Solute Movement in Soils

1. LEACHING OF NITRATES IN IRRIGATED FALLOW SOIL

D. K. Cassel

Many North Dakota farmers are increasing crop yields as a direct result of incorporating adequate soil fertilizers into their farm management system. Nitrogen (N) and phosphorous (P) fertilizers are the ones most commonly required in North Dakota, with 66,403 tons of actual nitrogen and 96,794 tons of phosphorous as P_2O_5 applied during the 1969 cropping season. In addition, 9,915 tons of potassium (K) as K_2O were used.

Recently, chemical fertilizers have received much criticism by ecologists and the general public as being one of the principle sources of pollution of lakes, streams and groundwater supplies. The conclusion reached by most of these people is that if more and more fertilizer is currently being applied to soils then more and more fertilizer must eventually find its way into water supplies. Possible mechanisms offered for the transport of these chemicals from the soil to the water supplies are 1) loss by erosion, 2) loss in run-off water, and 3) loss due to leaching downward through the soil profile. This article is concerned with possible leaching losses of fertilizer from the soil.

When nitrogen and phosphorous nutrients enter lakes and streams, they tend to increase the growth of unsightly and possibly odoriferous algae and thus increase the rate of aging of that particular body of water. This aging process, which is called eutrophication, is a natural process. Whether or not nutrients from chemical fertilizers are increasing the rate of eutrophication at a measurable rate at the present time in North Dakota is, at best, debatable. In addition, there is concern about babies and small children getting nitrate poisoning from waters containing large amounts of nitrates. Water which moves downward through the soil often intercepts the water table. This water, along with any dissolved solutes, including agricultural chemicals, eventually may reappear as surface water at seeps and springs.

Dr. Cassel is associate professor, Department of Soils.

To better understand the processes involved, let us briefly review some of the properties of the fertilizer chemicals most commonly used in North Dakota.

Potassium usually is applied to North Dakota soils as muriate of potash or potassium chloride (KCl) which, upon dissolving in the soil solution, dissociates into two particles called ions - a positively charged potassium (K) ion and a negatively charged chloride (Cl) ion. Soil particles, which have a net negative charge, adsorb the positively charged K ion; i.e., the K ions are securely fastened to the outside of the soil particles. Once adsorbed, the nutrients can be used by plants, but are not susceptible to appreciable leaching by water percolating downward through the soil. The negatively charged Cl ions, on the other hand, are not held by the soil particles but are free to move with water as it moves in the soil.

Phosphorous fertilizer usually is applied as super phosphate or concentrated super phosphate. Upon its addition to soil, it eventually dissociates into a positively charged ion and a negatively charged ion, which behave differently from the negatively charged Cl ion. The chemical properties of the negatively charged ions (HPO_4- or H_2PO_4-) are such that they rapidly become fastened or fixed to some of the organic or inorganic materials in the soil. Hence, the negatively charged phosphate ions are rendered immobile and are not subject to leaching in the same manner as the Cl ion.

Nitrogen fertilizer is added to the soil in a variety of forms. Ammonium nitrate (NH_4NO_3) is the most commonly used form in North Dakota. Upon addition to moist soil, this chemical dissociates into negatively charged nitrate ions (NO_3-) and positively charged ammonium ions (NH_4+). As one would expect, the ammonium form is adsorbed to the soil particles and is thus rendered partially immobile to leaching. The negatively charged NO_3- form, however, is not adsorbed by soil particles and hence is free to move with water as it percolates downward in the soil or moves upward as a result of evaporation at the soil surface.

Experimental Procedure

This experiment was conducted on Svea loam located on the Langdon Branch Experiment Station during the summer of 1969. Nitrogen at a rate of 800 lbs. N/acre was broadcast as ammonium nitrate (33-0-0). A dike was built around the nearly level soil plot; this dike permitted the desired quantity of irrigation water to be ponded on the soil. No vegetation was allowed to grow on the plot area throughout the summer. Specially designed suction tubes allowed duplicate soil solution samples to be extracted from the 1, 2, 3, 4 and 5 foot depths at the desired times. Analysis of these samples allowed the N status at these depths to be assessed throughout the summer. Note that the results obtained using this experimental procedure represent an extreme, since an extremely high rate of 33-0-0 was applied and no vegetation was allowed to grow. This high N application rate did, however, facilitate analysis of the soil solution for the individual ions.

Results and discussion

The date of each irrigation, the quantity of water applied and the amounts of precipitation received between irrigations are shown in Table 1. After the first two irrigations, water was applied at 10- to 14-day intervals, with a total of 22.5 inches of irrigation water being applied throughout the season. In addition, 5.6 inches of precipitation fell. Devils Lake weather station pan evaporation data, which also are shown in Table 1, indicate that the prevailing environmental conditions throughout the summer were conducive to good drying. Not as much water will evaporate from a soil surface as from an evaporation pan because once the soil surface has dried, it forms a barrier which tends to decrease the rate of evaporative soil water loss.

Table 1. Date of irrigation, quantity of water applied and the amounts of precipitation and pan evaporation occuring until the next irrigation.

Date	Quantity of Water applied (inches)	Precipitation until next irrigation (inches)	Pan Evaporation* until next irrigation (inches)
June 24	4.0	2.6	1.0
July 1	3.5	0.7	2.6
July 14	3.0	0.8	2.0
July 24	3.0	0.9	2.7
Aug. 6	3.0	0.2	2.4
Aug. 20	3.0	0.4	3.2
Sept. 3	3.0	--	--
Total	22.5	5.6	13.9

* Pan evaporation data obtained from Devils Lake Weather Station.

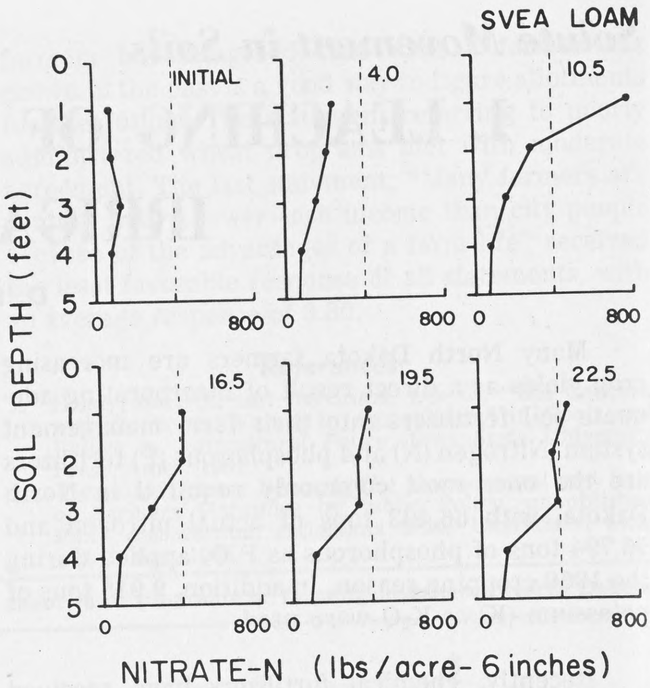

Figure 1. Nitrate-N distribution in a 5-foot profile of fallowed Svea loam initially and after 4.0, 10.5, 16.5, 19.5 and 22.5 inches of irrigation water was applied.

Figure 1 shows the amount of NO_3-N expressed as pounds N/acre 6-inch increment of soil. Data are shown for the 1-, 2-, 3-, 4- and 5-foot depths in the Svea soil profile initially and after applying 4.0, 10.5, 16.5, 19.5 and 22.5 inches of irrigation water. The data indicate a nearly uniform initial NO_3-N distribution in the soil profile. After drainage proceeded for one week after the initial 4.0 inches irrigation, a slight increase in NO_3-N was observed at the 3-foot depth, with larger increases being detected at the 1- and 2-foot depths. After a total of 10.5 inches of water was added, a great increase in NO_3-N was observed at the 1-foot depth. Each succeeding addition of irrigation water continued to move the NO_3-N deeper into the soil profile. After 19.5 inches of water was applied only a small increase in NO_3-N was observed at the 5-foot depth.

Additional measurements indicated that most of the NO_3-N detected at the 1- and 2-foot depths after applying 19.5 and 22.5 inches of water, resulted from downward leaching of NO_3-N which apparently was transformed from the immobile NH_4-N form by microorganisms. Hence, even though the immobile ammonium form of fertilizer is applied to soils, if temperature, moisture and other conditions are favorable for nitrification, the immobile NH_4-N may be converted to the mobile NO_3 form, which could conceivably be moved downward in the soil profile.

A second experiment, similar to the one above except that evaporation was prevented, showed that for the same irrigation regime the NO_3-N leached deeper in the soil profile. This result is expected since water in the upper portion of the soil profile moves upward in response to evaporation occuring at the soil surface. At depths near the soil surface, water and mobile nutrients move downward following an irrigation until evaporation reverses the direction of flow. It is thus possible, for example, to have water draining downward below the 1-foot depth and simultaneously have water moving upward toward the soil surface above the 1-foot depth.

The results would vary somewhat with soil texture. This experiment was conducted on a loam soil. If this identical irrigation regime (see Table 1) were used on a coarser-textured soil, a greater quantity of NO_3-N would have been leached below the 5-foot depth, since these soils have a smaller water holding capacity. On the other hand, the depth to which nitrates would move downward in a fine textured soil would tend to be less than for the loam. Table 1 shows that, in addition to the 22.5 inches of irrigation water, precipitation fell on the plot throughout the summer. Except for the 2.6 inches received during the week following the June 24 irrigation, the precipitation fell in such small amounts that it did not contribute to leaching but was intercepted and held near the soil surface, and was soon lost by evaporation.

Under actual cropped field conditions one would not observe downward movement of nitrates in the soil profile as great as those shown in Figure 1 for several reasons. First, such a large quantity of N would not be recommended by a soil testing laboratory. Such heavy applications would not be economical. However it is possible, indeed probable, that accidental applications this large may occur. Second, a crop would be planted after applying the fertilizer and thus utilize some of the added NO_3-N. For at least several weeks after a crop is planted the soil surface is essentially bare and losses of water to the atmosphere occur by evaporation. After the roots proliferate they, too, extract water from the soil and in turn, relinquish most of this water to the atmosphere by transpiration. These two processes combined (evapotranspiration) decrease the moisture content of the soil. When water is added to the soil, either as precipitation or irrigation, much of the water is used to replenish that depleted by the plant; consequently there is a reduction in the total quantity of water and soluble salts moving downward. In addition, the root system of the plant is absorbing some of the NO_3-N. Hence, most of the leaching of mobile nutrients from non-irrigated soils in North Dakota will occur either during late fall when the soil moisture is being recharged or in the spring when additional precipitation falls on a soil, the root zone of which is already recharged, and before there has been appreciable root development.

One may then speculate that leaching losses of NO_3-N out of the rooting zone are probably of more importance for fallow than for cropped soils. Twenty to 30 inches of precipitation may fall during the fallow period. Some of this water is lost to runoff and to evaporation. It is not rare, however, for water to infiltrate below the 5-foot depth. Since the nitrification process releases appreciable quantities of NO_3-N near the soil surface during this period, it is subject to leaching. Over a period of years an appreciable quantity of NO_3-N may be leached. Soil obtained from several 10-foot holes at the experimental site on the Longdon Branch Experiment Station before the experiment began showed an accumulation of more than 1,000 pounds of NO_3-N per acre.

Irrigated soils may be susceptible to leaching from early spring to late fall. Leaching results as a consequence of applying more water than is needed to recharge the rooting zone. This is an accepted practice in order to keep salt which is present in the water being applied from becoming excessive. In addition, in a semi-humid area like North Dakota, there is always the possibility of receiving heavy precipitation soon after irrigation.

Conclusion

Irrigation of bare Svea loam with 22.5 inches water during the summer of 1969 resulted in significant movement or leaching of NO_3-N downward in the soil profile. This observed leaching of NO_3-N probably establishes a maximum for loamy soils under North Dakota climatic conditions. It must be realized that although very little NO_3-N actually moved below 5 feet, the NO_3-N will continue to move downward the next time water infiltrates below the 5-foot depth unless, of course, the nitrate has been used by growing crops. Leaching of nitrate from cropped soil, either dryland or irrigated, will result in a lesser degree of movement than observed in this experiment. Fallow soil, on the other hand, will probably result in a greater loss of NO_3-N in contrast to a cropped soil. Investigations are currently in progress to assess possible NO_3-N leaching losses under cropped, fallow and irrigated soils.