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LONG–TERM MANURE AND FERTILIZER APPLICATION EFFECTS ON PHOSPHORUS AND NITROGEN IN RUNOFF

B. Eghball, J. E. Gilley, D. D. Baltensperger, J. M. Blumenthal

ABSTRACT. *Long–term manure and fertilizer applications to a soil can increase phosphorus (P) and nitrogen (N) transport in runoff. This study was conducted to determine P and N transport in runoff following long–term (since 1953) manure and fertilizer applications. Duplicate soil samples (32) were collected in 1998 from the top 0.1 m of selected plots of a long–term manure and fertilizer applications field experiment and later placed in 1 m^2 soil pans in the laboratory. Manure and fertilizer were mixed with 16 of the soil samples, while no treatment was applied to the other half (long–term residual effect). Simulated rainfall was then applied to the soil during initial and wet (24 hours later) events.*

Manure added just before simulated rainfall resulted in significantly greater concentrations of dissolved P (DP), bioavailable P (BAP), particulate P (PP), total P (TP), NO_3–N, and NH_4–N than when the last manure application was the previous year in 1997. Soil test P level was not a significant factor in DP loss when manure was applied just before rainfall. When the last manure application was the previous year, similar concentrations of DP, BAP, PP, and TP were measured on the manure and no–manure treatments. Concentrations of NO_3–N and NH_4–N in runoff were not influenced by long–term fertilizer application, but significantly increased with increasing N application rate when N was applied just before rainfall. Phosphorus concentration in runoff decreased with time of runoff up to 45 minutes, after which the P concentration remained constant. NO_3–N and total N concentrations continued to decrease for the entire runoff period. Manure and fertilizer should not be applied when the probability of rainfall immediately following application is great.

Keywords. *Eutrophication, Fertilizer applications, Hypoxia, Manure management, Manure runoff, Nutrient loss, Phosphorus, Water quality.*

Manure is an excellent source of nutrients and organic matter, but it can cause water, air, and soil quality concerns when it is applied to soil. Runoff from cropland areas receiving manure or fertilizer may contribute to increased phosphorus (P) and nitrogen (N) concentrations in streams and lakes (Eghball and Gilley, 1999). Transport (runoff and erosion) and source factors such as manure or fertilizer application method, loading rate, and soil test P level are the main factors controlling P movement in surface runoff (Lemunyon and Gilbert, 1993). Mueller et al. (1984) found that application of 8 Mg ha^{-1} (dry weight) of dairy manure resulted in significantly greater dissolved P (DP) and bioavailable P (BAP) loss in a no–till management system than in a conventional system. Bioavailable P loss followed the order no–till > conventional = chisel. Dissolved P is the water–soluble P fraction, while BAP is the algae–available P (Sharpley, 1993). Eghball and Gilley (1999) found that no–till application of manure resulted in greater DP but less particulate P (PP) loss in runoff than when manure was incorporated by disking.

Runoff and soil erosion amounts influence P loss in surface water. Eghball and Gilley (2001) found that soil erosion was the primary factor influencing loss of total and particulate P, while runoff amount and tillage system type affected loss of dissolved and bioavailable P. Sharpley et al. (1992) found that soluble, bioavailable, and particulate P were reduced by practices that minimized runoff and erosion. Soil test P level was correlated positively with DP loss in runoff (Pote et al., 1996; Sharpley et al., 1993). In these studies, DP in runoff increased as the soil test P level increased.

Nitrogen loss in runoff can contribute to environmental degradation. Ammonium loss into surface waters can result in poisoning of aquatic organisms if the concentration is >2.5 mg L^{-1} (USEPA, 1986). Nitrate in runoff from fields receiving manure, compost, or fertilizer may be carried to rivers and lakes. The elevated nitrate level in the Gulf of Mexico may contribute to the hypoxia condition, that is, a zone depleted of oxygen and marine life (Burkart and James, 1999).

Small soil pans or boxes on which simulated rainfall is applied have been used extensively to measure runoff, erosion, and nutrient movement from selected soils. The use of soil pans in a laboratory setting reduces the expenses and many of the difficulties associated with field rainfall simulation activities. By applying simulated rainfall to small soil pans in a laboratory setting, it is possible to conduct rainfall simulation tests throughout the year. The information

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obtained from the laboratory tests can be used to characterize conditions existing in the field.

Mitchell and Gunther (1976) used a laboratory rainfall simulator to find that the application of liquid swine manure provided a stabilizing effect on the soil surface, resulting in reduced rates of runoff and erosion. The effects of manure addition on soil erosion were found in a laboratory study conducted by Chandra and De (1982) to be influenced by the time required for organic matter to become incorporated into the soil and affect soil properties. Sharpley (1985) performed a laboratory rainfall simulation study that showed nutrient enrichment ratios can be used to quantify the effects of erosion on soil fertility and productivity.

Long–term manure application can change chemical and physical characteristics of a soil. The elevated soil P level following long–term manure or fertilizer application can be a source of P transport in runoff (Dormaar and Chang, 1995; Eghball et al., 1996; Sharpley et al., 1984). The critical period for nutrient loss in runoff is shortly after manure application (Eghball and Gilley, 1999; Sharpley, 1997). The negative effects of manure and fertilizer application on runoff P and N losses are reduced with time after application. The objective of this laboratory study was to determine the concentrations of DP, BAP, PP, total P (TP), NO_3–N, NH_4–N, total N (TN), and pH and EC levels in runoff following long–term (>45 yr) manure and fertilizer application when the last application was in 1998 (immediately before simulated rainfall) or the previous year.

MATERIALS AND METHODS

SOIL CHARACTERISTICS AND FERTILIZATION HISTORY

This study was conducted using a Tripp (coarse, mixed mesic Typic Haplustolls) sandy loam soil collected near Mitchell, Nebraska, that has been part of a rotation study since 1912. The Tripp series consists of deep, dark chestnut soils located on stream terraces and uplands. These fine granular, moderately permeable soils developed in old alluvium overlaid by loess deposits. The sand, silt, and clay contents of this soil are 71%, 26%, and 3%, respectively. Soil organic matter was 1.8% for manure and 1.3% for the no–manure treatment. Soil test P, NO_3–N, NH_4–N, EC, and pH levels for the manure and fertilizer treatments are listed in table 1.

From 1912 to 1941, one replication of the current long–term study was in continuous corn with no fertilizer or manure application. This replication was split into halves in 1942: one–half received an annual application of cattle feedlot manure (27 Mg ha^{-1}, wet basis), and no manure was applied to the other half. In 1953, the manure and no–manure plots were split again into six plots (5.5 × 12.5 m), each receiving annual fertilizer applications of 0, 45, 90, 135, and 180 kg N ha^{-1}, and 135 kg N ha^{-1} + 80 kg P ha^{-1}. The 45 and 135 kg N ha^{-1} treatments were not used in the laboratory study.

A second replication of the manure and fertilizer treatments was established in 1953 on adjacent Tripp soil, which was in a sugar beet and potato rotation that received a biennial application of cattle manure (27 Mg ha^{-1}, wet basis) from 1912 to 1952. This made the field experiment a split–plot with two replications where manure was the main plot and fertilizer was the subplot. A continuous corn cropping system has been used on both replications from 1953 to the present. Several tillage operations occur on this site each year.

Since 1953, fertilizer and manure were broadcast and incorporated by disking the soil each year in the spring before planting. Ammonium nitrate was the N source, and triple superphosphate (0–20–0, N–P–K) was the P source. The area was furrow irrigated, usually five to seven times each year, depending on crop water needs. Manure came from the same feedlot, which had no major changes in manure handling methods in the last 25 years. Selected soil characteristics and P leaching at the experimental site were reported by Eghball et al. (1996). The runoff and erosion components of this study were described by Gilley et al. (1999).

A shovel was used to collect soil samples from approximately the top 0.1 m (typical depth of manure and fertilizer disking operation) of the soil profile on 13 April 1998 before the annual application of manure and fertilizer. Two samples from each of 16 field experimental plots were placed in covered plastic containers, and the resulting 32 containers were stored at the soil water content during collection (17% gravimetric) and room temperature until testing. Samples for soil characterization (table 1) were obtained before subsequent addition of manure and/or fertilizer from each of the 32 containers using a 1.9 cm diameter coring device. The treatments used in this study are listed in table 2.

The manure used in this study was obtained from the same feedlot near Mitchell, Nebraska, used for the long–term field study. The manure had a water content of 37% and was kept in a cooler at 5° C until it was added to the soil samples. Manure and/or fertilizer were mixed in the laboratory with the topsoil at the time of testing for those experimental

Table 1. Long–term manure and fertilizer application effects on soil concentrations of sodium bicarbonate P (BICP), Bray and Kurtz #1 P (BKP), water soluble P (WSP), nitrate, ammonium, and electrical conductivity (EC) and pH levels.

Manure[a] (Mg ha^{-1})	N Fertilizer (kg ha^{-1})	BICP (mg kg^{-1})	BKP (mg kg^{-1})	WSP (mg kg^{-1})	NO_3–N (mg kg^{-1})	NH_4–N (mg kg^{-1})	EC (d S m^{-1})	pH
27	0	33.6	107.1	18.5	9.3	3.6	0.48	7.23
27	90	37.8	105.2	17.6	10.1	3.5	0.48	7.19
27	180	36.5	105.8	18.1	9.1	3.5	0.44	7.06
27	135 + 80 P	56.1	159.6	27.1	14.1	4.4	0.49	7.05
0	0	14.1	56.7	7.3	4.3	3.8	0.34	7.23
0	90	13.8	60.2	7.8	6.1	4.1	0.39	7.09
0	180	10.3	48.0	5.8	6.3	3.3	0.39	7.07
0	135 + 80 P	28.2	97.2	15.2	5.6	3.4	0.39	7.07
$LSD_{0.10}$		13.0	32.0	5.6	2.9	0.9	0.05	0.09

[a] Wet weight basis.

Table 2. Treatment arrangement and manure and fertilizer application times.

Runoff Measurement Time in Laboratory	Manure[a] (Mg ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})
Previous year (1997) manure and fertilizer addition[b]	27	0	0
	0	0	0
	27	90	0
	0	90	0
	27	135	80
	0	135	80
	27	180	0
	0	180	0
Manure and fertilizer addition just before simulated rainfall in 1998[b]	27	0	0
	0	0	0
	27	90	0
	0	90	0
	27	135	80
	0	135	80
	27	180	0
	0	180	0

[a] Wet weight basis.
[b] Manure and fertilizer application from 1953 to 1997 in the field.

treatments involving addition of manure and/or fertilizer. The manure had total N and P contents of 24 and 7.6 g kg^{-1} (dry weight basis), respectively. To produce a corn crop with a target yield of 9.4 Mg ha^{-1}, manure should be applied at rates of 15.7 and 5.6 Mg ha^{-1} (dry mass) to meet N (151 kg ha^{-1}) and P (25.5 kg ha^{-1}) requirements, respectively, assuming no residual effects from previous manure applications. Plant N and P availability of manure was assumed to be 40% and 60%, respectively, in the first year after application (Eghball and Power, 1999). Thus, the 17.0 Mg ha^{-1} (dry basis) of manure applied in this study was about 8% greater than that needed for an N–based application. Manure total N and P application rates were 408 and 129 kg ha^{-1}, respectively.

EXPERIMENTAL DESIGN

The principal experimental variables used in this study included manure or no manure application, fertilizer application rates, and timing of manure and fertilizer applications. The laboratory experimental design was a split–split treatment arrangement in a randomized complete block design with two replications. Manure was the main plot, fertilizer rate was the subplot, and time of application was the sub–subplot. Manure and fertilizer were applied to the soil samples at rates similar to the past field application rate history. For the long–term manure and fertilizer applications, rainfall simulation tests were run on 16 samples obtained on 13 April 1998. It had been approximately one year since manure and fertilizer were placed on the field plots from which the soil samples were collected.

Manure and fertilizer were also added immediately before the rainfall simulation tests to 16 additional soil samples also obtained on 13 April 1998. These soil samples represented conditions occurring in the spring immediately after the annual application of manure and fertilizer. The residual amounts of manure and fertilizer contained in the soil are at a minimum in the spring prior to the annual addition. In contrast, the greatest amounts of manure and fertilizer are present immediately after application. Experimental treatments in this study were selected to include both of these conditions, and the treatment arrangements are listed in table 2.

A 1 m^2 stainless steel soil pan, maintained at a 9% slope, was used in this study. The 9% slope was arbitrarily selected to provide optimum interrill detachment and transport conditions. A slope adjustment factor for interrill sediment delivery has been reported by Laflen et al. (1991). Three outlets were located on the floor of the 10.2 cm deep soil pan to provide drainage. To facilitate water movement to the outlets, two wire screens of 6 and 3 mm mesh covered with cotton fabric were placed on the pan floor before filling with soil (Lattanzi et al., 1974). The soil pan was constructed without an outside border around its perimeter. Thus, soil could be splashed out of the pan while none was splashed back in, resulting in a net splash loss. In this study, it was assumed that the quantity of soil material detached by rainfall impact was much greater than the amount transported by overland flow, making a border area unnecessary (Gilley et al., 1985).

Soil collected from the field was removed from an individual plastic storage container, large clods were broken by hand, and the soil was sieved through a 12–mm square hole sieve. The soil was then placed in the soil pan in three successive uniform layers. Each layer was compressed by hand with a wooden block to obtain a bulk density for the manure and no–manure treatments of approximately 1.3 and 1.4 g cm^{-3}, respectively. These bulk density values, averaged across treatments, had been obtained from field measurements. A fourth layer was applied on the top and leveled without compressing, resulting in a soil sample depth of approximately 7.6 cm. For the experimental tests involving manure and/or fertilizer application, the manure and/or fertilizer were thoroughly mixed with the soil to be used in the fourth layer (about 2 cm) before it was added to the soil pan. Following individual tests, all of the soil material was removed, the soil pan was cleaned, and material from another plastic container was placed in the soil pan for subsequent testing.

A rainfall simulator based on a design by Meyer and Harmon (1979) was used to apply water to each soil pan between May and July 1998. The rainfall simulator has the capability of applying a wide range of intensities that are typical of erosive rainstorms. An initial 1–hr rainfall application was made at an intensity of approximately 64 mm hr^{-1}, and a second 1–hr application (wet run) was conducted approximately 24 hours later at an intensity similar to the initial run. Tap water from the city of Lincoln, Nebraska, was used for this study; therefore, the N and P contents of the simulated rainfall application were assumed to be negligible.

A trough extending across the bottom of the pans collected runoff. Runoff was sampled at 5–min intervals using collection bottles. The runoff samples collected 5, 10, 15, 30, and 45 minutes after initiation of runoff from each pan were centrifuged, filtered, and analyzed for DP (Murphy and Riley, 1962), NO_3–N, and NH_4–N concentration using a Lachat (Zellweger Analytics, Milwaukee, Wisc.) system. Non–centrifuged samples were analyzed for TP (Johnson and Ulrich, 1959) and TN (Tate, 1994) concentrations, and measurement of pH and EC. Particulate P was calculated as the difference between TP and DP. Bioavailable P in runoff samples was measured using iron oxide–impregnated paper strips (Menon et al., 1990; Sharpley, 1993).

STATISTICAL ANALYSES

Mixed model analysis of variance was used to determine the effects of manure and fertilizer rate, application time, and time of runoff on concentrations of P and N components, and EC and pH levels (Littell et al., 1996). The least significant difference (LSD) test was used to determine the effects of the long–term application of manure and fertilizer on soil chemical properties (SAS, 1990). A probability level of ≤ 0.10 was considered significant.

RESULTS AND DISCUSSION

FIELD STUDY

Long–term (since 1953) manure application increased soil P, NO_3–N, and EC levels in the top 0.1 m soil profile (table 1). Manure plus P fertilizer addition increased the soil P levels much more than manure or fertilizer alone (table 1), reflecting differences in application rates. Manure and N fertilizer application decreased soil pH as compared to the application of manure without N fertilizer. Long–term ammonium–based N fertilizer application can result in a significant reduction in soil pH level (Eghball, 1999). Manure addition can also increase soil pH if it contains calcium carbonate (added in the diet) (Eghball, 1999).

LABORATORY STUDY

Runoff amounts were similar between the manure and no–manure treatments and also among fertilizer treatments (approximately 48 mm during both runs) (Gilley et al., 1999), indicating that differences in nutrient concentrations reflected differences in mass losses. Analysis of variance for the initial and wet rainfall simulation runs indicated three–way manure by fertilizer by application time interactions for DP, BAP (wet run), PP, TP, NH_4–N (wet run), total N, EC (initial run), and pH levels in runoff (all $P \leq 0.05$; table 3). During the initial and wet runs, runoff concentrations of DP and BAP were much greater for the 1998 samples, when manure and fertilizer were applied just before simulated rainfall, than for the 1997 samples, when manure and fertilizer were applied in the field (figs. 1 and 2).

Runoff concentrations of DP and BAP, for both the initial run and the wet run, were also significantly greater when chemical P fertilizer (80 kg P ha^{-1}) was applied just before simulated rainfall in 1998 than when the last P application was the previous year (figs. 1 and 2). When the last manure or fertilizer application was in 1997, runoff concentrations of DP and BAP for all manure and P fertilizer treatments were not statistically different from the no–manure, no–fertilizer check plot (figs. 1 and 2). This indicates that long–term manure and P fertilizer applications did not make a significant difference in runoff concentrations of DP and BAP as compared to the no–treatment application, even though the soil had sodium bicarbonate test levels that ranged from 10 to 56 mg kg^{-1} (Bray and Kurtz No. 1 levels of 56 to 160 mg kg^{-1}) (table 2).

Significant manure by application time by fertilizer interactions were observed for total N concentration, and EC and pH levels in runoff during the initial rainfall simulation run, and NH_4–N, TN, and pH levels during the wet run (tables 3 and 4). Runoff concentrations of total N and NH_4–N, and EC and pH levels were generally greater for manure treatments at all fertilizer rates except 90 kg N ha^{-1} for the 1997 samples, where the levels were greater for the no–manure treatment than for the manure treatment during both simulation runs (table 4). The reason for the difference at 90 kg N ha^{-1} in 1997 is not known.

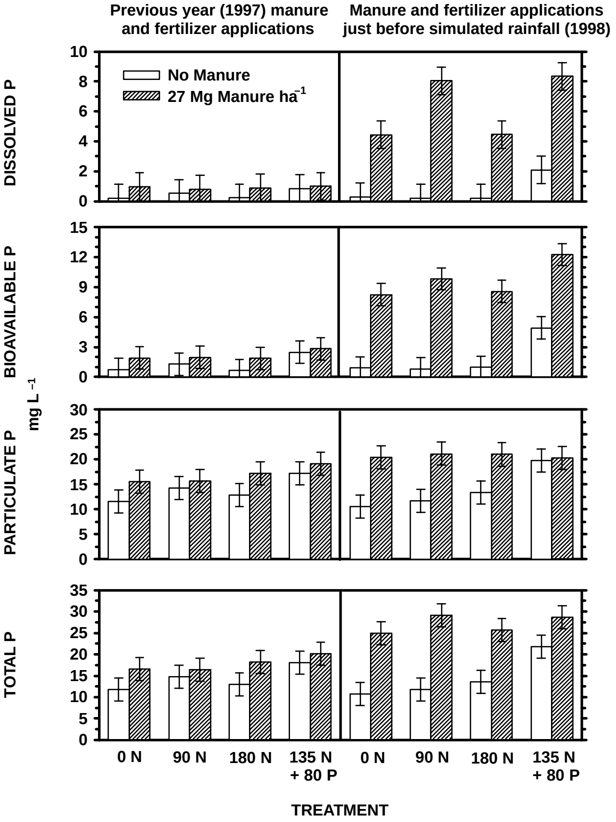

Figure 1. Dissolved, bioavailable, particulate, and total P concentrations in runoff during the initial simulated rainfall run (64 mm hr^{-1}) in 1998 from a soil receiving long–term (since 1953) manure and fertilizer applications. The vertical bars are standard errors and the last manure and fertilizer application times are noted.

Runoff PP and TP concentrations increased with P fertilizer application alone (no manure) during both simulation runs in both application years (figs. 1 and 2). Even though the runoff concentrations of PP and TP were greater for 1998 than for 1997, these differences were smaller than the DP and BAP differences between application years (figs. 1 and 2). This indicates that the PP and TP losses are influenced more by erosion than by DP and BAP. In this study, erosion was not significantly affected by manure or fertilizer application (Gilley et al., 1999). In three field rainfall simulation studies where manure, compost, and fertilizer were applied under no–till and disked conditions, Eghball and Gilley (2001) found that 78% and 88% of the variability in runoff loss of PP and TP in croplands, respectively, were explained by soil erosion.

A quadratic relationship between the soil test P level and runoff DP concentration was found when the last manure and fertilizer applications were made in 1997 (fig. 3). However, when manure and fertilizer were applied just before simulated rainfall in 1998, no significant relationship between soil test P and runoff DP concentration was observed (fig. 3). This is because the loss of P from applied manure or fertilizer dominates the effects (if any) of the soil P level on P loss in runoff. Sharpley and Tunney (2000) observed a similar trend

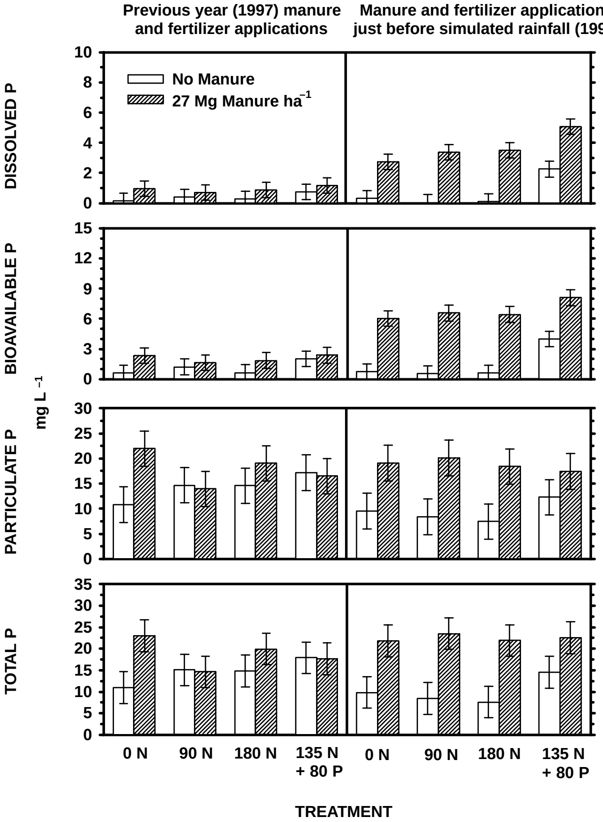

Figure 2. Dissolved, bioavailable, particulate, and total P concentrations in runoff during the wet simulated rainfall run (64 mm hr^{-1}) in 1998 from a soil receiving long–term (since 1953) manure and fertilizer applications. The vertical bars are standard errors and the last manure and fertilizer application times are noted.

when dairy manure was applied two weeks before simulated rainfall.

There were significant fertilizer by application time interactions for runoff NO_3–N and NH_4–N concentrations during the initial and wet rainfall simulation runs (table 3 and fig. 4). Nitrate and ammonium concentrations in runoff were similar for all fertilizer rates during both rainfall simulation runs when the last fertilizer application was in 1997 (fig. 4). However, runoff NO_3–N and NH_4–N concentrations increased with increasing N application rate when fertilizer was applied just before simulated rainfall in 1998 (fig. 4). This indicates that long–term fertilizer application may be less of a surface water quality concern than rainfall events occurring soon after fertilizer application, even when the fertilizer has been incorporated into the top 2 cm of soil.

Significant manure by application time interactions were observed for runoff NO_3–N and NH_4–N concentrations during the initial rainfall simulation run, and EC level during the wet run (table 3). While the runoff concentrations of NO_3–N and NH_4–N in runoff were similar between the manure treatments in 1997, manure application just before rainfall in 1998 increased nitrate concentration in runoff from 0.99 to 1.45 mg L^{-1} and ammonium concentration from 3.3 to 10.8 mg L^{-1}. No reason was apparent for the higher TN values for the 90 kg N ha^{-1} treatment with no manure as compared to manure addition during both rainfall simulation runs (table 4).

Time after initiation of runoff can influence the transport of nutrients. Table 5 shows that particulate and total P significantly decreased quadratically with time of runoff during the initial run; however, these parameters were not influenced by runoff time during the wet run. This indicates that most of the P loss occurred a few minutes following initiation of runoff. Sharpley (1997) found that when poultry litter was applied to different soils and placed in 0.15 m^2 pans, P loss decreased with rainfall time after application, and the highest concentrations of DP, BAP, TP, NO_3–N, NH_4–N, and TN were observed in runoff from the first rainfall, which occurred a week after soil/litter incubation. The trend for P and N loss was similar among soils, and runoff concentrations of P and N constituents remained constant for periods >28 d of soil/litter incubation (Sharpley, 1997). Nitrate decreased quadratically and total N decreased linearly with time of runoff during both rainfall simulation runs (table 5), indicating that the N loss from soil continued for a longer period than P loss. No effect of runoff time was observed for EC level.

Table 3. Analysis of variance (PR > F[a]) showing the effects of fertilizer, manure, time of application, and runoff time on runoff dissolved P (DP), bioavailable P (BAP), particulate P, total P, nitrate, ammonium, and total N concentrations and EC and pH levels.

Treatment	DP	BAP	Particulate P	Total P	NO_3–N	NH_4–N	Total N	EC	pH
Initial run									
Manure	0.01	0.01	NS	NS	NS	0.01	NS	NS	NS
Fertilizer (FER)	NS	0.08	0.03	0.04	0.01	0.01	NS	0.09	NS
Manure × FER	NS	NS	NS	NS	NS	NS	NS	0.05	NS
Application time (AT)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
FER × AT	0.01	0.01	NS	NS	0.01	0.01	NS	0.01	0.01
Manure × AT	0.01	0.01	0.01	0.01	0.06	0.01	0.07	0.01	0.01
FER × Manure × AT	0.01	NS	0.04	0.02	NS	NS	0.01	0.01	0.01
Wet run									
Manure	0.01	0.01	0.01	0.01	NS	0.01	NS	0.01	0.03
Fertilizer (FER)	0.08	NS	NS	NS	0.01	0.01	NS	NS	0.03
Manure × FER	NS	NS	NS	NS	NS	NS	NS	NS	NS
Application time (AT)	0.01	0.01	0.01	NS	0.01	0.01	0.01	0.01	0.01
FER × AT	0.01	0.01	NS	NS	0.01	0.01	0.10	0.01	0.01
Manure × AT	0.01	0.01	0.01	0.01	NS	0.01	NS	0.01	0.01
FER × Manure × AT	0.01	0.01	0.01	0.01	NS	0.05	0.05	NS	0.01

[a] A probability level ≤0.10 was considered significant; NS indicates a probability level >0.10.

Table 4. Application time by manure by fertilizer interaction means for runoff total N, EC, and pH levels during the initial rainfall simulation run, and ammonium, total N, and pH levels during the wet simulation rainfall run.

Application Time (year)	Manure Rate[a] (Mg ha^{-1})	Fertilizer Rate (kg N ha^{-1})	Initial Run Total N (mg L^{-1})	Initial Run EC (d S m^{-1})	Initial Run pH	Wet Run NH_4–N (mg L^{-1})	Wet Run Total N (mg L^{-1})	Wet Run pH
1997	0	0	97	0.50	7.9	0.07	90	8.2
1997	0	90	159	0.51	7.9	0.05	134	7.9
1997	0	180	81	0.48	8.0	0.28	117	8.0
1997	0	135 + 80 P	94	0.49	8.0	0.00	76	8.0
1997	27	0	118	0.46	8.0	0.00	172	8.1
1997	27	90	78	0.49	8.0	0.03	75	8.2
1997	27	180	128	0.48	8.0	0.00	132	8.2
1997	27	135 + 80 P	111	0.50	7.9	0.05	60	8.0
1998	0	0	70	0.54	7.9	0.00	51	8.1
1998	0	90	67	0.52	7.7	2.04	49	7.7
1998	0	180	74	0.55	7.6	6.08	54	7.7
1998	0	135 + 80 P	66	0.54	7.6	1.35	55	7.6
1998	27	0	97	0.74	7.9	3.83	95	8.1
1998	27	90	101	0.70	8.1	7.13	95	7.9
1998	27	180	89	0.66	8.0	10.40	78	8.0
1998	27	135 + 80 P	91	0.71	7.8	6.43	79	7.9
LSD$_{0.10}$			57	0.06	0.2	0.63	51	0.2

[a] Wet weight basis.

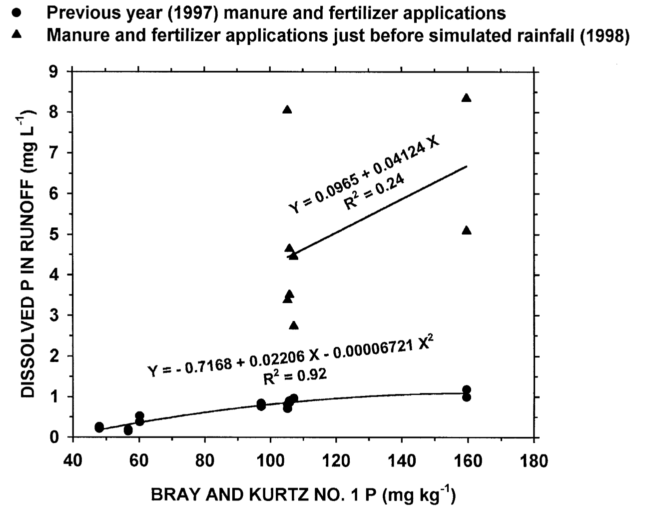

Figure 3. Dissolved P concentration in runoff during initial and wet simulated rainfall runs as influenced by the P test level in soils receiving long–term (since 1953) manure and fertilizer applications. The last manure and fertilizer application times are noted.

CONCLUSIONS

Runoff nutrient concentrations are influenced by soil nutrient content, which in turn is affected by the method, rate, and timing of manure or fertilizer application. The residual amount of manure and fertilizer contained in the soil is at a minimum in the spring prior to annual addition. In contrast, the greatest amounts of manure and fertilizer are present immediately after application. In this study, the long–term application of manure and fertilizer (since 1953) had no significant effect on runoff concentrations of DP, BAP, PP, and TP when the last manure or fertilizer application was the previous year (1997). However, when manure and fertilizer were applied just before simulated rainfall in 1998, significant losses of DP, BAP, PP, TP, NO_3–N, and NH_4–N in runoff occurred.

Soil test P was a not a significant factor in runoff DP concentration when manure application was made before simulated rainfall because DP loss from manure was much greater than from soil alone (even at a high soil P test). The quadratic relationship between runoff DP concentration and soil test P level indicated that soil test P can be an important

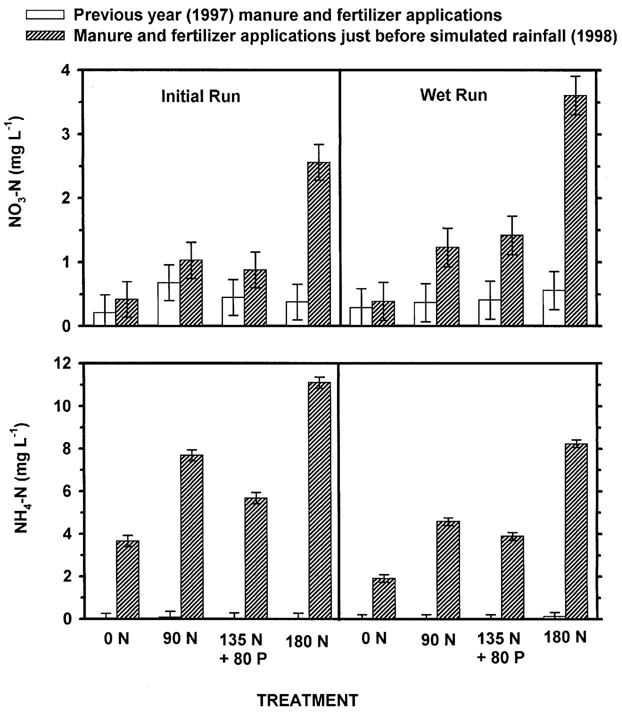

Figure 4. Nitrate and ammonium–N concentrations in runoff during the initial and wet simulated rainfall runs (64 mm hr^{-1} each) in 1998 from a soil receiving long–term (since 1953) manure and fertilizer applications. The vertical bars are standard errors and the last manure and fertilizer application times are noted.

Table 5. Effect of time of runoff on dissolved P (DP), bioavailable P (BAP), particulate P, total P, nitrate, ammonium, total N, and EC and pH levels in runoff during both the initial and wet rainfall simulation runs.

Time of Runoff (min)	DP (mg L^{-1})	BAP (mg L^{-1})	Particulate P (mg L^{-1})	Total P (mg L^{-1})	NO_3–N (mg L^{-1})	NH_4–N (mg L^{-1})	Total N (mg L^{-1})	EC (d S m^{-1})	pH
Initial run									
5	2.51	4.35	19.9	22.4	1.48	4.55	105	0.56	7.79
10	2.23	4.04	16.8	19.0	0.94	3.68	101	0.56	7.87
15	2.09	3.72	14.9	17.0	0.67	3.34	92	0.55	7.89
30	1.92	3.44	15.1	17.0	0.55	3.06	95	0.55	7.93
45	1.80	3.27	15.1	16.9	0.49	3.08	88	0.55	7.93
Linear[a]	NS	NS	***	***	***	NS	*	NS	***
Quadratic	NS	NS	***	**	**	NS	NS	NS	*
Wet run									
5	1.52	2.98	16.5	18.1	1.44	2.71	109	0.55	8.01
10	1.41	2.86	14.6	16.0	1.39	2.36	85	0.54	7.99
15	1.38	2.82	14.6	16.0	1.08	2.28	89	0.54	7.97
30	1.39	2.82	14.6	16.0	0.70	2.19	84	0.54	7.94
45	1.39	2.77	15.1	16.5	0.57	2.26	75	0.54	7.92
Linear[a]	NS	NS	NS	NS	***	NS	*	NS	*
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS

***, **, and * indicate 0.01, 0.05, and 0.10 probability levels, respectively. NS indicates non significant.

[a] Linear and quadratic indicate significance of the linear and quadratic regression coefficients.

factor in DP loss when manure or fertilizer P has adequate time to equilibrate with the soil. Manure or fertilizer application before rainfall can result in significant P and N loss in runoff. The greatest amounts of runoff P loss occurred during the first 45 minutes after runoff initiation, while N loss continued for a longer period (during the subsequent wet rainfall simulation run). The time period for which the most recent manure application dominates nutrient runoff concentrations is not known.

Rainfall simulation tests conducted throughout the year could serve to better define the interactions between long–term and recent manure and fertilizer applications on nutrient transport by runoff. The results of this laboratory study should provide a reasonable indication of field nutrient losses, since manure and fertilizer were mixed into the top 0.1 m of soil following field application and the laboratory pans contained the top 0.1 m soil from the field. Manure and fertilizer applications should be made when the probability of rainfall is low, if runoff loss of N and P are of concern.

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