DIVISION S-6—SOIL AND WATER MANAGEMENT AND CONSERVATION

Phosphorus Losses from Four Agricultural Watersheds on Missouri Valley Loess[1]

G. E. SCHUMAN, R. G. SPOMER, AND R. F. PIEST[2]

ABSTRACT

Phosphorus losses from four field-size experimental watersheds at Treynor, Iowa, were measured during 1969, 1970, and 1971. A contour-planted corn watershed and a pasture watershed were fertilized at the recommended P rate (39 kg/ha). A level-terraced and a second contour-planted corn watershed were fertilized at 2.5 times this rate. At the high level of P fertilization, phosphorus loss by surface runoff from the contour-planted corn watershed was 0.495 kg/ha in 1969, 1.034 kg/ha in 1970, and 2.130 kg/ha in 1971. Level terraces greatly reduced P loss by reducing runoff and erosion.

Water samples for all runoff events taken above the overfall of each watershed gully contained considerably more inorganic P in solution than samples taken at the weir site, 70 to 230 m downstream. This reduction in solution P was caused by the adsorption of P by the additional suspended soil material entering the stream from gully erosion.

Additional Index Words: inorganic P, sodium bicarbonate-extractable P, level terraces, sediment, watershed, agricultural runoff.

BECAUSE PHOSPHORUS is relatively immobile in soil, P is lost from agricultural lands primarily adsorbed to eroded soil transported by runoff. Soil loss by sheetrill ero-

[1] Contribution from The North Central Region, Agr. Res. Ser., USDA, in cooperation with the Nebraska and Iowa Agr. Exp. Sta. Published as Paper no. 3046, Journal Series, Nebraska Agr. Exp. Sta., Lincoln 68503. Received Sept. 5, 1972. Approved Jan. 18, 1973.

[2] Soil Scientist, USDA, Lincoln, Nebr.; Agricultural Engineer, USDA, Council Bluffs, Iowa; and Hydrologic Engineer, USDA, Columbia, Mo., respectively.

sion from a contour-farmed watershed near Treynor, Iowa, for one storm in June 1967 was 101 metric tons/ha (12). Six-year annual average soil loss for two contour-farmed watersheds has been 68 and 56 metric tons/ha (10). The sediment-laden water flows into gullies that efficiently transport the sediment to downstream rivers, ponds, or lakes. Soil losses of this magnitude are not uncommon (3, 8). In many cases, this sediment originates from agricultural lands receiving P fertilizers and, therefore, may be rich in adsorbed P.

Results of investigations conducted by other researchers on the P content of runoff water and sediment are variable and are primarily reported for small plot experiments. Engelbrecht and Morgan (1) reported P losses of from 0 to 16 kg/ha per year in surface drainage waters in Illinois. Scarseth and Chandler (11) reported that plots receiving 345 kg of P/ha over a period of 26 years lost 60% of the added P by soil erosion. Other research has shown losses of 0.72 kg/ha per year on plots in Wisconsin (5) and 0.03 to 0.04 kg/ha per year on plots in Georgia (14). More important, P runoff information from farm-size watersheds was needed to better calibrate data from small fractional-hectare plots.

A study was initiated in 1969 on four watersheds near Treynor, Iowa, to learn the effects of conservation practices on P in runoff and the relation of sediment P to solution P. Treatments included several conservation practices and two fertility levels.

MATERIALS AND METHODS

The research watersheds are on Missouri Valley deep loess soil. Soil types are Monona, Ida, and Napier silt loams. Slopes on the watersheds range from 2 to 4% on the ridges and bottoms and from 12 to 18% on the sides (9). All four watersheds have grassed waterways within the watershed. The watersheds are instrumented to record hydrologic variables and to measure sheetrill and gully erosion rates. Watershed size, crop, conservation practice, and fertilizer application rates are listed in Table 1.

Anhydrous NH_3 was placed 25 to 30 cm deep with 50-cm spacings at the rate of 389 kg N/ha for watersheds 1 and 4. An additional 59 kg N/ha was broadcast along with 97 kg P/ha, 28 kg K/ha, and 11 kg Zn/ha and plowed down. Anhydrous NH_3 was placed in the soil to a depth of 25 to 35 cm on 100-cm spacings at the rate of 168 kg/ha for watershed 2. The P, K, and Zn were broadcast at the rate of 39 kg P/ha, 28 kg K/ha, and 11 kg Zn/ha and plowed down. On watershed 3, in bromegrass pasture, all nutrients were broadcast on the surface.

Approximately 500 ml of the sediment-water runoff mixture was collected at intervals during each storm event at two locations in each drainageway: (i) immediately above the gully headcut and (ii) at the weir sites located in the channels several hundred feet downstream. No grassed waterways are located between sample sites. The samples collected above the headcut reflect P loss from sheet erosion of the fields; weir samples reflect the added material derived from the gullied channel downstream from the headcut. The data presented represent the P loss from sheet erosion of the fields, except for Table 6. Samples were stored at a temperature of 4C until analyzed to minimize chemical and microbiological conversions. A minimum of four samples was collected for each surface runoff event from each of the two locations in each watershed. These samples were taken after surface runoff first began, on the rise, at peak flow, and along the recession of the hydrograph.

Separation of the liquid and solid phases could not be carried out immediately because of the large number of samples and inaccessability of laboratory facilities. Therefore, the samples were allowed to settle and the supernatant decanted and filtered through Whatman No. 42 filter paper. (Name of product is listed for benefit of reader only and does not imply endorsement of the product named by the US Department of Agriculture.) Random samples were checked by centrifugation to insure that the solution was free of colloidal material. Inorganic P was measured in the clarified solution by the ascorbic acid method (6). The sediment was dried at 60C for 24 hours and ground to pass a 2-mm sieve. Then $NaHCO_3$-extractable P (7) was determined on 0.2 to 1.0 g of the dried sediment. This extracting procedure was used because the sediment originated from calcareous soils. Total P was not determined on sediment because it would not be meaningful from a pollution standpoint. Only a very small portion of the total P would be "available" for pollution of streams and ponds. Taylor (13) states that less than 10% of the total P of soils will be considered a part of the "labile pool." Soluble organic P was determined to be negligible; therefore, the analysis was discontinued.

Table 1—Watershed size, crop, conservation practice, and fertilizer application rates for four watersheds, Treynor, Iowa

Watershed	Drainage area	Crop	Conservation practice	Fertilizer N	P*	K	Zn†
	ha			kg/ha			
1	30	Corn (*Zea mays*)	Approx. contour	448	97	28	11
2	33	Corn (*Zea mays*)	Approx. contour	168	39	28	11
3	43	Bromegrass (*Bromus inermis* Leyss.)	Rotation grazing	168	39	28	0
4	60	Corn (*Zea mays*)	Level terraced	448	97	28	11

* Applied at the rate of 39 kg/ha in 1971 on all watersheds.
† Applied in 1969 only.

For simplicity, inorganic P in solution will be referred to as solution P and $NaHCO_3$-extractable P of the sediment will be referred to as sediment P throughout the paper.

Phosphorus losses were calculated by converting the P concentrations in solution or on dry sediment to a loss rate (g/min) on the basis of flow rate and sediment load. These calculations were based on the following equation:

$$Q_p = \text{concentration (ppm)} \times \text{runoff rate (cfs)} \times K \quad [1]$$

where Q_p is P loss rate (g/min) and K is the conversion factor for ppm and cfs. The constant for calculating solution P loss rates (K_{soln}) is 1.698 and for sediment P loss rates (K_{sed}) is 1.698×10^{-6} times sediment concentration.

For a given runoff event, the loss rate values were plotted against time and the area under the curve integrated to obtain a total loss for that event. If sample coverage was not complete for a storm, the loss rate of P was computed using a method similar to that derived by Frere (2) and knowledge obtained from previous events.

Random field samples of the surface 7.5 cm of soil were taken before the study to enable comparison of the runoff and sediment material to that of the uneroded material. This would allow the determination of enrichment ratios of the sediment. A soil/water (1:5) extract and $NaHCO_3$ extract were made of the uneroded material for this evaluation.

RESULTS AND DISCUSSIONS

Loss of soluble P and sediment P by surface runoff from the four agricultural watersheds for 1969, 1970, and 1971 is shown in Table 2. Heavily fertilized watershed 1 lost approximately 1.8 times more P in solution and on the sediment as did normally fertilized watershed 2 for the 3-year average. The watersheds are approximately the same size and have similar runoff characteristics (9). A treatment effect is still evident between the normal and heavily fertilized watersheds when the P loss is computed on the basis

Table 2—Annual loss of P by surface runoff and sediment from experimental watersheds, Treynor, Iowa, 1969–1971

Watershed	Loss of phosphorus by surface runoff: Solution	Sediment	Total loss of phosphorus*
	kg/ha/year		kg/ha/year
	1969		
1	0.189	0.306	0.495
2	0.093	0.164	0.257
3	0.193	0.058	0.251
4	0.081	0.009	0.090
	1970		
1	0.085	0.949	1.034
2	0.046	0.477	0.523
3	0.064	0.017	0.081
4	0.005	0.015	0.020
	1971		
1	0.237	1.893	2.130
2	0.189	1.101	1.290
3	0.386	0.126	0.512
4	0.059	0.229	0.288
	1969-1971 Average		
1	0.171	1.050	1.221
2	0.110	0.581	0.691
3	0.216	0.067	0.283
4	0.049	0.085	0.134

* Total loss values represent the inorganic P of the solution and the $NaHCO_3$-extractable P of the sediment.

Table 3—Average annual solution P and sediment P loss per unit of water and sediment yield from experimental watersheds, Treynor, Iowa, 1969–1971

Water-shed	Solution P concentration	Sediment P concentration
	kg P/ha-cm	kg P/metric ton
1	0.021	0.041
2	0.016	0.035
3	0.071	0.112
4	0.052	0.064

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

Water-shed	Precipitation	Surface runoff	Sediment yield
	cm		metric ton/ha
		1969	
1	79.81	6.43	4.10
2	80.11	5.97	2.37
3	77.83	4.39	0.27
4	77.98	0.69	0.13
		1970	
1	80.04	5.44	27.04
2	78.28	4.55	17.94
3	73.30	0.94	0.09
4	73.13	0.33	0.22
		1971	
1	73.48	12.55	44.80
2	73.71	9.75	29.50
3	75.44	3.86	1.43
4	76.10	1.80	3.63
		1969-1971 Average	
1	77.78	8.14	25.31
2	77.37	6.76	16.60
3	75.52	3.06	0.60
4	75.74	0.94	1.33

of a unit of runoff or sediment discharge (Table 3). The P loss per unit of runoff and sediment yield for the normally fertilized watershed were 0.016 kg/ha-cm and 0.035 kg/metric ton, respectively. Phosphorus loss per unit of runoff and sediment yield for heavily fertilized watershed 1 were 0.021 kg/ha-cm and 0.041 kg/metric ton. Therefore, the greater P loss may be associated with the higher application of P fertilizer.

The 1969 solution P loss in surface runoff from watershed 4 is high for the small volume of water discharge (Tables 2 and 4). Solution P concentrations were high (Table 5) and the small runoff amounts made it difficult

Table 5—Solution and sediment P concentration ranges and averages from watershed streamflow samples and uneroded soil material, Treynor, Iowa, 1969–1971

Watershed	Solution P: Range	Average	Enrichment ratio	Sediment P: Range	Average	Enrichment ratio
	ppm			ppm		
1	0.016–0.850	0.220	5.4	15–110	31.14	2.2
2	0.008–0.850	0.169	4.1	18–95	29.04	2.1
3	0.080–2.440	0.721	17.6	42–438	90.38	6.5
4	0.110–1.500	0.513	12.5	53–155	61.79	4.4
Loess (uneroded)*	0.008–0.080	0.041		8–29	14.0	

* Random field samples of surface soil to 7.5-cm depth.

to plot the loss rate for an event. More samples per runoff event were taken in 1970 and 1971, permitting more precise computation of the P discharge. However, the 3-year average P loss from watershed 4 was one-ninth that from watershed 1, although both received the high rate of P fertilization. Level terraces reduce P loss by reducing runoff and erosion. Loss of solution P from the pasture watershed was greater than from the other watersheds, even though it was fertilized at the recommended rate. However, the sediment P loss from the pasture watershed was only 10% of that from the normal-fertility, contour-corn watershed. This can be attributed to the small quantity of sediment yield. The differences in solution P were attributed to P leaching from the grass, fertilizer added to the surface without incorporation, and animal droppings. (The higher solution P concentrations occurred during the spring snowmelt runoff.) Field and laboratory studies in Minnesota (4, 15) showed that leaching of dead tissues of forage crops resulted in considerable P loss and that more than 70% was in the form of inorganic P. Also, P concentrations in spring runoff were considerably higher than in runoff occurring later in the season.

Phosphorus loss in 1970 and 1971 was generally greater than the loss in 1969 and was primarily the result of greater sediment discharges. The number of significant runoff events (with a peak rate greater than 0.142 m^3/sec) and the total runoff in 1969–1971 were below normal even though annual precipitation equaled, or was slightly above, the long-term average of 72.26 cm at Omaha, Nebraska.

Concentration ranges of solution P and sediment P for runoff, sediment, and uneroded loess are shown in Table 5. Enrichment ratios of the sediment and solution based on the average P concentrations are also shown in Table 5. The average solution P concentration for watershed 1 was 1.30 times greater than that of watershed 2. Concentrations from watershed 4 were variable and high because runoff and soil losses were small. Sediment P concentrations for the pasture watershed were quite high compared with the other watersheds. This was the result of high concentrations of solution P and small soil losses. The P level of the runoff and sediment was much higher from all watersheds than from the uneroded loess material. This suggests that sorting of soil particles occurs during the erosion process with finer particles that have a greater adsorption capacity being most readily transported.

Samples taken from the headcut and weir locations showed vast differences in solution and sediment P. The effects of sampling site for the contour-cropped watersheds are shown in Table 6 for two well-sampled runoff events in

Table 6—Phosphorus loss as affected by sampling site from agricultural watersheds, Treynor, Iowa*

Watershed*	Storm	Headcut Solution P	Headcut Sediment P	Headcut Total loss	Weir Solution P	Weir Sediment P	Weir Total loss
		kg/ha			kg/ha		
1	6/26/69	0.019	0.024	0.043	0.006	0.032	0.038
2	6/26/69	0.012	0.019	0.031	0.005	0.024	0.029
1	7/17/69	0.033	0.024	0.057	0.013	0.038	0.051
2	7/17/69	0.016	0.027	0.043	0.009	0.039	0.048
3	7/17/69	0.057	0.021	0.078	0.052	0.027	0.079

* Data from watersheds 3 and 4 not included because negligible runoff and erosion resulted from the 6/26/69 and 7/17/69 storms.

1969. The decrease in solution P in the runoff from the headcut to the weir was accompanied by an increase of P on the sediment transported. However, total P loss at the two sites agreed relatively well. The decrease in solution P concentration is partially due to the adsorption of P by sediments from the gullies. Flow rates and water turbulence at the overfall and in the gully are such that much of the water is exposed to the sediments. However, the time for the runoff mixture to pass between headcut and weir sites may not be adequate for achieving complete equilibrium and, undoubtedly, some adsorption occurred during sample handling before the liquid and solid phases were separated. Upon analyzing P loss at the headcut and weir sites, the data indicate that adsorption probably was taking place on the raw, exposed gully floor and walls and, in some instances, some of the P was not reaching the weir sites.

Most important, by the time this runoff reached any main body of water miles from the watershed, a large portion of the P was adsorbed by the suspended material and exposed gully edges of the channel. The calcareous loess from these watersheds and the till material in the gully have a great P-scavenging potential.

Data obtained on the Treynor experimental watersheds in 1969, 1970, and 1971 show that very small quantities of solution and sediment P were lost even at the high levels of fertilization under these conditions of precipitation and runoff. The year-to-year difference in P loss is attributed to the intensity, duration, and seasonal occurrence of the rainfall. In 1969 all the rainfall events in the spring were small, and the only rainstorms of consequence occurred on July 17 and August 20, late in the season when the crop was well established and runoff and erosion were minimal. However, in 1970 and 1971, a few major rainfall events occurred that accounted for about 80% of the P loss. Phosphorus concentrations in the snowmelt runoff were higher than runoff during other seasons, especially on the pasture watershed. The measured P loss from these watersheds seems to agree closely with the small plot data cited earlier (5). Data presented also reflect the benefits of level terracing in reducing plant nutrient losses transported by runoff and sediment.

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