Continuing Education

Nitrogen Leaching and Groundwater Quality

Better understanding of the role of irrigation in crop management is essential to reduce the risk to groundwater quality in the Midwest's crop production areas. While N fertilizer is implicated as a source for increased groundwater NO3 concentration, there have been few studies providing direct evidence of this correlation and quantifying the amount of NO3 leaching below crop rooting depths. Such quantification would determine how to manage soil nutrition for best overall results.

The study described in this article was designed to quantify NO3 leaching on irrigated sandy soil (Pratt loamy fine sand), using two different irrigation schedules and six N fertilizer treatments. The crop was a full-season corn variety. Results from this study can be combined with information about the water and N requirements of specific crop varieties offered for use on sandy soil.

Similar studies of crop, fertilizer, and irrigation management systems on soil NO3 leaching have been done in the recent past. Still, there is little information offered that would teach the effect of field-measured quantification of NO3 leaching on sandy irrigated soils for plants that require large amounts of N. This study used Darcy’s law drainage estimates with actual measurements of soil water NO3 concentration to evaluate the effect of N fertilizer and irrigation management. Darcy’s law (named for Henry Philip Gaspard Darcy, 1803-1858) is a generalized relationship for flow in porous media. It shows that the volumetric flow rate is a function of the flow area, elevation, fluid pressure, and a proportionality constant, which is found valid for any Newtonian fluid, and while it was established under saturated flow conditions, it may be adjusted to account for unsaturated and multiphasic fluid systems.

Because about one-half of the U.S. population depends on groundwater for drinking and household use, it is important to help crop managers determine N losses from crop production. Consuming drinking water that contains excessive amounts of NO3 is believed to cause birth defects, nervous system defects, and cancer. When NO3 is leached into groundwater supplies, it remains intact for a long time and is particularly difficult to remove. It has become an issue for environmental groups in recent years and is a target for environmental action. The coarsely-textured soils in this part of the West and Midwest have a low capacity to retain either water or nutrients and require large inputs to assure a good grain yield.

Methods

The study was conducted in south-central Kansas, along the Arkansas River. The soil is characterized as a Pratt loamy fine sand with about 12 g kg\(^{-1}\) organic matter, 16 mg kg\(^{-1}\) Bray-1 P, 53 mg kg\(^{-1}\) K, and a pH of 6.1. The soil was tilled using a chisel plow and a seedbed preparation pass and treated with pre-emergence herbicides. The crop was a full-season corn variety, planted about the first of May in both 2001 and 2002.

A randomized complete block design was used, with four replications of six N treatments. Plots were eight rows wide, with 0.76-b by 9.1-m rows. Nitrogen treatments were broadcast at 0.125 (split), 0.185 (split), 0.295 (split), 0.35 (split), and 0.39 kg ha\(^{-1}\). A portion (or all) of the N was applied within 5 d of planting and the remainder as a split between 5-d and side-dressing applications. Water was applied with a center pivot, either as an optimal amount (1.0 x irrigation schedule (IS)) or 25% greater than optimal (1.25 x IS), determined by using a water balance irrigation scheduling program. Soil samples were taken within 5 d of planting (before N application), and postharvest, and tested to provide data about the amount of N added to the soil that was not transferred to grain and plants.

Water flux was determined using tensiometric methods, which are inherently variable. Porous-cup solution samplers (one per plot) and tensiometers (three per plot) were installed within the center rows in all replications of the four highest N treatments. This was done in late May of each year. The solution samplers were installed at 152-cm depth, and the tensiometers were placed at 30, 137, and 318 cm deep. Water samples and tensiometric readings were taken at set intervals during the growing season. Six samples of soil water were collected during 2001, and nine samples were collected during 2002. The amount of leached NO3 in the zone below the roots was estimated using the concentration of NO3-N in the soil solution collected in the porous-cup samplers at 152-cm depth and drainage estimates that were produced by the tensiometric data. Soil water matric potential, \(h\) in cm of water, was calculated using data from the 137- and 168-cm tensiometers. Hydraulic head, \(H\) (cm), is calculated as the sum of \(h\) and gravitational potential head, \(H\) (cm), using the system proposed by Young and Sissom. Water flux at each plot location was calculated, and total water flux was determined using the mean daily water flux and the sampling time increment. Grain yield was determined by weighing a sample from a predetermined length of row and corrected for weight.

Air temperature were similar for both years; the average growing season minimum temperatures was 26°C each year, and average minimum temperatures were 16.7 and 16.4°C for 2001 and 2002, respectively. Total growing season rainfall...
plus irrigation was 552 (1.0 × IS) and 620 (1.25 × IS) mm in 2001 and 5437 (1.0 × IS) and 490 (1.25 × IS) mm in 2002. Rainfall was less than the 30-yr mean for the county in all months except May and September 2001 and August 2002, so corn production benefited from irrigation.

Grain Yield: Nitrogen and Water Ramifications

Full-season corn varieties grown in Kansas usually require 610 to 760 mm of precipitation for optimum production, according to studies at Kansas State University. Rainfall in northeast Kansas was 1396 mm in 1994. This means that supplemental irrigation was necessary to sustain yield during both years.

The best grain yields were produced by a split application of 125 kg N ha⁻¹ for the 1.0 × IS in 2001 and the same rate at 1.25 × IS in 2002. There was no statistical difference between mean yield for any of the N treatments greater than the control for the 1.0 × IS in 2001 and 2002. Both irrigation treatments resulted in maximum yield. Increased recovery of N by the corn plant occurs when N is split-applied, and maximum crop yield can be maintained while using reduced rates of fertilizer. The authors attribute the increased recovery to applying N just before the period of rapid N uptake by corn, resulting in a shorter time when leaching could occur and avoiding some risks of soil N loss.

Water flux for the 1.25 × IS was about the same or slightly greater than that for the 1.0 × IS throughout the entire growing season in 2001 and 2002, while there was no difference detected in water flux among N treatments in either year.

Difference in drainage between irrigation schedules was not significant on any specific sampling date, but increased drainage had occurred three times during the 2001 growing season. Rain in May and early June and in late August increased water flux, as did an increased frequency of irrigation when crop demand was high. Near the end of that growing season, water flux increased for higher irrigation schedule, probably as a result of greater soil profile moisture maintained for the 1.25 × IS, leading to hydraulic conductivity. It is clear that increased soil moisture increased hydraulic conductivity resulting in greater drainage. The relatively low level of water flux for the 1.0 × IS program was expected, as the irrigation management was designed to allow only enough water to the plants to produce the best possible crop growth and grain yield.

During the 2002 season, notable increases in water flux was observed for the 1.25 × IS, after two large rainfall events, followed by an increase during the third week of July. The results indicate that excess irrigation, even small amounts (as little as 25%), can increase water flux in sandy soils by as much as 10%.

Soil Water Sampling Results

The concentrations of NH₄-N were generally very low, less than 1 mg-L⁻¹ during 96% of the sampling events, which is consistent with previous reports. Preseason soil samples were used to check on NO₃-N concentrations in the soil water samples collected at the beginning of each season. The average preseason NO₃-N at depths of 120 and 180 cm was 4.3 mg kg⁻¹ in 2001 and 2.6 mg kg⁻¹ in 2002. As early as early June, tests indicated that there were significant differences in NO₃-N concentrations among N treatments, with the nitrate concentration for the 1.25 × IS being consistently greater than the 1.0 × IS during 2001 and with a significant difference noted between four sampling dates. Total NO₃-N leached below the root zone in 2001 was greatest for the 250 and 300 kg ha⁻¹ single applications and 1.25 × IS. Similar results were observed in 2002. Although considerable less N was leached during the growing season with the 1.0 × IS, even for the high N rates, it is important to remember that any NO₃-N remaining in the soil profile after the growing season is likely to leach when excess rainfall occurs during the fall and spring flood period.

Conclusion: Impact for Crop Managers

The goal of maximum grain production will most likely be met by careful management of both water and N additions. Excess water did not, in this study, enhance grain yields, as water percolates through sandy soil fairly rapidly. In fact, additional irrigation may increase the amount of N needed by the crop because of the N losses that occur as water moves below the root zone. Poor choices, either in irrigation timing or amount, or timing of N application, will result in an assortment of bads: poor grain yield, higher water and N input, and N leaching to groundwater and nearby streams.

To decrease NO₃ leaching to groundwater from sandy soils, it is important that application of N fertilizer and irrigation water fulfills crop requirements but does not exceed them. Nitrate leaching is increased by greater water flux down the soil profile and greater concentration of NO₃ in the soil matrix. If irrigation is increased beyond that required by crops, the downward flux can increase the rate of leaching, particularly if the NO₃ content in the soil is high, and the combination can carry excess NO₃ below the root zone rapidly, sending it into the groundwater. The study found that increasing water flow (irrigating longer or more frequently than required to maintain minimum soil moisture) doesn’t increase corn yield and that selecting the right amount of N fertilizer is important. Increasing N fertilizer rate doesn’t always translate into enhanced grain yield.

In short, crop managers should know how much N their specific crop will require, determine how to most effectively deliver that amount—and no more—to the soil in the region nearest to the roots, and manage both N applications and irrigation effectively. This entails knowing how much N will leach into the water in the soil and the water requirements to prevent it. Crop managers must be equally concerned about crop yield and adjacent water quality in order to prevent N loss, loss of grain yield, and excessive water use.