Preferential Flow of Liquid Manure to Subsurface Drains

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ABSTRACT

The land application of liquid manure can result in bacterial contamination of the effluent from subsurface drains. This contamination appears to occur rapidly during a precipitation event and may cause significant environmental impacts. A field study was initiated to better understand the preferential flow processes and to quantify the degree of tile effluent contamination from liquid manure. Two different initial soil moisture conditions were established in replicated plots prior to the application of liquid manure. A similar amount of liquid manure (47 m^3/ha) was applied to all the plots using a slurry tank wagon. Within 40 minutes after the start of irrigation , the tile began flowing from the wetter plots and was discolored and smelled of manure. A peak concentration of 110,000 colonies/100 ml of fecal coliform was measured. Although the tile discharge from the drier plots did not occur as rapidly, similar fecal coliform concentrations and preferential flow responses evolved. Fecal coliform peak concentrations were reduced by 1/3 when the irrigation was delayed 1 week after the application of the manure. The timing of the precipitation event after the manure application had a significant effect on the magnitude of fecal coliform concentration in the drain effluent. The primary influence of the initial soil moisture content was the length of time which elapsed prior to the observance of the peak fecal coliform concentrations and drain discharge.

Keywords: `Preferential Flow, Subsurface Drain, Manure, Bacteria`

INTRODUCTION

The USGS National Water Quality Assessment data for the Northeast indicate animal manure was the primary source of nitrogen (N) and phosphorus (P) inputs to the watersheds (about 3.7 and 0.85 t/ km^2, respectively). Manure source inputs of N and P exceeded fertilizer, atmospheric and other point sources of these nutrients. Manure N accounted for 36% of the total N inputs, slightly higher than the N inputs from the atmosphere, the next highest source. However, manure P accounted for 64% of the total P inputs, more than double that from fertilizer, the next highest source (US-GAO, 1995). It is believed that most of these nutrient inputs to watersheds will be absorbed (cycled) by land based plants or bound up in the soil, and will not likely end up in the surface and groundwaters. However, the fate and transport mechanisms of nutrients from manures is more complex than those from inorganic fertilizers and are still not well understood. The N in fresh manure is primarily in the ammonia form and is mineralized and nitrified to nitrate which is subject to leaching. The organic fraction of manure P for the dairy cow is about 40% (Barnett, 1994). According to Gerritse and Zugec (1977), the organic P compounds are generally more water soluble than the inorganic phosphate, causing the organic form to be more subject to leaching. In soils with shallow water tables, accumulations of soil N and P can lead to early breakthrough and the leaching of N and P in significant concentrations.

Much attention has been focused on water quality contamination from rapid surface runoff of manured areas (Brockamp, 1993). However, information on the water quality from tile beneath manured sites, and especially the portion attributable to preferential flow, is inadequate. A better understanding of these processes would be beneficial to improving manure application management decisions which maximize the nutrient benefits of manure while minimizing the contamination of receiving water bodies.

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Preferential transport processes can move significant quantities of contaminants very rapidly, with little alteration, to the shallow groundwater. A significant portion of cropland where manures are applied has also undergone various tile drainage improvements. In these areas, preferential flow contributes to the tile discharge which outlets to the surface. Numerous investigators have recently reported on the effects of preferential transport on the rapid breakthrough of nutrients such as nitrate and atrazine herbicides (Steenhuis et al., 1990; Kladivko et al., 1991; and Milburn et al., 1995). The appearance of herbicides in the shallow groundwater is much faster than predicted when using model simulations which assume convective-dispersive transport. Incorporation of a soluble chemical into the soil reduces the concentrations released to the drains (van Es et al., 1991). Experimental efforts with preferential transport have not been adapted specifically to manure to assess whether manure will also be rapidly transported.

Evans and Owens (1972) and Dean and Foran (1992) reported the application of liquid manures to tile drained fields resulted in elevated levels of nutrients and bacteria compared to normal tile discharges from unmanured sites. Fleming and Bradshaw (1992) reported maximum levels of 88.2 mg/l of NH_4^+-N, and 1020 mg/l total suspended solids; and McLellan et al. (1993) reported peak concentrations of 53,000 organisms/100 ml of *E. Coli* in tile discharges shortly after application of liquid manures which originally contained 149 mg/l NH_4^+-N and $7x10^6$ organisms/100 ml of *E. Coli*. For comparison, the accepted maximum effluent standard for most municipal wastewater treatment plants is 400 organisms/100 ml of *E. Coli* and 37 mg/l of total suspended solids. Bacteria typically range in size from 0.3 to 12 µm and protozoans such as *Cryptosporidium parvum* and *Giardia lamblia* are approximately 2-5 µm and 5-10 µm respectively (Pask, 1994). Thus, these limited observations of the occurrence of bacteria in the drain effluent may also be an indicator that these protozoa are also present. Consequently, it appears that preferential flow processes can have important implications on the fate and rapid transport of nutrients and pathogens from the applications of manures. High applications of manure solids also elevated P discharges from tile drains (Hergert et al., 1981) so regardless of the manure form, nutrient contamination of the shallow groundwater can occur. These observations indicate that transport of liquid manure contaminants may lead to high and undesirable concentrations of nutrients and bacterial pathogens to subsurface drains and subsequently into receiving water bodies.

METHODS AND MATERIALS

A field experiment was initiated at Cornell University's Willsboro Farm located in Northern New York and adjacent to Lake Champlain. The experimental plot area consists of 8 tile drained plots as shown in Fig. 1 where each plot consists of a single drain line discharging into a manhole. The plots are surrounded with a perimeter (cutoff) drain on all sides. The soil is a somewhat poorly drained Rhinebeck variant fine sandy loam (mixed mesic Aeric Ochraqualfs) which is representative of approximately 60.7 thousand hectares in New York which are primarily used for agriculture. The drainage characteristics of the Rhinebeck soil are also similar to 23 other soil series in New York which are representative of more than 400 thousand hectares of somewhat poorly drained soils commonly used for agriculture. The cropping management of these 8 plots for the past 16-20 years consisted of a corn/grass-legume mix rotation where the corn was managed as no-till and conventionally tilled (fall plow) plots. No manure was previously applied to these plots during this time. A Cornell University operated weather station is within 250 m of the plot site.

Corn (*Zea mays L.*) was planted into the 4 no-till and 4 conventionally tilled plots during the spring of 1996. Immediately after the harvest of corn silage and prior to any manure application, on 9/25/96 soil sampling to a 0.9 m depth (using 0-0.05, 0.05-0.15, 0.15-0.3, 0.3-0.45, 0.45-0.6, 0.6-0.9 m depth increment seperations) was carried out to establish a baseline of soil moisture content and soil nutrient status and availability. Four plots were pre-wetted with sprinkler irrigation (Plots # 3,4,5, and 6; 2 each of the no-till and conventional till) to establish a soil moisture differential and until drain flow

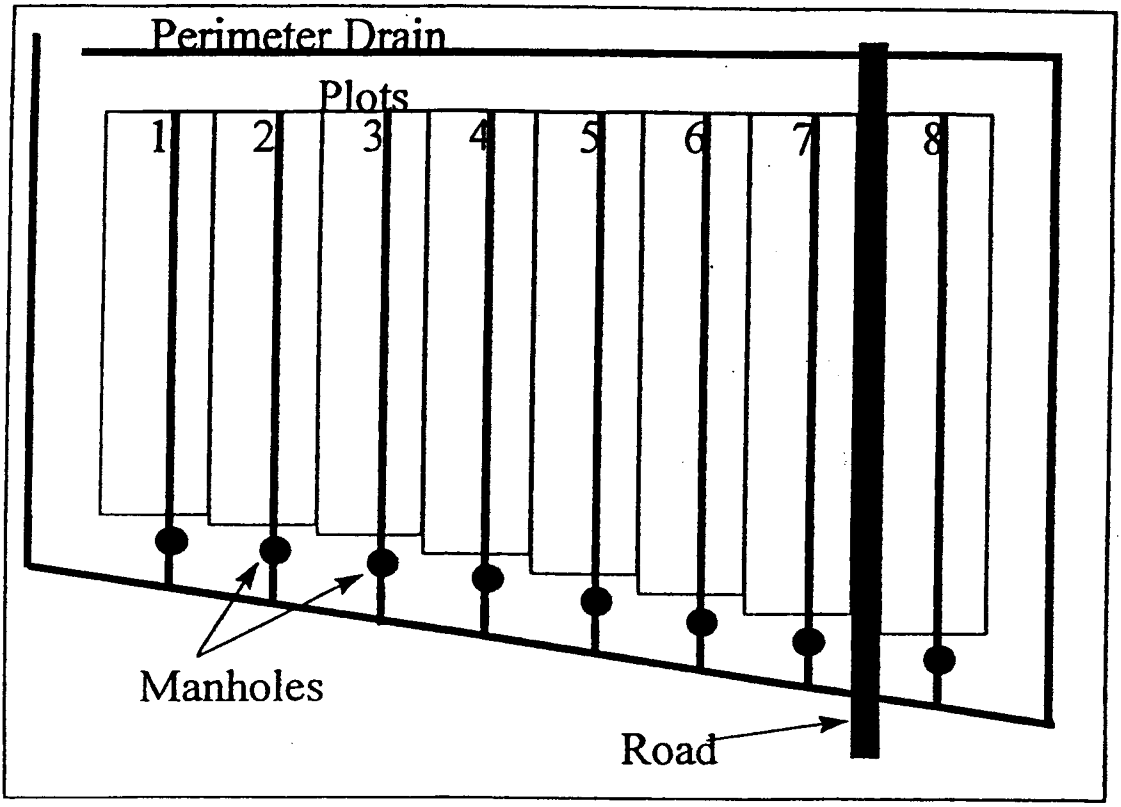

Figure 1. Schematic layout of experimental plot area at Cornell University Willsboro Research Farm.

commenced. Since no manure had been applied previously to these plots, no water samples for bacterial analysis were collected at this time to determine any background level for fecal coliform. A total of 78 mm of water was applied during the pre-wetting process in two separate irrigation events, which raised the gravimetric water content about 8 % on a dry-weight basis above that in Plots 1,2, 7 and 8.

Liquid dairy cow manure from an adjacent farm was applied with a Wic 3200 model bulk tank spreader at a rate of 47 m^3/ha (5000 gal/acre) across all 8 plots. Manure application uniformity measurements were taken several times as shown in Fig. 2, which resulted in an average uniformity coefficient of 0.66. Ten manure samples were drawn from the spreader and analyzed for its nutrient value. The liquid manure contained 6.7% solids and had a density of 1.028 g/cm^3. The nutrient content of this manure was 0.22% Nitrogen of which 0.09% was Ammonia-N, 0.07% Phosphorous, and 0.23% Potassium. The manure application rate was typical of what farmers in the area would normally spread and was selected to meet part of the nitrogen needs of the next year's corn crop.

Irrigation was initiated on Plots 1, 2, 3, and 4 within hours of manure application and before the manure had dried on the surface. The remaining four plots (Plots 5, 6, 7, and 8) were irrigated 1 week later, after the manure had an opportunity to dry on the surface. Irrigation was carried out with Rainbird 30H sprinklers which were set in a 12.2 m grid pattern providing an average application rate of 11.5 mm/hr. During and following irrigation, the drain discharge was measured and sampled using a grab sampling technique at 15 minute intervals. Irrigation was continued until all the plots exhibited drainflow. Water samples for bacterial analysis were refrigerated immediately and analyzed within 24 hours using standard water/wastewater techniques. Water samples for nitrogen and phosphorous compounds were frozen to - 4° C and analyzed at a later time. Soil sampling was again carried out following the completion of the irrigations to assist in quantifying effects on nutrient movement.

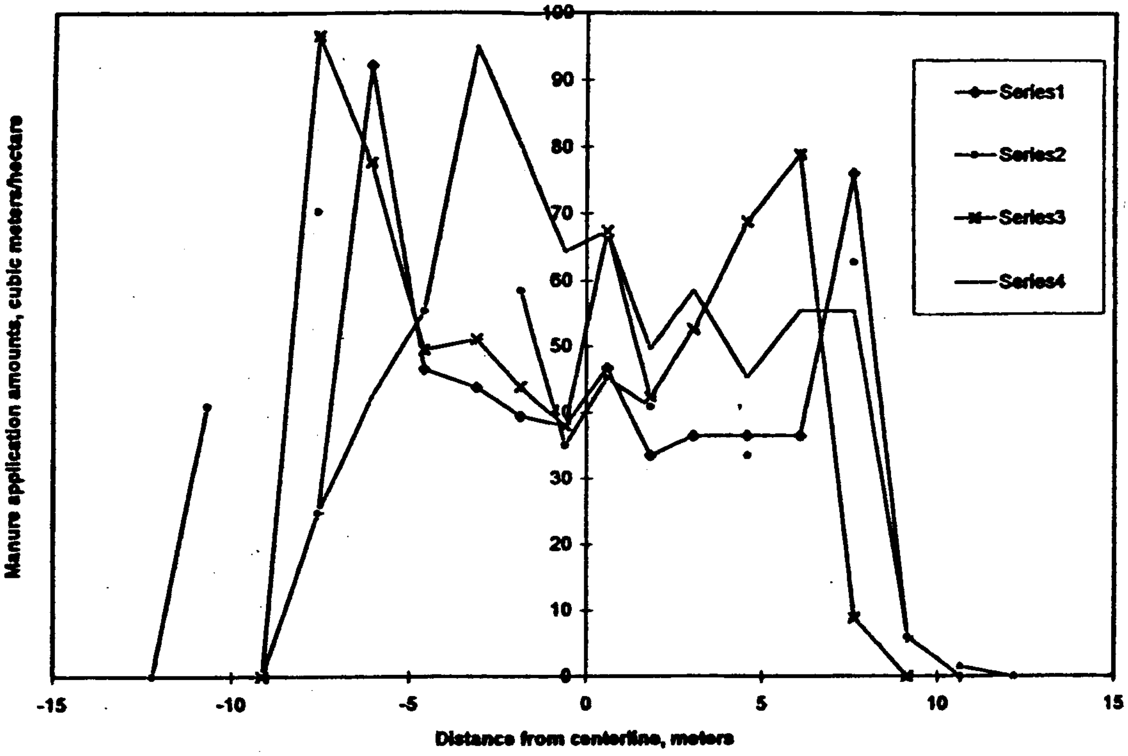

Figure 2. Liquid manure application patterns for bulk tank spreader.

RESULTS

The typical response of fecal coliform concentrations being discharged from the subsurface drain is shown in Figure 3 for Plot 4 which was irrigated within hours after the liquid manure application. Plot 4 had returned to a base flow discharge of 5 ml/s after the pre-wetting irrigation, and this was the condition during the application of the liquid manure. The preferential movement of fecal coliforms is demonstrated in the figure where the peak concentration of fecal coliforms occurred within 40 minutes after the start of irrigation and 95 minutes prior to the peak in the drain discharge. As the drain discharge began to increase, the fecal coliform concentration began to decline where it hovered around 25,000 to 30,000 colonies/100 ml until the irrigation was stopped. Smaller amounts of fecal coliforms continued to be discharged during the next 24 hours as the discharge gradually approached the previous base flow situation. The tile drainage effluent during this event exhibited the color and odor of liquid manure, and the discoloration could be directly associated with the changes in fecal coliform concentration.

Ammonium-Nitrogen from the liquid manure was also measured in the drain effluent and this likely was part of the cause of the manure odor which was perceived. Figure 4 shows that the NH_4^+-N in the drain discharge also exhibits preferential flow phenomena, reaching a peak concentration during the rising limb of the drain discharge hydrograph. Ammonium-N is generally believed to adsorb strongly to the soil but apparently preferential flow processes temporarily dominate this reaction. The similarities of fecal coliform and NH_4^+ -N preferential transport suggest that either one could be used as an indicator of the other. The data in Fig. 4 are the results of a natural rain event which delivered another 23 mm of water 2 days after the manure application.

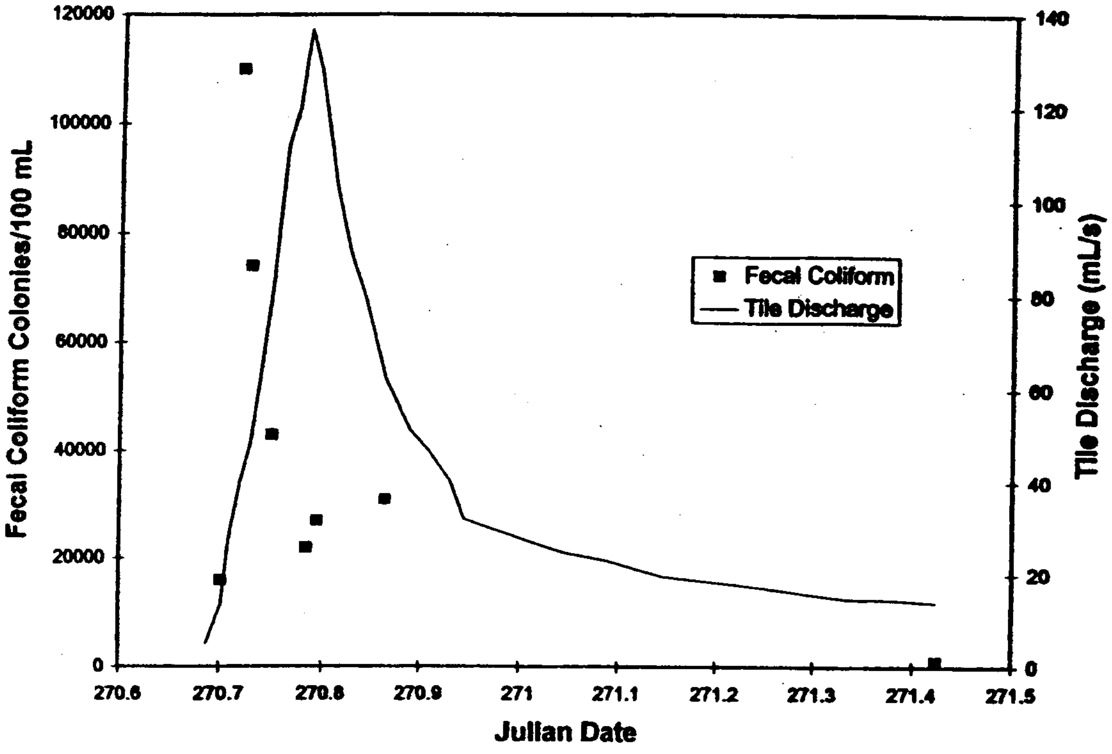

Figure 3. Fecal coliform discharge concentrations in relation to the tile discharge hydrograph for Plot 4.

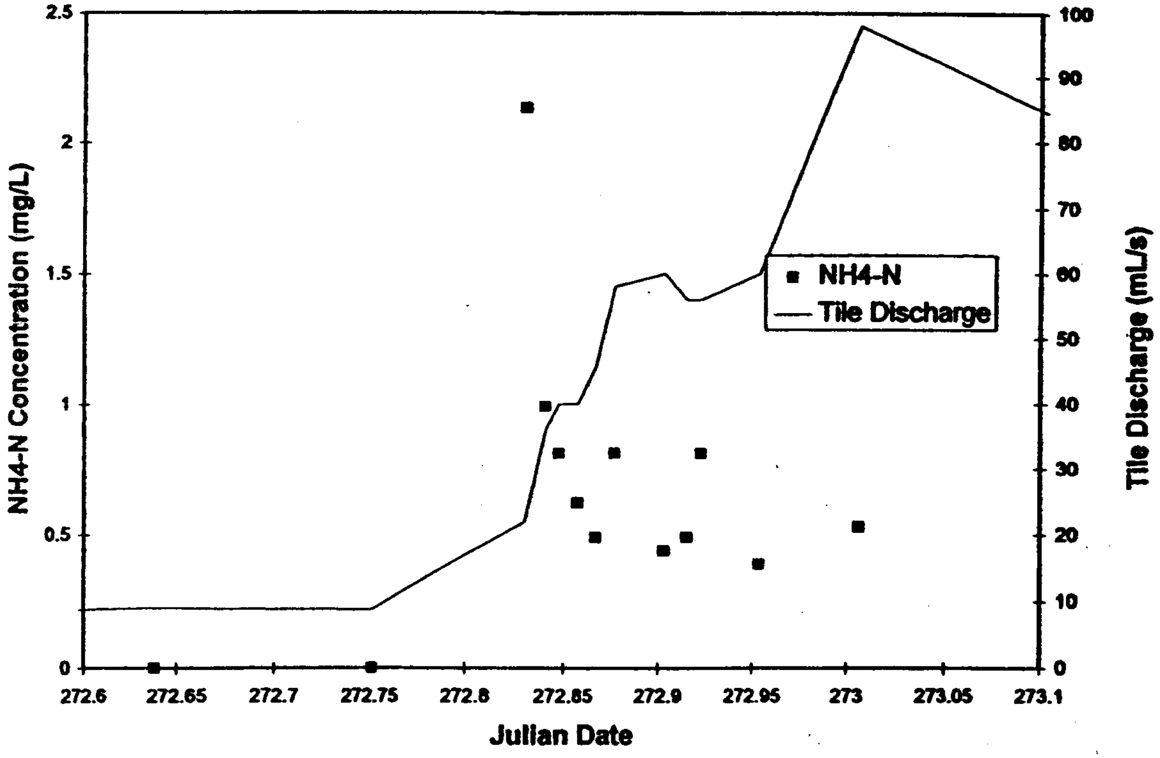

Figure 4. NH_4^+-N discharge concentrations in relation to the tile discharge hydrograph for Plot 4.

Figure 5 shows a similar response of fecal coliform bacteria concentrations in the drain discharge for Plot 5 which was irrigated 6 days after the liquid manure application. There was a natural precipitation event 2 days after the manure application which had also delivered a total of 23mm. The base flow in Plot 5 had returned to 8 ml/s prior to the start of the later irrigation event. In this case the peak concentration of fecal coliforms occurred within 65 minutes after the start of irrigation and 90 minutes prior to the peak in the drain discharge. Figures 3 and 5 show similar preferential flow responses despite the events being 6 days apart and the manure having had the opportunity to dry on the surface.. The only major difference in Figs. 3 & 5 is in the peak concentration of fecal coliform which is approximately 1/3 less. It is not clear whether this reduction in fecal coliform peak concentration is attributable to the plot variability, the leaching loss from the interim rainfall event or simply due to the 6 day delay after the manure application. Nevertheless, it is still surprising that this high a concentration was still observed given the time which had elapsed since the initial manure application.

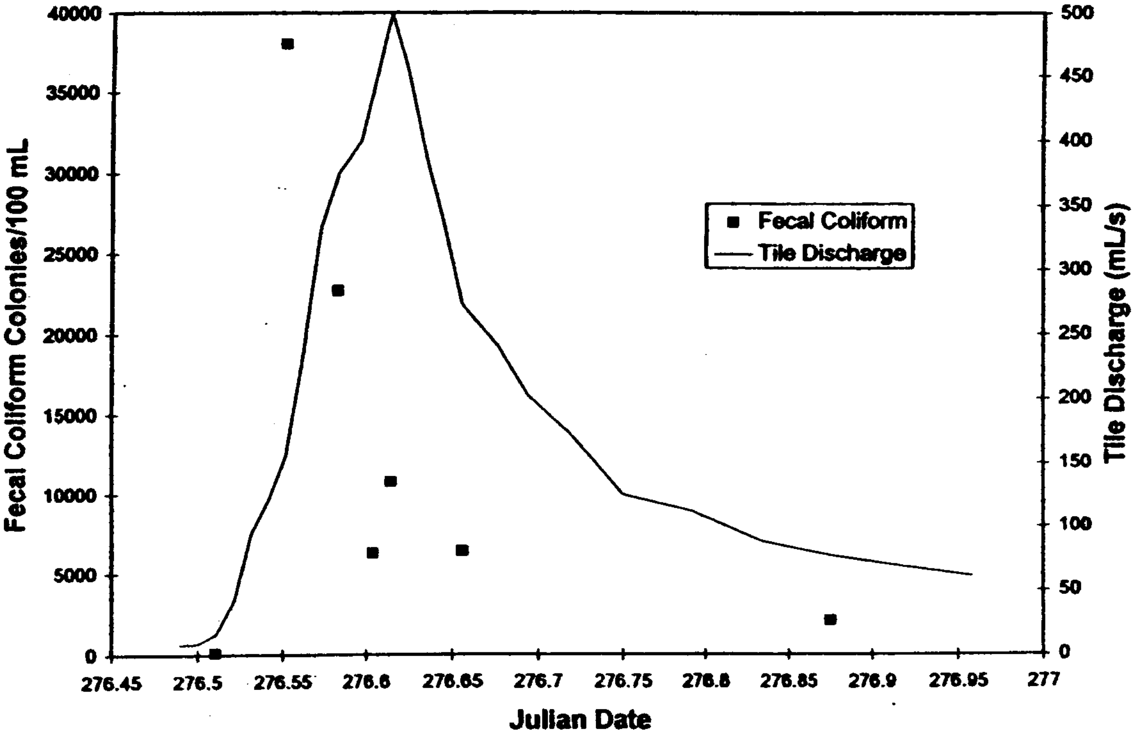

Figure 5. Fecal coliform discharge concentrations in relation to the tile discharge hydrograph for Plot 5.

Figure 6 shows the response of fecal coliform concentrations for Plots 5 & 6 which had been pre-wetted along with concentrations for Plots 7 & 8 which had not received the pre-wetting irrigations. In Plots 7 & 8 there was no drain flow during the application of the manure or prior to the irrigation event. For Plot 8 the peak fecal coliform concentration occurred 3.2 hours after the start of irrigation and 60 minutes before the peak in the drain discharge. The peak concentration for Plot 7 occurred 4 hrs. after the start of irrigation. Consequently, the major effect of pre-wetting the plots was the time elapsed from the start of irrigation to the first observance of drainflow. Plots which were pre-wetted began flowing within 40 minutes after the start of irrigation whereas the plots which were not pre-wetted required about 3 hours of irrigation to the first observance of drainflow. The concentrations of fecal coliforms in the tile discharge was not affected by pre-wetting the plots as similar peak concentrations were generally observed when both wet and dry plots were irrigated at the same time relative to the time of manure application.

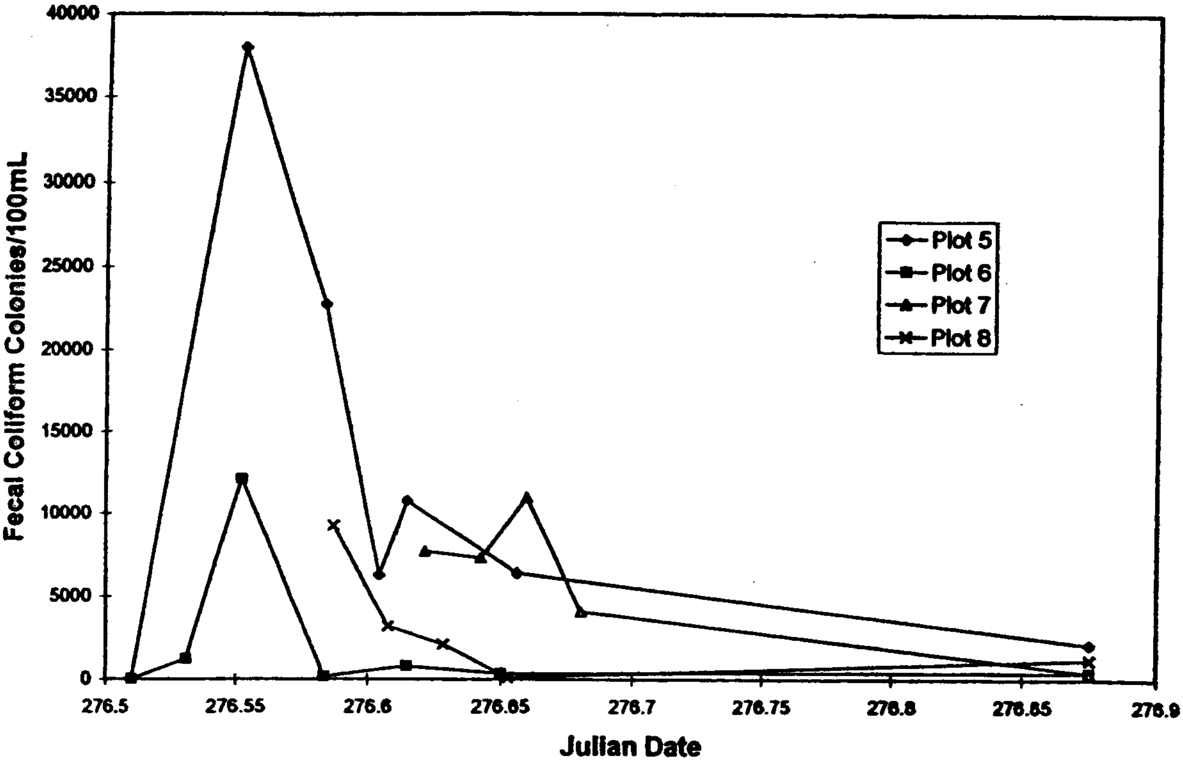

Figure 6. Fecal coliform discharge concentrations with respect to time for the pre-wetted plots (5 & 6) as compared to the dry plots (7 & 8) during the irrigation event 6 days after the manure application.

CONCLUSION

Liquid manure applied to the soil surface at nominal rates, and followed by a precipitation event, can result in bacterial contamination of a subsurface drain in soils which exhibit preferential flow characteristics. The timing of the precipitation event following the liquid manure application will influence the magnitude of the peak concentrations of bacteria such as fecal coliforms. Liquid manure which had dried on the surface did not eliminate the further risk of fecal coliform transport upon rewetting within a 6 day period. An irrigation event on the same day of liquid manure application resulted in a peak concentration of 110,000 colonies/100ml, and an irrigation 6 days after the manure application still resulted in a peak concentration of 38,000 colonies/100ml.

Given a constant precipitation rate, the initial soil moisture content at the time of a precipitation event will influence the length of time which elapses before preferential flow occurs. Liquid manure application to the soil surface when the drain is flowing will result in rapid movement (within minutes) during a precipitation event. For the case when the soil is drier and there is no drain flow, preferential movement of fecal coliform still occurred during a precipitation event when the event was extended for several hours. The peak concentration of fecal coliform did not appear to be affected by the initial soil moisture content.

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