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BACTERIAL QUALITY OF TILE DRAINAGE WATER FROM MANURED AND FERTILIZED CROPLAND*

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Abstract—Bacterial contamination of tile drainage water in three manured and one non-manured cropped fields was studied over a 4-year period at a large, mixed farm near Ottawa, Ontario, Canada. Concentrations of total coliforms, fecal coliforms (FC), fecal streptococci (FS) and Standard Plate Counts at 20 and 35°C, in both the drainage water and the applied dairy cattle liquid manure varied over a wide range. Bacterial concentrations in long-term winter-stored manure were much lower than in relatively fresh manure. Concentrations of FC and FS in the drainage water from the manured fields were lower than concentrations in the applied manure by 3-5 orders of magnitude. Bacterial concentrations in drainage water from all fields had low geometric mean and median values for all parameters tested. Water quality was satisfactory most of the time for recreational use or for use as a raw water source for drinking water supplies. Factors such as precipitation appeared to have a greater influence on drainage water quality than manure application. Influence of soil type on bacterial concentrations in drainage water from the manured fields was not evident. However, a lower unit-area tile outflow in coarse-textured soil compared to fine-textured soil indicated a greater potential in the former for fecal bacteria reaching groundwater beneath the tile drains.

Key words *—tile* drainage water, tile effluent, manured land, bacterial pollution, fecal bacteria

INTRODUCTION

Tile drainage water or tile effluent from agricultural land can reach water bodies, such as streams, rivers and lakes, which may be used for recreation and/or for public water supplies. It can also reach groundwater which may be a source of domestic water supplies. If this drainage water originates from cropped land that is regularly manured, a potential hazard exists due to possible release of harmful microorganisms into such water bodies.

The role of water-borne, animal-origin organisms in disease transmission has been reviewed by Decker and Steele (1966) and Diesch (1970). Based on laboratory and field experiments with silt loam and sandy soils, McCoy (1969) concluded that both the coliform and enterococci bacteria were efficiently removed during percolation through soil. Smith *et al.* (1972) concluded that filtration of irrigation water through predominantly silt loam soil greatly decreased the bacterial populations. In contrast, Evans and Owens (1972) found a 30-90-fold increase in fecal bacteria concentration in the tile effluent from a sandy clay loam pasture field within 2 h of spraying pig slurry. Bacterial concentrations returned to their normal levels within 2-3 days. Depth or layout of the drains in this study was not known. In a one-time observation, Patterson *et al. (1974)* found the water from 1.5 m deep drains in a plowed field to be cloudy and smelly within 30 min after a 0.5 cm application of pig slurry. The contamination largely disappeared within 24 h. As the medium loam soil of this field contained a "high proportion of moderately-sized stones", direct contamination of drainage water by slurry was a possibility. Long-term effect of land application of manure on bacterial quality of tile effluent has not been documented adequately before.

The objective of this study was to compare the longterm potential for bacterial contamination of tile effluents from manured and non-manured cropland.

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METHODS

The study site

Tile effluents were monitored in four, level to very gently sloping fields located about 1.5 km apart within the 1100 ha Research Farm of the Animal Research Centre near Ottawa, Canada. For discussion, the fields are identified as MCL (manured field with clay loam soil, large area), MCS (manured field with clay loam soil, small area), MSS (manured field with sandy soil, small area) and FCL (fertilized field with clay loam soil, large area) (Table 1). These fields were tile drained between 1967 and 1969 using 100 mm diameter clay pipe laid about 0.8 m deep with 18.3 m spacing between parallel lateral drains. The soil in fields MCL, MCS and FCL was poorly drained, dark-gray clay loam that was underlain by silty clay and clay of marine origin (Dalhousie Association). The predominant soil in field MSS was rapid to imperfectly drained, coarse-textured loamy sand to sandy loam (Uplands Association). Flows were measured in the three manured fields (Table 1). Daily precipitation was recorded on site.

Table 1. Details of the fields used to study the bacterial quality of tile drainage water.

Description	Field			
Nominal designation for identification	MCL Manured Clay Large	MCS Manured Clay Small	MSS Manured Sandy Small	FCL Fertilized Clay Large
Field area, ha	27.5	4.1	5.6	132
Flow monitoring	Continuous	Continuous	Continuous	None
Days of flow per year				
1975*	>71	105	>75	>119
1976	132	73	136	159
1977	119	74	152	147
1978	68	50	101	70
% of annual flow in spring				
1975	—	88	—	—
1976	>94†	100	97	—
1977	76	85	65	—
1978	95	95	98	—
Annual outflow in tile mains as % of annual precipitation:‡				
1975	—	40.6	—	—
1976	>14.2†	21.8	10.5	—
1977	20.3	14.8	4.8	—
1978	43.8	41.0	13.8	—

* 1975 data for fields MCL, MCS and FCL are for the period of mid-April to end of December.
† Excludes flow during a brief period of flooding of tile drain.
‡ Annual precipitation of 990, 935, 927 and 793 mm was recorded respectively in 1975, 1976, 1977 and 1978, compared to a long-term average of 860 mm.

The manured fields MCS, MCL and MSS were given the same treatment for a 4-year period, 1975-1978. Dairy cattle liquid manure (DCLM) was applied twice per year using the "rapid plow cover" technique (Feldman and Hore, 1971). Winter-stored manure from large, outdoor tanks was applied at the rate of 110 m^3 ha^{-1} in May before planting of silage corn. Relatively fresh manure from trenches beneath slotted floors in the barns was applied at the rate of 70 m^3 ha^{-1} in October after harvest. During the same 4-year period, the chemically fertilized field FCL was cropped to barley, alfalfa and/or silage corn. Bacterial quality of the tile effluent from field MCS was also monitored in 1972 when neither manure nor fertilizer was used for an oat crop, and in 1973 when DCLM was applied at the rate of 150 m^3 ha^{-1} in both the spring and autumn (sorghum crop).

Sample collection and analyses

From late March to early December each year, when the ground was not frozen, water samples were collected from the tile main outlets in each field. Sampling frequency varied from twice a day during high flows and during periods of manure application, to once per week during low flows. Samples were subjected to *Standard Methods* (APHA, 1971) MF procedures for the estimation of TC (total coliform), FC (fecal coliform) and FS (fecal streptococci) and for SPC (standard plate count) at 35 and 20°C.

Bacterial concentrations per gram of applied liquid manure were estimated using the above methods except for SPC at 35°C, when incubation was for a 48-h period instead of the 24-h period used for water samples. Manure dry matter was determined by drying to a constant weight at 105°C. Manure was not tested for bacteria after 1975. The source of manure was the same in subsequent years of the study.

RESULTS AND DISCUSSION

Flow in tile drains

Flow was generally related to the amount and frequency of precipitation. Most of the annual flow occurred in the spring between late March and the end of June. The remaining flow occurred essentially between October and December. Because of the humid and cool conditions during the October—June period, and the spring- and autumn-plowing of manure, chances of any fissures developing in the fields were minimal during the main period for flow in the tile drains. The annual drain outflow varied from about 5 to 44% of the annual precipitation (Table 1).

Bacterial counts in applied manure

Both the spring- and autumn-applied manures were potential sources of pollution indicator bacteria (Table 2). Compared to the relatively fresh autumn-applied manure, the winter-stored spring-applied manure had median TC values lower by two orders and median FC, FS and SPC values lower by one order of magnitude. Similar results were obtained in earlier studies (Tennant *et al.,* 1972; Toxopeus *et al.,* 1974). This reduction in pollution indicator bacteria during storage of manure without daily additions suggests that the potential for pollution of surface or ground water by land application is lower from stored manure than from relatively fresh manure.

Bacterial quality of tile drainage water

Bacterial concentrations in tile effluents are summarized in Tables 3 and 4 respectively. Table 5 shows the percentage of samples with indicator bacteria counts at various selected levels. In Table 6, bacterial quality of tile effluent in Field MCS is shown for 1972 when no manure was applied, and from 1973 to 1978 when manure was applied twice every year.

Table 2. Bacterial counts in the dairy cattle liquid manure applied to the fields.

Parameter	Median value		Range	
	Spring-applied manure	Autumn-applied manure	Spring-applied manure 22 samples	Autumn-applied manure 48 samples
% Dry matter	7.2	8.3	5.6 - 8.8	2.5 - 10.9
TC g^{-1} wet material	3.2×10^4	1.3×10^6	6.9×10^3 -2.3×10^5	1.0×10^5 -4.3×10^6
FC g^{-1} wet material	1.1×10^4	7.7×10^5	1.2×10^3 -5.2×10^4	3.4×10^4 -3.1×10^6
FS g^{-1} wet material	2.9×10^4	3.5×10^5	4.8×10^3 -3.1×10^6	4.6×10^4 -4.4×10^6
SPC 20°C g^{-1} wet material	5.8×10^6	9.5×10^7	1.2×10^6 -7.9×10^6	7.0×10^6 -3.6×10^8
SPC 35°C g^{-1} wet material	5.3×10^6	9.4×10^7	1.4×10^6 -1.3×10^7	6.0×10^6 -3.1×10^8

Effect of flow rate and precipitation. Increased bacterial concentrations in tile effluents were generally noted at all fields at times of high flows such as after heavy rainfall. However, the effect of flow rate or of precipitation on the observed bacterial concentrations was not consistent, and no precise relation could be established. This is not unexpected because of the many factors that influence bacterial survival and transport in fields. Qureshi and Dutka (1979) similarly found little relationship between the intensity and amount of rainfall and the incidence of indicator bacteria in urban storm drainage.

Comparison with manure. Comparison of bacterial concentrations in manure (Table 2) and in the tile effluent from the manured fields (Tables 3 and 4) shows that the concentrations in the effluents were 2-5 orders of magnitude lower than in the applied manure. In particular, FC were lower by 4-5 orders of magnitude and FS by 3-4 orders of magnitude. This reduction can be attributed to bacterial die-off and to the efficiency of soil as a filter medium. Even though the autumn-applied manure had higher bacterial counts compared to the spring-applied manure, no corresponding increase of counts in the tile effluents was noted in the autumn.

Effect of soil type on effluent quality in manured fields. Bacterial concentrations in effluents from the coarse-textured soil field MSS and the fine-textured soil fields MCL and MCS were similar (Tables 3 and 4). However, the annual tile flow in field MSS was only about 25-50% of the flow in fields MCL and MCS (Table 1), indicating that a greater proportion of the annual precipitation percolated to depths below the drains in the coarse-textured soil. Thus, the potential for fecal bacteria reaching the groundwater below the drains was greater in the coarse-textured soil than in the fine-textured soil.

Effect of manure vs fertilizer application. Although the range of values observed was wide, all parameters (Tables 3 and 4) had very low geometric mean (GM) and median values in both the manured and non-manured fields. Fecal bacteria in the tile effluent from the non-manured field were attributed to the native wildlife-groundhogs, mice, gulls, geese, rabbits, etc. Bacterial loads from gull droppings are significant (Gould and Fletcher, 1978). As native wildlife was also present in the manured fields, it was not possible to separate its effect from that of manure application on water quality. Compared to the unplowed, fertilized field FCL, bacteria in the manured fields had a shorter distance to reach the tile drains because manure was plowed under to a 20-30 cm depth. Bacteria were also better protected against sunlight, dehydration and loss in surface runoff in the manured fields. In spite of this, the bacterial quality of tile effluent was not greatly affected when manure instead of chemical fertilizer was used for crop production.

FC:FS ratio. Geldreich *et al. (1968)* proposed that in polluted waters an FC: FS ratio less than 0.7 indicated contamination of animal origin whereas a ratio greater than 4 indicated human origin, and ratios in between represented pollution from indeterminate sources. Feachem (1975) noted that differential die-away rates of FC and FS invalidate the use of the FC: FS ratio to distinguish between contamination resulting from human or animal sources, and that an improved estimate of pollution source can be obtained from a series of FC:FS determinations on a given sample over a period of time. There was no human fecal input in the restricted-entry study site. Table 3 shows the FC: FS values observed in this study. In the 463 tile effluent samples examined, the FC:FS ratio was > 4 in only 7 samples, <0.7 in 176 samples and had values in between in 280 samples. This suggests that when animal manure is the sole source contributing fecal bacteria to tile effluents in cropland, the FC:FS ratio seldom exceeds 4 but a value of 0.7 is frequently exceeded.

Comparison with water quality objectives and maximum permissible limits for bacterial concentrations. The percentage of samples meeting the recommended Canadian objectives and the maximum permissible limits (Department of the Environment, 1972) for TC and FC in water used for direct-contact recreation and as a source for treated drinking-water supplies is shown in Table 5. For each field, the objectives and permissible limits for FC were met respectively by at least 60 and 89% of the samples during the 4-year period. In the individual years, the non-manured field did not consistently show superior water quality compared to the manured fields. The tile effluents likely met the objectives and limits more frequently than indicated by the percentage of samples of acceptable quality because a large proportion of the samples was obtained during periods of substantial flow which are generally associated with higher bacterial counts.

Table 3. Bacterial pollution indicator bacteria in membrane filter counts per 100 ml and FC: FS ratios in tile drainage water from manured and non-manured fields.*

Field	Year	No. of samples	Total coliforms				Fecal coliforms				Fecal streptococci				FC: FS ratio			
			GM	Median	Min.	Max.	GM	Median	Min.	Max.	GM	Median	Min.	Max	GM	Median	Min.	Max.
Manured																		
MCL	1975	33	320	370	<2	480,000	23	12	<2	28,000	22	12	<2	19,000	1.05	1.10	0.02	3.6
	1976	35	54	32	<2	26,000	7	2	<2	5500	12	6	<2	8300	0.56	0.75	0.03	5.0
	1977	33	77	120	<2	8700	7	2	<2	290	14	24	<2	330	0.45	1.00	0.01	4.3
	1978	9	61	42	<2	11,000	6	2	<2	70	27	36	<2	510	0.24	0.21	0.02	3.0
	All	120	99	89	<2	480,000	9	2	<2	28,000	17	14	<2	19,000	0.55	1.00	0.01	5.0
MCS	1975	29	750	1100	4	23,000	34	20	<2	2600	69	54	<2	2600	0.49	0.71	0.10	1.1
	1976	14	31	18	<2	20,000	6	2	<2	6700	8	2	<2	8300	0.81	1.00	0.17	1.0
	1977	24	50	45	<2	2800	3	2	<2	16	11	5	<2	240	0.23	0.43	0.02	1.0
	1978	16	11	15	<2	1000	3	2	<2	20	14	15	<2	240	0.21	0.58	0.01	1.1
	All	83	89	78	<2	23,000	8	2	<2	6700	21	20	<2	8300	0.36	0.81	0.01	1.1
MSS	1975	21	590	720	50	8700	9	6	<2	170	11	12	<2	260	0.81	0.91	0.12	2.5
	1976	31	79	52	<2	40,000	9	4	<2	7000	8	2	<2	10,000	1.08	1.00	0.30	4.0
	1977	38	290	200	<2	210,000	10	4	<2	680	27	22	<2	7200	0.36	0.73	0.01	5.0
	1978	31	32	10	<2	30,000	4	2	<2	280	9	2	<2	4800	0.41	1.00	0.03	3.3
	All	121	130	110	<2	210,000	7	2	<2	7000	13	4	<2	10,000	0.57	1.00	0.01	5.0
Non-manured																		
FCL	1975	35	81	130	<2	4400	2	2	<2	68	4	2	<2	370	0.63	1.00	0.03	2.0
	1976	36	15	9	<2	4200	3	2	<2	44	6	2	<2	540	0.49	1.00	0.04	1.0
	1977	45	55	62	<2	120,000	10	2	<2	40,000	15	4	<2	50,000	0.65	1.00	0.04	3.0
	1978	23	11	3	<2	3500	5	2	<2	1100	5	2	<2	280	1.01	1.00	0.01	137.5
	All	139	33	32	<2	120,000	4	2	<2	40,000	7	2	<2	50,000	0.60	1.00	0.01	137.5

* TC, FC and FS values of <2 were taken as 2 in the calculation of the GM and the FC: FS ratio.

Table 4. Bacterial concentrations-Standard Plate Counts per ml of tile drainage water from manured and non-manured fields.

Field	Year	No. of samples	Counts at 20°C GM	Median	Min.	Max.	Counts at 35°C GM	Median	Min.	Max.
Manured										
MCL	1975	33	2700	1200	110	1,000,000	460	400	30	84,000
	1976	35	4200	5800	6	2,700,000	500	380	16	700,000
	1977	33	7400	8000	60	440,000	810	1500	39	19,000
	1978	19	8300	12,000	390	110,000	810	710	61	33,000
	All	120	4800	4400	6	2,700,000	600	450	16	700,000
MCS	1975	29	3900	2300	280	69,000	520	510	21	9200
	1976	14	1700	980	140	800,000	220	65	26	360,000
	1977	24	11,000	18,000	62	450,000	640	720	42	13,000
	1978	16	7400	16,000	360	150,000	650	890	30	22,000
	All	83	5200	3500	62	800,000	500	490	21	360,000
MSS	1975	21	960	930	110	11,000	220	260	42	1300
	1976	31	3600	3300	42	3,000,000	350	350	2	200,000
	1977	38	14,000	30,000	110	900,000	1200	1200	33	130,000
	1978	31	2300	800	120	160,000	440	260	30	18,000
	All	121	3900	3200	42	3,000,000	510	410	2	200,000
Non-manured										
FCL	1975	35	810	1000	22	47,000	100	75	12	9800
	1976	36	530	460	4	610,000	46	29	3	12,000
	1977	45	2500	1300	59	540,000	150	120	9	21,000
	1978	23	2400	1600	130	140,000	130	62	9	62,000
	All	139	1300	1000	4	610,000	98	68	3	62,000

Effluent quality before and after manure application. Results in Table 6 for field MCS show higher GM and median bacterial counts in the tile effluent during the non-manured year 1972 than in subsequent years when twice-yearly manure applications were made. The year 1972 had an abnormally high rainfall of 101 mm/month in the April to November sampling period compared to a long-term average of 84 mm/month. Rainfall for the same period in the other years ranged from 87 mm/month in 1973 to 68 mm/month in 1978. This demonstrates the strong influence of factors other than manure application, such as precipitation, on tile effluent bacterial quality. Consequently, a "safe" manure loading rate is difficult to establish, particularly

Table 5. Percent of tile drainage water samples from manured and non-manured fields with indicator bacteria counts at various selected levels.

Field	Year	No. of samples	% of samples with MF counts less than: total coliforms/100 ml 100*‡	500†	1000	5000§	fecal coliforms/100 ml 10‡	20*	100	200†	1000§	fecal strep./100 ml 10	100	1000
Manured														
MCL	1975	33	33	58	64	79	48	58	70	82	94	45	73	91
	1976	35	63	77	86	94	71	77	89	94	94	60	80	94
	1977	10	48	73	82	97	61	79	91	97	100	45	82	100
	1978	19	68	74	84	95	58	68	100	100	100	42	58	100
	All	120	52	70	78	91	60	71	86	93	97	46	72	96
MCS	1975	29	17	31	48	79	45	48	59	72	93	24	52	93
	1976	14	79	86	93	93	71	79	86	93	93	64	86	93
	1977	24	58	83	88	100	92	100	100	100	100	54	79	100
	1978	16	94	94	94	100	81	88	100	100	100	35	55	100
	All	83	54	67	76	92	70	76	83	89	96	43	69	96
MSS	1975	21	24	38	52	86	52	67	90	100	100	48	86	100
	1976	31	58	84	84	87	68	74	84	90	97	68	87	94
	1977	38	39	61	61	76	61	68	79	87	100	47	74	89
	1978	31	65	74	84	96	84	90	90	94	100	61	84	94
	All	121	48	66	72	84	67	75	85	92	98	56	82	93
Non-manured														
FCL	1975	35	40	91	94	100	97	97	100	100	100	83	97	100
	1976	36	81	92	92	100	86	94	100	100	100	72	92	100
	1977	45	60	71	82	96	67	73	82	82	96	60	73	96
	1978	23	87	91	91	100	74	83	91	96	96	78	96	100
	All	139	65	85	89	99	81	86	93	94	98	72	87	99

* Objective for direct-contact recreation water. † Permissible limit for direct-contact recreation water.
‡ Objective for raw water source for drinking water supplies.
§ Permissible limit for raw water source for drinking water supplies.

Table 6. Bacterial pollution indicator parameters and FC: FS ratios in tile drainage water from field MCS under manured and non-manured conditions.

Description		Year(s) 1972 (Non-manured)	1973, 1975-1978 (Manured)*
No. of samples		48	131
Sampling days		37	120
Total coliforms	GM	220	63
(MF counts/100 ml)	Med.	250	56
	Min.	2	2
	Max.	75,000	23.000
Fecal coliforms	GM	12	8
(MF counts/100 ml)	Med.	7	2
	Min.	2	2
	Max.	7200	9200
Fecal streptococci	GM	110	15
(MF counts/100 ml)	Med.	95	12
	Min.	2	2
	Max.	33,000	8300
FC: FS ratio	GM	0.12	0.55
	Med.	0.19	1.00
	Min.	0.01	0.01
	Max.	10.5	28.8

* Two applications per year. in May and in September—October, including the year 1974 when drainage water samples were not tested.
MF - membrane filter.

for regions where summer thunderstorms are frequent and widely scattered. However, certain management practices such as those used in this study can significantly reduce bacterial contamination of drainage water. These practices included spreading manure under dry conditions when rain was not anticipated, rapidly incorporating applied manure into soil, and avoiding excessive application rates. The application rates used in this study were twice the rate recommended locally for corn.

CONCLUSION

Under conditions similar to those of this study, the potential for bacterial pollution of tile drainage water due to manure incorporation in cropped land is not much more than that resulting from the use of chemical fertilizers, and is low most of the time.

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