Transport of Sediment Nitrogen and Phosphorus in Runoff through Cornstalk Residue Strips[1]

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ABSTRACT

A rainfall simulator study was conducted on a Sidell silt loam (Typic Arguidolls, fine-silty, mixed, mesic) in northwest-central Indiana to evaluate the effectiveness of different lengths and percentage covers of cornstalk residue strips in reducing total nitrogen and available phosphorus discharges associated with the sediment. A 2.7-m long residue strip with 50% surface cover reduced nutrient discharges by about 70% when the nutrient loads entering and leaving the residue strip were compared. Reductions in sediment and nutrient discharges with increasing length and percentage cover of the residue strips were almost proportional.

The sediment was separated by sieving and gravity sedimentation into 10 size fractions ranging from >2 to <0.002 mm in diam. About 50% of the sediment entering the residue strips was composed of particles >0.05 mm. The 2.7-m long residue strip with 50% surface cover filtered out most of the particles >0.05 mm. As a result, 85% of the sediment leaving this residue strip was in the <0.035-mm size fractions.

Nutrient concentrations of the fractions >0.21 mm entering the residue strips were higher than those concentrations of the 0.05- to 0.01-mm fractions entering the strips. Nutrient concentrations of the fractions <0.21 mm and >0.01 mm increased as the sediment moved through the residue strips, with the effect being related to residue length and percentage cover. Residue reduced the transport capacity of runoff below its sediment load, which caused the denser particles within these size fractions to be deposited. The less dense particles that were not deposited were composed of a greater proportion of small silt and clay primary particles, which increased the nutrient concentrations.

Additional Index Words: **enrichment ratios, aggregates, erosion, nonpoint source pollution.**

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MOST of the nitrogen (N) and phosphorus (P) discharged from gently-to-steeply sloping cropland is associated with the sediment fraction of runoff (Burwell et al., 1975; Alberts et al., 1978). Only a small portion of this N and P is immediately available to the biosystem (Holt et al., 1970). However, available inorganic forms can be released to the overlying water depending upon factors such as the supply of nitrifying organisms, oxidation potential, pH, and depth of the lake or water system (Keeney, 1973; Syers et al., 1973).

To control sediment and associated nutrient discharges, inexpensive and easily implemented conservation practices need to be identified. Some of the sediment load is deposited naturally at the base of concave slopes, in grassed waterways, or in grassed areas adjacent to streams and gullies (Foster and Meyer, 1977). Small reductions in runoff velocity cause significant deposition because transport capacity is proportional to the 5th power of velocity (Meyer and Wischmeier, 1969).

Strip cropping is an effective soil conservation practice (Hudson, 1971; Moldenhauer, 1979). Even though this practice is used little in many agricultural areas because of the decreased use of sod-based rotations, the concept can be applied to the control of nonpoint source pollution, particularly from small farm fields. Grass or crop-residue strips located at key locations on the landscape should significantly reduce the sediment and nutrient loads being transported.

The effect of simulated vegetation on flow hydraulics and sediment deposition has been intensively studied (Tollner et al., 1976; Tollner et al., 1977; and Kao and Barfield, 1978). However, little information is available on the transport of N and P through grass or crop-residue strips. Sediment deposition is a selective process where sand and large aggregates are deposited preferentially to silt- and clay-size particles (Massey and Jackson, 1952; Frere, 1976). Because of this selectivity, increased deposition may not reduce nutrient loads as much as it reduces the sediment load (Barrows and Kilmer, 1963; Frere et al., 1977).

Various mathematical models are being developed to estimate the detachment, transport, and deposition of different-sized soil particles (Foster, 1979). We need to know the effect of grass or crop-residue strips on the size distribution of the sediment deposited to permit us to analyze the particle-sorting process that occurs during deposition. Information is also needed on the N and P concentrations of different-sized eroded aggregates to evaluate the effect of sorting on the N and P loads being transported.

We conducted this study to evaluate the effect of different lengths and percentage covers of cornstalk residue strips on reducing total N and available P discharges associated with the sediment. We also evaluated the effect of these strips on the size distribution and N and P concentrations of 10 different-size fractions of the sediment.

MATERIALS AND METHODS

The study was conducted in the summer of 1977 on a Sidell silt loam (Typic Arguidolls, fine-silty, mixed, mesic) located on a 5% slope in northwest-central Indiana. The soil surface contained 29% sand, 54% silt, 17% clay, and 1.9% carbon. Total N and available P concentrations were 1,910 and 119 μg/g, respectively.

Two pairs of plots were used to evaluate the effectiveness of the cornstalk residue strips. Two 3.7- by 10.7-m plots, which were moldboard-plowed parallel to the slope the previous fall, had been used earlier in the summer to evaluate the effect of tillage on soil erosion (Johnson and Moldenhauer, 1979). These plots were later disked and divided lengthwise with metal strips to form the two pairs of 1.8-m wide plots.

The following cornstalk residue strip lengths and covers were applied sequentially to the lower end of one plot in each pair: (i) 1.8-m length, 27% cover; (ii) 1.8-m length, 50% cover; (iii) 2.7-m length, 50% cover; and (iv) 4.6-m length, 50% cover. The adjacent plot was used to estimate the sediment and nutrient loads entering the residue strip (Fig. 1). The lower end

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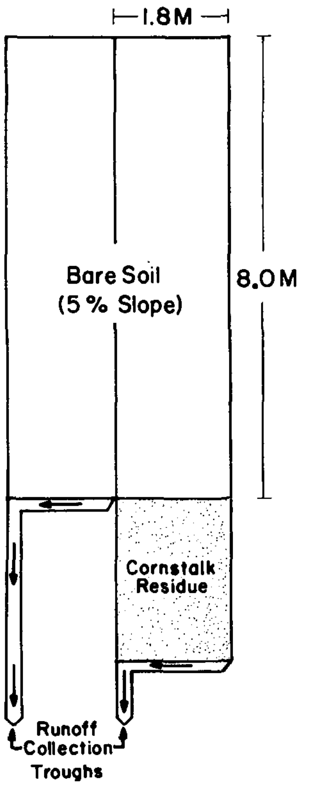

Fig. 1—Arrangement of the 2.7-m long cornstalk residue strip plots with 50% surface cover.

Table 1—Rates of runoff entering and leaving cornstalk residue strips with different lengths and covers.

Strip		Antecedent soil moisture condition	Runoff	
Length	Cover		Entering	Leaving
m	%		kg $hr^{-1}m^{-1}$ width of plot	
1.8	27	Dry	171.2	244.8
		Wet	294.1	387.2
		Very wet	319.6	373.0
1.8	50	Dry	202.0	287.1
		Wet	268.1	371.7
		Very wet	298.6	392.8
2.7	50	Dry	283.9	279.6
		Wet	364.3	406.7
		Very wet	386.3	461.2
4.6	50	Dry	267.0	245.7
		Wet	324.0	418.4
		Very wet	369.9	508.6

of this plot was directly across from the top of the residue strip, except for the 1.8-m long residue strip where runoff from the adjacent plot was collected at the end of 10.7 m. The residue that was spread over the lower end of the plots had been collected from the surrounding area earlier in the summer. Undoubtedly, most of the soluble N and P containing organic compounds had been leached from the residue before it was used in this study.

After the 1.8-m long residue strips with 27% cover were evaluated, the soil was allowed to dry for 3 or 4 days. The cornstalk residue was removed so all the plots could be hoed by hand to break the surface crust. New residue was then respread until the 1.8-m long residue strips with 50% cover were established. The meterstick method was used to estimate residue cover (Hartwig and Laflen, 1978). This same process continued for establishing the 2.7- and 4.6-m long residue strips, except that the lower end of the adjacent plot was moved upslope so that it was directly across from the top of the residue strip. Residue was spread on the other side of the divided plots after the two 1.8-m long residue strip treatments were evaluated.

A rainfall simulator (Meyer and McCune, 1958) having a raindrop-size distribution and kinetic energy near that of natural rainfall was used to apply rainfall at the rate of 6.4 cm/hour for three runs. The initial 1-hour run was followed 24 hours later by wet and very wet runs. These latter runs lasted 0.5 hour and were separated by a 15-min nonapplication period.

Runoff rates were measured using a standard precalibrated HS flume and water stage recorder. Sediment samples for gravimetric analysis were obtained from an electric rotating slot sampler that sampled 1% of the flow. Four or five samples for nutrient analyses were collected manually in 0.5-liter bottles from the runoff collection trough at the end of each plot at equal time intervals during the event.

Because total plot length was fixed at 10.7 m, the length of bare soil above the different residue strips ranged from 8.9 m for the 1.8-m long residue strips to 6.1 m for the 4.6-m long residue strips. To provide a more meaningful comparison of the effect of the different lengths and covers of residue strips on sediment and nutrient discharges, sediment losses were adjusted to a constant bare soil length of 6.1 m, using well-established erosion and plot length relationships (Wischmeier and Smith, 1978). Measured soil losses were adjusted by multiplying by the square root of the ratio of 6.1 to the actual length of bare soil. Nutrient losses were determined using these adjusted soil loss values. Water losses were corrected by multiplying measured losses by linear ratios of the adjusted to actual lengths.

Sediment was separated into 10 size fractions for N and P analyses by sieving and gravity sedimentation procedures. In the field, a stacked nest of four 13-cm-diam sieves, with screen openings of 2, 1, 0.5, and 0.21 mm, were enclosed in a plastic bag and gently swirled in the runoff for a few seconds or until about 2 liters of runoff had been collected. Two nested sieve samples were collected during each run after runoff had reached equilibrium. For the initial run, samples were obtained after 40 and 50 min of rainfall, whereas samples were taken after 10 and 20 min of rainfall during the wet and very wet runs.

The sediment trapped on each sieve was immediately washed into a container. Most of this sediment was well aggregated and stable with handling. The sediment that passed through the nested sieves into the plastic bags was stored at 4°C from 2 to 4 months until additional separations could be made. Analyses of data collected in 1976 showed that storage had little effect on aggregation, particularly after the 3rd day. The sediment was resuspended by gently rolling the plastic bags at the lower corners before it was passed through sieves having screen openings of 0.05 and 0.035 mm. Sediment passing the 0.035-mm sieve was transferred to glass beakers where gravity sedimentation was used to separate the 0.035- to 0.020-, 0.020-to 0.010-, 0.010- to 0.002-, and <0.002-mm particles. Settling rates of the 0.020- and 0.010-mm particles were calculated from Stokes' law assuming a particle density of 2.20 g/cm^3 (D. C. Long. 1964. The size and density of eroded soil material. M. S. Thesis. Iowa State Univ., Ames). Particles <0.002 mm were assumed to have a density of 2.65 g/cm^3.

The water level in each beaker was adjusted to a height of 7.5 cm with deionized water, and then the sample was gently stirred. After an appropriate settling time, the upper 5.0-cm layer was aspirated from each beaker and saved for further separation. The water level was then readjusted to a height of 7.5 cm, and the washings continued. To ensure good separation, each fraction was washed five times. The clay fraction (<0.002 mm) was flocculated by freezing in plastic buckets.

The weight of each fraction was determined after drying at 60°C. The percentage of sediment in each fraction was then determined by dividing the weight of each fraction by the total weight. All samples were ground to pass through a 0.18-mm sieve and stored in plastic bags for N and P analyses. Nitrogen analysis was performed using Kjeldahl digestion and steam distillation procedures (Nelson and Sommers, 1972). Available P was determined using the Bray P_1 test (Bray and Kurtz, 1945), with color development using the one-step method (Murphy and Riley, 1962). Results presented are mean values of duplicate analyses performed on each sample.

RESULTS AND DISCUSSION

Water and Soil Discharges

Rates of runoff leaving the residue strips were higher than those entering the residue strips from the bare soil above (Table 1). These differences reflected differences in plot length between the residue strip and adjacent plots (Fig. 1).

Cornstalk residue strips caused much of the sediment to be deposited as runoff moved through the strips, as indicated by the reductions in the sediment loads shown in Table 2. The 1.8-m long residue strip with 27% cover reduced the sediment load by 37% for the initial run. Sediment loads were only slightly reduced for the wet and very wet runs, which indicated that deposition rapidly reduced the trapping capacity of this strip. Increasing the cover to 50% on the 1.8-m long residue strip greatly increased the trapping efficiency for the wet and very wet runs. The 2.7- and 4.6-m long residue strips with 50% cover reduced the sediment loads by about 75%. Differences in the sediment loads entering and leaving the residue strips were statistically significant ($p \leq 0.01$), except for the 1.8-m long residue strip with 27% cover.

Reductions in runoff velocity because of slight ponding 30 to 50 cm above the residue strips caused many of the 1- and 2-mm aggregates to be deposited before entering the residue strips. Within the strips, much of the sediment was deposited in front of large cornstalks that lay perpendicular to the flow.

Table 2—Rates of sediment entering and leaving cornstalk residue strips with different lengths and covers.

Strip		Antecedent soil moisture condition	Sediment		Delivery ratio†
Length	Cover		Entering	Leaving	
m	%		kg $hr^{-1}m^{-1}$ with of plot		
1.8	27	Dry	9.5	6.0	0.63
		Wet	14.3	12.9	0.90
		Very wet	16.6	14.3	0.86
1.8	50	Dry	15.8	6.1	0.39
		Wet	18.6	9.7	0.52
		Very wet	19.4	11.8	0.61
2.7	50	Dry	22.7	4.9	0.22
		Wet	23.8	4.1	0.17
		Very wet	24.0	4.9	0.20
4.6	50	Dry	19.1	3.9	0.20
		Wet	18.3	5.8	0.32
		Very wet	20.6	8.0	0.39

† Ratio of sediment leaving residue strip to that entering residue strip from bare soil above.

Total N and Available P Concentrations

Nitrogen and P concentrations of the sediment leaving the residue strips (outflow sediment) were higher than those concentrations entering the residue strips (inflow sediment), as shown in Table 3. For the 1.8-m long residue strip with 27% cover, the average N concentration of the outflow sediment was about 4% higher than that of the inflow sediment. Increasing the cover to 50% on the 1.8-m long residue strip increased the average N concentration of the outflow sediment by about 8%, when compared to the outflow sediment of the 1.8-m long residue strip with 27% cover. However, the average N concentration of the inflow sediment of the 1.8-m long residue strip with 50% cover was about 10% lower than that of the inflow sediment of the 1.8-m long residue strip with 27% cover. Even though the plot surfaces were hoed between each set of runs, some pieces of the broken crust remained on or near the soil surface. Sediment from the next set of runs was undoubtedly composed of some particles detached from the crust fragments. Surface seals are composed mainly of silt and silt-sized particles (Moldenhauer and Koswara, 1968). Nitrogen concentrations of these breakdown particles would be lower than the aggregates and particles normally transported.

For the 1.8-m long residue strip with 50% cover, the average N concentration of the outflow sediment was about 25% higher than that of the inflow sediment. Increasing the length of this residue strip to 2.7 m increased the average N concentration of the outflow sediment

Table 3—Total N and available P concentrations of the sediment entering and leaving cornstalk residue strips with different lengths and covers.

Strip		Antecedent soil moisture condition	Total N			Available P		
Length	Cover		Entering	Leaving	Concentration ratio†	Entering	Leaving	Concentration ratio†
m	%		µg/g			µg/g		
1.8	27	Dry	2,380	2,740	1.15	110	133	1.21
		Wet	2,160	2,020	0.94	91	110	1.21
		Very wet	1,940	2,020	1.04	90	110	1.22
1.8	50	Dry	2,190	2,820	1.29	96	120	1.25
		Wet	1,900	2,340	1.23	89	110	1.24
		Very wet	1,770	2,190	1.24	88	110	1.25
2.7	50	Dry	2,040	2,860	1.40	128	132	1.03
		Wet	1,760	2,700	1.53	122	132	1.08
		Very wet	1,640	2,650	1.62	110	140	1.27
4.6	50	Dry	2,060	2,660	1.29	118	152	1.29
		Wet	1,850	2,450	1.32	106	130	1.23
		Very wet	1,610	2,620	1.63	103	120	1.16

† Ratio of nutrient concentration of sediment leaving residue strip to that entering residue strip from bare soil above.

by 52% compared with that of the inflow sediment. Differences in N concentrations between the inflow and outflow sediments were similar for the 2.7- and 4.6-m long residue strips. Differences in N concentrations of the inflow and outflow sediments were statistically significant ($p \leq 0.01$), except for the 1.8-m long residue strip with 27% cover.

Available P concentration ratios were not affected by increases in the length and cover of the residue strips (Table 3). Apparently, P enrichment of the sediment did not increase as the proportion of smaller particles comprising the sediment increased with greater trapping capacity. Available P concentrations of the various size fractions are discussed later. Differences in P concentrations of the inflow and outflow sediments were not statistically significant. The P saturation of the surface soil was different for the two pairs of plots, which contributed to a large error term in the analysis of variance.

Total N and Available P Discharges

The 2.7- and 4.6-m long residue strips with 50% cover reduced the N and P loads by about 70% (Table 4). Reductions in the N and P loads with increasing length and cover of the residue strips were about 5% less than the corresponding reduction in the sediment load.

Our data indicated that an inexpensive, 3-m strip length of cornstalk residue at the bottom of a concave slope or a farm field could be an effective management practice for reducing sediment and plant nutrient discharges. However, the effectiveness of the residue strips would decrease as slope and runoff from upland areas increased. Runoff from these areas would be concentrated in rills or channels which would tend to undercut or wash away the residue.

Size Distribution of Eroded Particles

About 50% of the inflow sediment was composed of particles >0.05 mm, which were concentrated primarily in the 1- to 0.21-mm size fractions (Fig. 2). Many of the particles <0.05 mm were in the 0.035- to 0.002-mm size fractions. Even though the percentages of a given size fraction of inflow sediment varied among the different residue strips, the differences were not statistically significant. The 1.8-m long residue strip with 27% cover did not greatly increase the proportion of small particles in the outflow sediment. Increasing the cover to 50% on the 1.8-m long residue strip increased the proportion of <0.05-mm particles by 68%, when that fraction entering and leaving the residue strip was compared. About 92% of the outflow sediment from the 2.7-m long residue strip with 50% cover was comprised of particles <0.05 mm, whereas only 41% of the inflow sediment was comprised of particles <0.05 mm.

Less than 3% of the inflow sediment was composed of undispersed clay particles (clay material that was naturally suspended), indicating that most of the particles eroded from the bare soil were aggregates. As the length and cover of the residue strips increased, the percentage of undispersed clay in the sediment also increased. Residue reduced the transport capacity of runoff below its sediment load, which caused many of the larger particles to be deposited. Because of this deposition, the sediment was comprised of a greater proportion of small particles, including the clay fraction.

Differences in the percentage of 1- to 0.5-, 0.21- to 0.05-, 0.05- to 0.035-, and 0.035- to 0.020-mm particles between the inflow and outflow sediments of the 1.8-m long residue strip with 50% cover were statistically significant ($p \leq 0.05$). For the 2.7-m long residue strip

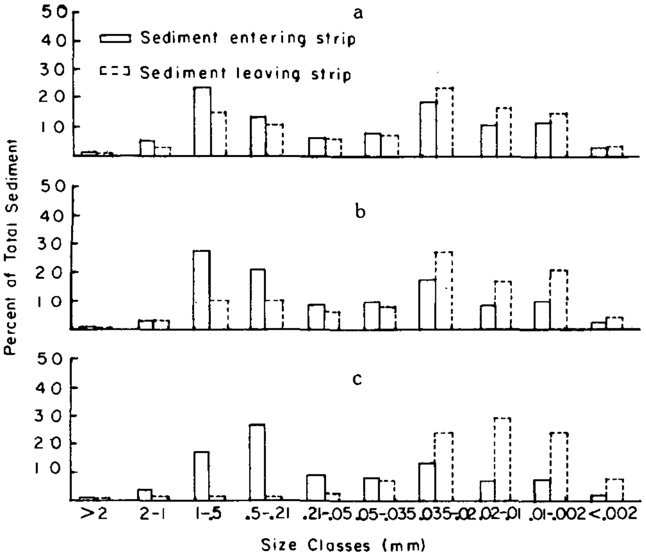

Fig. 2—Size distribution of eroded particles entering and leaving (*a*) 1.8-m long with 27% cover, (*b*) 1.8-m long with 50% cover, and (*c*) 2.7-m long with 50% cover cornstalk residue strips.

Table 4—Rates of total N and available P entering and leaving cornstalk residue strips with different lengths and covers.

Strip		Antecedent soil moisture	Total N			Available P		
Length	Cover	condition	Entering	Leaving	Ratio	Entering	Leaving	Ratio
			g hr⁻¹ m⁻¹ width of plot			g hr⁻¹ m⁻¹ width of plot		
1.8	27	Dry	22.5	16.5	0.73	0.98	0.77	0.79
		Wet	31.2	26.2	0.84	1.16	1.33	1.15
		Very wet	31.9	28.2	0.88	1.28	1.24	0.97
1.8	50	Dry	34.5	17.3	0.50	1.39	0.70	0.50
		Wet	35.2	22.6	0.64	1.68	1.26	0.75
		Very wet	34.3	25.8	0.75	1.73	1.55	0.90
2.7	50	Dry	45.3	14.1	0.31	2.63	0.48	0.18
		Wet	41.5	10.5	0.25	2.74	0.41	0.15
		Very wet	39.4	13.0	0.33	2.57	0.58	0.23
4.6	50	Dry	39.0	10.2	0.26	1.80	0.51	0.28
		Wet	34.1	13.6	0.40	1.79	0.56	0.31
		Very wet	33.0	19.2	0.58	1.94	0.63	0.32

with 50% cover, differences in the percentage of particles in all fractions between the inflow and outflow sediments were statistically significant ($p \leq 0.01$), except for the 0.05- to 0.035-mm fraction.

Gravity sedimentation procedures are generally used to separate various sizes of primary particles after soil dispersion (Jackson, 1975). The use of this procedure to separate different fractions of eroded aggregates <0.035 mm could break down some of the aggregates into primary silt and clay particles. To determine if breakdown of the aggregates occurred, we compared the undispersed clay content of the sediment by pipetting and gravity sedimentation procedures (Table 5). The undispersed clay content determined by gravity sedimentation was lower in all cases, indicating that the particles were stable and that no appreciable breakdown occurred during separation.

Total N and Available P Concentrations of Eroded Particles

Nutrient concentrations of the 2- to 0.21-mm particles entering the residue strips were quite similar for a specific rainfall simulator run (Table 6). Nitrogen concentrations of the 0.21- to 0.05-mm particles were about 22% higher than those for the >0.21-mm particles. Nitrogen concentrations of the 0.05- to 0.035- and the 0.035- to 0.020-mm particles were about 15 and 65% lower, respectively, than concentrations of the particles >0.21 mm. Nitrogen concentrations of the 0.020- to 0.010-mm particles were about 9% lower than the concentrations of the particles >0.21 mm. Nitrogen concentrations of the 0.010- to 0.002-mm particles were higher than the concentrations of the particles >0.21 mm, but were about 22% lower than the concentrations of <0.002-mm particles. Nitrogen concentrations of the <0.002-mm fraction were about 230% higher than the concentrations of >0.21-mm particles. Phosphorus concentrations of the different-sized particles showed trends that were somewhat similar to those observed for N. Phosphorus concentrations of the 0.21- to 0.05-mm particles entering the residue strips were generally the highest, except for the clay (<0.002 mm) fraction. However, the total amount of sediment in the 0.21- to 0.05-mm fraction was low (Fig. 2), indicating that this fraction did not contribute much to the total available P load. The P concentration of the <0.002-mm fraction was about twice that of the 2- to 0.21-mm fraction.

Table 5—Comparison of the undispersed clay content of the sediment by pipetting and gravity sedimentation procedures.†

Strip		Sampling location	Undispersed clay	
Length	Cover		Pipetting‡	Gravity sedimentation
m	%		—% of total sediment—	
1.8	27	Entering	4.2	2.8
		Leaving	6.2	3.2
1.8	50	Entering	4.4	2.5
		Leaving	8.2	4.4
2.7	50	Entering	3.4	2.8
		Leaving	10.7	8.2

† Averages of samples collected from dry and very wet rainfall simulator runs.

‡ Pipetting procedures were used to determine clay content of samples collected for particle size analysis. Clay weights were not corrected for weight of dissolved solids in the runoff. Such a correction would lower the values in this column.

For any rainfall simulator run, N and P concentrations of the 2- to 0.21-mm particles leaving the residue strips were similar (Table 7). Nitrogen concentrations of the 0.21- to 0.05- and 0.05- to 0.035-mm particles were about 53 and 16% higher, respectively, than the N concentrations of particles >0.21 mm. Nitrogen concentrations of the particles in the 0.035- to 0.020-mm fraction were about 48% lower than the concentrations of the >0.21-mm particles. Nitrogen concentrations of the 0.020- to 0.010-mm particles were higher than those of the particles >0.21 mm. Nitrogen concentrations of the 0.010- to 0.002- and <0.002-mm particles resembled those of the particles entering the residue strips. Phosphorus concentrations of the different-sized particles again showed trends that were similar to those observed for N. However, the enrichment of P in sediment was not as great as the enrichment of N when the proportion of <0.020-mm particles was increased.

Table 6—Total N and available P concentrations of particles entering cornstalk residue strips with different lengths and covers.†

Strip		Antecedent soil moisture condition	Nutrient contents of aggregates in size classes (mm)								
Length	Cover		2-1	1-0.5	0.5-0.21	0.21-0.05	0.05-0.035	0.035-0.020	0.020-0.010	0.010-0.002	<0.002
m	%		μg/g								
					Total N						
1.8	27	Dry	2,420	2,400	2,330	3,280	2,350	940	2,240	3,970	5,120
		Very wet	2,080	2,090	1,850	2,360	1,540	660	1,840	3,860	5,210
1.8	50	Dry	2,630	2,320	2,320	3,000	2,130	820	2,140	3,960	4,680
		Very wet	2,240	1,900	2,130	2,220	1,520	720	1,870	3,690	5,050
2.7	50	Dry	–‡	–	–	2,320	1,080	640	1,610	4,060	5,340
		Very wet	–	–	–	1,820	920	720	2,560	4,460	5,390
					Available P						
1.8	27	Dry	119	108	115	124	104	54	94	105	–
		Very wet	96	101	90	105	76	43	76	96	190
1.8	50	Dry	106	120	115	126	86	64	92	120	–
		Very wet	97	97	108	110	75	52	86	114	–
2.7	50	Dry	–	–	–	–	68	44	76	110	–
		Very wet	–	–	–	–	61	51	84	112	–

† Samples entering 4.6-m long residue strips were not separated by size class.

‡ No value because of insufficient sample for analysis.

Table 7—Total N and available P concentrations of particles leaving cornstalk residue strips with different lengths and covers.†

Strip		Antecedent soil moisture condition	Nutrient contents of aggregates in size classes (mm)								
Length	Cover		2-1	1-0.5	0.5-0.21	0.21-0.05	0.05-0.035	0.035-0.020	0.020-0.010	0.010-0.002	<0.002
m	%		μg/g								
					Total N						
1.8	27	Dry	2,370	2,440	2,900	3,900	3,100	970	2,900	3,760	5,490
		Very wet	2,350	1,900	1,870	2,580	1,540	800	1,960	3,840	5,240
1.8	50	Dry	2,350	2,390	2,460	3,960	3,400	2,060	2,840	4,090	4,890
		Very wet	2,180	2,190	2,380	3,750	2,720	940	2,460	4,320	5,460
2.7	50	Dry	-‡	-	-	3,740	3,910	1,240	2,740	3,760	5,170
		Very wet	-	-	-	4,400	3,680	980	2,670	4,380	5,130
					Available P						
1.8	27	Dry	-	104	-	-	104	94	162	168	-
		Very wet	95	105	97	107	77	50	83	112	-
1.8	50	Dry	100	104	101	124	130	88	91	126	-
		Very wet	104	109	116	130	96	61	94	138	-
2.7	50	Dry	-	-	-	-	122	70	91	117	158
		Very wet	-	-	-	-	112	50	96	114	143

† Samples leaving 4.6-m long residue strips were not separated by size class.
‡ No value because of insufficient sample for analysis.

Table 8—Total N and available P concentration ratios of different-sized particles entering and leaving cornstalk residue strips with different lengths and covers.†

Strip		Antecedent soil moisture condition	Nutrient concentration ratios of aggregates in size classes (mm)								
Length	Cover		2-1	1-0.5	0.5-0.21	0.21-0.05	0.05-0.035	0.035-0.020	0.020-0.010	0.010-0.002	<0.002
m	%										
					Total N						
1.8	27	Dry	0.98	1.02	1.24	1.19	1.32	1.03	1.29	0.95	1.07
		Very wet	1.13	0.91	1.01	1.09	1.00	1.21	1.06	0.99	1.01
1.8	50	Dry	0.89	1.03	1.06	1.32	1.60	2.51	1.33	1.03	1.04
		Very wet	0.97	1.15	1.12	1.69	1.79	1.31	1.32	1.17	1.08
2.7	50	Dry	-‡	-	-	1.61	3.62	1.94	1.70	0.93	0.97
		Very wet	-	-	-	2.42	4.00	1.36	1.04	0.98	0.95
					Available P						
1.8	27	Dry	-	0.96	-	-	1.00	1.74	1.72	1.60	-
		Very wet	0.99	1.04	1.08	1.02	1.01	1.16	1.09	1.17	-
1.8	50	Dry	0.94	0.87	0.88	0.98	1.51	1.38	0.99	1.05	-
		Very wet	1.07	1.12	1.07	1.18	1.28	1.17	1.09	1.21	-
2.7	50	Dry	-	-	-	-	1.79	1.59	1.20	1.06	-
		Very wet	-	-	-	-	1.84	0.98	1.14	1.02	-

† Concentration ratio is the ratio of the nutrient concentration of a particular size class leaving residue strip to that entering residue strip from bare soil above.
‡ No ratio because of insufficient sample for analysis.

Menzel (1980) found that the slope of the regression line between the logarithmic relationships of the enrichment ratio and sediment discharge was less negative for P than for N. This finding was confirmed by our data. Phosphorus concentrations did not increase nearly as fast as N concentrations when the sediment load was decreased and the proportion of smaller particles increased.

Differences in the N concentrations of all fractions between inflow and outflow sediments for the 1.8-m long residue strip with 27% cover were not statistically significant. For the 1.8-m long residue strip with 50% cover, differences in the N concentrations of the 0.21- to 0.05-, 0.05- to 0.035-, 0.035- to 0.020-, and 0.020- to 0.010-mm particles between the inflow and outflow sediments were statistically significant at the 0.10, 0.10, 0.01, an 0.01 probability levels, respectively. Differences in N concentrations of the 0.21- to 0.05-, 0.05- to 0.035-, 0.035- to 0.020-, and 0.020- to 0.010-mm particles between the inflow and outflow sediments of the 2.7-m long residue strip with 50% cover were statistically significant at the 0.01, 0.01, 0.05, and 0.10 probability levels, respectively.

Nitrogen concentrations of the 0.21- to 0.010-mm particles leaving the residue strips generally increased as the length and cover of the residue strips increased. An increase in the N concentration of a particular size fraction must be partially related to the effect of the residue on the composition and density of transported particles. Deposition occurs when the transport capacity of runoff becomes lower than its sediment load. Large particles and denser particles within the smaller size fractions are deposited. The average density of any size fraction < 0.05 mm is related to the percentage of silt and clay comprising these particles. If particles are composed primarily of silt particles with little adsorbed clay, their density would be higher than if they were composed of many clay particles with pore space in between. Particle density has a great influence on transport and deposition mechanics (S. S. Davis. 1978. Deposition of nonuniform sediment by overland flow on concave slopes. M. S. Thesis. Purdue Univ., West Lafayette, Ind.).

Other evidence indicating that sorting based upon particle density occurs during transport for particles <0.21 mm is shown in Table 8. These values are the ratios of the N and P concentrations of a size fraction leaving the residue strips to the concentrations of that size fraction entering the residue strips. Ratios for the 2-to 1-, 1- to 0.5-, 0.5- to 0.21-, 0.010- to 0.002-, and <0.002-mm particles were near 1.00, indicating that concentrations did not change during transport through the residue strips. For the 1.8-m long residue strip with 27% cover, N concentrations of the 0.21- to 0.010-mm particles leaving the residue strip were about 15% higher than the concentrations of those particles entering the residue strip. Nitrogen concentrations of the 0.21- to 0.010-mm particles leaving the 1.8- and 2.7-m long residue strips with 50% cover were about 60 and 220% higher, respectively, than the concentrations of those particles entering the residue strips. Except for the 0.05- to 0.035-mm fraction, P concentrations were not affected by the particle sorting that occurred during transport through the residue strips. We cannot fully explain this finding. Perhaps it was due to our method of separating the various size fractions <0.035 mm. During the gravity sedimentation of these particles, labile P would be desorbing from the mineral surfaces. We did not study the effect of desorption on our measurements, but it would be related to variables such as the time required to make the separations, the solution-to-soil ratio, the degree of particle aggregation, and the effect of aggregation on P desorption.

Nitrogen and P concentrations of the sediment are generally inversely related to sediment loss (Massey and Jackson, 1952; Stoltenberg and White, 1953). Increases in N and P concentrations have been generally attributed to an increase in the selectivity of the erosion process for the finer soil fractions (Frere, 1976). In the broadest sense, this concept of nutrient enrichment is correct because the percentage of clay in the sediment is generally inversely related to the amount of sediment transported. However, the concept of nutrient enrichment occurring only because of the preferential transport of the finer soil fractions is an oversimplification of a dynamic and complex process.

We found that some of the smaller fractions of the sediment (particularly those entering the residue strips) had the lowest N and P concentrations. Therefore, shifting the size distribution of sediment towards a greater proportion of small particles does not mean that N and P concentrations will always increase. Enrichment levels depend partly upon the ratio of the number of larger silt-sized particles (0.05 to 0.020 mm) to the number of smaller silt-sized particles (0.020 to 0.002 mm) transported in runoff.

Nutrient concentrations of many of the eroded particles <0.21 mm increased as the velocity and transport capacity of runoff decreased. When transport capacity is reduced, particles are dynamically sorted based upon their size and density, with the larger particles and denser smaller particles being deposited first. Smaller particles of high density (2.4 to 2.6 g/cm^3) are composed primarily of silt particles with some adsorbed clay. The less dense particles (1.8 to 2.0 g/cm^3) are composed of small silt and clay particles or clay particles themselves. Enrichment occurs because of dynamic sorting based upon particle density that allows the less dense particles of higher clay content to erode preferentially to the denser particles of lower clay content.

SUMMARY

Our study evaluated the effect of different lengths and percentage covers of cornstalk residue strips on the amount of total N and available P discharged with the sediment. We also studied the size distribution and N and P concentrations of 10 different fractions of eroded particles that entered and left the residue strips. We found that:

1) Nutrient loads leaving a 2.7-m long residue strip with 50% cover were about 70% less than those loads entering the residue strip from the bare soil above.

2) Reductions in nutrient loads for different lengths and covers of cornstalk residue strips were about 5% less than the reductions in the sediment load.

3) Nutrient concentrations of the 0.05- to 0.01-mm particles entering the residue strips were about 30% lower than those concentrations of the >0.21-mm particles entering the residue strips.

4) Nutrient concentrations of the 0.21- to 0.01-mm particles leaving the residue strips were higher than those concentrations of particles entering the residue strips, with the effect depending upon the length and cover of the residue strips.

5) Nitrogen concentrations of undispersed clay particles (<0.002 mm) were about 230% higher than the concentrations of eroded particles >0.21 mm in diameter.

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