THE EFFECTS OF LIVESTOCK MANURE APPLICATION AND MANAGEMENT ON SURFACE WATER QUALITY

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1.0 RATIONALE

Livestock production is an important agricultural industry in Ontario accounting for approximately 54% of farm cash receipts (approx. $3.1 billion) in 1991. The Agricultural Statistics for Ontario (1991) reported approximately 3 million swine, 0.7 million dairy cattle, 1.6 million beef cattle, and 28.4 million poultry. The disposal of the animal wastes generated by this industry can represent both a valuable agronomic resource and, potentially, an environmental liability. This study has focused on the disposal of liquid swine manure on soils managed under conservation tillage systems and examined the potential for the contamination of surface waters and methods of reducing that contamination.

The concern for the contamination of surface water by nitrogen and bacteria constituents found in manure arises from their threat to human health and wildlife habitat. Nitrate-N concerns are related primarily to infant health and in particular methaemoglobinaemia (infant cyanosis or blue baby) (Fraser and Chilvers, 1981). In recognition of this problem a safe limit of 10 mg NO_3-N L^{-1} has been established for drinking water (OME, 1992). While the evidence is less direct, nitrate and nitrite-N have also been linked with cancer by reactions leading to the formation of nitrosamines (Fraser et al. 1980). While nitrosamines are known to be very active carcinogens in animals, there is no direct evidence linking them to human cancer. A third potential drinking water health effect from nitrates, relates to malformations of the central nervous system and musculoskeletal system in infants (Dorsch et al. 1984). In addition, because nitrates are a concern for livestock health a provincial water quality guideline limit on livestock drinking water concentrations of 20 mg NO_3-N L^{-1} has been recommended for farm use.

Concentrations of ammonium in water is also a concern for wildlife populations with fish, for example, being highly sensitive to free NH_3 in water. Toxic to chronic toxicity concentrations of un-ionized ammonia for rainbow trout have been reported of 0.02 to 0.16 mg L^{-1} respectively (Thurston et al. 1984; Thurston and Russo 1983). By comparison, ammonium concentrations of up to 5 mg L^{-1} may be associated with manure spills while Spires and Miller (1978) report mean surface water runoff concentrations of 1.8 mg L^{-1} from manured fields.

The concentrations of bacterial populations in manure are such that any inputs to surface or subsurface water supplies may result in levels of contamination in the water in excess of water quality guidelines for Ontario. Ontario water quality bacteria standards for drinking and recreational use are 0 and 100 counts per 100 mL respectively of Escherichia coliform (E.coli.) and fecal coliform (OME, 1992).

The trends toward liquid manure handling systems and conservation tillage systems in Ontario have raised questions regarding the best manure management methods to achieve maximum economic yield while preventing nitrogen and bacterial contamination of tile drains and groundwater. Liquid manure application methods, application rates for different soils and crops, and the timing of application are among questions being asked by producers.

Beauchamp and Kachanoski (1990) have suggested that conservation tillage practices should work well with manure injection systems by conserving nitrogen and reducing nutrient runoff losses. In addition, chisel plowing after manure application should result in sufficient crop residues left on the soil surface to prevent significant runoff of nutrients. However, incorporation of manure into no-till cropping systems remains a problem. The authors cite a Quebec study that found when manure was used as a source of nitrogen in a no-till corn crop, poorer corn seedling emergence, weed control and an increased risk of frost damage occurred. In addition, the formation of macropores by earthworms, which is enhanced by a reduction in tillage, can increase the likelihood of manure contaminants reaching the tile drains. Research has indicated that while conventional injection methods may be effective in reducing odours and losses of ammonia to the air they may result in levels of tile water contamination equal to or greater than surface broadcasting methods (Fleming and Bradshaw, 1992).

While it is frequently assumed that bacteria are not transported great distances through the soil matrix, recent studies have suggested that bacterial transport through soil macropores may be a significant process in contamination of tile drainage waters. Patni et al. (1984) reported an increase of fecal bacteria populations in tile drain water minutes to hours after irrigation with liquid manure. In tile drains with an average depth of 75 cm Culley and Phillips (1982) observed high fecal bacteria counts for several days following fall or winter application of liquid manure. Recent studies by Dean and Foran (1991) in southwestern Ontario have further increased concerns with respect to direct transport of bacteria to tile drains from liquid manure applications. In their field studies they observed that tile drains became contaminated with fecal coliform shortly after liquid manure application for 9 of 12 events monitored. In these studies, tillage of the soils prior to manure application appeared to disrupt macropore continuity and prevent bacteria transport to the tile drains.

The role of macropores in the transport of surface applied nutrients is not yet well understood and is of particular concern for no-till fields where agricultural amendments are usually applied to the soil surface and macropore systems are not subjected to periodic disruption by tillage (Shipitalo et al. 1990). The lack of disturbance or disruption by tillage, which is associated with no-till systems, has also been shown to result in increased earthworm activity that can significantly contribute to macropore formation (Beven and Germann 1982; Edwards et al. 1988). The phenomenon of preferential flow by macropores acts to conduct water and solutes quickly to significant soil depths without the soil matrix being saturated (Beven and Germann, 1982; Thomas and Phillips, 1979). Measurement has been limited of the magnitude of nutrient losses by preferential flow in unsaturated soil and accompanying solute transport variability from a field scale under no-till management.

Objectives:

In a joint effort between Agriculture and Agri-Food Canada, the Upper Thames River Conservation Authority, the Ontario Ministry of Agriculture Food and Rural Affairs, and the Ontario Ministry of the Environment and Energy this study was conducted with the following objectives:

1) to evaluate several manure management application techniques and timing of application used in conservation management systems to determine the best method to minimize downward movement of nutrient and bacteria to tile drains;

2) to compare fuel consumption requirements of manure management application techniques and recommend practices with field scale testing;

3) to formulate remedial steps for reducing nutrient and bacteria contamination of tile drains.

2. METHODOLOGY:

The approach taken to meet the above objectives involved two primary phases : 1) Microplot Study and 2) Field Scale Study. The microplot study was completed prior to the field scale study and was meant to function as a screening process where methods of manure application would be selected to test in the field scale portion of the project. In addition, studies were completed to: 1) compare draft and fuel requirements for the manure application systems being tested and 2) carry out erosion model calibration. The methods employed in these four study components are described in following sections.

Microplot Study

Microplot studies (1 m^2 plots) were used to compare surface and subsurface transport of nutrients and bacteria from the application of liquid manure by 6 different methods under two different conservation tillage systems. Transport of bacteria was measured from simulated and natural rainfall events for two months from the time of manure application.

A corn field with a history of conservation management and silt loam soils was selected in the Kintore watershed of Oxford County. A 50 metre by 30 metre area was identified which was divided into a no-till and minimum tillage systems. Within this area, 30 one-metre square plots, in three rows of ten, were established with four of the ten plots within each row located on no-till soils and 6 on minimum tillage soils. Individual plots were separated from adjacent plots by a five metre buffer. Each row was a complete block and contained all treatments. While each of the 4 treatments within tillage type were randomly assigned to columns, each row was identical. As the plots were located in such close proximity to one another, it was not physically possible to apply a different treatment to plots within a column. Consequently, the individual plots were not considered true replicates, but rather subsamples. To determine plot to plot homogeneity, each plot was characterized and samples collected at varying depths for particle size analysis (soil texture), pH, organic matter content, and carbonate content.

Beneath each plot, subsurface drainage was installed at a depth of 45 cm with three two-inch tiles inserted into the soil profile parallel to one another at the natural field gradient without disturbing the overlying soil. This was accomplished by excavating pits adjacent to each plot on the down slope side and drilling holes horizontally beneath the plots. Covered collection buckets were then buried in the soil at the down slope end of each tile. An access tube originating at the soil surface was inserted through the lid to the bottom of the bucket. The area surrounding the buckets and access tubes was back filled and the ground levelled to its original elevation.

On both the no-till and minimum tillage plots, liquid swine manure was applied at a rate of approximately 90000 L ha^{-1} (8000 gals ac^{-1}), a typical application rate in the area which met the nitrogen requirements of the crop. The three different techniques used were: 1) surface applied with no cultivation; 2) conventional injection with no additional cultivation; and 3) injection by a modified injection system which cultivates the soil immediately prior to manure injection. Minimum tillage plots received two additional treatments which included: 1) surface application followed by cultivation and 2) conventional injection followed by cultivation. Environmental control plots on to which nothing was applied, were included under both tillage systems to serve as comparisons. A tracer E.coli bacteria was added to the applied manure to allow for the easy identification of manure in samples.

On the day following manure application, rainfall simulation experiments (Tossell et.al., 1987) were carried out on each of the one-metre squared plots. Metal edges and troughs were installed around each of the plots to isolate them from the surrounding soil and to collect surface runoff. During the rainfall simulation, 40 mm (1.5 in.) of rain was applied over a 15 minute period approximating a 1 in 50 year storm. Surface runoff water was collected from the trough located on the downslope side of the plot and the tile drains were monitored, by means of a vacuum pump connected to the access tubes, over a 30 minute period or until no flow was detected. Total volumes collected were recorded and samples taken for nutrient, bacterial and sediment analysis.

The complete experiment was conducted in the Spring (May) of 1992 and repeated in the Spring of 1993 at which point the treatments were reassigned randomly to columns within tillage blocks. Rainfall simulation experiments were conducted on the day following manure application and repeated on each of the plots 40 days following manure application in 1992, and 20 days following manure application in 1993.

Samples were collected and analyzed for nutrients and bacteria from the tile monitoring system following natural events for a period of two months after manure application.

A univariate analysis was carried out on each of the response variables and indicated that a log transformation was required to achieve a normal distribution. However, total N and total P variables were not log transformed as 0 values were present. Analysis of variance and LSD means separation were used to test for significant differences (at 5% level of significance) between application methods. Data was analyzed within the two tillage types (no-till and minimum till), between tillage types and within and between months (May and June). Two years of data and three replications for each month were included in the analysis.

Field Scale Study

A field was selected near the location of the microplot study which contained 12 parallel tile lines under no-till (NT) corn crop management. The degree of tile contamination following manure application observed in the Microplot Study phase was less severe under minimum tillage (MT) management and consequently the Field Scale Study focused on no-till management conditions. Tile drains were intercepted in a perpendicular transect spanning the field and 22 L buckets inserted into the tile lines (Figure 1). Small water pumps (2270 litres h^{-1} capacity) were placed in the buckets and monitored using a Campbell Scientific CR10 datalogger. Flow rates in the tiles were determined from the frequency and duration of the pump operation.

Manure was applied using the three application methods tested on the NT soils during the microplot phase of the study; (1) surface spreading, (2) conventional injection, and (3) modified injection (loosening the soil ahead of the injectors). In addition to the application treatments control plots were established. Both the control plots and each of the application methods were replicated 3 times. Manure was applied over each tile line in two passes covering a width of 8 m for 60 m of tile length. The manure applied had a bacterial and chemical (bromide) tracer added prior to application.

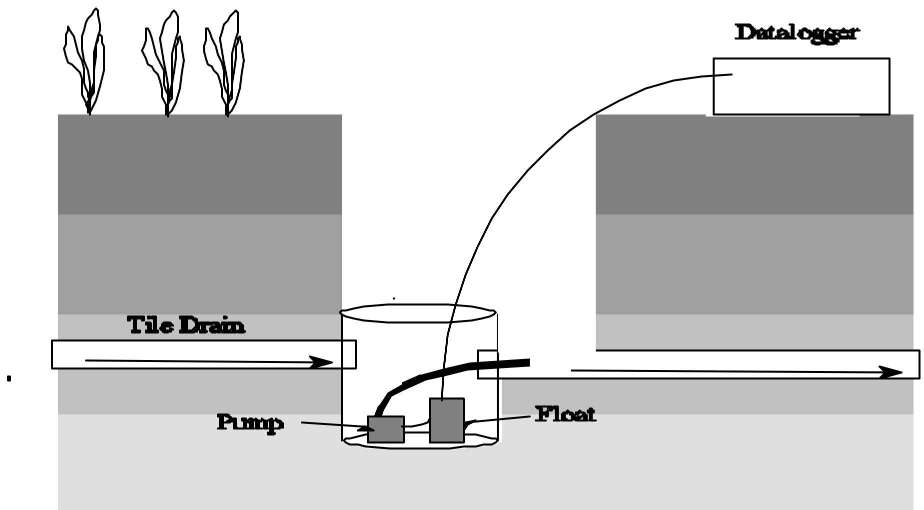

Figure 1: Tile drain monitoring installation for field scale study.

Following the application of manure the tiles were monitored every 15 minutes and sampled for flow rate, nutrients and bromide content for a period of three hours. Nutrient analysis included total nitrogen, ammonium and nitrate, total phosphorous, and soluble phosphorous. Samples were collected from the tile outflow for bacterial analysis at 30, 90 and 120 minutes following manure application. Bacterial analysis included fecal coliform, E. Coli. and the tracer bacteria.

On the day following manure application, the field was irrigated using a travelling gun. A sampling scheme was initiated immediately after irrigation of each tile line, identical to the one used following manure application. An ISCO automated water sampler was used at each of the tile lines to collect samples every 3 hours the subsequent night and for 5 days following plot irrigation.

A univariate analysis was carried out on each of the response variables for the Field Scale Study and indicated that a log transformation was again required to achieve a normal distribution. Total N and total P variables were not log transformed as 0 values were present. Analysis of variance and LSD mean separation were used to test for significant differences (at 10% level of significance) between application methods. Since several of the tiles received less than the complete amount of irrigation water, a covariate which accounted for this difference was included in the analysis where it was found to be significantly related to the response variable.

Draft and Fuel Consumption Comparison

Comparisons of draft and fuel consumption between methods of manure application were carried out in cooperation with Dr. N. McLaughlin of the Research Branch, Agriculture and Agri-Food Canada, Ottawa. A field experiment was conducted on two soil-crop conditions, alfalfa stubble and barley stubble, to measure draft and fuel consumption for each of the three manure application techniques used in the field scale study of the project. These measurements were made with Agriculture Canada's instrumented research tractor in August of 1993. Measurements were made at two speeds (4.3 and 6.5 km h^{-1}) over 30 m plots and were replicated five times. A correction factor of 0.95 kN per 1% slope was applied to the draft calculations to compensate for the effect of plot slope on the measured draft.

Erosion Modelling

Results of the surface runoff from the microplot study were used to calibrate CREAMS and compare predicted runoff values with observed values. CREAMS (Chemicals Runoff and Erosion from Agricultural Management Systems) is a process based model which predicts hydrology, erosion, chemicals and nutrients losses from continuous simulation. Data collected from the control plots under no-till and minimum tillage conditions were used for this purpose.

3. FINDINGS:

The findings of this study have been organized into sections relating to the major components of the project as they were outlined in the previous section. The results of the Microplot Study component have been further divided into surface runoff and subsurface (tile drains) data.

Microplot Study

The characterization of each of the microplots indicated that there was an acceptable level of variance between them. A summary of the soil particle size characteristics, averaged over all of the plots, is presented in Table 1.

Table 1: Summary of soil particle size analysis averaged for all plots.

Horizon	Sand	Silt	Clay
A	28.03 ± 3.01	53.80 ± 1.78	18.20 ± 1.73
B	33.43 ± 7.95	48.00 ± 6.52	18.60 ± 5.00
C	39.93 ± 10.72	44.50 ± 6.81	15.60 ± 6.12

Means ± one standard deviation.

Surface Runoff

A summary of the data for the surface runoff component concentrations and loading results is presented in Tables 2 and 3 respectively. Data for 1992 and 1993 have been combined as no statistical difference was observed for each of the variables between years. Data collected from the rainfall simulation experiments conducted immediately following manure application (May) indicated that on the NT soils the total runoff was least from the plots treated with the modified injection technique. Concentrations and total loads of ammonium measured in the surface runoff were significantly higher for the surface application treatment. Similarly, the phosphorous loads collected from the plots treated with the surface application technique were significantly higher than all other treatments. The concentrations of tracer bacteria in the surface runoff from the plots treated with manure showed no significant difference between the three treatments used on NT soils. The total loads of tracer bacteria observed in the surface runoff were significantly lower for the modified injection method compared to conventional injection and surface applied techniques.

Results from the rainfall simulation experiments conducted in June on the NT plots showed the conventional injection technique to produce the highest quantity of runoff (18.6 L) and the surface application technique to produce the lowest (10.2 L). Similarly, total nitrogen concentrations and loadings were highest for conventional injection and lowest for surfaced applied. While not statistically different, concentrations and total loadings of ammonium in surface runoff were lowest for the modified injection method and highest for conventional injection and surface applied techniques. Tracer bacteria levels were very low in June of 1993 (20 days after manure application) and not present at all in the samples collected in June of 1992 (40 days after manure application). No significant differences were observed for this data.

The total volume of water and nitrate concentrations collected from surface runoff were significantly higher in June compared to May. Conversely, the total concentrations of ammonium were significantly higher in May (5.4 mg L^{-1}) compared to June levels (1.9 mg L^{-1}).

Rainfall simulation experiments conducted on MT plots in May (24 hours following manure application) indicated that ammonium concentrations in surface runoff were significantly higher for the surface application method (11.3 mg L^{-1}) compared to the conventional injection (4.7 mg L^{-1}) and the modified injection (3.2 mg L^{-1}) methods. The conventional injection followed by cultivation and surface applied followed by cultivation resulted in the lowest total phosphorous and ammonium loadings in the surface runoff, although these differences were not significant.

The June rainfall simulation data (92/93) from the MT plots indicated significantly lower concentrations of nitrate in surface runoff from the modified injection (13.7 mg L^{-1}), conventional injection (12.5 mg L^{-1}), and conventional injection followed by cultivation (12.5 mg L^{-1}), when compared with the surface application method (19.9 mg L^{-1}). Ammonium concentrations were also highest for the surface application method and lowest for the modified injection method although these results were not significant. Similarly the lowest loadings and concentrations of total phosphorous resulted from the modified injection method and the conventional injection method followed by cultivation (not significant).

Table 2: ANOVA results of 1992/93 microplot study data - Surface runoff water concentrations

MONTH	TILLAGE	VARIABLE	UNITS	TREATMENTS C	MI	CI	NI	CIC	I	p-value
MAY	NT	Water Vol.	ML	14517.50 a	1878.33 b	4041.67 c	7605.00 d			0.0000
		TOTAL N*	mg/L	6.37 a	10.64 ab	23.78 bc	50.01 c			0.0085
		TOTAL P*	mg/L	2.44	2.20	6.49	6.53			0.3740
		NH4 N	mg/L	0.35 a	5.47 b	6.02 b	11.92 c			0.0000
		N03_N	mg/L	5.31 a	5.26 a	5.99 a	3.31 b			0.0059
		ORTHO P	mg/L	0.22 a	0.12 a	0.14 a	1.80 b			0.0004
		Fcoli	#/ 100 mL	150.00 a	64250.00 b	35116.67 b	25733.33 b			0.0021
		Ecoli	#/ 100 mL	150.00 a	61310.00 b	31916.67 b	22116.67 b			0.0858
		Tracer Bact	#/ 100 mL	133.33 a	33383.33 b	27100.00 b	10916.67 b			0.0001
	MT	Water Vol.	mL	2719.17	1831.67	2558.33	2913.33	796.67	1153.33	0.3214
		TOTAL N*	mg/L	7.41	10.26	13.03	18.22	10.25	81.10	0.3747
		TOTAL P*	mg/L	2.12 a	6.18 b	5.49 b	5.82 b	4.43 ab	3.68 ab	0.1003
		NH4 - N	mg/L	0.82 ab	3.17 abc	6.00 cd	11.32 d	0.74 a	5.74 abc	0.0504
		N03 N	mg/L	5.11	3.92	4.74	4.16	4.46	4.63	0.8200
		ORTHO P	mg/L	0.23	0.72	0.31	0.20	0.21	0.19	0.5400
		Fcoli	#/100 mL	55.00 a	21866.67 cd	333.33 b	119233.33 d	450.00 ab	7016.67 bc	0. 0002
		Ecoli	#/100 mL	55.00 a	18733.33 cd	183.33 ab	111950.00 d	450.00 abc	6485.00 bc	0.0053
		Tracer Bact	#/100 mL	55.00 a	21600.00 d	1233.33 b	40210.00 d	525.00 b	7966.67 bc	0. 0002
June	NT	Water Vol.	ML	12141.67 ab	11847.50 a	18631.67 b	10240.00 a			0.1575
		TOTAL N*	mg/L	31.45 a	37.67 a	52.53 b	26.82 a			0.0340
		TOTAL P*	mg/L	7.57 ab	11.83 bc	15.10 c	6.32 a			0.0080
		NH4 - N	mg/L	2.04 a	1.15 b	1.88 ab	1.99 ab			0.1579
		N03-N	mg/L	21.32	21.16	16.69	29.70			0.3585
		ORTHO P	mg/L	0.07 a	0.59 b	0.51 b	0.30 b			0.1282
	MT	Water Vol.	mL	20589.17	9103.33	9846.67	12525.00	9245.00	14601.67	0.5686
		TOTAL N*	mg/L	33.70	22.28	30.55	32.92	32.52	27.52	0.8509
		TOTAL P*	mg/L	12.48	8.28	11.67	11.43	10.88	11.03	0.8288
		NH4 - N	mg/L	0.69	1.00	1.24	1.54	1.09	1.21	0.7779
		N03 N	mg/L	10.84 a	13.70 ab	12.47 ab	19.91 c	12.54 ab	16.72 abc	0.0217
		ORTHO P	mg/L	0.15	0.10	0.14	0.05	0.21	0.60	0.1069

* Indicates data was not log transformed for statistical analysis
Different letters indicate statistical difference within rows [LSD 0.05]

Treatments:
C - Control
MI - Modified Injection
CI - Conventional Injection
NI - Sufrace Applied (non-incorporated)
CIC - Conventional inject then cultivate
I - Surface apply then cultivate

Tillage:
NT - Notill
MT - Minimum Tillage

Table 3: ANOVA results of 1992/93 microplot study data - Surface runoff water loadings.

MONTH	TILLAGE	VARIABLE	UNITS	TREATMENTS C	MI	CI	NI	CIC	I	p-value
MAY	NT	TOTAL N*	mg	**85.523 b**	18.606	91.718	345.242			0.0006
		TOTAL P*	mg	34.486 b	4.179 a	24.989 b	49.834167 b			0.0002
		NH4 N	mg	5.21597 a	7.387 ab	23.2788 b	92.130417 c			0.0001
		N03_N	mg	76.559 b	9.59626 a	23.9989 b	25.481289 c			0.0002
		ORTHO P	mg	3.0708 b	0.134 a	0.531933 a	13.780667 c			0.0000
		Fcoli	#	1846.167 a	63517.83 ab	121621.7 bc	202687.17 c			0.0132
		Ecoli	#	1846.167	55631.3	112382.8	176926.67			0.2312
		Tracer Bact	#	1636.833 a	29208.5 b	99273.17 c	86928 c			0.0006
	MT	TOTAL N*	mg	14.66925	19.3445	36.97183	57.139736	6.802667	110.1837	0.5802
		TOTAL P*	mg	4.190833	9.328	12.66783	17.308542	3.426417	4.203583	0.3338
		NH4 N	mg	1.884141	6.661613	68.3	27.62476	0.33566	5.923073	0.4292
		N03_N	mg	14.21791	6.54671	5.302883	14.042347	4.03502	5.571607	0.4711
		ORTHO P	mg	0.554708	1.359717	1.465033	0.5987	0.202067	0.160767	0.5723
		Fcoli	#	87.04167 a	26264.33 cd	1651.667 ab	317905.33 d	119.3333 ab	11188.17 bc	0.0010
		Ecoli	#	87.04167 a	18945 bc	1033.833 a	296040.67 c	119.3333 a	10303.27 ab	0.0066
		Tracer Bact	#	87.04167 a	37389 c	2526.833 ab	104476.27 c	238.8333 ab	10091.17 bc	0.0024
June	NT	TOTAL N*	mg	392.7642 a	395.7848 a	1028.786 6	282.98067 a			0.0302
		TOTAL P*	mg	90.53983 a	111.5868 a	283.4492 b	63.538333 a			0.0140
		NH4 - N	mg	29.05395	10.87951	49.04172	13.359849			0.2375
		N03-N	mg	291.7297	201.5764	355.4061	313.63394			0.9094
		ORTHO P	mg	0.8542	5.6947	13.24162	3.5220667			0.0883
	MT	TOTAL N*	mg	284.559	186.7173	295.1763	379.36017	239.212	231.9892	0.3740
		TOTAL P*	mg	175.689 c	71.55067 a	112.0108 abc	138.43217 bc	76.68 ab	116.1948 abc	0.23241
		NH4 - N	mg	16.58415	13.949	11.58303	21.493393	16.584	30.41	0.1542
		N03-N	mg	176.625	128.9392	121.5005	255.40637	90.577	254.5884	0.8840
		ORTHO P	mg	2.2	0.58835	1.417133	0.6238833	2.2264	15.65073	0.3140

* Indicates data was not log transformed for statistical analysis
Different letters indicate statistical difference within rows [LSD 0.05]

Treatments:
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Subsurface Results

Tables 4 and 5 summarize the results of the tile drain concentrations and loadings of nutrients and bacteria collected from the microplots. Total volumes of water entering the tile drains were found to vary considerably between treatments and rainfall simulation experiments. The volumes collected sometimes exceeded levels considered reasonable given the quantity of water being applied. Consequently, it is suspected that water and possibly liquid manure may have entered the tile water collection system from outside the meter squared plots. Therefore, the results from the subsurface collection must be primarily interpreted in a qualitative manor and with caution.

Ammonium concentrations observed in the water collected from the tile drains for the NT plots in May (24 hours following manure application) were lowest for the modified injection (10.5 mg L^{-1}) and conventional injection (10.7 mg L^{-1}) techniques but were not significantly lower than the surface application method (19.4 mg L^{-1}), (see Table 4). Similarly total nitrogen concentrations were highest for the surface application method (27.6 mg L^{-1}) and lowest for the modified injection method (14.2 mg L^{-1}), although the differences were not statistically significant. F. Coli and E. Coli concentrations and loadings were highest for modified injection method although not significantly higher than the conventional injection and surface applied techniques. Bacterial contamination concentrations and loadings for all manure application methods on the NT plots were in the order of 10^5 and 10^6, respectively. Similar tracer bacteria concentrations in the tile outflow indicated considerable downward movement of manure contaminants from the surface 0-15cm (depth of manure application) to the 45 cm tile depth.

The June rainfall simulation experiment data for the NT plots indicated that the modified injection (1.2 L) and conventional injection (0.8 L) methods resulted in the lowest quantities of water reaching the tiles compared with the surface applied treatment (4.4 L) that did not have a disturbed soil surface. The highest concentrations of nitrates resulted from the modified injection and conventional injection method with the surface applied method being significantly lower than the conventional injection method. Plots which had received conventionally injected manure in May had significantly higher concentrations of nitrate in the tile drain waters in the June experiment compared with the surface application treatment plots (83.7 mg L^{-1} and 57.5 mg L^{-1}, respectively).

Results obtained from the rainfall simulation experiments conducted on the MT plots in May (24 hours following manure application) indicated that the modified injection and surface application followed by cultivation treatments produced the highest concentrations of ammonium, yet surface applied and conventional injection followed by cultivation resulted in the lowest. These results were not, however, statistically significant. Similarly, the modified injection and surface applied followed by cultivation techniques produced the highest concentrations of bacterial contamination and conventional injection followed by cultivation resulted in the lowest.

The June rainfall simulation experiments on the MT plots indicated that the modified injection resulted in nitrate concentrations which were significantly higher than the surface applied and the conventional injection followed by cultivation treatments.

Table 4: ANOVA results of 1992/93 microplot study data - Tile drain water concentrations

MONTH	TILLAGE	VARIABLE	UNITS	TREATMENTS						p-value
				C	MI	CI	NI	CIC	I	
MAY	NT	Water Vol.	mL	11792.00	6622.50	5487.50	11051.67			0. 6355
		TOTAL N*	mg/L	16.86	14.20	15.58	27.62			0.4367
		TOTAL P*	mg/L	3.74	1.79	2.71	4.20			0.5985
		NH4 N	mg/L	0.48 a	10.49 b	10.71 b	19.43 b			0.0000
		N03_N	mg/L	7.91	7.31	8.07	4.41			0.4827
		ORTHO P	mg/L	0.21	0.19	0.14	0.85			0.2235
		Fcoli	#/100mL	1320 a	1002550 b	347767 b	360583 b			0.0267
		Ecoli	#/I00mL	1280 a	1002433 b	292150 b	306867 b			0.0463
		Tracer Bact	#/100mL	1040 a	718797 b		283867 b			0.1675
	MT	Water Vol.	mL	9351.00	6945.83	5003.50	10584.33	3389.00	11645.67	0.7292
		TOTAL N*	mg/L	17.83	26.72	9.51	18.12	13.40	17.12	0.7983
		TOTAL P*	mg/L	4.67	5.38	2.06	1.47	3.10	4.02	0.7072
		NH4 - N	mg/L	1.34 a	12.96 bc	7.60 ab	4.26 a	2.89 a	17.28 c	0.0249
		N03 N	mg/L	6.81	3.90	5.17	4.96	3.49	4.93	0.3820
		ORTHO P	mg/L	0.31 a	0.71 b	1.18 b	0.16 a	0.47 a	0.36 a	0.1044
		Fcoli	#/100mL	1238 a	717683 b	537833 b	304377 b	330240 b	350840 b	0.0225
		Ecoli	#/100mL	1188 a	716783 b	406000 b	254177 b	232220 b	261200 b	0.3200
		Tracer Bact	#/100 mL	604 a	436300 b	282050 b	163840 b	210100 b	164171 b	0.0187
June	NT	Water Vol.	mL	1314.17	1194.00	756.67	4421.50			0.2302
		TOTAL N*	mg/L	1.52	2.17	2.50	3.56			0.5784
		TOTAL P*	mg/L	1.94	1.62	2.48	1.42			0.3773
		NH4 - N	mg/L	3.26	1.76	3.20	3.99			0.7987
		N03-N	mg/L	30.49 a	68.68 bc	83.73 c	57.54 b			0.0169
		ORTHO P	mg/L	0.24	. 0.42	0.20	0.23			0.7233
	MT	Water Vol.	mL	5676.00	2634.17	1042-67	8204.17	7558.00	5863.33	0.7646
		TOTAL N*	mg/L	3.50	3.88	5.56	0.82	2.00	2.07	0.4280
		TOTAL P*	mg/L	2.54	2.40	1.22	1.56	1.77	0.99	0.3863
		NH4 - N	mg/L	0.42	2.89	0.87	0.41	0.79	1.61	0.3568
		N03 N	mg/L	14.35 a	121.05 c	50.40 bc	51.22 b	41.84 b	62.76 bc	0.0137
		ORTHO P	mg/L	0.11 a	0.44 a	0.17 a	0.12 a	0.73 b	0.06 a	0.0776

* Indicates data was not log transformed for statistical analysis
Different letters indicate statistical difference within rows [LSD 0.05]

Treatments:
C - Control
MI - Modified Injection
CI - Conventional Injection
NI - Sufrace Applied (non-incorporated)
CIC - Conventional inject then cultivate
I - Surface apply then cultivate

Tillage:
NT - Notill
MT - Minimum Tillage

Table 5: ANOVA results of 1992/93 microplot study data - Tile drain water loadings

MONTH	TILLAGE	VARIABLE	UNITS	TREATMENTS C	MI	CI	NI	CIC	I	p-value
MAY	NT	TOTAL N*	mg	112.59	132.44	109.00	3000.16			0.399
		TOTAL P*	mg	15.28	12.41	18.37	33.83			0.4656
		NH4 N	mg	5.63 a	139.28 b	90.22 b	222.74 b			0.0167
		N03_N	mg	80.31	42.32	39.13	34.06			0.6692
		ORTHO P	mg	2.20 ab	0.78 a	0.37 a	4.98 b			0.1392
		Fcoli	#	26900	1.2E+07	3470000	5570000			0.2487
		Ecoli	#	25900	1.2E+07	3070000	5360000			0.2965
		Tracer Bact	#	19900	9680000	2310000	4800000			0.4843
	MT	TOTAL N*	mg	337.07	34.26	61.94	203.59	58.10	345.91	0.4454
		TOTAL P*	mg	92.93	13.04	8.11	13.03	9.53	31.16	0.5010
		NH4 N	mg	13.11 a	37.45 a	25.73 a	62.31 a	15.32 a	247.20 b	0.1291
		N03_N	mg	63.25	45.70	33.42	71.69	18.16	58.34	0.7344
		ORTHO P	mg	2.49	2.09	3.37	0.92	2.19	2.21	0.7786
		Fcoli	#	9360	6830000	2180000	3850000	2080000	5630000	0.3139
		Ecoli	#	8560	6830000	1430000	3390000	1420000	4020000	0.3623
		Tracer Bact	#	3950	4010000	1190000	2560000	1270000	2930000	0.3060
June	NT	TOTAL N*	mg	1.60	0.82	1.55	20.47			0.1779
		TOTAL P*	mg	2.53	1.96	1.74	4.24			0.4288
		NH4 - N	mg	5.40	2.92	2.15	24.55			0.3844
		N03-N	mg	43.72	90.05	69.69	279.88			0.2270
		ORTHO P	mg	0.36	0.89	0.14	0.30			0.2669
	MT	TOTAL N*	mg	16.73	6.27	7.94	23.24	12.38	10.25	0.9060
		TOTAL P*	mg	8.18	4.80	1.28	13.95	4.70	6.26	0.6335
		NH4 - N	mg	3.85	3.78	0.80	8.29	3.41	10.07	0.6168
		N03-N	mg	90.60	174.74	54.57	267.63	124.05	347.46	0.4057
		ORTHO P	mg	0.65	0.47	0.22	0.76	3.39	0.52	0.2919

* Indicates data was not log transformed for statistical analysis
Different letters indicate statistical difference within rows [LSD 0.05]

Treatments:
C - Control
MI - Modified Injection
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Tillage:
NT - Notill
MT - Minimum Tillage

Tile drain outflows for all microplots (both NT and MT) were monitored following all natural rain events for a period of approximately two months following manure application (before and after the June rainfall simulation experiment). Soluble phosphorous and total nitrogen concentrations were comparable to those sampled during the May and June experiments. Nitrate concentrations in the tile outflows increased steadily from the time of manure application for all treatments from levels below the water quality guidelines of 10 mg L^{-1}, to well above that level (see Figure 2).

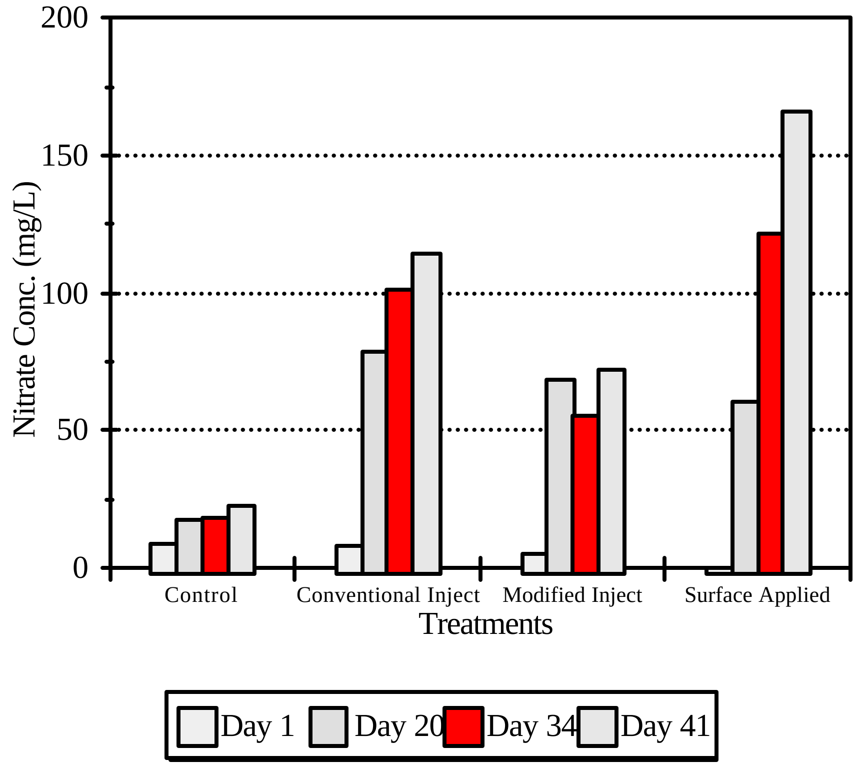

Figure 2: Nitrate concentrations from rainfall simulation experiments (days 1 and 20) and natural (days 34 and 41) events.

Field Scale Study

The results observed in the Microplot Study phase of the project identified the downward movement of manure contaminants as a potentially significant environmental problem. The Field Scale phase of the project allowed the testing of existing practices (conventional injection and surface application) and the modified injection method over established field tiles. An example of the flow rate data recorded by the datalogger is presented in Figure 3. The downward spikes observed on the hydrograph coincide with times of manual and ISCO automated sample collection.

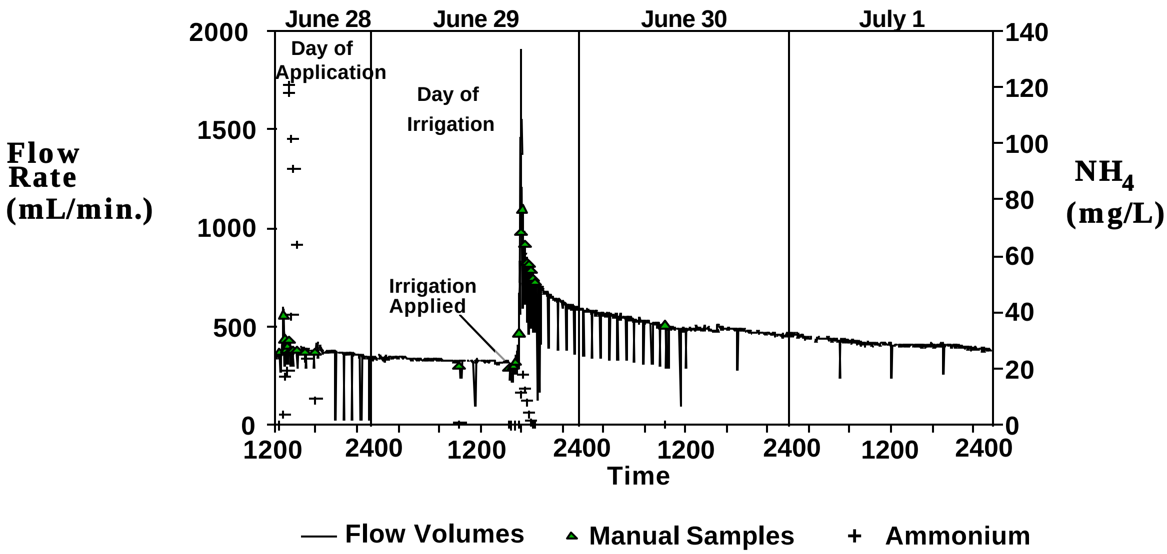

Figure 3: An example of a tile flow hydrograph with ammonium concentrations plotted for the field scale study.

A strong correlation was found between the log transformed values of Fecal coliform, E.coli and tracer bacteria concentrations. As a result, the effect of treatments on bacteria concentration was restricted to tracer bacteria values. The log transformed values of tracer bacteria and ammonium were correlated to tracer bacteria levels >1000 per 100 mL and ammonium concentrations above 1.0 mg L^{-1}. Total N and ammonium concentration were also strongly correlated. As a result of this correlation, and the greater degree of accuracy associated with the measurement of ammonium in the lab, emphasis has been placed on the ammonium data in statistical comparisons between treatments.

Bromide concentrations (used as a manure tracer) were strongly correlated to ammonium concentration. The log transformed values of bromide concentrations and tracer bacteria concentrations (Figure 4) were correlated with $r^2 = 0.79$. This finding is contrary to the literature which suggests that the differing factors which affect the retention of bacteria and bromide in the soil results in a poor correlation between the two variables in a soil solution. This may suggest the movement of manure by preferential or macropore flow which would minimize the contact of bacteria and bromide in the manure with soil particles.

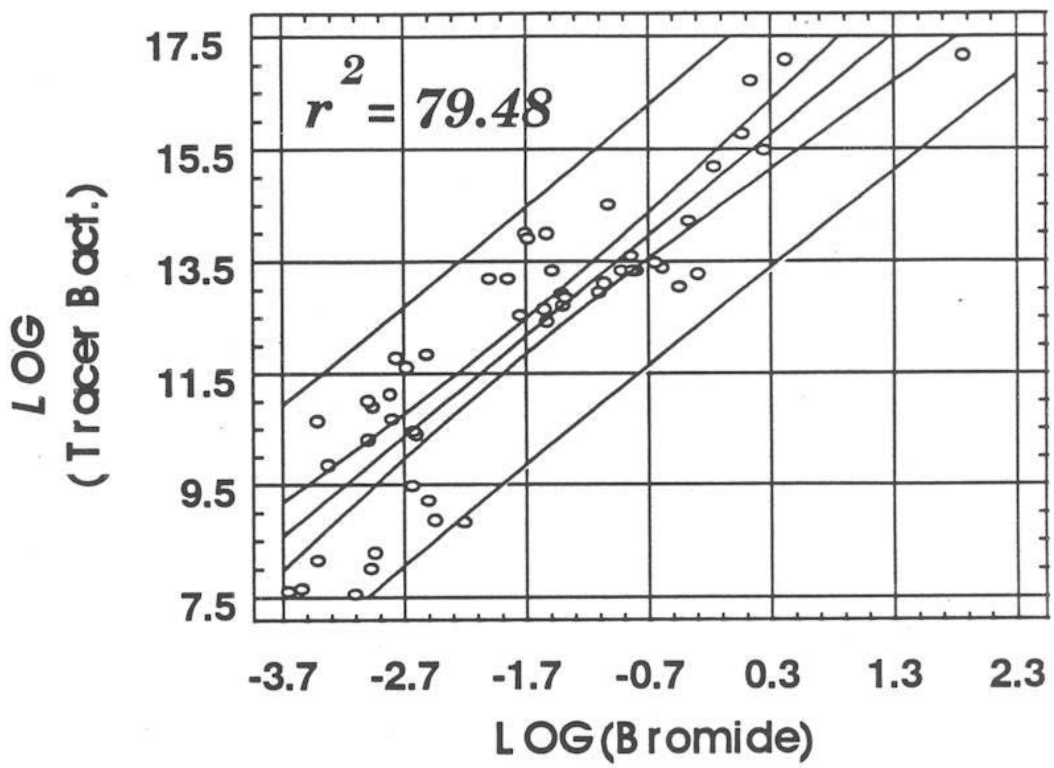

Figure 4. Linear Regression results of Log (Tracer Bacteria) vs Log (Bromide) for samples collected from the tile drains ofr the field scale study.

The results of the field scale study are summarized in Table 6. Each value in the table is an average of the three replications for each treatment. The application of manure to the plots, which were randomly established over existing field tile lines, resulted in increased flow rates for all treatments. The conventional injection method resulted in the greatest increases in flow rates immediately following manure application (day 1). While manure contamination was visually evident within as little as 15 minutes, the average length of time from manure application to peak flow rates was longest for the modified injection method (174 minutes) and shortest for the conventional injection and surface application methods (44 and 49 minutes, respectively). On the second day when the plots were irrigated, the surface application method plots had the highest flow rates. The modified injection method resulted in the lowest flow rates of the three manure treatments in the first three hours following manure application and irrigation. The time to peak flow rates following irrigation was approximately the same for all manure treated plots, ranging from 98 to 112 minutes, and longest for the control plots (167 minutes).

The results of the field scale experiment also suggest that the application of manure to a tile drain field using any of the methods tested will cause levels of ammonium to increase significantly within 3 hours of application. For the first day following manure application (i.e. 17 hour period), the conventional injection method resulted in the highest loadings of ammonium (7294 mg) to the tile drains and modified injection method the lowest (202 mg). Following irrigation, the total ammonium loadings to the tile drains from the manure treated plots were found to be significantly higher than the control plots. The modified injection method resulted in the lowest levels of

Table 6: ANOVA results of field scale manure study.

DATE		UNITS	VARIABLE	TREATMENT CI	MI	NI	C	p-value
June 28	3 Hour Loads	L	Flow *	83.52	60.68	62.78	58.90	0.6748
		Minutes	Time to Peak	44.00	174.67	49.33	na	0.1844
		mg	NH4*	7294.35 a	202.40 ab	1396.07 a	42.85 b	0.147
		mg	N03*	532.14	598.28	400.35	673.65	0.899
		mg	SolP *	205.56	169.32	4.81	0.00	0.247
		mg	Bromide	96.45	7.20	29.84	3.41	0.196
		mg	Total N	15878.40	358.24	4527.12	0.00	0.281
		mg	Total P	1375.42	62.75	409.16	0.00	0.265
	17 Hour Loads	L	Flow	419.49	362.65	358.01	435.36	0.94
		mg	NH4*	11601.74 a	417.20 bc	3195.83 ab	285.12 c	0.077
		mg	N03*	5270.05	3944.82	4041.26	5014.31	0.878
		mg	Sol P	488.17 a	291.44 ab	13.41 b	0.00 b	0.091
		mg	Bromide	127.47 a	19.30 ab	48.61 ab	12.87 b	0.191
June 29	3 Hour Loads	L	Flow *	205.10 b	213.80 b	294.97 a	92.19 c	0.0071
		Minutes	Time to Peak	112.33	112.00	98.33	167.67	0.1702
		mg	NH4*	868.87 a	428.50 a	1006.57 a	17.32 b	0.003
		mg	N03*	4504.67 ab	3718-57 b	6178.16 a	1428.84 c	0.008
		mg	Sol P *	32.98	260.85	188.70	78.23	0.431
		mg	Bromide	92.96 ab	45.57 b	102.00 a	3.17 c	0.0003
		mg	Total N	2699.12	747.13	2938.54	0.00	0.221
		mg	Total P	297.20	214.72	463.02	40.01	0.119
	17 Hour Loads	L	Flow	1130.22 ab	1386.29 a	1412.58 a	700.39 b	0.074
		mg	NH4*	1339.11 a	895.05 a	1338.49 a	256.75 b	0.1103
		mg	N03*	21364.75 a	22808.05 a	23675.80 a	11179.85 b	0.026
		mg	Sol P *	47.39	276.37	228.21	173.84	0.618
		mg	Bromide	196.38 ab	126.79 b	192.32 a	19.66 c	0.0003

* Indicates data was not log transformed for statistical analysis
Different letters indicate statistical difference within rows [LSD 0.05]

Treatments:
CI - Conventional Injection
MI - Modified Injection
NI - Sufrace Applied (non-incorporated)
C - Control

June 28
Day of manure application
June 29:
Day of water irrigation

ammonium loadings following irrigation, however, the differences were not statistically significant. The portion of the total ammonium applied which was lost to the tile drains within a 48 hour period following manure application was highest for conventional injection and lowest for the modified injection although the maximum amount lost didn't exceed 1 percent of the applied for any of the application methods.

The concentration of nitrate in the tile drain water prior to manure application (June 16, 1993) averaged 13.8 mg L^{-1} (standard deviation of 3.0 mg L^{-1}) which exceeds the water quality standards of 10 mg L^{-1}. The loadings of nitrate to the tiles was not significantly affected by the application of manure the first day following manure application, however, the loadings to the tiles after irrigation were significantly higher than the controls. There was not a significant difference between treatments, however, the modified injection method resulted in the lowest loadings of the 3 treatments. The modified injection method was significantly lower than the surface applied method for the first 3 hours following irrigation.

While there was not a statistically significant effect by the treatments on total nitrogen loadings, the average loadings suggests that the modified injection method resulted in a considerably lower loading to the tile drains for the first 3 hours following manure application (day 1) and irrigation (day 2).

Immediately following the application of manure (day 1), there was an increase in bromide concentrations in the tile drains for the manure treated plot. Although there was not a statistical difference between any of the treatments, levels were highest for conventional injection (93 mg) and lowest for modified injection (7 mg). Following irrigation, the bromide loadings to the tile drains were significantly higher for the manure application treatments compared with the controls. In addition, the modified injection method resulted in significantly lower bromide loadings (45.6 mg) to the tile compared with the surface application method (102.0 mg).

Due to laboratory limitations, it was not possible to collect a sufficient number of bacteria samples to allow for meaningful loading calculations. Comparisons between concentrations, however, indicates the modified injection method is effective in reducing contamination levels both immediately after manure application and following irrigation. The conventional injection method appears to result in the highest levels of bacterial contamination following manure application and is comparable to the surface application method following a simulated heavy rainfall.

Draft and Fuel Consumption Comparisons

The modified injection method of manure application required approximately 32% higher draft than the conventional injection method in the alfalfa stubble, and 18% higher draft in the barley stubble where the soil was softer. Additional engine power for the modified injection method over conventional injection was estimated to be 11.3 kw (15.2 HP) at a nominal ground speed of 6.5 km h^{-1} in the alfalfa stubble.

Fuel consumption for the modified injection method was 0.43 and 0.75 L ha^{-1} higher than that for conventional injection at ground speeds of 4.3 and 6.5 km h^{-1} respectively on the alfalfa stubble. These differences are negligible (3% and 8% increases respectively).

The results of this comparison indicate that the modified injection method does require more draft, power and fuel consumption than the conventional injection method, however, the difference is small enough that the modified injection method may be considered a practical method of liquid manure application.

Erosion Modelling

Calibration of the CREAMS model indicated that the model input parameters could be adjusted from those that were recommended in the manual to result in comparable values for total runoff losses of sediment and water. However, the nutrient component of the model tended to over-predict the total nitrogen losses and under-predict total phosphorous losses. The model output of the nutrient component could not be corrected by adjusting the input parameters within acceptable limits.

4. STUDY CONCLUSIONS:

Surface water runoff collected from microplots indicated the modified injection method under NT management significantly reduced nutrient and bacteria contamination compared to other conventional treatments. The loadings of nutrients and bacteria which were observed in the subsurface tile water may pose an environmental concern. The field scale study suggested liquid manure application on medium textured soils under NT tillage systems can result in excessive levels of nutrient and bacterial contamination in the tile drain waters. The observation of manure contaminants in tile drain waters shortly after manure application suggests downward movement by preferential flow. Disturbance of macropores by cultivation (eg. modified injection method) prior to liquid manure injection in NT fields can reduce the levels of contamination in surface runoff and tile drain waters compared to surface applied and conventional injection methods. The negligible differences in fuel consumption between the injection methods tested indicates that the modified injection method is also an economically viable alternative for farmers. The loss of nutrients to tile drains from liquid manure applied at a rate equivalent to crop production nitrogen requirements is relatively low from a crop production standpoint.

5. NEW TECHNOLOGIES AND BENEFITS :

The prototype manure injection system tested in this study was designed to disrupt soil pore continuity in reduced and no tillage systems while maintaining surface residues. As previously discussed, soil macropores or preferential flow can contribute significant quantities of nutrients and bacteria contaminants to tile drains which may pose an environmental concern. The reduction of macropores near the soil surface prior to the application of manure could therefore allow farmers using no-till systems to apply manure to those fields. The prototype liquid manure injection system was effective in sidedressing manure between corn rows at the six-leaf stage of corn growth which will allow farmers to supplement the nutrient requirements of the crop and improve the utilization of manures as a nutrient resource.

The system used for monitoring flow in tile drains proved to be an inexpensive and reliable method of monitoring flow rates continually over an extended period of time. The method may have applications for other research activities where the monitoring of water flows at relatively low rates (0 to 10 litres min^{-1}) is required.

6. IMPLICATIONS FOR THE GREAT LAKES BASIN ECOSYSTEM:

The potential for contamination of surface waters by surface runoff and tile drainage contributions from the application of liquid manure to agricultural fields has been clearly identified. Results of this study have indicated that while conventional injection methods of manure application are effective in reducing surface runoff losses, they continue to contribute equal or greater levels of manure contaminants to the tile drains as the surface application techniques. The results achieved with the prototype application system tested in this study indicates that by disturbing the soil surface prior to injection, the flow of manure to the tile drains can be reduced and thereby reduce the levels of nutrient and bacterial contaminants entering the rivers and lakes in the Great Lakes basin ecosystem.

7. TECHNOLOGY TRANSFER POTENTIAL:

The potential for transferring and disseminating the technological advancements of this study have been greatly enhanced by the collaboration of the Ontario Ministry of Agriculture Food and Rural Areas and the Upper Thames River Conservation Authority. These organizations are routinely involved in agricultural extension activities and have already proven effective in finding cooperating farmers for on-farm research activities. Their direct involvement in this research will facilitate a rapid dissemination of the study findings and an improved understanding of their implications. In addition, Husky Farm Equipment Ltd., the manufacturer of the prototype injection system, has been involved in the development of the tanker application unit and has provided ongoing support for the modification and maintenance of the applicator tanker as the project has been in progress.

The effectiveness of cultivating prior to manure injection has been demonstrated through the results of this study at the field scale. This is valuable and convincing information for the farming community so that the impacts of manure application to tile drained fields can be fully appreciated.

8. GAPS/NEEDS FOR FUTURE RESEARCH:

While this study has identified the levels of nutrients and bacteria in tile drains and surface runoff which may be expected from the application of liquid manure under the study conditions to soils at a particular rate under conservation tillage systems, more work is needed to establish a system to predict environmentally safe rates of manure application to land. In addition, the significance of the levels of contamination being observed at various rates of application to the ecological health of the receiving bodies of water requires further investigation.

Further work should be directed towards determining the relevance of the findings of this study to other soil types. While this study has pointed to macropore flow as a likely pathway of manure to the tile drains, additional research is needed to more precisely determine the pathways and processes of nutrient and bacteria transport. Additional validation of predictive water quality models with field scale data would enhance their use for predicting scenarios during which water quality standards are likely to be exceeded.

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