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NUTRIENT AND SOLIDS TRANSPORT TO SURFACE WATER IN A MANURED AND FERTILIZED CROPPING OPERATION

by

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ABSTRACT

Transport of nutrients and solids to surface drainage water was studied for 4 years in two, relatively level, cropped watersheds (catchments). One watershed received average applications of 168, 57 and 142 kg ha^{-1} yr^{-1} of N, P and K respectively. Liquid manure accounted for respectively 78, 65 and 80% of the total N, P and K applied. The other watershed received average applications of 44, 25 and 46 kg ha^{-1} yr^{-1} of N, P and K respectively from chemical fertilizers only. The range of annual transport of total solids, suspended solids, total Kjeldahl N, NO_3-N, total P and K respectively was 462-980, 55-504, 3.5-15.4, 7.1-23.7, 0.4-0.8, and 9.7 -14.2 kg ha^{-1} yr^{-1} from the manured watershed. The corresponding ranges from the fertilized watershed were: 383 -781, 32-153, 2.2-20.4, 6.1-26.4, 0.3-0.7, and 3.2-22.1 kg ha^{-1} yr^{-1}.

ABSTRACT

Transport of nutrients and solids to surface drainage water was studied for 4 years in two, relatively level, cropped watersheds (catchments). One 434 ha watershed received average applications of 168, 57 and 142 kg $ha^{-1} yr^{-1}$ of N, P and K respectively. Liquid manure applied by the immediate plowdown technique accounted for respectively 78, 65 and 80% of the total N, P and K applied. The other 160 ha watershed received average applications of 44, 25 and 46 kg ha^{-1} yr^{-1} of N, P and K respectively from chemical fertilizers only. The range of annual transport of total solids (TS), suspended solids (SS), total Kjeldahl N (TKN), NO_3-N, total P (TP) and K respectively was 462-980, 55-504, 3.5-15.4, 7.1-23.7, 0.4-0.8, and 9.7-14.2 kg ha^{-1} yr^{-1} from the manured watershed. The corresponding ranges from the fertilized watershed were: 383-781, 32-153, 2.2-20.4, 6.1-26.4, 0.3-0.7, and 3.2-22.1 kg ha^{-1} yr^{-1}. Most of the annual transport of TS, SS, TKN, TP and K occurred in the very early spring snowmelt runoff. Hydrological conditions of flow greatly influenced the total transport of SS, TKN and K. In some years, about half of the annual NO_3-N transport occurred after the early spring snowmelt. Nutrient and solids contribution to surface drainage water due to repeated annual application of large amounts of animal manures was not greatly in excess of the contribution that resulted from the use of chemical fertilizer only at much lower unit-area application rates. Information is required on the fate of nutrients in manure applied to limited land area for several years.

INTRODUCTION

Confinement production of large numbers of livestock and poultry requires disposal of large amounts of manure. This disposal is usually by land application. Repeated applications on limited land area are commonly made to control hauling costs. This practice can lead to transfer of pollutants and nutrients from manures to drainage water, and subsequent eutrophication of receiving water bodies. Most of the previous studies are based on small plot studies (Khaleel *et al.* 1980). Plot and small-area studies are useful for evaluation of relative effects of different treatments but may not adequately represent the actual conditions of large watersheds. This is because the effects of lateral surface and subsurface inputs, and subsurface inflow-outflow characteristics might be quite different (Amerman and McGuinness 1967).

Information is therefore required on sediment and nutrient transport to surface drainage from large areas that receive repeated applications of manures. In some of the previous studies on runoff from agricultural watersheds or catchments (Harms *et al.* 1974, Jones *et al.* 1976, Beak 1977, Hill 1978, Coote *et al.* 1978, Monke *et al.* 1981), nutrient applications from fertilizers and manures were not reliably known. In this study, both manure and fertilizer applications for large-scale crop production were reliably known because of controlled land use at a large research farm. The objective of this work was to study solids and nutrient contributions to surface drainage from two adjacent intensively cropped watersheds over a 4-year period. One of these watersheds received repeated applications of manure and fertilizer for several years while the other received applications of chemical fertilizer only.

STUDY SITE

The study was carried out in a 594-ha area of the 1100-ha experimental farm of the Animal Research Centre of Agriculture Canada near Ottawa, Ontario. Figure 1 shows the location of the two watersheds which were separated from each other and the surrounding areas by the local drainage system. Watershed M with 434 ha was cropped using chemical fertilizer as well as liquid manure. In addition, it received disposal- applications of large amounts of manure in the summer and fall after crop harvest every year since 1967. Surface water entering this watershed at Stations 6, 7, 8 and 22 was from adjacent uncultivated land, roadside drainage, and at Station 6, included some urban runoff as well. The drainage water left the area at Station 2.

Sixty percent of the land area in Watershed M has poorly-drained, dark-gray clay loam soil underlain by silty clay and clay of marine origin (Dalhousie association). Thirty percent of the area has imperfectly drained sandy loam to loamy sand of about 1-m depth, overlying fine-textured marine clay (Manotick association), and the remaining has imperfect to rapid-draining sandy loam to loamy sand of >2 m depth (Uplands association). All except 50 ha of this watershed is tile drained. The other study area, Watershed F with 160 ha immediately south of Watershed M was cropped using chemical fertilizer only after 1972.

All the surface water leaving this watershed at Station 3 originated within the watershed. More than 90% of the area in Watershed F has poorly drained clay loam soil of Dalhousie association, the balance ranging from loam to loamy sand (Chateauguay, Piperville and Manotick associations). The entire area of this watershed is tile drained. For both the watersheds, 96% of the drainage area was cultivated while the remainder was in roads and roadside ditches. The land in both the Watersheds M and F is mostly level or very gently sloping.

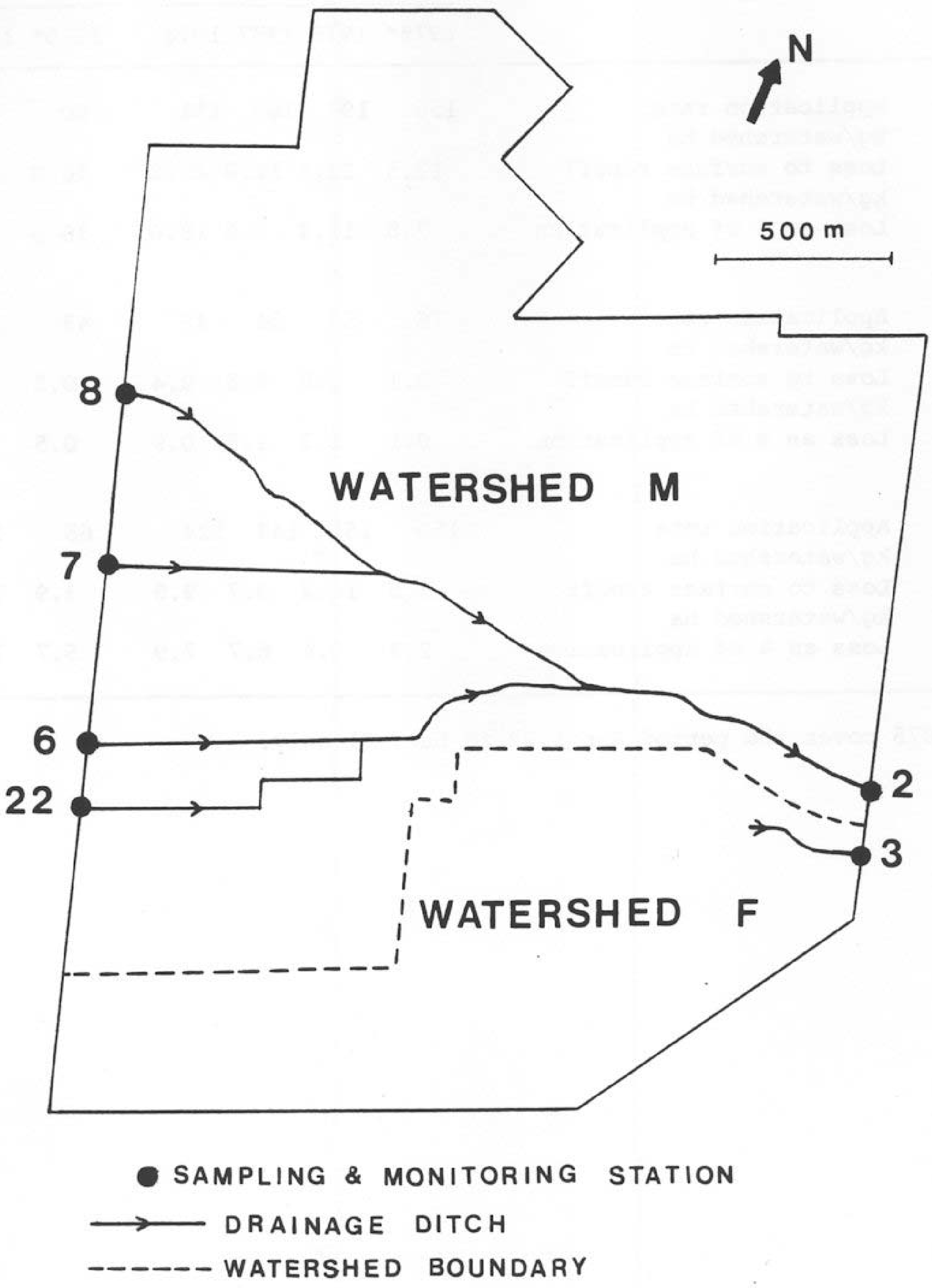

Figure 1. Site plan of the study area.

STUDY PROCEDURE

The transport of total solids, suspended solids, nitrogen (N), phosphorus (P) and potassium (K) to surface drainage in the two watersheds was studied from 1975 to 1978. Flow rates in surface drainage ditches were obtained at Stations 2, 3, 6, 7, 8 and 22 (Fig. 1) by velocity-area measurements. A Price Type AA current meter for high flows or a Pygmy meter for low flows was used. The frequency of flow measurement varied from twice per day during very high flows such as during snowmelt runoff to once per week during very low flows. The drainage ditches were generally dry during the summer months. Interpolated flow rates were used for the days when no flow measurements were made. Daily precipitation was recorded using a Belfort Universal precipitation gauge.

Grab samples of water were collected and analysed for total solids (TS), suspended solids (SS), total Kjeldahl nitrogen (TKN), nitrate nitrogen (NO_3-N), total phosphorus (TP) and K. Details of the analytical procedures used have been reported earlier (Patni and Hore 1978). Nutrient and solids content of the drainage water was calculated from the daily flow and concentrations. Interpolated values of concentrations were used for the days when water samples were not obtained. For Watershed M, the net transport or loading to the surface drainage water was calculated as the difference in nutrient or solids content of water leaving at Station 2 and entering at Stations 6, 7, 8 and 22. For Watershed F, the nutrient or solids content of the water leaving at Station 3 represented the loading.

For both the watersheds, annual records were kept for the percent of land area in different crops, and fertilizer and manure applications. Individual fields used for different crops in the watersheds ranged from 4 to 70 ha in area. Fertilizer applications were made at the recommended rates for different crops. Some fields received applications of manure only. About 16,000 to 22,000 m^3 of liquid manure (8 to 9% dry matter content) was applied each year on 100 to 150 ha area of the 434 ha Watershed M before planting in spring and after harvest in summer and fall. Due to wet field conditions in early spring and time constraints imposed by spring planting requirements, only ¼ or less of this volume of manure could be applied prior to planting, usually in May. Manure was incorporated into land immediately after application, and was not applied on frozen or snow-covered land. Of the total volume of manure incorporated, about 65% originated from dairy cattle, 30% from sheep and 5% from poultry. Representative samples of the applied manure were analysed each year for N, P and K. Unit-area application rates of N, P and K from manures and fertilizers were calculated from compositions and application rates.

RESULTS AND DISCUSSION

Land Use Practice

The percent of cultivated area under different crops in the two watershed during the period 1971-1978 is shown in Table 1. The main crops grown were silage and grain corn, alfalfa, mixed hay, barley, and oats. The percentage of area in different crops varied from year to year due to crop rotation practices at the Farm. Planting was generally completed in the month of May. Most of the surface runoff for the year was usually over by the time of planting.

TABLE I. Percent Of Cultivated Area Under Different Crops In Watersheds M And F.

Watershed	Year	Percent of cultivated area in					
		Corn	Forage legume	Legume-grass	Grass	Other grains	Fallow
M	1971	32.9	3.1	32.9	13.1	6.2	11.7
	1972	27.9	8.6	35.7	11.1	0.0	16.7
	1973	20.8	9.0	38.2	10.1	15.2	6.8
	1974	18.8	9.0	48.5	14.1	9.6	0.0
	1975	52.5	21.8	13.2	8.6	0.0	3.9
	1976	39.3	10.9	36.7	2.2	7.1	3.8
	1977	43.6	29.1	21.9	2.0	0.0	3.4
	1978	28.9	12.7	27.9	2.3	28.2	0.0
F	1971	39.7	0.0	60.3	0.0	0.0	0.0
	1972	85.2	0.0	14.8	0.0	0.0	0.0
	1973	85.2	0.0	14.8	0.0	0.0	0.0
	1974	85.2	0.0	14.8	0.0	0.0	0.0
	1975	59.8	0.0	0.0	0.0	40.2	0.0
	1976	14.8	40.2	0.0	0.0	45.0	0.0
	1977	14.8	40.2	0.0	0.0	45.0	0.0
	1978	14.8	85.2	0.0	0.0	0.0	0.0

Nutrient Applications

Unit-area annual rates of application of N, P and K from chemical fertilizer and manure sources are shown in Table II for the two watersheds for the period 1971-1978. During the 4-year study period (1975-1978), the average application rates for N, P and K from fertilizer plus manure in Watershed M were respectively 168, 57 and 142 kg ha^{-1} yr^{-1}. In these unit-area applications, 78% of N, 65% of P and 80% of K was from manure sources. During the same 4-year study period, the average application rates for N, P and K from chemical fertilizer in Watershed F were respectively 44, 25 and 46 kg ha^{-1} yr^{-1}. Thus, the average unit-area application rates of N, P and K in Watershed F were respectively only 26%, 16% and 32% of the average rates in Watershed M. The average rates for N, P and K from chemical fertilizer source in Watershed M during the 1975-1978 period were respectively 37, 20 and 29 kg ha^{-1} yr^{-1}.

Nutrient and Solids Contribution to Surface Drainage

Nutrient and solids transport to surface drainage from the manured and fertilized watersheds is shown in Table III. In Table IV, the annual total runoff and total transport are separated into two periods termed as "snowmelt" and "rainfall" periods. The snowmelt period was considered to start when the first flow started in the winter. This occurred in March in 1975, 1976 and 1977, and in January in 1978. The snowmelt period was considered to end on the last day with a snowcover on the ground. This varied between April 1 to April 19 during the 1975-1978 period. Most of the flow in surface drainage ditches during the snowmelt period was due to direct surface runoff. Flow during the remainder of the year was termed the rainfall-period flow. During this period, most of the flow resulted from discharge of subsurface tile drainage into surface drainage ditches. Because of the level topography of the watersheds, direct surface runoff during the rainfall period did not occur except during a few heavy rainfall events prior to the establishment of a crop cover. Annual precipitation of 990, 935, 927 and 793 mm was recorded respectively in 1975, 1976, 1977 and 1978 at the study site, compared to a long-term average of 860 mm for the region.

TABLE II. Nutrient Sources And Application Rates In Watersheds M And F.

Watershed (area ha)	Year	Nutrient application source* and rate, kg ha^{-1} yr^{-1}								
		Nitrogen			Phosphorus			Potassium		
		F	M	T	F	M	T	F	M	T
M	1971	72	33	105	28	10	38	51	28	79
(434 ha)	1972	54	105	159	23	28	51	43	86	129
	1973	54	86	140	27	22	49	46	62	108
	1974	51	115	166	23	32	55	44	83	127
	1975	36	120	156	38	38	76	40	110	150
	1976	51	146	197	17	36	53	32	119	151
	1977	29	140	169	15	39	54	26	118	144
	1978	33	118	151	10	35	45	19	105	124
F	1971	76	288	364	26	89	115	50	252	302
(160 ha)	1972	142	29	171	51	7	58	87	26	113
	1973	142	0	142	51	0	51	87	0	87
	1974	134	0	134	51	0	51	78	0	78
	1975	100	0	100	43	0	43	68	0	68
	1976	41	0	41	12	0	12	29	0	29
	1977	17	0	17	24	0	24	46	0	46
	1978	18	0	18	21	0	21	39	0	39

* F = chemical fertilizer, M = manure, T = total, i.e., fertilizer + manure.

TABLE III. Nutrient And Pollutant Contribution To Surface Drainage From Manured And Fertilized Watersheds.

Parameter	Year	Nutrient contribution kg $ha^{-1} yr^{-1}$ *	
		Watershed M	Watershed F
Total solids	1975*	293	781
	1976	980	558
	1977	462	385
	1978	846	383
Suspended solids	1975*	41	47
	1976	504	153
	1977	55	45
	1978	60	32
Total Kjeldahl nitrogen	1975*	5.1	9.6
	1976	15.4	20.4
	1977	4.0	2.0
	1978	3.5	2.2
Nitrate nitrogen	1975*	7.1	26.4
	1976	7.1	11.6
	1977	8.8	5.9
	1978	23.7	6.1
Total phosphorus	1975*	0.1	0.2
	1976	0.8	0.7
	1977	0.8	0.4
	1978	0.4	0.3
Potassium	1975*	3.5	3.9
	1976	14.2	22.1
	1977	9.7	4.0
	1978	9.8	3.2

* Data for 1975 cover the period April 22 to Dec. 31 only.

TABLE IV. Distribution Of Annual Runoff And Total Transport Between "Snowmelt" And "Rainfall" Periods For Manured And Fertilized Watersheds.

Parameter	Year	"Snowmelt" period		"Rainfall" period	
		Watershed		Watershed	
		M	F	M	F
Runoff - mm	1975*	-	-	81	195
	1976	155	291	114	71
	1977	122	142	56	31
	1978	223	150	82	20
Runoff - % of total	1976	58	80	42	20
	1977	69	82	31	18
	1978	73	88	27	12
Total solids - % of total	1976	83	72	17	28
	1977	60	70	40	30
	1978	67	83	33	17
Suspended solids - % of total	1976	91	85	9	15
	1977	89	87	11	13
	1978	86	99	14	1
Total Kjeldahl nitrogen % of total	1976	93	97	7	3
	1977	88	95	12	5
	1978	71	94	29	6
Nitrate nitrogen - % of total	1976	38	54	62	46
	1977	47	47	53	53
	1978	69	84	31	16
Total phosphorus	1976	70	73	30	27
	1977	91	93	9	7
	1978	84	98	16	2
Potassium	1976	77	88	23	12
	1977	82	82	18	18
	1978	71	90	29	10

* Runoff data for 1975 cover the period April 22 to December 31.

Differences in runoff from the two watersheds were observed yearly as well as during the snowmelt and rainfall periods (Table IV). These difference were due to different crop covers, watershed soil characteristics, and variable blockage by ice and weed growth in the drainage ditches. Year to year variations in runoff were influenced mainly by climatic factors, and to a small extent by the different crop covers each year. Table IV shows that most of the annual total flow in both the watersheds, 58 to 73% in Watershed M and 80 to 88% in Watershed F, occurred during the snowmelt period.

As bulk of the annual flow and nutrient and solids transport in a calendar year occurred prior to seeding and nutrient applications, the annual contributions shown in Table III were greatly influenced by the nutrient applications and residual crop covers in the watersheds in the preceding years.

Results in Table III show that except for NO_3-N, the annual contribution rates for all the parameters were the highest in 1976 in both watersheds. A rapid thaw occurred in 1976 which caused extremely high flows and flooding in the region for a few days during the snowmelt period. A large part of the annual transport of nutrients and solids occurred during these few days. The largest influence was on the transport of SS, TKN, P and K. In contrast to 1976, the runoff from spring snowmelt occurred intermittently in 1977 and 1978 due to repeated freeze-thaw conditions. Consequently, conditions of extreme flows did not occur, and unit-area contributions were considerably lower than in 1976. The unit-area contributions (Table III) for all the parameters except NO_3-N were of the same order of magnitude each year in both the watersheds.

Solids transport: Contribution of TS and SS was greater in Watershed M than in Watershed F every year except 1975 (Table III). In 1975, the greater TS contribution from Watershed F was essentially due to an increase in the contribution of dissolved solids (TS minus SS). Unit-area transports for 1975 in Table III are for surface drainage resulting mainly from discharge of tile drains into drainage ditches. The high rates of fertilizer nutrient applications, in Watershed F in 1975 and in previous years

(Table II), coupled with the relatively high runoff in 1975, resulted in a large contribution of dissolved solids to drainage water.

Extremely heavy flows for a few days during the snowmelt period due to a rapid thaw in 1976 increased the transport of SS by one order of magnitude over other years in both the watersheds but the effect on TS transport was not so large. Harms *et al.* (1974) observed average TS and SS contributions of 334 and 286 kg ha^{-1} yr^{-1} respectively from chemically fertilized cultivated land in a 2-year study. The corresponding values for alfalfa-brome fields were 32 and 4 kg ha^{-1} yr^{-1}. Values for the individual years were not reported. Coote *et al.* (1978) reported 2-year means of SS transport to range from 60 to 960 kg ha^{-1} yr^{-1} in eleven agricultural watersheds in southern Ontario. In comparison, SS transport ranged from 55 to 504 kg ha^{-1} yr^{-1} in the manured watershed, and from 32 to 153 kg ha^{-1} yr^{-1} in fertilized watershed in this study.

These values are considerably lower than a 10-year average 2548 kg ha^{-1} yr^{-1} loss of sediment from plots on silty clay soil in north central Ohio (Schwab *et al.* 1980). Monke *et al.* (1981) found sediment transport in three predominantly agricultural watersheds in north-eastern Indiana to range from 380 to 3740 kg ha^{-1} yr^{-1} during a 2-year study. Unit-area transport of sediment in the first year was about 3 to 9 times more than the next year. In the present study, unit area transport of SS in the manured Watershed M was 8 to 9 times more in 1976 than in 1977 and 1978, whereas in the fertilized Watershed F, it was only 4 to 5 times more. Manure plowdown activity thus appeared partly to contribute more suspended solids during increased flows compared to chemical fertilizer use. Table IV results show that 85% or more of the annual transport of SS in both the watersheds occurred in the short snowmelt period, irrespective of the absolute values of unit area transports (Table III).

Nitrogen: Results in Tables III and IV on transport of TKN again show that unit-area transports can vary by an order of magnitude from year to year, and that most of the annual TKN transport occurred in the short snowmelt period. A large part of the TKN transport appears to be associated with transport of *SS.* Data for NO_3-N also show year to year variation of an order of magnitude in unit-area transport values. The magnitude of these transports appears to be related to nitrogen applications. The high value of NO_3-N transport rate in Watershed F in 1975 is related to the high nitrogen fertilizer applications during the 1972 to 1975 period, and the relatively high runoff from this watershed in the 1975 rainfall period (Table IV).

This greater runoff resulted in increased leaching of NO_3-N to tile drains contributing to the flow at Station 3 (Figure 1). The high unit-area loss of NO_3-N from Watershed M in 1978 occurred largely (69% of total) during the snowmelt period (Table IV). Apparently, this was because the large field between Stations 6 and 7 in Figure 1 was used for disposal applications of manure in the summer and fall of 1977. Application rate of manure nitrogen to this field during that period was 790 kg N ha^{-1}. It appears that a substantial portion of this applied nitrogen was nitrified. During the spring snowmelt runoff of 1978, large amounts of NO_3-N appear to have leached to the two drainage ditches on the north and south sides of the field. This was indicated by a significant increase in the concentration of NO_3-N at Station 2 during the snowmelt period of 1978 over the corresponding values noted in 1976 and 1977. More than 10% of the annual transport of NO_3-N in 1978 occurred during a brief January thaw. In other years, manure applications in Watershed M were made at moderate rates of N application, and to areas that were relatively remote from the drainage ditches. In 1976 and 1977, about half of the annual transport of NO_3-N in both the watersheds occurred in the rainfall period. In 1978, a larger percentage of NO_3-N transport in Watershed F occurred in the snowmelt period because of very low flows during the rainfall period.

A number of investigators have reported on nitrogen transport to surface water from agricultural land. Harms *et al.* (1974) reported TKN transport of 0.7 to 1.1 kg ha^{-1} yr^{-1} and NO_3-N transport of 0.24 to 0.37 kg ha^{-1} yr^{-1} from chemically fertilized fields in alfalfa-brome, pasture or under cultivation. These values are significantly lower than those found in the present work and by other investigators. Coote *et al.* (1978)

reported unit area transport of TKN to range from 1.1 to 8.5 kg ha^{-1} yr^{-1}, and (NO_3 + NO_2)-N from 2.6 to 36.0 kg ha^{-1} yr^{-1} in eleven agricultural watersheds in southern Ontario. A large part of these transports occurred in the January to April period. Jones *et al.* (1976) reported the mean transport of NO_3-N in 34, mainly agricultural watersheds in north-western Iowa to be 6.7 kg ha^{-1} yr^{-1}. In a 25-month study, Hill (1978) estimated average NO_3-N transport in 21 watersheds near Toronto, Ontario, to range from 1.4 to 7.3 kg ha^{-1} yr^{-1}. A significant correlation between NO_3-N transport and percentage of each watershed in crops and abandoned agricultural land was noted. The transport rates for the TKN and NO_3-N noted in the above studies are in agreement with the values noted in Table III.

Transport of total nitrogen to surface water has been reported in some studies. In the present study, the unit-area total N transport ranged from 12.8 to 27.2 kg ha^{-1} yr^{-1} in Watershed M, and from 7.9 to >36 kg ha^{-1} yr^{-1} in Watershed F. These values are consistent with reported values of 3.8 to 40.2 (Coote *et al.* 1978), 6.6 to 53.0 (Monke *et al.* 1981), 12.6 to 44.8 (Burwell *et al.* 1977), and 32 to 67 kg N ha^{-1} yr^{-1} (Beak 1977). Literature on transport of total N in runoff from plots receiving animal manures was reviewed by Khaleel *et al.* (1980). Total N transport ranging from 0.4 to 97.7 kg ha^{-1} yr^{-1} was noted under various conditions.

In conclusion, unit-area annual transports of both TKN and NO_3-N can vary by an order of magnitude. Transport of TKN appears to be associated with transport of sediment, and therefore influenced strongly by hydrological conditions. Transport of NO_3-N appears to be associated with nitrogen application rates, particularly in the case of fertilizer N applications. Successive years of manure applications in Watershed M did not result in total N transport far in excess of that from the chemically fertilized Watershed F.

Phosphorus: Results on transport of TP in Tables III and IV for both the watersheds show an annual transport of up to 0.8 kg ha^{-1} yr^{-1}, with most of the transport occurring during the short snowmelt period. Annual unit-area transport was slightly higher in the manured Watershed M than the fertilized Watershed F. Order-of-magnitude increases in the 1976 transport over the 1977 and 1978 transports that were noted for *SS,* TKN and K were not noted for TP. Transport of SS did not appear to influence the transport of TP to the same extent as the transport of TKN and K. The relatively small difference in the transport of TP in Watersheds M and F appears to be consistent with the findings of Coote *et al.* (1978) who noted that surface soil clay content and row crops, rather than TP application rates, were the major causes of TP transport to streams. During the 1976-1978 period, Watershed F had 14.8% of its area in row crops compared to 28.9 to 43.6 of the area in Watershed M. However, 90% of Watershed F has clay loam soil compared to 60% in Watershed M. Therefore, the effects of surface soil clay content and of the area in row crops tended to cancel each other out.

Values for TP transport obtained in this study (Table III) compare well with those reported by others. Beak (1977) estimated the mean transport of TP from livestock areas to be 0.87 kg ha^{-1} yr^{-1} (0.33 to 2.3 range), and from non-livestock agricultural areas to be 0.33 kg ha^{-1} yr^{-1}. Some other reported values are 0.2 to 1.5 (Coote *et al.* 1978), 0.35 (Jones *et al.* 1976), 1.0 to 5.4 (Monke *et al.* 1981), and 0.24 to 0.85 kg ha^{-1} yr^{-1} (Burwell *et al.* 1977).

Potassium: Results for K in Tables III and IV show that the annual transport from the manured Watershed M was more than that from the fertilized Watershed F in 1977 and 1978 but not in 1976, and that most of the annual transport occurred during the snowmelt period. Transport of K in 1976 was about 1.5 times more than the 1977 and 1978 transport in Watershed M, but was 5 to 7 times more in Watershed F. The heavy flows in 1976 appeared to have caused a greater unit-area transport of K in Watershed F than in Watershed M. Information on transport of K to surface water is very limited. Schwab *et al.* (1980) found the average transport of K to be 31.6 kg ha^{-1} yr^{-1} in a 10-year plot study in north-central Ohio. Fertilizer K application rate of 93 kg ha^{-1} yr^{-1} in their study was much higher than the fertilizer application rate in the present study.

Nutrient application rates and losses: Table V shows the annual unit-area application rates and loss of N, P and K to surface drainage from 1975 to 1978. Also shown is the loss as a percentage of the applied nutrients. In spite of considerably higher nutrient application rates in Watershed M than in Watershed F, the unit-area losses in the two watersheds are of the same order of magnitude. The loss as percent of applied nutrients is higher for Watershed F because of lower nutrient application rates. The percent loss values in Table V are considerably lower than those of Burwell *et al.* (1977) who reported a loss of 70 and 64% respectively of the applied N and P to surface water from chemically fertilized corn fields. Plot studies of Schwab *et al.* (1980) indicated that 13, 2.5 and 34% respectively of the annually applied N, P and K was lost to surface runoff.

In the present study, much higher nutrient application rates in the manured watershed did not cause correspondingly high transport of nutrients to surface drainage water. This is partly because of the relatively level topography and immediate incorporation of manure after application. Information is required on the fate of nutrients in manure applied to limited land for several years. The proportion that remains in the soil, leaches to deep groundwater or is lost by volatilization needs to be established. If a large proportion remains in the soil, excessive nutrient accumulation from repeated manure applications may adversely affect long-term soil fertility.

TABLE V. Nutrient Loss From Manured And Fertilized Watersheds As A Percentage Of Applied Nutrients.

Nutrient	Description	Watershed M				Watershed F			
		1975*	1976	1977	1978	1975*	1976	1977	1978
Nitrogen (TKN+NO_3-N)	Application rate kg/watershed ha	156	197	169	151	100	41	17	18
	Loss to surface runoff kg/watershed ha	12.5	22.5	12.8	27.2	36.0	32.0	7.9	8.3
	Loss as % of application	7.8	11.4	7.6	18.0	36.0	78.0	46.5	46.1
Phosphorus (TP)	Application rate kg/watershed ha	76	53	54	45	43	12	24	21
	Loss to surface runoff kg/watershed ha	0.1	0.8	0.8	0.4	0.2	0.7	0.4	0.3
	Loss as % of application	0.1	1.5	1.5	0.9	0.5	5.8	1.7	1.4
Potassium (K)	Application rate kg/watershed ha	150	151	144	124	68	29	46	39
	Loss to surface runoff kg/watershed ha	3.5	14.2	9.7	9.8	3.9	22.1	4.0	3.2
	Loss as % of application	2.3	9.4	6.7	7.9	5.7	76.2	8.7	8.2

* Data for 1975 cover the period April 22 to Dec. 31 only.

CONCLUSIONS AND RECOMMENDATIONS

1. Repeated annual applications of liquid manure on a limited land area by the immediate plowdown technique did not result in contributions of TS, SS, TKN, NO_3-N, TP and K to surface drainage water that were far in excess of contributions from chemically fertilized land.

2. Hydrological conditions of flow greatly influenced the transport of nutrients and solids to surface drainage water in both fertilized and manured land. An order-of-magnitude difference in annual unit-area transports was noted for SS, TKN, NO_3-N and K. Variability due to climatic factors can overpower the influence of cropping practices on the annual transport of sediment and associated constituents to runoff water.

3. Information is required on the fate of nutrients in manure applied to limited land area for several successive years.

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