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INFILTRATION OF FECAL BACTERIA THROUGH SOILS: TIMING AND TILLAGE EFFECTS

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INTRODUCTION

Land-applying animal wastes potentially exposes humans and animals to fecal pathogens, either by direct contact with soil and produce, or via ground water contamination. Some of these organisms are *Salmonella*, certain pathogenic *Escherichia coli* strains, protozoa such as *Cryptosporidium* and *Giardia*, and enteric viruses. Whether soil adequately filters these pathogens before they reach ground water depends on the interaction of porosity, texture, depth, water content, rainfall intensity and duration, and soil management.

Some generalizations can be made about filtration: i) it is the major limitation to pathogen movement through soil; ii) pathogens move only a few inches into unsaturated soil but much greater distances into saturated soil; (iii) the smaller the soil particle size (the finer the texture) the better the filtering of pathogens; (iv) pathogen adsorption to soil restricts movement and is affected by clay content, pH, and cation concentration in soil water.

Macropore flow (flow through those pores that drain water freely) is often used to explain how microbes can move rapidly through unsaturated soil. If you imagine the soil as being full of macropores, then you don't think of it as a filter (where everything moves at about the same rate and is affected uniformly). Instead, you think of it as a sieve with many different sized holes ranging from the very small to the very large. Water dribbles through the smallest holes and pours through the largest holes. This means that when macropore flow occurs, a lot of water (and some pathogens) move through soil without being filtered.

Agronomic practices and crop management techniques, such as manure application and no-tillage, influence soil structure and affect water movement. Soils that are well-structured have more macropore flow and more movement of both water and microbes than soils that aren't well-structured. Unfortunately, too few studies have looked at how tillage (or the lack of it) affects microbial movement. The possibility that pathogenic microbes will leach to ground water is a big concern where ground water occurs at shallow depths. Work at the University of Kentucky suggests that no-tillage, which results in more macropores, could enhance microbial movement. So, we designed a field experiment, using typical agronomic practices, to examine fecal bacteria transport through shallow no-tillage and chisel/disk soils to which dairy manure was applied at different times of the year, and to assess the survival of the fecal bacteria in manure treated soil.

METHODS

This experiment was conducted at the Kentucky Agricultural Experiment Station in Lexington between April 1993 and April 1995. The site was on a well drained Maury silt loam that had 6 treatments: 1) no-tillage, no manure; 2) no-tillage, fall manure; 3) no-tillage, spring manure; 4) no-tillage, fall + spring manure; 5) chisel disk, no manure; 6) chisel disk, spring manure.

Fresh dairy manure was surface applied with a commercial spreader before planting in late April to early May for the spring manure treatments, and after harvest in early to mid-November for the fall manure treatments. The fresh manure was 20-35% solids. Manure spreaders were calibrated to deliver approximately 4.5 tons/acre (dry weight). The actual delivery rates (all in terms of dry weight) were 4.6 tons/acre in Spring 1993, 3.8 tons/acre in Fall 1993, 5.2 tons/acre in Spring 1994, and 7.1 tons/acre in Fall 1994.

Tilled treatments were chiseled 8-10 inches deep and disked twice immediately following spring manure application. Chiseling was performed using twisted shanks on 12 inch centers. Pioneer '3279' corn was planted on 21 May 1993 and 10 May 1994 at 23,000 seeds/acre. After harvest, but before fall manure application, winter rye (*Secale cereale* L.) was drilled in 7 inch rows on all plots (about mid-November).

We collected water samples 35 inches below the soil surface and measured volume after every rain that caused leaching. We took our first samples on 14 June 1993 and continued through 15 March 1995. Within 24 hours of collecting either a soil or water sample we analyzed it for fecal coliforms. These are bacteria that indicate whether a sample has potentially been contaminated by fecal waste and are used to assess the microbiological quality of surface and ground water.

RESULTS AND DISCUSSION

Bacterial Survival in Soil

The unmanured soil had low fecal coliform counts (background level). Adding dairy manure increased their numbers enormously (Table 1). After manure application, fecal coliforms decreased to background levels in about 6 months. The fecal coliforms in manure added to soil usually began to die-off immediately, but in some seasons, death was delayed by up to 2 weeks. Fecal indicator bacteria die-off quickest in hot, dry, sunny conditions. In this study, fecal coliforms died significantly faster in fall than in spring-applied manure treatments. This was most likely due to freezing conditions, which are usually lethal for indicator bacteria. Table 2 shows the number of days it took for the fecal coliform numbers to decline by 50% in each season (the half life).

There wasn't any difference in the die-off rates due to tillage treatments after the 1994 spring manure application. Greater soil-manure contact often results in increased microbial die-off rates, but we saw almost no difference between incorporated and unincorporated manure. We suspect that die-off promoted by greater soil-manure contact in chisel/disk treatments was counterbalanced by greater ultraviolet radiation kill in no-tillage treatments. However, tillage did result in fewer fecal coliforms over time. This is partly because tilling the manure into soil helps to dilute the bacterial numbers.

Transport of Bacteria

Fecal coliform movement to at least 35 inches occurred with the first leaching rain after manure application. Fecal coliform concentrations were greater than 8000 CFU/100 mL (100 mL is about 3.4 fluid ounces) just after the spring 1994 manure application. For comparison, the primary water contact standard in Kentucky (bathing and swimming water) is only 200 fecal coliform CFU/100 mL and the potable water standard is <1 fecal coliform CFU/100 mL. Fecal coliform concentrations in leachate from manured treatments declined to non detectable levels within 60 days, and were not significantly different from unmanured treatments until the next manure application. Bacterial concentrations fluctuated frequently, however, often increasing again after the initial drop in concentration. Bacteria adsorbed to soil can become resuspended and travel significant distances under saturated conditions. In winter, ample precipitation created near-saturated soil conditions and increased water flow. This may have caused fecal coliforms that were previously adsorbed to soil particles to move into the lysimeters.

The average fecal coliform concentrations in leachate from the various tillage systems are presented in Table 3. Chisel disk treatments had consistently greater water flow overall, so they had the potential to carry more fecal coliforms through the soil profile. Overall, chisel/disk treatments tended to have higher average fecal coliform concentrations in leachate than no-tillage treatments, but these differences were small and not statistically different. Fecal coliform concentrations were greatest in the spring and fall (particularly in 1994 when manure application rates were higher), but declined to low levels in other periods.

The appearance of elevated fecal coliform concentrations with the first rain after manure application to cause leachate collection was consistent with other studies. Our results suggest that macropore flow rapidly transmitted fecal organisms from the surface past the soil matrix. The immediate potential contamination of shallow ground water from surface-applied manure was similar regardless of when manure was applied.

CONCLUSIONS

Regardless of when manure was applied, fecal bacteria moved downward to a depth of at least 35 inches in this study. This suggests that fecal bacteria could contaminate ground water in a well-structured, shallow soil. Fecal bacteria moved past the root zone as soon as rain of sufficient duration or intensity caused leaching. Macropore flow was probably the main factor contributing to the rapid fecal bacteria movement through soil. Within 60 days, water quality was back to normal because bacteria died off. In Kentucky, abundant winter precipitation facilitates percolation of bacteria toward ground water after fall manure application. This risk is less with spring manure application because of reduced water flow at this time.

No-tillage practices appear to be compatible with manure use on shallow, well-drained soils. While spring applied manure was usually a statistically significant factor in many responses, the manure by tillage interaction was not. Therefore, the benefits (increased yields) and problems (increased fecal contamination of leachate) of manure application seem to be similar in both tillage systems used in this experiment. Fecal contamination did not persist in soil. Dairy manure can be used on a long term basis without degrading the bacteriological quality of shallow water below the rooting depth, but it has potentially serious short-term effects, particularly where ground water levels are near the soil surface.

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Table 1. Concentration of fecal coliforms (Colony Forming Units per gram of soil in manured and unmanured soils.

Manure application date	Unmanured	Manured
10 May 1993	72	510,000
24 November 1993	10	660,000
20 April 1994	31	690,000

Table 2. Half lives of fecal coliforms after manure application.

Year	Period	Tillage	Half life (days)
1993	Spring	No-Tillage	7.7
	Fall	No-Tillage	5.8
1994	Spring	No-Tillage	6.9
	Spring	Chisel/Disk	6.9

The half-life is the time (in days) needed to reduce fecal coliform populations by 50%.

Table 3. The average fecal coliform concentrations in lysimeter pans installed at a depth of 36 inches as affected by manure and tillage for the eight periods of the study (April 1993-April 1995).

Comparisons		Period							
Manure	Tillage[a]	Spring 1993	Summer 1993	Fall 1993	Winter 1994	Spring 1994	Summer 1994	Fall 1994	Winter 1995
		Average Colony Forming Units per 100 mL							
Manure x tillage									
None	CD	2	4	3	<1	54	7	2	<1
None	NT	12	3	3	1	30	4	2	1
Spring	CD	18	7	15	1	221	2	2	1
Spring	NT	16	4	2	<1	148	5	2	1
Manure timing									
None	NT	22	7	3	1	110	9	2	1
Spring	NT	7	7	<1	<1	200	3	<1	2
Fall	NT	16	15	99	2	164	4	245	2
Fall + Spring	NT	55	25	45	1	2208	2	665	4

[a] CD = chisel/disk, NT = no tillage

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