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Seasonal Runoff Losses of Nitrogen and Phosphorus from Missouri Valley Loess Watersheds

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ABSTRACT

Seasonal losses of nitrogen and phosphorus in surface runoff were determined for a 7-year period from three corn-cropped watersheds in southwestern Iowa. Three seasonal periods were defined: fertilizer, seedbed, and establishment period from April through June (P1); reproduction and maturation period from July through November (P2); and residue period from December through March (P3).

Most of the average annual total N and P losses were associated with the sediment portion of runoff and occurred during P1. The extreme susceptibility of the loess soils to erosion during P1 must be taken into account when designing conservation practices to control plant nutrient losses. Seasonal discharges of runoff, sediment, and nutrients were much lower from a level-terraced watershed than from two contour-farmed watersheds, which demonstrates the benefit of terracing in resource conservation.

Average annual soluble N and P losses were quite low and never exceeded 1% of the annual fertilizer application. These losses were the highest during P3 from the contour-farmed watersheds.

Water and sediment weighted nutrient concentrations were the highest from the contour-farmed watersheds during P3, when residues covered the soil surface. Leaching of soluble nutrients from the residue and the greater selectivity of the soil erosion process for the finer fractions of the soil (i.e., clay and organic material) during snowmelt runoff are probably the factors responsible.

Additional Index Words: **water quality, nutrient loss, surface runoff, erosion.**

Nitrogen (N) and phosphorus (P) are two of the major plant nutrients applied to cropland to supplement natural fertility. However, these nutrients are susceptible to losses in agricultural runoff, which not only represents an economic loss to the farmer, but also may enhance algal and other aquatic plant growth in impounded waters. Furthermore, this agricultural runoff might possibly have seasonal significance. Growing public concern for water quality has encouraged research to identify and to determine the full extent of pollution from agricultural lands.

Because nutrient losses can be minimized using good conservation practices, much research has been conducted to evaluate the effect of various management practices on N and P losses in surface runoff. Research has shown that most of the N and P discharged from cropland is associated with the eroded soil transported by runoff. Earlier results of this study (Schuman et al., 1973a and 1973b; Burwell et al., 1974) showed the effectiveness of level terraces in controlling N and P losses from agricultural watersheds. Schuman et al. (1973a) reported that the average annual total N loss from a contour-farmed corn watershed and a level-terraced corn watershed annually fertilized at the same rate (448 kg N/ha) was 39.64 and 3.04 kg/ha, respectively. About 92% of the total N lost from the contoured watershed was associated with the sediment. Schuman et al. (1973b) found that the average annual P losses associated with the sediment from four agricultural watersheds ranged from 0.08 to 1.05 kg/ha, whereas soluble P losses ranged from 0.05 to 0.22 kg/ha. Burwell et al. (1974) compared N and P losses in surface runoff from a 157.5-ha well-planned conservation watershed and a 33.6-ha contour-farmed watershed in southwestern Iowa. The results showed that level terraces were extremely beneficial in reducing water, sediment, and nutrient discharges. Timmons et al. (1968) in Minnesota and Olness et al. (1975) in Oklahoma showed that cropping systems that reduced soil erosion also reduced N and P losses.

Rather low annual losses of soluble N and P in surface runoff have generally been reported. Jackson et al. (1973) found NO_3-N losses to be <0.50 kg/ha in runoff from a small corn watershed in Georgia. Klausner et al. (1974) reported NO_3-N discharges as high as 29.20 kg/ha from poorly managed wheat plots that had been fertilized (241 kg N/ha) before heavy fall rains. However, most of the reported soluble N losses have been <5 kg/ha (Olness et al., 1975; Schuman et al., 1973a). Kilmer et al. (1974) and Schuman et al. (1973b) showed that losses of soluble P from soils are often negligible.

The composition of surface runoff, however, can be affected by factors other than cropping and fertility management practices. Timmons et al. (1970) and White (1973) showed that the drying and freezing of plant tissue can increase the amount of N and P in leachate. Precipitation can also contribute large annual amounts of N. In Ohio, Taylor et al. (1971) found that soluble N in precipitation averaged about 20 kg/ha, six times the amount of soluble N lost in surface runoff. Klausner et al. (1974) found that soluble N losses in surface runoff for a 10-mo period did not exceed that contributed in rainfall, except for a heavily fertilized wheat treatment. Schuman and Burwell (1974) reported that 7.3 kg/ha of soluble N (NO_3-N and NH_4-N) was contributed annually by precipitation in southwestern Iowa. They found that the equivalent of 69% of the soluble N in runoff from a normally fertilized (168 kg N/ha) corn watershed could be attributed to the precipitation that ran off.

The 1972 Federal Water Pollution Control Act Amendments require that guidelines be developed for identifying and controlling nonpoint sources of pollution. Seasonal losses of runoff, erosion, and plant nutrients are important criteria in developing conservation practices to control pollution. In west-central Minnesota, Burwell et al. (1975b) found snowmelt to be the most critical runoff period for soluble nutrient losses. For N and P losses associated with the sediment, the most critical period was from corn planting until 2 mo later which corresponded to the period of limited or no soil cover. Kilmer et al. (1974) found on grassed watersheds in

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North Carolina that N and P losses were highest during the winter and spring months. Additional information on seasonal losses of N and P is needed, particularly from different soils and climatic regions. Our study reports on seasonal losses of N and P in surface runoff for a 7-year period (1969-75) from three corn-cropped watersheds in southwestern Iowa. Our objectives were (i) to determine N and P losses for three seasonal runoff and erosion periods, and (ii) to determine water and sediment weighted nutrient concentrations for each seasonal period.

MATERIALS AND METHODS

Nitrogen and phosphorus discharge data were obtained from three agricultural watersheds located in southwestern Iowa near Treynor. The watersheds are within, and typically represent, the deep loess hills region of western Iowa and northwestern Missouri. The rolling topography is characterized by gently sloping ridges, steep side slopes, and well-defined alluvial valleys. Slope lengths on the research watersheds often reach 300 m, with slopes of 2-4% on the ridges and valleys and 12-18% on the sides. Principal soil types are the Typic Hapludolls, Typic Haplorthents, and Cumulic Hapludolls. These well-drained soils are classified as fine, silty mixed mesics. Percent N of these soils range from 0.08 to 0.24% depending upon past management history and slope position. Gully and sheet-rill erosion are serious problems in this area unless adequate soil conservation practices are used.

The outlet of each watershed is instrumented with a broad-crested, V-notch weir and water stage recorder to measure streamflow. Precipitation is measured by recording raingauges distributed over each watershed. Each of the watersheds is entirely tillable and has been in continuous corn since 1964. The size and management history of the three watersheds is shown in Table 1.

Conventional tillage operations consisted of moldboard plowing or deep disking to incorporate the corn residue followed by a shallower disking immediately before planting. Watersheds 1 and 2 are farmed on the contour which represents the prevailing conservation practice used in the region. In 1972, the terrace system on watershed 4 was redesigned and the terrace spacing doubled to better accommodate larger row-crop machinery. An underground pipe-drainage system with perforated vertical pipes was installed in the low points of each terrace channel to reduce surface ponding detention time. Coincident with the terrace reconstruction, a till-plant system was initiated using a Buffalo[3] till-planter and cultivator. At least one cultivation is needed with this tillage system to build a ridge for corn planting the following year.

Fertilizer was applied on the watersheds in the spring before any pre-plant tillage operations. Watershed 2 received the recommended fertilizer application rates of 168 kg N/ha and 39 kg P/ha annually. Both watersheds 1 and 4 received excessive fertilizer application rates of 448 kg N/ha and 97 kg P/ha annually for a portion of the study. About 80% of the N fertilizer was applied as anhydrous ammonia knifed in to a depth of 25-35 cm. The remaining N was broadcast on the soil surface as NH_4NO_3 and incorporated by a preplant tillage operation. All the P fertilizer was broadcast on the surface as superphosphate and incorporated. Since 1972, the granular fertilizer applied to watershed 4 was not incorporated before planting with the till-planter.

Nutrient samples were manually collected at the watershed outlet to represent runoff from the cropland area. A minimum of four samples/event was usually obtained from the rising, peak, and recession stages of the hydrograph. After collection, the samples were stored at 4°C until nutrient analyses were completed. The water and sediment portions of the runoff were separated by centrifugation and/or filtering through Whatman no. 42[3] filter paper. Nitrate-N and NH_4-N concentrations of the clarified solution were determined by steam distillation procedures (Bremner, 1965a) from January 1969 until July 1970. For the remainder of the study, NO_3-N and NH_4-N concentrations were determined by continuous flow colorimetric procedures (Henriksen and Selmer-Olsen, 1970). Sediment N, which is mainly composed of organic forms in these soils, was determined by micro-Kjeldahl procedures (Bremner, 1965b). Solution P of the clarified solution was determined by the ascorbic acid method (Murphy and Riley, 1962). Sediment P was determined by extracting with $NaHCO_3$ (Olsen et al., 1954). Sediment concentrations were determined by gravimetric procedures.

From 1969-71, most events were intensively sampled with as many as 24 samples being collected during a single rainstorm event. Nutrient losses were determined by integrating concentrations with water or sediment flux over small, discrete time intervals (Schuman et al., 1973a). However, other results from this study (Burwell et al., 1975a) showed that N and P losses could be adequately estimated as the product of the mean nutrient concentration of three samples collected during the major portion of runoff (defined as >0.23 m^3/sec) and the quantity of water or sediment discharged. Due to savings in sampling and analytical time, this procedure was used to determine nutrient losses associated with surface runoff for the remainder of the study (1972-75).

Three periods, based on the amount of surface cover and distribution of erosive rainfall within the year, were selected for evaluating seasonal N and P losses: P1—fertilizer, seedbed, and establishment period (April-June); P2—reproduction and maturation period (July-November); and P3—residue period (December-March). In the western Corn Belt, severe thunderstorms are likely in the spring and early summer when there is little or no soil cover. This period extends from the time fertilizer is applied in the spring until about 2 mo after corn planting (P1). During the reproduction and maturation period (P2), the crop is rapidly growing and maturing with the canopy helping to minimize raindrop impact on the soil surface. Precipitation during the latter portion of this period is often high and is usually caused by frontal systems that produce rains of lower intensity and longer duration. Precipitation during the residue period (P3) is usually minor and often occurs as snowfall on frozen ground. About 8.5 metric ton/ha of residue are left on the watersheds after corn harvest. These residues help protect the soil surface against erosion during the late fall, winter, and until seedbed preparation begins the following spring.

Estimated losses of N and P were determined for each of the three seasonal periods as the product of the 12-year (1964-75) average water and sediment discharge and the respective weighted nutrient concentrations determined from the 7-year (1969-75) nutrient sampling period. Weighted nutrient concentrations were determined for each period by dividing the average annual nutrient loss by the average annual surface runoff or sediment yield. The resulting values, having units of kg/ha cm for the soluble nutrients and kg/metric ton for the sediment nutrients, were then converted to units of ppm.

[3] Name of product is listed for benefit of the reader only and does not imply endorsement or preferential treatment by the USDA.

Table 1—Management history of corn-cropped watersheds, Treynor, Iowa

Watershed	Size	Tillage	Conservation practice	Fertilizer N	Fertilizer P
	ha			kg/ha	
		1969-1971			
1	30	Conventional	Contour	448	97†
2	33	Conventional	Contour	168	39
4	60	Conventional	Level-terrace	448	97†
		1972-1975			
1		Conventional	Contour	448‡	39
2		Conventional	Contour	168	39
4		Mulch	Parallel terraces with pipe drains	168	39

† P applied at the rate of 39 kg/ha in 1971.
‡ N applied at the rate of 168 kg/ha in 1975.

RESULTS AND DISCUSSION

Hydrology and Erosion

Average precipitation during the 7-year nutrient sampling period was 79.0 cm (Table 2), 7.1 cm above the 100-year average measured at Omaha, Nebraska. About

Table 2—Precipitation, surface runoff, and sediment yield by seasonal periods

Year	Precipitation			Surface runoff			Sediment yield		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
	cm						metric tons/ha		
	Watershed 1—30-ha contoured corn								
1969	33.10	37.51	9.18	0.67	1.27	4.47	0.65	3.02	0.38
1970	23.12	52.91	4.01	1.51	2.90	1.06	16.08	9.99	0.07
1971	35.20	31.16	7.44	9.67	0.40	2.50	44.19	0.31	0.29
1972	29.38	50.62	6.20	2.44	1.05	0.37	15.90	0.81	0.11
1973	26.24	55.17	24.54	0.49	2.18	3.97	0.11	1.70	0.49
1974	19.15	38.65	5.27	0.54	0.60	0.23	0.72	0.38	0.00
1975	26.49	38.05	13.71	0.70	1.49	0.44	2.07	1.35	0.06
1969–75 Avg.	27.53	43.44	10.05	2.29	1.41	1.86	11.39	2.51	0.20
1964–75 Avg.	32.78	41.84	9.01	5.45	1.91	1.92	38.56	4.03	0.60
	Watershed 2—33-ha contoured corn								
1969	33.53	37.39	9.19	0.48	1.15	4.30	0.47	1.75	0.13
1970	22.38	51.90	4.01	1.36	1.62	0.88	11.89	4.70	0.02
1971	34.61	32.03	7.44	6.11	0.34	3.31	29.46	0.15	0.10
1972	29.03	51.22	6.20	1.85	1.10	0.86	16.68	0.70	0.27
1973	25.32	54.63	24.64	0.43	2.70	4.37	0.02	0.76	0.24
1974	18.82	38.07	5.27	0.52	0.65	0.35	0.54	0.22	0.00
1975	25.88	39.06	13.71	0.59	1.36	0.16	1.08	0.65	0.03
1969–75 Avg.	27.08	43.47	10.07	1.62	1.27	2.03	8.59	1.28	0.11
1964–75 Avg.	32.38	41.63	9.01	4.88	1.65	2.08	31.93	2.11	0.44
	Watershed 4—60-ha terraced corn								
1969	30.33	14.20	8.27	0.14	0.18	0.38	0.02	0.09	0.00
1970	20.78	48.25	4.09	0.08	0.17	0.10	0.22	0.00	0.00
1971	35.84	32.79	7.78	1.28	0.09	0.38	3.56	0.04	0.00
1972†	37.92	51.05	6.27	7.26	2.41	1.04	13.85	0.43	0.39
1973	25.22	53.26	23.98	1.14	2.87	4.48	0.18	1.07	0.92
1974	17.35	31.17	5.29	0.34	0.26	0.06	0.16	0.02	0.00
1975	26.67	34.49	12.60	0.80	1.04	1.06	0.27	0.12	0.03
1969–75 Avg.	27.73	37.89	9.75	1.58	1.00	1.07	2.61	0.25	0.19
1964–75‡ Avg.	33.04	37.84	8.68	1.38	0.63	1.04	2.73	0.18	0.14

† Initiation of till-plant system.
‡ Sediment yield based on 1966–75 avg.

one-third of the average precipitation occurred during P1, but the erosivity of the rainfall during this period was often high due to the intense nature of the thunderstorms.

Water and sediment losses from the three watersheds were quite variable depending upon the amount, duration, and intensity of the rainfall. Table 2 shows that average water and sediment losses from the two contour-farmed watersheds for the 1969–75 nutrient sampling period were considerably lower than those measured for the 1964–75 period. The contour-farmed watersheds differed in runoff and sediment losses primarily because of differences in slope and other topographical features. Significant amounts of runoff and erosion often occurred during P1 after the soil had been tilled for planting. Intense rainstorms on bare loessial soils caused pronounced surface sealing which greatly reduced infiltration and increased runoff and subsequent erosion. Snowmelt during P3 was often a significant portion of annual runoff, especially those years when heavy snowfall was recorded. Average sediment losses from the contour-farmed watersheds were higher than those regarded as tolerable for this agricultural region. The high sediment losses during P1 illustrate the high susceptibility these soils have to erosion if inadequate conservation practices are used.

Table 3—N losses in surface runoff by seasonal periods

Year	Solution N						Sediment N		
	NO_3-N			NH_4-N					
	P1	P2	P3	P1	P2	P3	P1	P2	P3
	kg/ha								
	Watershed 1—30-ha contoured corn								
1969	0.24	0.53	1.53	0.01	0.04	0.49	0.96	4.33	0.56
1970	0.70	0.32	0.43	0.14	0.14	0.14	21.80	12.79	0.14
1971	0.79	0.02	0.50	1.00	0.03	1.07	67.62	0.75	0.69
1972	0.51	0.10	0.04	0.23	0.02	0.04	20.90	2.16	0.36
1973	0.56	0.71	0.76	0.04	0.08	0.21	0.29	3.37	1.53
1974	0.41	0.45	0.18	0.05	0.02	0.01	0.53	0.55	0.00
1975	0.17	0.12	0.24	0.02	0.04	0.02	2.61	1.70	0.12
1969–75 Avg.	0.48	0.32	0.53	0.21	0.05	0.28	16.39	3.66	0.49
	Watershed 2—33-ha contoured corn								
1969	0.11	0.33	1.01	0.01	0.03	0.91	0.82	1.90	0.24
1970	0.19	0.14	0.20	0.13	0.15	0.06	18.77	6.35	0.03
1971	0.39	0.01	0.55	0.58	0.02	0.86	40.73	0.15	0.42
1972	0.38	0.08	0.03	0.11	0.02	0.01	24.65	2.03	0.54
1973	0.05	0.26	0.29	0.05	0.07	0.10	0.04	1.58	0.40
1974	0.15	0.09	0.07	0.03	0.02	0.65	0.34	0.34	0.00
1975	0.20	0.08	0.04	0.01	0.02	0.00	2.34	1.61	0.04
1969–75 Avg.	0.21	0.14	0.31	0.13	0.05	0.37	12.53	1.99	0.24
	Watershed 4—60-ha terraced corn								
1969	0.08	0.07	0.09	0.00	0.02	0.10	0.06	0.25	0.00
1970	0.05	0.04	0.05	0.01	0.01	0.01	0.52	0.00	0.00
1971	0.10	0.00	0.06	0.30	0.04	0.25	7.03	0.00	0.00
1972	2.79	0.46	0.01	0.27	0.03	0.06	21.74	0.78	0.56
1973	0.51	1.31	0.74	0.06	0.11	0.16	0.78	2.03	1.38
1974	0.28	0.20	0.06	0.01	0.00	0.00	0.51	0.04	0.00
1975	0.46	0.10	0.24	0.01	0.02	0.16	0.74	0.26	0.11
1969–75 Avg.	0.61	0.31	0.18	0.09	0.03	0.11	4.48	0.48	0.29

The surface runoff and sediment loss data from watershed 4 illustrate the benefits of terraces in soil and water conservation. Terraces were extremely effective in reducing runoff and sediment losses the first 3 years of the study. However, the losses were greater in 1972 immediately after the new terrace system was constructed and to some extent in 1973. These increases could be attributed to several factors: (i) terrace overtopping and failure caused by an intense thunderstorm in May 1972, (ii) increased drainage of the terrace channels through the stand-pipe and underground drainage system, and (iii) compaction from large earth-moving equipment reducing the infiltration capacity of the soil. Sediment losses from the terraced watershed are expected to be much lower than those from the contoured watersheds given rainfalls of equal intensity and duration. Storm runoff volumes from the terraced watershed are expected to resemble those from the contoured watersheds. However, runoff rates will be significantly reduced because of ponding and subsequent drainage through the stand-pipe and underground drainage system.

Measured Nitrogen and Phosphorus Losses

Most of the N discharged from the watersheds was associated with the sediment portion of runoff (Table 3). Sediment N transported from the contoured watersheds accounted for 92% of the total N discharged. Over 80%

of the average sediment N discharged from the contour-farmed watersheds occurred during the critical erosion period (P1). Intense thunderstorms and limited soil cover were the factors responsible for this high seasonal loss of sediment N. This finding illustrates that conservation practices must be designed to control erosion and associated N losses during the critical erosion period. Sediment N losses during P2 were much lower because the corn canopy protected the soil surface against raindrop impact and particle detachment. Nitrogen losses associated with the sediment were low during P3.

The data illustrate that conservation practices that control erosion are also very effective in reducing N losses (Table 3) since most of the N loss is associated with sediment loss. Terraces were very effective in reducing sediment N losses during the critical erosion period. The average sediment N loss from the terraced watershed during P1 was about one-third that from the contour-farmed watersheds. Average sediment N losses from the terraced watershed during P2 and P3 were also reduced as compared with those losses from the contour-farmed watersheds.

The amount of solution N (NO_3-N and NH_4-N) discharged from the watersheds was quite low (Table 3), $< 1\%$ of the amount of N applied as fertilizer annually. This figure does not account for N contributed from other sources such as precipitation, mineralization of the soil organic matter, and leaching from the corn residue. Average solution N losses from the contoured watersheds were the highest for P3, primarily due to higher solution N concentrations.

Soil erosion also accounted for most of the P discharged from the watersheds (Table 4). About 76% of

Table 4—P losses in surface runoff by seasonal periods

Year	Solution P			Sediment P		
	P1	P2	P3	P1	P2	P3
	kg/ha					
	Watershed 1—30-ha contoured corn					
1969	0.008	0.029	0.153	0.054	0.220	0.032
1970	0.015	0.054	0.016	0.549	0.395	0.004
1971	0.152	0.005	0.080	1.836	0.016	0.029
1972	0.019	0.019	0.002	0.503	0.044	0.007
1973	0.037	0.031	0.107	0.006	0.067	0.031
1974	0.005	0.011	0.003	0.042	0.031	0.000
1975	0.014	0.022	0.007	0.121	0.116	0.007
1969-75 Avg.	0.036	0.024	0.053	0.444	0.127	0.016
	Watershed 2—33-ha contoured corn					
1969	0.005	0.012	0.077	0.046	0.104	0.013
1970	0.013	0.018	0.015	0.322	0.154	0.001
1971	0.075	0.002	0.112	1.077	0.003	0.019
1972	0.016	0.008	0.004	0.377	0.049	0.000
1973	0.038	0.068	0.099	0.001	0.035	0.012
1974	0.009	0.011	0.006	0.040	0.017	0.000
1975	0.015	0.035	0.002	0.108	0.190	0.003
1969-75 Avg.	0.024	0.022	0.045	0.282	0.079	0.007
	Watershed 4—60-ha terraced corn					
1969	0.007	0.006	0.068	0.002	0.007	0.000
1970	0.002	0.006	0.001	0.015	0.000	0.000
1971	0.037	0.000	0.022	0.228	0.000	0.000
1972	0.101	0.014	0.004	0.453	0.025	0.016
1973	0.139	0.059	0.040	0.051	0.074	0.036
1974	0.008	0.008	0.002	0.026	0.006	0.000
1975	0.040	0.038	0.050	0.065	0.035	0.031
1969-75 Avg.	0.048	0.019	0.027	0.120	0.021	0.012

the sediment P discharged from the contour-farmed watersheds occurred during P1. Data from watershed 4 illustrate that terraces were extremely effective in reducing P losses during the critical erosion period.

Solution P losses were a small percentage of the annual P fertilizer application. For the contour-farmed watersheds, about one-half of the average solution P discharged occurred during snowmelt runoff (P3).

Nitrogen and Phosphorus Concentrations

Low N and P losses are insignificant economically, but may be important from a water-quality viewpoint. Because the concentration of plant nutrients in runoff is important to downstream water users, agriculture must assess the effect of various management practices on the quality of water discharged from cropland areas. These watersheds, each instrumented to obtain accurate flow data, offered an excellent opportunity to provide information on nutrient concentrations in surface runoff.

Water weighted NO_3-N concentrations were higher from the 30-ha contour-farmed watershed annually fertilized at 448 kg N/ha than from the 33-ha contour-farmed watershed annually fertilized at 168 kg N/ha (Table 5). However, NO_3-N concentrations did not exceed the upper limit of 10 ppm established by the Federal Water Pollution Control Administration (1968). Ammonium-N concentrations frequently exceeded the 0.5 ppm lower limit considered necessary to stimulate algal growth in impounded waters. Sediment N concentrations were very similar for the two contour-farmed watersheds fertilized at differential rates. Nitrogen fertilizer apparently had little effect on the organic N level of the soil because of the large organic reserve present.

Solution and sediment N concentrations from the contour-farmed watersheds were the highest during P3 when runoff velocities were low and the soil was covered with corn residue. Higher solution N concentrations during snowmelt runoff can be attributed to several factors including NH_4-N adsorption by the snow and leaching of the residue during runoff. Parker (1962) found that 26.6% of the total N in cornstalk residue at harvest was extractable in cold water. In the field, this soluble N may be removed from the residue by snowmelt runoff. Higher sediment N concentrations during

Table 5—Average annual (1969–1975) water and sediment weighted nutrient concentrations by seasonal periods

Period	NO_3-N	NH_4-N	Solution P	Sediment N	Sediment P
	ppm				
	Watershed 1—30-ha contoured corn				
P1	2.10	0.92	0.16	1,439	39
P2	2.27	0.35	0.17	1,458	51
P3	2.85	1.51	0.28	2,450	80
	Watershed 2—33-ha contoured corn				
P1	1.30	0.80	1.15	1,459	33
P2	1.10	0.39	1.17	1,555	62
P3	1.53	1.82	0.22	2,182	64
	Watershed 4—60-ha terraced corn				
P1	3.86	0.57	0.30	1,716	46
P2	3.10	0.30	0.19	1,920	84
P3	1.68	1.03	0.25	1,526	63

P3 may be attributed to lower flows transporting a disproportionate amount of clay and organic soil material. Nitrate-N and sediment N concentrations were higher from the terraced watershed during P1 and P2 than from the contour-farmed watersheds. This is probably related to more organic matter in the surface soil on the terraced watershed due to the lower rate of soil erosion since terracing.

Solution P concentrations exceeded the 0.03 ppm lower limit often thought necessary to stimulate the growth of algal and other aquatic plants in surface waters. Water and sediment weighted P concentrations from the contour-farmed watersheds were the highest during P3 when snowmelt was a large percentage of the annual runoff. Leaching of the residue and greater selectivity of the soil erosion process during snowmelt runoff were probably the factors responsible.

Estimated Nitrogen and Phosphorus Losses

Average water and sediment losses during P1 from the contoured watersheds were much lower for the 1969–75 nutrient sampling period than for the 12-year (1964–75) average (Table 2). Because the 1964–75 water and sediment losses were thought to be more representative of the long-term water and sediment regime of this region, these differences must be taken into account when evaluating the effect of seasonal losses of plant nutrients on surface water quality. Other results from this watershed study (Burwell et al., 1975a) have shown that the quantities of water and sediment discharged are the most important factors for estimating nutrient losses. Therefore, we multiplied the 1964–75 average water and sediment discharges by the respective weighted nutrient concentrations determined for the 1969–75 period to obtain a reasonable estimate of watershed nutrient loss.

The estimated average sediment N discharge from the contoured watersheds was about 57 kg/ha (Table 6). Most of the N was organic which is unavailable for immediate plant use. However, organic N is a potential source of plant available N because it is mineralized to more available forms (NH_4-N and NO_3-N) by biological activity. The highest annual solution N loss was <3.0 kg/ha from the 30-ha contour-farmed watershed annually fertilized at the excessive rate of 448 kg N/ha. About 54% of the annual solution N and 90% of the annual sediment N discharged from the contour-farmed watersheds occurred during P1.

Table 6—Estimated N and P losses by seasonal periods based on 12-year (1964–75) avg. water and sediment losses

Period	NO_3-N	NH_4-N	Solution P	Sediment N	Sediment P
	kg/ha				
	Watershed 1—30-ha contoured corn				
P1	1.14	0.50	0.09	55.49	1.50
P2	0.43	0.07	0.03	5.88	0.21
P3	0.55	0.29	0.05	1.48	0.05
Avg. annual	2.12	0.86	0.17	62.85	1.76
	Watershed 2—33-ha contoured corn				
P1	0.63	0.39	0.07	46.58	1.05
P2	0.18	0.06	0.03	3.28	0.13
P3	0.32	0.38	0.05	0.98	0.03
Avg. annual	1.13	0.83	0.15	50.84	1.21
	Watershed 4—60-ha terraced corn				
P1	0.53	0.08	0.04	4.69	0.13
P2	0.20	0.02	0.01	0.34	0.01
P3	0.17	0.11	0.03	0.21	0.01
Avg. annual	0.90	0.21	0.08	5.24	0.15

Phosphorus transported by the sediment from the contour-farmed watersheds accounted for about 90% of the total P discharged. About 85% of the sediment P was discharged during P1. The highest annual total P (solution P + sediment P) loss was 1.93 kg/ha from the 30-ha contoured watershed, which is about 6% of the recommended annual P fertilizer rate.

Because the transport of N and P by eroded soil is the most severe during P1, adequate conservation practices must be designed to control nutrient discharges during this critical period. Terracing was an extremely effective nutrient conservation practice because N and P losses during P1 were reduced about tenfold when compared to those losses from the contour-farmed watersheds.

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