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Nitrogen Surface Runoff Missouri Valley Loess

Nitrogen Losses in Surface Runoff from Agricultural Watersheds on Missouri Valley Loess[1]

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ABSTRACT

Nitrogen losses from surface runoff from four field-size (30 to 60.8 ha) watersheds in southwestern Iowa, near Treynor, were measured during 1969, 1970, and 1971. A contour-planted corn watershed and a pasture watershed were fertilized at the recommended N rate (168 kg/ha). A level-terraced and a contour-planted corn watershed were fertilized at 2.5 times this rate. The conservation practice of level-terraced corn or pasture was very effective in reducing water, sediment, and N yields when compared with the contour-planted corn watersheds.

Annual water-soluble N losses were low from all watersheds. The 3-year average annual solution N loss from the contour-planted corn watershed, fertilized at 2.5 times the recommended rate, was 3.05 kg/ha; the comparable watershed, fertilized at the recommended rate, lost only 1.89 kg/ha.

Nitrogen losses associated with sediment in the runoff accounted for 92% of the total loss for the 3-year period from the contour-planted corn watersheds. A large portion of the N loss for the terraced watershed was also associated with the sediment; however, N loss was only one-tenth that of the contour-planted watersheds. Sediment-N concentrations were similar for watersheds receiving 168 kg/ha and 448 kg/ha annual N applications.

Water-soluble-N and sediment-N losses in runoff were usually highest at the beginning of the cropping season and decreased progressively throughout the year, reflecting a seasonal effect believed to be associated with nutrient removal by the crop, leaching, and N tie-up in organic matter.

Additional Index Words: fertilizer, sediment, erosion.

Much public attention has been focused recently on environmental quality as influenced by agricultural practices. Considerable interest has centered around the nitrate content of water resources, since accumulations can be hazardous to human health (8). Nitrogen concentrations in excess of 10 ppm NO_3-N have been found in water supplies during the period that use of commercial fertilizers has increased rapidly (13). Viets (15) points out that circumstantial evidence indicates water-quality deterioration should be associated with increased fertilizer use, but positive evidence is not available.

Nitrogen losses in runoff from agricultural lands and forested areas have been reported by many researchers (2, 10, 11). Losses from forested areas generally range from less than 1 to 3.36 kg/ha and represent land areas that have been affected least by man's activities (5, 7). Timmons et al. (14) found N losses as high as 14.5 kg/ha per year from corn-cropped plots. These losses were affected greatly by the management practices used. Total N loss was much greater from nonfertilized, cultivated fallow and normally fertilized, continuous corn than from land in a 3-year rotation receiving normal, annual fertilization. The sediment in the runoff contained most of the N lost.

The present study provides information on N losses in surface runoff from field-size agricultural watersheds (30 to 61 ha) as related to conservation management practices, rate of N fertilizer application, and seasonal differences in climate.

MATERIALS AND METHODS

The four experimental watersheds are located in southwestern Iowa near Treynor. The topography of the area is characterized by a loess cap, underlain by till, ranging in thickness from 24.4 m on the ridges to less than 4.6 m 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 Marshall, Monona, Ida, and Napier silt loams. These loessial soils have good internal drainage. Slopes on the watersheds range from 2 to 4% on the ridges and bottoms to 12 to 18% on the sides (12).

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The four watersheds were instrumented in 1964 to measure precipitation and streamflow. Precipitation measurements were obtained from recording raingages strategically located on each watershed. Streamflow discharge was 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.

Watersheds 2 and 3 received the normal, recommended fertilizer application rates of 168 kg N/ha and 39 kg P/ha in 1969, 1970, and 1971. Anhydrous ammonia was knifed in to a depth of 25 to 35 cm on 100-cm row spacings, and P was broadcast and plowed down on Watershed 2. All fertilizer (NH_4NO_3 and superphosphate) was broadcast on the sod surface of the bromegrass pasture on Watershed 3. Watersheds 1 and 4 received a high fertilizer application rate of 448 kg N/ha annually. A high rate of 97 kg P/ha was applied to these watersheds in 1969 and 1970, but the P fertilizer application rate was reduced to 39 kg P/ha in 1971. For these high-fertility watersheds, anhydrous ammonia was knifed in to a 25- to 30-cm depth on 50-cm shank spacings at the rate of 389 kg N/ha in 1969 and 1971. An additional 59 kg N/ha as NH_4NO_3 was broadcast and plowed down as a part of the preplant tillage operations on these watersheds. In 1970, only 60% of the N was applied as anhydrous ammonia, whereas 91% was applied as anhydrous ammonia in 1969 and 1971. The additional N was broadcast as NH_4NO_3. Potassium was applied at the rate of 28 kg K/ha annually on all watersheds. All fertilizer was applied in the spring before preplant tillage operations.

All corn watersheds were harvested for grain and the stalks left on the watershed. The corn watershed yields ranged from 6780 to 8537 kg/ha. The pasture watershed also had considerable residues and animal wastes remaining in the fall after grazing by cattle during the summer. Animal numbers on pasture varied from 75 to 130 and grazed the pasture from May to November. Therefore, residue was present on all watersheds during the winter and precropping period.

Approximately 500 ml of the soil-water runoff mixture was collected manually at time intervals during each surface runoff event to determine the concentrations of sediment, NO_3-N, NH_4-N, and sediment N. Samples were usually collected at the gully headcut site on Watersheds 1 and 2 and at the weir site on Watersheds 3 and 4. Gully headcut samples represent sheet-rill erosion from the cropland area, and weir samples represent sheet-rill plus gully erosion. The gullies on Watersheds 3 and 4 have been inactive, and samples collected at the weir represent cropland area discharges. Samples were collected during the rise, peak, and recession of streamflow for most surface runoff events. A minimum of four samples was collected for each sampled event. Samples were stored at 4C to minimize chemical and microbiological conversions.

The liquid and solid phases were separated by Whatman No. 42[3] filter paper and checked by centrifugation to insure that the liquid was free of colloidal material. Ammonia-N and nitrate-N were determined on the clarified solution by steam distillation with MgO and Devarda's alloy into boric acid and titration with dilute H_2SO_4 (3). A Technicon AutoAnalyzer[3] was obtained in July 1970 with which NH_4-N and NO_3-N were then determined, using continuous-flow colorimetric procedures (1, 9).

The sediment content of each sample was determined gravimetrically, the sediment dried at 60C for 24 hours, then ground to pass a 2-mm sieve. Total-N was determined on the sediment using micro-Kjeldahl procedures as described by Bremner (4).

Nitrogen losses were calculated by converting the NH_4-N, NO_3-N, and total-N concentrations to a loss rate (g/min) on the basis of flow rate and sediment load. These calculations were based on the following equation:

$$Q_N = \text{concentration (ppm)} \times \text{runoff (cfs)} \times K$$

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

Ammonia-N and NO_3-N in solution will be referred to as solution N, and total N of the sediment will be referred to as sediment N throughout the paper.

It was necessary to estimate losses of N for unsampled and partially sampled runoff periods to obtain quantities lost on a yearly basis. Frere (6) reported that soluble-N concentrations during each peak water flow were constant within the limits expected from the sampling variation and that the amount of the constituent transported could be estimated adequately as the product of the mean concentration from representative samples at each high water flow and the volume of water transported during that flow. Unpublished data from the experiment reported herein agree with Frere's findings that similar quantities of soluble N are obtained by the concentration-mean and integrated-computation methods. In addition, these unpublished data show that quantities of sediment N can be estimated adequately as the product of the concentration mean and sediment volume. Therefore, in periods when soluble and sediment N were unsampled, quantities were determined as the product of the concentration mean and the concurrent volumes of water or sediment. To determine quantities of N lost during completely unsampled surface runoff events, a concentration-mean value was selected from the nearest sampled surface runoff event. Usually, the time lapse between sampled and unsampled events was only a few days. Estimated quantities represented about 10% of the total annual quantities lost.

Nitrogen losses presented in this paper deal only with the surface runoff and do not include base flow which will be covered in a later paper. Soluble-N losses by base flow appear to be more important than surface losses.

RESULTS AND DISCUSSION

Precipitation, Runoff, and Sediment Yield

Precipitation, surface runoff, and sediment yield for the watersheds are shown in Table 2. Precipitation for each

Table 2—Precipitation, runoff, and sediment yield from agricultural watersheds, Treynor, Iowa*

Watershed	Precipitation	Surface runoff	Sediment loss by sheet-rill erosion
	cm	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

*Unpublished data, R. G. Spomer, K. E. Saxton, and H. G. Heinemann.

[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—Watershed description, crop, conservation practice, and fertilizer application rates for 1969, 1970, and 1971, Treynor, Iowa

Watershed	Size	Crop	Conservation practice	Fertilizer N	Fertilizer P
	ha			kg/ha	kg/ha
1	30.0	Corn	Contour	448	97*
2	33.6	Corn	Contour	168	39
3	43.0	Bromegrass	Rotation grazing	168	39
4	60.8	Corn	Terraced	448	97

* Phosphorus fertilizer was applied at the rate of 39 kg/ha on all watersheds in 1971.

of the 3 years was slightly above the long-term average annual precipitation (72.26 cm) measured at Omaha, Nebraska. Surface runoff from the contour-planted, corn-cropped watersheds in 1969, 1970, and 1971 was 52, 43, and 96%, respectively, of the average annual runoff measured during the 1964–1971 period. Sediment yield from the contour-planted, corn-cropped watersheds in 1969, 1970, and 1971 was 6, 42, and 69%, respectively, of the average annual sediment yield measured during the 1964–1971 period. (Cropping and conservation practices do not differ for these time periods except for fertility treatments discussed.) Average annual surface runoff and sediment yield for contour-planted watersheds during the 3-year (1969–1971) study period were 64 and 39% of the losses measured for the long-term period (1964–1971).

Conservation Practice Effect

The level-terraced and pasture watersheds were very effective in reducing water and sediment losses. Solution and sediment N losses were also greatly affected by the conservation management practices (Table 3). The average annual total N (solution plus sediment) losses were 32.35, 3.05, and 2.36 kg/ha for the contour-planted, corn-cropped; level-terraced, corn-cropped; and pasture watersheds, respectively. Sediment N losses from the contour-planted, corn-cropped watersheds were 92% of the total N loss. Sediment N losses were 86 and 51%, respectively, of the total N losses for the level-terraced, corn-cropped, and pasture watersheds.

Fertility Level Effect

The influence of fertilizer application rates on nutrient losses in surface runoff is evaluated by comparison of Watershed 1, which received 448 kg N/ha, and Watershed 2, which received 168 kg N/ha annually. Historical records (1964–1971) revealed that runoff and erosion characteristics differ for these two watersheds. Watershed 1 has consistently had more runoff and erosion than Watershed 2. To evaluate the fertility treatment effect, the runoff and erosion differences for the two watersheds must be considered. Data reported in Table 4, representing weighted concentrations of nutrients in the transporting medium, were derived by dividing solution and sediment N losses shown in Table 3 by the corresponding water and sediment yields shown in Table 2. The annual loss per unit of transporting material of solution and sediment N is expressed as kilograms of N per hectare-centimeter of surface runoff and kilograms of N per metric ton of sediment yield. The average annual sediment N loss per unit of sediment for the recommended and high N fertilizer application rates was 1.35 and 1.42 kg N/metric ton of sediment, respectively. These data indicate little fertility treatment effect on the amount of N carried by unit weight of sediment. The average annual sediment N loss per unit of sediment was higher on Watersheds 3 and 4 than on Watersheds 1 and 2. Sediment N loss per unit of sediment for Watersheds 3 and 4 was 2.10 and 2.23 kg N/metric ton of sediment, respectively. Historically, lower erosion from Watersheds 3 and 4 than from Watersheds 1 and 2 may have resulted in organic matter accumulation differences, accounting for these sediment N differences. The average organic matter content of randomly selected sediment samples from the contour-cropped, pasture, and level-terraced watersheds was 2.8%, 7.9%, and 7.1%, respectively.

The average annual solution N loss per unit of runoff for the recommended and high N fertilizer application treatments was 0.29 and 0.38 kg/ha-cm (2.8 and 3.7 ppm), respectively. Although these solution N losses per unit of runoff are considered low, the data suggest a fertility treatment effect for the 3-year period.

Seasonal Effect

Differences in solution N loss per unit of runoff among the 3 years (Table 4) are not clearly understood but appear to be influenced by climatological differences. The seasonal distribution of precipitation and runoff characteristics varied considerably among the 3 years. Snowmelt runoff from the contour-planted, corn watersheds in 1969, 1970, and 1971 was 60, 19, and 20%, respectively, of the annual surface runoff. Ammonia-N and nitrate-N concentrations were generally higher in snowmelt and

Table 3—Nitrogen loss in surface runoff from agricultural watersheds, Treynor, Iowa

Watershed	Solution N			
	NO_3-N	NH_4-N	Sediment N*	Total loss
	kg/ha			
	1969			
1	2.30	1.55	5.86	9.71
2	1.45	0.95	2.96	5.36
3	1.14	0.66	0.52	2.32
4	0.24	0.12	0.31	0.67
	1970			
1	1.46	0.41	34.78	36.65
2	0.53	0.35	25.18	26.06
3	0.17	0.09	0.21	0.47
4	0.15	0.03	0.52	0.70
	1971			
1	1.31	2.11	69.13	72.55
2	0.94	1.46	41.35	43.75
3	0.96	0.43	2.89	4.28
4	0.16	0.58	7.04	7.78
	1969–1971 average			
1	1.69	1.36	36.59	39.64
2	0.97	0.92	23.16	25.05
3	0.76	0.39	1.21	2.36
4	0.18	0.24	2.62	3.04

* Kjeldahl nitrogen.

Table 4—Loss per unit of transporting material of soluble N and sediment N expressed on the basis of runoff and sediment yield

Watershed	Soluble nitrogen		
	NO_3-N	NH_4-N	Sediment nitrogen
	—kg/ha-cm runoff—		kg/metric ton sediment
	1969		
1	0.36	0.24	1.43
2	0.24	0.16	1.25
3	0.26	0.15	1.93
4	0.35	0.17	2.38
	1970		
1	0.27	0.08	1.29
2	0.12	0.08	1.40
3	0.18	0.10	2.33
4	0.45	0.09	2.36
	1971		
1	0.10	0.17	1.54
2	0.10	0.15	1.40
3	0.25	0.11	2.02
4	0.09	0.32	1.94
	1969–1971 weighted mean		
1	0.21	0.17	1.45
2	0.15	0.14	1.39
3	0.12	0.13	2.06
4	0.20	0.26	1.98

Table 5—Cumulative seasonal sampled losses of surface runoff water and sediment and related losses of soluble N (NO_3-N + NH_4-N) and sediment N (TKN) for 1969-1971

Seasonal periods*	Water-shed	Surface runoff	Sediment loss	Water-soluble, N†	Sediment N, TKN‡
		cm	metric tons/ha	kg/ha-cm runoff	kg/metric tons sediment
Residue cover and	1	5.08	0.36	0.58	1.93
precropping§	2	5.23	0.09	0.42	4.42
Seedbed and	1	11.63	59.08	0.23	1.48
establishment	2	7.54	40.06	0.16	1.42
Reproduction and	1	2.90	9.64	0.15	1.30
maturation	2	2.29	4.69	0.11	1.33

* Seasonal period definition: Residue cover and precropping, Nov. 1-May 1; seedbed and establishment, May 1-Aug. 1; reproduction and maturation, Aug. 1-Nov. 1.
† Concentration equivalent (ppm) = kg/ha-cm runoff × 9.74.
‡ Concentration equivalent (ppm) = kg/metric ton sediment × 1,000.
§ Snowmelt surface runoff represents a large portion of the total runoff for this period.

spring runoff than in runoff that occurred later in the cropping season. This may be attributed to ammonia absorption by the snow and/or leaching of decomposed organic residue from the previous cropping season. The 1969 cropping season runoff was characterized by several small runoff events. Solution-N concentrations were higher from these small events in 1969 than from larger events in 1970 and 1971. The 1970 surface runoff was characterized by a large event in early May and a large event in early August. Solution-N concentrations were higher in May than in August. The 1971 cropping season runoff was characterized by several large events in May and smaller events later in the season. In 1971, solution-N and sediment-N concentrations were highest at the beginning of the cropping season and decreased progressively during the cropping season. The seasonal decrease of soluble and sediment N may be attributed to progressive N removal by crop use, leaching, N tie-up in organic matter, and overland movement.

To further evaluate the seasonal effect on solution-N and sediment-N losses, residue cover and precropping, crop seedbed and establishment, and crop reproduction and maturation periods were considered. The data in Table 5 show that the crop seedbed and establishment period is the critical period for runoff and erosion. Since nutrient losses are closely associated with amounts of runoff and erosion, this period is also critical for soluble-N and sediment-N losses. The data also show that the precropping period is critical for soluble-N losses because surface runoff is substantial when the soil is frozen, and soluble-N losses are high. Sediment-N losses were high for the residue cover and precropping period, but sediment losses were low because of winter conditions and, thus, would not be considered a critical N-loss period. The soluble-N and sediment-N losses show a definite progressive decrease throughout the cropping season.

SUMMARY

The material presented indicates that the most practical first step in eliminating N as a pollutant in surface runoff is to control erosion. Losses of N associated with runoff and erosion can be greatly reduced by effective erosion-control practices since a large part of the total N lost is associated with the sediment. Nitrogen concentrations of sediment were similar for contour-planted, corn-cropped watersheds receiving annual applications of N at rates of 168 or 448 kg/ha during a 3-year period. Water-soluble-N content of surface runoff was low for each of the 3 years. However, water-soluble N was greater for the contour-planted, corn-cropped watershed fertilized at 2.5 times the recommended rate than for the contour-planted, corn-cropped watershed fertilized at the recommended rate during the 3-year study period. Water-soluble-N and sediment-N content in runoff was usually highest at the beginning of the cropping season and decreased progressively throughout the year. This suggests a seasonal effect related to progressive N removal by crop use, leaching, N tie-up in organic matter, and overland movement. This seasonal effect is important for designing practices to control N losses during critical runoff-erosion periods.

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