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Nitrogen in Subsurface Discharge from Agricultural Watersheds

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ABSTRACT

The nitrogen in subsurface discharge and surface runoff was measured from four agricultural watersheds on Missouri Valley deep loess near Treynor, Iowa, from April 1969 through March 1974.

The data showed that, with the agricultural management practices used on the watersheds, the subsurface discharge of water ranged from 62 to 88% of the average annual stream flow. Nitrate in subsurface discharge accounted for 84 to 95% of the total average annual soluble N discharged in stream flow.

A terraced watershed continuously cropped to corn (*Zea mays* L.) had reduced surface runoff, sheet-rill erosion, and associated nitrate-nitrogen discharges, but had increased subsurface discharge of water and soluble N as compared with two contoured corn watersheds. Nitrogen fertilizer applied at a high rate (448 kg ha^{-1} $year^{-1}$) exceeding crop needs on the terraced and contoured corn watersheds, increased five- and threefold the average annual subsurface discharge of NO_3-N, respectively, as compared with a contoured watershed fertilized with N at a normal rate (168 kg ha^{-1} $year^{-1}$).

To control the watershed discharge of N and subsequent pollution of stream flow from the Iowa and Missouri deep loess hills requires N fertilizer application rates that do not exceed crop needs and using conservation practices that minimize soil erosion and deep percolation.

Additional Index Words: soluble nutrients, fertilizer, percolation, ground water, surface runoff.

The increased use of commercial fertilizers has been cited as one cause for the deterioration of streams, lakes, ponds, and ground-water supplies. Much research has been conducted to characterize the transport of plant nutrients by surface runoff, but the quantities reported in these studies varied widely because of differences in experimental conditions (Bormann et al., 1968; Burwell et al., 1974; Harrold, 1971; Massey et al., 1953; Schuman et al., 1973; Schuman, Spomer, and Piest, 1973; Timmons et al., 1968; Timmons et al., 1973). Their results generally indicated that sediment was the major transporting agent and that usually quantities of soluble nutrients in surface runoff water were small. However, in their studies subsurface discharge was not measured because it was either nonexistent or not readily measurable. A 2-year study by Minshall et al. (1969) showed that the average annual base flow from streams in southwestern Wisconsin was 60% of total annual stream flow and that the annual discharge of N in the base flow was about one-fourth of that discharged in surface runoff. Saxton et al. (1971) reported that average annual base flow from four Missouri Valley loess research watersheds was 33 to 89% of the total stream flow, depending on watershed treatment. Since this subsurface discharge was derived from percolation through the soil profile, it may have contained soluble fertilizer. The purpose of our 5-year study was to determine the amount of soluble N being discharged by the subsurface flow from four differentially fertilized watersheds in southwestern Iowa.

WATERSHED DESCRIPTION AND MANAGEMENT PRACTICES

The watersheds are located in the Missouri Valley deep loess hills of western Iowa and northwestern Missouri. The loess cap over glacial till on the research watersheds ranges in depth from 5 m in the valleys to more than 24 m on the ridges. Most of the main and upland valleys have deeply incised channels that terminate upslope as an active gully head.

The deep loess soils are highly productive, which encourages farmers to intensively row crop. Soils on the four research watersheds are Typic Hapludolls, Typic Haplorthents, and Cumulic Hapludolls, which are fine silty, mixed, mesic with moderate to moderately rapid permeability. The watersheds' slopes range from 2 to 4% on the ridges and in the valleys, and 12 to 18% on the hillsides.

The nearly impermeable glacial till underlying the loess cap forms an important hydrologic boundary. Saxton et al. (1971) reported that percolated water moves nearly vertically to the saturated zone above the glacial till, then horizontally, to reappear as seepage in the gully channels. Soil moisture and ground-water storage capacities are large compared with the average annual percolation below the root zone; thus, considerable subsurface travel time is in-

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Table 1—Watershed description—size, crop, management practice, and annual application of N for 1960–1974, Treynor, Iowa

Watershed no.	Year	Area	Crop	Management practice	Nitrogen applied
		ha			kg ha^{-1} $year^{-1}$
1	1960–62	6.5	Corn (*Zea mays* L.)	Contour-conventional tillage	90
			Soybeans (*Glycine max* Merrill)	Contour-conventional tillage	0
		23.6	Clover (*Trifolium partense* L.)		0
			Alfalfa (*Medicago sativa* L.)		0
	1963	30.1	Corn	Contour-conventional tillage	90
	1964–68	30.1	Corn	Contour-conventional tillage	135
	1969–73	30.1	Corn	Contour-conventional tillage	448
2	1960–62	16.6	Corn	Contour-conventional tillage	90
			Soybeans	Contour-conventional tillage	0
		16.9	Oats (*Avena sativa* L.)		0
			Clover		0
			Alfalfa		0
	1963	33.5	Corn	Contour-conventional tillage	90
	1964–68	33.5	Corn	Contour-conventional tillage	133
	1969–73	33.5	Corn	Contour-conventional tillage	168
3	1960–62	9.7	Corn	Contour-conventional tillage	36
		33.5	Alfalfa-Brome (*Medicago sativa* L.-*Bromus inermis* Leysi)	Soil bank and pasture	0
			Oats	Pasture	0
	1963	43.2	Oats		0
			Alfalfa-Brome	Pasture	0
	1964–68	43.2	Alfalfa-Brome	Pasture	0
	1969–71	43.2	Alfalfa-Brome	Pasture	168
	1972–73	43.2	Corn	Contour-mulch tillage	168
4	1960–63	43.3	Corn	Level terraces, contour-conventional tillage	68
		17.3	Soybeans	Contour-conventional tillage	0
			Oats		0
			Milo (*Sorghum vulgare* Pers.)		0
			Clover		0
			Alfalfa		0
	1964–68	60.6	Corn	Level terraces, conventional tillage	106
	1969–71	60.6	Corn	Level terraces, conventional tillage	448
	1972–73	60.6	Corn	Terraces with pipe outlets, mulch tillage	168

volved. Percolation from areas near the stream channels was discharged sooner than that from upslope areas because of the shallower loess and shorter horizontal distances. As a result, the subsurface discharges measured during this study represent water percolated through the shallower profiles in the lower slope position during the study plus that which moved through the deeper profiles in the upper slope positions before the study.

Watershed size, cropping, conservation, and fertility management treatments for 1960 through 1973 are shown in Table 1. Adjoining watersheds 1 and 2 are 4.8 km south of adjoining watersheds 3 and 4.

Watersheds 1, 2, and 4 were cropped to corn (*Zea mays* L.) continuously from 1960 through 1973, and watershed 3 was in bromegrass (*Bromus inermis* Leysi) pasture from 1964 through 1971 and farmed with mulch-tilled corn in 1972 and 1973. Watersheds 1 and 2 were farmed on a field contour using conventional tillage and planting methods. Watershed 4 was level terraced from 1964 through 1971, 92% of the land area above terraces. These terraces had storage capacity of about 5 cm of surface runoff. The terrace system and tillage practice were changed in 1972. The terrace interval was doubled and underground pipe outlets were installed to prevent crop drowning in the terrace channels, and mulch-tillage corn planting was initiated. A subsurface field tile drained a 6.1-ha alluvial plain at the base of the slopes on watershed 4 for the entire study period.

Watersheds 1, 2, and 3 were fertilized with N at a rate of 448, 168, and 168 kg ha^{-1} $year^{-1}$, respectively, from 1969 through 1973. Watershed 4 was also fertilized at 448 kg ha^{-1} $year^{-1}$ in 1969, 1970, and 1971 but was fertilized with N at 168 kg ha^{-1} $year^{-1}$ in 1972 and 1973. The high rate of N fertilization, more than 2.5 times the recommended rate, was used on watersheds 1 and 4 to study the fate of fertilizer applied in excess of crop requirements. Most of the N was applied as anhydrous ammonia and chiseled into the soil to a 25- to 35-cm depth on a 100-cm row spacing, but about 50–100 kg/ha of the excessive rate was surface applied as granular ammonium nitrate.

Before initiating the watershed research project in 1964, each watershed had been farmed in smaller field units. The size, crops grown, and N fertilizer application varied considerably among years within each watershed. Available records showed that N fertilizer was only applied to corn from 1960 through 1963 (Table 1). The cropping and N fertilization information indicated that N probably had not been applied in excess of crop use and, therefore, probably did not contribute materially to subsurface discharges of NO_3-N during a 5-year period between 1969 and 1974.

FIELD SAMPLING AND LABORATORY ANALYSES

The main drainage channel of each watershed was instrumented with a broad-crested, V-notch weir and water stage recorder to determine rates and amounts of stream flow at the watershed outlet. Three recording rain gages on each watershed measured precipitation.

Water quality sampling of the subsurface discharge (base stream flow) was started in April 1969. Samples were first collected at gully headcut seepage sites (100 to 250 m upstream from the weirs) at monthly intervals from April 1969 through March 1971. Beginning in April 1971, the samples were taken weekly at the weir sites. From April 1969 through March 1974, 176 samples of subsurface discharge were collected from each watershed. All samples were stored at 4C immediately after collection to minimize chemical and microbiological conversion.

Laboratory analyses for NO_3-N and NH_4-N were by steam distillation with MgO and Devarda's alloy into boric acid and titrated with dilute H_2SO_4 (Bremner, 1965) for samples collected from April 1969 through June 1970. After June 1970, the NO_3-N and NH_4-N were determined by continuous flow colorimetric procedures (Bolleter et al., 1961; Henricksen and Selmer-Olsen, 1970).

RESULTS AND DISCUSSION

Precipitation and Subsurface Discharge

Monthly precipitation and subsurface discharge for the watersheds are shown in Fig. 1 and 2, respectively. Precipitation during each of the 5 study years (1969–1974, Table 2) was greater than the 105-year average annual precipitation (72.4 cm/year) measured at Omaha, Nebr. The 5-year average was 84.5 cm/year with small variation among the four watersheds.

The rates of subsurface discharge (base flow) for the four watersheds are shown in Fig. 2. Watersheds 1 and 2 (contour corn) had similar rates for each of the 5 years, except that watershed 2 had a higher rate during the last 6 months of the study period (Fig. 2). Watershed 3 (pasture) had rates similar to watersheds 1 and 2 in 1969, 1970, and 1971, but rates almost doubled in 1972 and were 1.5 times greater in 1973. This increase for watershed 3 in 1972 and 1973 was attributed to increased percolation from the management change to mulch-tilled corn in 1972. The subsurface discharge from level-terraced watershed 4 was about 1.5 times greater than that from watersheds 1 and 2 for all years. Water detention and increased percolation caused by the terrace system were the probable cause for the greater subsurface discharge.

Average 12-month subsurface discharges for the study years 1969–1974 (Table 2) were greater than those measured for 1964–1974. The 10-year average annual subsurface discharges for 1964–1974 were 7.7, 8.4, 11.0, and 17.0 cm, respectively, for watersheds 1, 2, 3, and 4. The above average amounts of subsurface discharge in 1973 contributed markedly to the high average annual values obtained for the 5-year water quality sampling period. The subsurface discharge rate increased significantly within a few months after above normal precipitation and changes in management practices (Fig. 2).

Soluble Nitrogen Discharges

The relationship between fertilizer nutrients applied to the soil and those measured in subsurface discharge in the stream channels is complicated by the variable subsurface travel times within the watershed. Field variables that influence this relationship include water movement characteristics of the loess profile, soil moisture contents, N content within the profile, crop use of water and N, and loess depth to the water table. Therefore, the subsurface discharges reflect water and nutrient percolation both before and during the study period.

In studies on watersheds 1 and 2 to determine the magnitude of NO_3-N movement within the soil profile, Schuman et al. (1975) showed an increase of 720 kg/ha of NO_3-N in the 1.8- and 6.1-m zone of watershed 1 over a 3-year period (1971 to 1974). This NO_3-N is below the corn root zone and is a potential pollutant to the groundwater and subsurface flow. Their data showed no increase in the NO_3-N below the crop root zone of watershed 2.

Nitrate-nitrogen (NO_3-N) in subsurface discharge was an important component of the total soluble N transport (Table 2). Subsurface discharges from each of the four watersheds accounted for 84% or more of the total annual stream discharges of soluble N. Of the total soluble N (NO_3-N + NH_4-N) discharges in subsurface flow, 95% was NO_3 (Table 2). Average annual discharges of NH_4 in subsurface flow were low for each of the watersheds, and concentrations were consistently below the 0.50-ppm upper limits for potable water quality proposed by the National Academy of Science-National Academy of Engineering (1973).

Figures 3 and 4 show monthly weighted concentrations and monthly discharge quantities of NO_3 in subsurface flow, respectively. Average monthly water weighted concentrations (Fig. 3) indicated that subsurface flow of NO_3 for watersheds 2 and 3 was below 13 ppm for the entire study period and below 5 ppm until 1973 and 1974. These two watersheds received annual N applications of 168 kg/ha. By comparison, NO_3 from watershed 1 which received 448 kg ha^{-1} $year^{-1}$ N exceeded 10 ppm for 33 of the 60 months sampled. The highest monthly concentration for watershed 1 was 42.5 ppm in May 1973. These data suggest that the N application rate had a pronounced effect on NO_3 concentration in subsurface discharges.

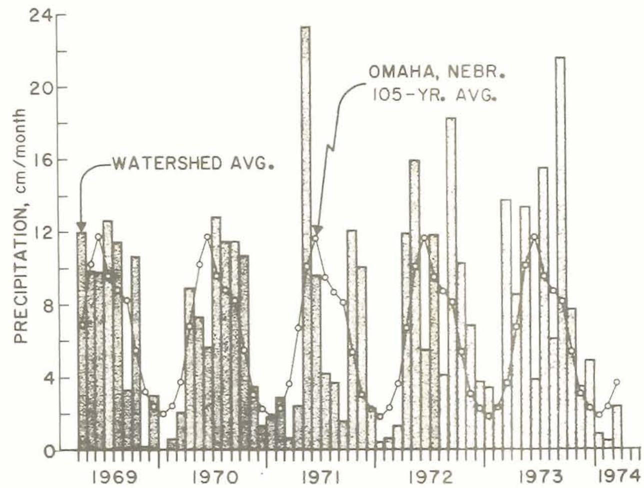

Fig. 1—Monthly precipitation during the study period (averaged for all watersheds) and the 105-year average precipitation, Treynor, Iowa.

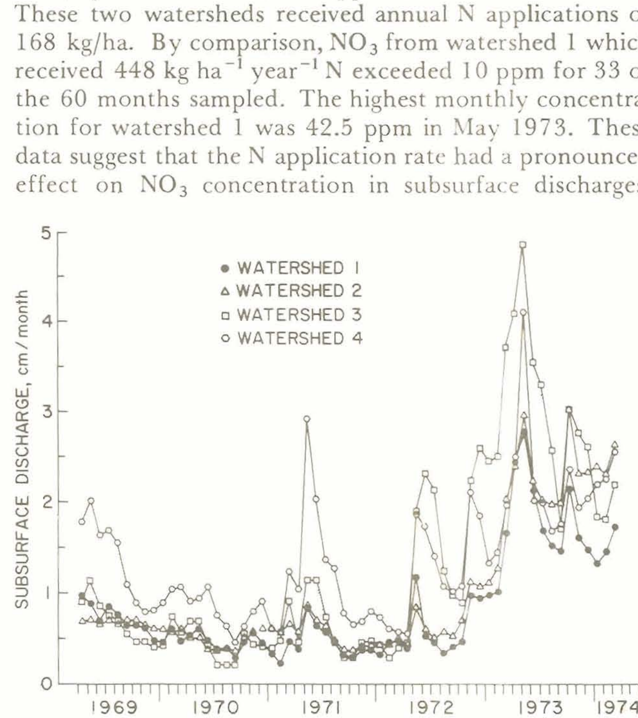

Fig. 2—Monthly subsurface discharge by watersheds, Treynor, Iowa.

Table 2—Annual precipitation and stream discharges of water and soluble N from agricultural watersheds, Treynor, Iowa

Watershed no.	Year	Precipitation	Water: Subsurface	Water: Surface	Water: Total stream	Soluble nitrogen: NO_3-N Subsurface	NO_3-N Surface†	NH_4-N Subsurface	NH_4-N Surface†	Total soluble N
		cm				kg/ha				
1	1969‡	73.69	6.50	1.96	8.46	9.71	1.09	0.33	0.06	11.19
	1970	80.04	5.61	5.44	11.05	4.83	1.46	0.03	0.41	6.21
	1971	73.81	5.23	12.55	17.78	3.64	1.31	0.07	2.11	6.74
	1972	86.21	6.78	3.84	10.62	7.80	0.65	0.08	0.28	8.81
	1973	105.94	20.78	6.63	27.41	65.45	1.79	0.22	0.33	67.79
	1974¶	3.38	4.47	0.20	4.67	12.19	0.00	0.08	0.00	12.27
60-month total		423.07	49.37	30.62	79.99	103.62	6.30	0.81	3.19	113.01
12-month average		84.61	9.87	6.12	16.00	20.72	1.26	0.16	0.64	22.60
2	1969‡	73.99	6.12	1.65	7.77	1.31	0.33	0.29	0.03	1.96
	1970	78.28	5.97	4.52	10.49	1.01	0.53	0.26	0.35	2.15
	1971	74.09	6.65	9.75	16.40	1.63	0.94	0.06	1.46	3.96
	1972	86.46	7.62	3.91	11.53	3.52	0.49	0.06	0.17	4.24
	1973	104.60	25.58	7.49	33.07	20.79	0.59	0.28	0.21	21.87
	1974¶	3.38	7.32	0.36	7.68	5.92	0.08	0.31	0.03	6.34
60-month total		420.80	59.26	27.68	86.94	34.18	2.96	1.26	2.25	40.52
12-month average		84.16	11.85	5.54	17.39	6.84	0.59	0.25	0.45	8.10
3	1969‡	72.06	6.20	1.07	7.27	0.42	0.30	0.33	0.07	1.13
	1970	73.30	5.56	0.94	6.50	0.45	0.17	0.15	0.09	0.86
	1971	75.74	7.21	3.86	11.07	1.76	0.96	0.07	0.43	3.21
	1972	95.22	15.80	2.11	17.91	6.94	0.43	0.12	0.08	7.57
	1973	103.20	37.01	2.72	39.73	40.09	0.93	0.40	0.17	41.59
	1974¶	3.71	5.82	0.03	5.85	6.02	0.00	0.11	0.00	6.13
60-month total		423.23	77.60	10.73	88.30	55.68	2.79	1.18	0.84	60.49
12-month average		84.65	15.52	2.15	17.67	11.14	0.56	0.24	0.17	12.10
4§	1969‡	72.44	12.19	0.30	12.49	11.01	0.11	1.26	0.02	12.40
	1970	73.13	10.13	0.33	10.46	6.10	0.15	0.28	0.03	6.56
	1971	76.40	14.02	1.73	15.75	26.80	0.16	0.09	0.58	27.63
	1972	95.25	14.60	10.72	25.32	28.72	3.26	0.10	0.37	32.45
	1973	102.39	30.51	8.48	38.99	85.46	2.59	0.35	0.35	88.75
	1974¶	3.53	6.40	0.08	6.48	17.50	0.02	0.15	0.00	17.67
60-month total		423.14	87.85	21.64	109.49	175.59	6.29	2.23	1.35	185.46
12-month average		84.63	17.57	4.33	21.90	35.12	1.26	0.45	0.27	37.10

† The 1969, 1970, and 1971 surface flow nutrient data also reported by Schuman et al. (1973).
‡ Measurements only April through December.
§ Subsurface water and subsurface soluble N include small amounts of discharge from subsurface tile flow.
¶ Measurements only January through March.

Average annual water weighted concentrations of NO_3 in subsurface discharge were 21.0, 5.8, 7.2, and 20.0 ppm N for watersheds 1, 2, 3, and 4, respectively. Increases in monthly discharges of NO_3 (Fig. 4) in 1972 and 1973 were caused both by increases in subsurface flow (Fig. 2) and NO_3 concentrations (Fig. 3).

The effect of terraces on NO_3 in subsurface flow was evaluated by comparing watersheds 1 and 4, both cropped to corn and fertilized with N at 448 kg ha^{-1} year^{-1} from 1969 through 1971. Nitrogen fertilization of these two watersheds before 1969 was not greater than corn crop use (Table 1) and probably did not contribute markedly to discharges of NO_3 in subsurface flow measured during the study. The initial NO_3 concentration measured in April 1969 before the two N application treatments were imposed was similar for both watersheds 1 and 4 (Fig. 3). However, the differences in the volume of subsurface

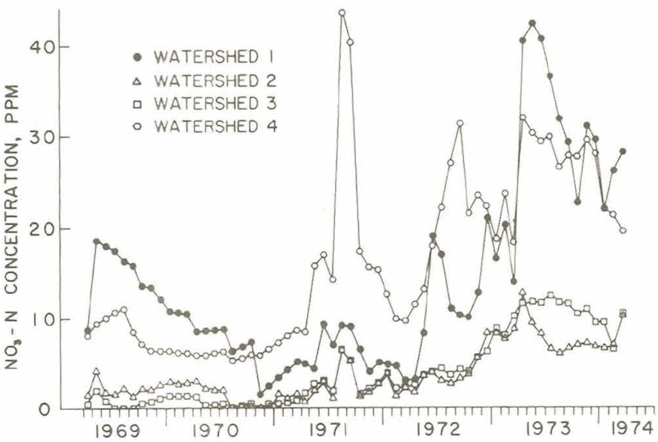

Fig. 3—Monthly average water weighted concentrations of nitrate-nitrogen in subsurface discharge, Treynor, Iowa.

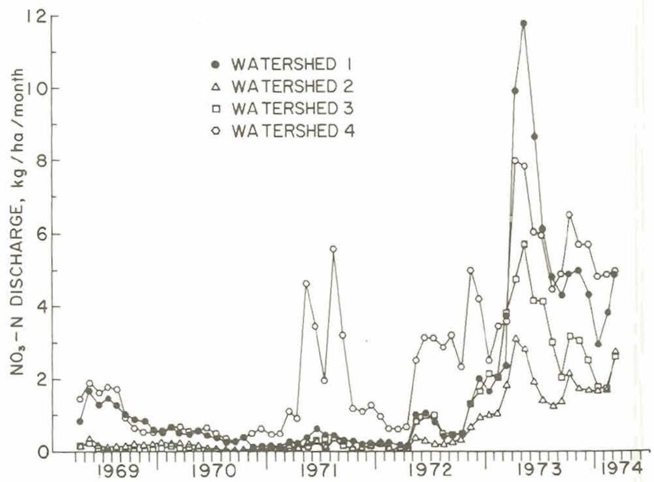

Fig. 4—Monthly quantities of nitrate-nitrogen in subsurface discharge, Treynor, Iowa.

Table 3—Nitrogen sources in streamflow relative to total transport

Watershed no.	Total N transport†	Nitrogen source		
		Surface runoff		Subsurface discharge¶
		Sediment‡	Water§	
	kg/ha	% of annual N discharge		
1	50.07	55	3	42
2	27.77	71	3	26
3	14.13	14	5	81
4	44.82	17	4	79

† Average annual for April 1969 through March 1974 study period.
‡ Includes organic forms of N associated with sediment discharge.
§ Soluble N forms in sediment-free filtered water.
¶ Soluble N in subsurface discharge (base streamflow).

flow for 1964 to 1969 were large. Saxton et al. (1971) reported 6.40- and 16.84-cm average annual subsurface flows for watersheds 1 and 4, respectively. They attributed this difference to detention of surface water by the terraces and subsequent percolation into the ground water. The underground pipe outlets installed in the terrace channels of watershed 4 in 1972 increased surface runoff and decreased subsurface flow in 1972 and 1973 as compared with previous years. This change in drainage pathways for watershed 4 decreased subsurface flow discharge of NO_3 as compared with that of previous years and that from watershed 1.

Changing watershed 3 from pasture to mulch-planted corn in 1972 increased subsurface flow and NO_3 discharges in 1972 and 1973. Data collected from watersheds 3 and 4 after the management changes were made were insufficient for conclusive evaluation of these management practices.

Table 3 shows the sources of N discharged to the total stream flow. The N associated with sediment in surface runoff was appreciable for those watersheds with management practices conducive to erosion (watersheds 1 and 2 vs. watersheds 3 and 4). The N transported with sediment is primarily organic and unavailable for immediate plant use but represents a potential source of plant nutrient as well as a surface water pollution source. Sediment N concentrations were similar for the two fertilizer application rates. Soluble N losses associated with surface runoff were low for each of the watershed management treatments, but varied with fertilizer application rates.

SUMMARY

The N in subsurface discharge and surface runoff was measured on four agricultural watersheds on Missouri Valley deep loess near Treynor, Iowa, from April 1969 through March 1974.

Subsurface discharge of water was a major portion (62 to 88%) of the average annual stream flow and varied depending on watershed treatment. Nitrate in subsurface discharge accounted for 84 and 95% of the average annual soluble N discharged by the stream flow.

Average annual water weighted concentration of NO_3-N in subsurface discharge for the 5-year study period was 5.8 ppm (6.8 kg ha^{-1} $year^{-1}$) for a continuously corn-cropped watershed farmed on the contour and fertilized with N at a rate of 168 kg ha^{-1} $year^{-1}$. In comparison, the average annual water weighted concentration of NO_3-N in subsurface discharge was 21.0 ppm (20.7 kg ha^{-1} $year^{-1}$) for a similarly managed watershed but fertilized with N at 448 kg ha^{-1} $year^{-1}$. A terraced watershed continuously cropped to corn and fertilized with N at an average annual rate of 336 kg ha^{-1} $year^{-1}$ had an average annual weighted NO_3-N concentration of 20.0 ppm (35.1 kg ha^{-1} $year^{-1}$). Subsurface NO_3 discharges were appreciably greater for the terraced watershed than for the contoured watersheds because of greater percolation through the loess profile.

The terrace system very effectively reduced surface runoff and erosion and, thus, greatly reduced N losses associated with sediment discharges as compared with the contoured watersheds. Sediment N concentrations were similar for the contoured watersheds fertilized with N at normal and high rates. The quantity and concentration of soluble N discharged in surface runoff were low for each of the four watersheds.

This watershed study showed that control of N pollution of stream flow from the Iowa and Missouri deep loess hills will require N fertilizer application rates that do not exceed crop needs and using conservation practices that jointly minimize soil erosion and deep percolation.

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