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Nitrate-N Percolation Through Irrigated Sandy Soil as Affected by Water Management[1]

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ABSTRACT

Fertilizer N has been considered as a source of groundwater pollution because of NO_3-N mobility in soil. This study was conducted on a Torripsammet soil (Valent fine sandy loam) during three consecutive growing seasons to determine the magnitude and differences in NO_3-N losses below corn (*Zea mays* L.) roots from two different, but current, farmer-used fertilizer management practices. Three farmer-owned and -operated center pivot sprinkler irrigation systems (designated A, B, and C) near Crook, Colo. were used each year. Nitrate-N percolation losses were measured in water samples collected at 150 cm below the soil surface in vacuum extractors located in a line 91, 182, and 372 m for the pivot in each field. The A, B, and C systems were managed so that 4.8, 2.5, and 10.2% respectively, of the growing season water (irrigation plus rain) percolated to the 150-cm depth. Three-year average annual NO_3-N collected in the extractors was 30.4, 19.0, and 59.7 kg/ha for the A, B, and C systems, respectively. Nitrate-N and water percolating to the 150-cm depth were highly correlated ($r = 0.95$), with each centimeter of water carrying an average 10.2 kg/ha NO_3-N. Average annual total dry matter production for the systems, in the same order, was 20,763, 21,876, and 18,858 kg/ha, respectively, and was negatively related to NO_3-N percolating to the 150-cm depth ($r = -0.99$), showing that production was highly related to NO_3-N loss. Total dry matter production decreased 65 kg/ha for each kg/ha of NO_3-N percolating to the 150-cm depth. Soil NO_3-N changed very little from spring to fall in each of the systems but the soil under the A and B systems contained more than 250 kg/ha NO_3-N to a depth of 180 cm, whereas soil under the C system contained only 20 kg/ha to this depth.

Additional index words: **N recovery, Soil NO_3-N, Plant N uptake.**

NITROGEN fertilizer has received attention as a source of groundwater pollution because of the mobility of NO_3-N through the soil and because of the large amount of fertilizer N used (8.2 million tons in 1972). However, documentation is lacking that NO_3-N detected in groundwater resulted from fertilizer. Nitrate-N is also formed by natural processes such as decomposition of organic matter. This naturally formed NO_3-N can move to the groundwater by unsaturated water flow, as evidenced by NO_3-N found in groundwater some 24 m below the soil surface in eastern Colorado before virtually any commercial fertilizer N had been used (4). In Nebraska, a high NO_3-N concentration in the lower soil profile apparently had nothing to do with fertilizer practices (7). The probability of large quantities of NO_3-N movement into the groundwater is low because conditions in the vicinity of the water table are very favorable for denitrification (3).

The probability of NO_3-N from fertilizer N leaching into groundwater is increased if the crop is irrigated. Preliminary evidence in Colorado indicates that 9 to 14 kg/ha of NO_3-N is lost to groundwater during an average year under irrigated corn and sugarbeets (8). However, a study on fine-textured soil in eastern Nebraska showed that irrigated corn effectively utilized NH_4-N and NO_3-N accumulation in the crop root zone, thereby limiting N losses below the 180-cm soil depth (6).

Of greatest concern for fertilizer N movement into the groundwater are the sandy soils extensively fertilized and sprinkler irrigated in eastern Colorado and western Nebraska. These soils have low available-water-holding capacities (0.06 to 0.14 cm/cm of soil); therefore, most of the crop water needs must be applied by frequent irrigations. Consequently, many irrigation systems are operated continuously during the growth period regardless of actual crop water needs, resulting in over-irrigation. These sandy soils also have low natural fertility, and require high fertilizer rates to obtain respectable yields. Over-watering, coupled with high fertilizer applications, can ultimately develop a potential for groundwater pollution.

With properly designed and managed irrigation systems, little or no NO_3-N should move below the root zone (2). Even with the best design and management of irrigation systems on sandy soils, however, water can exceed crop needs because of high rainfall from thunderstorms. The study reported here was conducted to determine the magnitude and differences in NO_3-N losses from two widely different but current farmer-used fertilizer management practices with scheduled irrigation systems on sandy soils.

MATERIALS AND METHODS

This experiment was conducted during three consecutive corn growing seasons on three farmer-owned and -operated center pivot sprinkler irrigation systems in northeast Colorado, near Crook. Two of the systems (designated A and B) were operated by the same farmer and the irrigations were scheduled so that from the average annual water application (irrigation plus rain) of 60.0 and 62.2 cm, respectively, an average of only 4.8 and 2.5%, respectively, moved to the 150-cm depth (5). The third system (designated C) could not apply less than 20 mm per irrigation and was managed so that an average of 10.2% of the 71.1 cm of water applied annually (irrigation plus rain) moved to the 150-cm depth (5). The soil of each system was a loamy fine sand and had an average available-water-holding capacity of 0.11 cm/cm in the top 20 cm and 0.06 cm/cm to a depth of 150 cm as determined by measuring soil water content at field capacity and lowest soil water content obtained following soil water extraction by growing corn roots. Organic matter content of the soil was 1.0% in the top 20 cm and gradually declined to 0.1% at the 150-cm depth. Of the 224-kg/ha annual N application on the A and B systems, 94% was anhydrous ammonia applied equally as preplant and sidedress applications and the remainder was NH_4NO_3 applied at planting as starter. On the C system 5% of the annual 291-kg/ha N application was applied as the starter fertilizer and the remainder applied as liquid urea-ammonium nitrate solution through the irrigation system in seven to 10 equal applications during the growing season. During the 3-year study on the C system, some of the applications of N in the water required over-irrigation. In these instances rain had met crop water needs, but because the crop

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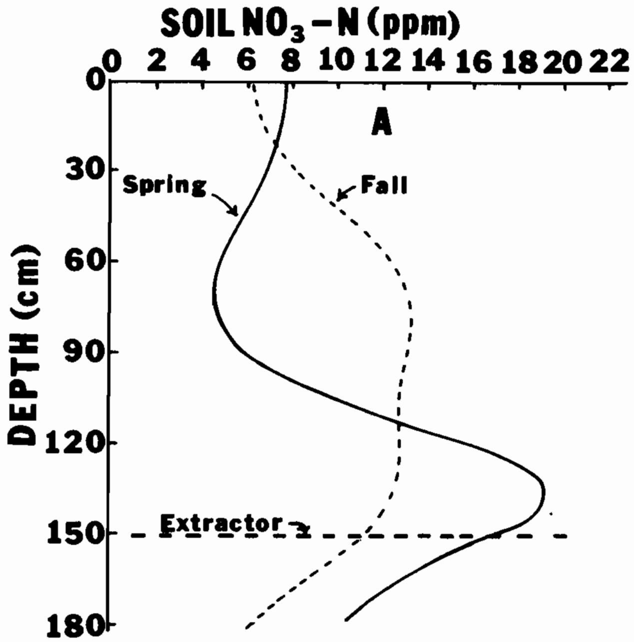

Fig. 1. Nitrate-N distribution in soil to 180-cm depth in the spring and fall where 4.8% of supplied water percolated to 150-cm depth (3-year average).

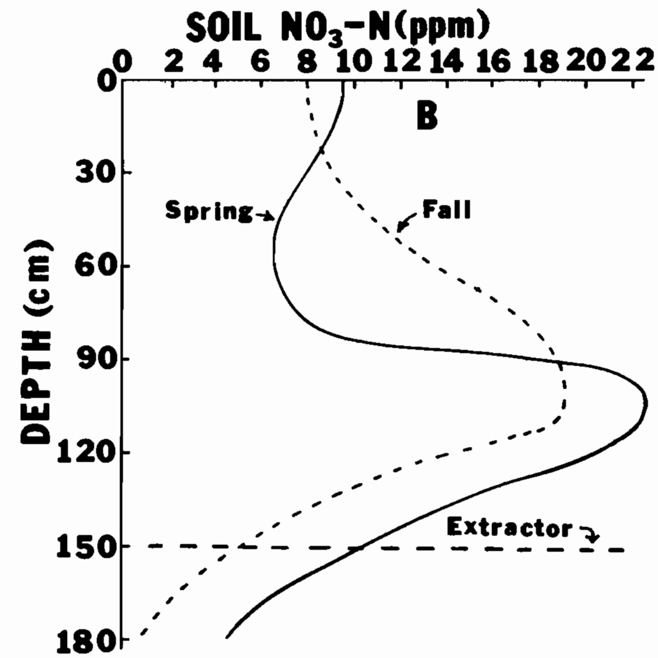

Fig. 2. Nitrate-N distribution in soil to 180-cm depth in the spring and fall where 2.5% of applied water percolated to 150-cm depth (3-year average).

required N which was applied through the irrigation system, 20 mm of water had to be applied.

Vacuum extractors (1) consisting of a porous ceramic tube 305 cm long in the bottom of a galvanized metal trough 15 cm wide, 15 cm deep, and 320 cm long were buried at 150 cm in three locations under each sprinkler system. The 150-cm depth was considered below normal rooting of corn grown on these soils because root samplings have shown 120 cm to be the maximum rooting depth. The locations were in a line 91, 182, and 273 m from the pivot. A continuous vacuum equivalent to the soil water suction at the same depth outside the metal trough, was applied to each ceramic tube. Water percolating through the soil into the trough moved through the ceramic tube into a collection container which was measured weekly. A sample was kept for NO_3-N concentration analysis.

Soil samples for NO_3-N analysis were collected in 30-cm increments to a 180-cm depth just before corn planting and immediately after harvest each year. Twelve sites were sampled parallel to and within 3 m of each extractor location and analyzed with all values included for a system average. The phenoldisulfonic acid method was used to determine NO_3-N concentration in both soil and water samples, except during the 1st year a nitrate electrode was used to measure NO_3-N concentration in the water samples.

Corn (*Zea mays* L.) was planted in rows 76 cm apart with average populations of 68,943, 66,963, and 68,695 plants/ha for the A, B, and C systems, respectively. At physiologic maturity, total dry matter production and grain yields were determined from 40 plants harvested at each extractor site in each system. Ten plants (every fifth plant) were harvested in four rows growing over the extractor. Vegetative tissue and grain were analyzed by Kjeldahl procedures for total N.

RESULTS AND DISCUSSION

Average annual NO_3-N collected in the water at the 150-cm depth was 30.4, 19.0, and 59.7 kg/ha for the A, B, and C systems respectively. Average annual measured deep percolation losses for these same three systems were 2.9, 1.6, and 7.3 cm, respectively which are a direct reflection of the operator water application management and sprinkler system application characteristics. The correlation between water loss and NO_3-N loss was high ($r = 0.95$) and revealed that each centimeter of water percolating through the soil to 150 cm carried an average of 10.2 kg/ha of NO_3-N. When the NO_3-N concentration in the root zone is maintained at a high level either by residual fertilizer build-up or frequent N fertilizer applications, the amount of NO_3-N lost below the root zone of corn grown on sandy soil is proportional to the amount of water that percolates below the root zone of the growing corn crop. These results are similar to those reported from California (9).

Total NO_3-N content of the soil under these three systems was fairly uniform because the standard deviation between the 12 sampling sites per sample increment per extractor location never exceeded 3.8 ppm NO_3-N and the maximum coefficient of variation between extractor locations within systems was 7%. The total soil NO_3-N content within each system changed very little from spring to fall (Fig. 1, 2, and 3). However, the A and B systems contained an average of 290 and 266 kg/ha NO_3-N, respectively, in the soil to a depth of 180 cm at both sampling times whereas the C system contained only 20 kg/ha NO_3-N to this soil depth. Although total NO_3-N content of the soil under systems A and B was essentially the same at both sampling times, there was notable redistribution within the profile from spring to fall (Fig. 1 and 2). The spring to fall NO_3-N redistribution involved an increase above the 90-cm depth and a decrease below the 90-cm depth. The increase above 90 cm was due to applied fertilizer. The decrease below 90 cm is believed to have occurred when the small quantities of water percolated through the soil above the extractors periodically during the

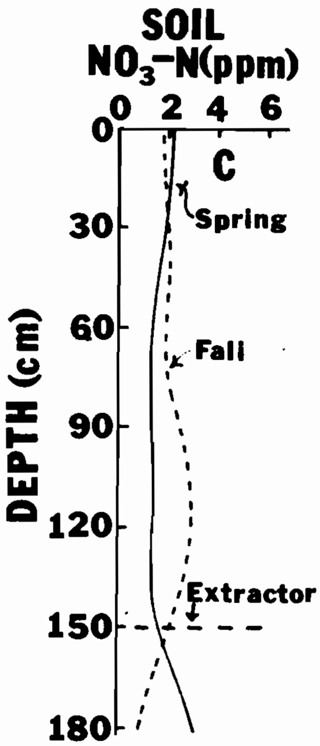

Fig. 3. Nitrate-N distribution in soil to 180-cm depth in the spring and fall where 10.2% of applied water percolated to 150-cm depth (3-year average).

interval between the spring and fall soil samplings. As the water percolated through the soil the NO_3-N concentration of the water increased, thereby resulting in some removal of NO_3-N from the soil when the water reached the 150-cm depth. Some individual water samples collected in the extractor reached NO_3-N concentrations of 300 ppm, but since the soil contains only 11% water at field capacity the concentration of NO_3-N per given volume of soil would be much lower (Fig. 1 and 2) than the 100% water samples collected in the extractor. The soil NO_3-N decrease below 90 cm from spring to fall was equal to about 60% of the NO_3-N collected in the extractor of the A system but in the B system, spring to fall soil NO_3-N decrease in the 90- to 150-cm depth was 3.4 times greater than the extractor catch. Assuming equal plant N uptake for the two systems, there seems to be no relation between growing season soil NO_3-N decrease below 90 cm and NO_3-N collected with the extractor. The low NO_3-N content of the soil under the C system in both the spring and fall (Fig. 3) is attributed to: a) management and sprinkler system application characteristics that permitted 10.2% of the applied water to percolate to the 150-cm depth coupled with b) small periodic applications of N during the growing season that did not permit NO_3-N to accumulate.

Average annual grain production for the three systems were similar but total dry matter production was signficantly higher from the A and B systems than from the C system (Table 1). For all systems, average annual total dry matter production was highly negatively correlated with average annual NO_3-N collected at the 150-cm depth ($r = -0.99$). This relationship showed an average total dry matter production decrease of 65 kg/ha for each kg/ha NO_3-N lost at the 150-cm depth. The grain and stover components of total dry matter production showed similar relationships ($r = -0.87$) and ($r = -0.97$), respectively. Thus, when NO_3-N was removed from these sandy soils by water percolating below the root zone, dry matter production was lowered.

Table 1. Average annual grain and stover yield for three irrigation systems (3-year average).

Irrigation system	Yield		
	Grain	Stover	Total
	kg/ha		
A	11,039	9,724	20,763 b*
B	11,114	10,762	21,876 b
C	10,054	8,804	18,858 a

* Values accompanied by the same letter are not significantly different at P = 0.05.

Table 2. Average annual N uptake by grain and stover from three irrigation systems (3-year average).

Irrigation system	N uptake		
	Grain	Stover	Total
	kg/ha		
A	139	82	221 ab*
B	154	91	245 b
C	128	76	204 a

* Values accompanied by the same letter are not significantly different at P = 0.05.

Table 3. Nitrogen balance for three irrigation systems (3-year total).

Component measurement	Irrigation system		
	A	B	C
	kg/ha		
Plant uptake	663	735	612
Deep percolation	91	57	179
Total depletion	754	792	791
Total applied N	731	731	875
Soil change	103	113	-33
Total available N	834	844	842
Unaccounted for	-80	-52	-51
Recovery	90.4%	93.8%	93.9%

Average annual plant N uptake was less from the C system than from the A and B systems (Table 2), which reflects the lower dry matter production (Table 1). Plant population differences are not believed to be a factor; therefore, differences in N uptake are attributed to irrigation and fertilizer management differences.

Nitrate-N collected from extractors, changes in soil NO_3-N, and plant N uptake for the 3 years accounted for 90.4, 93.8, and 93.9% of the total N available for the A, B, and C systems, respectively (Table 3). Potential mineralizable native N is low and N losses to the atmosphere were not considered significant; therefore, these factors were not considered when N recovery was calculated. However, recovery of applied N was high.

CONCLUSIONS

Nitrate-N movement through sandy soils is dependent on a source of NO_3-N and water movement through the soil. The actual amount of NO_3-N that will move through the soil is proportional to the concentration of NO_3-N in the soil and amount of water that moves through the soil. We believe the movement of fertilizer N below the major root zone of corn grown on these loamy fine sand soils can be kept very small with proper water and fertilizer management as shown with the B system in this study, thereby minimizing the NO_3-N pollution potential of the groundwater.

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