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Nutrient Transport in Surface Runoff as Influenced by Soil Cover and Seasonal Periods[1]

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ABSTRACT

Nitrogen (N), phosphorus (P), and potassium (K) losses in surface runoff water and sediment were determined for five soil cover conditions on a Barnes loam soil in west-central Minnesota. The five soil cover conditions studied were: (1) continuous, clean-cultivated fallow; (2) continuous corn (*Zea mays* L.); (3) corn in rotation; (4) oats (*Avena sativa* L.) in rotation; and (5) hay in rotation.

Losses of water, sediment, and nutrients were determined for three seasonal periods; (P1) critical runoff period caused by melting snow and ice, (P2) critical erosion period from corn planting to 2 months later and (P3) noncritical runoff-erosion period exclusive of periods 1 and 2.

Much of the annual sediment and nutrient losses occurred during the critical erosion period (P2). Snowmelt runoff (P1) accounted for much of the annual water and soluble nutrient losses.

Average annual quantities of NH_4-N and NO_3-N contributed by precipitation exceeded the annual losses in surface runoff, but ortho-P losses in surface runoff were greater than the amount contributed by precipitation.

Additional Index Words: **nitrogen, phosphorus, potassium, water, sediment, snowmelt, precipitation, erosion.**

THE QUANTITIES of sediment and water lost in surface runoff from agricultural and nonagricultural land are influenced by numerous factors. Both the sediment and water components of runoff may degrade the quality of surface waters with nutrients that could have been utilized by growing plants. Thus, these nutrients not only contribute to water quality deterioration but also represent an economic loss of fertility for the farmer. The ammonium and nitrate forms of nitrogen and the orthophosphate form of phosphorus are readily available for algae and aquatic plant growth (Lee, 1970). These nutrients are also required by agronomic plants and are often supplied by commercial fertilizer.

Recently, application of simulated rainfall to small plots has been utilized for studying nutrient losses in surface runoff. Moe et al. (1967) reported that mineral N losses from fallow and sod plots established on an Indiana fragipan soil (13% slope) ranged from 2 to 15% of the applied ammonium nitrate (224 kg/ha) after 12.7 cm of rainfall. In a similar study, Moe et al. (1968) reported that mineral N losses from ammonium nitrate and urea treated plots (448 kg/ha) ranged from 2.4 to 12.7% with ammonium nitrate less susceptible to runoff loss than urea. In Georgia, White et al. (1967) found only 0.15 to 2.3% of broadcast N (224 kg/ha as NH_4NO_3) in surface runoff from sandy loam soils with a 5% slope.

Using simulated rainfall, Nelson and Römkens (1970) found that 1.0 and 1.26% soluble phosphate P was removed in 24.5 cm of runoff water from plots which received 56 and 112 kg/ha of P, respectively. Römkens et al. (1973) studied the influence of tillage methods on N and P composition of surface runoff. They reported losses of soluble nutrients for two successive simulated rainstorms in the order, coulter > till > chisel > double disk > conventional; whereas, sediment N and P losses were greatest from conventional and till systems. Timmons et al. (1973) found that incorporation of broadcast fertilizer by plowing down and disking resulted in N and P losses in surface runoff about equal to losses from unfertilized plots.

Nutrient losses in surface runoff have also been determined on a watershed basis. Taylor et al. (1971) found that N and P losses from a farmland watershed were significantly greater than those from a woodland watershed at

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Coschocton, Ohio. Nitrogen losses in surface runoff were measured by Schuman et al. (1973) for four agricultural watersheds near Treynor, Iowa. The 3-year average annual solution N losses were low from all watersheds and ranged from 0.42 to 3.05 kg/ha for the various conservation practices; whereas average annual sediment N ranged from 1.21 to 36.59 kg/ha. They also found that 92% of the total N lost in the runoff from contour-planted corn watersheds was associated with sediment. Schuman, Spomer, and Piest (1973) reported that level terraces greatly reduced P loss by reducing runoff and erosion. This watershed study also showed that a reduction of inorganic P in solution was caused by the adsorption of P by additional suspended soil material entering the stream from gully erosion. Burwell et al. (1974) compared N losses in surface runoff and base flow from a level-terraced and a contour-corn watershed near Treynor, Iowa. They found the average annual N loss (for a 2-year period) from the contour-corn watershed was about six times greater than that from the level-terraced watershed.

Under certain conditions leaching of the vegetative cover by surface runoff water could contribute substantial amounts of N and P to surface waters. Timmons et al. (1970) reported that soluble N and P in leachates from alfalfa (*Medicago sativa* L.) and bluegrass (*Poa pratensis* L.) were greatly increased by drying or freezing, two processes which occur naturally in the field.

Precipitation may contribute substantial amounts of N. Taylor et al. (1971) reported that N in precipitation averaged 20.3 kg/ha annually for a 2-year period and exceeded by six times the average annual N in runoff. During a 2-year period, Schuman and Burwell (1974) found that precipitation contributed an average of 7.26 kg/ha inorganic N annually. This was four and seven times greater than the average annual surface runoff N from the high- and normal-fertility watersheds, respectively.

Many lakes in Minnesota are surrounded by intensively cropped agricultural land. Information is needed concerning nutrient losses in surface runoff for major crops and runoff and erosion periods so that management practices can be developed to minimize soil, water and nutrient losses consistent with maintaining high production.

The objectives of this study were (i) to evaluate annual nutrient losses for five soil cover cropping conditions in the west-central Minnesota soil-climatic area, and (ii) to determine the nutrient losses for three seasonal runoff and erosion periods in the water and sediment components of surface runoff.

EXPERIMENTAL PROCEDURE

Natural-rainfall erosion plots were established in 1961 on a Barnes loam soil (6% slope) to determine runoff and sediment losses in the west-central Minnesota soil-climatic area. From 1966 through 1971, surface runoff from these plots was sampled to determine nitrogen (N), phosphorus (P), and potassium (K) composition so that nutrient losses could be calculated.

Five soil cover conditions were studied: (1) continuous, clean-cultivated fallow; (2) continuous corn; (3) corn in rotation; (4) oats (*Avena sativa* L.) in rotation; and (5) hay (alfalfa) in rotation. Rather than representing a farming practice used in the area, the continuous fallow treatment was included to determine the erodibility of Barnes soil for the universal soil loss equation. Each soil cover condition was replicated three times on 4.05 m-wide and 22.13 m-long plots. Standard runoff- and erosion-measuring equipment was used to determine sediment and water losses. The runoff collection units for one replication were automatically heated to permit measurement of snowmelt runoff.

The prevailing practice of fall plowing was used. Tillage and planting operations were upslope from the runoff collection trough. Each spring before planting fertilizer was broadcast and disked in as follows:

1) Continuous fallow—336 kg N/ha as 16–20–0 (only in 1961).
2) Continuous corn—112 kg N/ha as 33–0–0 and 29 kg P as 0–46–0.
3) Rotation corn—56 kg N/ha as 33–0–0 and 29 kg P as 0–46–0.
4) Rotation oats—18 kg N/ha as 33–0–0 and 30 kg P as 0–46–0.
5) Rotation hay—None.

The fertilizer rates were those recommended for efficient crop production. Weeds were controlled by mechanical cultivation without the use of herbicides. Crop residues remained on the plots except for two hay cuttings removed annually.

After each runoff event, one runoff sample was collected from each tank for nutrient analyses. The samples were collected in 1-liter polyethylene containers when measurements for sediment and water losses were obtained. The nutrient samples were separated into the water and sediment components by filtration under vacuum. Until chemically analyzed, the water samples were refrigerated at 2 to 3C and the sediment samples were air-dried immediately after filtration.

Water samples were analyzed for organic N by the macro-Kjeldahl method, for NH_4-N and $NO_3 + NO_2$-N by steam distillation, for total P by digestion with perchloric acid and color development using the Murphy and Riley method, for ortho-P using the Murphy and Riley method for color development, and for K using an atomic absorption spectrophotometer.

Sediment samples were also analyzed for organic N by the macro-Kjeldahl method, for NH_4-N and $NO_3 + NO_2$-N by steam distillation, for total P by digestion with perchloric and nitric acids and color development using the Murphy and Riley method, for available P using Bray's No. 1 extractant and the molybdenum blue reaction for color development, and for exchangeable K by extraction with ammonium acetate (1*N*) and measurement on an atomic absorption spectrophotometer. For both water and sediment samples, organic N was determined by subtracting NH_4-N from Kjeldahl N.

Measured nutrient losses in the eroded sediment and runoff water were determined for each plot for each runoff event as the product of sediment and water loss quantities and the respective nutrient concentrations. Seasonal sediment, water, and nutrient losses were determined as the accumulated sum for each of three periods: (P1) critical runoff period caused by snowmelt runoff; (P2) critical erosion period from corn planting to 2 months later; and (P3) noncritical runoff-erosion period exclusive of periods 1 and 2.

Estimated nutrient losses for P1, P2, and P3 were calculated as the product of the 10-year (1962–71) average sediment or water losses for each period and the respective average nutrient losses per metric ton of sediment or per hectare-centimeter of runoff for 1966–71, and losses for the three seasonal periods were summed to obtain the estimated annual nutrient losses. The average kilograms of N, P, and K per metric ton of sediment and per hectare-centimeter of runoff for each seasonal period were based on the number of seasons in which runoff occurred because this varied among years and seasonal periods for the different soil cover conditions.

Rainfall and snowfall samples were collected from April 1972 through March 1974 to determine the content of NH_4-N, NO_3-N and ortho-P in precipitation. The annual precipitation contribution of these inorganic forms of N and P were compared to the estimated average annual losses of these nutrients

Table 1—Average H_2O and sediment losses in surface runoff from Barnes loam soil by seasonal period

Cropping treatment	Years	Runoff				Sediment loss			
		P1*	P2†	P3‡	Annual	P1	P2	P3	Annual
		cm				metric tons/ha			
Fallow	1962-65	3.84	3.78	3.10	10.72	3.16	46.12	23.05	72.33
	1966-71	11.46	1.01	1.57	14.04	2.06	5.94	5.45	13.45
	1962-71	8.41	2.13	2.18	12.72	2.51	22.01	12.48	37.00
Corn-Cont.	1962-65	3.56	3.56	2.39	9.51	5.94	25.49	2.42	33.85
	1966-71	6.38	0.91	0.74	8.03	0.09	3.86	0.94	4.89
	1962-71	5.23	1.98	1.40	8.61	0.55	12.51	3.41	16.47
Corn-Rot.	1962-65	0.99	2.87	1.12	4.98	0	13.23	1.43	14.66
	1966-71	3.45	0.91	0.41	4.57	0.01	2.47	0.31	2.79
	1962-71	2.46	1.57	0.71	4.74	0.01	6.77	0.76	7.54
Oats-Rot.	1962-65	4.37	2.90	2.21	9.48	0.54	9.37	0.09	10.00
	1966-71	6.48	0.33	0.08	6.89	0.16	0.20	0.22	0.58
	1962-71	5.64	1.35	0.94	7.93	0.31	3.88	0.16	4.35
Hay-Rot.	1962-65	10.52	0.81	0.41	11.74	0	0	0	0
	1966-71	14.17	0	0.03	14.20	0	0	0.04	0.04
	1962-71	12.70	0.33	0.18	13.21	0	0	0.02	0.02
Rot. Avg.	1962-65	5.28	2.18	1.24	8.70	0.18	7.53	0.52	8.23
	1966-71	8.03	0.46	0.05	8.54	0.04	0.90	0.20	1.14
	1962-71	6.93	1.09	0.61	8.63	0.11	3.54	0.31	3.96

* Critical runoff period from snowmelt.
† Critical erosion period from corn planting to 2 months later.
‡ Remaining runoff and erosion period exclusive of Periods 1 and 2.

measured in surface runoff from each soil cover treatment. This comparison permitted an assessment of precipitation and soil cover treatment as separate sources of inorganic N and P measured in annual runoff.

RESULTS

Water and Sediment Losses

Average annual water and sediment losses caused by rainfall during P2 and P3 for the 1966–71 nutrient sampling period were considerably less than those measured for 1962–65 when nutrient samples were not collected (Table 1). However, snowmelt runoff (P1) during the 1966–71 nutrient sampling period was considerably more than for 1962–65 when nutrient samples were not collected. The differences between water and soil losses for the nutrient sampling and nonsampling periods must be considered in determining reasonable average annual nutrient loss values because the quantities of water and sediment lost by surface runoff are prime factors affecting quantities of nutrients lost.

Losses of water and sediment were greatly influenced by soil cover treatment as shown in Table 1. Of the five soil cover treatments, the greatest annual (1962–71) water loss occurred from rotation hay. Almost all of the annual water loss from the hay and oats crops occurred as snowmelt (P1) runoff. Snowmelt also accounted for 50% or more of the average annual (1962–71) runoff from the fallow and the corn cropped plots. Average seasonal water losses which occurred during the 2-month period following corn planting (P2) were generally < 4 cm for all soil cover treatments. Runoff from corn and fallow plots during P2 caused appreciable amounts of soil loss because the soil surface was not adequately protected by vegetative cover. Runoff at other times of the year (P3) caused very little soil loss for all cover conditions except fallow because the crop cover protected the soil surface from eroding forces.

Annual sediment losses from hay plots were very low ($<$ 0.1 ton/ha). Sediment losses progressively increased in the order of rotation oats, rotation corn, continuous corn, and fallow. This progressive increase in sediment loss among the soil cover treatments was inversely related to the amount of cover provided during P2. Soil erosion during P2 accounted for a large amount of the average annual sediment losses. Sediment losses during this period exceeded the desired upper limit (11.2 tons/ha)[3] for the fallow and continuous corn soil cover treatments. Sediment losses which occurred during P1 and P3 were within allowable limits for all soil cover treatments except fallow. The sediment loss for the Barnes soil emphasizes the need for erosion control practices during the early part of the corn production season. Average annual sediment losses indicate that the corn-oats-hay rotation was effective in controlling erosion (Table 1). However, this rotation cropping system is not usually accepted as economically feasible.

Measured Nutrient Losses

Most of the annual losses of N, P, and K measured in surface runoff from corn cropped plots were associated with sediment losses which occurred during the critical erosion period (P2) from corn planting time to 2 months later (Tables 2 and 3). Limited soil cover during this period was a major factor contributing to these high seasonal losses of sediment nutrients. Soil cover provided by the corn crop 2 months after planting (P3) drastically reduced losses of sediment N, P, and K (Tables 2 and 3—fallow vs. corn). The measured nutrient losses for the fallow treatment were about equal for seasonal periods 2 and 3. Soil cover provided by the oats and hay was highly effective in reducing losses of sediment nutrients during the cropping season. Sediment nutrient losses during the snowmelt runoff period (P1) were low for each of the soil cover treatments.

Losses of soluble N, P, and K in runoff water were much less than the losses of these nutrients transported by sediment (Tables 2 and 3), except for the hay treatment which had little sediment loss (Table 1). Most of the soluble nutrient losses occurred in snowmelt runoff (P1) because most of the annual runoff was from melting snow (Table 1). Soluble nutrient losses in snowmelt runoff were greater for the hay treatment than for the other soil cover treatments

[3] Soil Conservation Service Technical Guide for Minnesota. Sec. III-B-2, July 1973.

Table 2—Average N losses measured in surface runoff for soil cover conditions by seasonal period

	Solution N									Sediment N						Solution + sediment N*		
	NO_3-N*			NH_4-N			Organic N			NH_4+NO_3-N*			Organic N*					
Treatment	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
	kg/ha																	
Fallow	1.37	0.07	0.37	0.38	0.02	0.03	0.58	0.06	0.09	0.06	0.19	0.30	3.97	22.22	24.58	6.17	22.56	25.38
Corn - Continuous	1.04	0.08	0.09	0.28	0.06	0.03	0.58	0.07	0.07	0.01	0.28	0.07	0.32	16.34	4.52	2.02	16.81	4.80
Corn - Rotation	0.40	0.03	0.01	0.11	0.04	0.03	0.24	0.04	0.05	<0.01	0.17	0.03	0.06	11.32	1.62	0.92	11.59	1.73
Oats - Rotation	1.52	0.01	0.04	0.27	0.01	<0.01	0.69	0.01	<0.01	0	0.01	0.02	0	0.68	1.21	2.22	0.72	1.28
Hay - Rotation	0.62	0	<0.01	1.40	0	0.01	1.66	0	<0.01	0	0	<0.01	0	0	0.17	3.91	0	0.18
Rotation Average	0.85	0.01	0.02	0.59	0.02	0.01	0.86	0.02	0.02	0	0.06	0.02	0.02	4.00	1.00	2.35	4.10	1.06

* Based on 6 years (1966-71) measurements; NH_4-N and organic N in solution based on 4 years (1968-71) measurements.

Table 3—Average P and K losses measured in surface runoff for soil cover conditions by seasonal period

	Solution									Sediment								
	Total P			Ortho P*			K*			Total P*			Available P*			Exchangeable K*		
Treatment	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
	kg/ha																	
Fallow	0.10	0.02	0.03	0.04	0.01	0.02	0.29	0.06	0.09	0.87	5.37	5.43	0.03	0.12	0.12	0.20	1.15	1.14
Corn - Continuous	0.15	0.16	0.02	0.06	0.09	0.03	0.20	0.05	0.10	0.06	4.20	0.96	<0.01	0.25	0.04	0.01	0.65	0.22
Corn - Rotation	0.07	0.08	0.02	0.05	0.04	0.02	0.25	0.03	0.06	0.01	2.63	0.33	<0.01	0.11	0.02	<0.01	0.40	0.09
Oats - Rotation	0.19	0.02	<0.01	0.07	0.01	<0.01	0.25	0.02	<0.01	0	0.15	0.28	0	0.01	0.01	0	0.03	0.06
Hay - Rotation	0.59	0	<0.01	0.30	0	<0.01	3.57	0	<0.01	0	0	0.04	0	0	0.01	0	0	0.01
Rotation Average	0.28	0.03	0.01	0.14	0.02	0.01	1.36	0.02	0.02	0	0.93	0.22	0	0.04	0.01	0	0.14	0.05

* Based on 6 years (1966-71) measurements; total P in solution based on 3 years (1969-71) measurements.

because the winter-dormant alfalfa plants were leached by the melting snow and because they provided greater snowcatch and subsequent greater snowmelt runoff than the fall-plowed soil surface condition represented by the other treatments. Soluble nutrient losses caused by rainfall runoff during P2 and P3 were very low for all soil cover treatments and were considered insignificant compared to the amounts of nutrients applied by fertilization and used by corn.

The measured losses of soluble and sediment associated nutrients strongly reflected the influence of vegetative cover on runoff and erosion among soil cover treatments and seasonal periods. The losses of each nutrient constituent were further evaluated among soil cover treatments and seasonal periods by examining soluble nutrient losses in kilograms per hectare-centimeter of runoff and sediment nutrient losses in kilograms per metric ton of sediment lost. The per-unit loss values were low for soluble nitrogen and phosphorus nutrient constituents and differences among soil cover treatments and seasonal periods were insignificant. The per-unit loss values for soluble K were also low but were generally higher when vegetative cover was present, indicating that leaching of plant material was a prime source of soluble K measured in runoff water.

Since sediment nutrient losses represented a major portion of the total nutrient losses during the cropping season, a comparison was made of kilograms of sediment nutrients lost per metric ton of sediment lost for P2 and P3 for three sampling intervals (Table 4). These data show little difference within each nutrient constituent among soil cover treatments and seasonal periods for the three sampling periods. The values for NH_4-N, organic N, total P, and available P were consistently lower for the fallow treatment than for the other soil cover treatments. The fallow treatment was not fertilized with N and P after 1961 and was void of plant residues which probably caused the lower values for these nutrient constituents. The exchangeable K values for the corn treatments were consistently higher for P3 than P2. Since the corn crop provided more vegetative cover during P3 than P2, greater leaching of K from the corn by rainfall during P3 than P2 may have been reflected in exchangeable K measured in sediment lost by runoff.

Exchangeable K values for the oats treatment were similar for P2 and P3. Vegetative cover provided by the oat crop was similar for these two periods. Exchangeable K values for oats during P2 were consistently greater than for corn during the same period. The oat crop provided more vegetative cover during P2 than did the corn crop.

Estimated Nutrient Losses

Estimated annual nutrient losses based on the 10-year (1962–71) average water and sediment losses and the 6-year (1966–71) average nutrient losses are given in Table 5. This estimation was made because average seasonal water and sediment losses caused by rainfall during P2 and P3 for

Table 4—Comparison of average nutrient losses per unit of sediment for P2 and P3 during three sampling intervals*

Years	NO_3-N		NH_4-N		Organic N		Total P		Available P		Exchangeable K	
	P2	P3	P2	P3	P2	P3	P2	P3	P2	P3	P2	P3
	kg/metric ton											
	Fallow											
1966-71	0.01	0.01	0.03	0.04	3.83	4.40	0.91	0.94	0.02	0.02	0.20	0.23
1968-71	0.01	0.01	0.02	0.04	3.73	4.30	0.89	0.90	0.02	0.02	0.20	0.24
1969-71	0.01	0.01	0.02	0.04	3.71	4.29	0.90	1.03	0.02	0.02	0.19	0.24
	Corn - Continuous											
1966-71	0.02	0.01	0.07	0.07	4.41	4.87	1.12	1.10	0.06	0.05	0.18	0.27
1968-71	0.02	0.01	0.07	0.07	4.47	4.77	1.14	1.08	0.06	0.06	0.18	0.28
1969-71	0.02	0.01	0.06	0.06	4.17	4.67	1.11	1.18	0.07	0.06	0.17	0.26
	Corn - Rotation											
1966-71	0.02	0.01	0.06	0.06	4.49	4.89	1.05	1.03	0.05	0.05	0.18	0.28
1968-71	0.02	0.01	0.06	0.07	4.63	4.99	1.08	1.01	0.04	0.05	0.18	0.29
1969-71	0.02	0.01	0.05	0.06	4.63	4.94	1.08	1.11	0.05	0.05	0.16	0.28
	Oats - Rotation											
1966-71	0.01	0.01	0.08	0.06	4.92	4.76	1.16	1.05	0.05	0.05	0.23	0.23
1968-71	0.01	0.01	0.08	0.07	5.07	4.81	1.20	1.04	0.05	0.05	0.24	0.21
1969-71	0.01	0.01	0.07	0.08	5.04	5.46	1.22	1.25	0.05	0.03	0.22	0.23

* Sediment loss occurred only once from rotation hay during period P3.

the 1966–71 nutrient sampling period were considerably less than those measured for 1962–65 when nutrient samples were not collected. Snowmelt runoff (P1) during the 1966–71 nutrient sampling period was considerably more than for 1962–65. Since amounts of water and soil lost were prime factors affecting quantities of nutrients lost, the 10-year average seasonal losses provided more reasonable loss values than provided for by the 1966–71 sampling period. The consistency of per-unit losses of soluble and sediment nutrient constituents within soil cover treatments and seasonal periods discussed previously provided additional confidence for estimating average annual nutrient losses.

Average annual losses of N transported in runoff by water and sediment ranged from 4.1 kg/ha for the hay treatment to 150.3 kg/ha for the fallow treatment (Table 5). The data show that N transported by sediment accounted for 96% or more of the total losses of N from fallow, continuous corn and rotation corn treatments. The average annual losses of total P in runoff ranged from 0.68 kg/ha for the hay treatment to 33.3 kg/ha for the fallow treatment. Phosphorus transported by sediment accounted for 95% or more of the annual P losses for all soil cover treatments except hay. The average annual K losses in runoff ranged from 1.90 kg/ha for rotation corn to 8.41 kg/ha for the fallow treatment. Except for hay, potassium transported by sediment also represented a major portion of the K lost annually in surface runoff.

The annual losses of total N and total P transported by sediment were appreciable compared with annual fertilizer application and crop use. Most of the nutrients transported by sediment were in forms unavailable for plant use but represented a potential source of plant food supply. The large quantities of sediment nutrients lost during the critical erosion period emphasize the need for erosion control practices on the Barnes soil to conserve nutrients for future plant use and abate pollution of surface water.

The average annual losses of soluble nutrients in runoff were much less than those transported by sediment (Table 5). Annual losses of soluble nutrients were very low compared with fertilizer applications and crop use, but NH_4-N, NO_3-N and ortho-P in runoff water may enhance eutrophication of surface waters.

Precipitation Contribution of N and P Relative to Runoff Losses

Inorganic N (NH_4-N and NO_3-N) and ortho-P contributed by precipitation was measured for a 2-year period (April 1972 through March 1974) and compared with the soluble nutrients in surface runoff for each soil cover treatment. Average annual precipitation from April 1972 through March 1974 was 57.2 cm (63.6 and 50.8 cm for each 12-month period) which contained 5.09 kg of NH_4-N/ha and 2.45 kg of NO_3-N/ha. Estimated average annual inorganic N losses in surface runoff (water + sediment) based on 1962–71 water and sediment losses ranged

Table 5—Estimated nutrient losses based on 10-year average (1962–71) water and sediment losses and nutrient losses measured during 1966–71

Total N*			Total P			Inorganic P†			K‡		
Solution	Sediment	Annual	Solution	Sediment	Annual	Solution	Sediment	Annual	Solution	Sediment	Annual
kg/ha											
Fallow											
3.43	146.85	150.28	0.19	33.15	33.34	0.10	0.74	0.84	0.81	7.60	8.41
Corn - Continuous											
2.42	75.56	77.98	0.41	18.19	18.60	0.25	0.94	1.19	0.58	3.26	3.84
Corn - Rotation											
1.18	34.77	35.95	0.23	8.43	8.66	0.15	0.45	0.60	0.47	1.43	1.90
Oats - Rotation											
2.59	21.00	23.59	0.24	5.01	5.25	0.14	0.21	0.35	0.94	1.00	1.94
Hay - Rotation											
4.01	0.09	4.10	0.66	0.02	0.68	0.39	0	0.39	4.56	0	4.56

* Organic N + NH_4-N + NO_3-N. † Ortho-P in solution and Bray's No. 1 P in sediment. ‡ Water-soluble K in solution and exchangeable K in sediment.

from 0.76 kg/ha to 1.75 kg/ha for NH_4-N and from 0.61 kg/ha to 2.29 kg/ha for NO_3-N depending on soil cover treatment. These data indicate that more NH_4-N and NO_3-N were contributed annually by precipitation than was lost in surface runoff, and that the soil and/or vegetation acted as a nutrient sink for the inorganic N contributed by precipitation.

The ortho-P content of average annual precipitation for the 2-year period was 0.125 kg/ha. Based on 1962–71 water and sediment losses, estimated average annual P losses in surface runoff (ortho-P in water + available sediment P) ranged from 0.35 to 1.19 kg/ha depending on soil cover treatment. Since surface runoff contained more soluble P than was contributed annually by precipitation, soil and/or plant material were major sources of inorganic P lost in runoff. The contribution of soluble N and P from precipitation, soil and/or plant material needs to be determined for individual runoff events.

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