NO_3$-N. In this case, it appears that the $NO_3$-N may pose a threat to subsurface waters due to leaching. Although (P) can contaminate surface runoff, it is rarely thought of as a threat to subsurface water, due to it adsorption to soil particles. However, Breeuwwsma et al. (1995) found P contamination of groundwater that was believed to be from manure application, although it shows, that initial levels of P in the soil, were above the saturation level. Evans et al. (1984) and Bradshaw and Fleming (1992) indicate that following manure application, levels of $NO_3$-N contamination increased in tile drainage. Evans et al. (1984) also mention that over-application of manure; that is to say, more than the plants require for optimum growth, is a practice that can contribute significantly to contamination of subsurface waters by nutrients.

## MATERIALS AND METHODS

This study was conducted on a Nicollet silt loam soil at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames, Iowa, in July and August of 1997. The

study consisted of three replications of four treatments (in addition, two replications of a control were included). See Table 5 for a summary of these treatments. The study utilized fourteen of sixteen lysimeters that were installed in 1982 (the two not used were deemed non-functional because they did not allow water to flow through the soil). Each lysimeter was 2.29 m long by 0.97 m wide by 1.37 m deep. A gravedigging machine was used to excavate and separate the soil profile into horizons (A, B, subsoil layer, and the calcareous loam till layer). An impermeable liner, 1.1 mm thick with an imbedded polyester netting, completely sealed except at the soil surface, was placed in the excavated volume. A 0.1-m diameter perforated plastic tile drain tube was installed on the bottom of the liner, and the original layers were replaced to their initial depths. A metal border was placed around the top of the liner at the surface of the soil to prevent surface runoff water from running onto or off each lysimeter. The lysimeter walls and bottom isolated each plot area from surrounding soil, and this prevented any lateral movement or downward loss of water and applied manure to beneath the tile line depth. Soil water that infiltrated to the bottom of the lysimeter was pumped from the tile drain through a 0.95-cm polyvinylchloride access tube that extended from the surface to the low point in the drainage system. Subsurface sampling was initiated 1 h after liquid manure application. Following that, samples were taken twice daily or as flow was available, which was dictated by manure application volume, rainfall events, and supplemental irrigation.

Table 5. Treatments

| Treatment | Management | Application Volume (cm) | Rate Designation |
|---|---|---|---|
| 1 | No Till | 2.8 | 1X |
| 2 | Till | 2.8 | 1X |
| 3 | Air Pressure - No Till | 2.8 | 1X |
| 4 | No Till | 8.3 | 3X |

Subsurface samples, for bacterial analysis, were collected in sterile plastic bags and analyzed within 24 h (if not analyzed immediately, samples were stored at 4°C, but not for more than 24 h). Analysis for FC and fecal *Streptococcus* (FS) was done according to Standard Methods for the Examination of Water and Wastewater, 18th edition (1992). In addition, analysis was done for *E.coli* (EC). This procedure utilized a media, m-coli blue, developed by Hach Company. Enumeration of FC, FS, and EC was done using membrane filtration techniques plating on m-FC agar for FC, m-*Enterococcus* agar for FS, and m-coli blue for EC. All bacterial counts were recorded in terms of colony forming units (CFU) per 100 mL.

Subsurface samples, for nutrient analysis, were collected in clean plastic bottles and stored at 4°C until analyzed. The samples were analyzed for $NO_3$-N, $NH_4$-N, total kjeldahl nitrogen (TKN), $PO_4$-P, total phosphorus (TOT-P) and chloride (Cl). $NO_3$-N was determined by the cadmium reduction method (American Public Health Association, 1971), $NH_4$-N by an Orion ammonia electrode and $PO_4$-P by the ascorbic acid reduction method (American Public Health Association, 1971). TOT-P analysis was done using the perchloric acid digestion method. TKN was determined by use of a Technicon Auto Analyzer; this method measures organic N and $NH_4$-N. Cl analysis followed the automated ferricyanide method outlined by Standard Methods for the examination of Water and Wastewater 18th edition (1992).

Treatments were all based on the depth (volume) of application. The tilled, no-till, and air-pressure treatments all received 2.8 cm of lagoon water, which was in two minutes forty seconds using a sprinkler cans. The 3X treatment received three times, or 8.3 cm of lagoon effluent, which was applied in roughly forty seconds and was applied directly from a 80-L garbage can. The control plots received 2.8 cm of well water, again by sprinkler can, to obtain background values for the bacterial and nutrient analyses. The air-pressure treatment was developed as a concept to pressurize the macropores with air, thus hopefully preventing immediate contamination to the subsurface via preferential flow. Tilled lysimeters were hand-spaded to a depth of roughly 15 cm the day of

application. Comparisons could then be made to no-till, which should have more macropore flow than tilled soils, which should have fewer macropores due to the shearing of those at surface. The air-pressure plots had connections installed to the subsurface access pipe. Following this, air compressors were used to apply air pressure at a head of 2 m. This pressure was continually monitored/maintained with a 2 m column of water, where bubbles were formed at a depth of 2 m. Pressurization continued as long as the soil surface had effluent visably ponded on the surface. The 3X treatment was used to simulate the effect of over-application due to effluent running to a low point in the field, following application. Thus the ponding creates the increased potential of macropore flow. The 3X treatment was applied to only no-till lysimeters. Statistical analysis was done using SAS, and found the only significant difference (0.05 level) was in application rate, that is to say that the only significant difference was found in comparing the 2.8 cm volume and the 8.3 cm volume.

## RESULTS AND DISCUSSION

Table 6 presents the inputs of water (this includes lagoon water, rain water, and irrigation water) for this 21-day study by date. Table 7 details the outflows or drainage volumes of this study, as well as, nutrient amounts, and bacteria concentrations. It can be seen that the soil matrix in the

Table 6. Water inputs

| Date | Water Source | Amount (cm) |
|---|---|---|
| 7/16/97 | Application (Lagoon) | 2.78 / 8.34 |
| 7/20/97 | Rain | 0.76 |
| 7/21/97 | Irrigation | 1.78 |
| 7/23/97 | Rain | 0.91 |
| 7/24/97 | Rain | 6.50 |

lysimeters is fairly effective in retaining additions to the surface. The antecedent gravimetric moisture content of the soil was on average 16.2%. Assuming volumetric field capacity is 35%, available storage in the top 90 cm would be 10.8 cm, and the volumes applied could have been retained by the

Table 7. Inflow and outflow amounts for water, nutrients, and bacteria (and percent loss) for lysimeter study

| Inflow | Water[1] | $NO_3$-N[2] | TKN[2] | Cl[2] | $PO_4$-P[2] | TOT-P[2] | FC[3] | FS[3] | EC[3] |
|---|---|---|---|---|---|---|---|---|---|
| 1x | 12.73 | 0.04 | 35.58 | 21.06 | 7.82 | 6.50 | 2.40E+08 | 1.07E+08 | 7.36E+07 |
| 3x | 18.30 | 0.13 | 106.74 | 63.23 | 23.49 | 19.53 | 7.20E+08 | 3.22E+08 | 2.21E+08 |
| **Outflow** | **Water** | **$NO_3$-N** | **TKN** | **Cl** | **$PO_4$-P** | **TOT-P** | **FC** | **FS** | **EC** |
| 3x | 9.02 | 9.896 | 2.817 | 9.721 | 0.595 | 0.647 | 7.02E+06 | 4.20E+06 | 4.37E+06 |
| Tilled | 3.90 | 3.617 | 0.017 | 0.987 | 0.032 | 0.016 | 1.22E+05 | 1.66E+06 | 1.29E+04 |
| No-till | 4.77 | 4.731 | 0.059 | 1.512 | 0.026 | 0.020 | 3.73E+05 | 4.12E+05 | 2.60E+04 |
| Air-press. | 4.45 | 3.424 | 0.025 | 1.163 | 0.025 | 0.007 | 1.71E+05 | 5.93E+05 | 2.69E+04 |
| Control | 4.52 | 4.492 | 0.051 | 1.255 | 0.028 | 0.014 | 2.00E+04 | 1.12E+05 | 6.16E+03 |
| **% Loss** | **Water** | **$NO_3$-N** | **TKN** | **Cl** | **$PO_4$-P** | **TOT-P** | **FC** | **FS** | **EC** |
| 3x | 49.3 | 7592 | 2.64 | 15.37 | 2.53 | 3.32 | 0.97 | 1.31 | 1.98 |
| Tilled | 30.6 | 8326 | 0.05 | 4.69 | 0.41 | 0.25 | 0.05 | 1.55 | 0.02 |
| No-till | 37.5 | 10889 | 0.17 | 7.18 | 0.34 | 0.30 | 0.16 | 0.38 | 0.04 |
| Air-press. | 35.0 | 7882 | 0.07 | 5.52 | 0.32 | 0.11 | 0.07 | 0.55 | 0.04 |
| Control | 35.5 | | | | | | | | |

[1] values for water are in cm

[2] values for nutrients are in kg/ha

[3] values for bacteria are in CFU/100 ml

soil, if applied slow enough, avoiding macropore flow. The soil matrix retained between 85-99 percent of the nutrients applied and between 98-99 percent of bacteria applied. An overview of the hydrology of the lysimeters can be obtained by observing Figure 12. This graph shows the input of water (cm) with time, as well as, the accumulated output or drainage (cm) from the lysimeters with time. It can be seen that the water retention characteristics of the lysimeters follow similar patterns after reaching saturation. Initially, flow patterns seem to vary, which can be explained by management practices. The tilled soil retained more water earlier in the study, as well as, the air treatment; this could be explained by the elimination of macropore flow. Following this, after hour 113 h after application, the lysimeters had similar drainage patterns. This could be explained by the fact that all lysimeters were near saturation. Bacterial and nutrient contamination of subsurface waters followed the same basic trends. The highest amount of contamination occurred with the highest application volume. Increased contamination of the subsurface drainage water closely followed the rainfall/irrigation water additions. When water was added to the surface of the lysimeter, whether it was by rain or irrigation, nutrient concentrations and bacterial densities in subsurface waters increased. This trend was particularly noticeable in the $NO_3$-N and bacterial data. Results in Figure 13 show the contamination of $NO_3$-N in tile flow. It can be seen that the highest concentration occur with the 3X treatment, with initial flows occurring in only the 3X treatment, the no-till, and the air-pressure treatments. The initial flows in these treatments can be explained by macropore flow. It can be seen that the outflow $NO_3$-N concentrations are higher than the input concentration. This observation could be explained by the lagoon effluent dissolving $NO_3$-N from the soil matrix. It should be mentioned that the initial movement of water to the drain tube in the air-pressure treatment occurred in only one of the three replications of this experiment in the short term. Otherwise this treatment was effective in eliminating applied manure from immediately reaching subsurface drainage. For the most part the $NO_3$-N levels stayed near the 10 mg/L MCL, with the exception of the 3X treatment, which at one point peaked at just over 18 mg/L. The remaining results for nutrients

(TKN, Cl, $PO_4$-P, and TOT-P) are outlined in Figures 14-17. Nutrient analysis was completed for ammonia concentrations in subsurface drainage, but due to a miscommunication with the laboratory, limited data is available. The ammonia data shown in Table B.4 of the appendix shows Initial high concentrations high concentrations in the subsurface drainage from the 3X treatment, but shortly falls down to much lower levels. These nutrient concentrations basically follow similar trends, but with less variability than $NO_3$-N, with initially high concentrations in the 3X treatment in the subsurface water with smaller concentrations initially observed in the air-pressure and no-till treatments. This is followed by low, and decreasing concentrations of these nutrients. Bacterial concentrations follow similar trends to $NO_3$-N concentrations in that, irrigation water and rain water carry contaminants to the subsurface waters. Figures 18-20 show bacterial concentrations throughout the study. It should be mentioned that the high value for FS at the eighth sampling period is greatly influenced by one lysimeter of the three in the treatment. Two of the lysimeters had very low numbers followed by one lysimeter, which had very consistent numbers of bacteria in all three dilutions plated to determine bacterial density. It can be seen from the nutrient and bacterial graphs that the largest threat to subsurface waters exists shortly after application, thereby suggesting that manure management strategies are essential when considering the preservation of groundwater quality.

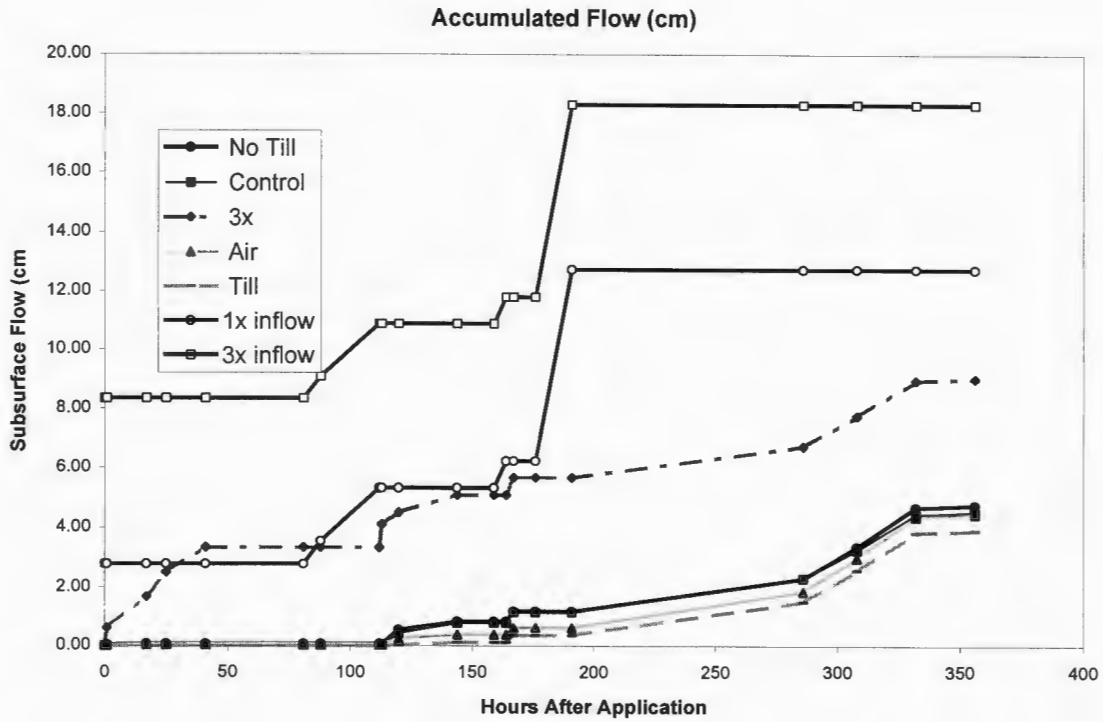


Figure 12. Accumulated inflow and outflow (cm)

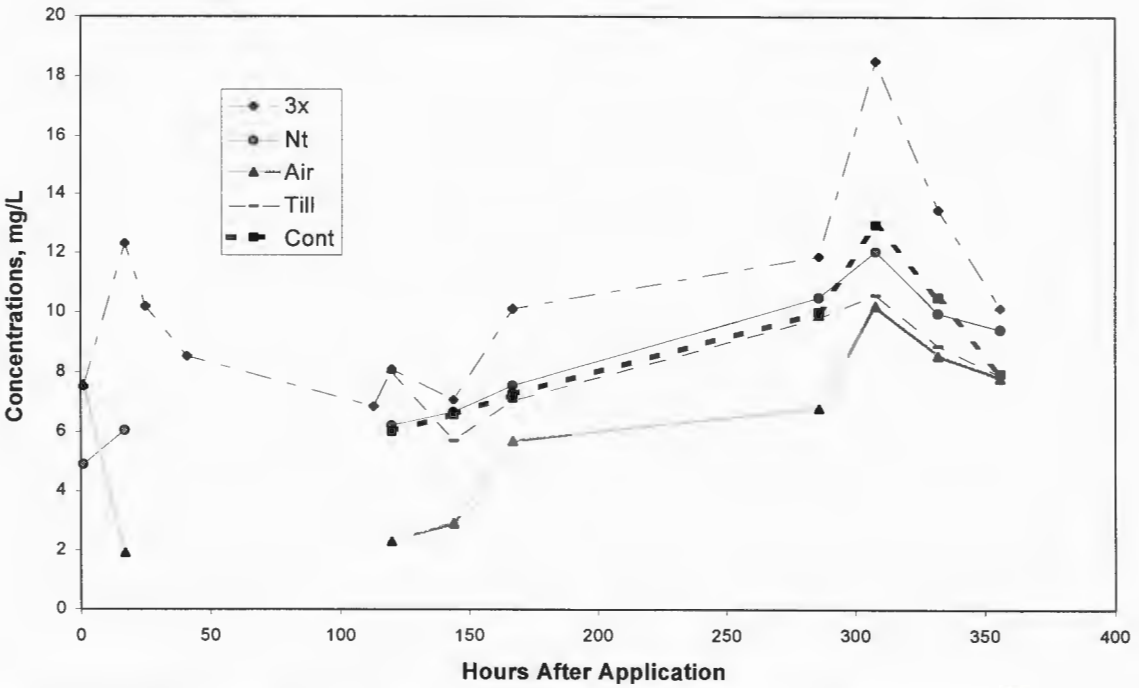


Figure 13. $NO_3$-N concentrations (mg/L) in tile flow (inflow concentration was .16 mg/L)

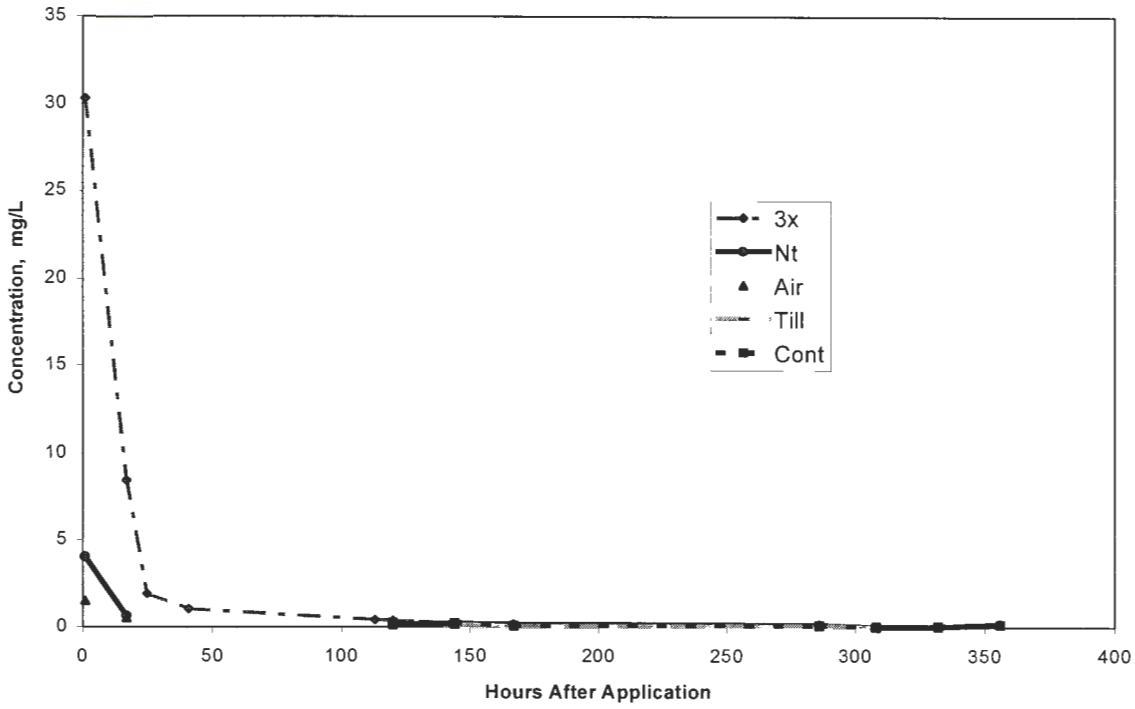


Figure 14. TKN concentrations (mg/L) in tile flow (inflow concentration was 128.3 mg/L)

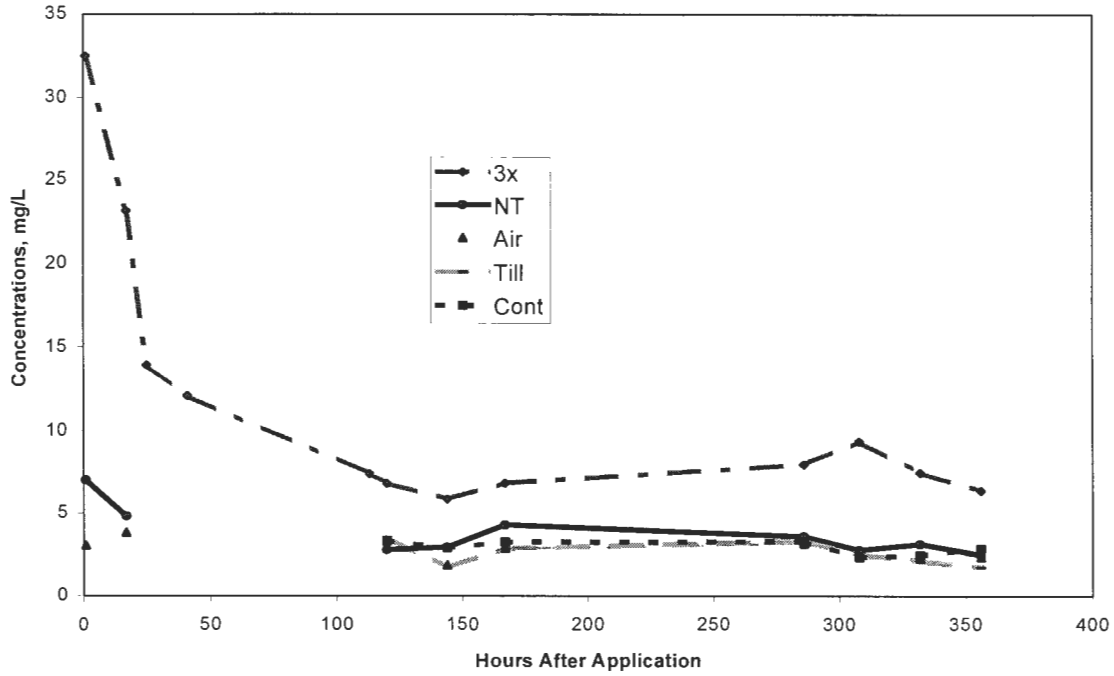


Figure 15. Cl concentrations (mg/L) in tile flow (inflow concentration was 76.0 mg/L)

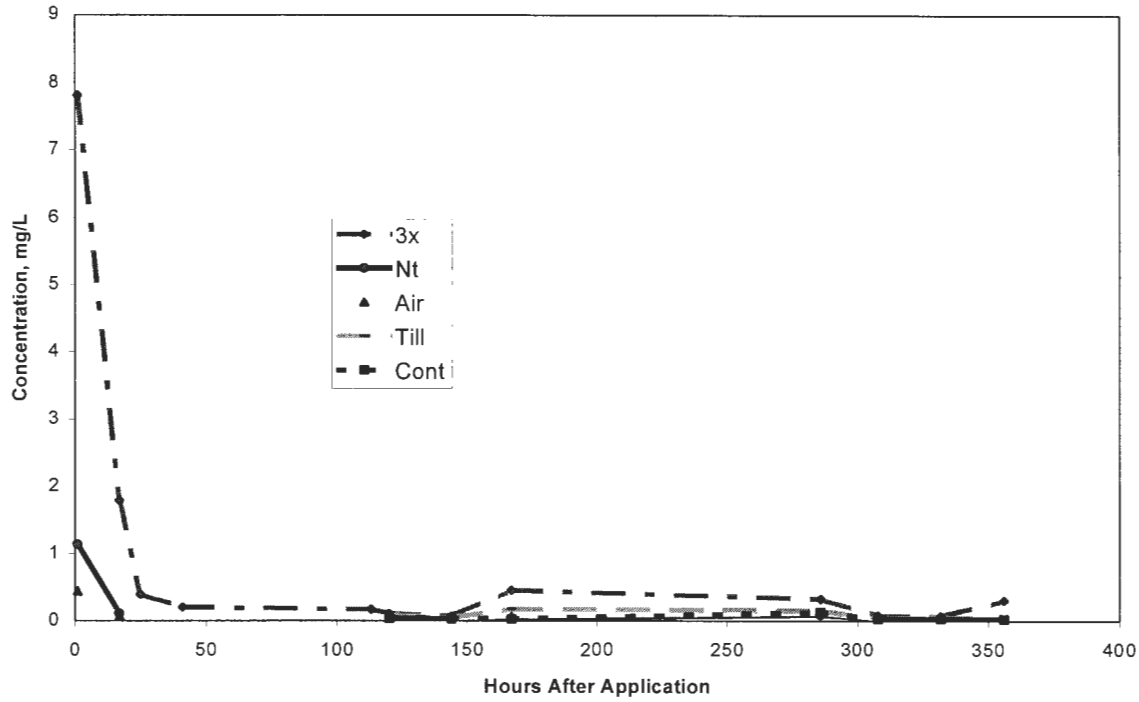


Figure 16. $PO_4$-P concentrations in tile flow (inflow concentration was 28.4 mg/L)

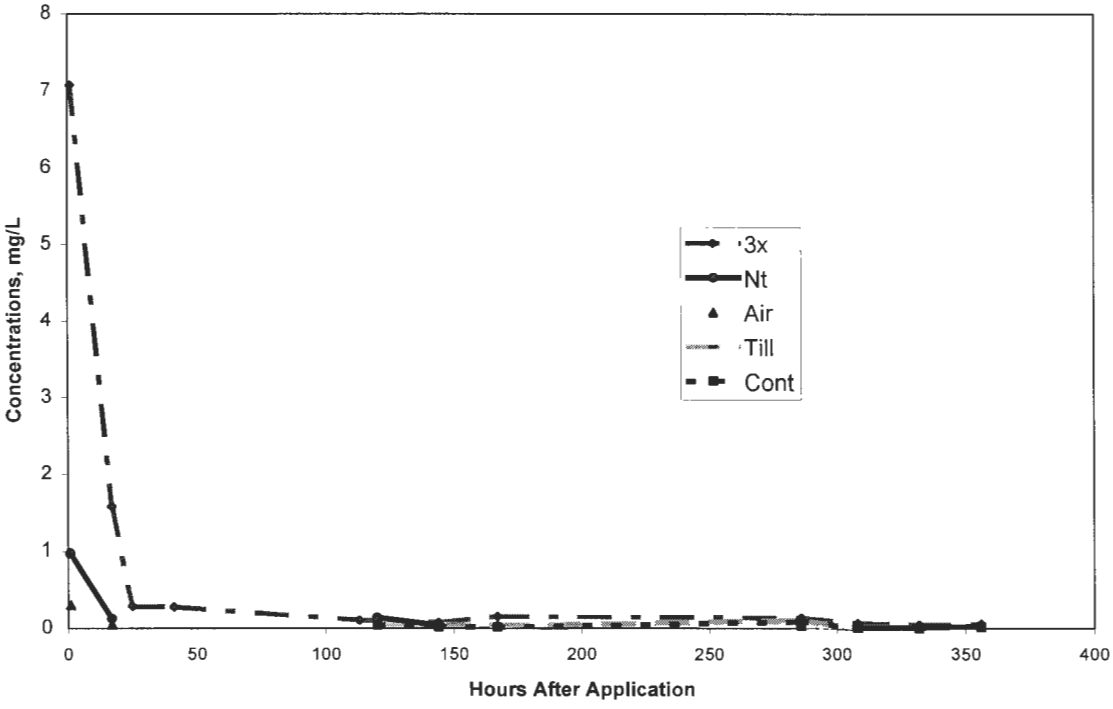


Figure 17. TOT-P concentrations (mg/L) in tile flow (inflow concentration was 23.5mg/L)

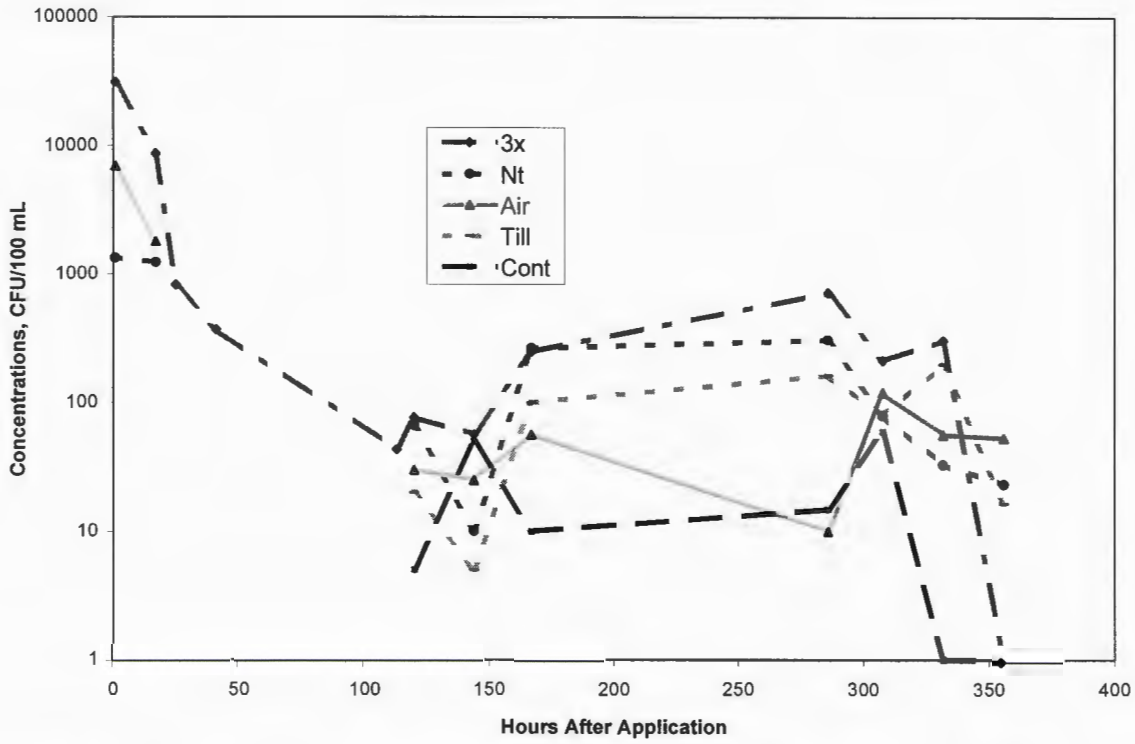


Figure 18. FC counts (CFU/100 mL) in tile flow (inflow density was 391,667 CFU/100mL)

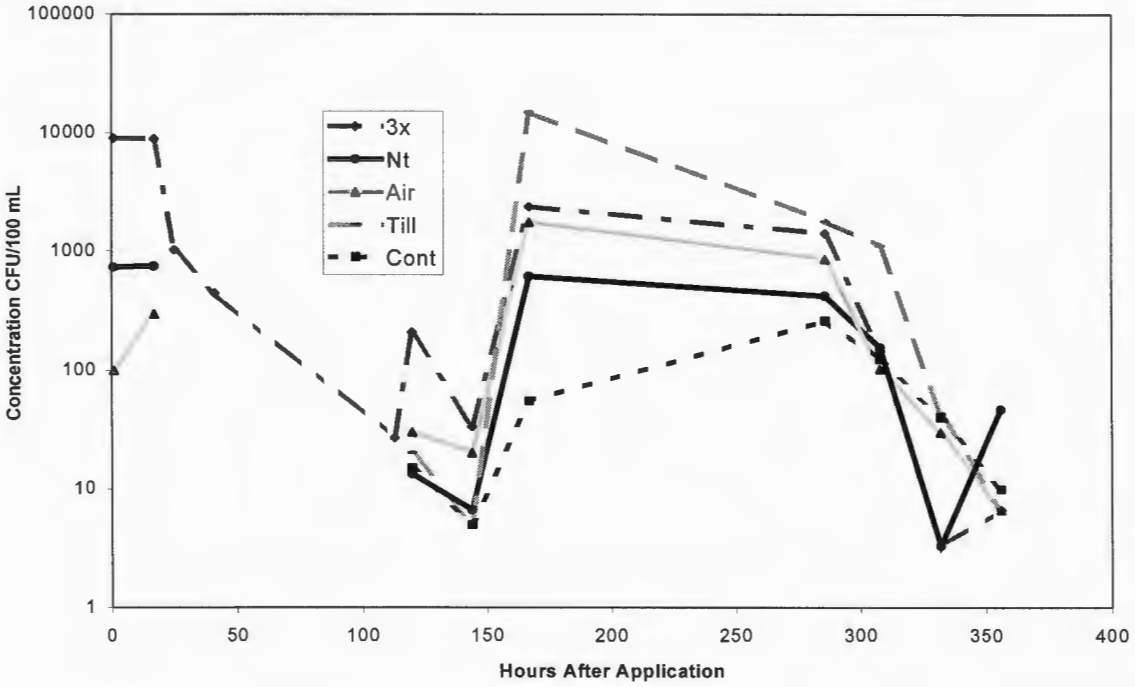


Figure 19. FS counts (CFU/100 mL) in tile flow (inflow density was 175,000 CFU/100 mL)

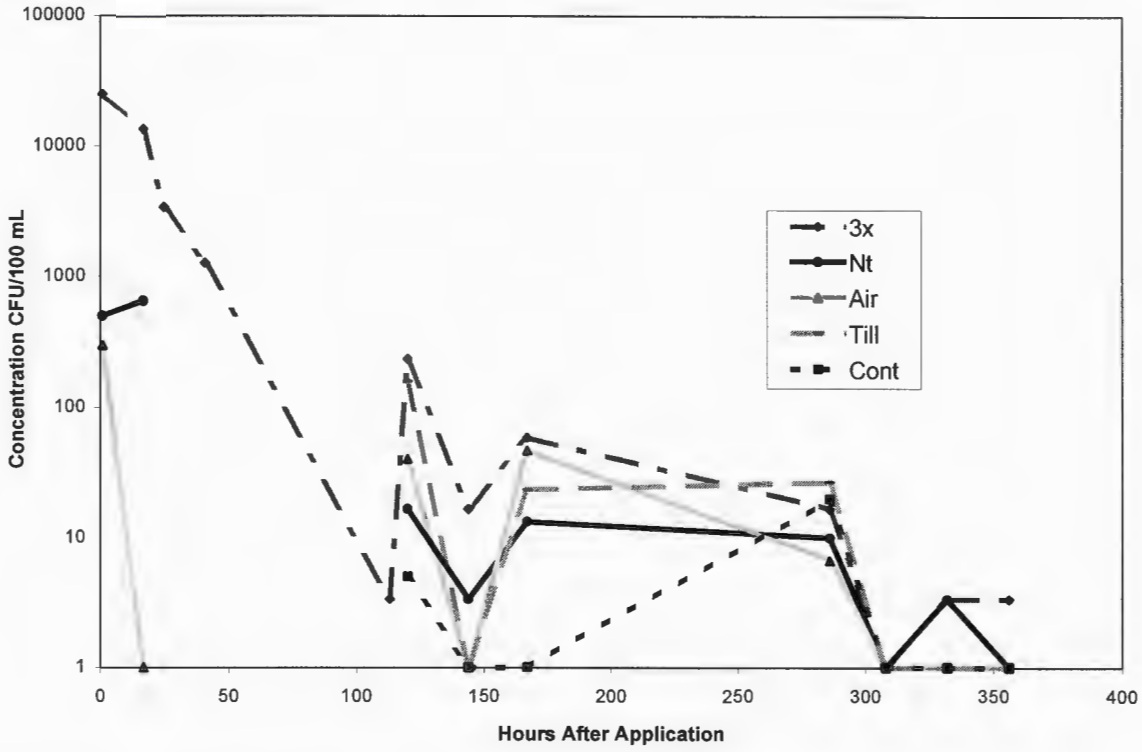


Figure 20. EC counts (CFU/100 mL) in tile flow (inflow density was 120,000 CFU/100 mL)

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## GENERAL CONCLUSIONS

The objective of these studies was to examine various manure management strategies relative to the effects of rate, method, and timing of swine manure application on surface and groundwater quality. These studies considered the application of lagoon and pit manure to lysimeters and field-scale plot studies, respectively.

Many questions surround the application of manure, such as which method will minimize nutrient losses in order to promote crop growth, or more appropriately for these studies, which method will minimize losses of nutrients and bacteria to water resources. Observations of total losses can give one insight to which treatment may have a lesser impact on water resources. It can be seen that the time immediately following manure application may pose the largest threat to the quality of water receiving either surface or subsurface drainage manure-treated plots. Also it can be seen that during periods of high flow subsurface drainage may have high bacterial densities, suggesting that bacteria will leach to subsurface waters. Also periods of high flow or high precipitation result in high surface water contamination. Therefore, with these observations, one can deduce that application prior to a heavy rainfall event is measure that has the potential to produce high losses and a high degree of environmental degradation and should be avoided if possible..

For the field study, in 1996, it was observed that manure application regardless of application rate, timing, or method proved to have minimal contamination to subsurface waters. This study also showed that bacterial densities (FC and FS) typically follow each other by date, but not necessarily by treatment. For the same treatment, bacterial densities were generally lower in 1997 than in 1996. The data for 1997 shows higher bacterial densities in subsurface drainage in the later part of the year, which may be explained by occurance of runoff events. With a runoff event, surface ponding exists, and with that the potential for macropore flow, which could be an explanation for the elevated densities in subsurface waters directly following a runoff event. When observing bacterial densities in

surface runoff, no clear trends were seen. The two events discussed show relatively high contamination across the treatments, even for the control plots which received no manure.

In the lysimeter study bacterial and nutrient concentrations were observed in subsurface flow. The results of this study follows similar trends to the field study, in that during periods of high flow higher subsurface contamination occurred. Management strategies to prevent initial contamination of the subsurface drainage water were incorporated. These measures, the air-pressure and tilled treatments, appear to have some effects to minimize initial contamination of the subsurface drainage, when considering total losses. It was also seen that the no-till and 8.3 cm treatment had initial contamination of the subsurface which was thought to be due to macropore flow. For all nutrients, with the exception of $NO_3$-N, there was a high intitial concentration in the subsurface drainage waters which was followed by relatively low levels of contamination. The $NO_3$-N concentrations were a bit more variable and affected more by the addition of water (rainfall or irrigation water) to the surface following application. The additional water dissolving $NO_3$-N from the soil matrix could explain this. Bacterial data proved variable, but some basic trends can be identified. Bacterial densities in subsurface waters tend to follow water additions, in that, drainage after periods of rainfall or irrigation tend to have higher contamination than for drier periods. This trend would indicate that bacteria tend to behave as $NO_3$-N, in that, bacteria can leach to subsurface water. The management strategies, air-pressure and tillage were effective in managing initial subsurface contamination, when looking at total loss. It can be seen that regardless the management strategies, the soil matrix is fairly effective in protecting subsurface water quality.

From these two studies, one can see that the filtering effect of soil matrix is quite effective in protecting our ground water resources. Utilizing various management strategies is helpful in minimizing initial subsurface contamination, which can pose the largest threat. One management strategy that is very useful in protecting water resources that is rarely mentioned is the notion of application before a rain. It can be seen that precipitation is major carrier of contamination. Knowing

this, application of manure before a rainfall event, if avoidable may be the best management strategy that we know.

Future possible work should continue to look at the potential contamination of surface and subsurface drainage. Other possible experiments could determine survival of the pathogens at various soil depths. With this knowledge one can obtain information for the most effective layer of filtering based on soil type. Other studies could include the air-pressurization of tile drainage using tracers to further determine the effectiveness of this treatment. Also research could be done to try to tie the behavior of bacterial leaching to a particular nutrients behavior, for modeling purposes.

# APPENDIX A: FIELD PLOT MANURE IMPACT STUDY DATA

**Table A.1**. Bacterial Data for 1996

| | | | FC | | | | FS |
|---|---|---|---|---|---|---|---|
| Date | rep | trmt. | cfu/100ml | Date | rep | trmt. | cfu/100ml |
| 13-Jun | 1 | 1 | 0 | 13-Jun | 1 | 1 | 18 |
| 13-Jun | 1 | 6 | 0 | 13-Jun | 1 | 6 | 10 |
| 13-Jun | 1 | 7 | 0 | 13-Jun | 1 | 7 | 8 |
| 13-Jun | 1 | 8 | 0 | 13-Jun | 1 | 8 | 14 |
| 13-Jun | 1 | 9 | 12 | 13-Jun | 1 | 9 | 24 |
| 13-Jun | 2 | 1 | 2 | 13-Jun | 2 | 1 | 14 |
| 13-Jun | 2 | 6 | 0 | 13-Jun | 2 | 6 | 4 |
| 13-Jun | 2 | 7 | 12 | 13-Jun | 2 | 7 | 18 |
| 13-Jun | 2 | 8 | 26 | 13-Jun | 2 | 8 | 12 |
| 13-Jun | 2 | 9 | 8 | 13-Jun | 2 | 9 | 8 |
| 13-Jun | 3 | 1 | 0 | 13-Jun | 3 | 1 | 4 |
| 13-Jun | 3 | 6 | 24 | 13-Jun | 3 | 6 | 8 |
| 13-Jun | 3 | 7 | 0 | 13-Jun | 3 | 7 | 6 |
| 13-Jun | 3 | 8 | 0 | 13-Jun | 3 | 8 | 12 |
| 13-Jun | 3 | 9 | 0 | 13-Jun | 3 | 9 | 8 |
| 19-Jun | 1 | 1 | 8 | 19-Jun | 1 | 1 | 14 |
| 19-Jun | 1 | 6 | 0 | 19-Jun | 1 | 6 | 28 |
| 19-Jun | 1 | 7 | 60 | 19-Jun | 1 | 7 | 10 |
| 19-Jun | 1 | 8 | 18 | 19-Jun | 1 | 8 | 600 |
| 19-Jun | 1 | 9 | 0 | 19-Jun | 1 | 9 | 22 |
| 19-Jun | 2 | 1 | 7 | 19-Jun | 2 | 1 | 7 |
| 19-Jun | 2 | 6 | 230 | 19-Jun | 2 | 6 | 185 |
| 19-Jun | 2 | 7 | 0 | 19-Jun | 2 | 7 | 0 |
| 19-Jun | 2 | 8 | 14 | 19-Jun | 2 | 8 | 36 |
| 19-Jun | 2 | 9 | 0 | 19-Jun | 2 | 9 | 16 |
| 19-Jun | 3 | 1 | 0 | 19-Jun | 3 | 1 | 32 |
| 19-Jun | 3 | 6 | 0 | 19-Jun | 3 | 6 | 4 |
| 19-Jun | 3 | 7 | 2 | 19-Jun | 3 | 7 | 0 |
| 19-Jun | 3 | 8 | 40 | 19-Jun | 3 | 8 | 8 |
| 19-Jun | 3 | 9 | 2 | 19-Jun | 3 | 9 | 12 |
| 26-Jun | 1 | 1 | 0 | 26-Jun | 1 | 1 | 12 |
| 26-Jun | 1 | 6 | n/a | 26-Jun | 1 | 6 | 0 |
| 26-Jun | 1 | 7 | 2 | 26-Jun | 1 | 7 | 8 |
| 26-Jun | 1 | 8 | 8 | 26-Jun | 1 | 8 | 8 |
| 26-Jun | 1 | 9 | 0 | 26-Jun | 1 | 9 | 36 |
| 26-Jun | 2 | 1 | 0 | 26-Jun | 2 | 1 | 4 |
| 26-Jun | 2 | 6 | 70 | 26-Jun | 2 | 6 | 52 |
| 26-Jun | 2 | 7 | 0 | 26-Jun | 2 | 7 | 2 |
| 26-Jun | 2 | 8 | 0 | 26-Jun | 2 | 8 | 12 |
| 26-Jun | 2 | 9 | 0 | 26-Jun | 2 | 9 | 4 |
| 26-Jun | 3 | 1 | 0 | 26-Jun | 3 | 1 | 2 |
| 26-Jun | 3 | 6 | 0 | 26-Jun | 3 | 6 | 16 |
| 26-Jun | 3 | 7 | 400 | 26-Jun | 3 | 7 | 500 |
| 26-Jun | 3 | 8 | 0 | 26-Jun | 3 | 8 | 8 |
| 26-Jun | 3 | 9 | 0 | 26-Jun | 3 | 9 | 10 |

**Table A.1**. Bacterial Data for 1996, continued

| Date | rep | trmt. | FC cfu/100ml | Date | rep | trmt. | FS cfu/100ml |
|---|---|---|---|---|---|---|---|
| 1-Jul | 1 | 6 | 0 | 1-Jul | 1 | 6 | 0 |
| 1-Jul | 1 | 7 | 0 | 1-Jul | 1 | 7 | 0 |
| 1-Jul | 1 | 8 | 0 | 1-Jul | 1 | 8 | 2 |
| 1-Jul | 1 | 9 | 0 | 1-Jul | 1 | 9 | 32 |
| 1-Jul | 2 | 1 | 22 | 1-Jul | 2 | 1 | 0 |
| 1-Jul | 2 | 6 | 0 | 1-Jul | 2 | 6 | 12 |
| 1-Jul | 2 | 7 | 0 | 1-Jul | 2 | 7 | 4 |
| 1-Jul | 2 | 8 | 0 | 1-Jul | 2 | 8 | 2 |
| 1-Jul | 2 | 9 | 0 | 1-Jul | 2 | 9 | 2 |
| 1-Jul | 3 | 1 | 0 | 1-Jul | 3 | 1 | 0 |
| 1-Jul | 3 | 6 | 0 | 1-Jul | 3 | 6 | 2 |
| 1-Jul | 3 | 7 | 300 | 1-Jul | 3 | 7 | 80 |
| 1-Jul | 3 | 8 | 0 | 1-Jul | 3 | 8 | 10 |
| 1-Jul | 3 | 9 | 0 | 1-Jul | 3 | 9 | 22 |
| 10-Jul | 1 | 1 | 0 | 10-Jul | 1 | 1 | 0 |
| 10-Jul | 1 | 6 | 0 | 10-Jul | 1 | 6 | 0 |
| 10-Jul | 1 | 7 | 0 | 10-Jul | 1 | 7 | 0 |
| 10-Jul | 1 | 8 | 0 | 10-Jul | 1 | 8 | 0 |
| 10-Jul | 1 | 9 | 0 | 10-Jul | 1 | 9 | 2 |
| 10-Jul | 2 | 1 | 0 | 10-Jul | 2 | 1 | 0 |
| 10-Jul | 2 | 6 | 0 | 10-Jul | 2 | 6 | 0 |
| 10-Jul | 2 | 7 | 0 | 10-Jul | 2 | 7 | 22 |
| 10-Jul | 2 | 8 | 0 | 10-Jul | 2 | 8 | 2 |
| 10-Jul | 2 | 9 | 0 | 10-Jul | 2 | 9 | 0 |
| 10-Jul | 3 | 1 | 0 | 10-Jul | 3 | 1 | 2 |
| 10-Jul | 3 | 6 | 0 | 10-Jul | 3 | 6 | 0 |
| 10-Jul | 3 | 7 | 14 | 10-Jul | 3 | 7 | 0 |
| 10-Jul | 3 | 8 | 0 | 10-Jul | 3 | 8 | 0 |
| 10-Jul | 3 | 9 | 0 | 10-Jul | 3 | 9 | 0 |
| 15-Jul | 1 | 1 | 0 | 15-Jul | 1 | 1 | 0 |
| 15-Jul | 1 | 6 | 0 | 15-Jul | 1 | 6 | 0 |
| 15-Jul | 1 | 7 | 0 | 15-Jul | 1 | 7 | 0 |
| 15-Jul | 1 | 8 | 0 | 15-Jul | 1 | 8 | 2 |
| 15-Jul | 1 | 9 | 0 | 15-Jul | 1 | 9 | 4 |
| 15-Jul | 2 | 1 | 0 | 15-Jul | 2 | 1 | 0 |
| 15-Jul | 2 | 6 | 0 | 15-Jul | 2 | 6 | 0 |
| 15-Jul | 2 | 7 | 0 | 15-Jul | 2 | 7 | 8 |
| 15-Jul | 2 | 8 | 0 | 15-Jul | 2 | 8 | 6 |
| 15-Jul | 2 | 9 | 0 | 15-Jul | 2 | 9 | 0 |
| 15-Jul | 3 | 1 | 0 | 15-Jul | 3 | 1 | 0 |
| 15-Jul | 3 | 6 | 0 | 15-Jul | 3 | 6 | 0 |
| 15-Jul | 3 | 7 | 2 | 15-Jul | 3 | 7 | 0 |
| 15-Jul | 3 | 8 | 0 | 15-Jul | 3 | 8 | 0 |
| 15-Jul | 3 | 9 | 0 | 15-Jul | 3 | 9 | 4 |
| 22-Jul | 1 | 1 | 0 | 22-Jul | 1 | 1 | 4 |

**Table A.1**. Bacterial Data for 1996, continued

| Date | rep | trmt. | FC cfu/100ml | Date | rep | trmt. | FS cfu/100ml |
|---|---|---|---|---|---|---|---|
| 22-Jul | 1 | 9 | 0 | 22-Jul | 1 | 9 | 5 |
| 22-Jul | 2 | 1 | 0 | 22-Jul | 2 | 1 | 1 |
| 22-Jul | 2 | 6 | 0 | 22-Jul | 2 | 6 | 2 |
| 22-Jul | 2 | 7 | 0 | 22-Jul | 2 | 7 | 3 |
| 22-Jul | 2 | 8 | 0 | 22-Jul | 2 | 8 | 0 |
| 22-Jul | 2 | 9 | 0 | 22-Jul | 2 | 9 | 1 |
| 22-Jul | 3 | 1 | 0 | 22-Jul | 3 | 1 | 9 |
| 22-Jul | 3 | 6 | 0 | 22-Jul | 3 | 6 | 5 |
| 22-Jul | 3 | 7 | 0 | 22-Jul | 3 | 7 | 4 |
| 22-Jul | 3 | 8 | 0 | 22-Jul | 3 | 8 | 2 |
| 22-Jul | 3 | 9 | 0 | 22-Jul | 3 | 9 | 8 |
| 29-Jul | 1 | 1 | 10 | 29-Jul | 1 | 1 | 0 |
| 29-Jul | 1 | 6 | 0 | 29-Jul | 1 | 6 | 0 |
| 29-Jul | 1 | 7 | 0 | 29-Jul | 1 | 7 | 0 |
| 29-Jul | 1 | 8 | 52 | 29-Jul | 1 | 8 | 75 |
| 29-Jul | 1 | 9 | 0 | 29-Jul | 1 | 9 | 0 |
| 29-Jul | 2 | 1 | 0 | 29-Jul | 2 | 1 | 0 |
| 29-Jul | 2 | 6 | 0 | 29-Jul | 2 | 6 | 4 |
| 29-Jul | 2 | 7 | 0 | 29-Jul | 2 | 7 | 0 |
| 29-Jul | 2 | 8 | 0 | 29-Jul | 2 | 8 | 6 |
| 29-Jul | 2 | 9 | 0 | 29-Jul | 2 | 9 | 4 |
| 29-Jul | 3 | 1 | 0 | 29-Jul | 3 | 1 | 0 |
| 29-Jul | 3 | 6 | 0 | 29-Jul | 3 | 6 | 4 |
| 29-Jul | 3 | 7 | 0 | 29-Jul | 3 | 7 | 2 |
| 29-Jul | 3 | 8 | 0 | 29-Jul | 3 | 8 | 0 |
| 29-Jul | 3 | 9 | 130 | 29-Jul | 3 | 9 | 0 |
| 6-Aug | 1 | 1 | 17 | 6-Aug | 1 | 1 | 16 |
| 6-Aug | 1 | 6 | 90 | 6-Aug | 1 | 6 | 48 |
| 6-Aug | 1 | 7 | 0 | 6-Aug | 1 | 7 | 29 |
| 6-Aug | 1 | 8 | 0 | 6-Aug | 1 | 8 | 0 |
| 6-Aug | 1 | 9 | 0 | 6-Aug | 1 | 9 | 0 |
| 6-Aug | 2 | 1 | 0 | 6-Aug | 2 | 1 | 19 |
| 6-Aug | 2 | 6 | 0 | 6-Aug | 2 | 6 | 34 |
| 6-Aug | 2 | 7 | 0 | 6-Aug | 2 | 7 | 37 |
| 6-Aug | 2 | 8 | 0 | 6-Aug | 2 | 8 | 5 |
| 6-Aug | 2 | 9 | 0 | 6-Aug | 2 | 9 | 54 |
| 6-Aug | 3 | 1 | 0 | 6-Aug | 3 | 1 | 3 |
| 6-Aug | 3 | 6 | 0 | 6-Aug | 3 | 6 | 27 |
| 6-Aug | 3 | 7 | 0 | 6-Aug | 3 | 7 | 7 |
| 6-Aug | 3 | 8 | 0 | 6-Aug | 3 | 8 | 2 |
| 6-Aug | 3 | 9 | 0 | 6-Aug | 3 | 9 | 5 |
| 13-Aug | 1 | 1 | 0 | 15-Aug | 1 | 1 | 15 |
| 13-Aug | 1 | 6 | 0 | 15-Aug | 1 | 6 | 9 |
| 13-Aug | 1 | 7 | 2 | 15-Aug | 1 | 7 | 14 |
| 13-Aug | 1 | 8 | 6 | 15-Aug | 1 | 8 | 0 |

**Table A.1**. Bacterial Data for 1996, continued

| | | | FC | | | | FS |
|---|---|---|---|---|---|---|---|
| Date | rep | trmt. | cfu/100ml | Date | rep | trmt. | cfu/100ml |
| 13-Aug | 2 | 7 | 0 | 15-Aug | 2 | 7 | 7 |
| 13-Aug | 2 | 8 | 0 | 15-Aug | 2 | 8 | 4 |
| 13-Aug | 2 | 9 | 0 | 15-Aug | 3 | 6 | 3 |
| 13-Aug | 3 | 1 | 0 | 15-Aug | 3 | 7 | 16 |
| 13-Aug | 3 | 6 | 0 | 15-Aug | 3 | 8 | 0 |
| 13-Aug | 3 | 7 | 0 | 15-Aug | 3 | 9 | 9 |
| 13-Aug | 3 | 8 | 0 | 12-Oct | 1 | 1 | 16 |
| 13-Aug | 3 | 9 | 10 | 12-Oct | 1 | 6 | 77 |
| 3-Oct | 1 | 1 | 0 | 12-Oct | 1 | 7 | 21 |
| 3-Oct | 1 | 6 | 34 | 12-Oct | 1 | 8 | 60 |
| 3-Oct | 1 | 7 | 11 | 12-Oct | 1 | 9 | 11 |
| 3-Oct | 1 | 8 | 21 | 12-Oct | 2 | 1 | 0 |
| 3-Oct | 1 | 9 | 21 | 12-Oct | 2 | 6 | 8 |
| 3-Oct | 2 | 1 | 0 | 12-Oct | 2 | 7 | 16 |
| 3-Oct | 2 | 6 | 0 | 12-Oct | 2 | 8 | 62 |
| 3-Oct | 2 | 7 | 0 | 12-Oct | 2 | 9 | 15 |
| 3-Oct | 2 | 8 | 0 | 12-Oct | 3 | 1 | 0 |
| 3-Oct | 2 | 6 | 30 | 12-Oct | 3 | 6 | 9 |
| 3-Oct | 2 | 7 | 20 | 12-Oct | 3 | 7 | 27 |
| 3-Oct | 2 | 8 | 46 | 12-Oct | 3 | 8 | 0 |
| 3-Oct | 2 | 9 | 12 | 12-Oct | 3 | 9 | 8 |
| 3-Oct | 3 | 6 | 5 | 15-Aug | 2 | 9 | 0 |
| 3-Oct | 3 | 9 | 17 | 15-Aug | 3 | 1 | 0 |

**Table A.2.** Tileflow and rainfall data, 1996

| Week | Total Tileflow, cm | Total Rainfall, cm |
|---|---|---|
| Mar 24-30 | 0.00 | 0.99 |
| Mar 31-Apr 6 | 0.00 | 0.31 |
| Apr 7-13 | 0.00 | 0.00 |
| Apr 14-20 | 0.00 | 0.15 |
| Apr 21-27 | 0.00 | 0.24 |
| Apr 28-May 4 | 0.00 | 1.72 |
| May 5-11 | 0.05 | 2.11 |
| May 12-18 | 0.22 | 0.95 |
| May 19-25 | 0.32 | 1.88 |
| May 26-Jun1 | 0.44 | 1.87 |
| Jun 2-8 | 0.37 | 0.64 |
| Jun 9-15 | 0.33 | 0.28 |
| Jun 16-22 | 0.28 | 3.79 |
| Jun 23-29 | 0.38 | 0.47 |
| Jun 30-Jul6 | 0.26 | 0.00 |
| Jul 7-13 | 0.18 | 0.13 |
| Jul 14-20 | 0.22 | 2.88 |
| Jul 21-27 | 0.30 | 0.06 |
| Jul 28-Aug3 | 0.12 | 1.04 |
| Aug 4-10 | 0.08 | 1.58 |
| Aug 11-17 | 0.10 | 0.30 |
| Aug 18-24 | 0.13 | 1.69 |
| Aug 25-31 | 0.14 | 1.33 |
| Sep 1-7 | 0.06 | 0.00 |
| Sep 8-14 | 0.05 | 0.56 |
| Sep 15-21 | 0.02 | 0.41 |
| Sep 22-28 | 0.05 | 2.21 |
| Sep 29-Oct5 | 0.16 | 0.00 |
| Oct 6-12 | 0.10 | 0.02 |
| Oct 13-19 | 0.03 | 0.00 |
| Oct 20-26 | 0.13 | 1.89 |
| Oct 27-Nov2 | 0.00 | 0.89 |
| Nov 3-9 | 0.07 | 1.16 |
| Nov 10-16 | 0.06 | 0.68 |
| Nov 17-23 | 0.21 | 1.49 |

**Table A.3**. Bacterial data for subsurface flow 1997

| Date | REP | TRT | FC cfu/100 mL | FS cfu/100 mL | EC cfu/100 mL |
|---|---|---|---|---|---|
| 23-Apr | 1 | 1 | 0 | 0 | 0 |
| 1-May | 1 | 1 | 1 | 0 | 0 |
| 7-May | 1 | 1 | 2 | 0 | 0 |
| 14-May | 1 | 1 | 0 | 0 | 1 |
| 20-May | 1 | 1 | 1 | 0 | 0 |
| 27-May | 1 | 1 | 0 | 0 | 0 |
| 3-Jun | 1 | 1 | 0 | 0 | 0 |
| 10-Jun | 1 | 1 | 0 | 0 | 0 |
| 18-Jun | 1 | 1 | 0 | 0 | 0 |
| 25-Jun | 1 | 1 | 240 | 71 | 0 |
| 30-Jun | 1 | 1 | 5 | 13 | 0 |
| 6-Jul | 1 | 1 | 0 | 2 | 0 |
| 28-Jul | 1 | 1 | 740 | 6200 | 6 |
| 23-Apr | 1 | 2 | 1 | 0 | 0 |
| 1-May | 1 | 2 | 2 | 0 | 0 |
| 7-May | 1 | 2 | 1 | 0 | 0 |
| 14-May | 1 | 2 | 0 | 0 | 1 |
| 20-May | 1 | 2 | 0 | 0 | 0 |
| 27-May | 1 | 2 | 0 | 0 | 1 |
| 3-Jun | 1 | 2 | 0 | 0 | 0 |
| 10-Jun | 1 | 2 | 27 | 0 | 0 |
| 18-Jun | 1 | 2 | 0 | 0 | 0 |
| 25-Jun | 1 | 2 | 0 | 0 | 0 |
| 30-Jun | 1 | 2 | 0 | 5 | 0 |
| 6-Jul | 1 | 2 | | | |
| 28-Jul | 1 | 2 | | | |
| 23-Apr | 1 | 3 | 16 | 1 | 0 |
| 1-May | 1 | 3 | 2 | 0 | 0 |
| 7-May | 1 | 3 | 0 | 0 | 0 |
| 14-May | 1 | 3 | 0 | 0 | 0 |
| 20-May | 1 | 3 | 0 | 0 | 0 |
| 27-May | 1 | 3 | 2 | 1 | 5 |
| 3-Jun | 1 | 3 | 0 | 0 | 0 |
| 10-Jun | 1 | 3 | 0 | 0 | 0 |
| 18-Jun | 1 | 3 | 0 | 0 | 0 |
| 25-Jun | 1 | 3 | 0 | 35 | 0 |
| 30-Jun | 1 | 3 | 0 | 38 | 0 |
| 6-Jul | 1 | 3 | 0 | | 0 |
| 28-Jul | 1 | 3 | 900 | 5800 | 2 |
| 23-Apr | 1 | 4 | 6 | 0 | 4 |
| 1-May | 1 | 4 | 5 | 0 | 0 |
| 7-May | 1 | 4 | 3 | 0 | 0 |
| 14-May | 1 | 4 | 0 | 0 | 0 |
| 20-May | 1 | 4 | 0 | 0 | 0 |
| 27-May | 1 | 4 | 1 | 6 | 2 |

**Table A.3**. Bacterial data for subsurface flow 1997, continued

| Date | REP | TRT | FC cfu/100 mL | FS cfu/100 mL | EC cfu/100 mL |
|---|---|---|---|---|---|
| 25-Jun | 1 | 4 | 6 | 51 | 0 |
| 30-Jun | 1 | 4 | 0 | 16 | 0 |
| 6-Jul | 1 | 4 | 2 | | 0 |
| 28-Jul | 1 | 4 | | | |
| 23-Apr | 1 | 5 | 0 | 2 | 0 |
| 1-May | 1 | 5 | 0 | 0 | 0 |
| 7-May | 1 | 5 | 0 | 0 | 0 |
| 14-May | 1 | 5 | 0 | 0 | 1 |
| 20-May | 1 | 5 | 0 | 0 | 0 |
| 27-May | 1 | 5 | 0 | 0 | 1 |
| 3-Jun | 1 | 5 | 0 | 0 | 0 |
| 10-Jun | 1 | 5 | | | |
| 18-Jun | 1 | 5 | 0 | 0 | 0 |
| 25-Jun | 1 | 5 | 0 | 0 | 1 |
| 30-Jun | 1 | 5 | 0 | 0 | 0 |
| 6-Jul | 1 | 5 | | | |
| 28-Jul | 1 | 5 | | | |
| 23-Apr | 1 | 6 | 4 | 0 | 6 |
| 1-May | 1 | 6 | 1 | 0 | 0 |
| 7-May | 1 | 6 | 1 | 0 | 0 |
| 14-May | 1 | 6 | 0 | 0 | 0 |
| 20-May | 1 | 6 | 0 | 0 | 0 |
| 27-May | 1 | 6 | 6 | 0 | 0 |
| 3-Jun | 1 | 6 | 0 | 0 | 0 |
| 10-Jun | 1 | 6 | 0 | 0 | 0 |
| 18-Jun | 1 | 6 | 0 | 0 | 0 |
| 25-Jun | 1 | 6 | 0 | 63 | 10 |
| 30-Jun | 1 | 6 | 3 | 8 | 1 |
| 6-Jul | 1 | 6 | 27 | 0 | 0 |
| 28-Jul | 1 | 6 | 1180 | 0 | 54 |
| 23-Apr | 1 | 7 | 0 | 0 | 0 |
| 1-May | 1 | 7 | 0 | 0 | 0 |
| 7-May | 1 | 7 | 2 | 0 | 0 |
| 14-May | 1 | 7 | 1 | 0 | 0 |
| 20-May | 1 | 7 | 0 | 0 | 4 |
| 27-May | 1 | 7 | 4 | 0 | 0 |
| 3-Jun | 1 | 7 | 2 | 0 | 0 |
| 10-Jun | 1 | 7 | 0 | 0 | 0 |
| 18-Jun | 1 | 7 | 0 | 0 | 0 |
| 25-Jun | 1 | 7 | 6 | 12 | 0 |
| 30-Jun | 1 | 7 | 2 | 3 | 3 |
| 6-Jul | 1 | 7 | | | |
| 28-Jul | 1 | 7 | 0 | | 360 |
| 23-Apr | 1 | 8 | 14 | 0 | 7 |
| 1-May | 1 | 8 | 2 | 0 | 0 |

**Table A.3**. Bacterial data for subsurface flow 1997, continued

| Date | REP | TRT | FC cfu/100 mL | FS cfu/100 mL | EC cfu/100 mL |
|---|---|---|---|---|---|
| 27-May | 1 | 8 | 0 | 0 | 3 |
| 3-Jun | 1 | 8 | 0 | 0 | 0 |
| 10-Jun | 1 | 8 | 7 | 2 | 0 |
| 18-Jun | 1 | 8 | 0 | 0 | 0 |
| 25-Jun | 1 | 8 | 0 | 32 | 2 |
| 30-Jun | 1 | 8 | 0 | 18 | 0 |
| 6-Jul | 1 | 8 | | | |
| 28-Jul | 1 | 8 | | | |
| 23-Apr | 1 | 9 | 11 | 1 | 7 |
| 1-May | 1 | 9 | 2 | 0 | 0 |
| 7-May | 1 | 9 | 10 | 3 | 1 |
| 14-May | 1 | 9 | 1 | 0 | 1 |
| 20-May | 1 | 9 | 1 | 0 | 0 |
| 27-May | 1 | 9 | 0 | 1 | 0 |
| 3-Jun | 1 | 9 | 0 | 0 | 0 |
| 10-Jun | 1 | 9 | 0 | 0 | 0 |
| 18-Jun | 1 | 9 | 0 | 0 | 0 |
| 25-Jun | 1 | 9 | 0 | 21 | 0 |
| 30-Jun | 1 | 9 | 0 | 0 | 0 |
| 6-Jul | 1 | 9 | 0 | 0 | 0 |
| 28-Jul | 1 | 9 | 0 | 7000 | 0 |
| 23-Apr | 2 | 1 | 5 | 1 | 1 |
| 1-May | 2 | 1 | 3 | 0 | 0 |
| 7-May | 2 | 1 | 1 | 1 | 0 |
| 14-May | 2 | 1 | 0 | 0 | 0 |
| 20-May | 2 | 1 | 0 | 0 | 0 |
| 27-May | 2 | 1 | 4 | 1 | 0 |
| 3-Jun | 2 | 1 | 0 | 0 | 0 |
| 10-Jun | 2 | 1 | 3 | 0 | 0 |
| 18-Jun | 2 | 1 | 0 | 0 | 0 |
| 25-Jun | 2 | 1 | 6 | 32 | 0 |
| 30-Jun | 2 | 1 | 1 | 8 | 0 |
| 6-Jul | 2 | 1 | 3 | 0 | 0 |
| 28-Jul | 2 | 1 | | | |
| 23-Apr | 2 | 2 | 10 | 2 | 7 |
| 1-May | 2 | 2 | 14 | 0 | 0 |
| 7-May | 2 | 2 | 2 | 1 | 0 |
| 14-May | 2 | 2 | 0 | 0 | 0 |
| 20-May | 2 | 2 | 3 | 0 | 0 |
| 27-May | 2 | 2 | 33 | 38 | 0 |
| 3-Jun | 2 | 2 | 0 | 0 | 0 |
| 10-Jun | 2 | 2 | 8 | 0 | 1 |
| 18-Jun | 2 | 2 | 0 | 0 | 0 |
| 25-Jun | 2 | 2 | 4 | 28 | 1 |
| 30-Jun | 2 | 2 | 0 | 1 | 0 |

**Table A.3**. Bacterial data for subsurface flow 1997, continued

| Date | REP | TRT | FC cfu/100 mL | FS cfu/100 mL | EC cfu/100 mL |
|---|---|---|---|---|---|
| 1-May | 2 | 3 | 0 | 0 | 0 |
| 7-May | 2 | 3 | 2 | 1 | 0 |
| 14-May | 2 | 3 | 0 | 0 | 0 |
| 20-May | 2 | 3 | 3 | 0 | 5 |
| 27-May | 2 | 3 | 1 | 1 | 11 |
| 3-Jun | 2 | 3 | 0 | 0 | 0 |
| 10-Jun | 2 | 3 | 1 | 0 | 0 |
| 18-Jun | 2 | 3 | 0 | 1 | 0 |
| 25-Jun | 2 | 3 | 0 | 4 | 4 |
| 30-Jun | 2 | 3 | 73 | 0 | 0 |
| 6-Jul | 2 | 3 | 0 | 0 | 0 |
| 28-Jul | 2 | 3 | 0 | 0 | 0 |
| 23-Apr | 2 | 4 | 5 | 1 | 0 |
| 1-May | 2 | 4 | 49 | 0 | 0 |
| 7-May | 2 | 4 | 8 | 1 | 0 |
| 14-May | 2 | 4 | 2 | 0 | 0 |
| 20-May | 2 | 4 | 0 | 0 | 0 |
| 27-May | 2 | 4 | 0 | 74 | 0 |
| 3-Jun | 2 | 4 | 0 | 0 | 0 |
| 10-Jun | 2 | 4 | 0 | 0 | 0 |
| 18-Jun | 2 | 4 | 0 | 0 | 0 |
| 25-Jun | 2 | 4 | 3 | 38 | 0 |
| 30-Jun | 2 | 4 | 1 | 3 | 0 |
| 6-Jul | 2 | 4 | 0 | 1 | 0 |
| 28-Jul | 2 | 4 | 0 | 1400 | 0 |
| 23-Apr | 2 | 5 | 2 | 0 | 10 |
| 1-May | 2 | 5 | 2 | 0 | 0 |
| 7-May | 2 | 5 | 0 | 0 | 1 |
| 14-May | 2 | 5 | 0 | 0 | 0 |
| 20-May | 2 | 5 | 0 | 0 | 0 |
| 27-May | 2 | 5 | 3 | 0 | 0 |
| 3-Jun | 2 | 5 | 0 | 0 | 0 |
| 10-Jun | 2 | 5 | 0 | 0 | 0 |
| 18-Jun | 2 | 5 | 0 | 0 | 0 |
| 25-Jun | 2 | 5 | 0 | 10 | 0 |
| 30-Jun | 2 | 5 | 0 | 5 | 0 |
| 6-Jul | 2 | 5 | | | |
| 28-Jul | 2 | 5 | | | |
| 23-Apr | 2 | 6 | 16 | 9 | 9 |
| 1-May | 2 | 6 | 0 | 0 | 54 |
| 7-May | 2 | 6 | 31 | 1 | 0 |
| 14-May | 2 | 6 | 0 | 1 | 0 |
| 20-May | 2 | 6 | 15 | 0 | 0 |
| 27-May | 2 | 6 | 40 | 5 | 36 |
| 3-Jun | 2 | 6 | 0 | 0 | 0 |

**Table A.3**. Bacterial data for subsurface flow 1997, continued

| Date | REP | TRT | FC cfu/100 mL | FS cfu/100 mL | EC cfu/100 mL |
|---|---|---|---|---|---|
| 30-Jun | 2 | 6 | 5 | 5 | 0 |
| 6-Jul | 2 | 6 | 37 | 0 | 0 |
| 28-Jul | 2 | 6 | 0 | 1800 | 0 |
| 23-Apr | 2 | 7 | 0 | 0 | 0 |
| 1-May | 2 | 7 | 0 | 0 | 0 |
| 7-May | 2 | 7 | 0 | 0 | 0 |
| 14-May | 2 | 7 | 0 | 0 | 9 |
| 20-May | 2 | 7 | 0 | 0 | 0 |
| 27-May | 2 | 7 | 3 | 27 | 0 |
| 3-Jun | 2 | 7 | 1 | 0 | 0 |
| 10-Jun | 2 | 7 | 44 | 0 | 0 |
| 18-Jun | 2 | 7 | 0 | 0 | 0 |
| 25-Jun | 2 | 7 | 8 | 14 | 0 |
| 30-Jun | 2 | 7 | 2 | 40 | 1 |
| 6-Jul | 2 | 7 | 3 | 1 | 0 |
| 28-Jul | 2 | 7 | | | |
| 23-Apr | 2 | 8 | 0 | 0 | 0 |
| 1-May | 2 | 8 | 0 | 0 | 0 |
| 7-May | 2 | 8 | 0 | 1 | 0 |
| 14-May | 2 | 8 | 0 | 0 | 0 |
| 20-May | 2 | 8 | 0 | 0 | 0 |
| 27-May | 2 | 8 | 0 | 7 | 7 |
| 3-Jun | 2 | 8 | 4 | 0 | 0 |
| 10-Jun | 2 | 8 | 2 | 0 | 0 |
| 18-Jun | 2 | 8 | 0 | 0 | 0 |
| 25-Jun | 2 | 8 | 0 | 6 | 0 |
| 30-Jun | 2 | 8 | 2 | 20 | 0 |
| 6-Jul | 2 | 8 | 8 | 34 | 0 |
| 28-Jul | 2 | 8 | 1420 | 0 | 10 |
| 23-Apr | 2 | 9 | 7 | 1 | 6 |
| 1-May | 2 | 9 | 0 | 0 | 0 |
| 7-May | 2 | 9 | 1 | 0 | 1 |
| 14-May | 2 | 9 | 0 | 0 | 0 |
| 20-May | 2 | 9 | 0 | 0 | 0 |
| 27-May | 2 | 9 | 15 | 0 | 0 |
| 3-Jun | 2 | 9 | 0 | 0 | 0 |
| 10-Jun | 2 | 9 | 4 | 0 | 0 |
| 18-Jun | 2 | 9 | 0 | 0 | 0 |
| 25-Jun | 2 | 9 | 0 | 13 | 4 |
| 30-Jun | 2 | 9 | 8 | 0 | 2 |
| 6-Jul | 2 | 9 | 0 | 3 | 0 |
| 28-Jul | 2 | 9 | | | |
| 23-Apr | 3 | 1 | 2 | 2 | 0 |
| 1-May | 3 | 1 | 0 | 0 | 0 |
| 7-May | 3 | 1 | 0 | 2 | 0 |

**Table A.3**. Bacterial data for subsurface flow 1997, continued

| Date | REP | TRT | FC cfu/100 mL | FS cfu/100 mL | EC cfu/100 mL |
|---|---|---|---|---|---|
| 3-Jun | 3 | 1 | 0 | 0 | 0 |
| 10-Jun | 3 | 1 | 5 | 0 | 0 |
| 18-Jun | 3 | 1 | 0 | 0 | 0 |
| 25-Jun | 3 | 1 | 3 | 1 | 0 |
| 30-Jun | 3 | 1 | 0 | 0 | 0 |
| 6-Jul | 3 | 1 | | | |
| 28-Jul | 3 | 1 | 0 | 310 | 0 |
| 23-Apr | 3 | 2 | 3 | 1 | 0 |
| 1-May | 3 | 2 | 0 | 0 | 0 |
| 7-May | 3 | 2 | 1 | 0 | 0 |
| 14-May | 3 | 2 | 0 | 0 | 0 |
| 20-May | 3 | 2 | 0 | 0 | 0 |
| 27-May | 3 | 2 | 0 | 1 | 0 |
| 3-Jun | 3 | 2 | 0 | 0 | 0 |
| 10-Jun | 3 | 2 | 0 | 0 | 0 |
| 18-Jun | 3 | 2 | 0 | 0 | 0 |
| 25-Jun | 3 | 2 | 22 | 23 | 0 |
| 30-Jun | 3 | 2 | 2 | 0 | 0 |
| 6-Jul | 3 | 2 | 0 | 0 | 0 |
| 28-Jul | 3 | 2 | 0 | 400 | 0 |
| 23-Apr | 3 | 3 | 3 | 0 | 7 |
| 1-May | 3 | 3 | 0 | 0 | 0 |
| 7-May | 3 | 3 | 0 | 0 | 0 |
| 14-May | 3 | 3 | 10 | 0 | 0 |
| 20-May | 3 | 3 | 2 | 0 | 0 |
| 27-May | 3 | 3 | 1 | 1 | 0 |
| 3-Jun | 3 | 3 | 2 | 0 | 0 |
| 10-Jun | 3 | 3 | 0 | 0 | 0 |
| 18-Jun | 3 | 3 | 0 | 0 | 0 |
| 25-Jun | 3 | 3 | 3 | 152 | 3 |
| 30-Jun | 3 | 3 | 1 | 13 | 1 |
| 6-Jul | 3 | 3 | 3 | 1 | 0 |
| 28-Jul | 3 | 3 | | | |
| 23-Apr | 3 | 4 | 0 | 0 | 0 |
| 1-May | 3 | 4 | 0 | 0 | 0 |
| 7-May | 3 | 4 | 1 | 1 | 0 |
| 14-May | 3 | 4 | 9 | 0 | 0 |
| 20-May | 3 | 4 | 1 | 0 | 0 |
| 27-May | 3 | 4 | 220 | 25 | 0 |
| 3-Jun | 3 | 4 | 26 | 0 | 0 |
| 10-Jun | 3 | 4 | 7 | 0 | 0 |
| 18-Jun | 3 | 4 | 1 | 0 | 0 |
| 25-Jun | 3 | 4 | 12 | 50 | 0 |
| 30-Jun | 3 | 4 | 10 | 9 | 0 |
| 6-Jul | 3 | 4 | | | |

**Table A.3**. Bacterial data for subsurface flow 1997, continued

| Date | REP | TRT | FC cfu/100 mL | FS cfu/100 mL | EC cfu/100 mL |
|---|---|---|---|---|---|
| 7-May | 3 | 5 | 2 | 4 | 0 |
| 14-May | 3 | 5 | 1 | 0 | 0 |
| 20-May | 3 | 5 | 0 | 0 | 0 |
| 27-May | 3 | 5 | 10 | 38 | 0 |
| 3-Jun | 3 | 5 | 0 | 0 | 0 |
| 10-Jun | 3 | 5 | 0 | 0 | 0 |
| 18-Jun | 3 | 5 | 0 | 0 | 0 |
| 25-Jun | 3 | 5 | 22 | 153 | 1 |
| 30-Jun | 3 | 5 | 18 | 0 | 0 |
| 6-Jul | 3 | 5 | | | |
| 28-Jul | 3 | 5 | 0 | 5000 | 0 |
| 23-Apr | 3 | 6 | 0 | 0 | 0 |
| 1-May | 3 | 6 | 1 | 0 | 0 |
| 7-May | 3 | 6 | 0 | 1 | 0 |
| 14-May | 3 | 6 | 0 | 0 | 0 |
| 20-May | 3 | 6 | 1 | 0 | 0 |
| 27-May | 3 | 6 | 4 | 0 | 0 |
| 3-Jun | 3 | 6 | 0 | 0 | 0 |
| 10-Jun | 3 | 6 | 0 | 0 | 1 |
| 18-Jun | 3 | 6 | 0 | 0 | 0 |
| 25-Jun | 3 | 6 | 1 | 7 | 1 |
| 30-Jun | 3 | 6 | 11 | 0 | 0 |
| 6-Jul | 3 | 6 | 7 | 0 | 0 |
| 28-Jul | 3 | 6 | | | |
| 23-Apr | 3 | 7 | 11 | 0 | 0 |
| 1-May | 3 | 7 | 3 | 0 | 0 |
| 7-May | 3 | 7 | 0 | 0 | 1 |
| 14-May | 3 | 7 | 1 | 0 | 0 |
| 20-May | 3 | 7 | 0 | 0 | 0 |
| 27-May | 3 | 7 | 4 | 0 | 0 |
| 3-Jun | 3 | 7 | 0 | 0 | 0 |
| 10-Jun | 3 | 7 | 1 | 0 | 0 |
| 18-Jun | 3 | 7 | 0 | 0 | 0 |
| 25-Jun | 3 | 7 | 62 | 44 | 0 |
| 30-Jun | 3 | 7 | 0 | 4 | 0 |
| 6-Jul | 3 | 7 | 3 | 2 | 0 |
| 28-Jul | 3 | 7 | 1240 | 0 | 0 |
| 23-Apr | 3 | 8 | 1 | 0 | 0 |
| 1-May | 3 | 8 | 0 | 16 | 0 |
| 7-May | 3 | 8 | 1 | 0 | 4 |
| 14-May | 3 | 8 | 4 | 0 | 0 |
| 20-May | 3 | 8 | 0 | 0 | 0 |
| 27-May | 3 | 8 | 2 | 0 | 0 |
| 3-Jun | 3 | 8 | 0 | 0 | 0 |
| 10-Jun | 3 | 8 | 1 | 0 | 0 |

**Table A.3**. Bacterial data for subsurface flow 1997, continued

| Date | REP | TRT | FC cfu/100 mL | FS cfu/100 mL | EC cfu/100 mL |
|---|---|---|---|---|---|
| 6-Jul | 3 | 8 | | | |
| 28-Jul | 3 | 8 | | | |
| 23-Apr | 3 | 9 | 0 | 1 | 0 |
| 1-May | 3 | 9 | 370 | 22 | 0 |
| 7-May | 3 | 9 | 80 | 8 | 0 |
| 14-May | 3 | 9 | 1 | 0 | 1 |
| 20-May | 3 | 9 | 1 | 0 | 1 |
| 27-May | 3 | 9 | 3 | 2 | 0 |
| 3-Jun | 3 | 9 | 1 | 0 | 1 |
| 10-Jun | 3 | 9 | 1 | 0 | 0 |
| 18-Jun | 3 | 9 | 1 | 0 | 0 |
| 25-Jun | 3 | 9 | 8 | 25 | 0 |
| 30-Jun | 3 | 9 | 330 | 14 | 0 |
| 6-Jul | 3 | 9 | 0 | 1 | 0 |
| 28-Jul | 3 | 9 | 70 | 260 | 0 |

**Table A.4.**. Tileflow and rainfall data 1997

| Week of: | Total Tileflow, cm | Total Rainfall, cm |
|---|---|---|
| Mar 23-29 | 0.08 | 0.00 |
| Mar 30-Apr 5 | 0.17 | 0.30 |
| Apr 6-12 | 0.00 | 2.69 |
| Apr 13-19 | 0.11 | 0.69 |
| Apr 20-26 | 0.14 | 0.00 |
| Apr 27-May 3 | 0.23 | 0.00 |
| May 4-10 | 0.47 | 2.31 |
| May 11-17 | 0.66 | 4.65 |
| May 18-24 | 0.30 | 0.00 |
| May 25-31 | 0.28 | 3.81 |
| Jun 1-7 | 0.49 | 0.00 |
| Jun 8-14 | 0.19 | 1.65 |
| Jun 15-21 | 0.10 | 6.50 |
| Jun 22-28 | 0.42 | 0.91 |
| Jun 29-Jul 5 | 0.17 | 0.64 |
| Jul 6-12 | 0.12 | 0.56 |
| Jul 13-19 | 0.02 | 0.10 |
| Jul 20-26 | 0.00 | 8.23 |
| Jul 27-Aug 2 | 0.01 | 0.29 |
| Aug 3-9 | 0.00 | 0.00 |
| Aug 10-16 | 0.00 | 3.24 |
| Aug 17-23 | 0.00 | 0.41 |
| Aug 24-30 | 0.00 | 0.22 |
| Aug 31-Sep 6 | 0.00 | 0.00 |
| Sep 7-13 | 0.00 | 2.65 |
| Sep 14-20 | 0.00 | 0.19 |
| Sep 21-27 | 0.00 | 2.84 |

**Table A.5.** Bacterial data for surface runoff for 1997

| Date | Rep | Trt | FC cfu/100mL | FS cfu/100mL | EC cfu/100mL |
|---|---|---|---|---|---|
| 21-Jun | 1 | 1 | 7750 | 24000 | 100 |
| 21-Jun | 2 | 1 | 2400 | 20000 | 800 |
| 21-Jun | 3 | 1 | 48000 | 85000 | 7000 |
| 21-Jun | 1 | 2 | na | na | na |
| 21-Jun | 2 | 2 | 9300 | 35500 | 3200 |
| 21-Jun | 3 | 2 | 700 | 14400 | 400 |
| 21-Jun | 1 | 3 | 6000 | 13500 | 400 |
| 21-Jun | 2 | 3 | 2500 | 38000 | 3600 |
| 21-Jun | 3 | 3 | 500 | 6700 | 100 |
| 21-Jun | 1 | 4 | 4500 | 43000 | 0 |
| 21-Jun | 2 | 4 | 0 | 29000 | 700 |
| 21-Jun | 3 | 4 | 900 | 24000 | 400 |
| 21-Jun | 1 | 5 | 100000 | 600000 | 1000000 |
| 21-Jun | 2 | 5 | 3200 | 15000 | 1300 |
| 21-Jun | 3 | 5 | 100 | 8600 | 440 |
| 21-Jun | 1 | 6 | 4400 | 17000 | 18000 |
| 21-Jun | 2 | 6 | na | na | na |
| 21-Jun | 3 | 6 | 200 | 23500 | 600 |
| 21-Jun | 1 | 7 | 1400 | 23500 | 200 |
| 21-Jun | 2 | 7 | 9300 | 16250 | 630 |
| 21-Jun | 3 | 7 | 3600 | 10500 | 200 |
| 21-Jun | 1 | 8 | 200 | 5100 | 100 |
| 21-Jun | 2 | 8 | 0 | 26000 | 2100 |
| 21-Jun | 3 | 8 | 0 | 19000 | 700 |
| 21-Jun | 1 | 9 | 4300 | 12500 | 100 |
| 21-Jun | 2 | 9 | 3300 | 28000 | 3800 |
| 21-Jun | 3 | 9 | 2300 | 12000 | 200 |
| 25-Jul | 1 | 1 | 31000 | 62000 | 1200 |
| 25-Jul | 2 | 1 | na | na | |
| 25-Jul | 3 | 1 | 41000 | 80000 | 0 |
| 25-Jul | 1 | 2 | 36000 | 81000 | 3500 |
| 25-Jul | 2 | 2 | 44000 | 44000 | 0 |
| 25-Jul | 3 | 2 | 31000 | 80000 | 1000 |
| 25-Jul | 1 | 3 | 13000 | 80000 | 2000 |
| 25-Jul | 2 | 3 | na | na | na |
| 25-Jul | 3 | 3 | na | na | na |
| 25-Jul | 1 | 4 | na | na | na |
| 25-Jul | 2 | 4 | 700000 | 700000 | 400 |
| 25-Jul | 3 | 4 | 16000 | 150000 | 700 |
| 25-Jul | 1 | 5 | 1100 | 260000 | 5800 |
| 25-Jul | 2 | 5 | 20000 | 20000 | 2100 |
| 25-Jul | 3 | 5 | 1000 | 310000 | 5900 |
| 25-Jul | 1 | 6 | na | na | na |
| 25-Jul | 2 | 6 | na | na | na |
| 25-Jul | 3 | 6 | 26000 | 740000 | 5800 |

**Table A.5.** Bacterial data for surface runoff for 1997, continued

| Date | Rep | Trt | FC cfu/100mL | FS cfu/100mL | EC cfu/100mL |
|---|---|---|---|---|---|
| 25-Jul | 1 | 8 | 33000 | 60000 | 2900 |
| 25-Jul | 2 | 8 | 35000 | 72000 | 500 |
| 25-Jul | 3 | 8 | na | na | na |
| 25-Jul | 1 | 9 | 0 | 59000 | 3900 |
| 25-Jul | 2 | 9 | 20000 | 20000 | 300 |
| 25-Jul | 3 | 9 | na | na | na |

**Table A.6.** Runoff flow values (cm)

| Rep | Plot | 6/21/97 Flow (cm) | 7/25/97 Flow (cm) |
|---|---|---|---|
| 1 | 1 | 0.75 | 1.11 |
| 2 | 1 | 0.74 | 0.00 |
| 3 | 1 | 0.63 | 0.59 |
| 1 | 2 | 0.00 | 1.00 |
| 2 | 2 | 0.78 | 0.31 |
| 3 | 2 | 0.88 | 1.26 |
| 1 | 3 | 0.11 | 0.82 |
| 2 | 3 | 0.00 | 0.00 |
| 3 | 3 | 0.27 | 0.00 |
| 1 | 4 | 0.06 | 0.00 |
| 2 | 4 | 1.04 | 2.31 |
| 3 | 4 | 0.00 | 0.08 |
| 1 | 5 | 0.18 | 0.37 |
| 2 | 5 | 0.73 | 1.92 |
| 3 | 5 | 1.49 | 1.68 |
| 1 | 6 | 0.08 | 0.00 |
| 2 | 6 | 0.00 | 0.00 |
| 3 | 6 | 0.59 | 1.68 |
| 1 | 7 | 0.77 | 0.63 |
| 2 | 7 | 0.50 | 1.96 |
| 3 | 7 | 0.85 | 1.55 |
| 1 | 8 | 0.11 | 0.26 |
| 2 | 8 | 0.27 | 1.29 |
| 3 | 8 | 0.53 | 0.00 |
| 1 | 9 | 0.00 | 0.71 |
| 2 | 9 | 0.65 | 1.96 |
| 3 | 9 | 0.53 | 0.00 |

# APPENDIX B: LYSIMETER TILLAGE/PRESSURE PONDING STUDY DATA

**Table B.1.** Nutrient data insubsurface flow 1997

| Lysimeter | Sampling | NH4-N mg/L | NO3-N mg/L | TKN mg/L | CL mg/L | PO4-P mg/L | TOT-P mg/L |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.87 | 8.345 | 5.68 | 6.84 | 2.03 | 1.357 |
| 1 | 6 | | 5.28 | 0.16 | 1.26 | 0.037 | 0.026 |
| 1 | 7 | | 5.57 | 0.24 | 1.93 | 0.027 | 0.035 |
| 1 | 8 | | 5.79 | 0.05 | 3.41 | 0.026 | 0.01 |
| 1 | 9 | | 11.85 | 0.08 | 2.48 | 0.056 | 0.01 |
| 1 | 10 | | 16.38 | 0 | 1.82 | 0.026 | 0 |
| 1 | 11 | | 12.24 | 0 | 2.21 | 0.018 | 0 |
| 1 | 12 | | 10.89 | 0.29 | 1.73 | 0.024 | 0.013 |
| 2 | 1 | 1.13 | 4.22 | 5.4 | 9.85 | 0.994 | 1.331 |
| 2 | 2 | 0.15 | 4.34 | 1.19 | 7.33 | 0.164 | 0.16 |
| 2 | 6 | | 5.4 | 0.28 | 4.23 | 0.043 | 0.049 |
| 2 | 7 | | 5.75 | 0.25 | 4.93 | 0.029 | 0.046 |
| 2 | 8 | | 7.17 | 0.1 | 5.7 | 0.027 | 0.02 |
| 2 | 9 | | 8.99 | 0.17 | 4.71 | 0.14 | 0.046 |
| 2 | 10 | | 8.33 | 0 | 3.38 | 0.026 | 0 |
| 2 | 11 | | 7.09 | 0.08 | 3.71 | 0.047 | 0.01 |
| 2 | 12 | | 6.41 | 0.1 | 3.09 | 0.029 | 0.029 |
| 3 | 6 | | 6.85 | 0.29 | 3.63 | 0.046 | 0.029 |
| 3 | 7 | | 8.13 | 0.32 | 2.6 | 0.064 | 0.023 |
| 3 | 8 | | 8.75 | 0.19 | 3.19 | 0.023 | 0.02 |
| 3 | 9 | | 10.1 | 0.09 | 3.07 | 0.062 | 0.016 |
| 3 | 10 | | 16.66 | 0.02 | 1.62 | 0.03 | 0 |
| 3 | 11 | | 13.63 | 0.16 | 1.75 | 0.037 | 0.01 |
| 3 | 12 | | 8.95 | 0.21 | 2.48 | 0.033 | 0.029 |
| 4 | 1 | 29.2 | 8.89 | 45.2 | 47 | 8.652 | 9.65 |
| 4 | 2 | 7.99 | 18.605 | 13.2 | 29.5 | 3.168 | 2.254 |
| 4 | 3 | | 13.33 | 2.99 | 17 | 0.545 | 0.44 |
| 4 | 4 | | 10.66 | 1.45 | 14.6 | 0.24 | 0.212 |
| 4 | 5 | | 7.09 | 0.29 | 7.71 | 0.314 | 0.156 |
| 4 | 6 | | 10.84 | 0.46 | 7.1 | 0.156 | 0.147 |
| 4 | 7 | | 7.32 | 0.27 | 5.38 | 0.118 | 0.081 |
| 4 | 8 | | 13.72 | 0.51 | 7.15 | 0.245 | 0.241 |
| 4 | 9 | | 14 | 0.06 | 7.85 | 0.33 | 0.228 |
| 4 | 10 | | 27.43 | 0.19 | 10.6 | 0.139 | 0.108 |
| 4 | 11 | | 16.09 | 0 | 7.59 | 0.118 | 0.068 |
| 4 | 12 | | 10.57 | 0.21 | 6.01 | 0.088 | 0.078 |
| 6 | 8 | | 10 | 0.15 | 2.7 | 0.107 | 0.052 |
| 6 | 9 | | 11.28 | 0.07 | 3 | 0.189 | 0.049 |
| 6 | 10 | | 14.81 | 0 | 2.27 | 0.027 | 0 |
| 6 | 11 | | 9.86 | 0 | 2.15 | 0.04 | 0 |
| 6 | 12 | | 12 | 0.16 | 3.01 | 0.024 | 0.013 |
| 7 | 6 | | 2.85 | 0.08 | 3.11 | 0.058 | 0.071 |
| 7 | 7 | | 3.26 | 0.1 | 1.71 | 0.046 | 0.068 |
| 7 | 8 | | 3.13 | 0.08 | 2.8 | 0.073 | 0.039 |
| 7 | 9 | | 4.32 | 0.07 | 2.8 | 0.107 | 0.036 |

**Table B.1.** Nutrient data insubsurface flow 1997, continued

| Lysimeter | Sampling | NH4-N mg/L | NO3-N mg/L | TKN mg/L | CL mg/L | PO4-P mg/L | TOT-P mg/L |
|---|---|---|---|---|---|---|---|
| 8 | 8 | | 5.23 | 0.06 | 2.8 | 0.358 | 0.02 |
| 8 | 9 | | 9.96 | 0.11 | 2.73 | 0.12 | 0.042 |
| 8 | 10 | | 11.16 | 0 | 1.77 | 0.023 | |
| 8 | 11 | | 9.72 | 0 | 1.93 | 0.025 | 0 |
| 8 | 12 | | 8.53 | 0.06 | 1.59 | 0.027 | 0.026 |
| 9 | 1 | 18 | 2.515 | 33.3 | 32 | 7.396 | 7.912 |
| 9 | 2 | 2.72 | 5.01 | 7.94 | ns | 1.099 | 1.262 |
| 9 | 3 | | 5.22 | 1.32 | 10.6 | 0.318 | 0.248 |
| 9 | 4 | | 4.09 | 0.53 | 8.19 | 0.177 | 0.554 |
| 9 | 5 | | 3.39 | 0.41 | 5.28 | 0.092 | 0.098 |
| 9 | 6 | | 3.62 | 0.28 | 4.53 | 0.078 | 0.098 |
| 9 | 7 | | 4.03 | 0.14 | 4.67 | 0.041 | 0.049 |
| 9 | 8 | | 6.13 | 0.02 | 5.52 | 0.559 | 0.202 |
| 9 | 9 | | 8.05 | 0.13 | 6.62 | 0.324 | 0.137 |
| 9 | 10 | | 10.89 | 0 | 8.44 | 0.047 | 0.033 |
| 9 | 11 | | 8.6 | 0 | 5.56 | 0.047 | 0.003 |
| 9 | 12 | | 7.06 | 0.07 | 5.16 | 0.41 | 0.039 |
| 10 | 7 | | 3.19 | 0.05 | 0.44 | 0.009 | 0.033 |
| 10 | 8 | | 7.41 | 0.09 | 2.8 | 0.12 | 0.075 |
| 10 | 9 | | 9.19 | 0.11 | 3.59 | 0.11 | 0.065 |
| 10 | 10 | | 8.16 | 0 | 2.7 | 0.028 | 0.007 |
| 10 | 11 | | 5.63 | 0 | 1.48 | 0.038 | 0 |
| 10 | 12 | | 4.47 | 0.09 | 0.82 | 0.013 | 0.01 |
| 12 | 1 | 0.38 | 2.12 | 1.06 | 4.27 | 0.415 | 0.222 |
| 12 | 3 | | 7.74 | 0.11 | 2.28 | 0.05 | 0.098 |
| 12 | 6 | | 7.93 | 0.08 | 2.75 | 0.031 | 0.349 |
| 12 | 7 | | 8.65 | 0.14 | 1.85 | 0.024 | 0.036 |
| 12 | 8 | | 9.72 | 0.3 | 3.68 | 0.057 | 0.013 |
| 12 | 9 | | 10.66 | 0.09 | 3.49 | 0.068 | 0.036 |
| 12 | 10 | | 11.44 | 0 | 2.97 | 0.035 | 0 |
| 12 | 11 | | 10.61 | 0 | 3.35 | 0.026 | 0.016 |
| 12 | 12 | | 11.03 | 0.13 | 2.51 | 0.021 | 0.026 |
| 13 | 6 | | 8 | 0.15 | 3.5 | 0.086 | 0.059 |
| 13 | 7 | | 8.2 | 0.14 | 2.88 | 0.077 | 0.078 |
| 13 | 8 | | 8.47 | 0 | 2.83 | 0.038 | 0 |
| 13 | 9 | | 10.31 | 0.13 | 3.68 | 0.242 | 0.202 |
| 13 | 10 | | 12.42 | 0 | 2.89 | 0.05 | 0.016 |
| 13 | 11 | | 11.33 | 0 | 2.75 | 0.116 | 0.046 |
| 13 | 12 | | 10.7 | 0.16 | 2.66 | 0.019 | 0.023 |
| 14 | 1 | 1.44 | 11.17 | 12.4 | 18.4 | 1.513 | 3.666 |
| 14 | 2 | 0.83 | 13.305 | 4.16 | 16.7 | 0.746 | 1.207 |
| 14 | 3 | | 11.99 | 1.46 | 14.1 | 0.178 | 0.179 |
| 14 | 4 | | 10.83 | 1.15 | 13.4 | 0.07 | 0.075 |
| 14 | 5 | | 10.04 | 0.56 | 9.1 | 0.054 | 0.055 |
| 14 | 6 | | 9.82 | 0.4 | 8.67 | 0.042 | 0.046 |

**Table B.1.** Nutrient data insubsurface flow 1997, continued

| Lysimeter | Sampling | NH4-N mg/L | NO3-N mg/L | TKN mg/L | CL mg/L | PO4-P mg/L | TOT-P mg/L |
|---|---|---|---|---|---|---|---|
| 14 | 10 | | 17.22 | 0 | 8.91 | 0.045 | 0.042 |
| 14 | 11 | | 15.73 | 0.06 | 9.11 | 0.091 | 0.055 |
| 14 | 12 | | 12.82 | 0.23 | 7.79 | 0.03 | 0.036 |
| 15 | 1 | 0.13 | 7.59 | 1.53 | 3.05 | 0.445 | 0.31 |
| 15 | 2 | 0.05 | 1.915 | 0.52 | 3.83 | 0.07 | 0.049 |
| 15 | 6 | | 1.79 | 0.19 | 2.75 | 0.013 | 0.026 |
| 15 | 7 | | 2.58 | 0.21 | 1.93 | 0.011 | 0.01 |
| 15 | 8 | | 3.92 | 0.02 | 3.03 | 0.02 | 0.033 |
| 15 | 9 | | 4.77 | 0.07 | 3.6 | 0.039 | 0.007 |
| 15 | 10 | | 7.74 | 0 | 2.75 | 0.045 | 0.013 |
| 15 | 11 | | 6.82 | 0 | 2.68 | 0.022 | 0 |
| 15 | 12 | | 5.51 | 0.16 | 2.2 | 0.018 | 0.01 |
| 16 | 6 | | 5.17 | 0.24 | 2.9 | 0.052 | 0.049 |
| 16 | 7 | | 5 | 0.19 | 3.1 | 0.021 | 0.013 |
| 16 | 8 | | 5.76 | 0 | 3.26 | 0.021 | 0 |
| 16 | 9 | | 9.94 | 0.14 | 3.48 | 0.208 | 0.157 |
| 16 | 10 | | 9.27 | 0.02 | 2.95 | 0.021 | |
| 16 | 11 | | 7.38 | 0 | 3.09 | 0.034 | 0 |
| 16 | 12 | | 6.98 | 0.1 | 3.19 | 0.025 | 0.023 |

**Table B.2.** Fecal bacterial populations in subsurface drainage.

| Lysimeter | Sampling | FC cfu/100ml | FS cfu/100ml | EC cfu/100ml |
|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 |
| 1 | 6 | 10 | 0 | 0 |
| 1 | 7 | 170 | 0 | 0 |
| 1 | 8 | 0 | 90 | 0 |
| 1 | 9 | 20 | 0 | 0 |
| 1 | 10 | 0 | 0 | 0 |
| 1 | 11 | 0 | 0 | 0 |
| 1 | 12 | 0 | 0 | 0 |
| 2 | 1 | 2400 | 1200 | 1300 |
| 2 | 2 | 0 | 300 | 0 |
| 2 | 6 | 90 | 40 | 30 |
| 2 | 7 | 20 | 0 | 10 |
| 2 | 8 | 100 | 250 | 0 |
| 2 | 9 | 270 | 730 | 30 |
| 2 | 10 | 0 | 370 | 0 |
| 2 | 11 | 0 | 10 | 0 |
| 2 | 12 | 0 | 40 | 0 |
| 3 | 6 | 10 | 30 | 0 |
| 3 | 7 | 0 | 0 | 0 |
| 3 | 8 | 0 | 40 | 0 |
| 3 | 9 | 30 | 200 | 0 |
| 3 | 10 | 0 | 60 | 0 |
| 3 | 11 | 0 | 10 | 0 |
| 3 | 12 | 0 | 0 | 0 |
| 4 | 1 | 3900 | 12500 | 22000 |
| 4 | 2 | 5200 | 9100 | 23000 |
| 4 | 3 | 620 | 80 | 5900 |
| 4 | 4 | 210 | 30 | 1100 |
| 4 | 5 | 100 | 0 | 10 |
| 4 | 6 | 30 | 490 | 50 |
| 4 | 7 | 50 | 80 | 20 |
| 4 | 8 | 150 | 480 | 145 |
| 4 | 9 | 520 | 2800 | 40 |
| 4 | 10 | 260 | 170 | 0 |
| 4 | 11 | 10 | 10 | 0 |
| 4 | 12 | 0 | 10 | 0 |
| 6 | 8 | 30 | 30 | 20 |
| 6 | 9 | 20 | 480 | 0 |
| 6 | 10 | 0 | 1380 | 0 |
| 6 | 11 | 70 | 60 | 0 |
| 6 | 12 | 50 | 30 | 0 |
| 7 | 6 | 30 | 0 | 0 |
| 7 | 7 | 40 | 20 | 20 |
| 7 | 8 | 20 | 20 | 0 |
| 7 | 9 | 10 | 60 | 10 |

**Table B.2**.Fecal bacterial populations in subsurface drainage, continued

| Lysimeter | Sampling | FC cfu/100ml | FS cfu/100ml | EC cfu/100ml |
|---|---|---|---|---|
| 8 | 8 | 60 | 10 | 0 |
| 8 | 9 | 60 | 70 | 20 |
| 8 | 10 | 40 | 390 | 30 |
| 8 | 11 | 130 | 240 | 0 |
| 8 | 12 | 250 | 0 | 0 |
| 9 | 1 | 59000 | 10100 | 41000 |
| 9 | 2 | 8800 | 12200 | 8100 |
| 9 | 3 | 850 | 1800 | 2200 |
| 9 | 4 | 660 | 1100 | 1400 |
| 9 | 5 | 0 | 70 | 0 |
| 9 | 6 | 70 | 90 | 40 |
| 9 | 7 | 70 | 10 | 0 |
| 9 | 8 | 540 | 6700 | 10 |
| 9 | 9 | 1420 | 1230 | 10 |
| 9 | 10 | 300 | 80 | 0 |
| 9 | 11 | 870 | 0 | 0 |
| 9 | 12 | 0 | 0 | 0 |
| 10 | 7 | 10 | 0 | 0 |
| 10 | 8 | 100 | 42000 | 50 |
| 10 | 9 | 0 | 1260 | 10 |
| 10 | 10 | 90 | 320 | 0 |
| 10 | 11 | 340 | 100 | 0 |
| 10 | 12 | 40 | 0 | 0 |
| 12 | 1 | 4000 | 1000 | 1500 |
| 12 | 3 | 700 | 0 | 0 |
| 12 | 6 | 60 | 1200 | |
| 12 | 7 | 110 | 0 | 20 |
| 12 | 8 | 0 | 20 | 0 |
| 12 | 9 | 520 | 1600 | 40 |
| 12 | 10 | 650 | 450 | 0 |
| 12 | 11 | 220 | 100 | 0 |
| 12 | 12 | 100 | 0 | 10 |
| 13 | 6 | 70 | 100 | 0 |
| 13 | 7 | 20 | 20 | 160 |
| 13 | 8 | 0 | 10 | 0 |
| 13 | 9 | 140 | 2800 | 0 |
| 13 | 10 | 450 | 3800 | 40 |
| 13 | 11 | 20 | 2800 | 0 |
| 13 | 12 | 10 | 30 | 0 |
| 14 | 1 | 31000 | 4500 | 11900 |
| 14 | 2 | 12000 | 5500 | 9300 |
| 14 | 3 | 990 | 1200 | 2200 |
| 14 | 4 | 230 | 200 | 1300 |
| 14 | 5 | 30 | 10 | 0 |
| 14 | 6 | 130 | 50 | 620 |

**Table B.2**.Fecal bacterial populations in subsurface drainage, continued

| Lysimeter | Sampling | FC cfu/100ml | FS cfu/100ml | EC cfu/100ml |
|---|---|---|---|---|
| 14 | 10 | 80 | 190 | 0 |
| 14 | 11 | 30 | 0 | 10 |
| 14 | 12 | 0 | 10 | 10 |
| 15 | 1 | 7000 | 100 | 300 |
| 15 | 2 | 1800 | 300 | 0 |
| 15 | 6 | 30 | 40 | 60 |
| 15 | 7 | 10 | 20 | 0 |
| 15 | 8 | 120 | 4800 | 130 |
| 15 | 9 | 0 | 290 | 20 |
| 15 | 10 | 50 | 90 | 0 |
| 15 | 11 | 20 | 20 | 0 |
| 15 | 12 | 50 | 10 | 0 |
| 16 | 6 | 0 | 0 | 10 |
| 16 | 7 | 100 | 10 | 0 |
| 16 | 8 | 20 | 70 | 0 |
| 16 | 9 | 0 | 330 | 40 |
| 16 | 10 | 120 | 190 | 0 |
| 16 | 11 | 0 | 70 | 0 |
| 16 | 12 | 0 | 20 | 0 |

**Table B.3.** Flow data 1997

| Lysimeter | Sampling | Drainage Gallons | Drainage cm | Drainage Liters |
|---|---|---|---|---|
| 1 | 1 | 0.25 | 0.04 | 0.95 |
| 1 | 6 | 2.00 | 0.34 | 7.58 |
| 1 | 7 | 0.50 | 0.09 | 1.90 |
| 1 | 8 | 0.50 | 0.09 | 1.90 |
| 1 | 9 | 7.00 | 1.20 | 26.53 |
| 1 | 10 | 6.50 | 1.12 | 24.64 |
| 1 | 11 | 8.00 | 1.37 | 30.32 |
| 1 | 12 | 0.50 | 0.09 | 1.90 |
| 2 | 1 | 0.25 | 0.04 | 0.95 |
| 2 | 2 | 0.50 | 0.09 | 1.90 |
| 2 | 6 | 2.50 | 0.43 | 9.48 |
| 2 | 7 | 1.50 | 0.26 | 5.69 |
| 2 | 8 | 1.50 | 0.26 | 5.69 |
| 2 | 9 | 6.00 | 1.03 | 22.74 |
| 2 | 10 | 6.00 | 1.03 | 22.74 |
| 2 | 11 | 7.50 | 1.29 | 28.43 |
| 2 | 12 | 0.50 | 0.09 | 1.90 |
| 3 | 6 | 2.50 | 0.43 | 9.48 |
| 3 | 7 | 2.50 | 0.43 | 9.48 |
| 3 | 8 | 2.25 | 0.39 | 8.53 |
| 3 | 9 | 6.00 | 1.03 | 22.74 |
| 3 | 10 | 5.50 | 0.94 | 20.85 |
| 3 | 11 | 7.50 | 1.29 | 28.43 |
| 3 | 12 | 0.50 | 0.09 | 1.90 |
| 4 | 1 | 2.50 | 0.43 | 9.48 |
| 4 | 2 | 6.00 | 1.03 | 22.74 |
| 4 | 3 | 4.00 | 0.69 | 15.16 |
| 4 | 4 | 4.50 | 0.77 | 17.06 |
| 4 | 5 | 5.00 | 0.86 | 18.95 |
| 4 | 6 | 2.50 | 0.43 | 9.48 |
| 4 | 7 | 4.00 | 0.69 | 15.16 |
| 4 | 8 | 4.00 | 0.69 | 15.16 |
| 4 | 9 | 6.00 | 1.03 | 22.74 |
| 4 | 10 | 5.50 | 0.94 | 20.85 |
| 4 | 11 | 7.00 | 1.20 | 26.53 |
| 4 | 12 | 0.33 | 0.06 | 1.25 |
| 6 | 8 | 0.50 | 0.09 | 1.90 |
| 6 | 9 | 7.00 | 1.20 | 26.53 |
| 6 | 10 | 6.50 | 1.12 | 24.64 |
| 6 | 11 | 8.00 | 1.37 | 30.32 |
| 6 | 12 | 0.50 | 0.09 | 1.90 |
| 7 | 6 | 0.50 | 0.09 | 1.90 |
| 7 | 7 | 0.50 | 0.09 | 1.90 |
| 7 | 8 | 1.00 | 0.17 | 3.79 |
| 7 | 9 | 6.50 | 1.12 | 24.64 |

**Table B.3.** Flow data 1997, continued

| Lysimeter | Sampling | Drainage Gallons | Drainage cm | Drainage Liters |
|---|---|---|---|---|
| 8 | 8 | 0.50 | 0.09 | 1.90 |
| 8 | 9 | 7.00 | 1.20 | 26.53 |
| 8 | 10 | 6.00 | 1.03 | 22.74 |
| 8 | 11 | 8.00 | 1.37 | 30.32 |
| 8 | 12 | 0.50 | 0.09 | 1.90 |
| 9 | 1 | 3.00 | 0.52 | 11.37 |
| 9 | 2 | 6.50 | 1.12 | 24.64 |
| 9 | 3 | 5.50 | 0.94 | 20.85 |
| 9 | 4 | 5.00 | 0.86 | 18.95 |
| 9 | 5 | 4.50 | 0.77 | 17.06 |
| 9 | 6 | 2.75 | 0.47 | 10.42 |
| 9 | 7 | 3.75 | 0.64 | 14.21 |
| 9 | 8 | 3.75 | 0.64 | 14.21 |
| 9 | 9 | 6.00 | 1.03 | 22.74 |
| 9 | 10 | 6.00 | 1.03 | 22.74 |
| 9 | 11 | 7.50 | 1.29 | 28.43 |
| 9 | 12 | 0.50 | 0.09 | 1.90 |
| 10 | 7 | 1.25 | 0.21 | 4.74 |
| 10 | 8 | 3.00 | 0.52 | 11.37 |
| 10 | 9 | 6.50 | 1.12 | 24.64 |
| 10 | 10 | 6.50 | 1.12 | 24.64 |
| 10 | 11 | 8.00 | 1.37 | 30.32 |
| 10 | 12 | 0.50 | 0.09 | 1.90 |
| 12 | 1 | 0.25 | 0.04 | 0.95 |
| 12 | 3 | 0.50 | 0.09 | 1.90 |
| 12 | 6 | 3.75 | 0.64 | 14.21 |
| 12 | 7 | 3.00 | 0.52 | 11.37 |
| 12 | 8 | 4.00 | 0.69 | 15.16 |
| 12 | 9 | 6.50 | 1.12 | 24.64 |
| 12 | 10 | 6.00 | 1.03 | 22.74 |
| 12 | 11 | 7.50 | 1.29 | 28.43 |
| 12 | 12 | 0.33 | 0.06 | 1.25 |
| 13 | 6 | 0.50 | 0.09 | 1.90 |
| 13 | 7 | 0.33 | 0.06 | 1.25 |
| 13 | 8 | 0.75 | 0.13 | 2.84 |
| 13 | 9 | 6.50 | 1.12 | 24.64 |
| 13 | 10 | 6.00 | 1.03 | 22.74 |
| 13 | 11 | 6.00 | 1.03 | 22.74 |
| 13 | 12 | 0.25 | 0.04 | 0.95 |
| 14 | 1 | 5.25 | 0.90 | 19.90 |
| 14 | 2 | 6.00 | 1.03 | 22.74 |
| 14 | 3 | 5.00 | 0.86 | 18.95 |
| 14 | 4 | 5.00 | 0.86 | 18.95 |
| 14 | 5 | 4.00 | 0.69 | 15.16 |
| 14 | 6 | 1.50 | 0.26 | 5.69 |

**Table B.3.** Flow data 1997, continued

| Lysimeter | Sampling | Drainage Gallons | Drainage cm | Drainage Liters |
|---|---|---|---|---|
| 14 | 10 | 6.50 | 1.12 | 24.64 |
| 14 | 11 | 6.50 | 1.12 | 24.64 |
| 14 | 12 | 0.25 | 0.04 | 0.95 |
| 15 | 1 | 0.25 | 0.04 | 0.95 |
| 15 | 2 | 1.00 | 0.17 | 3.79 |
| 15 | 6 | 2.50 | 0.43 | 9.48 |
| 15 | 7 | 2.00 | 0.34 | 7.58 |
| 15 | 8 | 2.50 | 0.43 | 9.48 |
| 15 | 9 | 8.00 | 1.37 | 30.32 |
| 15 | 10 | 7.50 | 1.29 | 28.43 |
| 15 | 11 | 8.50 | 1.46 | 32.22 |
| 15 | 12 | 0.50 | 0.09 | 1.90 |
| 16 | 6 | 2.50 | 0.43 | 9.48 |
| 16 | 7 | 1.50 | 0.26 | 5.69 |
| 16 | 8 | 2.00 | 0.34 | 7.58 |
| 16 | 9 | 7.50 | 1.29 | 28.43 |
| 16 | 10 | 5.50 | 0.94 | 20.85 |
| 16 | 11 | 6.50 | 1.12 | 24.64 |
| 16 | 12 | 0.33 | 0.06 | 1.25 |

Key to treatments

| Lys # | Trt |
|---|---|
| 1 | NT |
| 2 | NT |
| 3 | CTL |
| 4 | 3X |
| 6 | Air |
| 7 | Air |
| 8 | Till |
| 9 | 3X |
| 10 | Till |
| 12 | NT |
| 13 | Till |
| 14 | 3X |
| 15 | Air |
| 16 | CTL |

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