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EC91-735 The Impact of Nitrogen and Irrigation Management and Vadose Zone Conditions on Ground Water Contamination by Nitrate-Nitrogen

K.D. Frank

University of Nebraska at Lincoln, kfrank1@unl.edu

Darrell Watts

University of Nebraska at Lincoln

Andrew Christiansen

University of Nebraska at Lincoln

Edwin Penas

University of Nebraska at Lincoln

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The Impact of Nitrogen and Irrigation Management and Vadose Zone¹ Conditions on Ground Water Contamination by Nitrate-Nitrogen

by

Darrell Watts, Andrew Christiansen, Kenneth Frank and Edwin Penas²

Summary

Nitrate-nitrogen (nitrate-N) is essential to corn production. However, when leached from the crop root zone it can become a major source of ground water contamination. There are serious contamination problems in shallow aquifers beneath several river valleys in Nebraska. Increasing nitrate-N concentrations are beginning to appear in deeper aquifers. Deep soil sampling in irrigated corn fields in South Central Nebraska has shown enough nitrate-N in transit to the water table to eventually increase the concentration in the ground water well above the U.S. Environmental Protection Agency's public water supply maximum contaminant level (MCL) in a number of locations. The time delay between the leaching of nitrate from the crop root zone and its entry into the ground water can vary from a few weeks to over 30 years, depending on N and irrigation management and vadose zone conditions. Improved N and irrigation management can decrease present and future aquifer contamination rates.

Introduction

The single largest contaminant found in ground water samples taken throughout Nebraska is nitrate-N. Much of it reaches the ground water as a "non-point source" contaminant leached out of the crop root zone. There are many areas that don't now seem to have a problem. However, in almost all regions with concentrated irrigated corn production, it appears that sooner or later a nitrate contamination problem will develop in the ground water.

A natural background level of nitrate-N is always present in the soil and the ground water. It is not some "foreign" contaminant resulting purely from human activity. Our highest quality ground waters contain moderate levels of nitrate-N. This is the result of the leaching action of water draining from the root zone over long periods of time. Water moving through the vadose zone transports this highly water soluble form of N from the upper soil horizons to the water table.

¹The vadose zone is the unsaturated region from the soil surface to the water table. In this paper we use the term to refer to the zone between the bottom of the crop root zone and the water table. The latter is often referred to as the "intermediate vadose zone."

²Extension Water Quality Specialist, Department of Biological Systems Engineering; Extension Agent, Hamilton County; Associate Professor, Department of Agronomy; Extension Soils Specialist, Southeast Research and Extension Center.



Problems arise when we manipulate the mineral N supply in the soil to meet the needs for crop production. Excess rainfall or irrigation can readily move nitrate-N *from any source* out of the root zone to the ground water. Sources include not only fertilizer N, but also nitrate-N from manure and waste products, and that mineralized from legume N or soil organic matter. **Nitrate-N becomes a problem in the ground water when the concentration exceeds the U.S. Environmental Protection Agency's public water supply maximum contamination level (MCL) of 10 parts per million (ppm).**

Some ground water nitrate contamination problems can be traced to point sources. For example, localized problems with manure management around concentrated animal production facilities or improper disposal of sewage effluents and sludge or fertilizer spills can lead to point source nitrate contamination. Local ground water contamination has been caused by excessive N and water application to urban lawns in some areas. Problems of inadequate well construction or siting can also lead to drinking water contamination. All of these may contribute to local water quality problems. Nonetheless, in Nebraska's rural areas, the major ground water quality problem is non-point source contamination by nitrate-N. Agriculture must shoulder most of the responsibility for the development of this problem.

We emphasize that this is an issue of **responsibility** and not **blame**. Much of the nitrate contamination of ground water has come about even though, in general, farmers have used the best available management information, *within existing economic constraints*. Now the situation is changing. Management goals must include **both** producing a profit **and** keeping ground water pollution to an acceptable level.

The purpose of this Extension Circular is to show where and why ground water contamination problems are now occurring in Nebraska; to show that they are likely to occur or intensify in other locations in the next few years; and to discuss how management of irrigation and all sources of N can affect the contamination rate.

How Fast Does Ground water Flow?

To understand the nitrate contamination problem, it is helpful to have an understanding of how ground water moves. Some people visualize ground water flowing as an "underground" river, with water rushing along much as it might in a surface stream. In a few extremely rare cases, such as limestone caverns, that may be true. However, it is **not** true for most ground water flow.

In most areas of Nebraska, ground water moves slowly on a downhill gradient (slope) through the aquifers in a general west to east direction. Flow velocities vary from a fraction of an inch to a foot or two per day. In central Nebraska, velocities are on the order of 1 to 1.5 ft. per day. This translates into 365 to 550 ft. per year, or at most 1 mile in 10 years. Thus, those who would like to blame nitrate leached from feedlots in northeastern Colorado for the ground water nitrate problems in central Nebraska would have to wait over 3000 years for the polluted water to travel the distance, if it could. (In fact, it can't. There are geologic barriers that prevent ground water from flowing the entire distance.)

Our ground water comes from Nebraska, not elsewhere. Almost all of it has accumulated from subsurface drainage out of the root zone of the prairie grasses and the crop lands. Drainage occurs during those days or weeks when more rainfall or irrigation water enters the soil than the soil moisture reservoir can hold. Water draining from the root zone readily moves highly soluble nitrate-N to the water table. **The logical conclusion is that most of the nitrate in the ground water beneath our farms has come from our own activities or those of our close "upstream" neighbors.**

An Expanding Nitrate Problem

Under Great Plains growing conditions it is almost impossible to produce continuous corn under irrigation without some leaching loss of nitrate-N. Under furrow irrigation, the first irrigation of the season is very often excessive. Subsequent irrigations are also likely to be

greater than crop needs, resulting in nitrate-N leaching through the growing season. Even under dryland production, there may be leaching during prolonged periods of above-average rainfall.

The actual rate of N loss from the root zone is governed by a number of factors including the soil, water and N management by the producer, and the weather. Importance of each of these varies from one year to another. In many cases, especially for sprinkler-irrigated land and dryland production, much of the loss may occur during the spring, when rainfall may be much greater than water use by the crop or evaporation from the soil. As soon as the root zone moisture reservoir is refilled by off-season precipitation, any additional rainfall will cause leaching of residual nitrate-N.

Nitrate contamination of ground water usually appears first where there is a shallow water table. A good example of this is the Central Platte Valley where the water table may be only 5 - 30 ft. below the land surface. The contamination problem has developed due to N application beyond crop needs over the past 30 years, together with excess irrigation. This has resulted in

substantial leaching of nitrate-N from the crop root zone, into the ground water.

Nearly 250,000 acres in the Central Platte had ground water with nitrate-N concentrations in excess of 10 ppm in 1974 (1)³, as shown by the darkest areas in Figure 1. The contaminated area increased to 450,000 acres by 1984 (cross hatched area in Figure 1) while the average concentration continued to increase by nearly 1 ppm per year (2). Today, over 500,000 acres are underlain by ground water with nitrate levels above the drinking water standard.

The initial contamination was centered in areas of sandy soils and shallow ground water, where travel time for nitrate was short, between the root zone and the water table. Today the contaminated area has expanded to include finer textured soils and areas where the water table is somewhat deeper. In such cases the travel time for nitrate to reach the water table is also greater, delaying but not preventing aquifer contamination. **In general, the deeper and finer textured**

³Numbers in parentheses refer to references and information sources tabulated at the end of this circular.

Concentration of Nitrate-Nitrogen in Groundwater

10 or more ppm Central Platte Region, Nebraska

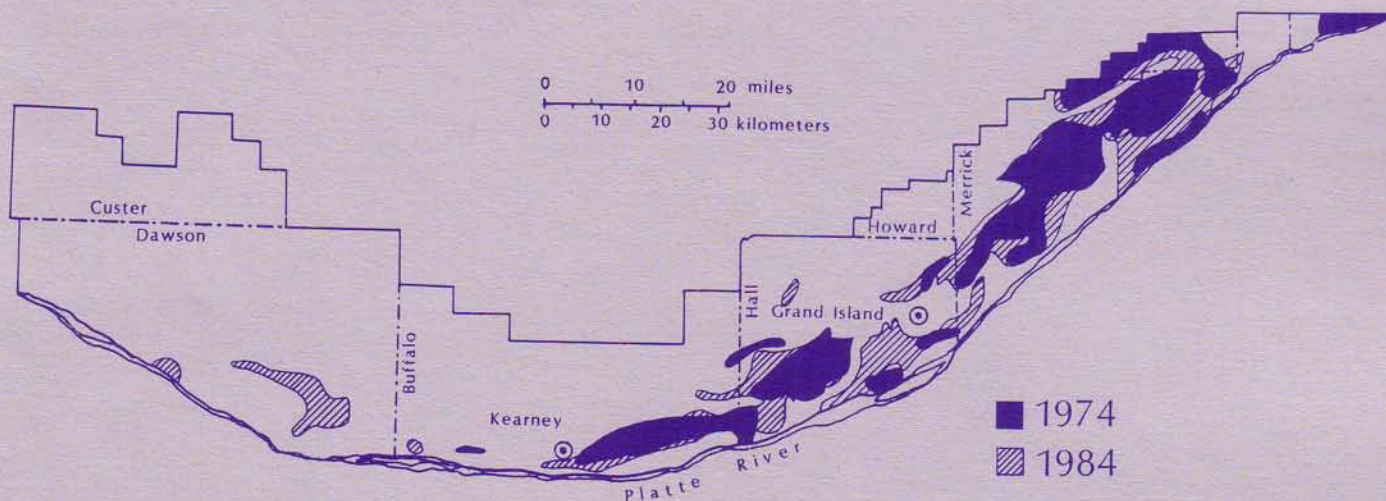


Figure 1. Map showing expansion of area of nitrate concentration in the Central Platte region between 1974 and 1984 (1) (2).

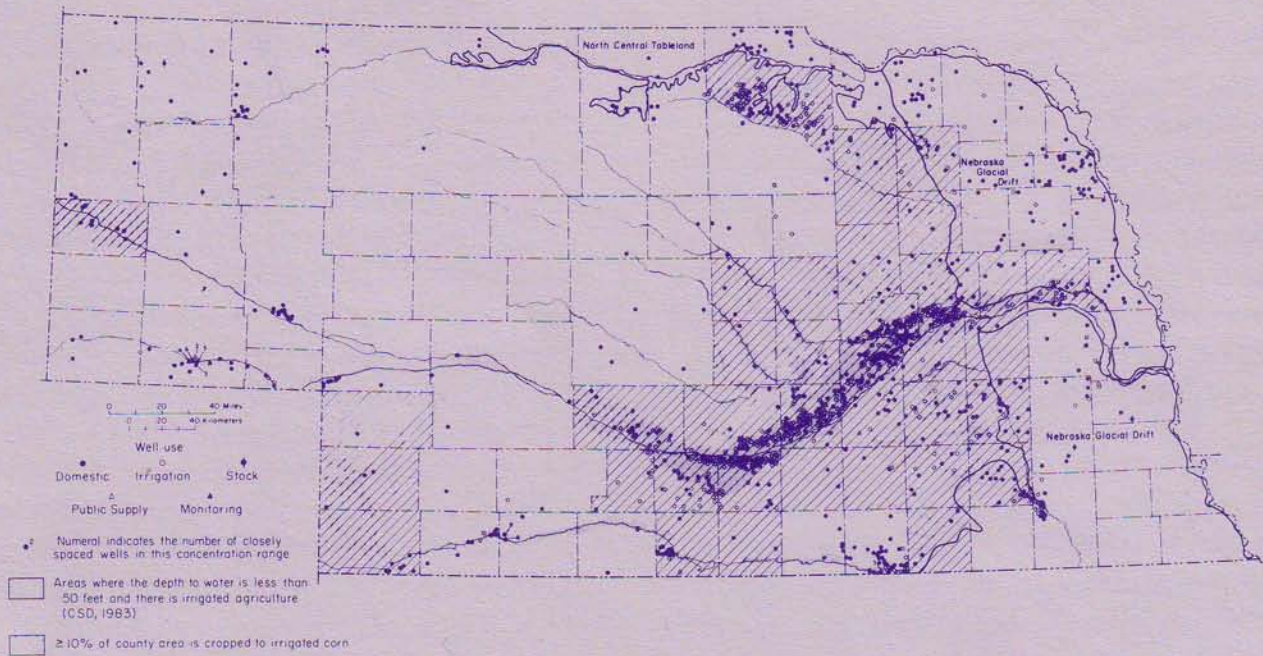


Figure 2. Locations of sampling wells where nitrate nitrogen concentration exceeded 10 ppm (3).

the vadose zone, the longer the delay between nitrate loss from the root zone and the accumulation of nitrate in the aquifer.

Since N fertilizers have been intensively used in corn production for the last 30 years, there are now a number of areas outside the river valleys where nitrate-N concentrations in the ground

water are increasing. Figure 2 is a map showing the location of wells where concentrations were above 10 ppm in a recent compilation of sampling results across Nebraska (3). The Platte Valley stands out, as well as northern Holt County, where most intensive corn production is on sandy soils. However, many wells in South

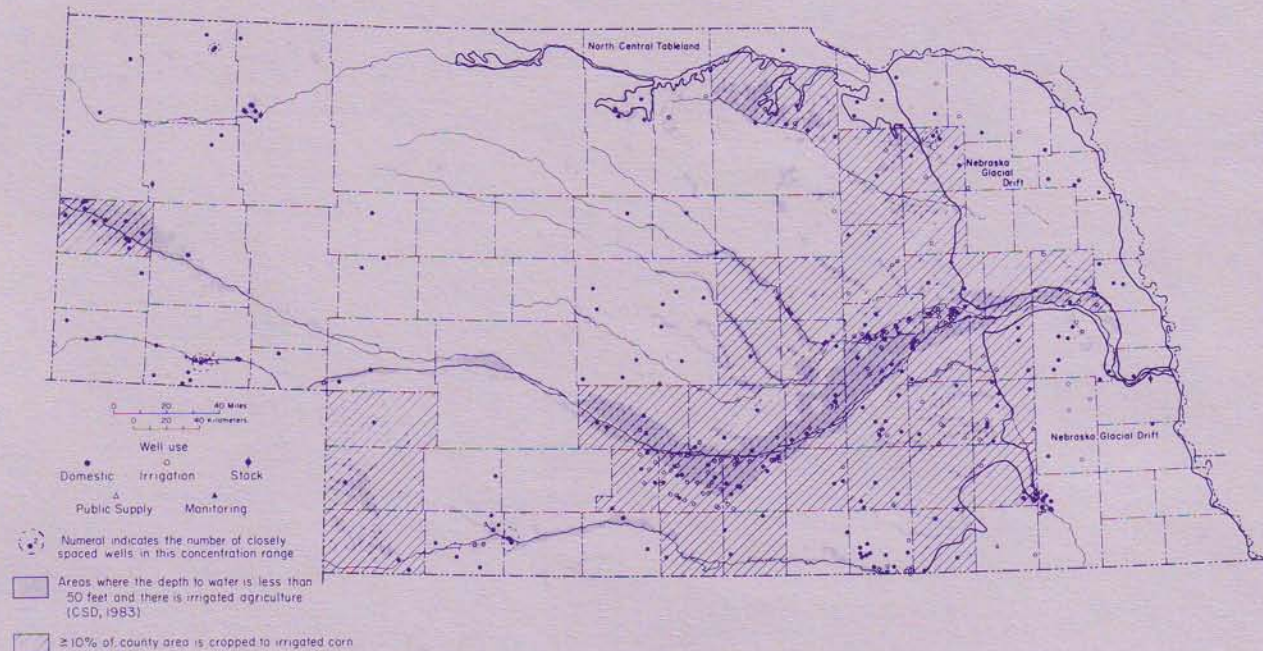


Figure 3. Locations of sampling wells where nitrate nitrogen concentration was between 7.5 and 9.9 ppm (3).

Central Nebraska are also beginning to show increasing nitrate-N concentrations, as well as smaller numbers in other locations.

There are also a number of wells with increasing nitrate-N levels which haven't yet reached the 10 ppm safe drinking water limit. Figure 3 shows the location of wells where nitrate-N concentrations are between 7.5 and 9.9 ppm. This highlights a very significant, potential future problem south of the Platte, when nitrate-N now in transit through the vadose zone eventually enters the ground water.

Impact of Soil, Vadose Zone and Aquifer Conditions on Nitrate-N Movement and Build-up

The following three examples will help clarify questions of travel time for nitrate-N leaving the root zone to reach the aquifer and time required to contaminate an aquifer. All are for irrigated corn production under different condi-

tions. **In all cases a leaching loss from the crop root zone of 50 lbs/ac of nitrate-N per year is assumed, with a total deep percolation loss of 10 in. per year** (combined irrigation loss and excess winter and spring moisture).

The percolation and N loss estimates are for average management under Nebraska conditions. Research has shown an average N loss of 5 - 10 lbs/ac for each inch of deep percolation when recommended N fertilizer amounts are applied, depending on irrigation management (4). Higher N amounts increase the N loss per inch of percolation. Excess irrigation amounts increase total N loss. **We emphasize that the situation in a given field may vary considerably from the examples.** Their purpose is to show how a given rate of loss of water and nitrate-N may have very different short-term impacts on water quality, depending on vadose zone conditions. Actual vadose zone conditions may also be more complicated than assumed here. The three example situations are pictured in Figure 4 and are de-

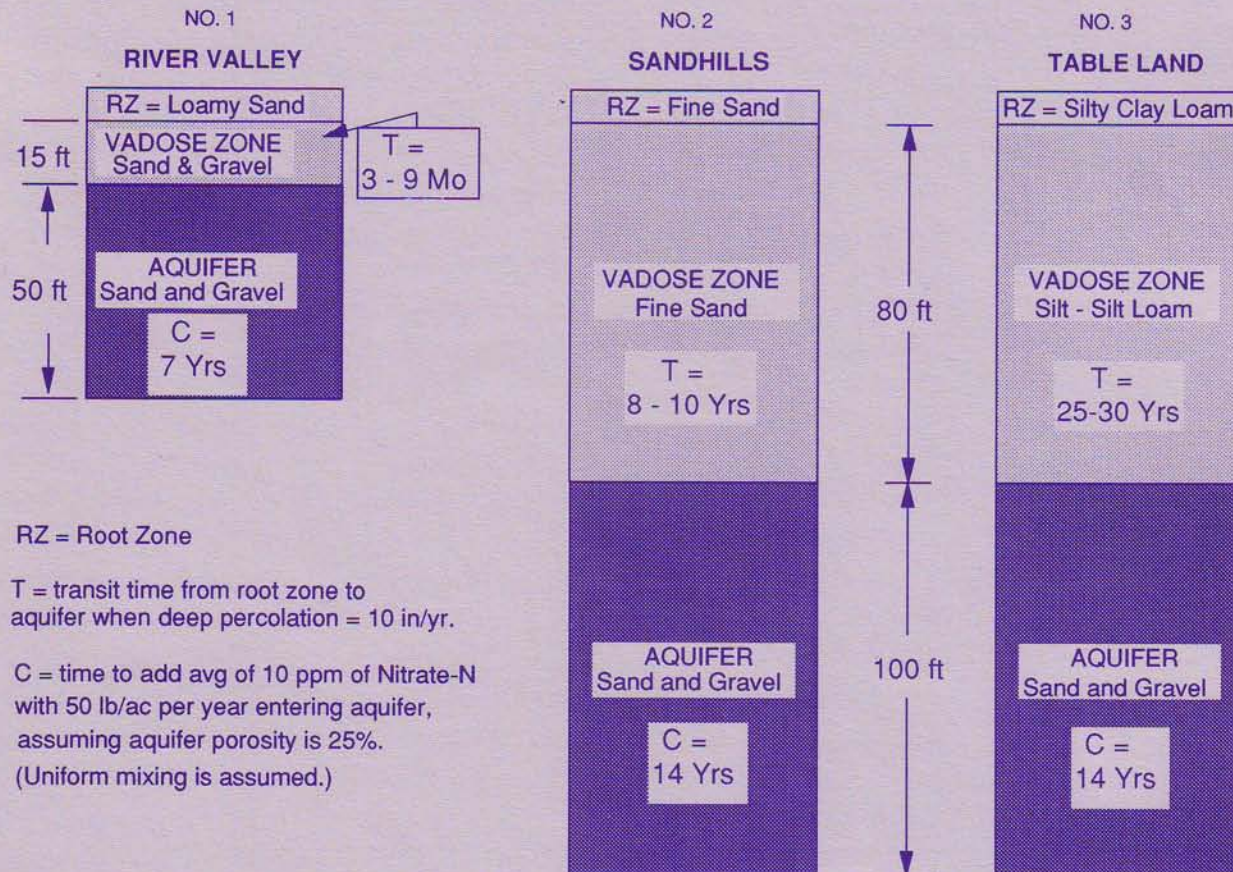


Figure 4. Summary of nitrate-nitrogen transit times and aquifer contamination times for three example situations.

tailed in the paragraphs which follow. A summary is presented in Table 1 at the end of this section.

Example 1—River Valley Situation: Travel time to the shallow aquifer is fast because of the short distance and porous vadose zone material. Only a few weeks are required for nitrate-N to move from the root zone to the water table. Since the aquifer is thin, it has relatively little storage capacity. As a result, concentration within the aquifer can increase quickly. If relatively rapid mixing in the aquifer is assumed, only about 7 years would be required to increase the initial concentration by 10 ppm.

In the Platte Valley, most of the soils are still furrow irrigated. Under average irrigation practice deep percolation may exceed 20 inches, more than double the assumed value of 10. Some irrigators put on as much as 4 inches of water every five days. Travel time to the water table is a matter of a few weeks at most. **Under these conditions, N loss may greatly exceed the assumed value of 50 lb/ac.**

Example 2—Sandhills Region: For a deep, sandy vadose zone in the Nebraska Sandhills, nitrate-N moves about 7 1/2 - 10 ft. per year with 10 in. of percolation. There is an 8 - 10 year delay from the start of N loss until the nitrate concentration in the aquifer begins to increase, because of the travel time through the 80 ft. vadose zone from the root zone to the water table. After that, it takes about 14 more years to increase the average concentration by 10 ppm of nitrate-N in a 100 ft. thick aquifer (with 25% porosity). **Growing season nitrate-N leaching losses may be less than the assumed 50 lb/ac with careful scheduling of pivot irrigation, or more if scheduling is haphazard. Off-season losses will be high regardless of irrigation scheduling if the N fertilizer rate is above crop needs.**

Example 3—Table Land (or loess plateaus): In these fine-textured soils, the delay

between the start of high N fertilizer applications and the beginning of aquifer contamination can be up to 25-30 years. Nitrate-N movement is on the order of 3 ft. per year through the vadose zone, with 10 inches of percolation. Since the aquifer thickness is assumed to be the same as in Example 2 (100 ft.), the contamination time would also be about 14 years, once nitrate-N began to arrive.

The long travel time for nitrate-N also stretches out the time between implementation of an improved practice and its impact on water quality. If all N loss from the root zone could be stopped as soon as the first year's loss arrived at the water table, and if the assumed 10 inches of deep percolation per year continued, the aquifer in this example would continue to show a concentration increase for the next 25+ years. This would add another 18-20 ppm to the nitrate-N concentration in the aquifer. Cutting the percolation in half would slow the rate of aquifer contamination. However, the main point is that contaminants already in transit will eventually enter the ground water, no matter what new practice is implemented at the surface.

If, for any reason, the amounts of deep percolation were increased in any of these examples, the transit times would decrease more or less in proportion. For example, if percolation loss is increased from 10 in. to 15 in. on the deep silt loam soil, the transit time would be cut by about one-third (i.e., from 30 years to 20 years, etc.).

Also, note that the time required to increase aquifer concentration **after** arrival of nitrate-N depends on the thickness of the aquifer and the nitrate loading rate. At a 50 lb/ac loss rate for nitrate-N, it took 7 years to increase the thin (50 ft.) aquifer by 10 ppm and it took double that time (14 years) to equally contaminate the 100 ft. thick aquifer. **Cutting the N loss rate stretches out the contamination time, while a higher N loss rate shortens the time, as compared to the calculations above.**

Table 1. Summary of Ground water Contamination Examples.*

<i>Factor Affecting Pollution</i>	<i>Example 1</i>	<i>Example 2</i>	<i>Example 3</i>
Location	River bottom	Sandhills	Table Land
Soil	Loamy sand	Fine sand	Silty clay loam
Vadose Zone	Sand and gravel	Fine sand	Silt, Silt loam
Distance from bottom of root zone to top of aquifer	15 ft.	80 ft.	80 ft.
Travel time to aquifer (years)	1/4-3/4	8-10	25-30
Thickness of aquifer	50 ft.	100 ft.	100 ft.
Time from initial pollution to increase average concentration in aquifer by 10 ppm (years)**	7	14	14
N lbs/ac added to aquifer to increase concentration by 10 ppm	340	675	675

NOTES:

* This table assumes an annual percolation loss of 10 inches per year and an annual N leaching loss of 50 lb/ac.

** This assumes a porosity of 25% in the aquifer. A greater porosity would increase the time and a smaller value would reduce it.

Contaminant Mixing in the Aquifer

In discussing aquifer contamination, we have assumed that the nitrate-N is "mixed" uniformly in the aquifer. In the real world there often tends to be a higher concentration in the upper part of the aquifer, as shown in Figure 5. Mixing usually occurs slowly, over a period of years, especially in relatively deep aquifers. Because domestic wells are often shallower than irrigation wells, household water supplies tend to tap the upper part of the aquifer, which is often higher in nitrate-N. An exception to this is the situation in thin, shallow aquifers (30-50 ft.). Mixing can be relatively rapid and uniform, as shown in Figure 6, particularly if there is a lot of irrigation pumping from the aquifer.

The Effect of Denitrification on Aquifer Contamination

There are a few locations where nitrate-N concentration in the aquifer has shown little change even though the N and irrigation manage-

ment practices and depth to the aquifer all indicate that there should be a problem. In general, study of these situations has shown that either the root zone or the subsoil has conditions that promote denitrification. Soil microbes convert all or part of the downward moving nitrate-N to N gases, which eventually return to the atmosphere.

Any time a soil is wet there can be a small amount of denitrification. However, for this to be a major factor in N loss, special conditions must exist. The soil microbes which carry out the denitrification process require a soil that is nearly saturated so that little oxygen remains in the soil pores (anaerobic conditions). In addition, there must be a source of organic carbon (organic matter) to supply energy for the microbes.

Denitrification is more likely to be important on fine-textured soils which remain wet for relatively long periods of time. This could occur during a long, rainy period or because of frequent and/or excessive irrigation.

Denitrification can also be a significant part of N loss in any soil where an impeding layer greatly decreases the downward drainage of ex-

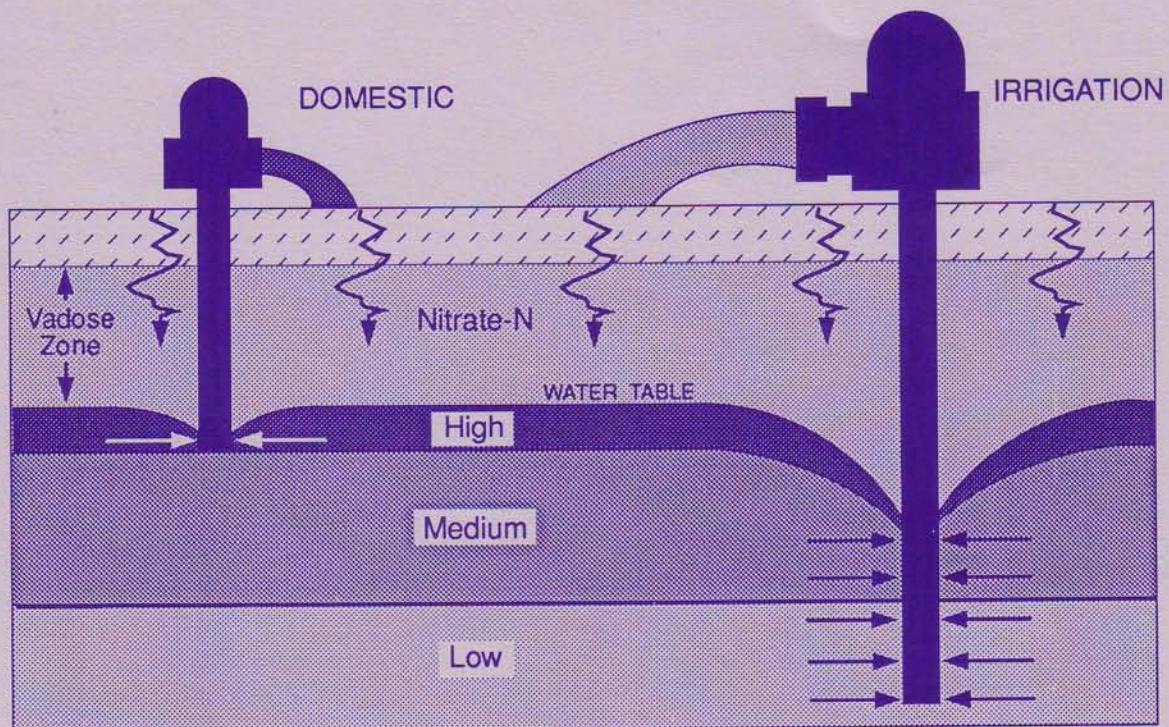


Figure 5. Stratification of nitrate mixing in a deep aquifer.

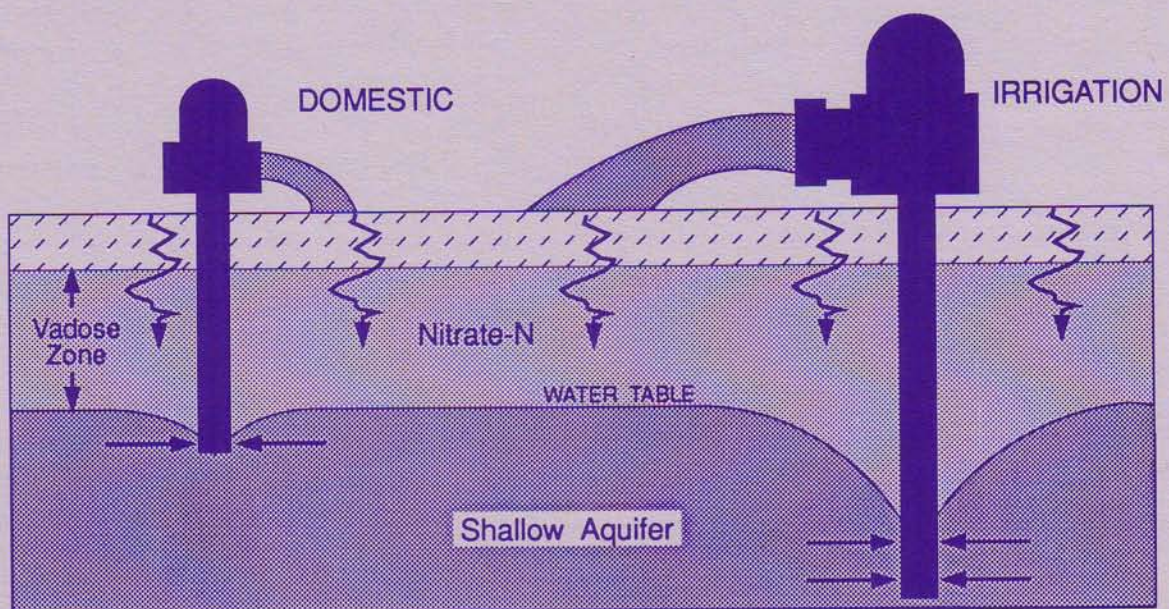


Figure 6. Nitrate may be well mixed in shallow aquifers with intensive irrigation pumping.

cess water. When the soil above the layer becomes nearly saturated so that oxygen becomes limited, and if there is a source of organic carbon, denitrification may remove substantial amounts of nitrate-N from the soil. Under such circumstances, management practices may have little to do with nitrate-N concentrations in ground water.

A condition where almost all nitrate-N in the lower root zone is lost by denitrification is relatively rare on irrigated lands in Nebraska. However, there are a number of locations where denitrification may decrease the amount of nitrate-N leached from the root zone. This will reduce but not prevent ground water contamination.

Effect of N Fertilizer Level

Above what N fertilizer level does N leaching become a serious problem? It's very difficult to give an ironclad response to this. It depends on the N mineralization rate of the soil, residual N

from fertilizer and organic sources, uptake of N by the crop, and the producer's water management. However, a long-term N study conducted at the South Central Research and Extension Center near Clay Center, Nebraska provides an indication for one set of conditions (5).

Continuous corn was produced on furrow-irrigated plots from 1971 through 1985, with the exception of two years when the plots were in soybeans. Nitrogen amounts of 0, 100, 200, 300 and 400 lbs/ac were applied as preplant ammonium nitrate on the same plots each year, when corn was produced. In 1986 soil cores were taken from the surface to a depth of 60 ft. (6). Results are shown in Figure 7.

Under 0 and 100 lbs. of N per acre, the N distributed through the subsoil is a relatively small amount (120 and 160 lbs/ac for these two rates). At 200 lbs/ac of N application, leaching losses increased significantly. Figure 7 shows approximately 280 lbs/ac being in transit to the water table at this N rate. Above this fertilizer level, subsoil N content becomes very high with

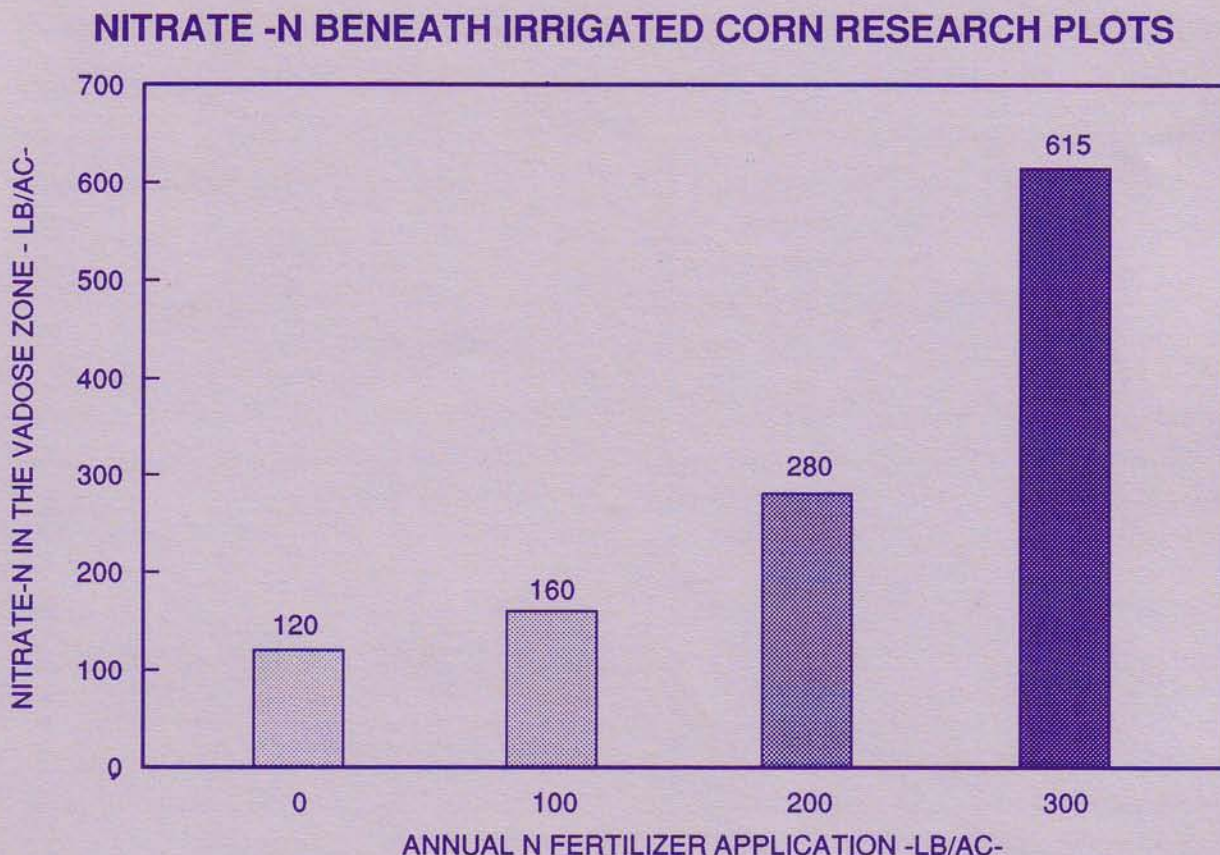


Figure 7. Nitrate-N in the vadose zone following long term N rate trials on irrigated corn at the University of Nebraska's South Central Research and Extension Center (6).

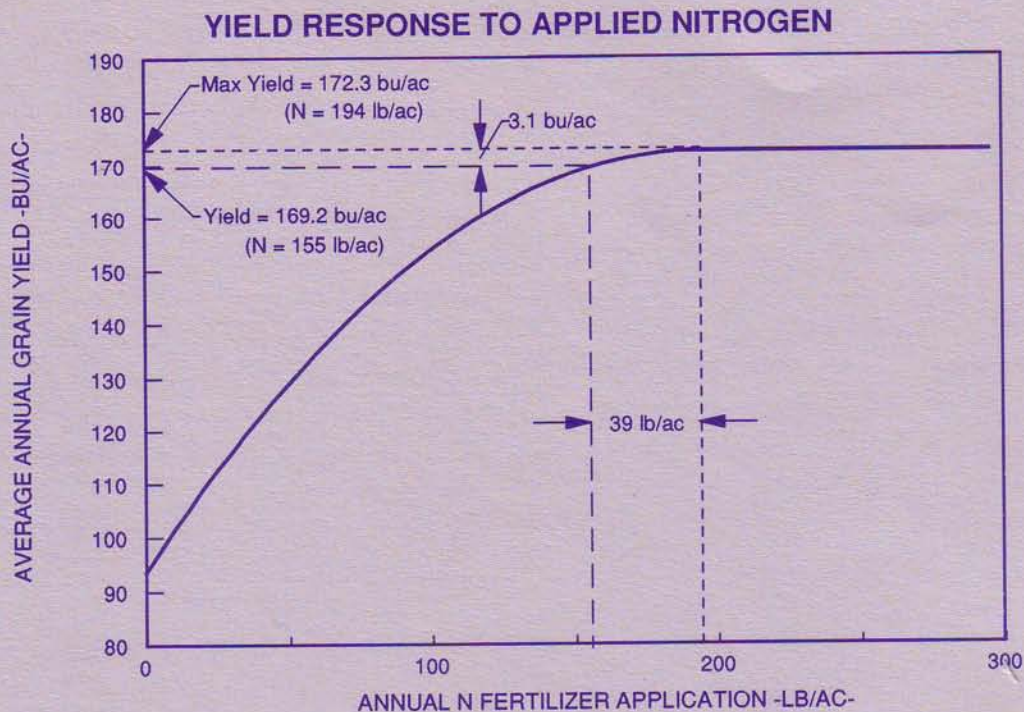


Figure 8. Nine year average of corn yield response to preplant application of ammonium-nitrate at the South Central Research and Extension Center (5).

about 615 lbs. in transit at the 300 lb. rate and over 1325 lbs. at the 400 lb. rate (not shown in the figure). In general it would appear that maintaining N rates below 200 lbs. helps hold down the leaching losses.

How is yield affected by different N amounts? Figure 8 shows a nine-year average yield response to N, for the experiment just described. The average maximum yield was 172.3 bu/ac, for an N application of 194 lb/ac. There was no yield response to N amounts greater than 194 lb/ac.

As yields approach a maximum practical level, larger amounts of N are required to produce each additional bushel of yield. As a result, N amounts can be reduced significantly below the requirements for maximum yield with little impact on economic yield. For example, a 10% reduction in N (194-175 lb/ac) results in only 0.3% yield reduction (172.3-171.7 bu/ac). Cutting N by 20% (194-155 lb/ac) reduces yield by less than 2% (172.3-169.2 bu/ac).

In this experiment all N was applied preplant. Other recent work at the same location has shown that optimum yields (190+ bu/ac) can

be obtained with only 135 lb/ac of N applied as sidedress anhydrous ammonia, when sprinkler irrigation and irrigation scheduling are used to minimize in-season leaching losses of nitrate-N (7).

Results from On-Farm Sampling

On-farm data collected by Cooperative Extension and Soil Conservation Service personnel in Hamilton County give an overview of nitrate-N in the vadose zone for a wide range of management situations (8). Soil samples were collected from 0-25 ft. under several center pivots and surface irrigated corn fields. Samples were also collected in an unfertilized pasture for comparison.

The results (Figure 9) show 447 lb/ac of nitrate-N in the top 25 ft. of soil under center pivots, with 80% being below root zone depth and, therefore, in transit to the water table. This compares with 79 lb/ac to the same depth under the pasture. This shows clearly that pivot irrigators are not immune from substantial nitrate leaching losses. Excess N application

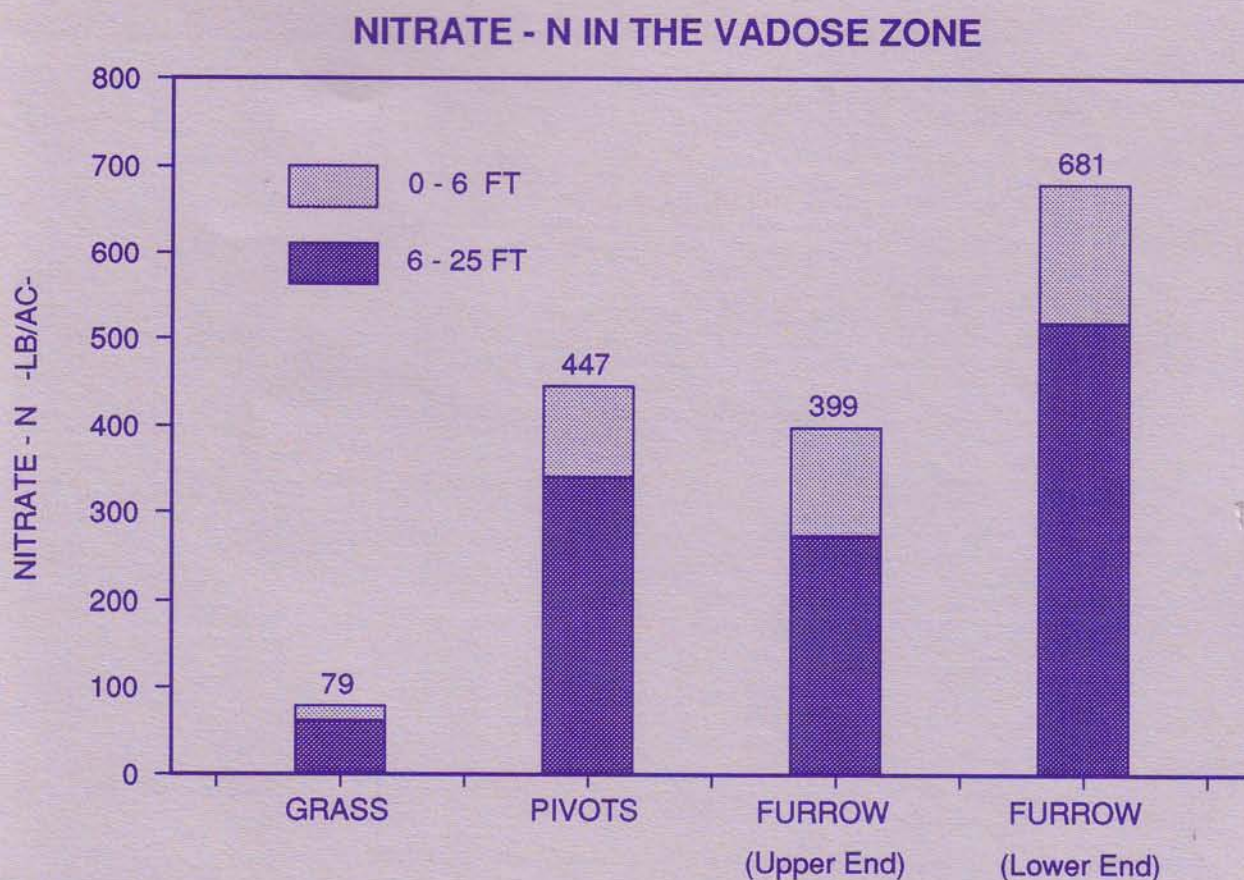


Figure 9. Average lb/ac of nitrate -N in deep soil samples under 4 center pivot and 10 furrow irrigated corn fields in Hamilton County (8).

combined with excess rainfall and/or irrigation causes N loss under sprinkler irrigation just as it does under furrow irrigation.

The amount of nitrate-N in the soil under furrow systems depended on location in the field. The total nitrate-N in the 25 ft. profile averaged almost 400 lb/ac at the upper end and 680 lb/ac at the lower end. This difference is the result of more infiltration and leaching at the head of the field, as compared to the lower end. The greater intake opportunity time at the upper end of the field during a typical irrigation almost always results in a non-uniform water distribution, with a high probability of deep percolation.

This can be seen more clearly in Figure 10, which shows nitrate-N concentration profiles to a depth of 80 ft. in a silt loam soil, at the upper and lower ends of one of the furrow-irrigated fields with a 1/4 mile run. Concentrations in the soil

vary between 1 and 7 ppm.⁴ The total amount of nitrate-N in the profile averages about 700 lbs/ac across the field. This would be enough to eventually add over 10 ppm of nitrate-N to the ground water in a typical 100 ft. thick aquifer.

Figure 11 shows data for a furrow-irrigated field with a 1/2 mile run. At the upper end there are over 900 lbs. of nitrate-N in the profile and over 2400 lbs. at the lower end! Why the difference? Figure 12 shows that at the upper end, the 24-hr. set time has provided enough deep percolation to more or less continually flush nitrate from the root zone to the water table. At the lower end of the field the amount of percolation **during the irrigation season** is considerably

⁴1 ppm is about 3.6 lbs N/ac per foot of soil. If this were all dissolved in the soil water held in a silt loam at *field capacity*, it would result in a nitrate-N concentration of about 3 ppm in the water.

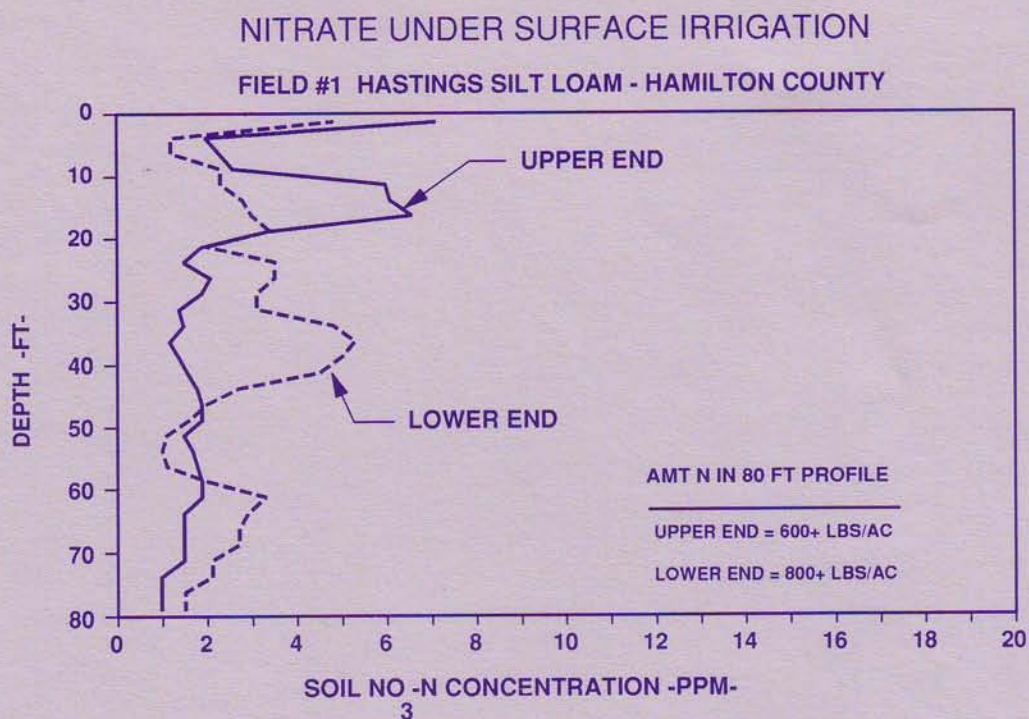


Figure 10. Nitrate-nitrogen in the vadose zone beneath furrow irrigated corn with 1/4 mile irrigation run; Hamilton County, Nebraska (Christiansen, 1988).

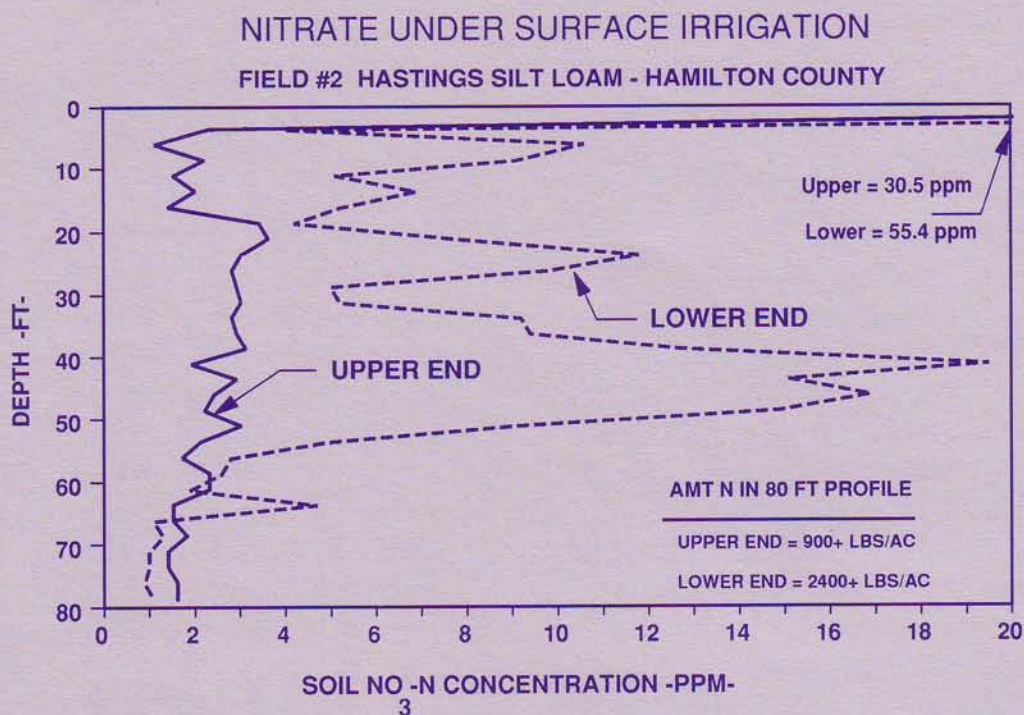


Figure 11. Nitrate-nitrogen in the vadose zone beneath furrow irrigated corn with 1/2 mile irrigation run; Hamilton County, Nebraska (Christiansen, 1988).

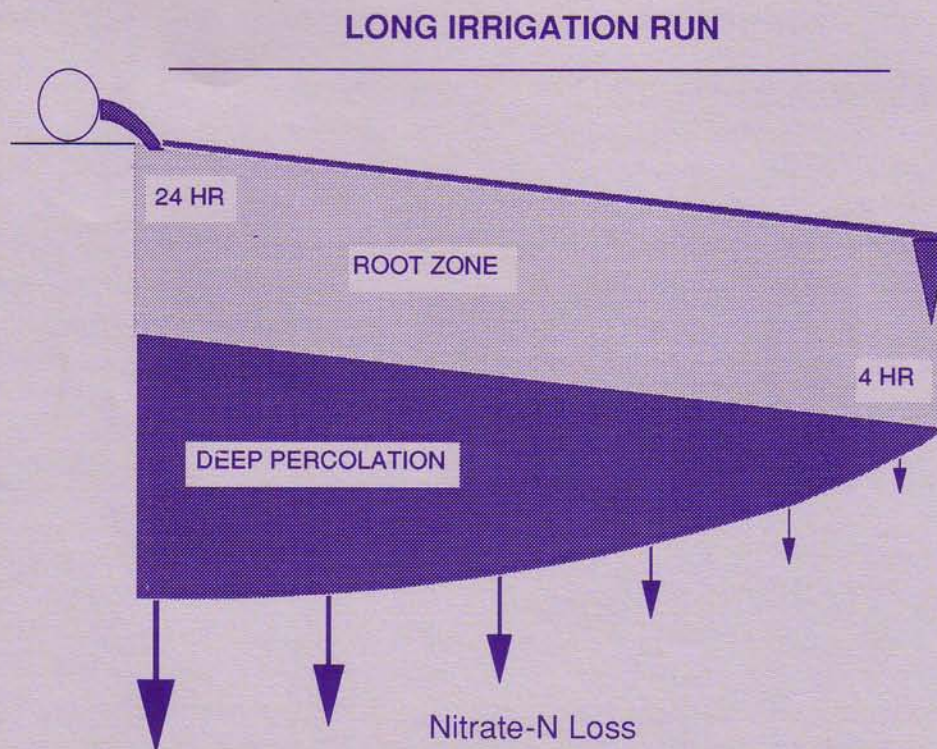


Figure 12. Leaching pattern for nitrate-nitrogen during the irrigation season, for long set times and/or long irrigation runs.

less, resulting in minimum in-season N losses.

N losses may occur during the non-growing season. Deep percolation, such as may occur in a wet spring, is often sufficient to move some or even most of the residual nitrate-N into the vadose zone, as shown in Figure 13. That loss will often be greater at the lower end of the field since residual N is usually higher there at harvest.

In general, the amount of off-season percolation at the lower end will be less than in-season amounts at the upper end of the field. The net result is a slower downward movement of nitrate-N at the lower end of the field. There, a substantial amount of the nitrate-N leached from the root zone over the last 20+ years is still in the vadose zone, in transit to the ground water.

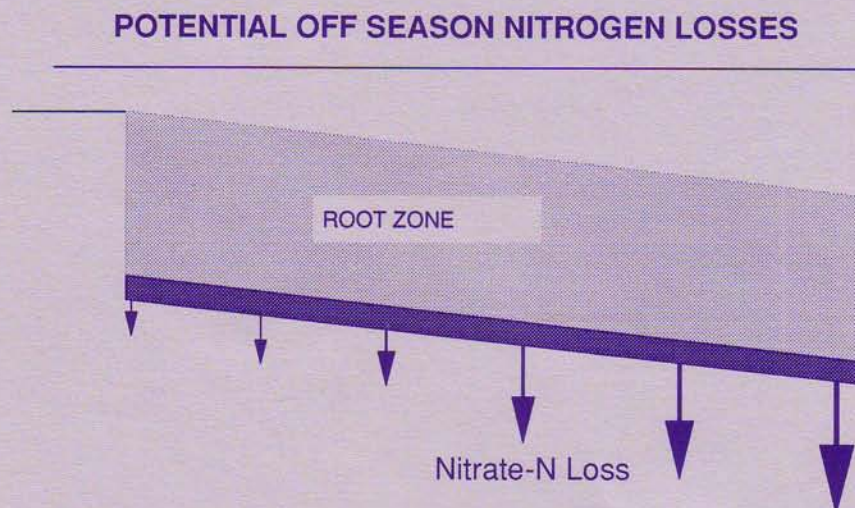


Figure 13. Off-season leaching pattern and potential off-season nitrate-nitrogen losses for the field of Figure 12.

An exception to this is where furrow irrigators block the end of the field and pond irrigation tailwater there instead of letting it run to a reuse pit. In such cases, the lower end of the field under the ponded area will have **maximum leaching during the growing season.**

The high amount of deep nitrate-N below the root zone in Figure 11 also suggests that in the past, N applications have been well in excess of crop needs. **Even when percolation amounts are relatively low, excess N applications will eventually result in substantial amounts of nitrate-N moving to the water table.**

In considering the rate of pollution build-up in the ground water, many operators don't have the "cushion" of build-up time shown in Table 1. Today ground water nitrate levels are usually not beginning at zero. They may already be well on the way to a problem, as indicated in Figure 3. In the case of the farm in Figure 11, the irrigation water was already at 14 ppm when the sampling was done. By the time the Nitrate-N in the soil profile is added to that in the aquifer, the concentration will increase by another 20+ ppm over the next 15-30 years.

In some situations a large part of the annual nitrate leaching loss can occur during the non-irrigation season. Nitrate-N leaching potential increases when (a) excess N remains in the root

zone at the end of the cropping season either due to excess N application or reduced crop yield due to weather, etc. and (b) especially if the soil moisture reservoir is near field capacity at the end of the growing season and/or there is above-average precipitation from September to the following June. This makes it very important to schedule the last irrigation early enough to let the soil dry down near the end of the growing season. It not only reduces irrigation costs, but N leaching as well.

Impact of Furrow Irrigation Management on N and Water Loss

Water distribution is seldom if ever uniform along an irrigated furrow. The time water is over a given point (and consequently the time available for intake at that point) is different for every point along the row. The nonuniformity is further increased because soil intake characteristics vary from one location to another in the field.

In spite of this "natural" nonuniformity, the way surface irrigation is managed has a major impact on how much deep percolation and nitrate leaching will occur, and where it occurs in the field. Poor land preparation, failure to match set time and flow rate to row length, and failure to manage tailwater can greatly add to the amount

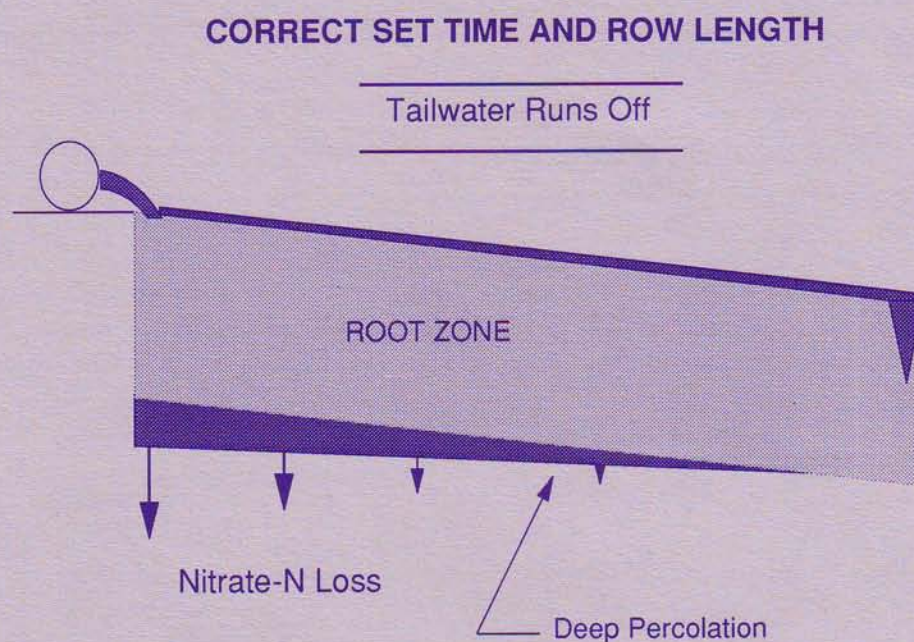


Figure 14. Seasonal percolation and nitrate-N loss pattern for well-managed furrow irrigation.

CORRECT SET TIME AND ROW LENGTH

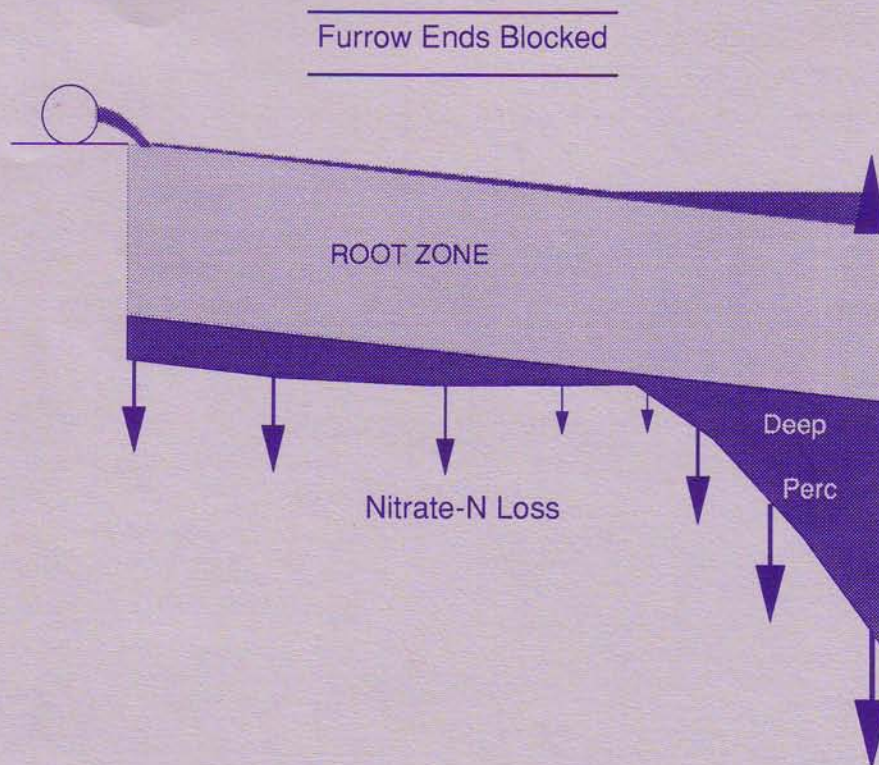


Figure 15. Seasonal percolation and N loss pattern for the system of Figure 14, when furrows are blocked.

of water and N lost from the bottom of the root zone. The paragraphs and figures which follow describe some typical situations found in furrow irrigated fields in Nebraska.⁵

1. OPTIMUM—Set time and flow rate OK; tailwater reused:

Figure 14 shows the water and nitrate-N loss pattern for a furrow system where set time, and flow rate are matched to row length, and where a tailwater recovery system is used. This loss represents the combined effect of all irrigations applied during the season. It assumes that during each irrigation, runoff is allowed to continue until intake at the lower end of the field refills the root zone, while the reuse system recovers the tailwater. At the upper end of the field there is more intake because water enters the soil there during all the time it takes for the furrow stream to run through the field as well as during the time it takes to fill the root zone at the lower end.

Over the course of a growing season, there is likely to be a small amount of deep percolation and leaching at the upper end of the field. Under most circumstances, the losses would be relatively small because a relatively rapid advance through the field reduces the difference in intake opportunity time from one end of the field to the other. **For this type of system the general rule is that the greatest leaching losses will be at the head of the field, where the intake opportunity time is the greatest.**

An exception to this pattern can be found under carefully controlled surge irrigation, particularly when used on an every-other-row basis. It is possible to irrigate and apply less than the amount required to refill the root zone. In such case, the percolation resulting from irrigation could be essentially zero.

2. Set time and flow rate OK; furrows blocked:

The picture changes a great deal when the furrow ends are blocked to hold back the tailwater, as shown in Figure 15. When this happens,

⁵For more information on furrow irrigation management, see NebGuide G91-1021, "Managing Furrow Irrigation Systems."

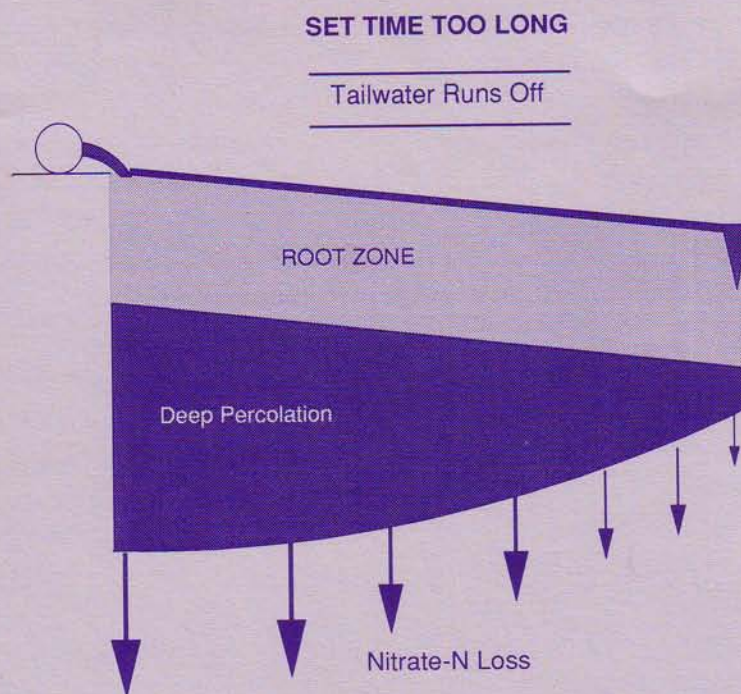


Figure 16. Effect of too long a set time on deep percolation and nitrate-N loss.

most of the water ponded at the lower end will drain on through the root zone, taking nitrate-N with it. If water is cut off too soon at the head of the field in order to reduce the ponding at the bottom, an under irrigated area may appear in the lower 1/3 of the field, just upstream from the

ponded area caused by the furrow block. When the irrigation set time is well matched to row length and the furrows are blocked, the largest amounts of percolation and nitrate leaching will be at the lower end of the field.

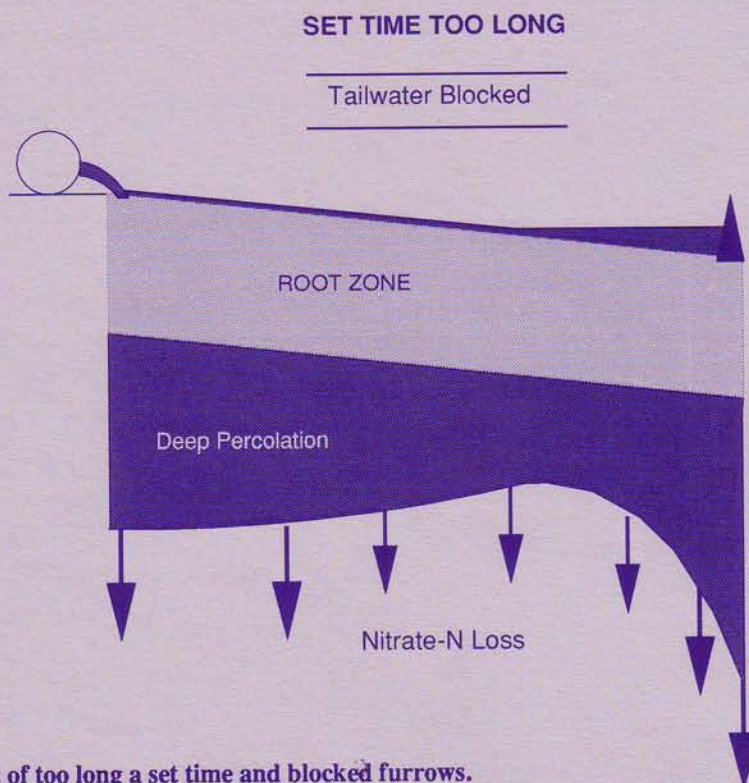


Figure 17. Combined effects of too long a set time and blocked furrows.

3. Set time too long; tailwater reused:

When set time is too long, there is water and N loss along the entire length of the field, as shown in Figure 16. If tailwater is reused, the pattern follows the general rule for unblocked furrows, the greatest loss is at the upper end of the field. This is typical of irrigation sets that are always 12 or 24 hours long, no matter what the field conditions.

4. Set time too long; furrows blocked:

This is a situation in which water and N loss is very high across the entire field (Figure 17). The maximum loss may be at either end of the field, depending on the amount of water that accumulates at the lower end. This typifies the type of practice that is seriously contaminating the ground water in the Platte Valley and in some other locations.

Managing Nitrogen and Water to Reduce Leaching

How can the nitrate contamination of our ground water be slowed or stopped? Clearly, steps must be taken to minimize N loss from the crop root zone. The question that must be answered is how to do so while maintaining profitable production. There are no absolute answers. However, there are some key points that must be considered.

1. Nitrogen loss is closely linked to the amount and timing of *both* water and N applications, with respect to crop needs.

Even with the best water management there is always a potential for some nitrate-N loss under irrigated corn production. Where irrigation is carefully managed during the growing season, in-season nitrate loss may be minimized (but will be greater than zero). Leaching losses of nitrate will

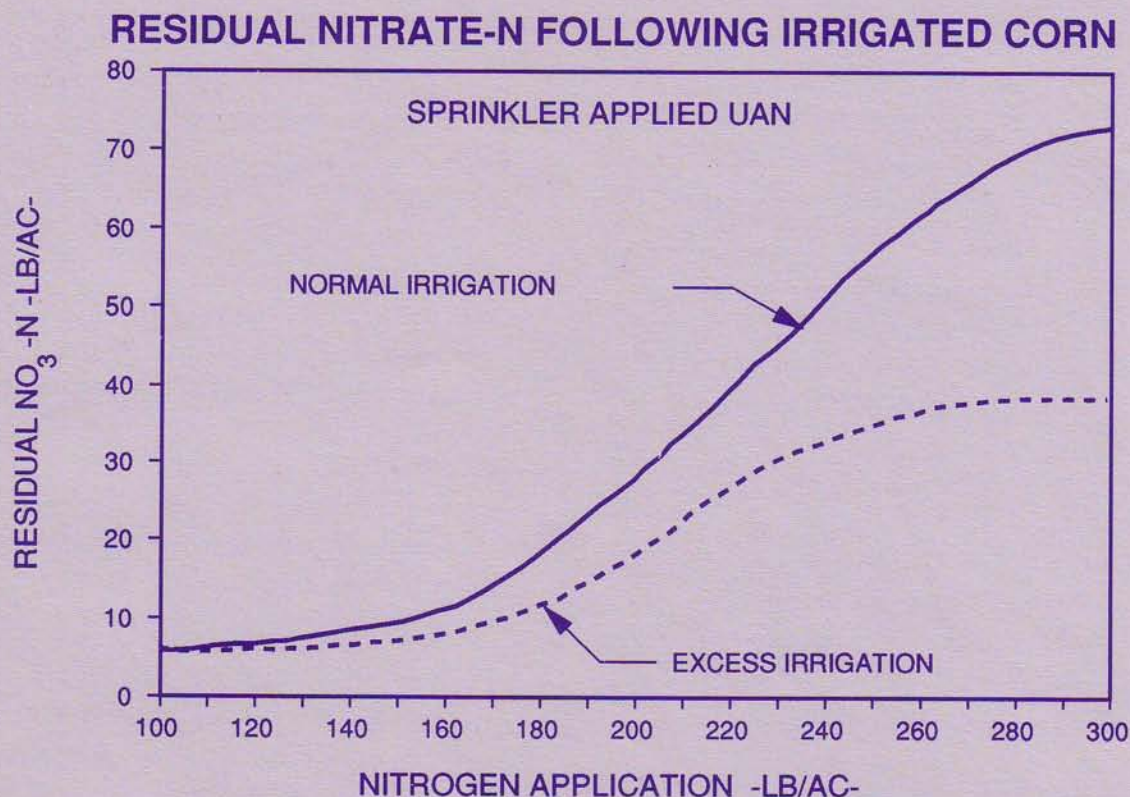


Figure 18. Residual nitrate-N to a 5 ft depth following irrigated corn, for two irrigation management levels, McPherson County (9).

most likely come during the off-season or at the beginning of the following growing season. They result from deep percolation following a wet period in the spring after the soil moisture reservoir has been refilled. A high level of soil moisture in the fall as the result of late irrigation accentuates the problem.

When N application exceeds requirements, the potential N loss goes up rapidly. This is illustrated in Figure 18 which shows, for different N fertilizer amounts, the residual nitrate-N following corn harvest on a deep, sandy soil (9). For good water management, residual nitrate-N increased rapidly beyond an N application of 150 lb/acre.

With excess irrigation, there was substantial in-season N loss even though fertigation permitted a delayed N application. Under the normal irrigation, some of the residual N remained in the root zone for use the following season. However, most was leached out in the spring, with the remainder providing a very minor benefit.

2. When residual nitrate-N is high at the end of the growing season, the potential is very high for off season nitrate loss.

Setting a realistic expected yield, accounting for all N inputs, then applying the recommended N to maximize crop uptake will greatly reduce this high N loss potential.

3. The total amount of N supplied to a corn crop should be based on expected yield, with *all* sources of N taken into account.

Total N needed for a given crop yield less N credits for all sources equals the amount of N needed from fertilizer.

The corn crop will utilize N from any source that is available.

Nitrogen in the soil is an important source for the corn crop. Since the N content of soils can vary greatly, soil samples must be collected and the amount available determined by soil test. This amount is a direct credit to the N needs of the crop.

Nitrate-N in irrigation water is another source of N for the crop. The amount supplied will depend on the concentration of nitrate-N in the water and the amount of water applied. This

estimated amount is subtracted from the total amount of N needed.

Nitrogen supplied by legumes, manure, sewage sludge, and other organic wastes should be estimated and that amount deducted from the total N needs.

4. Nitrogen fertilizer source and time of application are important in terms of minimizing the potential for N loss by leaching.

Sidedress application of N usually results in the most efficient N use by irrigated corn. This is because application is close to the period of rapid uptake by the crop. Leaching by pre-season rainfall is eliminated. All sources of N should be equally effective if properly applied. Application with irrigation water is effective and efficient. Although N can be applied in both furrow and sprinkler irrigation, it is easier and more commonly done with sprinkler. Furrow application, using present technology, is likely to result in a non-uniform distribution and runoff losses. Urea-ammonium nitrate solution is the most used source of N in irrigation water; however, other sources can be used.

Nitrogen should not be applied in the fall on sandy soils and only anhydrous ammonia is acceptable for spring preplant application on sands. Anhydrous ammonia is the only acceptable source of N for fall application on non-sandy soils and is the preferred source for spring preplant application. Application of N in the fall, particularly in the eastern half of Nebraska, has a higher risk of N loss by leaching as compared to spring or sidedress applications. Anhydrous ammonia should not be applied in the fall until soil temperature is 50°F or below. If soil temperature is higher than 50°F at the time of application, a nitrification inhibitor should be applied with the anhydrous ammonia to delay nitrification (conversion of ammonium-N to nitrate-N).

5. If excess irrigation is applied, it is highly likely that N will be leached from the root zone, even if fertilizer amounts are closely matched to crop needs.

Nitrate-N is quite soluble and moves readily with water. Every irrigation moves some nitrate downward within the root zone. Research data

clearly show that excess water flushes nitrate out of the root zone where it will usually be transported to the ground water. Sidedress application of N or fertigation will help reduce N loss. However, such technologies cannot eliminate nitrate leaching when irrigation amounts are too high.

6. Irrigation scheduling and water control are essential keys to reducing N loss.

Unfortunately, many irrigators are not sure how much water they are applying. A flow meter on a pump may turn out to be a very significant money saving device, as well as a means of gauging how much water has been put on and when excess may be contributing to pollution.

Scheduling for both sprinkler and surface systems and better water distribution in furrow systems is essential in reducing nitrate leaching losses.

7. Without careful scheduling, leaching can be significant under sprinkler irrigation.

Sprinkler irrigators have the potential to uniformly apply a controlled amount of water. This allows them to achieve a high irrigation efficiency and minimize in-season leaching. Sprinkler users are more likely to over irrigate early and again late in the season when they may overestimate crop water needs. However, during a season of normal or above normal rainfall, leaching can occur at any time, either because of starting too soon or because of a rain immediately following an irrigation. At a minimum, using the checkbook scheduling method⁶ or even the hand-feel method⁷ and a soil probe can give an indication of whether irrigation can be postponed a day or two (or longer).

8. Better timing of furrow irrigations can often eliminate one irrigation during the season and save several inches of percolation and associated N loss.

The same scheduling tools work for surface irrigators as for sprinkler irrigators. However, they need to use them in a different way.

In general, many irrigators (sprinkler or surface) tend to continue too long into the fall, leaving the root zone moist and, consequently, vulnerable to leaching by spring rains. A very substantial reduction in nitrate leaching loss can be obtained simply by allowing the soil to dry down some as the crop moves to maturity. Irrigating corn near to or after black layer is a total waste of water, N, labor and energy.⁸

9. Under furrow irrigation, more attention has to be paid to getting a more uniform distribution of water down the length of the field.

Land grading is a major factor in getting a better water distribution. On lands where the general slope is 0.2 percent or less, grading with a laser controlled scraper can make a big difference in assuring that the low spots and flat areas along the row are eliminated.

Surge irrigation is a tool that can improve the water distribution along the furrow and reduce runoff as well.⁹ It often gets the water through the field with up to one-third less infiltration and with a more uniform distribution along the row. Surge on an every-other-row basis can further decrease N and water loss.

Once a suitable grade has been established, *every-other-row irrigation* will produce just as high a yield and cut water and N leaching losses significantly on medium and fine textured soils. Research has consistently shown these two methods give equal yields except on very sandy soils.

Techniques and equipment modifications are under development for incorporating fertigation with surge irrigation. This would permit delayed N application in furrow irrigation and reduce the amount of early season leaching losses that now occur when all N is applied preplant.

⁶See NebGuide G85-753, "Irrigation Scheduling Using Crop Water Use Data."

⁷See NebGuide G84-690, "Estimating Soil Moisture by Appearance and Feel."

⁸See NebGuide G82-602, "Predicting the Last Irrigation for Corn, Grain Sorghum and Soybeans."

⁹See NebGuide G91-1018, "Fundamentals of Surge Irrigation," and NebGuide G91-1017, "Application of Surge Irrigation."

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