Managing to Reduce Nitrate Leaching: What is in it for the Farmer?

Water Quality

Utah State University Cooperative Extension Service

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Nitrates leached into groundwater may be associated with the following: (1) methemoglobinemia (blue baby) in humans and other mammals; (2)-cardiovascular collapse and shock in horses; (3) possibility of cancer (EPA); and (4) eutrophication of water bodies (IFIA) when nitrate contaminated groundwater reaches surface water through wells or springs. Nitrate leaching is not only a possible source of environmental damage but also the loss of an input before it is used in production.

Utah has approximately one million acres of farmland under irrigation (USDA). This is the most productive farmland in the State, because water is less limiting as a factor of production. The amount of nitrogen needed to achieve the greater yields under irrigation is much greater than the amounts needed when water is a limiting factor of production.

Drainage water can carry nitrate as well as other soluable salts below the root zone.

Irrigated land generally must have some drainage to maintain salt balance. Drainage water can carry nitrate as well as other soluble salts below the root zone. "The amount of NO_3^- that leaches from a soil depends on the amount of water that moves through the soil and the amount of NO_3^- in the soil when water drains through and out of the soil profile" (Pratt).

Other factors that affect the amount of nitrate leached and/or the concentration levels in groundwater include: (1) soil characteristics; (2) amount and timing of water applied as irrigation water or natural precipitation; (3)amount, timing, and species of nitrogen applied; (4) nature of the aquifer, i.e., recharge area and rate, depth, and rock formations (Edwards); (5) crop and plant population (IFIA).

This fact sheet evaluates the economic incentives that the farmer has to manage irrigation and nitrogen in commercial fertilizers to control nitrate leaching out of the root zone. Some of the benefits and/or costs associated with controlling the amount of nitrate that is leached out of the root zone are identified.

Since so many factors affect nitrate leaching, as noted previously, it was necessary to use a simulation model to evaluate the effects of the individual factors. Three soils—a fine sandy loam, a silt loam, and a silty clay—were selected on the basis of water-holding capacity and other soil characteristics. The total soil profile was 66 inches deep for each soil simulated. Soil characteristics were obtained from soil survey data (Chadwick et al.).

Average temperature and precipitation data for Corinne, Box Elder County, Utah, for April 1st through 31st of March (USC) were used in the simulations. Actual temperature and precipitation data for the 1982-83 were also used to simulate what may happen under precipitation levels much greater than normal. The 1982-83 precipitation level was 160 percent of the 30-year average.

Corn was selected as the crop for simulation because of its high nitrogen requirement which results in increased potential for nitrate leaching. Corn growth for silage (approximately 36,000 plants per acre) was simulated under constant management practices (except irrigation and nitrogen) for each soil type and weather condition. Management practices are typical for Box Elder County in Northern Utah (UASS 1989).

Irrigation regimes were chosen to approximate what farmers were doing or could do in Eastern Box Elder County. Furrow irrigation was used for each of the three soils simulated for 6- and 4-inch applications. Sprinklers are necessary for 3- and 2-inch applications on fine sandy loam and silt loam and 2-inch applications on silty clay (Allen). It was assumed that the distribution of the irrigation water was uniform over the entire field. This is a departure from field conditions. Center pivots were assumed for the analysis of irrigation levels requiring sprinkler applications because they are capable of irrigating corn.

Nitrogen was applied at the rate of 200 pounds of elemental N per acre. Ammonium nitrate, anhydrous ammonia, and urea were chosen as the sources of nitrogen because they are the most widely used nitrogen fertilizers in the area. Single applications were applied the day before planting. Split applications were made with 50 percent being applied the day before planting and 50 percent before the rows closed. Fertigation (nitrogen fertilizer added to irrigation water) was also simulated on fine sandy loam using anhydrous ammonia divided equally among all irrigations. At the beginning of the season the residual nitrogen level was assumed to be 41 pounds per acre in the top foot of the soil. This amount of available nitrogen (241 lbs/acre) was expected to yield 38 tons of silage per acre (James and Topper). This target yield was chosen to evaluate the effects of high yield goals on the amount of nitrate leached below the root zone. This yield goal is substantially higher than most farmers are likely to obtain, given a county average of 22.5 tons per acre (UASS).

Costs of tillage events and other cultural and management practices were calculated. Prices for new machinery and machinery useful life were estimated. The yearly planned use for each machine was 10 percent of useful life hours. This assumption "envisions" the farmer to replace the machinery compliment every ten years. Prices of other inputs were obtained from suppliers and farmers. Operating capital was charged a 12 percent annual rate from the day of the field operation until October 31st. A land charge equal to the annual cash rental value for each soil type was also included in the budget analysis.

> **"... both the farmer and the environment were better off if the level of irrigation was reduced from 6 to 4 inches every two weeks."**

Results of the Simulations

Table 1 illustrates that the amount of water and nitrate leached is related to the water-holding capacity of the soil. To avoid excessive leaching the farmer needs to know how much water the soil profile will hold and how much water can be applied before leaching occurs.

The following discussion of the results will center on one soil and the two weather scenarios, but other soils and water scenarios were evaluated. Fine sandy loam was selected as the soil because it is the most susceptible to leaching due to its low water-holding and high infiltration capacity.

A move from 6-inch irrigations to 4-inch irrigations every two weeks results in an increase of about $4 per acre in returns to management after the increased labor cost is paid for. Thus, the farmer has the incentive to move to 4-inch irrigations. The amount of nitrate that leaches out of the root zone was reduced from about 71 pounds per acre to about 3 pounds per acre. The move from 6-inch to 4-inch irrigations was an improvement for both the farmer and the environment under average weather conditions.

The incentive of the same move under high precipitation is less clear because the returns to management are about equal, so there would be little incentive to change. The simulation of the change did result in a reduction of nitrate leached by about 40 percent. Thus, if the farmer expects precipitation to be near normal for any given year, the economic incentive is to move to 4-inch irrigations every two weeks.

Farmers may decide to apply more nitrogen fertilizer rather than increase their labor to the level needed to apply four inches of irrigation water every two weeks. An additional 40 pounds of nitrogen (the amount that the estimated added cost of labor to change to 4-inch irrigations could purchase) applied as ammonium nitrate was simulated for 6-inch irrigations every two weeks for the average precipitation and the high precipitation conditions. The results showed that the farmers have no economic incentive to apply more nitrogen because returns to management decreased and the amount of nitrate leached increased in both cases.

The above must, however, be weighed against other goals. For example, farmers may reduce the number of 6-inch irrigations to the number required to meet the evapotranspiration (ET) needs of the crop. The ET need of corn in Corinne is about 25 inches. Four 6-inch irrigations would supply 24 inches of water. Simulations were run using 6-inch irrigations spaced by estimated ET. Four irrigations were used for the average precipitation simulation, and the result was returns to management decreased by about $10 per acre. Thus, the farmer may be willing to forego $10 per acre to eliminate two irrigations. Moreover, nitrate leaching was decreased to about 5 pounds per acre. The high precipitation scenario yielded three 6-inch irrigations. This reduced the returns to management by about $21 per acre, while nitrate leached decreased by 28 percent.

The marginal cost of reducing nitrate leaching in the simulations from 70 pounds per acre to 3 pounds per acre was about -$0.06 (not actually a cost, but a benefit) per pound per acre under average precipitation. As a result, both the farmer and the environment were better off if the level of irrigation was reduced from 6 to 4 inches every two weeks. This could be done by shortening the length of the sets and increasing the furrow head inflow rate. The marginal cost of reducing the amount of nitrate leached from 70 pounds per acre using 6-inch irrigations every two weeks to 5 pound per acre by irrigating by estimated ET was about 15 cents per pound per acre. The marginal cost of eliminating the last three pounds of nitrate leached per acre was over $8.00 per pound. A technological change (center pivots) is required to keep the last three pounds from leaching. The above analysis demonstrates that fairly large improvements can be made in reducing nitrate leaching by irrigation management with little change in technology at relatively low cost. This analysis, however, assumes farmers can operate close to maximum yield. In field situations, soil spatial variability and irrigation application variability make this more risky.

> **"... uniformity of application of irrigation water has an important impact on both profitability and environmental quality."**

The analysis so far has assumed that irrigation water is uniformly distributed. Analysis can be made for different nonuniform irrigations by using relative weights of the simulation results. As an example, assume that 30 percent of a field receives 6-inch irrigations, 40 percent receives 4-inch irrigations, and 30 percent receives 3-inch irrigations every two weeks. This results in an average of 4 inches but the economic and environmental outcomes are not the same as the results obtained for the uniform simulation. Net returns to management are $255.74 per acre as compared with $268.96 per acre under the 4-inch uniform simulation, while the amount of nitrate leached is 22.55 pounds per acre compared to 3.29 pounds per acre for the uniform application.

Improving the uniformity of application to 20 percent 6-inch, 60 percent 4-inch, and 20 percent 3-inch irrigations every two weeks results in higher returns to management and less environmental impact. Returns to management increased by $4.41 per acre and nitrate leached was reduced by about 6 pounds per acre as compared to the less uniform system. Thus, uniformity of application of irrigation water has an important impact on both profitability and environmental quality. There is still the problem of soil spatial variability. Farmers have historically over-irrigated to mask the "ugly" effects of visual spatial variability without regard to economic cost nor environmental impact. In the future, farmers may need to live with variability.

Figure 1 illustrates the movement over time of nitrate through the soil profile using 4-inch irrigation every two weeks and the high precipitation scenario as an example. Data are shown for June 19 which was just before irrigating starts. July 19 was after two 4-inch irrigations. August 18 was after four 4-inch irrigations. October 7 is after six 4-inch irrigations and after the harvest. All of the nitrate in the soil profile is found below 30 inches by harvest time. Most of the nitrate that was in the soil profile on October 7 had leached below 68 inches by March 26. Thus, irrigation pushed the nitrate down in the soil profile where winter precipitation could push it out of the root zone. Only in those areas where winter precipitation is minimal is there likely to be much nitrate carryover on coarse textured soils.

> **"Late season irrigations seem to be a prime source of nitrate leaching out of the root zone."**

Silt loam—The profit-maximizing irrigation level on silt loam was 6-inch irrigations by estimated ET. In the simulations this resulted in no nitrate being leached out of the root zone. Thus, the economic interest of the farmer is in harmony with environmental quality. Late-season irrigations seem to be a prime source of the nitrate leaching out of the root zone over the non-growing season. This is illustrated by the simulations of the 4-inch and 2-inch irrigations by estimated ET where the last irrigation occurred later than the last irrigation of the 6-inch irrigations by estimated ET. The nitrate leaching that occurred during the growing season was related to over-irrigating at one time or too often.

Silty clay—The profit-maximizing production level was achieved in the simulations on silty clay using 3-inch irrigations scheduled by estimated ET. This resulted in no nitrate leaching in the simulations. Nitrate leaching out of the root zone only occurred when weekly 3-inch irrigations were simulated. The study did not include the potential problems for this soil resulting from erosion or runoff due to low infiltration capacity.

> **Each of the soils simulated had a different profit-maximizing irrigation schedule.**

Nitrogen source made little difference in the amount of nitrate leached below the root zone when the amount of irrigation water applied was near estimated ET. Under conditions of over-irrigation sources of nitrogen which did not contain nitrate exhibited less nitrate leaching than nitrate bearing fertilizers. Non-nitrate nitrogen fertilizers should not be looked at as a panacea to stop nitrate leaching since all forms of nitrogen are nitrified over relatively short time periods.

Compared to single applications, split applications of nitrogen fertilizers significantly reduced the amount of nitrate leached out of the root zone only in the over-irrigation simulations. This is another indicator that irrigation management is a key tool in managing nitrate leaching. When water management is difficult or costly nitrogen source and application timing may be important tools to manage nitrate leaching. The simulations indicate that for farmers that use sprinkler irrigations, fertigation may be a method of "spoon-feeding" crops the nitrogen they need as they need it, thus reducing the amount of nitrate leaching out of the root zone.

Conclusions

The results of the analysis point to the following conclusions:

1. Soil characteristics are important in determining the amount of water and nitrate that leaches through the soil profile and should be considered important in determining the proper irrigation management techniques.
2. Each of the soils simulated had a different profit-maximizing irrigation schedule.
3. The profit-maximizing level of irrigation resulted in some nitrate being leached out of the root zone on the fine sandy loam simulated.
4. The amount of nitrate that leaches out of the root zone can be greatly affected by irrigation management on sandy soils.
5. The profit-maximizing levels of irrigation are near the estimated ET requirements in total amount of water applied but the amount of water applied per application and the timing varied by soil type in the simulations.
6. The profit-maximizing level of irrigation per application for each soil type was little affected by the different weather scenarios.
7. The profit-maximizing level of irrigation on coarser soils pushed the residual nitrate down in the soil profile where it is more likely to be pushed out of the root zone, either by precipitation during the non-growing season or by excess irrigation the next year before the plant roots can reach the nitrate.
8. Split applications of nitrogen did not reduce the amount of nitrate leached significantly except when over-irrigation occurred.
9. Changing from ammonium nitrate to urea or anhydrous ammonia increased returns to management and

Table 1.Water and Nitrate Leached Under 6-Inch Irrigation with 30-Year Average Precipitation, Corinne, Box Elder County, Utah.

Soil Type	Inches of Water Held in Soil Profile of Field Capacity	Water Leached Out of Soil Profile in Inches	Nitrate Leached Out of Soil Profile in Pounds per Acre
Fine sandy loam	11.79	15.48	70.33
Silt loam	19.19	13.74	29.20
Silty clay	23.72	0.39	0.0

may reduce the amount of nitrate leached because of the time r e - quired for nitrification to occur.

10. Fertigation may increase returns to management for farmers that use sprinkler irrigation, reduce nitrate leaching and the total amount of nitrogen applied.

11. The maintenance of high water quality (low nitrate content) was not different from farmer goals in most cases.

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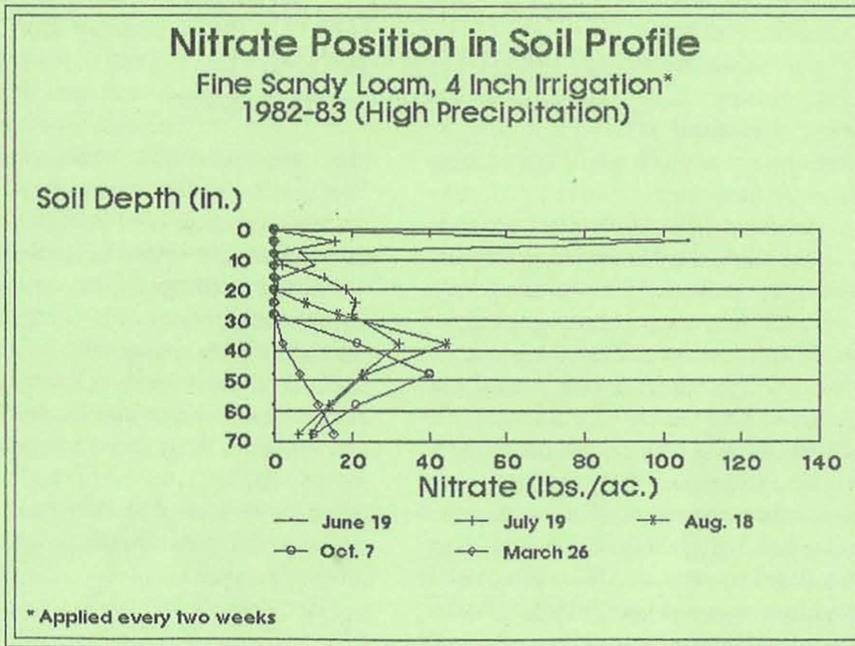

Figure 1.Nitrate position in soil profile on selected days for high precipitation with 4-inch irrigations simulation on fine sandy loam.

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