Pollution Potential and Corn Yields from Selected Rates and Timing of Liquid Manure Applications

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ABSTRACT

A 6-year study was conducted to determine the effects of rate and time of liquid manure application, chemical fertilizer application, and no fertilizer, on the chemical composition of surface and subsurface water and on crop yield. Liquid manure was applied at three rates of 224, 560 and 897 kg/(ha•yr) of N in accordance with four application schedules (i.e. spring, fall, split rates in spring and fall, and winter). In all cases except winter application, manure was incorporated by plowing at time of application.

During spring snow-melt, surface runoff concentrations of inorganic N, P, and K from winter-applied manure increased approximately in proportion to increased application rate. Also, they were much higher than concentrations from spring, fall, spring-fall, and chemical fertilizer treatments.

In contrast to spring snowmelt surface runoff, tile drain effluent NO_3-N concentrations from the plots receiving manure at nearly 900 kg/(ha•yr) of N appeared to be little different from the plot chemically fertilized with 134 kg/(ha•yr) of N. However, at and above the 560 kg/(ha•yr) of N (140 kg/(ha•yr) of P) rates of manure the drain effluent PO_4-P concentrations tended to be higher than the concentration resulting from chemical fertilizer applications.

Most of the nitrogen and phosphorus in surface runoff during June storms was associated with suspended sediment that resulted from erosion. Neither the amounts of sediment nor their total N and total P contents were affected by manure or fertilizer applications. Although the concentrations of inorganic N and PO_4-P in the water portion of June storm runoff were small (<3 percent) compared to those in the sediment, plots with higher rate spring-applied manure tended to have higher concentrations of inorganic N, PO_4-P and K.

No significant differences in silage corn yields were observed amongst any of the manure and the chemical fertilizer treatments.

Based on trends in the water quality results, it is concluded that winter application of manure at any rate on areas that contribute runoff directly to bodies of surface water is not recommended. Non-winter applications of manure at and above rates of 560 kg/(ha•yr) of N may also lead to water quality impairment.

INTRODUCTION

Changes in water quality indicators such as bacterial counts, pesticide residues, sediment loads, heavy metals, BOD, COD, and dissolved chemical concentrations in groundwater and surface water, have been linked to normal agricultural practices such as tillage, continuous cropping, use of pesticides, and spreading of manure and chemical fertilizers. In 1973, a long-term field plot experiment was initiated to study the effects of time and rate of liquid manure application on land cropped continuously in corn. The objective was to determine the nutrient losses to water supplies and accumulations in soil over a wide range of manure management alternatives. This paper is concerned with the effects of manure on nitrogen (N), phosphorus (P) and potassium (K) in subsurface and surface runoff, and on crop response.

EXPERIMENTAL DESIGN AND PROCEDURES

A gradually sloping (0.8 percent) field of an imperfectly drained Aquic Eutrochrept on the Central Experimental Farm, Ottawa, Ontario, was divided into 14 plots, each 75.6 m by 11.6 m, that has been cropped continuously in silage corn since 1973 (Fig. 1). The soil (Mountain series) is a sandy clay loam to a depth of about 80 cm covering clay loam. Selected manure and fertilizer treatments (Table 1) were randomized and applied each year to these plots. Manure rates were based on the mass of N and were chosen to be 224, 560, and 897 kg/(ha•yr) of N in accordance with four alternate application schedules: spring (usually the first week of May), fall (usually the last week of September), one-half of rate in spring - one-half in fall, and winter (usually the first week of December when ground is frozen and/or snow covered). One of the remaining two plots received no amendment while other received chemical fertilizer at the annual rate of 134 kg/(ha•yr) of N, 49 kg/(ha•yr) of P, and 93 kg/(ha•yr) of K, broadcast prior to seeding.

Each plot contained a subsurface plastic drain, positioned longitudinally down the center line of the plot at a depth of 0.7 m, which discharged into a continuous recording flow meter housed in an instrument pit (Fig. 1). Exterior runoff and cross flow between plots was controlled by a system of ditches and perimeter dikes and the plot surface runoff was measured by a continuous-recording flume mounted in the instrument pit (Fig. 1).

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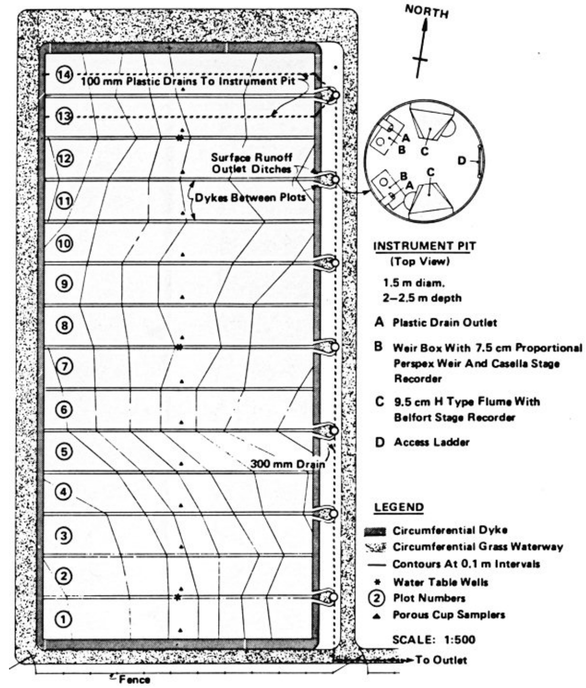
FIG. 1 Experimental plot area at the Central Experimental Farm, Ottawa.



Attempts were made to maintain flow measuring equipment during freezing months but results from December to April proved unreliable, so the equipment was removed at this time.

Manured plots received dairy cattle liquid manure (average dry matter content of 8.8 percent) spread directly from tanker trucks since treatments began in the fall of 1973. Manure volumes required to match the chosen application rates of N were estimated from an initial analysis of the manure N, one day prior to spreading. At the time of application, manure samples were taken for analysis of total N, P and K to determine the actual application rates. Except for the winter treatments, the manured plots were plowed down immediately to minimize odor problems. All plots were fall plowed and 6 of the plots (spring, spring-fall schedules) received two plowings per year. All plots were disked three times prior to seeding. Corn (United H-7) was seeded in mid-May at 46,200 plants/ha. During the first week of September, four 2.5 m length rows from the east and west halves of each treatment were harvested and weighed. Subsamples were dried at 70 °C and weighed to determine yields on a dry-weight basis.

TABLE 1. Planned Manure Treatments And Average Rates (Standard Deviations In Brackets) Of Nitrogen, Phosphorous And Potassium Applied To Plots Over Six Years Ending Spring, 1979.

Plot no.	Treatment K		Nutrient applied, kg/(ha•yr)		
	Timing schedule	Rate of N kg/(ha•yr)	N	P*	K†
12	Spring	224	230 (27)	58 (7)	201 (69)
7	Fall	224	228 (19)	54 (6)	239 (92)
11	Spr.-Fall	112/112	212 (50)	57 (21)	191 (63)
3	Winter	224	223 (33)	48 (10)	174 (28)
2	Spring	560	570 (69)	150 (32)	505 (198)
10	Fall	560	568 (67)	134 (19)	600 (254)
6	Spr.-Fall	280/280	572 (51)	141 (16)	551 (204)
5	Winter	560	526 (85)	124 (29)	413 (77)
4	Spring	897	891 (125)	234 (42)	792 (290)
8	Fall	897	923 (96)	217 (28)	973 (405)
9	Spr.-Fall	448/448	897 (67)	222 (22)	870 (328)
13	Winter	897	861 (115)	203 (42)	678 (109)
1	Spring	Chem. Fert.	134	49	93
14	Control	0	0	0	0

* P x 2.29 = P_2O_5
† K x 1.2 = K_2O

Flow events induced by snow-melt or rainfall, which involved at least 11 of the 14 plots, were sampled manually and subjected to nutrient analysis to determine the effects of treatments. Recognizing that water quality during a given event can change with time, samples were taken at intervals during each event to give a representative average value. For long events such as spring snowmelt, which extend over several weeks, grab samples were taken twice daily; sampling for events of relatively short duration, such as storm runoff, was done at the beginning, peak and end of the flow event. Therefore average nutrient concentrations for snow-melt and rainfall events were expected to be based on at least 2 to 3 samples per event-day. All samples were stored in glass bottles at 1°C prior to analysis.

Snow-melt surface runoff samples were analyzed for nitrate plus nitrite (NO, + NO_2) nitrogen, (Keng and Menage, 1970)ammonium-nitrogen (NH_4 -N)(Quin *et.*

al., 1974) and orthophosphorus (PO_4-P)(Sowden 1972) using an autoanalyser. Potassium (K) concentrations were determined using atomic absorption spectroscopy. Storm surface runoff samples that contained suspended sediment were centrifuged at 15,000 rpm for 10 min; the sediments were analyzed for total N and total P (after digestion in concentrated HNO_3- $HClO_4$ acid). The supernatant received the same analyses as snow-melt runoff samples. Subsurface drainage water was analyzed for (NO_3 + NO_2)-N, NH_4-N, PO_4-P and K in a manner similar to snowmelt runoff samples. As NO_2 concentrations in water and waste water are generally very low, and as NO_2 is readily converted to NO_3 by bacteria (Sawyer and McCarty, 1967), (NO_3 + NO_2)-N is denoted as NO_3-N below.

Total nitrogen of the manure and a few runoff samples was determined by the standard Kjeldahl method. Prior to determining phosphorus and potassium manure was digested in nitric-perchloric acid. The P in solution was determined by colorimetry while the K was determined by atomic absorption spectroscopy.

RESULTS AND DISCUSSIONS

Manure Application

Six-year averages of N, P and K applied to the experimental plots are shown in Table 1. Mean N rates actually applied are all within 6 percent of the chosen rates. The standard deviations of the N applied are mostly within about 13 percent of the chosen rates indicating a consistent application program. The applications of P and K show more variability but met or exceeded the yearly crop requirements.

Nutrient Content of Runoff Water

During the six-year study period there were occasions when rainfall induced flow on several plots. However, there were only a total of 12 surface and subsurface "Flow Events" used to determine the effect of treatments as was explained in the procedures. Spring snow-melt constituted the major portion of the annual surface and subsurface runoff (eight events) with June storms and late fall rains contributing small amounts of runoff some years (four events). Snow-melt surface runoff was estimated to average about 15 cm per year and contained little suspended sediment. June storm runoff volumes were relatively small (< 1 cm per event) compared to spring snow-melt, but carried substantial amounts of sediment from the plot surface. The potential for storm runoff was negligible during July, August, and September due to the protective effects of the corn plant. Late in the fall there is also a potential for subsurface flow in this region. However, with the exception of two very brief events, fall rainfall during the course of this study was insufficient to cause much subsurface runoff at this site. Therefore snow-melt accounted for over 90 percent of the runoff from these plots.

The treatment effects are discussed in terms of nutrient concentrations in the runoff. Although treatment comparisons of amounts lost based on concentrations and flow volumes are important, slight non-uniformity in the very gradual plot slopes caused appreciable plot variation in flow volumes during events, and precluded these comparisons. Others (Zwerman *et al.*, 1974; Klausner *et al.*, 1976, Gast *et al.*, 1978) have recognized such variations in surface and subsurface runoff from plots where treatment comparisons were made.

Nutrient concentrations for each snow-melt event represent the average of 12 to 24 plot-samples, while 2 or 3 plot-samples were obtained per rainfall induced flow event.

Surface water: Winter applications of manure at all three rates consistently resulted in higher concentrations of (NO_3 + NH_4)-N*,PO_4-P and K (Table 2) in snowmelt runoff water compared to other schedules and spring applied chemical fertilizer. In addition, these data show that increasing the rate of winter applied manure increased the concentration of these constituents in runoff

* Total Kjeldahl nitrogen (TKN) was not done routinely but results from selected spring runoff samples from winter-spread plots suggested the concentration of TKN was approximately twice the concentration of (NO_3 + NH_4)-N.

TABLE 2. Average N, P, And K Concentrations In Surface Runoff During Five Springtime Flow Events From Plots Receiving Three Rates Of Manure At Four Scheduled Times Of Application.

Nutrient	Source	Application rate, kg/(ha•yr) of N	Time of application			
			Fall	Winter	Spring	Spr.-Fall
(NO_3 + NH_4) -N	Manure	224	ND*	6.7	3.5	2.2
mg/L	Manure	560	3.9‡	11.6	3.0	4.8 ‡
	Manure	897	2.0§	23.3	4.7	4.8 ‡
	None	0			2.4†	
	Fertilizer	134			2.1†	
PO_4 -P	Manure	224	ND	2.70	0.54	0.10
mg/L	Manure	560	0.78‡	4.11	0.32	1.13 ‡
	Manure	897	0.36§	10.68	0.80	0.77 ‡
	None	0			0.09†	
	Fertilizer	134			0.08†	
K	Manure	224	ND	7.2	2.6	1.4
mg/L	Manure	560	3.5‡	14.3	2.7	3.4 ‡
	Manure	897	3.5§	30.2	6.5	5.7 ‡
	None	0			1.1†	
	Fertilizer	134			1.3†	

* no data † Four-year average ‡ Three-year average § Two-year average

TABLE 3. Average N, P, And K Concentrations In Water Portions Of Surface Runoff From Plots Receiving Three Rates Of Manure At Four Scheduled Times Of Application During Two June Storms.

Nutrient	Source	Application rate, kg/(ha•yr) of N	Time of application			
			Fall	Winter	Spring	Spr.-Fall
$(NO_3 + NH_4)$ -N mg/L	Manure	224	1.1	1.9	2.0	1.8
	Manure	560	1.0	1.1	5.1	2.3
	Manure	897	1.3	1.4*	6.5	4.1
	None	0			0.9	
	Fertilizer	134			2.2	
PO_4-P, mg/L	Manure	224	0.18	0.24	0.26	0.33
	Manure	560	0.35	0.51	0.70	0.61
	Manure	897	0.52	1.20*	1.48	1.95
	None	0			0.12	
	Fertilizer	134			0.39	
K, mg/L	Manure	224	2.6	3.5	2.7	3.1
	Manure	560	3.8	3.2	8.7	4.3
	Manure	897	7.0	4.2*	23.4	16.3
	None	0			1.7	
	Fertilizer	134			6.1	

* One storm

approximately in direct proportion to the rate applied. Schulte *et al.* (1979) in a 3-yr comparative study of winter, spring and fall-applied swine manure, also observed higher concentrations of inorganic N and orthophosphate from non-incorporated winter applications as well as increased concentration with increased rate. The results of Klausner et al. (1976) on runoff losses from winter-applied dairy cattle manure, when converted from unit area losses to concentration units, showed similar increased values of N and P with increased manure application rates except for N at the highest application rate of 200 t/ha.

The random nature of the N, P and K concentrations in the spring surface runoff resulting from the other non-winter treatments suggests that the effects of such treatments did not differ although the chemical fertilizer treatment tended to yield the lowest nutrient concentrations, particularly the P concentration. Schulte *et al.* (1979) obtained a similar trend but higher concentrations for P, possibly because manure was incorporated by disking only, in contrast to this study in which the manure and fertilizer were incorporated in the soil by plowing and disking.

In June, 1975 and 1976, storms caused surface runoff but the amount, typically 4 mm in 1976, was small compared to spring runoff. Treatments did not affect the runoff sediment concentrations which averaged about 10 g/L, nor did they affect total N and total P contents of the sediments, which were typically 0.8 and 0.3 percent respectively. Therefore, sediment-associated N and P concentrations in the runoff were about 80 mg/L and about 30 mg/L respectively, regardless of treatment. The fact that manure for all treatments was well incorporated into the soil prior to runoff could explain this lack of treatment differences. The presence of sediments in this runoff can be attributed to lack of protective crop vegetation and the experimental facilities which reflect conditions comparable to those where zero distance exists between the cropped area and the body of water receiving the surface runoff.

Analyses of the water portion of June-storm surface runoff showed concentrations of $(NO_3 + NH_4)$-N, PO_4-P and K increased from two to six times (Table 3) with increased application rates of 560 and 897 kg/(ha•yr) of N for spring and spring-fall applied manure. It does not seem surprising that runoff from these particular plots was enriched in N, P and K, as high amounts of manure were applied just weeks previously, as compared to more than 5 months previously for the other plots. However, this difference apparently had no influence on the erosion nutrient losses. The effect of rate on concentrations of PO_4-P was evident also on the fall and winter plots, but was not apparent for $(NO_3 + NH_4)$-N or K. The chemical fertilizer treatment concentrations were comparable to the overall mean concentrations of 2.3 mg/L for $(NO_3 + NH_4)$-N, 0.63 mg/L for PO_4-P, and 6.5 mg/L for K. It should be noted that these dissolved inorganic N and P concentrations in June storm runoff were small (<3 percent) compared to the sediment associated N and P.

In summarizing the results so far, winter spreading affected the quality of snowmelt runoff and spring manure application influenced runoff quality from June storms. In both types of runoff the level of dissolved nutrients were roughly in proportion to the rates applied.

Subsurface water: No NH_4-N was detected in drain effluents except for low concentrations (<0.5 mg/L) that resulted from winter applications at the two highest rates.

Treatment effects on concentrations of NO_3-N, PO_4-P and K (Table 4) for the three springtime tile drain flow events were slightly different from those for the surface flows.

Although time of application had little influence on the average NO_3-N concentrations, they did increase with increased application rates for all four application schedules. This was not unexpected; similar increased concentrations have occurred with increased nitrogen applications from chemical fertilizer (Gast *et al.*, 1978). However, even at the 897 kg/(ha•yr) of N rate of application, concentrations of NO_3-N were comparable to those under the chemical fertilizer treatment.

A comparison between the N concentrations of springtime subsurface drainage and surface runoff resulting from the high application rates, shows that the drain NO_3-N concentrations were 4 to 5 times higher than the surface $(NO_3 + NH_4)$-N concentrations except for the winter schedule treatment; however, the N in surface runoff for the winter treatment consisted largely of NH_4-

TABLE 4. Average N, P, And K Concentrations In Tile Drain Effluent During Three Springtime Flow Events From Plots Receiving Three Rates Of Manure At Four Scheduled Times Of Application.

Nutrient	Source	Application rate, kg/(ha•yr) of N	Time of application			
			Fall	Winter	Spring	Spr.-Fall
NO_3-N mg/L	Manure	224	11.0	12.3*	6.9	5.1
	Manure	560	12.1	14.0	12.8	19.4
	Manure	897	25.3	16.8	20.2	20.7
	None	0			8.4	
	Fertilizer	134			18.4	
PO_4-P, mg/L	Manure	224	0.03	0.03*	0.02	0.02
	Manure	560	0.04	0.13	0.17	0.06
	Manure	897	0.05	0.11	0.04	0.04
	None	0			0.01	
	Fertilizer	134			0.01	
K, mg/L	Manure	224	0.8	0.3*	0.7	0.8
	Manure	560	0.9	0.7	0.8	0.8
	Manure	897	1.0	1.2	0.8	1.0
	None	0			0.4	
	Fertilizer	134			0.3	

* Two-year average

N. Results from 50 measurements summarized by Baker and Johnson (1977) indicate that, in general, concentrations of NO_3-N in subsurface flow from tile drains are higher than concentrations in surface runoff.

The effect of high manure applications on PO_4-P concentrations in drain effluents is more pronounced than the NO_3-N results when compared to the control plot values. At the 560 and 897 kg/(ha•yr) of N rates of manure application (i.e. about 140 and 220 kg/(ha•yr) of P respectively), concentrations tend to be higher than those for the low manure application rate and the chemical fertilizer treatments, particularly for the winter application schedule. Both the no-fertilizer and the chemical fertilizer treatments yielded a similar concentration of PO_4-P which was not greatly lower than the concentrations resulting from the spring and spring-fall plots manured at the rate of 224 kg/(ha•yr) of N. The PO_4-P concentrations in all drain effluents were about one order of magnitude lower than those from surface runoff for comparable treatments.

Tofflemire and Chen (1976) measured 5-day PO_4-P absorption rates and capacities of A horizons ranging from 220 kg/ha of P for sand and gravel outwash materials to about 980 kg/ha of P for medium to coarse textured surface layers. Absorption rates and capacities of B horizons were generally higher than those of A horizons, and long term absorption rates were estimated to be at least twice the 5-day rates. It is reasonable to assume that PO_4-P saturation of the soil above the tile drains did not occur over the first 6 years of this study, if one considers the application rates given in Table 1. Bielby *et al.* (1973) observed considerable leaching of poultry liquid manure when applied to frozen, snow covered sandy loam. They speculated that thawing of the soil may have caused channeling thus resulting in higher PO_4-P in subsurface runoff from winter spread plots as compared to other application times.

Drainage water concentrations of K from manure applied plot were generally about twice the control plot values and were little affected by either rate or time of manure application.

During the study period, there were two subsurface runoff events induced by late fall rains. Runoff volumes averaged about 1 cm for each event. The average concentrations of PO_4-P and K (Table 5) were similar to those in snow-melt induced subsurface runoff (Table 4). However, the NO,-N concentrations were noticeably higher for most plots. Also the NO,-N concentrations,

TABLE 5. Average N, P, And K Concentrations In Subsurface Runoff From Plots Receiving Three Rates Of Manure At Four Scheduled Times Of Application During Two Late Fall Rains.

Nutrient	Source	Application rate, kg/(ha•yr) of N	Time of application			
			Fall	Winter	Spring	Spr.-Fall
NO_3-N mg/L	Manure	224	23.2	23.9*	17.3	15.8
	Manure	560	25.0	24.5	9.8*	30.0
	Manure	897	33.8	38.2	32.7*	44.4
	None	0			11.4	
	Fertilizer	134			30.7	
PO_4-P, mg/L	Manure	224	0.02	0.01*	0.01	0.02
	Manure	560	0.03	0.11	0.23*	0.03
	Manure	897	0.06	0.03	0.02*	0.02
	None	0			0.01	
	Fertilizer	134			0.01	
K, mg/L	Manure	224	0.8	0.7*	0.7	0.7
	Manure	560	0.9	0.7	0.4*	0.8
	Manure	897	1.2	1.0	0.7*	1.1
	None	0			0.6	
	Fertilizer	134			0.4	

* One event

TABLE 6. Six-year Average (1974-1979) Silage Corn Yields From Plots Receiving Three Rates Of Manure At Four Scheduled Times Of Application.

Source	Application rate, kg/(ha•yr) of N	Time of application			
		Fall	Winter	Spring	Spr.-Fall
		- - - - - - t/ha - - - - - - -			
Manure	224	11.68	11.13	11.82	11.16
Manure	560	10.59	11.65	11.92	11.69
Manure	897	12.72	11.70	10.87	12.00
None	0			8.60	
Fertilizer	134			11.39	

Standard error of the mean = 0.32

although generally higher than in the snow-melt induced drainage, show little difference between manure and chemical fertilizer treatments.

Silage Corn Yields

Since treatments were not replicated within years, plot uniformity was assessed by measuring corn yields in 1973 prior to the first application of manure or fertilizer. Yields averaged 10.01 t/ha from plots 1 to 5 with a coefficient of variability (c.v.) of 4 percent, 9.05 t/ha from plots 6 to 9 with a c.v. of 3 percent, and 8.62 t/ha from plots 10 to 14 with a c.v. of 6 percent. Thus, a significantly (Tukey's W test at 5 percent) decreasing productivity from south to north was apparent.

Corn yields, averaged over the 6 yr of treatment, were not significantly increased with increased manure application rate, nor were they affected by time of application (Table 6). Similarly, average annual yields from all manured plots (11.58 t/ha) and those from the chemically fertilized plot (11.39 t/ha) were not significantly different. However, the yield from the no-fertilizer treatment was significantly lower than those from all other treatments. These results, which indicate no improvement in corn yields at the higher rates of 560 and 897 kg/(ha•yr) of N, are consistent with those results from a 2-yr study in Indiana (Sutton *et al.,* 1978) where no yield response was observed from swine liquid manure applied in the spring at N rates above 250 kg/(ha•yr).

With spring application scheduling, consistently lower values for yield have been observed each year at the highest manure rate compared with the 560 kg/(ha•yr) rate of N. Elsewhere, high springtime application rates of manure have resulted in decreased silage corn yields possibly as a result of increased soil salinity during the growing season (Haghiri *et al.*, 1978, Shortall and Liebhardt 1975, Mathers and Stewart 1974).

CONCLUSIONS

On the basis of six years of study, and under these soil conditions, snow-melt induced runoff contributes the bulk of the total annual runoff. Winter-applied manure resulted in considerably higher concentrations of nitrogen, phosphorus and potassium in runoff than spring, fall and spring-fall applications. The higher the rate of winter application, the higher the concentrations

but this relationship was not as apparent for the non-winter application schedules. Therefore, winter applications of manure on areas that contribute snow-melt runoff directly to bodies of surface water should not be recommended.

Limited data from rain storm-induced surface runoff indicate that spring plow-down of manure at rates of 560 and 897 kg/(ha•yr) of N leads to greater concentrations of inorganic N and K in the water portion (excluding sediment) of the runoff compared to spring plow-down of manure at 224 kg/(ha•yr) of N or chemical fertilizer application at the rate of 134 kg/(ha•yr) of N.

Non-winter applications of manure at rates above 224 kg/(ha•yr) of N have not affected corn yields, but the tendency toward increased soluble orthophosphorus concentrations in tile drain effluent for manure rates at and above 560 kg/(ha•yr) of N (about 140 kg/(ha•yr) of P) compared to the chemical fertilizer application of 49 kg/(ha•yr) of P suggest that these rates of manure P could lead to water quality impairment.

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