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Nitrates
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Soil Profile

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ABSTRACT

Nitrate movement within the 6.1-m soil profile of a watershed in southwestern Iowa, fertilized at 448 kg N/ha per yr, resulted in a 720-kg/ha increase in NO_3-N below the corn root zone during the 3-year study. The NO_3-N concentration of the baseflow from the watershed increased during this period, indicating that some of the leached NO_3-N reached the ground water. The watershed fertilized at the recommended N rate (168 kg/ha per yr) did not increase the quantity of NO_3-N below the corn root zone; however, some NO_3-N leaching did occur.

Between April 1971 and April 1974, the accumulation of NO_3-N in the profile of the excessively fertilized watershed moved from the 1.0- to 3.1-m depth. Three-fourths of NO_3-N movement occurred between June 1972 and April 1973 when 80 cm of precipitation caused 21 cm of percolation below the corn root zone (183 cm). The watershed fertilized with 168 kg N/ha per yr did not show any zones of significant NO_3-N accumulation in the soil profile at any of the sampling dates.

The depth to the water table on the lowest contour sampled on the excessively fertilized watershed was 4.6 and 4.9 m in April 1973 and April 1974, respectively. The average NO_3-N concentration for these two sampling dates at the water table depth increased from 3.7 to 12.9 ppm. The average NO_3-N concentration at the water table depth on the normally fertilized watershed was 2.0 and 4.5 ppm in April 1973 and April 1974, respectively, with a water table depth of 3.0 m.

Additional Index Words: **percolation, ground water, nitrogen.**

MUCH PUBLIC ATTENTION has been focused on environmental quality as influenced by agricultural practices, including fertilizer use. Considerable interest has been centered around the nitrate (NO_3^-) content of water because its accumulation is hazardous to human health (Gruener and Schuval, 1970). Viets (1971) points out that circumstantial evidence indicates water-quality deterioration could be associated with increased fertilizer use; however, positive evidence is not available.

Using fertilizers is necessary to meet our food demands, a need which will be even greater in the future. In 1971, the U.S. used almost 7.3 million metric tons of nitrogen (N) fertilizer and 1.9 million metric tons of phosphorus (P). Ibach (1966) estimated that by 1980 the U.S. will need 11.1 million metric tons of N and 2.6 million metric tons of P to meet its fertilizer requirements for food production. If poorly managed, this large amount of fertilizer could be a great potential for loss by leaching or overland movement of surface runoff and associated sediment.

Linville and Smith (1971) found in Missouri that corn fertilized at 112 and 134 kg N/ha per yr for 6 to 20 years showed no evidence of NO_3^- movement below the 244-cm depth. However, a large accumulation of NO_3-N was found below 244 cm when 168 kg N/ha per yr or more was applied.

Pratt et al. (1972) concluded that if fertilizer N application did not exceed crop needs, no NO_3^- would be available for leaching. Power (1970) similarly concluded that as long as the fertilizer N rate was less than the rate of total N removed by the harvested crop, it is unlikely that NO_3^- will leach.

The available data on nitrate movement in soil usually involves laboratory soil column studies or studies that char-

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acterize the surface 1 to 2 m and, generally, represent either a single sampling or set of samples taken at the beginning and/or end of the study (Nelson and MacGregor, 1973; MacGregor, Blake and Evans, 1974; Lund, Adriano and Pratt, 1974). Other data available represent a time period of a few days or months and soil cores taken to 3.0 m or less (Olsen et al., 1970; Felizardo, Benson and Cheng, 1972; Endelman et al., 1974). Wagner (1962, 1965) used porous ceramic cups to sample the soil water at 15-, 30-, 61-, 91-, and 122-cm depths in the profile to characterize NO_3-N leaching over a period of 35 months. The study by Wagner (1965) follows the NO_3-N movement with time; however, sample depth intervals were not small enough and the relationship between the porous cup technique and the standard soil-coring technique has not been established (England, 1974). Detailed data are needed that follow with time the NO_3^- movement through the soil to the water table. This type of data is not generally available and is necessary for developing a model for describing ion movement through the soil.

The objective of this study was to obtain information on the extent and rate of NO_3^- movement within a deep loess soil under a normal and excessive N application, with precipitation as the only soil water source.

MATERIALS AND METHODS

Soil profile sampling sites were located on 30-ha (Watershed #1) and 33-ha (Watershed #2) watersheds in southwestern Iowa (Fig. 1), 18 km east of Council Bluffs, Iowa. The topography of the area is characterized by a loess cap, which ranges in thickness from 25 m on the ridges to > 5 m in the valleys and is underlain by till. A water table lies just above the loess-till interface. 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 valleys to 12 to 18% on the sides.

Both watersheds were cropped to continuous corn with approximate contour planting as the only conservation practice. Nitrogen was spring-applied to Watershed 1 and Watershed 2 at the rate of 448 kg/ha per yr (92% as anhydrous ammonia and 8% as NH_4NO_3) and at 168 kg/ha per yr (80% as anhydrous ammonia and 20% as NH_4NO_3), respectively, from 1969 to 1974. These N application rates were selected; however, actual amounts applied varied slightly, with an average application of 447 and 178 kg/ha per yr for Watersheds 1 and 2, respectively (Table 2). A zero fertilizer treatment was not included in this study because nitrogen budgeting was not an objective of the research, and much literature is available on soil profile studies to assess mineralization and denitrification. As stated earlier, the purpose of the study was to follow with time NO_3-N movement through the soil profile of a normally fertilized watershed (the recommended N fertilizer application rate was considered the control) and one fertilized at 2.5 × the recommended rate.

Plant and grain samples were collected and analyzed for total N by the method described by Schuman, Stanley, and Knudsen (1973). These data, along with forage and grain yields, were used to calculate N removal by the crop.

The watersheds were instrumented to measure precipitation (Fig. 2) and surface runoff. The long-term annual precipitation for this area is 72 cm. Percolation amounts were estimated using hydrologic data and a computer model, described by Saxton, Johnson, and Shaw (1974). Mean hydrologic data for the two watersheds were used to estimate the percolation. Precipitation-derived N for the watersheds is 7.26 kg/ha/yr (Schuman and Burwell, 1974). Average annual surface runoff losses of soluble

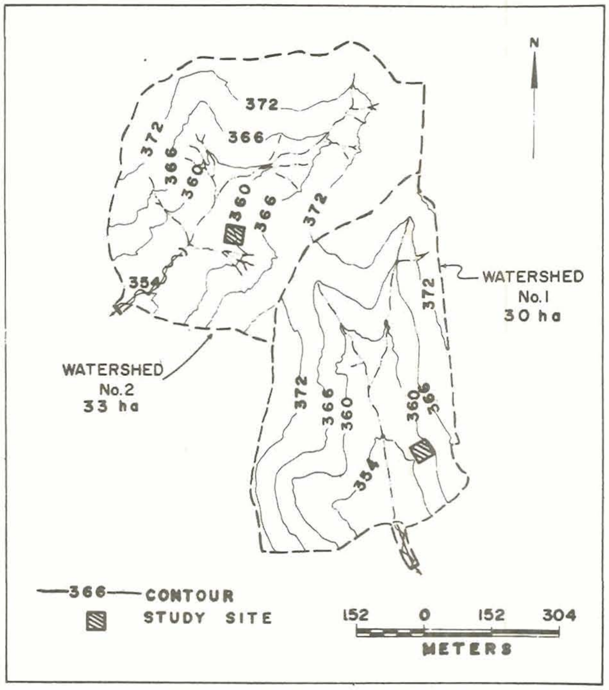

Fig. 1—Location of soil core sites on Watersheds 1 and 2, Treynor, Iowa.

N for Watersheds 1 and 2 are 3.05 and 1.89 kg/ha/yr, respectively (Schuman et al., 1973).

Continuous soil cores, 0 to 6.1 m deep, were sampled on Watershed 1 on 13 April and 10 November 1971; 27 March and 13 June 1972; 24 April 1973; and 8 April 1974; and on Watershed 2 on 13 June 1972; 24 April 1973; and 8 April 1974. These cores were subdivided into 7.6-cm sections, placed in airtight, plastic vials, frozen in dry-ice storage chests, and transported to the laboratory. The samples were then dried at 65C, ground, and extracted with 1*N* KCl. Nitrate-nitrogen was analyzed on the extract using continuous-flow colorimetric procedures (Henriksen and Selmer-Olsen, 1970). The NO_3-N concentrations are expressed on a dry-soil basis.

The average elevations for the sample sites on Watershed 1 were: 356.7 m, 358.1 m, 359.6 m, and 361.1 m. The elevations for sample sites on Watershed 2 were: 359.4 m, 360.4 m, 361.5 m, and 362.7 m. The bottom contour was located so that the lowest sampling depth was 1 to 2 m above the saturated zone in 1971. The remaining contours were located at a constant horizontal interval upslope. The core sites formed a grid pattern with about 12.5 m between sites in each direction. The grid on Watershed 1 was on a 12%, west-facing slope and that on Watershed 2 on an 8%, northwesterlyfacing slope. Agronomic management on the sampling area was the same as followed on the watershed.

All 16 core sites were sampled in April 1971 and June 1972. The number of cores taken on other sampling dates is shown on the profile graphs of the data (Figs. 3 and 4). Each profile is an arithmetic mean of the cores sampled, and the confidence limits are (±) one standard error of the mean ($\sigma_{\bar{x}}$).

The grid configuration was used to represent the various slopes on the watershed. The arithmetic mean of the sites was considered representative of the entire watershed, so the data could be used also in developing a model for describing NO_3^- movement through the soil profile. This configuration was selected to evaluate the NO_3^- variability in the soil profile between core sites and between contours. The data will be further evaluated statistically to define the variability between sites and contours at various soil depths and to determine the optimum number of cores needed to adequately characterize the soil profile for assessing chemical differences.

Table 1—Precipitation, percolation, and NO3-N quantities in the profile of Watersheds 1 and 2 at the sampling dates

	1971				1972				1973		1974
	13 April		10 Nov		27 Mar		13 June		24 April		8 April
Watershed 1											
Precipitation (cm)*		60.4		10.2		27.6		79.8		86.4	
Estimated percolation below the 183-cm depth (cm)*		5		2		5		21		29	
Total NO_3-N in 6.1-m profile (kg/ha)†	525		990		900		1,375		1,080		1,130
NO_3-N below 183-cm depth (kg/ha)	250		405		480		590		870		970
Watershed 2											
Precipitation (cm)*								79.8		85.1	
Estimated percolation below the 183-cm depth (cm)*								21		29	
Total NO_3-N in 6.1-m profile (kg/ha)†							640		280		475
NO_3-N below 183-cm depth (kg/ha)							365		215		330

*Data represent the precipitation and percolation that occurred between sampling dates

†Amounts are all based on 6.1-m profiles; where data were not obtained to 6.1 m, the last value was used as a constant for remaining depths. Data on profiles obtained to 6.1 m show that the NO_3-N is fairly constant after 4.6 m.

Table 2—Nitrogen fertilizer application and crop removal for Watersheds 1 and 2, Treynor, Iowa.

Year	Time of N application	Watershed 1		Watershed 2	
		N applied	Crop removal	N applied	Crop removal
		kg N/ha			
1971	12-24 April	443	245		
1972	5-14 April	419	180	180	156
1973	28 April-12 May	478	200	175	159

RESULTS AND DISCUSSION

Watershed 1—448kg N/ha per yr

The measured NO_3-N profiles for the six sampling dates are shown in Fig. 3. Nitrate-nitrogen amounts in the 6.1-m profile and associated precipitation and percolation are shown in Table 1 and Fig. 2. Between April 1971 and April 1974, the NO_3-N bulge moved from the 1.0-m to 3.1-m depth. A large percentage (75%) of this movement occurred between the June 1972 and April 1973 sampling dates. During this period, the precipitation was 80 cm and percolation of 21 cm was estimated passing below the rooting depth (183 cm). The NO_3-N profiles (Fig. 3) show the increase in NO_3-N concentration with depth and time, especially between 1.5 and 4.5 m. The high NO_3-N concentrations near the soil surface for the June 1972 sampling reflect the recent fertilizer application.

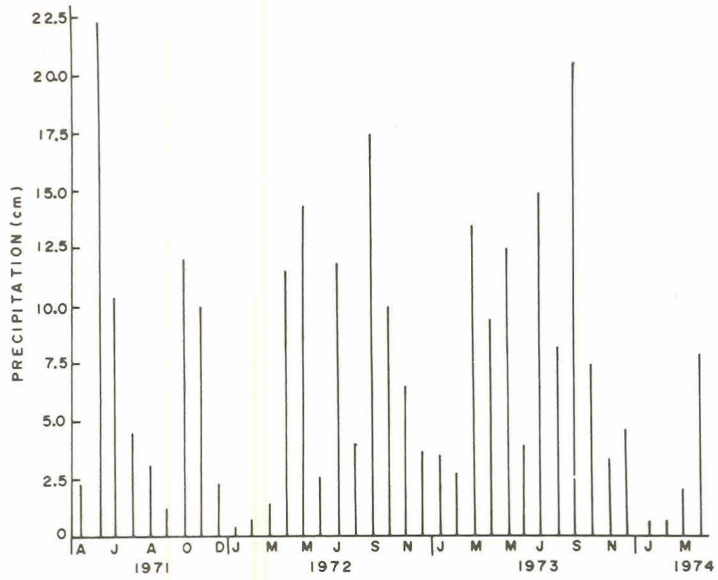

Fig. 2—Precipitation distribution (April 1971–April 1974) at research watersheds, Treynor, Iowa.

Large amounts of percolation during 1973 raised the saturated zone 2 to 3 m. The depth to the water table along the lowest contour in April 1973 and April 1974 was only 4.6 and 4.9 m, respectively. The average NO_3-N concentration (soil basis) for these four core sites on the lowest contour at the water table depth was 3.7 and 12.9 ppm for April 1973 and April 1974, respectively. This indicates the applied N was reaching the saturated zone above the glacial till. The saturated zone performs as a ground-water aquifer by discharging into local streams as a baseflow. The baseflow is a significant part of the total streamflow in this area.

The measured NO_3-N concentration of the baseflow from Watershed 1 has increased in the past several years, which is another indication that some of the leached NO_3-N, as indicated by the profiles of Fig. 3, reached the ground water and moved laterally into the streamflow.

The NO_3-N in the 6.1-m profile increased from 525 kg/ha to 1130 kg/ha during the study period (Table 1). The amount of NO_3-N below the root zone increased from 250 kg/ha to 970 kg/ha during the study. This 605-kg/ha increase in the total 6.1-m profile represents the difference between fertilization and crop removal for the 3-year study (Table 2). During the 3 years crop N removal was 625 kg/ha, while 1340 kg N/ha was actually applied. Therefore, NO_3-N remaining in the profile and N removed by the corn is equivalent to 92% of the N applied as fertilizer. The 8% not accounted for represents the maximum that may have leached into the water table and removed by baseflow, surface runoff, and denitrification. No attempt has been made to account for N mineralization. If N loss during anhydrous-ammonia application were considered, the percentage of N unaccounted for would be even smaller; however, the objectives of the study did not include trying to establish a nitrogen balance.

The greatest amount of water percolation below the root zone occurred between the April 1973 and April 1974 samplings. The 29 cm of estimated percolate (Table 1) did not move the NO_3-N accumulation significantly; however, it did leach the upper 3.0 m of the profile and decreased the average NO_3-N concentration by one-half between 1.5 and 3.0 m and increased the concentration below the 3.2-m depth.

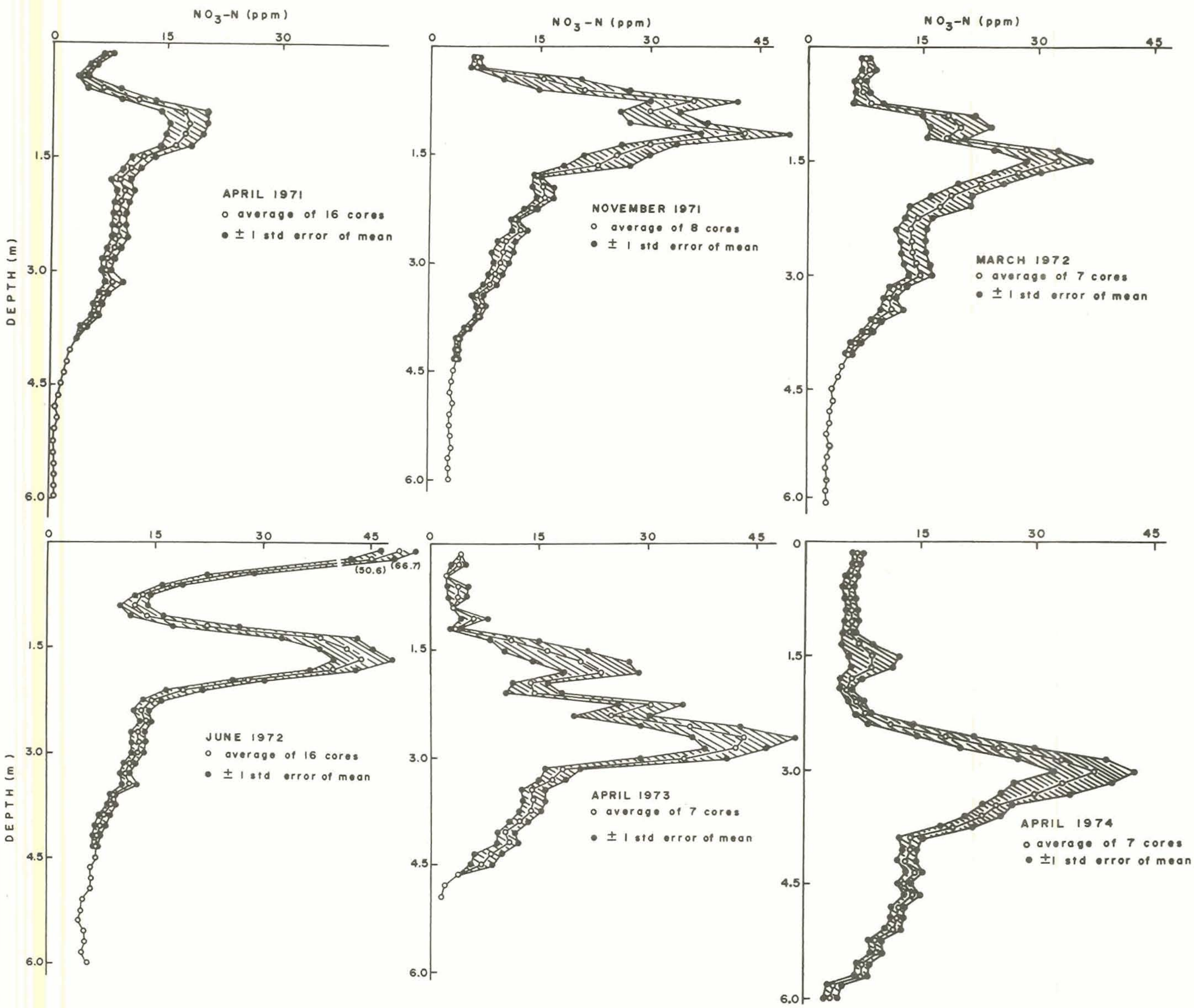

Fig. 3—Average nitrate-nitrogen concentration (dry soil basis) and distribution in 6.1-m soil profiles of Watershed 1 (fertilized at 448 kg N/ha per yr) at six sampling dates, Treynor, Iowa.

The data clearly indicated that NO_3^- leaching below the root zone of the crop can occur when excessive rates of fertilizer are applied and water percolates through the rooting zone. Once N has moved below the crop root zone (about 183 cm for corn), it is potentially a ground-water pollutant. Under the climatic, soil, and crop conditions studied, the nitrogen application rate of 448 kg/ha/yr, which is 2.5× the recommended rate, is a hazard to water quality in groundwater and streamflow.

Watershed 2—168kg N/ha per yr

Samples were taken on this watershed only in June 1972, April 1973, and April 1974. The average of the sampled profiles is shown in Fig. 4; the average NO_3-N concentration, precipitation, and percolation data are given in Table 1 and Fig. 2. No significant zones of NO_3-N accumulation were evident in any of the sampled profiles on the three sampling dates. The June 1972 data show the presence of the spring-applied N fertilizer (Fig. 4; Table 1) for the 1972 corn crop.

The quantity of NO_3-N did not increase significantly below the root zone (183-cm depth). During the 22-month period, 318 kg N/ha has removed by the corn crops and 175 kg/ha applied in 1973. Beginning with the 640 kg/ha measured in the 6.1-m profile in June 1972, the budgeted amount showed an expected amount of 500 kg/ha in April 1974 and 475 kg/ha was measured. Therefore, 95% of the N applied can be accounted for as NO_3-N remaining in the profile and as N removed by the corn crop. The soil N contribution was not evaluated.

The average NO_3-N concentration (soil basis) at the water table depth for the four cores on the lowest contour was 2.0 ppm and 4.5 ppm for April 1973 and April 1974, respectively. The water table depth was 3.0 m at both sampling dates. Therefore, even when fertilized at the level of plant removal, the NO_3-N concentration has increased

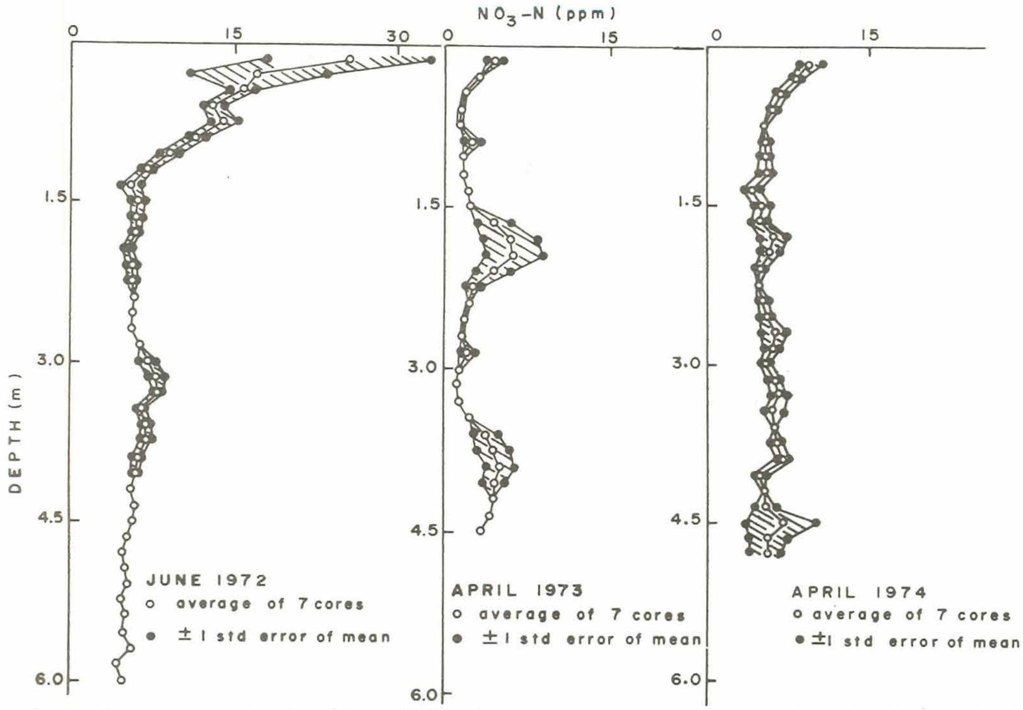

Fig. 4—Average nitrate-nitrogen concentration (dry soil basis) and distribution in 6.1-m soil profiles of Watershed 2 (fertilized at 168 kg N/ha per yr) at three sampling dates, Treynor, Iowa.

slightly at the 3.0-m depth. Baseflow NO_3-N concentrations fluctuated with a slightly increasing trend. Nitrate-nitrogen below the root zone (183-cm depth) has varied but not consistently increased during the study period (Table 1).

SUMMARY

Nitrate movement was considerable within the 6.1-m soil profile of a watershed fertilized at 448 kg N/ha. The NO_3-N concentration at the water table was in excess of 10 ppm NO_3-N (soil basis) on the April 1974 sampling. An increase of 605 kg N/ha was measured in the total 6.1-m profile during the 3-year study.

Nitrate accumulation was minimal in the soil profile of the watershed fertilized at the annual recommended rate of 168 kg N/ha. The NO_3-N concentration increased from 2.0 to 4.5 ppm at the groundwater depth. The total amount of NO_3-N in the 6.1-m profile did not increase significantly during the study period.

Precipitation during the study period was average to above average for southwestern Iowa (Table 1, Fig. 2); however, much of the precipitation occurred in low-intensity, long-duration rains, which caused above-normal percolation. Under these climatic, crop, and soil conditions, the study has shown that excessive N fertilization can cause NO_3-N to build up in the soil profile below the crop root zone and move into the groundwater and subsurface streamflow.

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