Sediment Missouri Valley Loess Surface Runoff

PHYSICAL AND CHEMICAL CHARACTERISTICS OF SEDIMENTS ORIGINATING FROM MISSOURI VALLEY LOESS

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ABSTRACT

Nitrogen (N) and phosphorus (P) associated with sediment in surface runoff accounted for at least 85% of N and P discharged from agricultural watersheds. The N and P content of the sediment is related to its carbon (C) content. At low flow, the C concentration of the sediment increased, indicating the selectivity of the erosion process for organic material. The sediment showed an enrichment in the clay fraction over that contained in the surface soil, and this increase can result in a disproportionate increase in the discharge of those chemicals adsorbed to clay material.

INTRODUCTION

Recently much research has focused on agriculture's contribution to the deterioration in the quality of some of our water resources by eroded soil and agricultural chemicals. Assessing the problem has been difficult because of the diverse land and climatic situations involved.

Plant nutrient discharge occurs as water-soluble ions in runoff and adsorbed ions associated with the sediment portion of the runoff. Harms, Dornbush, and Andersen (1974) concluded that a large percentage of the nutrients discharged from seven sites in eastern South Dakota were soluble; however, sediment loss from these sites was quite low. Schuman et al. (1973a) found that N (nitrogen) losses in the soluble form were low and that sediment-associated N accounted for 94% of the N loss for a 3-year period on a contour-planted, corn watershed. However on a grass watershed where sediment discharge was low the soluble N loss accounted for 50% of the total N discharge. Burwell, Timmons and Holt (1975) also found that sediment-associated N accounted for a large percentage of the N discharged in surface runoff. Schuman and Burwell (1974) pointed out that at least one-half to two-thirds of the soluble N in surface runoff was equivalent to the amount of N in the precipitation; therefore, the soluble-N discharge attributable to fertilizer N may be a very small fraction of the total N discharge. Schuman et al. (1973b) reported that a large percentage of the P (phosphorus) discharged in surface runoff is also associated with the sediment. Investigators have reported that the transport of sediment-borne chemicals from agricultural watersheds is disproportionately large in comparison to the chemical content of surface soils, due to selective erosion of clays (Massey et al., 1953 ; Scarseth and Chandler, 1938).

Runoff and erosion are important to everyone because of economic and environmental concerns. Approximately 4 billion tons of sediment are carried into U. S. streams each year (Wadleigh, 1968). This figure could be reduced if good conservation and management practices were used to protect erosive cultivated cropland. Sediment is also a major cost item in reservoir sedimentation. Syers et al. (1973), Keeney (1973), and Kerr et al. (1973) thoroughly reviewed the literature on P, N, and C and their relationship to, and cycling in, the sediment water system. The purpose of the study reported here-in was to evaluate the N and P discharges and the N, P, and C content of sediment in surface runoff in western Iowa and to ascertain how these are related to the selectivity (enrichment) of the erosion process.

MATERIALS AND METHODS

The four experimental watersheds are located in southwestern Iowa near Treynor. The area is characterized by a deep loess cap, underlain by till, ranging in thickness from 25 m (82 ft) on the ridges to less than 5 m (16 ft) in the valleys. Gully and sheet-rill erosion are serious problems, and many valleys have deeply incised channels that extend upstream to an active gully head.

Principal soil types are Typic Hapludolls, Typic Haplorthents, and Cumulic Hapludolls. These soils are fine, silty, mixed mesics, with moderate to moderately rapid permeability. Slopes on the watersheds range from 2 to 4% on the ridges and bottoms to 12 to 18% on the sides.

The four watersheds were instrumented in 1964 to measure precipitation and streamflow. Precipitation measurements were obtained from recording raingages located on each watershed. Stream discharges were measured by waterstage recorders used with calibrated broad-crested, V-notch weirs. Watershed size, crop, conservation practice, and fertilizer application are shown in Table 1. The contour-planted corn watershed (WS-2) and the pasture watershed (WS-3) were fertilized at the recommended rate, 168 kgN/ha and 39 kgP/ha (150 lbN/A and 35 lbP/A). The level-terraced (WS-4) and a contour-planted (WS-1) corn watershed were fertilized at 2.5 times the recommended rates. These treatments were selected to enable us to evaluate the conservation watersheds (WS-3 and 4) in controlling or reducing nutrient loss due to surface runoff and erosion.

Table 1. Watershed description, crop, conservation practice, and fertilizer application rates for 1969, 1970, 1971, and 1972, Treynor, Iowa

Water-shed	Size		Crop	Conservation practice	Fertilizer N	Fertilizer P
	ha	(acres)			kg/ha (lb/A)	
1	30.4	(74.5)	Corn	Contour	448 (400)	97[1/] (87)
2	33.6	(83)	Corn	Contour	168 (150)	39 (35)
3	43.3	(107)	Brome-grass[2/]	Rotation grazing[2/]	168 (150)	39 (35)
4	60.8	(150)	Corn[3/]	Terraced	448 (400)	97 (87)

1/ Phosphorus fertilizer was applied at the rate of 39 kg/ha (35 lb/acre) on all watersheds in 1971 and 1972.

2/ Watershed 3 was changed to a mulch-tillage, contour planted corn watershed in 1972.

3/ Watershed 4 was changed to mulch tillage, with terrace channels having surface pipe drains and fertilized at 168 kgN/ha (150 lbs N/acre) and 39 kgP/ha (35 lbs P/acre).

Samples of approximately 400 ml (16 oz) of the soil-water runoff were collected manually during each surface runoff event to determine sediment concentration and particle sizes and N, P, and C content of the sediment. The sediment content of each sample was determined gravimetrically. Total N was determined on the oven-dried sediment, using micro-Kjeldahl procedures as described by Bremner (1965). The sediment P content was determined on a $NaHCO_3$ extract (Olsen et al., 1954; Murphy and Riley, 1962). Total P was not determined on the sediment because it would not be meaningful from a pollution standpoint. Taylor (1967) states that less than 10% of the total P of soils will be considered a part of the "labile pool." Carbon content of the sediment was determined by dry combustion with a high-temperature induction furnace. The N, P, and C concentrations are expressed on a dry-sediment basis. Surface soil samples 0- to 10-cm (0- to 4-inch) were collected at Watershed 2 for comparison with sediment moved in storm runoff. Particle size distribution of streamflow and surface soil samples were determined by the sieve and pipette methods. Watershed 2 surface soils were sampled at 26 locations representing the ridges, side slopes, and colluvial deposits; the particle-size analyses showed that they were quite uniform within and among the slope classes. Seventy-three particle-size analyses of sediment in runoff at watershed 2 were the basis for calculating the discharge-weighted sediment outflow for the 11-year period of record, 1964-1974; this was accomplished by the flow duration-sediment transport curve procedure (Campbell and Bauder, 1940), where the 11-year runoff record was tabulated by 1- or 2-minute increments during periods of rapidly changing flow--and the runoff-sediment relation for each of four size classes was compiled (figure 3)

RESULTS AND DISCUSSION

Nitrogen, Phosphorus, and Carbon Content of Sediment

Nutrient discharges associated with the sediment was 37.59 kgN/ha (32.64 lbN/A) and 1.05 kgP/ha (0.936 lbP/A) for WS-1 and 23.16 kgN/ha (20.66 lbN/A) and 0.581 kgP/ha (0.518 lbP/A) for WS-2 (Table 2 and 3). Nitrogen and phosphorus associated with the sediment accounted for 94 and 85%, respectively, of the total discharge in surface runoff from the contour-cropped watersheds 1 and 2 at Treynor, Iowa. Sediment N losses were 86 and 51%, of the total N losses for the level terraced (WS-4) and pasture watershed 3, respectively. To evaluate the fertility treatment effect, the erosion differences for the watersheds must be taken into account. Weighted concentrations of nutrients in the transporting medium can be derived by dividing sediment N and P losses (Tables 2 and 3) by the corresponding sediment yields (Table 4). The average annual sediment N loss per unit of sediment for the recommended (WS-2) and high N fertilizer (WS-1) application rates was 1.40 and 1.45 kgN/MT of sediment (2.79 and 2.89 lbN/t), respectively. These data indicate little fertility treatment effect on the amount of N carried by the sediment. Sediment N loss per unit of sediment for Watersheds 3 and 4 was 2.01 and 1.97 kgN/MT of sediment (4.00 and 3.99 lb/t), respectively. The same rela-

Table 2. Nitrogen loss in surface runoff from agricultural watersheds, Treynor, Iowa

Water-shed	Solution N: NO_3-N	Solution N: NH_4-N	Sediment N[1/]	Total loss
	kg/ha (lb/acre)			
1969				
1	2.30 (2.05)	1.55 (1.38)	5.86 (5.23)	9.71 (8.66)
2	1.45 (1.29)	0.95 (0.85)	2.96 (2.64)	5.36 (4.78)
3	1.14 (1.02)	0.66 (0.59)	0.52 (0.46)	2.32 (2.07)
4	0.24 (0.21)	0.12 (0.11)	0.31 (0.28)	0.67 (0.60)
1970				
1	1.46 (1.30)	0.41 (0.37)	34.78 (31.02)	36.65 (32.69)
2	0.53 (0.47)	0.35 (0.31)	25.18 (22.46)	26.06 (23.24)
3	0.17 (0.15)	0.09 (0.08)	0.21 (0.19)	0.47 (0.42)
4	0.15 (0.13)	0.03 (0.03)	0.52 (0.46)	0.70 (0.62)
1971				
1	1.31 (1.17)	2.11 (1.88)	69.13 (61.66)	72.55 (64.71)
2	0.94 (0.84)	1.46 (1.30)	41.35 (36.88)	43.75 (39.03)
3	0.96 (0.84)	0.43 (0.38)	2.89 (2.58)	4.28 (3.82)
4	0.16 (0.14)	0.58 (0.52)	7.04 (6.28)	7.78 (6.94)
1969-1971 average				
1	1.69 (1.51)	1.36 (1.21)	37.59 (32.64)	39.64 (35.36)
2	0.97 (0.87)	0.92 (0.82)	23.16 (20.66)	25.05 (22.35)
3	0.76 (0.67)	0.39 (0.35)	1.21 (1.08)	2.36 (2.10)
4	0.18 (0.16)	0.24 (0.22)	2.62 (2.34)	3.04 (2.72)

1/ Kjeldahl nitrogen

Table 3. Annual loss of P by surface runoff and sediment from experimental watersheds, Treynor, Iowa, 1969-1971

Watershed	Loss of phosphorus by surface runoff: Solution	Loss of phosphorus by surface runoff: Sediment	Total loss of phosphorus[1/]
	kg/ha (lb/acre)		
1969			
1	0.189 (0.169)	0.306 (0.273)	0.495 (0.442)
2	0.093 (0.083)	0.164 (0.146)	0.257 (0.229)
3	0.193 (0.172)	0.058 (0.052)	0.251 (0.224)
4	0.081 (0.072)	0.009 (0.008)	0.090 (0.080)
1970			
1	0.085 (0.076)	0.949 (0.847)	1.034 (0.923)
2	0.046 (0.041)	0.477 (0.426)	0.523 (0.467)
3	0.064 (0.057)	0.017 (0.015)	0.081 (0.072)
4	0.005 (0.005)	0.015 (0.013)	0.020 (0.018)
1971			
1	0.237 (0.211)	1.893 (1.689)	2.130 (1.900)
2	0.189 (0.169)	1.101 (0.982)	1.290 (1.151)
3	0.386 (0.344)	0.126 (0.112)	0.512 (0.456)
4	0.059 (0.053)	0.229 (0.204)	0.288 (0.257)
1969-1971 average			
1	0.171 (0.152)	1.050 (0.936)	1.221 (1.088)
2	0.110 (0.098)	0.581 (0.518)	0.691 (0.616)
3	0.216 (0.191)	0.067 (0.060)	0.283 (0.251)
4	0.049 (0.043)	0.085 (0.075)	0.134 (0.128)

[1/] Total loss values represent the inorganic P of the solution and the $NaHCO_3$-extractable P of the sediment.

Table 4. Annual precipitation, runoff, and sediment yield for experimental watersheds, Treynor, Iowa, 1969-1971

Watershed	Precipitation	Surface runoff	Sediment yield
	cm (inches)		metric ton/ha (ton/acre)
1969			
1	79.81 (31.42)	6.43 (2.53)	4.10 (1.83)
2	80.11 (31.54)	5.97 (2.35)	2.37 (1.06)
3	77.83 (30.64)	4.39 (1.73)	0.27 (0.12)
4	77.98 (30.70)	0.69 (0.27)	0.13 (0.06)
1970			
1	80.04 (31.51)	5.44 (2.14)	27.04 (12.06)
2	78.28 (30.82)	4.55 (1.79)	17.94 (8.00)
3	73.30 (28.86)	0.94 (0.37)	0.09 (0.04)
4	73.13 (28.79)	0.33 (0.13)	0.22 (0.10)
1971			
1	73.48 (28.93)	12.55 (4.94)	44.80 (19.98)
2	73.71 (29.02)	9.75 (3.84)	29.50 (13.16)
3	75.44 (29.70)	3.86 (1.52)	1.43 (0.64)
4	76.10 (29.96)	1.80 (0.71)	3.63 (1.62)
1969-1971 average			
1	77.78 (30.62)	8.14 (3.20)	25.31 (11.29)
2	77.37 (30.46)	6.76 (2.66)	16.60 (7.40)
3	75.52 (29.73)	3.06 (1.20)	0.60 (0.27)
4	75.74 (29.82)	0.94 (0.37)	1.33 (0.59)

tionship can be shown for sediment P per unit of sediment. Although these weighted concentration are higher for watersheds 3 and 4, the small sediment discharge from these conservation watersheds held nutrient losses to a minimum.

Historically, lower erosion from WS-3 and 4 than from WS-1 and 2 may have resulted in organic matter accumulation differences, accounting for these sediment N differences. The organic C differences of the sediment from the various watersheds can be seen in Figure 1. The C:N ratio of the sediment ranges from 7:1 to 11:1. The sediment originating from the grass pasture and level-terraced corn watershed is generally one-half to two times higher in C than the sediment from the contour-planted corn watersheds. This difference in C content of the sediment is related to the watershed management which has resulted in the accumulation of organic material.

The sediment N and P concentrations are fairly constant during a runoff event except at low flows. Schuman et al. (1973a) and Burwell et al. (1975) postulated that the increase in sediment N concentration at low flow was related to a greater percentage of the total sediment sample being coloidal-size organic residue. Figure 1 shows that the sediment N and P vary with the C content of the sediment for the May 6, 1971, storm on all watersheds. Figure 2 shows that at low flows the C content of the sediment increased and is inversely related to the sediment concentration.

ENRICHMENT OF SEDIMENT

The particle size distribution of the sediment in transport from the contour Watershed 2 has shown a general increase in the clay size fraction from 26 to 29% over that of the 0- to 10-cm (0- to 4-inch) depth of surface soil (Table 5). For this watershed, the 11-year average sediment loss per year is 1452 MT/yr (1600 t/yr). Therefore, if we have a 3% clay enrichment, we would have a 43 MT (48 t) more clay discharge than without enrichment. Figure 3 shows that the concentration of all size fractions increased as runoff increased. The rate of increase is greatest with coarse fractions and least with the clay fraction; therefore, at low flows the percentage of clay in the total sample will be greater. The effect of clay enrichment on nutrient transport can be investigated best by considering the specific surface of the sediment and surface soil material. The specific surface (SS) can be described by equation 1 (Frere et al., 1975):

$$SS = 200\ (\%\ clay) + 40\ (\%\ silt) + 0.5\ (\%\ sand) \qquad (1)$$

For these calcualtions, the following specific surfaces of the separate fractions are assumed: clay, 200 m^2/g ($6.1X10^4$ ft^2/oz); silt, 40 m^2/g ($1.2X10^4$ ft^2/oz); and sand, 0.5 m^2/g ($1.5X10^2$ ft^2/oz). Therefore, the specific surface for the sediments and surface soil from Watershed 2 (Table 5) are 8482 m^2/g ($2.6X10^6$ ft^2/oz) and 7962 m^2/g ($2.4X10^6$ ft^2/oz),

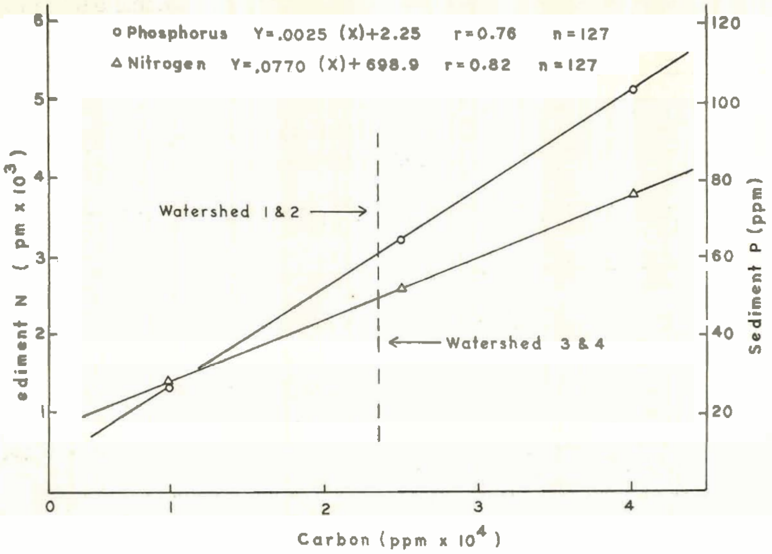

Figure 1. Relationship between N, P, and C content of sediment originating from agricultural watersheds on Missouri Valley loess.

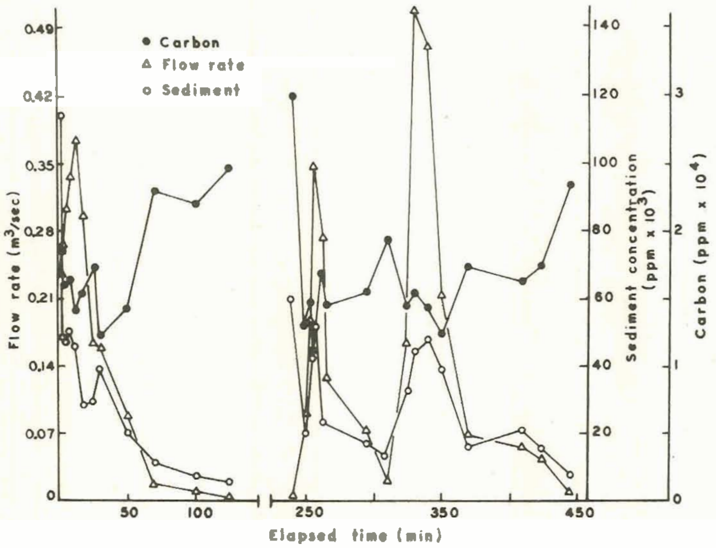

Figure 2. The effect of streamflow rate and sediment concentration on the C content of the sediment, Watershed 1, May 6, 1971, event, Treynor, Iowa.

Table 5. Size fractions of surface soil and streamflow samples from Watershed 2, Treynor, Iowa

Description of samples	Number of samples	% finer than indicated size mm (inches)		
		0.002 (0.0001)	0.020 (0.0008)	0.05 (0.002)
Surface soil	26	26	52	95
Weighted streamflow sediment 1/	73	29	57	96

1/ Based on flow duration-sediment transport relationship.

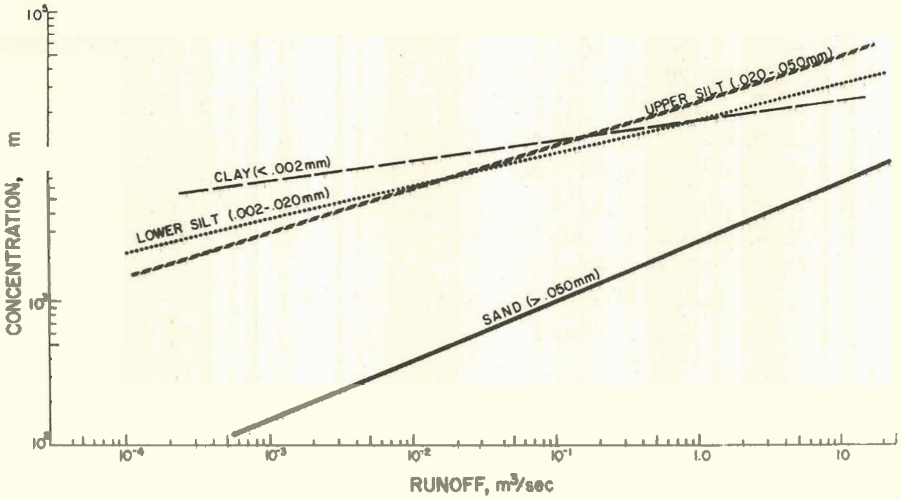

Figure 3. The effect of runoff rate on sediment concentration by particle size fraction.

respectively. These data indicate that the 3%-greater clay content of the sediment gives a 6.5%-greater specific surface and a similar capacity for adsorbed nutrient discharge. A small increase in clay content in eroded soil significantly increases the potential for nutrient transport during periods of runoff from agricultural lands. It is probable clay enrichment from the grass watershed or the terraced watershed would be greater than from the contour-corn watershed because (1) flows are generally lower so that the larger particles are not readily moved and (2) the greater roughness on the watershed due to vegetation results in deposition of the larger soil particles or filtering and thus favors clay movement.

The data presented point out the selectivity of the erosion process and how this can influence the chemical characteristics of the sediment discharged. The sediment fraction of surface runoff is responsible for the major nutrient discharges from cultivated cropland unless conservation and management practices are utilized to reduce erosion. The use of adequate management is becoming more important, both environmentally and to maintain maximum production.

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