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Nitrate-Nitrogen Leached Below the Root Zone During and Following Alfalfa[1]

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ABSTRACT

The nitrate-nitrogen (NO_3-N) contribution to subsurface drainage water by irrigated alfalfa (*Medicago sativa* L.) in crop rotations was evaluated by measuring the soil water flux and NO_3-N concentration below the root zone of alfalfa and crops following alfalfa with and without additional nitrogen fertilization. Under alfalfa grown on Portneuf silt loam (Durixerollic Calciorthid) with a permeable hardpan, 44 kg NO_3-N ha^{-1} $year^{-1}$ moved below the root zone at concentrations between 3 and 15 ppm. During the growing season following alfalfa, 85–96 kg NO_3-N ha^{-1} $year^{-1}$ moved below the root zone under nonfertilized bean (*Phaseolus vulgaris*) crops at concentrations between 1 and 83 ppm. The second growing season after alfalfa, 17–29 kg NO_3-N ha^{-1} $year^{-1}$ at 3–15 ppm NO_3-N moved below the root zone of nonfertilized bean and wheat (*Triticum aestivum* L.) crops. A field planted to corn (*Zea mays* L.) and fertilized with 200 and 170 kg N ha^{-1} the first and second year after alfalfa lost 153 and 108 kg NO_3-N ha^{-1}, respectively, from leaching. Leachate N concentrations varied from 1 to 64 ppm. Unfertilized corn lost 60 and 17 kg NO_3-N/ha the first and second year after alfalfa, respectively, at leachate concentrations of 1–31 ppm. The NO_3-N concentration in the soil solution below only slightly permeable hardpan areas was between 13 and 67 ppm, but only 10–23 kg ha^{-1} $year^{-1}$ moved below the root zone because of the lower water flux through the hardpan. Comparing these results with previous data for the same area suggests that considerable denitrification and/or dilution takes place at the water table interface since 5.2 ppm NO_3-N was the highest concentration measured in the subsurface drainage water with an average of 3.2 ppm NO_3-N. The NO_3-N contributed by alfalfa in the crop rotation was estimated to equal just half of that accounted for in the subsurface drainage in a previous study on the same irrigated tract.

Additional Index Words: **denitrification, subsurface drainage water, irrigation return flow, pollution, nutrient load, N fertilizer leaching, green manure.**

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The potential health hazards of nitrate nitrogen (NO_3-N) in surface and subsurface water has drawn increased public attention to agricultural practices as a possible source of nonpoint source NO_3-N water pollution. Because high NO_3-N concentrations in drinking water are considered to pose health hazards to livestock and humans, particularly infants, the U.S. Public Health Service has set a maximum of 10 ppm NO_3-N as the standard for drinking water (13). The high NO_3-N levels found in some areas may come from any of several sources, and the sources must be idenified if management practices are to be changed to reduce nonpoint NO_3-N sources entering subsurface, and eventually, surface waters.

Nitrate leaching rates are a function of irrigation and precipitation rate and timing, nitrogen fertilizer application rate and timing (1, 6), and the crops grown (9, 12). Alfalfa (*Medicago sativa* L.) removes water and NO_3-N from deeper in the soil profile than other crops (2, 7, 11), and is an excellent NO_3 scavenger for reducing the amount of NO_3-N leaching following a high N fertilized crop, or where alfalfa crops have received excessive N fertilizer applications (7). This characteristic has been utilized in renovating high N waste waters.

When an alfalfa crop is plowed under, the plant roots are killed and N is mineralized from the decomposing plant material. A 225-kg/ha ammonium nitrate-N application produced about the same results on corn (*Zea mays* L.) yield as did N released from a 3-year-old alfalfa stand with about 0.1 m of early spring growth, plowed under just prior to planting the corn crop. The above-ground early spring growth and surface residue accounted for only half of the N taken up by the corn. The remainder apparently came from the roots and other N added to the soil during the 3 years of alfalfa growth (2). However, no data are available for the NO_3-N concentration in the soil solution moving below the root zone following the killing of an alfalfa crop.

The preplant irrigation of bean and corn crops leaches recently mineralized NO_3-N below the root zone before the crop is planted, thus, subsequent crops will have shallower root profiles than alfalfa—initially and possibly during the entire growing season. Therefore, the subsequent crops will not extract NO_3-N throughout the original alfalfa root profile during the entire growing season.

The purpose of this study was to measure the NO_3-N concentration and flux below the root zone during and following alfalfa crops and to estimate the contribution of alfalfa to the total NO_3-N load in the subsurface drainage for a large irrigation tract.

METHODS

Seven sites, six of which had been cropped to alfalfa the previous year, were selected in south central Idaho for intensive NO_3-N concentration and water content measurements (Table 1). All sites were on Portneuf silt loam (Durixerollic Calciorthid). The study area yearly precipitation average is 210 mm. The major crops in this irrigated area are alfalfa (19% of total area), dry beans (*Phaseolus vulgaris*) (18%), small grains (16%), pasture (11%), sugar beets (*Beta vulgaris* L.) (10%), and corn (7%). The remaining 19% is in miscellaneous crops, town sites, farmsteads, roads, etc.

Site 1 was in second-year alfalfa during the 1976 growing season. After the third cutting, the alfalfa was allowed to grow to a height of 0.1–0.2 m before it was crowned (a means of killing the crop by cutting the root off just below the soil surface with a heavy cultivating blade) in late October. The site was later plowed, and planted to dry beans in the spring of 1977. Site 2 was located in a field where the alfalfa had been killed in the fall of 1975 by the same crowning and plowing procedure. Dry beans were planted in 1976 and spring wheat (*Triticum aestivum* L.) was grown in 1977. No nitrogen fertilizer was applied to either crop. Sites 1 and 2 were 400 m apart on the same farm. Sites 3 and 4 were sprayed with 2,4-D [2,(4-dichlorophenoxy) acetic acid] in the fall of 1975 to kill the 2-year-old alfalfa stand and were then plowed the next spring. Dry beans were grown on both sites in 1976 and 1977 without N fertilization. These sites were 300 m apart in the same field. Site 5 was in alfalfa, planted in 1976, with a companion crop of peas (*Pisum sativum* L.) adjacent to site 4, but was sampled only in 1977. The second-year alfalfa, on sites 6 and 7, was crowned in the fall of 1975 and plowed and planted to corn in 1976 and 1977. The two sites were next to each other in the same field, but site 7 (a 10 by 15 m plot) did not receive N fertilizer during the study period. Site 6 received 110 kg N ha^{-1} as ammonium nitrate plowed down on 26 Apr. 1976, and 60 and 30 kg N ha^{-1} on 23 July and 2 Aug. 1976, respectively, as ammonia applied in the irrigation water. On 3 May 1977, 170 kg N ha^{-1} as ammonium nitrate were applied to site 6. Corn is only a minor crop in this area and, consequently, did not receive the emphasis that beans did.

All sites, except 5, were sampled at monthly intervals from late April to late December 1976. No samples were taken in January 1977 because the soil was frozen. During 1977, all seven sites were sampled monthly from February through May and were then sampled every 2 weeks until the end of September and once again at the end of October.

Soil samples were taken in 0.25-m increments to a depth of 2.0 m. A subsample was taken from each larger sample for moisture content determination on an oven-dry basis (105°C) and the remainder was air dried, ground, and stored for later analysis. The NO_3-N concentrations were determined on saturated soil extracts made from the air-dried soil samples, using a NO_3 electrode (8). The soil solution NO_3-N concentrations were then calculated from the original moisture contents and the saturation extract moisture content and NO_3-N concentration.

In order to estimate the NO_3-N variability, unpublished data from a previous study where three irrigation treatments were replicated four times and each plot was sampled in duplicate, were analyzed for standard deviation. The samples taken from the same depths of the same soil as for this study had NO_3-N standard deviations (12 values) ranging between 26 and 52% of the mean with an average of 38%. No N treatments were applied in that study.

Unsaturated hydraulic conductivity values for each soil sample were determined from tables derived for Portneuf silt loam. These values for the 1.5- to 2.0-m depth in the soil profile have a standard deviation of about 10% of the mean at any given moisture content (10).

The NO_3-N concentrations and the unsaturated soil water flow rates were then used to calculate the NO_3-N flux for the 1.50 to 1.75- and 1.75 to 2.00-m depth increments. The mean of the two NO_3-N fluxes on each sampling date was used to calculate the NO_3-N movement below the 2-m depth for each site and each sampling period. There is probably very little activity that would alter the NO_3-N concentration in this depth, since it is well drained at all sample sites and is below the profile hard zone which restricts most root growth.

Alfalfa is cut for hay on about 20 June, 5–10 August and 5–25 September and will be irrigated five to nine times during the summer in this area. Beans are preplant-irrigated in late May and planted in early to mid-June. They are usually watered in late June and at 7- to 10-day intervals through early to mid-August, depending on variety. Small spring grains are usually irrigated three or four times with the last irrigation being in late June or early July. Corn is planted in early to mid-May, usually following a preplant irrigation. Corn is irrigated five to nine times with the last irrigation being in late August.

The results of this study were then compared with the results of an earlier study which dealt with the NO_3-N concentration and net outflow in the subsurface drainage water for this same irrigation tract (3, 4).

RESULTS AND DISCUSSION

The NO_3-N concentrations below the site 1 root zone (1.5–2.0 m) ranged from 3 to 15 ppm (Table 2) during 1976. The cumulative NO_3-N leached below the root zone remained below 5 kg ha^{-1} through June and then increased to 44 kg NO_3-N ha^{-1} by the end of 1976 (Fig. 1A). The soil solution NO_3-N concentration below the root zone remained low until June 1977, and then increased sharply and remained high through the end of the sampling period. The NO_3-N flux below the root zone also remained low through May 1977, increased

Table 1—Deep percolation and NO_3-N data for the 1.5–2.0 m depths.

						NO_3-N concentration in drainage							
	Crops			Deep percolation		1976			1977			NO_3-N leached	
Site	1975	1976	1977	1976	1977	Min	Max	Mean†	Min	Max	Mean†	1976	1977
				mm		ppm						kg/ha	
1	Alfalfa	Alfalfa	Beans	680	460	3	15	6	1	81	21	44	96
2	Alfalfa	Beans	Wheat	580	350	6	83	15	3	21	8	85	29
3	Alfalfa	Beans	Beans	310	150	7	60	28	3	34	11	87	17
4	Alfalfa	Beans	Beans	70	40	13	50	32	12	58	32	23	12
5		Peas‡	Alfalfa	§	30	--	--	--	21	67	38	‡	10
6	Alfalfa	Corn + N	Corn + N	550	450	1	64	28	16	63	24	153	108
7	Alfalfa	Corn	Corn	480	390	1	31	13	2	15	4	60	17

† Weighted means for the calendar year.
‡ Alfalfa was seeded with a pea nurse crop in 1976.
§ Samples were not taken on this field in 1976.

rapidly until late September, and leveled off as the soil moisture flux decreased with the termination of irrigation about 1 September. The total NO_3-N leached below the root zone during the sampling period was 140 kg ha^{-1} (44 kg ha^{-1} in 1976 and 96 kg ha^{-1} in 1977) at this site.

The NO_3-N concentration and flux patterns below the root zone at sites 2 and 3 for 1976 were similar to those at site 1 during 1977 (Fig. 1A, 1B and Table 2), the first year after alfalfa. High NO_3-N concentrations below the root zone of sites 2 and 3 early in 1977 appear to be carry over from the previous year, however, the water fluxes at this time of year were low enough that the net NO_3-N flux below the root zone was not significant. Once irrigation water started moving through the profile, the second year after alfalfa (July 1977), NO_3-N concentration decreased below 10 ppm and contributed less to the net NO_3-N outflow.

Sites 4 and 5 had a harder, less conductive subsurface layer (0.3–1.0 m depth) than at the other three sites that restricted water movement (10). Low total NO_3-N movement on these two sites (Fig. 1B) resulted from low water fluxes through the hard layer in the upper profile, even though the measured NO_3-N concentrations below the root zone were considerably higher than for the same crops grown where the hard pan was more conductive (Table 2). Devitt et al. (5) obtained the same results on layered soils with restrictive zones in the profile. They suggested that reducing conditions caused denitrification for short periods after irrigation in the zone above the restrictive layers. The more restrictive layers also hold water and NO_3-N within the root zone longer, allowing roots greater opportunity to extract NO_3-N from the soil solution before it moves below the root zone.

Table 2—Soil solution NO_3-N concentration in the 1.5 to 2.0-m depth increments.

Sample date	Sample sites 1	2	3	4	5	6	7
	NO_3-N ppm						
1976							
30 Apr.	3	6	7	13		1	1
31 May	4	8	15	17		4	7
30 June	7	17	12	44		21	22
30 July	8	25	28	34		17	22
18 Aug.	5	71	45	40		51	31
17 Sept.	15	83	60	50		64	30
11 Oct.	9	52	37	49		55	24
22 Nov.	8	23	30	39		31	15
22 Dec.	12	54	43	56		22	10
1977							
14 Feb.	4	21	22	28	57	24	5
14 Mar.	1	10	21	32	37	26	9
18 Apr.	1	10	34	37	39	19	12
9 May	1	14	9	12	25	20	2
1 June	21	13	10	19	21	56	4
20 June	9	12	9	15	34	42	10
6 July	17	12	4	58	48	33	15
19 July	24	4	7	32	37	36	5
1 Aug.	81	3	3	40	36	35	12
15 Aug.	70	8	3	29	45	63	12
29 Aug.	50	4	5	28	42	29	11
12 Sept.	30	4	6	21	39	23	3
26 Sept.	37	5	7	38	67	19	6
31 Oct.	41	3	8	28	48	16	3

Site 6, which received 200 kg N ha^{-1} in 1976 and 170 kg N ha^{-1} in 1977, lost 153 kg NO_3-N ha^{-1} in 1976 and 108 kg NO_3-N ha^{-1} in 1977 (Fig. 1C) below the root zone at concentrations of from 1 to 64 ppm. The nonfertilized plot (site 7) lost 60 kg NO_3-N ha^{-1} in 1976 and 17 kg NO_3-N ha^{-1} in 1977 below the root zone at concentrations of from 1 to 31 ppm. The fertilized site lost 93 kg NO_3-N ha^{-1} more in 1976 and 91 kg NO_3-N ha^{-1} more in 1977 than did the unfertilized site. The greater NO_3-N loss from the fertilized over the nonfertilized site was equivalent to 47 and 54% of the fertilizer N applied in the respective years. These data suggest that NO_3-N additions to the ground water could be reduced by re-

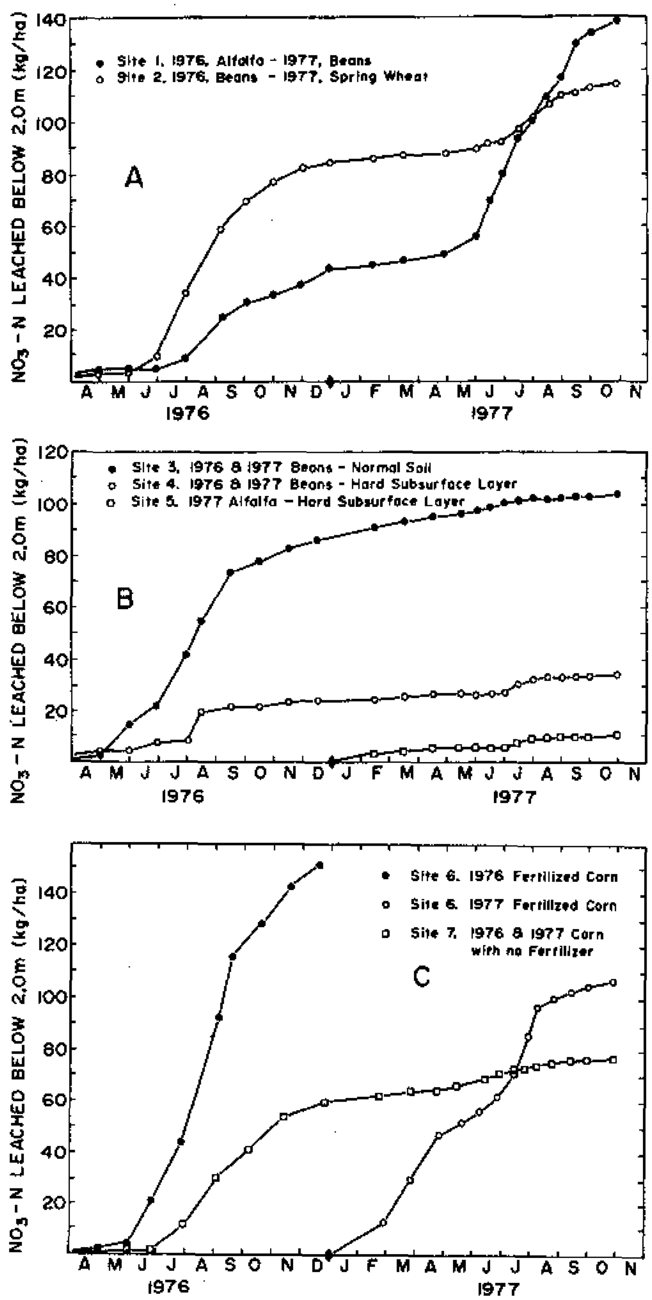

Fig. 1—(*A, B, C*)—Accumulative NO_3-N (kg/ha) leached below the root zone (2.0 m) under alfalfa crops and under fertilized and nonfertilized crops following alfalfa for two growing seasons.

duced fertilizer use or by better water management practices on irrigated corn crops.

The amount of NO_3-N reaching the water table is a function of concentration and water flux. The data in Table 2 suggests that the NO_3-N concentrations in the unsaturated depths below the root zone are a function of the amount of decomposable material and the soil temperature in the upper root zone since the NO_3-N concentrations were highest during the warmest part of the season after the alfalfa crop was killed on soils without restrictive layers. The second year after alfalfa the NO_3-N concentrations were considerably lower presumably due to the absence of decomposable, high N organic matter in the root zone. During the period following an alfalfa crop, NO_3-N concentrations in the soil solution below the root zone were above the recommended 10-ppm drinking water concentration for at least 1 year under normal soils and were above 20 ppm for longer periods below hardpan areas. The rate at which the high NO_3-N soil solution moves downward is a function of the water content in the soil and, thus, the greatest NO_3-N flux is during the irrigation season. The depth of water moving below the root zone at sites 1, 2, 6, and 7 for both years and site 3 in 1976 are all in excess of 50% of the potential evapotranspirations for the particular crops for the study area (3). This is equivalent to a leaching fraction in excess of 33% which represents an excessive irrigation water application.

When these data are compared to previous NO_3-N data in subsurface drains for this same area (4) it is apparent that additional factors are involved in the final subsurface drainage NO_3-N concentration, because the maximum measured NO_3-N concentration in subsurface drainage was 5.2 ppm over a 28-month period, with an overall average of 3.2 ppm. Some of the nitrate is probably being lost to denitrification at the water table surface where reducing conditions are likely to exist. Seepage loss from canals and ditches within the irrigation tract that contain an average of 0.12 ppm NO_3-N (4) and deep drainage from fields low in NO_3-N will also have a diluting effect on the overall NO_3-N concentration in the subsurface drains.

A crop inventory in this same study area showed that 19% of the land was in alfalfa in 1969 (3). Using these data and assuming that alfalfa is left in production for 2 years, not counting the year it is established, 9.5% of the area would be in the first season after alfalfa and 9.5% of the area would be in the second season after alfalfa. If it is assumed that 40 kg NO_3-N ha^{-1} $year^{-1}$ is leached below the alfalfa root zone and 80 and 20 kg NO_3-N ha^{-1} $year^{-1}$ are leached below the root zone of subsequent crops the first and second years after alfalfa, respectively. Thirty-eight percent of the 82,032 ha area will contribute 1,440 metric tons of NO_3-N below the root zone from alfalfa alone. For the 1969 growing season it was estimated (3) that 4,920 metric tons of N fertilizer was applied to the area, giving a total of 9,360 metric tons added from alfalfa and commercial fertilizers. The previous study accounted for 2,900 metric tons of the added N in the form of NO_3-N in the subsurface drainage water. The NO_3-N contributed by growing and plowed down alfalfa equaled, by these estimations, about half that accounted for in the subsurface drainage study (3).

These data suggest that care should be used in determining N fertilizer application rates and timing to crops planted on land plowed out of alfalfa and that irrigation should be carefully managed to avoid leaching any more NO_3-N out of the new crop root zone than necessary. Nearly half of the water diverted to this irrigation tract is accounted for in the deep drainage water (3). Under irrigation agriculture it is practical to control the timing and amount of water applied to the soil. Improvement in these two management areas could decrease the required N application rates, make more N available to the growing crop, and decrease the NO_3-N leached below the root zone.

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