University of Nebraska Cooperative Extension EC98-786-S

Managing Irrigation and Nitrogen to Protect Water Quality








Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Kenneth R. Bolen, Director of Cooperative Extension, University of Nebraska, Institute of Agriculture and Natural Resources

Contents

Foreword

Nonpoint source contamination of groundwater by nitrate-nitrogen is a growing problem across Nebraska. Each Natural Resources District (NRD) has developed a groundwater management plan which outlines actions to be taken to address this issue.

Producer education is a key component of many groundwater management plans. To help NRDs provide a quality educational program, The University of Nebraska Cooperative Extension has developed this manual. It outlines the knowledge base needed by producers to help reduce nonpoint source nitrogen contamination, while continuing to farm for a profit.

At the end of each section in this manual there is a list of publications that can be used for getting additional information on the topics discussed. These publications are NebGuides, NebFacts and Extension Circulars published by University of Nebraska Cooperative Extension. Some of these publications may also be referenced directly in the text. All listed publications should be available from any local Cooperative Extension Office. NebGuides and Extension Circulars are also available by contacting University of Nebraska, Communications and Information Technology, P.O. Box 830918, Lincoln, NE 68583-0918. Most of the publications are also available on the Web, electronically accessed through the University of Nebraska Cooperative Extension home page:
http://ianrwww.unl.edu/ianr/coopext/coopext.htm

Section A

The nitrate contamination concern

Impacts on town and rural water supplies

Today, residents of cities, small towns and rural areas are having to deal with excess nitrate concentration in their water supplies. In Nebraska, much (but certainly not all) of the groundwater nitrate is the result of **nonpoint source** contamination coming from intensive production of irrigated corn. Nitrogen leaching loss from applied fertilizer and the spreading of manure is often increased by excessive applications and/or by over-irrigation. With improper management of nitrogen sources, *non-irrigated* crop production can also contribute to the problem. In addition, there are urban sources of contamination, including nitrate leaching from areas such as lawns and golf courses.

The U.S. Environmental Protection Agency has set a maximum contaminant level (MCL) of 10 parts per million (ppm) for nitrate-nitrogen in public water supplies. An increasing number of small towns and villages have to find alternative drinking water supplies or treat water to meet the 10 ppm standard. This is proving to be both difficult and costly. Although the users of private wells are not required to meet the MCL, they should monitor nitrate levels in the water supply. If nitrate levels are excessive, they will need to find alternative water supplies or use water treatment to assure that they have safe water to drink.

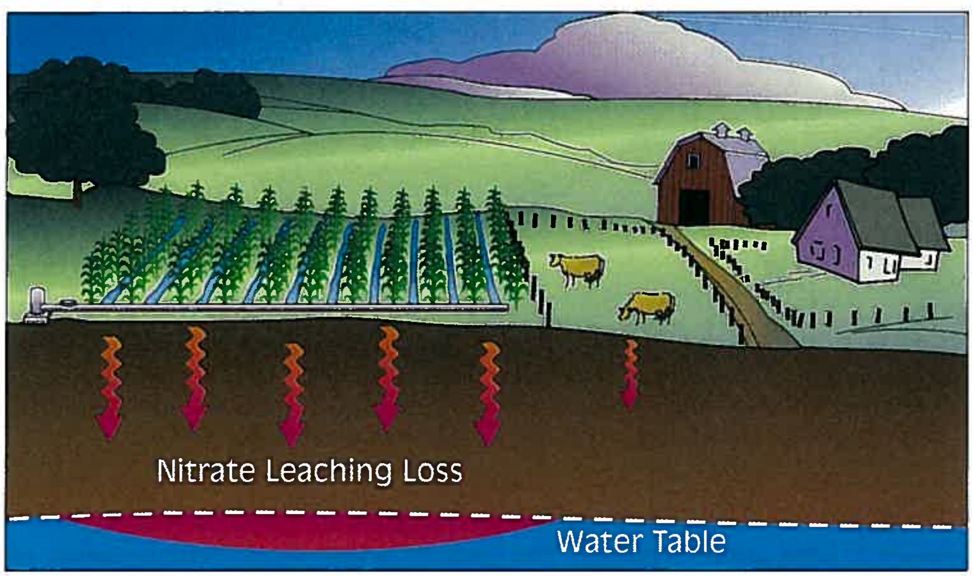


Figure A-1. Nonpoint source nitrate contamination of groundwater can come from intensive production of irrigated corn.

There are several health concerns related to consumption of high nitrate water. Methemoglobinemia (blue baby syndrome) in infants under six months of age is the only illness clearly caused by drinking water with elevated nitrate levels. Pregnant women and other adults with certain health conditions may also be at increased risk.The current 10 ppm standard was set to prevent the occurrence of infant methemoglobinemia and provides a reasonable margin of safety to do so. Other adverse health effects reported to be associated with drinking nitrate-contaminated groundwater include hypertension, clinical methemoglobinemia in older children, increased infant mortality, and birth defects of the central nervous system. None of these have been proven. There are also research findings that suggest that increased levels of nitrate in the drinking water may increase the risk of stomach, esophagus, and urinary bladder cancer. A recent report of research in Nebraska indicates that *long-term* exposure to elevated nitrate levels in drinking water may contribute to the risk of non-Hodgkin's lymphoma, a type of cancer. Elevated nitrate levels in livestock water can also be a concern.

Figure A-2 shows the location of wells where nitrate-nitrogen concentrations were above 10 ppm, in a recent compilation of sampling results across the state. 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 Central Nebraska, as well as a smaller but growing number in other locations, are also beginning to show increasing nitrate-nitrogen concentrations.

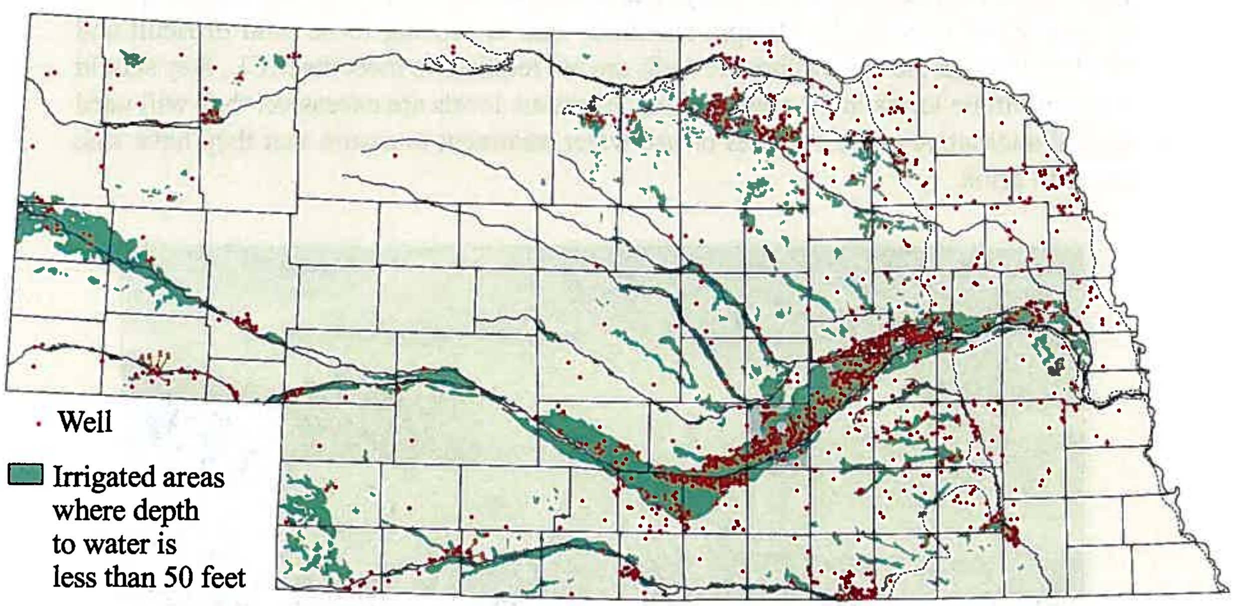


Figure A-2. Dots show where ground water nitrate-nitrogen concentration was above 10 ppm (from Occurrence of Pesticides and Nitrate in Nebraska Ground Water, *1990).*

Research suggests that the problem will continue to grow unless significant steps are taken by producers to limit nitrate leaching. The concern is that nitrate contamination will become a more widespread and serious threat to rural drinking water supplies. A major question that we have to deal with is how to protect groundwater quality while also meeting the needs of farmers to manage production to obtain a good yield and a reasonable profit.

Why does nitrate contamination of groundwater happen?

When nitrogen fertilizer, manure or some other nitrogen source is added to the soil, microorganisms gradually convert the various nitrogen forms to nitrate-nitrogen. Nitrate is highly soluble in water. Since the soil is a porous system, as water is added to the soil by rain or irrigation some nitrate will be leached (washed) from the root zone. Water moving through the soil and the subsoil will carry nitrate with it to the groundwater. If irrigation is excessive or if rain comes right after an irrigation, leaching losses of nitrate may be increased during the growing season.

A crop such as corn is unable to remove all available nitrogen from the root zone. Even if the crop is under-fertilized, there will be residual nitrate-nitrogen in the root zone at the end of the growing season. In addition, the crop's nitrogen fertilizer needs are different each year. The farmer never can know ***exactly*** how much to apply. The tendency is to err on the side of assuring adequate production and put on extra nitrogen. During the growing season, part of the excess can be leached by over-irrigation or rain. Some of the end-of-season residual can be pushed below the root zone by winter snow melt and spring rains.

Nitrate leaching occurs under both pivot- and furrow-irrigated fields. Figure A-3 shows the results of deep soil sampling in Hamilton County in the late 1980s. Samples were taken to a depth of 25 ft under four pivots and ten furrow systems, and under a field in permanent grass pasture. The 79 lb/acre of nitrate-nitrogen under the pasture came mainly from natural soil processes, not added fertilizer. In contrast, there was five times as much (447 lb/acre) in the top 25 ft of soil under the pivots. About 80 percent was below the root zone depth and, therefore, would eventually reach the water table. This clearly shows that there is loss of residual nitrate-nitrogen under sprinkler irrigation just as there is under furrow irrigation. If nitrogen applications are excessive, off-season losses can be high even if careful irrigation management is practiced.

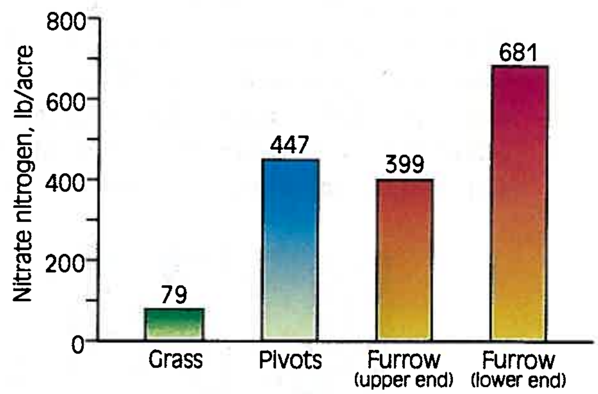


Figure A-3. Nitrate-nitrogen in the top 25 ft of soil below irrigation systems in Hamilton County.

The amount of nitrate-nitrogen under the furrow systems in Figure A-3 depended on location in the field. The total amount of nitrate-nitrogen in the top 25 ft averaged almost 400 lb/acre at the upper end of the field and close to 700 lb/acre at the lower end. The smaller amount on the upper end does not mean there is less loss there. There may be more. During furrow irrigations water is on the upper end of the field much longer than on the lower end. The additional infiltration and leaching at the upper end keeps the top 25 ft of soil material "washed" cleaner of nitrate, pushing it more quickly to the groundwater.

While nitrate loss cannot be stopped entirely, it can be reduced with good management. An increasing number of corn fields are now sampled every year for residual nitrate before planting, to help determine the right nitrogen fertilizer rate. Also a growing number of producers use nitrification inhibitors, sidedress, or fertigation applications and other steps to increase the efficiency of nitrogen use. Some irrigators are using improved technologies such as center pivots or surge irrigation to apply water more uniformly over the field. With good irrigation scheduling, these improved systems can significantly reduce excess water application and reduce nitrate leaching during the growing season.

Despite these improvements, in some locations substantial amounts of nitrate leaching and groundwater contamination are still occurring. Surveys in the Central Platte Valley show that 15 to 20 percent of the producers are still over-applying nitrogen, while a larger percentage of irrigators, particularly furrow irrigators, are over-watering. Similar problems are occurring in other parts of Nebraska.

Annual nitrate leaching loss amounts from sprinkler-irrigated corn

How much leaching loss of nitrate-nitrogen can be expected per year from irrigated corn with good water management? From 1991 through 1996, University of Nebraska researchers measured water and nitrogen loss from the root zone of sprinkler-irrigated corn on a deep, silt loam soil. They found annual losses ranging from 40 to 80 lb/acre of nitrate-nitrogen. This occurred with an average of 8 in./yr of drainage from the bottom of the root zone. This amounts to 5 to 10 lb/acre of nitrogen loss per inch of water loss. Yearly average concentrations of nitrate-nitrogen in the drainage water ranged from 22 to 44 ppm. This is representative of the range of loss expected under continuous corn production, when following a program of recommended nitrogen sidedress amounts and carefully scheduled sprinkler irrigation.

How long does it take for nitrate contamination of an aquifer to occur?

Nitrate contamination of groundwater has been recognized for many years in some of Nebraska's river valleys where nitrate leaving the crop root zone can move rapidly through the sandy subsoil. In this situation, nitrate can reach the shallow water table in a matter of weeks, or at most, a few months.

Today the nitrate problem is also beginning to appear in areas like South Central Nebraska, where the water table may be 75 to 100 ft or more below the surface and is covered almost entirely with fine-textured soil material. Some years ago people thought that these conditions would prevent aquifer contamination. We now understand that nitrate moves slowly in such materials, but it moves. In this case the travel time from the root zone to the water table may be 20 to 30 years or more. Continuous soil samples were taken from the bottom of the root zone to the water table under furrow-irrigated fields near Clay Center. The samples showed as much as 1300 lb/acre of nitrate-nitrogen in transit to the groundwater. The rate of movement was about 3 ft/yr, under good water management. For a water table at 75 ft below the land surface, the travel time would be around 25 years. If these data are representative of the area, the contamination problem may increase over the next 10 to 20 years, as the nitrate loss from previous growing seasons reaches the water table.

There are a few areas in Nebraska where subsoil conditions greatly limit or completely stop the movement of nitrate to the water table. Groundwater in these areas is not significantly affected by farming practices. Unfortunately, such areas seem to be the exception rather than the rule.

See these Extension publications for additional information:

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

Other reference material: "Occurrence of Pesticides and Nitrate in Nebraska's Ground Water" available from the University of Nebraska's Water Center.

Section B

Soil characteristics that influence nitrogen and water management

Soil characteristics vary across the landscape

We are all aware of the variability of soil from one field to another, and often within the same field. Soil differences certainly affect yield potential from one part of a field to another, and also impact how water and fertilizer have to be managed to maintain good production levels. Some important characteristics that change across a landscape include soil texture, organic matter content of the top 6 to 8 in., pH (how acidic or basic the soil is), and the thickness and density of the clay accumulation horizon.

Soils are formed by climate acting on "parent material" over long periods of time. The parent material can be rock that has weathered in place, or material that has been deposited by the wind, laid down by water, or brought in by glaciers. An area of soil that has the same parent material and has similar characteristics throughout is called a **soil series**. Different soils develop in a region as slope, drainage, vegetation and parent materials change (Fig. B-1).

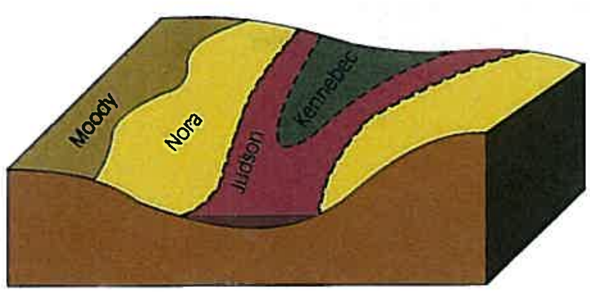


Figure B-1. Different soil series form as slope and drainage vary. The soil series changes from the top of the hill downward to the bottom land areas.

Some important features of a soil profile are shown in Figure B-2. Two features are particularly important to nitrogen management.

- The organic matter in the top few inches is a vast storehouse of organic nitrogen, which soil microbes slowly mineralize into a form of nitrogen that crops can use. The organic matter together with the clay particles in the "plow layer" holds many nutrients that are essential for plant growth. The amount of organic matter in the surface horizon also greatly improves the soil tilth.

- The clay accumulation horizon slows the rate of water drainage and nutrient loss from the upper root zone. This horizon can also limit root zone expansion if it is thick and/or compacted.

Not all soils show the characteristics shown in Figure B-2 to the same degree. Even in the same climate zone, the parent material and age of the soil make a lot of difference in soil characteristics. For example, compare two soils: a silty clay loam formed from fine-textured, wind-deposited material in South Central Nebraska, and a sandy loam formed from river deposits in the Platte River Valley. The silty clay loam has a thicker, high organic matter horizon, and a much thicker and denser horizon of clay accumulation. It also has much slower internal drainage, which means that nitrate leaching occurs more slowly. The silty clay loam also mineralizes more nitrate from organic matter over the growing season.

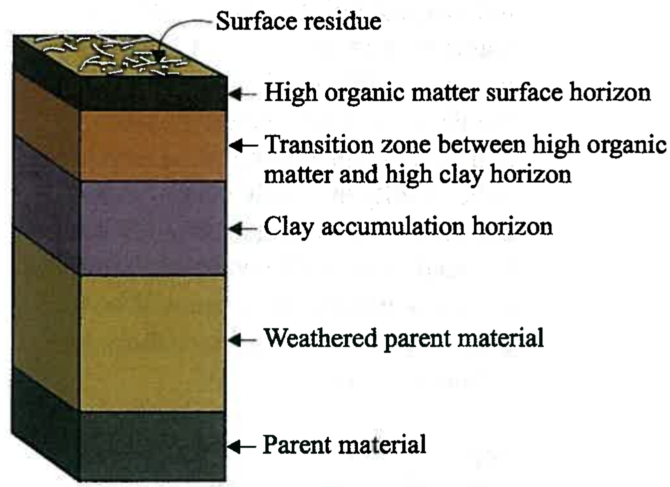


Figure B-2. Important features of a soil profile.

With all the differences between soil series and even within a soil series, in any field there can be variability in water intake, water movement and storage, and available nutrients within distances of only 10 to 20 feet. **If nitrate leaching losses from the root zone are to be held to a minimum, the characteristics of different soils and soil variability over the farm have to be considered in planning fertilizer and water management programs.**

Soil water storage and availability for plant use

To correctly estimate when to irrigate, farmers need to know how much **available water** the soil can hold and what percent of it is remaining in the soil. Water-holding capacity is determined primarily by soil texture, although soil structure is also important in fine-textured soils. Available water is the amount held by the soil between two limits: **field capacity**, the upper limit, and **permanent wilting point**, the lower limit.

Right after irrigation or rainfall, the soil water content may be temporarily above field capacity. However, in two or three days, the excess water drains away due to the pull of gravity. The soil water content is then at field capacity. At the other extreme, the permanent wilting point is the water content when the soil is so dry that the plants wilt and cannot recover. Below the wilting point there is still some water held in the smallest pores, but it's unavailable to plants. About half the water held between field capacity and permanent wilting is considered to be **readily available water**. In general, if a crop is irrigated by the time the readily available water in the root zone has been used, there will be no crop stress. These relationships are summarized in Figure B-3.

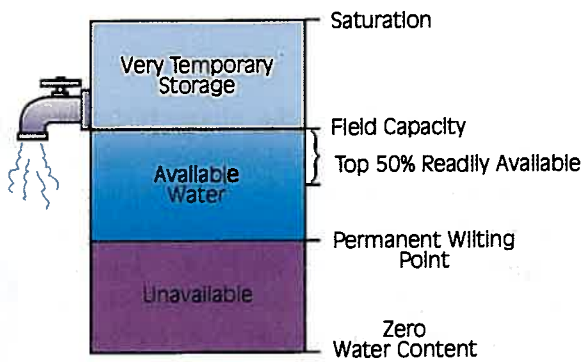


Figure B-3. Limits of soil water availability.

Table B-1 shows the amount of available water per foot of soil for a range of soil textures. These are only approximate values. Better estimates for individual soils can be obtained from the reports that come with county soil maps, available through the Natural Resources Conservation Service, the Natural Resources Districts, or the local Extension office.

In addition to water-holding capacity, the total amount of water available to the plant also depends on the depth of the root zone. If the first irrigation of corn is needed by the time the plants are 3 ft tall, the effective root zone may not be more than 2 ft deep (Fig. B-4). For later irrigations, scheduling is often based on the amount of available water remaining in the top 3 ft of the soil. Even though corn and soybean usually root to 4 ft or beyond, the water stored below the 3 ft depth is often managed as a "reserve," in case of problems with the irrigation equipment (Fig. B-5).

Table B-1. **Approximate ranges of available water held in soils of different textures**

Soil Texture	Available Water (in./ft) Range	Typical
Coarse sand and gravel	0.3 - 0.6	0.5
Sand	0.5 - 0.8	0.6
Fine sand	0.7 - 1.1	1.0
Loamy sand	0.8 - 1.2	1.1
Loamy fine sand	0.9 - 1.3	1.2
Sandy loam	0.9 - 1.5	1.4
Fine sandy loam	1.1 - 1.9	1.6
Loam	1.2 - 2.3	1.8
Silt loam	1.4 - 2.6	2.0
Silty clay loam	1.5 - 2.5	2.2
Clay loam	1.4 - 2.4	2.0
Clay	1.6 - 2.2	1.8

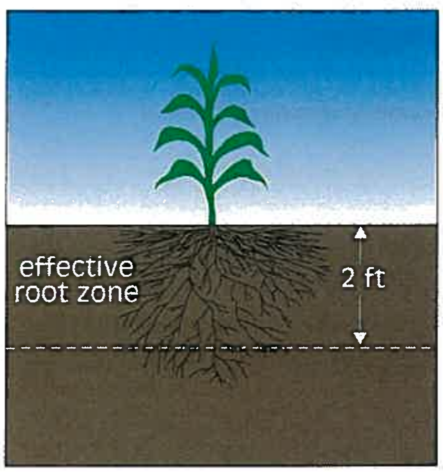


Figure B-4. The effective root zone may be shallow for the first irrigation.

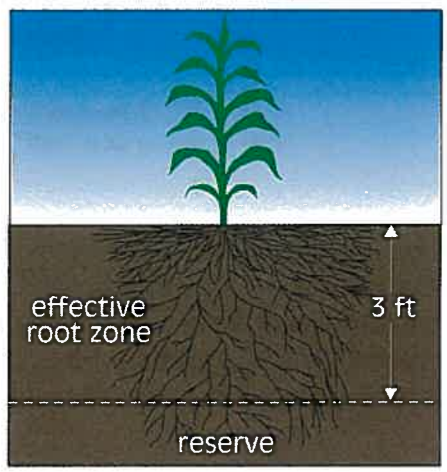


Figure B-5. The effective root zone is deeper later in the growing season.

Water infiltration rates

The performance of both furrow and sprinkler irrigation is greatly affected by the **infiltration rate** of water into the soil. (This is sometimes called the intake rate.) When water is first applied to a dry soil, it can enter the soil very rapidly. Depending on soil texture, the **initial infiltration rate** may be several inches per hour. However, it quickly begins to slow down. After a few hours it becomes more or less constant. This nearly constant rate is called the **basic infiltration rate**.

An example of this is seen in Figure B-6, which shows the infiltration rate at the upper end of a row being furrow irrigated on a Hastings silt loam soil. The example is for a "soft" (non-trafficked) furrow during the first irrigation. When water first enters the furrow, the **initial infiltration rate** at the top of the field is about 1.5 in. per hour. After 2 hours, it has decreased to 0.46 in. per hour and after 6 hours is close to the basic rate of 0.25 in. per hour. For a 12-hour irrigation, the total infiltration at the upper end of the field is 4.6 in. with a little over half coming in the first 4 hours.

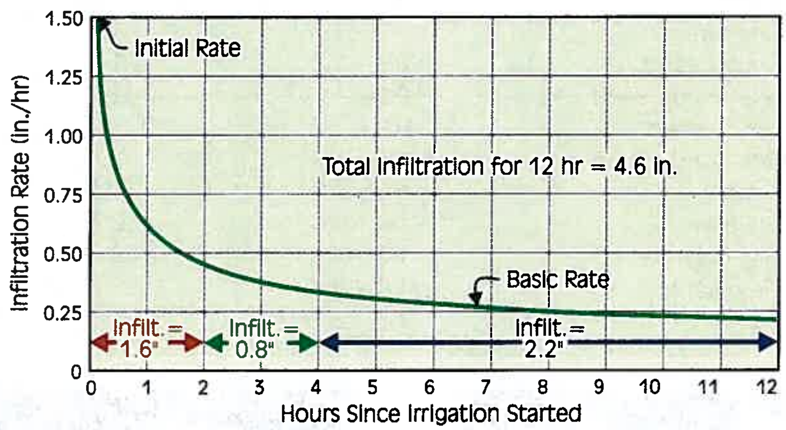


Figure B-6. Typical infiltration rate curve for Hastings silt loam, first irrigation on a "soft" row.

Infiltration rates can be very different from one soil type to another. Some typical infiltration rate curves for different soils are shown in Figure B-7. They have the same general shape, but the finer-textured soils usually reach their basic rate much faster than the medium- or coarse-textured soils. The basic rate for a very sandy soil may be higher than the initial rate for a very fine-textured soil.

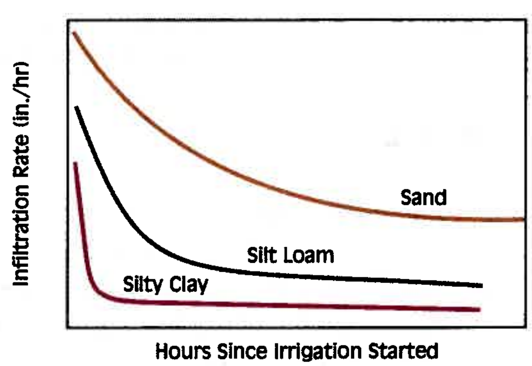


Figure B-7. Typical infiltration rates for different soils.

The infiltration rate can vary widely in the same field even when the soil "appears" to be uniform. The rate will often be very different for a wheel-track "hard" row, as compared to a non-wheel-track "soft" row. The infiltration rate will change from one irrigation to another, especially between the first and second irrigations. Decreases of 20 to 50 percent are typical. Infiltration rate is also affected by soil surface conditions (wet or dry, cloddy or smooth, cracked or solid, compacted or loose). Because of all this variability over time and space, it is not practical to assign a single infiltration rate value to a field. However, as will be shown in Sections I and J, it is important to understand how infiltration works, since it greatly affects both center pivot and furrow irrigation.

Infiltration rates also can change over a period of years. Residue that accumulates under ridge-till tends to increase infiltration rates. This reduces runoff under sprinkler irrigation, but can make it more difficult to get water to the end of the row under furrow irrigation. Generally, 10 to 12 years of ridge-till are enough to cause a major increase in infiltration rates.

Soil compaction

Most of the time, soil compaction complicates irrigation management, and can sometimes be a limiting factor in production. A typical soil has a density of 1.3 to 1.5 times that of water. When wheel traffic or tillage forms a compacted layer with a density of approximately 1.8 or greater, roots cannot penetrate it, and can only grow sideways. Even though roots can't grow further downward, water may still slowly pass through the layer. Water and nutrients moving below the compacted zone are effectively lost to the crop (Fig B-8).

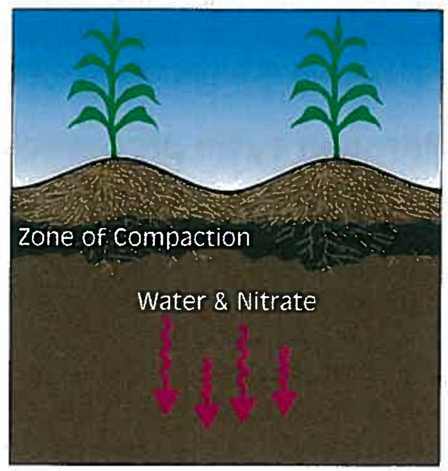


Figure B-8. Water and nitrate in solution can move below root zone restricted by compaction.

See these Extension publications for additional information:

G90-964	How Soil Holds Water
G87-831	Identification of Soil Compaction and Its Limitations to Root Growth

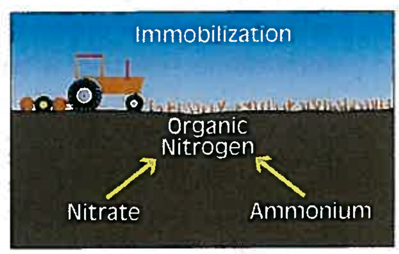
Section C

What happens to nitrogen once it is applied to the soil

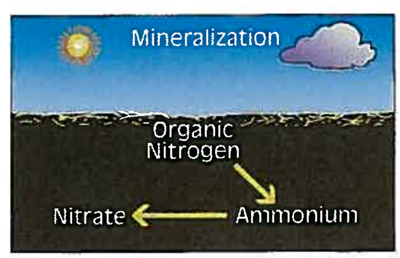
Nitrogen Cycle

All nitrogen resources in or added to the soil are subject to the processes in the nitrogen cycle. Some of these processes are beneficial to plant nutrition while others are not. For example, nitrogen in soils can be lost by leaching or escaping into the atmosphere (gaseous forms). Nitrogen in the soil can be in organic forms which are not available to plants, or in mineral forms which plants can use. Understanding the nitrogen cycle can provide insight and reasons for making management decisions on how much and when to apply supplemental nitrogen. The following paragraphs will introduce nitrogen cycle processes, and provide more detail on one, leaching.

Nitrogen cycle processes

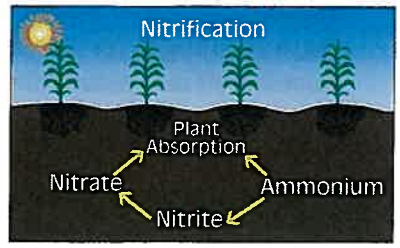


*1. **Immobilization:*** In this process the mineral nitrogen forms, ammonium and nitrate, are converted to organic nitrogen. Example: Corn stalks are tilled into the soil. This furnishes food (carbon) for soil bacteria which use the available mineral nitrogen to increase their populations rapidly. This process is sometimes called nitrogen tie-up. About 20 to 60 lb/acre of nitrogen can be immobilized for a short time period, perhaps 3 to 6 weeks. As stalk decay becomes more complete, plant available nitrogen will be released back to the soil.

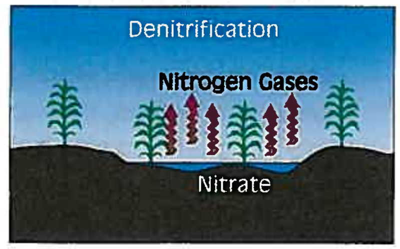


*2. **Mineralization:*** This is the conversion of organic nitrogen forms to mineral nitrogen. Very large amounts of organic nitrogen (up to several thousand lb/acre) are held in the top 8 in. of most soils. Nitrogen in this form is ***not*** available to plants. Nitrogen from the large soil organic pool (including recently decayed crop residue) is broken down by soil bacteria into ammonium. The rate at which the bacteria work depends on soil temperature. In the spring, as soils begin to warm up from their winter frozen state, the bacteria become increasingly active. By planting time, most Nebraska fine-textured soils will have mineralized 20 to 40 lb/acre of nitrogen. Soils with lower organic matter will mineralize less. This process continues through the summer and fall, slowing as soils cool.

3. Nitrification: This is the conversion of one form of mineral nitrogen to another. In this process the ammonium form is transformed into the nitrate form by soil bacteria. This key process is important in understanding leaching. Nitrogen in the *ammonium* form is held by clay and organic material and is *immobile*. The *nitrate* form is very *mobile* and will move with the water as it flows through the soil.

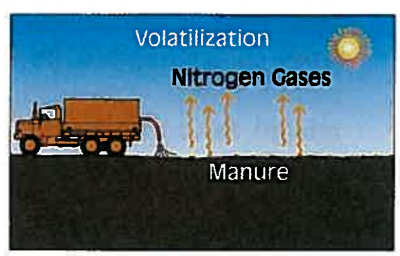


4. Denitrification: In this process mineral nitrogen in the soil is converted to gaseous forms of nitrogen that escape from the soil into the atmosphere. The amount escaping in any one year is extremely variable. Soils with more than 40 percent clay are subject to excessive denitrification if they are continuously wet for a number of days. The process is dependent on soil bacteria. Almost all denitrification takes place in very wet or compacted soils that have a limited oxygen supply. When there is no oxygen available, some bacteria are capable of using the oxygen from nitrate. Once the oxygen is stripped from the nitrate-nitrogen, the nitrogen escapes to the atmosphere as a gas. For example, extreme denitrification occurs in places where water stands for a couple of weeks. The very yellow leaves that develop on corn indicate that much of the mineral nitrogen has been lost.



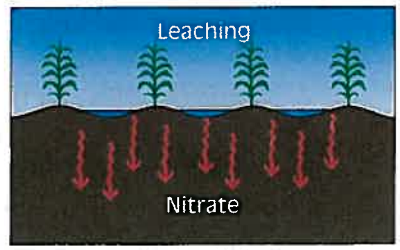
5. Fixation: Nitrogen gas in the atmosphere is converted into plant available forms through the process of fixation. This occurs naturally through *symbiotic fixation*, involving bacteria in association with legumes; *non-symbiotic fixation*, involving free-living soil organisms; and *industrial fixation*, the process by which fertilizers are produced.

6. Volatilization: Nitrogen forms on the soil surface can be converted to nitrogen gases that escape into the atmosphere. There are two ways nitrogen can volatilize. The first is through the loss of ammonia from either fertilizer or animal manures. The second is through the breakdown (hydrolysis) of urea. In both cases loss occurs when the material is left on the soil surface. Rainfall or sprinkler irrigation of 0.5 in. will move urea into the soil and minimize volatilization.



*7. **Surface runoff:*** Whenever water runs off land after rain or irrigation, the water carries sediment. Ammonium may be attached to the sediment and nitrate may be in solution in the runoff water. This physical process is another form of nitrogen loss from a field. Any practices that reduce runoff may reduce nitrogen losses. Incorporating any nitrogen resources that are applied to the field will reduce nitrogen losses by runoff, but may increase sediment losses because of reduced residue cover.

*8. **Leaching:*** Leaching is the physical transport of nitrate-nitrogen by water moving downward through the crop root zone. Application of nitrogen too far in advance of crop uptake will increase the risk of leaching. By avoiding poorly timed applications and excessive amounts of nitrogen and irrigation, crop growers can manage nitrogen in ways to minimize nitrogen leaching.



Leaching of residual nitrate

At the end of the growing season there is always residual nitrate-nitrogen in the soil. Almost all of it is dissolved in the water that is held in the pore space between the soil particles. When the water moves, nitrate moves. Consequently, the distribution of the residual nitrate through the soil profile at harvest time will depend to some extent on the method of irrigation and the care taken to manage the water correctly during the growing season.

In the fall, a typical distribution of residual nitrate under well managed sprinkler irrigation might look like the one shown in Figure C-1. There is a relatively high concentration in the surface four inches because of mineralization that continues after the crop has taken up most of its needs. In the middle third of the root zone there is also residual nitrate from spring-applied fertilizer. If there had been excess irrigation or rainfall, this zone of higher concentration would be deeper or more spread out.

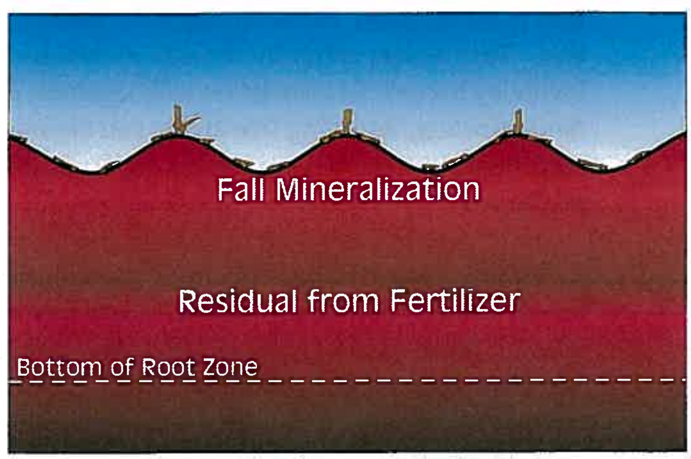


Figure C-1. Typical fall pattern of residual nitrate under sprinkler irrigation.

Under typical furrow irrigation, the nitrate from late season mineralization may be spread more deeply through the upper profile by harvest time, in comparison to a sprinkler-irrigated soil. This would be particularly true if very late irrigations are applied. The residual nitrate from spring-applied fertilizer will also be deeper in the profile, as shown in Figure C-2, if it has not been lost earlier in the season. In finer-textured soils, if good water management is practiced, the fertilizer residual will probably still be in the root zone. In any soils that are consistently over-irrigated, most of the residual nitrate from fertilizer may already be below the root zone, on its way to the groundwater.

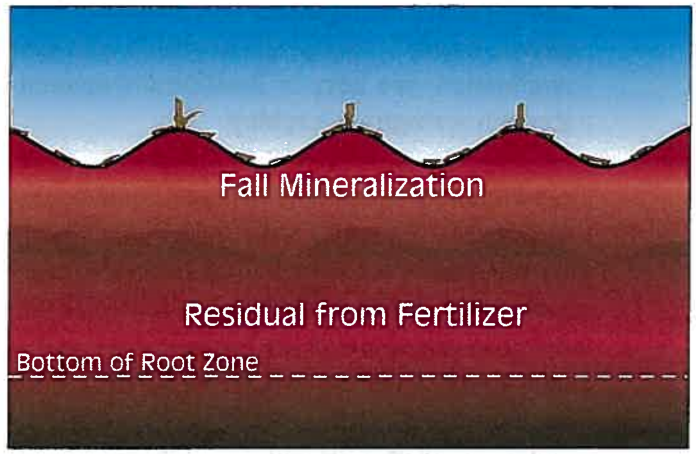


Figure C-2. Typical fall pattern of residual nitrate under furrow irrigation.

Winter and spring precipitation can cause nitrate leaching regardless of the irrigation method. If several inches of rain or snow melt enter the soil between fall and the end of the following May, a substantial part of the surface residual nitrate will move deeper in the root zone as the water drains through. In most cases the residual from fall mineralization will still be shallow enough in the spring to be available for the next crop. However, much of the deeper residual nitrate from the previous year's fertilizer may be pushed near the bottom of the root zone, or be so deep that it is unavailable for the next crop (Fig. C-3). The amount of residual retained within the root zone depth depends to a great extent on how much excess water moves through the soil. In very sandy soils, most fertilizer residual will be lost. Some of the residual from mineralization may also be lost if the springtime precipitation is high enough. Careful scheduling of the last irrigation can safely leave the soil drier in the fall. This leaves room to store part of the off-season precipitation, reducing springtime leaching loss. Under a well-managed sprinkler system, most leaching loss of nitrate occurs in the spring, before the irrigation season starts. This is mainly the loss of the residual nitrate from the previous year's fertilizer (Fig. C-3). During the irrigation season,

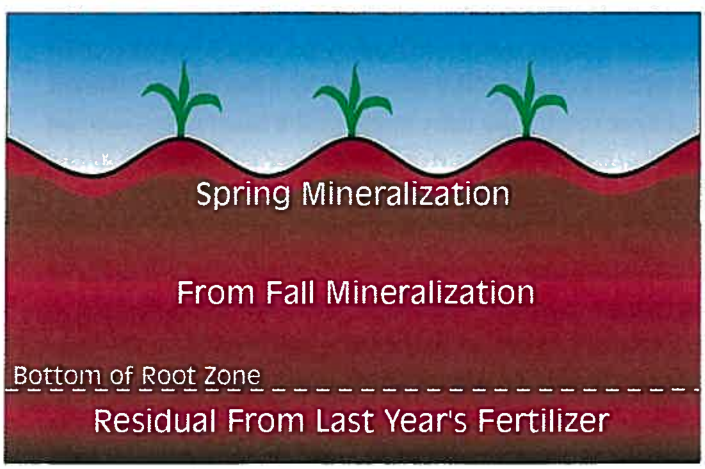


Figure C-3. Springtime residual nitrate pattern for sandy soils, or medium textured soils following a wet spring.

careful water management will minimize leaching unless there are extended periods of excess rainfall. Applying the proper nitrogen amount together with careful timing of application are keys to limiting the amount of residual fertilizer nitrate and its loss through springtime leaching.

Under furrow irrigation there may be both springtime nitrate loss and additional loss during the growing season. Often the first irrigation of the season is excessive. The root zone is shallow and the infiltration rate is high because the soil surface is loose. The result is a wetting pattern similar to that shown in Figure C-4. Much of the residual nitrate near the bottom of the root zone may be pushed out. Residual nitrate that was moved from the surface to the middle of the root zone by off-season precipitation may now be pushed toward the bottom by the excess irrigation. If excess water applications continue after the first irrigation, nitrate from spring applied fertilizer may also be lost.

Figure C-4. The wetting pattern under furrow irrigation may be deep and uneven especially during the first irrigation.

Movement of fertilizer nitrogen during the growing season

Most nitrogen fertilizer is eventually converted into nitrate by soil bacteria. Since nitrate is highly soluble in water, it goes where the water goes. However, not all of the water moves at the same speed. Some of the water is held in medium and larger sized pores and can move relatively fast. The rest of the water is held in the small soil pores and moves very slowly or may be trapped and not move at all.

Because of the way water flows, it does not "flush" the soil clean of nitrate. Instead, it tends to spread any concentrated bands of nitrate both downward and out through the root zone, taking some nitrate along and leaving some behind in the water held in small soil pores. Nitrate-nitrogen concentrations in the soil water around a nitrogen fertilizer band may reach 600 ppm or higher. However, by the time some of the nitrate reaches the bottom of the root zone, concentrations in the root zone drainage water tend to be in the range of 15 to 50 ppm.

The way water is applied affects how both water and nitrate move down through the soil. When the application rate is less than the intake rate (such as from a gentle rain or well designed sprinkler system), water tends to move downward in a relatively uniform manner. For example, Figure C-5 shows a band of nitrate that has formed from a previous application of anhydrous ammonia. A wetting front is moving down under rainfall. When the wetting front reaches the band, the nitrate tends to spread mainly downward (Fig. C-6).

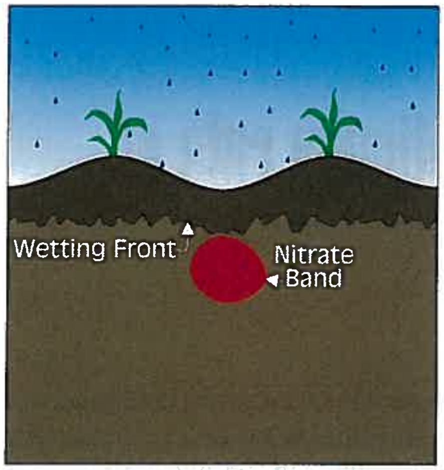


Figure C-5. Wetting front from sprinkler irrigation approaches nitrate band.

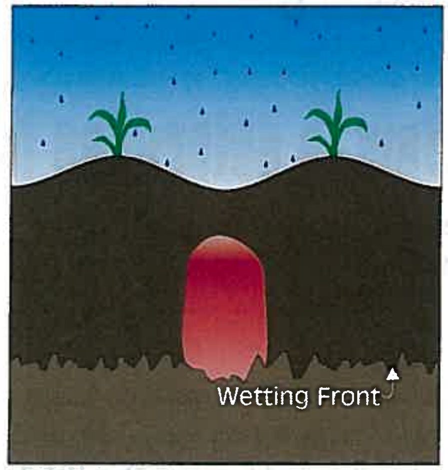


Figure C-6. Water spreads nitrate through root zone.

Under furrow irrigation, part of the surface is completely saturated. This allows the water to flow through the largest pores. There is a faster and more uneven wetting of the soil profile. Also, the depth of water applied at each irrigation is larger than under sprinkler irrigation. Under this condition, a nitrate band will tend to spread further, both vertically and horizontally (Fig. C-7). Excess irrigation will move the nitrate even deeper.

Figure C-7. Furrow irrigation may move fertilizer nitrogen deeper than sprinkler irrigation.

See these Extension publications for additional information:

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

Section D

How to determine the optimum rate of nitrogen fertilizer

The major fertilizer question facing crop producers is "How much nitrogen do I need to apply?" The question is simple but the answer is complex because of the many alternative management practices, differences among soils, and the uncertainty of climate. The total amount of nitrogen **from all sources** that is required by the plant is based on an **estimate of expected yield** and the **estimated amount of nitrogen consumed by the plant** for each unit of production, as shown in Table D-1. That is ***not*** the amount of fertilizer that is needed; some nitrogen will come from other sources.

Table D-1. **Nitrogen required per unit of production**

Crop	Estimated Nitrogen Required
Corn	1.2 lb nitrogen/bushel
Wheat	2.0 lb nitrogen/bushel
Grain sorghum	1.0 lb nitrogen/bushel
Sugar beets	20 lb nitrogen/ton
Grass pastures	40 lb nitrogen/ton
Brome grass hay	35 lb nitrogen/ton

The optimum nitrogen fertilizer rate cannot be determined with absolute certainty. There are too many unknown factors. However, enough is known or can be estimated to arrive at a rate that is reasonable. Large errors in selecting nitrogen rates can have serious consequences. A rate much lower than optimum will increase the risk of lower yields, which will affect farm income. Selecting a rate above optimum will cost more, may offer no benefits in additional yield, and will most likely degrade groundwater quality when the excess or unused nitrogen is leached from the root zone. Using the results of many years of field research, the University of Nebraska has developed the following procedure to help determine the appropriate nitrogen fertilizer rate.

Realistic crop yield expectations

Selecting an optimum rate of nitrogen fertilizer for corn is based upon the expected yield for a given field. The total nitrogen required by corn is related to yield. The

University of Nebraska recommendation system requires a realistic estimate of expected yield. To set a realistic expected yield for a given field, use the average of the five most recent crop yields plus 5 percent. An unusually bad year can be omitted.

Example: Calculation of realistic expected yield

Irrigated corn
5 years' yields (bu/acre)
178, 191, 185, 146 (hail), 182
Average all years = 176 bu/acre
Average with 146 bu/acre omitted = 184 bu/acre

Expected yield (EY) in this case is 184 x 1.05 = 193 bu/acre.

Caution: Do not over-estimate crop yields for nitrogen use decisions. Increasing the average yields by 5 percent will provide enough increase in the nitrogen recommendation to account for the increasing yield potential provided by advancing technology.

Soil sampling

Currently there is no way to accurately estimate the amount of residual soil nitrate-nitrogen without soil testing. Proper sampling for soil testing is a critical step in making a realistic estimate of the residual. Because residual nitrate is very soluble and moves with the water in the soil profile, deep samples are necessary. It is possible for residual nitrate-nitrogen to have a higher concentration in the lower part of the root zone than in the top foot. For example, Figure D-1 shows the same total amount of nitrate-nitrogen distributed very differently in a 4-ft. profile.

Sampling depth: In order to assess soil nitrate-nitrogen availability, the sampling depth ideally should be as deep as the effective rooting depth for the crop. Preferred sampling depths for nitrate-nitrogen are 2 ft for wheat, 4 ft for corn, and 6 ft for sugar beets. Samples taken to a depth of 2 ft or greater are acceptable for corn. The greater the sampling depth, the more accurate the estimate of available soil residual nitrate-nitrogen. Samples to a depth of 3 ft are most commonly collected, providing an adequate estimate of residual nitrate-nitrogen at an acceptable cost.

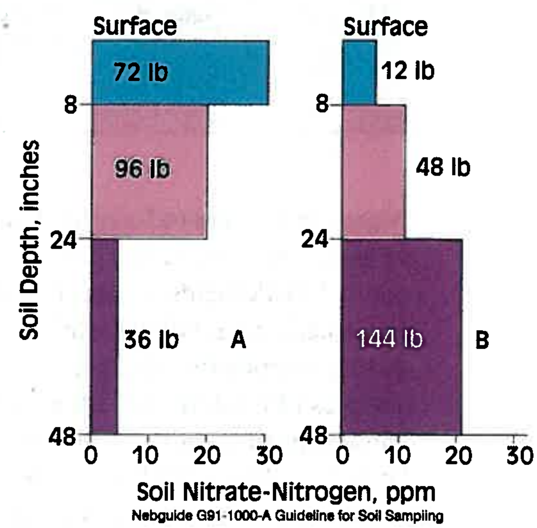


Figure D-1. Distribution of nitrate-nitrogen in two soils, each containing 204 lb/acre nitrate-nitrogen in a depth of 4 feet.

Continuous soil cores to the sampled depth are acceptable; for example, 0 to 36 in. in one core. However, collecting cores in depth increments can increase the information gained from sampling by providing an estimate of the distribution of nitrate-nitrogen in the root zone (Fig. D-1). The 0 to 8 in. depth increment should be analyzed for general fertility (organic matter, pH, phosphorus, potassium, zinc, etc.) as well as nitrate-nitrogen, while deeper increments should be analyzed for nitrate-nitrogen only.

Table D-2 **Desirable sampling depth for residual soil nitrate-nitrogen**

Wheat	2 ft
Corn	4 ft
Sugar beets	6 ft

Table D-3 **Sampling depth according to information needs**

Depth Increment (inches)	Soil Information Collected
0 - 8	Information on liming and crop nutrients including nitrate-nitrogen
8 - 24	Information on upper soil nitrate-nitrogen
24 - 48	Information on lower soil nitrate-nitrogen
48 - 72	Sugar beets only, information on nitrate-nitrogen

Number of cores to be collected: A better estimate of a field's fertility can be obtained by taking more samples. Fields should be divided into areas generally no larger than 40 acres. Divide fields according to patterns of cropping history, topography, soil type, etc. From each area, collect a minimum of 10 cores (0 to 8 in. depth) for general fertility status, compositing the cores into one sample for each area. At least four deep soil samples (2 ft minimum, 3 ft acceptable and 4 ft preferred for corn) should be collected and composited into one sample from each area as well. Additional deep samples would be better. Many NRDs require eight deep cores. This will increase the accuracy of sampling results. Check with the local NRD for their regulations.

Interpretation of soil test results

The interpretation of soil test results will influence fertilizer recommendations. Normally, labs will report soil residual nitrate-nitrogen in parts per million (ppm) or pounds per acre (lb/acre). University of Nebraska nitrogen fertilizer recommendations for corn are based on the average ppm nitrate-nitrogen in the root zone, as long as the soil sample is collected to a 2-ft depth or greater. If a continuous core is taken from the surface to the sampling depth, the reported nitrate-nitrogen concentration is used in making the nitrogen fertilizer recommendation. If the core is separated into increments to determine the distribution of nitrate-nitrogen in the root zone, a weighted average nitrate-nitrogen concentration must be calculated, as illustrated below.

Example: Weighted average of nitrate-nitrogen concentration

Depth Increment (in.)	Sample Length (in.)	x	Nitrate-nitrogen (ppm)	=	Length x ppm
0-8	8		30		240
8-24	16		20		320
24-48	24		5		120
				Total	680

$$\text{Average ppm nitrate-nitrogen} = \frac{\text{Total}}{\text{in. of depth}} = \frac{680}{48} = 14.2 \text{ average ppm nitrate-nitrogen}$$

How a nitrogen fertilizer recommendation is determined

The University of Nebraska's approach to nitrogen recommendations, as outlined in this manual, uses a realistic expected yield and considers credits for various sources of nitrogen. After expected yield is estimated, the next step is to calculate the total amount of nitrogen needed for production. Fertilizer needs are then determined by reducing the total nitrogen needs according to existing soil nitrate levels, expected mineralization from soil organic matter and other nitrogen credits. In the next section the various credits are explained in detail.

Most agronomists agree that the above approach is correct in principle. Minor differences may occur due to specific details of how much to credit soil nitrate, organic matter release and previous crops. In practice producers sometimes ignore or discount specific sources of nitrogen credit. Farmers and consultants may not have experience calculating these credits, may not be familiar with the research which supports their use, or may consider the risk of reducing fertilizer amounts to be too great. The result is often a higher than necessary nitrogen fertilizer application which increases costs and reduces water quality.

Determining nitrogen fertilizer needs for corn

The University of Nebraska has developed an equation to estimate nitrogen fertilizer needs for corn. This is based on 81 nitrogen rate experiments conducted on Nebraska soils over a range of organic matters, soil textures and residual nitrate levels. This equation is:

Nitrogen fertilizer needed (lb/acre) =

35 + (1.2 x EY) - (8 x average nitrate ppm) - (0.14 x EY x OM) - (other credits)

- EY is Expected Yield.
- OM is the percent Organic Matter determined from a surface soil sample. (Do not use greater than 3 percent OM.)
- Other credits are nitrogen from legumes, manure, other organic wastes and irrigation water. (See Section E.)

Example: Calculation of nitrogen fertilizer needed

Using an expected yield of 193 bu/acre, a soil organic matter of 2 percent and soil nitrate of 14.2 ppm, the following calculation can be made:

Nitrogen fertilizer needed (lb/acre) = 35 + (1.2 x 193) - (8 x 14.2) - (0.14 x 193 x 2) - (other credits)

Nitrogen fertilizer needed (lb/acre) = 35 + 231.6 - 113.6 - 54.04 - (other credits)

Nitrogen fertilizer needed (lb/acre) = 100 (rounded from 98.96) - (other credits)

For a complete explanation of the formula and interpretation of soil tests for other nutrients, please see NebGuide G74-174 (Revised July 1995) "Fertilizer Suggestions for Corn."

See these Extension publications for additional information:

EC97-147-S	Nitrogen Rate Slide Chart
G91-1000	Guidelines for Soil Sampling
G74-174 (Rev. 7/95)	Fertilizer Suggestions for Corn

Section E

Giving credit for non-fertilizer nitrogen sources

This section presents information on how to estimate the "other credits" in the fertilizer need equation explained in Section D

Mineralization of nitrogen from soil organic matter

Soil organic matter is a major soil component. It consists of plant and animal residue in various stages of decay and holds large amounts of nitrogen in organic forms. This nitrogen is unavailable to the crop until it is mineralized by soil microorganisms. **Mineralization** transforms organic nitrogen into ammonium, which the crop can use (see page 12).

Soils in Nebraska typically range from 0.5 to 3.0 percent organic matter and occasionally higher. A soil with 2 percent organic matter has almost 20 tons/acre of organic matter in the top 6-in. depth. This much organic matter contains roughly 2,000 lb of nitrogen in organic form. Only 1 to 2 percent of the organic nitrogen is mineralized per year. About 70 to 80 percent of the total organic matter decays very slowly. The remaining 20 to 30 percent, the humus, is in a stable advanced state of decay. Table E-1 shows the minimum estimated amount of nitrogen made available annually by mineralization, according to the organic matter content of the soil.

Table E-1. **Minimum estimated nitrogen contributed to the crop from mineralization of soil organic matter**

Soil Test Organic Matter (%)	Nitrogen Contributed to Crops From Mineralization (lb/acre/yr)
1	14
2	28
3	42

Mineralized nitrogen is available for crop use while the crop is growing. The actual amount of nitrogen coming from mineralization will vary due to temperature and moisture conditions, and can be different from the values in the table. However, the amount mineralized is related to the amount of organic matter in a soil. Therefore, the **minimum** nitrogen expected to become available for crop use can be reliably estimated. The nitrogen credit for mineralization is already included in the nitrogen fertilizer calculation in Section D by including organic matter (OM) as part of the equation.

Previous legume crop credit

Legumes fix nitrogen from the air and store it in root nodules. This nitrogen becomes available when the plant dies and decays. If the previous crop was a legume, a credit should be used when calculating fertilizer needs. This is one of the "other credits" in the nitrogen fertilizer need equation.

Legume nitrogen starts with the formation of a root nodule. Each nodule represents an invasion of specific soil bacteria in the root. The bacteria multiply and result in enlarged or mature nodules. The bacteria in the nodules can fix enough nitrogen gas from the soil air to meet a substantial part of the plant's nitrogen needs. The amount actually fixed depends on the amount of residual nitrogen in the soil. The legumes will use the available soil nitrogen first, before they fix enough nitrogen to meet the rest of their needs. This is why residual soil nitrate is usually low following a legume crop.

When a legume crop is killed or dies, the plant residue decays easily because of the high nitrogen content in the legume leaves and stems. The amount of nitrogen the decaying legume residue contributes to the next crop varies. Table E-2 shows the expected nitrogen credit when a grain crop follows a legume.

Table E-2 **Estimated nitrogen credit when the previous crop is a legume**

Legume Crop	Medium & Fine Textured Soils	Sandy Soils
	(lb/acre nitrogen credit)	
Alfalfa 70 - 100% stand (More than 4 plants per sq ft)	150	100
Alfalfa 30 - 69% stand (1.5 to 4 plants per sq ft)	120	70
Alfalfa 0 - 29% stand (Less than 1.5 plants per sq ft)	90	40
Sweet clover & red clover	80% of credit allowed for alfalfa	
Soybean	45	45
Dry edible beans	25	25

Irrigation water credit

Nitrate-nitrogen in irrigation water is available to a growing crop and is another credit to include in the fertilizer need equation. Each ppm will add 2.72 lb of nitrogen to the soil with each foot of water applied (or 0.23 lb/acre of nitrogen with each inch of water applied).

When irrigation water contains 10 or more ppm of nitrate-nitrogen, the amount of nitrogen fertilizer added to a crop should be reduced to credit the nitrogen coming from irrigation water. Table E-3 shows how much nitrogen is added for different amounts of irrigation water. *(Note: Some water analyses give nitrate-nitrogen concentrations in parts per million [ppm] and others give values in milligrams per liter [mg/l]. They are the same.)*

Table E-3 **Crop available nitrogen in irrigation water**

Water Applied (inches)	Nitrate-nitrogen in water (ppm)							
	5	10	15	20	25	30	35	40
	(lb of nitrogen added per acre)							
6	7	14	20	27	34	41	48	54
9	10	20	30	41	51	61	72	82
12	14	27	41	54	68	81	95	109
15	17	34	51	68	85	102	119	136
20	23	45	68	91	114	136	159	182
25	28	57	85	114	142	170	199	227

Example: Calculating the irrigation water credit

Irrigation water contains 15 ppm nitrate-nitrogen. Ten inches of water are applied to corn by furrow irrigation during July and early August. How much crop available nitrogen is in the water?

(ppm) x (0.23) x (in. of water) = lb of nitrogen/acre in the water

15 ppm x 0.23 x 10 in. = 34.5 lb of nitrogen/acre

The timing of irrigation application in relation to the period of rapid nitrogen uptake by the crop affects the value of the nitrogen in the water. The rapid uptake period includes about four to five weeks before pollination and a week or so after. Uptake after tasseling is quite hybrid specific. Nitrogen in irrigation water applied during the rapid uptake period is just as useful to the crop as the same amount of nitrogen fertilizer. Nitrogen in water applied late in the growing season, after the crop has already taken up most of its nitrogen needs, is of limited value. Part of the nitrogen in the irrigation water will be lost if any water drains below the active root zone.

To estimate an irrigation water nitrogen credit, a practical upper limit on the inches of water applied should be used in the calculation. For furrow irrigation this varies from 6 in. in Eastern Nebraska to 9 in. in Central Nebraska, and 15 in. in the Panhandle.

Residual soil nitrogen credit

The amount of residual nitrate-nitrogen in the soil is related to a combination of several management practices and climatic conditions. Each of the following can contribute to a greater or lesser amount of residual nitrate:

- Past amounts of fertilizer nitrogen applied
- Past amounts of biosolids applied (manure, sludge, compost, etc.)
- Crop: some crops remove more soil nitrogen than others
- Rainfall: more residual nitrogen is present with dry fall and spring conditions; less residual nitrogen is present with wet fall and wet spring conditions
- Irrigation water management
- Soil texture

Table E-4 **Nitrogen fertilizer rate reduction for residual soil nitrate**

Residual Soil Nitrate-nitrogen* (ppm)	Reduction in Nitrogen Fertilizer Needed by Crop (lb/acre of nitrogen)
1	8
3	24
6	48
9	72
12	96
15	120
18	144

**Average ppm in at least the top two feet. Deeper samples are better. The University of Nebraska uses 3 ppm soil nitrate levels if no soil test is available.*

Residual soil nitrogen is available for meeting part of the nitrogen requirement of crops. The fertilizer nitrogen requirement for a crop is reduced by 8 lb/acre for each ppm of residual nitrate-nitrogen found in the soil. This is summarized in Table E-4. The residual soil nitrogen credit is already included in the equation for calculating nitrogen fertilizer need in Section D.

Organic resource credit

Livestock and poultry manures, composted meat processing wastes, dewatered sewage sludge, and composted plant material are examples of organic resources. They may contain a combination of organic nitrogen, ammonium and nitrate. All of the ammonium and nitrate is potentially available to the crop the first year. In contrast, a fraction of the organic nitrogen will become available only after mineralization by soil microorganisms. This occurs over a period of several months to several years.

The amount of nutrients released from organic resources varies considerably. Thirty to seventy percent of the nutrients in organic form can be made available to the next crop after application, depending on the type of organic resource and soil conditions (mainly moisture and temperature). Research and on-farm evaluations have been used to project the amount of nitrogen available to the next crop from organic resources (Table E-5). The values in the table are conservative and can be used with confidence. These amounts will vary depending on the method and timing of application and nitrogen content of the organic resource. Producers should have samples of organic resources analyzed to determine a more accurate credit.

Organic resources are usually used to supply nitrogen for the next crop. However, there are other nutrients in organic resources such as phosphorus, potassium, sulfur, and trace elements like iron, zinc, and copper which can also be beneficial in subsequent crop years.

Long-term use of organic resources to fully meet nitrogen requirements usually results in build-up of available phosphorus and potassium in the soil. To avoid this problem, organic material application should be made based on replacing the phosphorus removed in the crop. Applying organic resources to meet the crop's needs for phosphorus instead

Table E-5 **The amount of available nitrogen expected from application of organic resources**

Source	Available Nitrogen Furnished * to the Next Crop
Beef feedlot manure	4-5 lb/ton
Dairy cattle manure	3 lb/ton
Sheep manure	5 lb/ton
Poultry manure	15 lb/ton
Swine manure	10 lb/ton
Plant compost	3-5 lb/ton
Meat processing waste	1-6 lb/1,000 gal
Sewage sludge	2-3 lb/ton
Swine slurry	2-10 lb/1,000 gal
Beef slurry	2-10 lb/1,000 gal
Dairy slurry	2-6 lb/1,000 gal

* *These amounts include ammonium and nitrate in the material plus nitrogen mineralized from the material after application.*

of nitrogen will require 3 to 7 times more land area. (See "Estimating Manure Nutrients from Livestock and Poultry," G97-1334-A, for more information.) Heavy applications of organic resources without consideration of crop needs can result in over-application of nutrients. Groundwater and surface water contamination can then occur.

See these Extension publications for additional information:

G97-1334-A	Estimating Manure Nutrients from Livestock and Poultry
G97-1335-A	Determining Crop Available Nutrients from Manure
G95-1135-A	Estimating Percent Residue Cover Using the Calculation Method
G77-361	Using Starter Fertilizers for Corn, Grain Sorghum, and Soybeans

G94 -1178, Fertilizer Nitrogen Best Management Practices *is out of print, but can still be obtained at most local Extension offices.*

Section F

How to properly apply nitrogen fertilizer

Good nitrogen management is essential for protecting groundwater quality. Proper nitrogen management includes managing nitrogen rate, source, timing, and placement. The primary goal of nitrogen best management practices is attaining high nitrogen use efficiency. This assures the most effective use of nitrogen fertilizer.

Good nitrogen management requires understanding:

- How nitrogen is used by the crop
- When nitrogen is used by the crop
- What environmental influences affect the use of soil and fertilizer nitrogen by the growing crop
- How management of nitrogen and irrigation water affect the leaching of residual nitrate, which eventually affect water quality

Nitrogen uptake across the growing season

The rate of nitrogen uptake depends on the stage of crop development. Figure F-1 shows

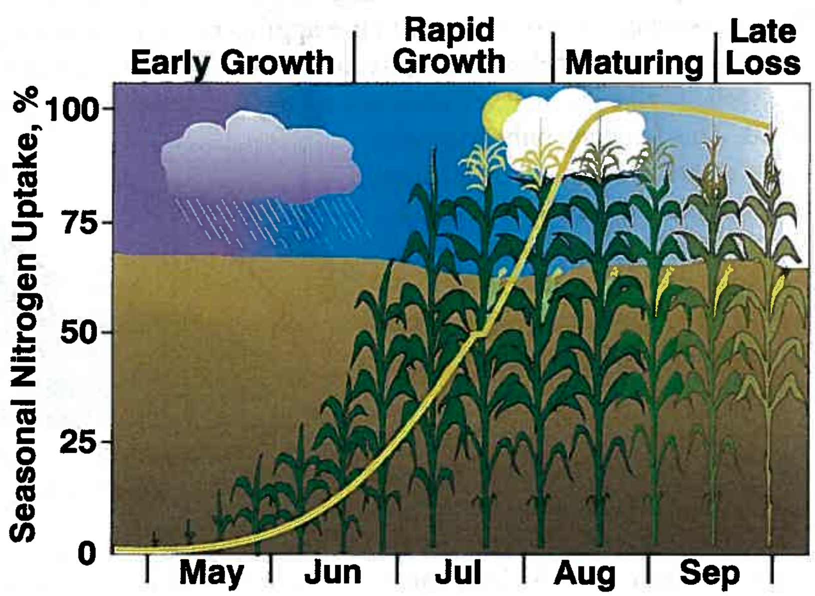


Figure F-1. Cumulative nitrogen uptake across the growing season.

that early in the growing season the plant demand for nitrogen is low. During the late vegetative and early reproductive stage the demand for nitrogen is high. Application of nitrogen just before or during the time of most rapid nitrogen uptake assures the most efficient use of nitrogen by the crop.

Springtime leaching potential

The potential for leaching of nitrate by rainfall is highest in the spring before the crops start growing rapidly (Fig. F-2). On average, the highest rainfall in Nebraska occurs in May and June. During this time crop water use is low and very little nitrogen uptake occurs. The water content of the root zone is likely to be at or near field capacity. The probability is high that at least part of the water entering the soil will move all the way through the root zone, taking nitrate with it.

The potential for springtime leaching loss can be reduced by careful scheduling of the last irrigation of the previous season to leave the root zone drier over the winter, and by proper selection of nitrogen form and timing of application. When the nitrogen fertilizer rate is below optimum, yield is lost. When it is above optimum, excess residual nitrogen remains which can be lost before the next growing season. Such losses contribute to groundwater contamination.

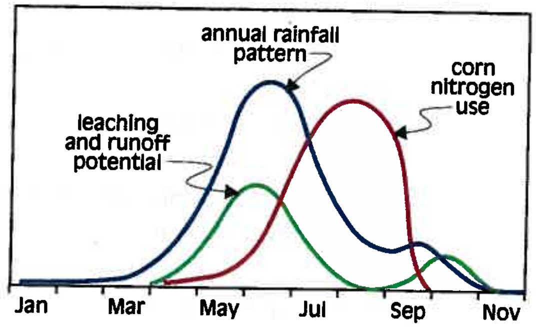


Figure F-2. Highest potential for leaching by rainfall comes before the rapid nitrogen uptake period.

Nitrogen use efficiency

The amount of nitrogen applied has a very large effect on **nitrogen use efficiency**. Efficiency is a measure of the crop's ability to use applied nitrogen. It is defined as the percent of applied nitrogen fertilizer that is recovered in the harvested portion of the crop. Under excellent management, efficiencies up to 60 percent (sometimes higher) can be obtained. This happens only when the nitrogen application is near the minimum needed to obtain optimum yield and is applied near or during the rapid uptake period. An efficiency in the range of 50 percent down to 20 percent (or lower) results when nitrogen applications are applied well before the crop needs it and/or are excessive.

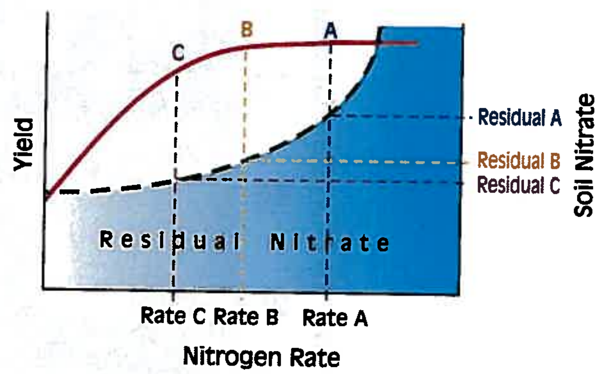


Figure F-3. Impact of excessive nitrogen rates on soil residual nitrogen.

Figure F-3 shows a typical yield response of corn to nitrogen application. In this figure near maximum yield and optimum nitrogen use efficiency are gained from rate B. Maximum profit is slightly to the left of B since fertilizer is not free. There is little increase in yield above this rate. If farmers reduce their nitrogen application to rate C, nitrogen use efficiency may be slightly higher than at point B, but there will be a moderate yield loss. With any nitrogen application (or even none) there is some level of soil residual nitrate. As nitrogen is added up to the point of maximum crop response to nitrogen, the residual soil nitrate level does not increase very much above where little or no nitrogen is applied. However, beyond the point of maximum response from applied nitrogen, soil residual nitrate increases rapidly and nitrogen use efficiency declines.

At nitrogen rate A there is no gain in yield but there is a significant rise in the residual nitrate and a large decrease in nitrogen use efficiency. This extra nitrogen residual over and above the point of optimum use efficiency is available for leaching.

Field data from Central Nebraska illustrate these concepts in the following example.

Example: Five-year average of nitrogen applied, yield and residual soil nitrogen

Point	Nitrogen applied lb/acre	Yield bu/acre	Residual soil nitrate-nitrogen, lb/acre
C	90	168	73
B	140	176	76
A	190	181	104

In this example the yield for the 90 lb/acre average nitrogen application corresponds to point C in Figure F-3. If the nitrogen fertilizer amount is increased from 90 to 140 lb/acre, the yield increases by 8 bu/acre, while the residual nitrate-nitrogen increases slightly. This corresponds approximately to point B. Adding an additional 50 lb/acre of nitrogen results in slightly more yield, while the residual nitrate goes up by 28 lb/acre. This would be represented by point A in Figure F-3.

Timing

Crops have their highest daily use for nitrogen during the rapid growth period (Fig. F-1). During this time the crop takes up **at least half** of its total nitrogen requirement. Nitrogen applications during this period will generally be more efficient because there is a short time between application and uptake. This limits exposure of the nitrogen to leaching by excess rainfall or irrigation. The relative ranking of nitrogen use efficiency for different application timings is summarized in Table F-1. These rankings are correct for irrigated production. In rainfed areas that don't have adequate moisture in late May and June, waiting to apply nitrogen may decrease nitrogen efficiency. Decreased efficiency results since nitrogen will not move to the roots in dry soil.

Table F-1. Nitrogen use efficiency according to timing of application

Highest	Sprinkler applied during rapid growth
	Sidedress just before rapid growth
	Post-plant incorporated
	Pre-plant incorporated
Lowest	Fall application for next year's crop

Any nitrogen application made long before the rapid growth period will have a higher probability of loss and, consequently, there will be less available for uptake by the crop. Fall application and early spring application in some years on any soil, or in most years on sandy soils can be a poor choice. In these situations nitrate-nitrogen has a lot of time to be leached from the root zone or to be denitrified.

As the soil temperature decreases in the fall, the activity of soil microorganisms declines. At a temperature of 50° F in the top few inches of the soil, the rate of nitrification of ammonium drops to about 20 percent of its maximum rate in a warm soil. As long as the soil stays cold, only a limited amount of fertilizer material in ammonium form will nitrify and be subject to leaching. Figure F-4 shows that, on average, a soil temperature of 50° F is reached around November 1 in South Central Nebraska. For this reason, waiting until November 1 to make fall application of anhydrous ammonia is recommended. Of course, as the soil warms in the spring, nitrification accelerates so that fall-applied nitrogen is subject to leaching by spring precipitation.

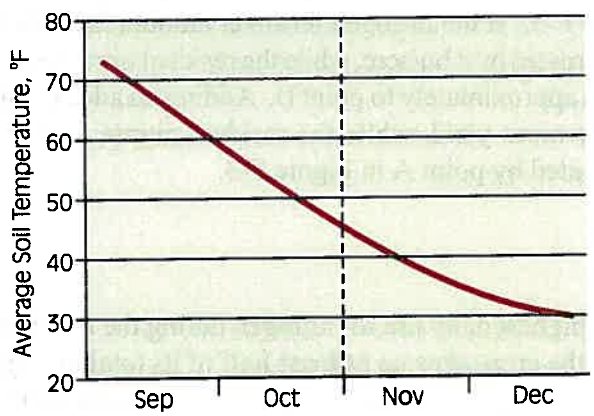


Figure F-4. Average soil temperature, 1984-1993, Clay Center, Nebraska

Sandy soils have a greater leaching potential during the growing season than finer-textured soils. Under sprinkler irrigation on sandy soil one of the best choices for nitrogen fertilizer timing is to use a small amount of nitrogen as a starter, with the bulk of the nitrogen applied either sidedress or through the sprinkler irrigation system.

Placement

Nitrogen placement can affect nitrogen use efficiency. Below are some points to help make wise placement decisions.

- Subsurface or incorporated nitrogen has a lower opportunity for surface runoff losses than surface broadcast application.
- Most surface-applied fertilizer should be incorporated with tillage to reduce surface runoff and volatilization. (There is a tradeoff between less volatilization loss following tillage and increased erosion potential on sloping lands due to reduced residue cover.)
- If nitrogen is surface applied, banding reduces potential volatilization loss. Using an urease inhibitor will also reduce volatilization loss.
- Nitrogen applied with the planter will provide early season nitrogen but caution needs to be exercised to avoid salt injury and/or ammonia toxicity.
- With furrow-irrigated ridge-till, placement in a band on the side of the ridge, at least 6 in. from the row, can reduce downward percolation of nitrogen.
- Small consecutive applications of nitrogen through the sprinkler system can improve nitrogen use efficiency.
- If the total nitrogen applied is greater than crop needs, nitrogen use efficiency will be reduced and nitrate loss to groundwater will likely be increased, regardless of timing or placement.

Selecting nitrogen sources to protect groundwater quality

Environmental concerns related to nitrogen fertilizer sources are based on leaching potential. Nitrate-nitrogen will move with the soil water. Ammonium sources will attach to soil and organic matter and resist leaching. However, nitrification will change ammonium forms to nitrate over a three- to six-week period. Some leaching potential can be overcome by the use of nitrification inhibitors. Inhibitors are substances added to nitrogen fertilizer which slow the conversion from the non-mobile ammonium form to the mobile nitrate form. When nitrification inhibitors are used, significant leaching of applied fertilizer may be prevented if a heavy rainfall event occurs within four weeks after application. Inhibitors will not prevent the leaching of residual nitrate that is already in the soil at the time fertilizer is applied.

Both the ammonium and nitrate forms of nitrogen are available for crop use. Anhydrous ammonia is the only fertilizer form that is totally non-leachable immediately after application. Urea and nitrate can both leach right after application. Urea will be converted to ammonium in a very few days. There is a potential for volatilization loss of surface applied nitrogen. There is also a possibility for loss in runoff if heavy rains occur before these materials are mixed into the soil. With proper application, when nitrogen is incorporated and applied at the right time, all nitrogen sources will provide good crop nutrition.

Cost per pound of nitrogen, availability, supplier services, application cost, storage cost, and transportation all influence the crop grower's decision on which nitrogen fertilizer to buy and from which supplier. Cost per ton can be converted to a price per pound of nitrogen by a quick calculation.

Example: Converting fertilizer cost/ton to nitrogen cost/lb

82-0-0, Anhydrous ammonia (82 percent nitrogen) costs $315/ton

82 percent x 2000 = 1640 lb nitrogen/ton
$315 ÷ 1640 lb = $0.19/lb

28-0-0, Urea ammonium nitrate solution (28 percent nitrogen) costs $135/ton

28 percent x 2000 = 560 lb nitrogen/ton
$135 ÷ 560 lb = $0.24/lb

See these Extension publications for additional information:

EC94-737-D	Calibrating Anhydrous Ammonia Applicators
G93-1171	Using a Chlorophyll Meter to Improve N Management

Section G

Understanding crop water use

It's a certainty that producers want their crops to have enough water. It's also clear that people have very different ideas about how much is enough. Almost everyone has neighbors who apply very different amounts of irrigation water to the same crop on the same type soil. To better estimate the right amount, it's very helpful to understand how crop water use changes according to weather and crop conditions.

Components of crop water use

Crop water use is made up of two parts: **evaporation (E)** from the soil surface and **transpiration (T)** from the crop leaves. The sum of these is called **evapotranspiration**, or **ET** for short. We will use ET and crop water use interchangeably. Over a growing season, 70 to 80 percent of all ET is made up of water that moves from the soil through the crop's root system and is transpired from the leaves. This is useful water since it cools the leaves and helps move nutrients from the soil into the plant. The remaining 20 to 30 percent of the ET is direct evaporation from the soil (Fig. G-1). Most soil evaporation is a waste. It can't be avoided; however, it can be controlled to some degree by residue cover and by when and how much tillage is done.

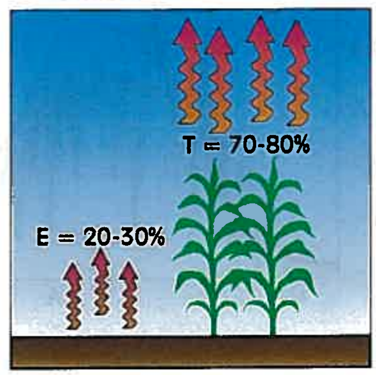


Figure G-1. Components of evapotranspiration.

Crop characteristics influence water use

We know that alfalfa is a high water use crop. In this section water use by corn or soybean will be compared with the ET of alfalfa when it is at **full cover**, just before cutting.

When a corn or soybean crop first emerges in late spring, almost all water use will be evaporation from the soil. The evaporation rate may be only 10 to 20 percent of the water use rate of alfalfa. For example, the evaporation rate from an essentially bare soil (with a dry surface) may be only 0.02 to 0.03 in./day, while ET from full cover alfalfa would be 0.20 to 0.25 in./day at that time. The exception to this would be right after a rain. Evaporation from the wet soil may almost equal alfalfa ET for a day or so and will be higher than a "dry surface" condition for three to four days.

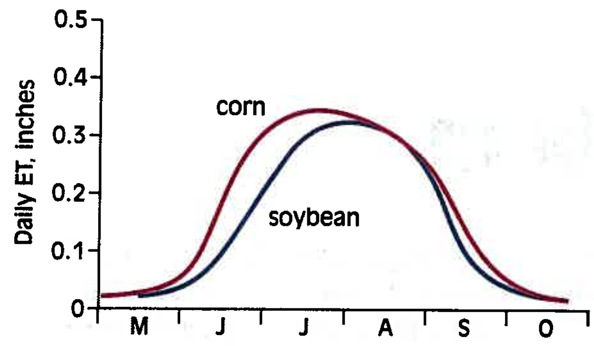


Figure G-2. Average water use rates by corn and soybean in Central Nebraska.

When a corn or bean crop is small, actual ET will be low. However, as the leaf area expands to give more "evaporating surface," the crop ET rate comes closer and closer to the alfalfa rate. At **full cover**, when the corn or bean crop fully shades the ground, the ET rate will be the same or even a little more than that of alfalfa. Average ET rates over the growing season are shown in Figure G-2 for both corn and soybean.

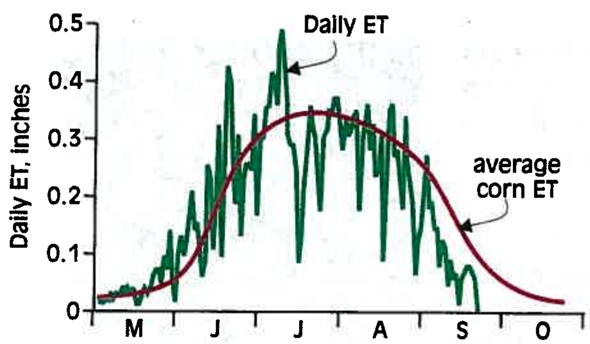


Figure G-3. Comparing average ET rate for corn with daily data for a specific year.

Around beginning dent in corn or pod fill in soybean, the plants begin to lose their capacity to transpire at high rates. Actual ET rates begin to fall off in comparison to alfalfa, even though the corn and soybean crops are still at full cover.

Actual crop water use can be very different from the average because of variability in the weather. This is shown in Figure G-3, where actual daily ET amounts across a particular growing season are compared with the average for corn, as shown in Figure G-2. In any one year, average values can give only a rough guideline to water use. That's why irrigation scheduling is more accurate when it's done by using ET estimated from daily weather data rather than long-term average values.

Daily ET varies with weather conditions

Irrigators all understand that weather affects crop water use. The question is, "How much?" The energy that's needed to evaporate water from the leaves and soil comes directly from solar radiation and from air that has been heated by the sun. ET rates are higher when the relative humidity is low and lower when the relative humidity is high. Wind also increases ET, but as many farmers have observed, it has a greater effect when the relative humidity is low. Table G-1 gives some typical ET values for different conditions during late July, when a corn or soybean crop would fully shade the ground, assuming that soil water is not limiting. **The main point here is that when corn or soybean is at full cover, ET on any day can vary from less than a tenth of an inch to almost a half-inch, depending on weather conditions.**

Table G-1.

Effect of weather on water use by a crop with full canopy cover

ET in./day	0.22-0.25	0.30-0.33	0.32-0.35	0.42-0.47	0.19-0.22	0.24-0.27	0.09-0.12
Daytime Temp	Sunny Mid 90's	Sunny Mid 90's	Sunny Mid 90's	Sunny Mid 90's	Partly Cloudy Mid 70's	Partly Cloudy Mid 70's	Thick Clouds Mid 60's
Nighttime Temp	Mid 70's	Mid 70's	Upper 60's	Upper 60's	Mid 50's	Mid 50's	Low 60's
Relative Humidity	High	High	Mod to Low	Mod to Low	Moderate	Moderate	Very High
Wind	Low Day & Night	High Day & Mod Night	Low Day & Night	High Day & Mod Night	Low Day & Night	High Day & Mod Night	Low Day & Night

Total water use is different from one year to another

Total ET during the growing season will vary from year to year, just as the climate varies. Table G-2 shows a range of seasonal water use that will cover about 90 percent of the years in Nebraska. There will be extremes on both ends that go higher or lower.

Table G-2. **Seasonal crop water use (ET) in Nebraska when water is not limiting**

Crop	Western	Central	Eastern
	- - - - - - - - - -	inches/year	- - - - - - - - - -
Corn	23-26	24-27	25-28
Soybean	20-22	21-23	22-25
Dry edible beans	15-16	---	---
Sorghum	18-20	19-22	20-23
Winter wheat	16-18	16-18	16-18
Alfalfa	31-33	32-35	34-36
Sugar beet	24-26	---	---

Plant population effects on ET

Plant population also affects crop ET. However, under irrigated production the impact is minimal. For example, suppose that a corn variety typically planted under irrigation in Nebraska is seeded at two populations: a high population of 34,000 plants/acre and a low of 17,000. With adequate water and fertility, a considerable yield difference between the two populations would certainly be expected. However, the difference in ET may be no more than an inch across a growing season. To get significant water use savings, populations of modern, upright leaf varieties have to drop below 13,000 to 14,000 plants/acre. Substantial savings come only when populations are in the range of 8,000 to 10,000 plants/acre. For shorter season varieties (with fewer leaves), populations go up by 10 to 20 percent to reach these thresholds, but the principle is the same. There may be good reasons to reduce populations on some soils or in certain areas of an irrigated field. However, water savings is probably not one of them.

Residue cover can reduce soil evaporation

When the soil surface is wet, the evaporation rate depends mainly on how much solar energy it receives. The lowest evaporation rates occur from shaded and mulched soil surfaces. As crops grow, they shade more and more of the soil surface. Evaporation slows a lot, but does not stop, even under full shade. Residue covers can greatly slow the evaporation rate when no crop is present, and continue to help as the crop canopy grows. In general, a residue cover can cut 1 to 3 in. from total water use during the growing season.

Available soil water affects the ET rate

The amount of available water remaining in the root zone also affects the ET rate. Under average conditions a plant can use 60 percent or more of the available water without reducing the ET rate. As the plant begins to extract the last 35 to 40 percent of the available water, the actual ET rate declines in comparison to a non-stressed crop. The plant responds to water stress by taking steps to conserve what is left, including closing the stomates (pores) in the leaves to limit water vapor loss and rolling the leaves so they will catch less sun. After irrigation the ET rate will return to normal unless the plant has been severely stressed.

See these Extension publications for additional information:

G90-992-A Evapotranspiration (ET) or Crop Water Use

Section H

Irrigation management for profitable crop production and water quality protection

Irrigation Efficiency

In order to manage irrigation water you must understand the basic concepts of irrigation system efficiency. No irrigation system is 100 percent efficient in applying water to the field; part of the water applied will not be available for use by the crop. An estimated value of irrigation system efficiency must be used to calculate the gross amount of irrigation water that needs to be pumped or delivered to the field in order to apply a given net amount of irrigation water. Keep in mind that amounts of irrigation water are normally expressed as a depth, in inches. The net irrigation depth is the water which infiltrates into the soil *and* is stored in the root zone. The irrigation system application efficiency is a measure of the amount of water that is made available for crop use by an irrigation. Application efficiency is defined as:

$$\textbf{Application Efficiency} = \frac{\textbf{Net Irrigation Depth}}{\textbf{Gross Irrigation Depth}}$$

The major ways water is lost from an irrigated field are illustrated in Figure H-1. The primary losses from furrow-irrigated fields will be runoff and deep percolation with a small amount of direct evaporation from the flowing water. For sprinkler systems that throw water in the air, evaporation occurs while the droplets are in the air and after they reach the crop surface. Evaporation from the crop surface appears to be the most significant loss. If the wind blows, droplets may be blown outside the land being irrigated,

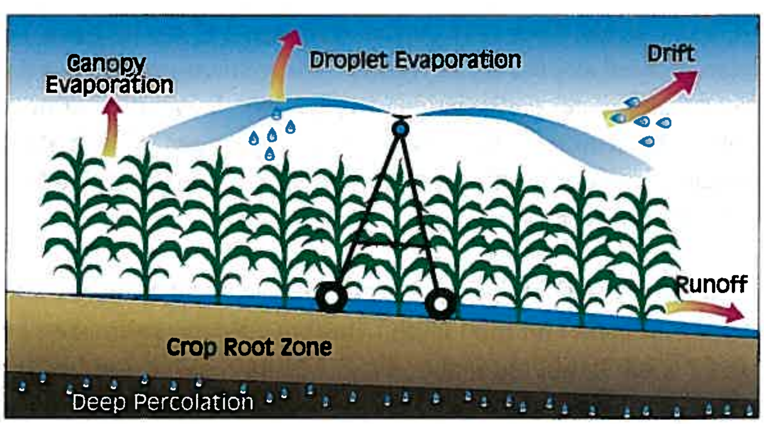


Figure H-1. Water losses from an irrigated field, that reduce irrigation application efficiency.

resulting in a "drift" loss. Runoff loss can also occur under a sprinkler system if water is applied at a rate greater than the infiltration rate of the soil. If good irrigation scheduling is practiced, deep percolation losses during the growing season should be minimal under sprinkler systems.

Typical system efficiencies are shown in Table H-1. Keep in mind that these are average application efficiencies and there can be a broad range of efficiencies in the field. The actual application efficiency of your systems will depend on system characteristics, management, soil conditions, crop conditions and the weather, especially rainfall. Irrigating when there is little storage space available in the soil will lower the irrigation system efficiency. More detailed efficiencies for sprinkler systems are given in Section J.

Table H-1 **Efficiency of irrigation systems**

System Type	Efficiency Factor
Conventional gated pipe	0.50
Gated pipe w/reuse	0.70
Alternate furrow	0.60
Alternate furrow w/reuse	0.75
Surge flow, well managed	0.80
Pivot, linear move	0.85-0.90

A key to good irrigation management is knowing how much water you apply

The inches of water applied per acre can be calculated if the irrigator knows the total volume of water pumped and the area irrigated. The total volume pumped is easily determined by using a water meter on the irrigation pipeline. A water meter provides the most accurate means for determining the volume of water pumped. The application depth (in inches) is calculated by dividing the total acre-inches of water applied by the total acres on which the water was applied.

When a water meter is not installed on the system, the water flow or delivery rate from the irrigation pump or canal and the length (time) of the irrigation can be used to estimate the volume of water delivered to the field. The total volume applied to the irrigated area is calculated by multiplying the flow rate times the irrigation time. Flow rates from pumps are normally given in gallons per minute (gpm) and flows from canals in cubic feet per second (cfs). These flow rates will need to be converted to acre-inches per hour (acre-in./hr) to make the calculation.

Typical flow measuring devices on open ditch systems provide a flow rate measurement. When a well is not equipped with a flow meter, flow rates should be measured periodically with some type of measuring equipment. Many NRDs have ultrasonic flow meters and will measure irrigation pumping rates as a service for producers. Keep in mind that flow rates may vary throughout the year and from year to year. An accurate record of irrigation time can be maintained by installing an hour meter on the irrigation pumping plant. The following example shows how the flow rate and time information is used.

Example: Using flow rate and time to estimate volume applied

An ultrasonic meter indicates your pumping rate is 600 gpm (1.33 acre-in./hour). The hour meter shows you pumped for 84 hours.

The total volume pumped is 1.33 acre-in./hr x 84 hr = 111.72 acre-inches.

It is highly beneficial to have a water measuring device that provides you with the total volume of water delivered to the field. Most in-line pipeline water meters give the total volume of water pumped and an instantaneous flow rate. Water meters are also valuable tools to monitor changes in well output, indicate potential pump problems, and help monitor pumping plant performance. A meter is a management tool that can help protect water quality and save operating dollars.

Key relationships that you can use are:

450 gpm = 1 cfs = 1 acre-in./hr

1 acre-in. = 27, 154 gal

1 acre-ft = 325,851 gal

Since a volume of 1 acre-in. will cover 1 acre with 1 in. of water, water from a 450 gpm pump will apply 1 in. of water to 1 acre in 1 hour. Similarly, a delivery of 1 cfs from a canal will apply 1 in. of water to 1 acre in an hour.

Using your flow or delivery rate you can determine average application depth using the following formula:

$$\text{Gross Depth of Irrigation (in.)} = \frac{\text{Flow Rate (acre-in./hr) x Time of Irrigation (hr)}}{\text{Acres Irrigated (acres)}}$$

Example: Gross irrigation depth for furrow irrigation

A 900 gpm well is pumping water for 12 hr through 40 open gates (every-other-row irrigation, 30-in. row spacing and 1/4 mile, 1320 ft, furrow length). What is the depth of irrigation?

The flow rate is converted from gpm to acre-in./hour.

$$\text{Flow Rate} = \frac{\text{900 gpm}}{\text{450 gpm/acre-in./hr}} = \text{2 acre-in./hr}$$

The area irrigated is:

$$\text{Area Irrigated} = \frac{\text{40 gates x 2 rows per gate x 2.5 ft per row x 1320 ft}}{\text{43,560 sq ft/acre}} = \text{6 acres}$$

The gross depth of irrigation is:

$$\text{Gross Irrigation Depth} = \frac{\text{2 acre-in./hr x 12 hr}}{\text{6 acres}} = \text{4 in.}$$

Example: Gross irrigation depth for center pivots

A center pivot irrigates 128 acres and is supplied with a well that pumps 750 gpm. If you make a revolution in 84 hr, what is the gross depth of irrigation?

$$\text{Flow rate} = \frac{\text{750 gpm}}{\text{450 gpm/acre-in./hr}} = \text{1.67 acre-in./hr}$$

$$\text{Gross Irrigation Depth} = \frac{\text{1.67 acre-in./hr x 84 hr}}{\text{128 acres}} = \text{1.1 in.}$$

Irrigation scheduling is the major component of irrigation management

It's easy to see the crop stress that results if irrigation is delayed too long. Curled leaves and wilted plants leave little to the imagination. Unfortunately, the losses of water and nitrogen that result from irrigating too early or too much are invisible, at least at the time they happen. That's where field checks of soil moisture and irrigation scheduling come in. Careful scheduling of irrigations helps to:

- Assure that plant water needs are met
- Conserve water supplies
- Avoid excess water application
- Reduce nitrate leaching losses
- Save pumping costs

Irrigation scheduling includes deciding **when to irrigate** and **how much** water to apply. A key indicator for making irrigation scheduling decisions is the amount of water present in the soil. As a "rule of thumb," ***irrigations should be scheduled so that the plant available soil moisture in the crop root zone remains above 50 percent of the available water-holding capacity.***

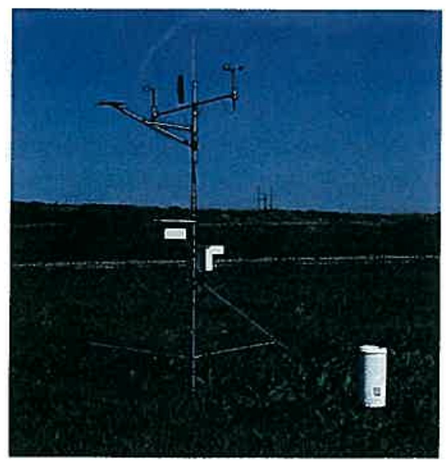
The amount of plant available water remaining in the root zone along with the expected ET can be used to project the time remaining before the crop will be stressed. The crop's stage of growth also must be considered; moisture stress is more damaging during the reproductive growth stages. The amount of room left in the active root zone to store water determines how much water can be effectively applied and when the irrigation should be started.

In the field, soil water can be measured or estimated using a soil probe and the "feel" method to estimate soil water content. (See "Estimating Soil Moisture by Appearance and Feel," NebGuide G84-690.) Other instruments, such as tensiometers or electrical resistance blocks are sometimes used. Soil water also can be estimated by calculating a "soil water balance"—subtracting water that has been used for ET and adding effective rainfall and net irrigation water from a beginning balance. This process is like balancing your checkbook and is sometimes called the "checkbook" method for irrigation scheduling (Table H-2). Spreadsheets for personal computers and irrigation scheduling software have made this process easier, but it still requires gathering basic information. Even with the checkbook method it is important to periodically verify the actual soil moisture status in the field. A soil probe is the most versatile tool available for soil moisture monitoring.

Table H-2. **Basic 'checkbook' soil water balance calculation**	
Beginning soil water balance	_______inches
Effective rainfall	+_______inches
Net irrigation	+_______inches
Crop water use (ET)	-_______inches
Current soil water balance*	=_______inches

* The current soil water balance can be no larger than the available water capacity of the active crop root zone.

A key input into "checkbook" scheduling is estimated crop water use (ET). Average ET values for the various crop growth stages can be used, but estimates based on daily weather data will be much more accurate. A series of automated weather stations across Nebraska, operated by the University of Nebraska's High Plains Climate Center, provide daily weather data used to make crop water use estimates. The crop water use information can be accessed directly from the High Plains Climate Center by computer modem. This access is available for a nominal fee. Several Natural Resources Districts and County Cooperative Extension offices put the estimated crop water use on telephone hotlines that can be accessed 24 hours a day. In addition, the information is broadcast on some radio and TV stations and is published by newspapers and in some weekly newsletters.



The irrigation timing is determined by considering two factors: 1) the amount of soil water remaining between the current soil water balance and the minimum allowable soil water balance (typically, 50 percent of the available water capacity) and 2) the projected estimated crop water use. Dividing the amount of usable water that remains in the soil by the estimated crop water use will give the days remaining before irrigation is required. Start irrigation early enough so no portion of the field drops below the minimum allowable soil water balance.

$$\textbf{Estimated Days before Next Irrigation} = \frac{\textbf{Remaining Available Water}}{\textbf{Forecasted ET}}$$

Example:

$$\text{Estimated Days} = \frac{1.0 \text{ in.}}{0.30 \text{ in./day}}$$

Estimated Days = 3 1/3 days, so start in about 3 days.

The net irrigation amount or depth to apply should be no larger than the available soil water storage space in the active crop root zone minus any allowance left for rainfall that may occur immediately following an irrigation.

The net irrigation amount is divided by the estimated irrigation system efficiency to get the gross irrigation amount required. The following examples illustrate the effect of irrigation system efficiency on the gross irrigation amount. If you have storage space for 1.5 in. of water in the root zone and you don't leave space for immediate rainfall, the net irrigation amount will be 1.5 inches. Gross irrigation amounts for different situations are shown in Table H-3.

Table H-3. **Gross irrigation amounts for different irrigation system efficiencies**

	Irrigation System Application Efficiency			
	90%	75%	60%	45%
Net Irrigation, inches	1.5	1.5	1.5	1.5
Gross Irrigation,* inches	1.7	2.0	2.5	3.3

$$\text{* Gross Irrigation} = \frac{\text{Net irrigation}}{\text{Efficiency}}$$

Scheduling the last irrigation of the season is important to assure optimum yields and reduce the potential for leaching during the off-season

Applying a late irrigation, if unneeded, will reduce the storage available for off-season precipitation by 1 to 3 inches. This is likely to result in more leaching loss of residual nitrate-nitrogen during the off-season and will directly increase pumping costs by $1 to $8 per acre. On the other hand, failing to apply a needed irrigation could mean a loss of several bushels per acre in crop yield. Irrigation management near the end of the season should leave enough soil water to carry the crop to maturity, but at the same time deplete soil moisture as much as possible. This provides storage for off-season precipitation and can greatly reduce leaching loss of residual nitrogen. The need for the last irrigation can be predicted using the following information:

- Predicted crop water use before maturity
- Measured remaining available water in the root zone

The remaining usable water is the difference between the current remaining available soil water in the field and the minimum allowable soil water at maturity. In most cases the soil water at crop maturity can be depleted to the point that only 40 percent of the available water remains in the crop root zone without causing yield reduction. Subtracting the remaining usable water from the crop's need for water gives the amount of irrigation needed to finish the growing season.

Normal water requirements to reach maturity for corn and soybean are shown in Table H-4. Since probabilities for significant rainfall are low during the later part of the growing season, rainfall is not usually considered in the last irrigation decision. Center pivot irrigators may have more flexibility to consider rainfall since they can apply an inch of water in a three- to four-day period if needed.

Table H-4. **Normal water requirements for corn and soybean between various stages of growth and maturity in Nebraska**

Stage of Growth	Approximate number of days to maturity	Water use to maturity (inches)
Corn		
Blister kernel	45	10.5
Dough	34	7.5
Beginning dent	24	5.0
Full dent	13	2.5
Physiological maturity	0	0
Soybean		
Full pod development	37	9.0
Beginning seed fill	29	6.5
Full seed fill	27	3.5

For a complete explanation of when to apply the last irrigation of the season, please see NebGuide G82-602, "Predicting the Last Irrigation for Corn, Grain Sorghum and Soybeans."

See these Extension publications for additional information:

NF96-290	Irrigation Management Practices in Nebraska
G93-1191-A	Glossary of Water-Related Terms
NF93-39	Precipitation and Irrigation Monitoring for Managing Irrigation Scheduling
G92-1099-A	Estimating Effective Rainfall
NF91-39	Precipitation and Sprinkler Irrigation Monitoring for Managing Irrigation Scheduling
EC89-723	Irrigation Scheduling Using Soil Moisture Blocks in Silty Soils
EC89-724	Irrigation Scheduling Using Tensiometers in Sandy Soils
G85-753-A	Irrigation Scheduling Using Crop Water Use Data
G84-690	Estimating Soil Moisture by Appearance and Feel
G82-602	Predicting the Last Irrigation for Corn, Grain Sorghum and Soybeans
G78-392	Selecting and Using Irrigation Propeller Meters
G78-393	Water Measurement Calculations

Section I

Understanding furrow irrigation management

The goal of every irrigator should be to apply the right amount of water as uniformly as possible to meet the crop needs and minimize leaching of nitrogen from the root zone. Achieving a uniform water application is not easy when using furrow irrigation. To do the job right, irrigators need to take into account how much water is applied and where the water goes (how uniformly water infiltrates the soil profile). With a better understanding of how furrow irrigation management affects water distribution and a willingness to make management changes, furrow irrigation uniformity and efficiency can be improved on almost any field.

Advance time

Soil texture, slope, and surface conditions (whether the furrow is smooth or rough, wet or dry) all influence how quickly water advances down the furrow. The speed of advance is directly related to how uniformly irrigation water is distributed within the soil profile. The *advance time* is the number of hours needed for water to reach the lower end of a set. If the advance time is long (i.e., almost as long as the total set time), there may be uneven infiltration along the row and excessive deep percolation at the head of the field (Fig. I-1a). Shorter, more suitable advance times yield a more uniform infiltration profile along the length of the furrow (Fig. I-1b).

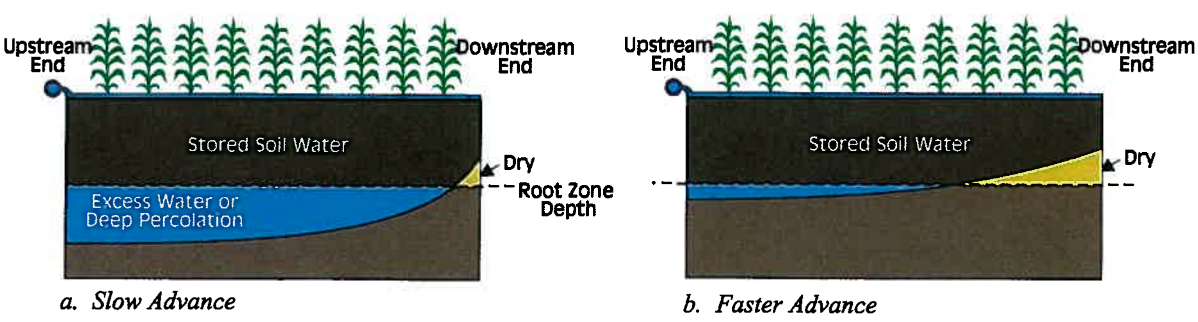


Figure I-1. Infiltration profiles under conventional furrow irrigation.

Set size and set time

It's easy enough to increase or decrease furrow advance time by changing the number of gates opened. Changing the set size has a direct impact, not only on how fast water advances down the field, but more importantly, on the total amount of water applied. Prior to irrigation, the soil surface conditions should be evaluated and the set size and corresponding furrow stream size (gpm/furrow) chosen accordingly. Using a small set (relatively few gates open) and a long set time may cause excessive runoff. On the other hand, too many furrows running will slow the water's advance rate, resulting in excessive deep percolation, the situation shown in Figure I-1a. To apply water uniformly and efficiently, surface irrigators must be willing to change both stream size and set time. Changing only one of these may make things worse instead of better.

Managing runoff

To adequately irrigate the lower end of the field, water must be present at the lower end long enough to get a reasonable amount of water into the root zone. With furrow irrigation this generally means that some runoff is necessary. Nebraska law makes it illegal for water pumped from groundwater to leave the farm. Runoff can be handled in several ways including installation of reuse systems to pump it back to the top of the field, pumping runoff to another field, or blocking the end of the furrow to hold it at the end of the row.

Runoff management greatly affects the amount of water lost to deep percolation below the root zone, and therefore, the nitrate leaching which results. If irrigation is to be efficient, the time that water takes to get through the field needs to be adjusted according to how the runoff is managed.

1. Systems with reuse of runoff

One way to improve on-farm surface irrigation efficiency is to reuse the runoff. Runoff is collected and either diverted to another field, or pumped back to the top of the same field. If runoff is reused, larger furrow stream size can be used to advance water through the field faster. This will provide more uniform infiltration without wasting water.

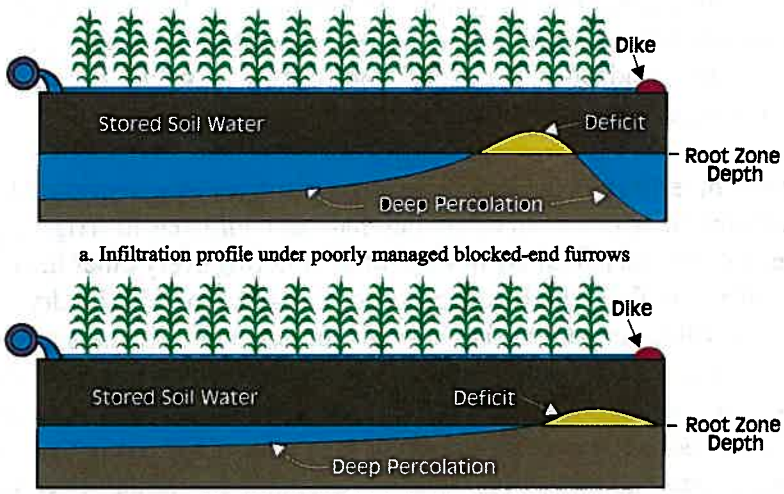
If the irrigation is to be relatively uniform, how long should it take to get water to the lower end of the field? **When runoff is reused, apply the less-than-half rule** to obtain uniform application: **The average furrow advance time should be less than half of the total set time**. For example, if the total set time is 12 hours, the advance time should be 6 hours or slightly less.

For the first irrigation of the season some adjustments are needed. If the irrigator normally uses 12-hour set times, shorter set times should generally be used during the first irrigation to avoid uniformly over-irrigating the whole field. The active root zone is very shallow early in the season. Water storage capacity in this shallow depth is small. Furthermore, the infiltration rate is highest during the first irrigation, so less time is needed to refill the root zone. The easiest adjustment is to shorten the set time as compared to later irrigations. Turning off the water two hours after runoff begins will result in the advance time being 65 to 75 percent of the total set time. The less-than-half rule will be easier to follow as the season progresses and advance times are faster as furrows become smoother.

2. *Systems without reuse of runoff*

When no runoff reuse system is available, systems should be managed to minimize runoff losses at the lower end of the field. This changes the amount of time needed for advance. **If there is no reuse system, apply the three-quarters-plus rule** to estimate the advance time: **Water should get to the end of the field in about three-fourths of the total irrigation set time**. This rule applies throughout the growing season, both for early season and later irrigations. For example, if you run 12-hour irrigations, your set size should be adjusted so that water reaches the end of the field in an average of nine hours. Although a nine-hour advance time follows the three-quarters-plus rule, a 12-hour set time may still over-irrigate the entire field, resulting in very low efficiency. For the first irrigation of the season when the root zone is shallow, 12-hour sets are likely too long on quarter-mile rows.

Blocking the lower end of the field is one method used to retain water that would otherwise become runoff. If too much water accumulates at the blocked end, nitrate leaching and excessive deep percolation can result (Fig. I-2a). If blocked-end furrows are used, **apply the three-quarters-plus rule** for advance time, as discussed earlier. By properly managing blocked-end furrow irrigation, deep percolation cannot be eliminated, but it can be minimized (Fig. I-2b).



a. Infiltration profile under poorly managed blocked-end furrows

b. Infiltration profile under properly managed blocked-end furrows

Figure I-2. Infiltration profiles under blocked-end furrow irrigation.

Runoff is not always a water loss or a waste. When irrigation water is supplied from a stream by a canal or pipe system or by direct pumping from the stream, runoff from furrow-irrigated fields in the river valleys actually becomes return flow to the river or canal system. The runoff water is available for diversion again downstream. (It may, however, contain increased levels of nutrients and pesticides). This process of returning and reusing runoff water occurs on a continual basis in the river valleys, making irrigation more efficient across the system as a whole. Furrow stream size and set times must still be managed to achieve uniform irrigation.

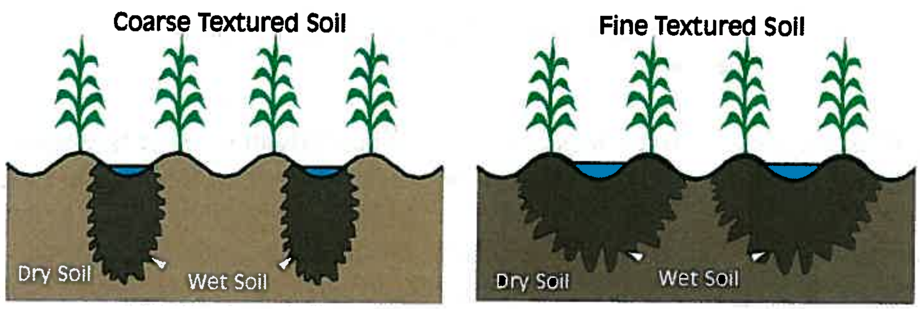
Long rows and long set times

Half-mile rows can be irrigated with reasonable uniformity on fine-textured soils with low infiltration rates. However, irrigation can also be very inefficient under such conditions, especially if 24-hour sets are used. When water is on the upper part of the field for 24 hours and on the lower end for only 2 or 3, there will be a substantial difference in infiltration even if infiltration rates are low. **In most cases, irrigation is more efficient if a larger furrow stream size is used and set time is cut to 12 hours or if the field is split into two quarter-mile runs**. When 24-hour sets are used on medium-textured soils, excess water application is unavoidable along most of the length of the row. On very fine-textured soils, the problem may not be as serious except for the first irrigation of the season.

Every-other-furrow irrigation

When irrigation is required, it may be important to irrigate the entire field as quickly as possible. Irrigating every other furrow supplies water to one side of each furrow ridge, but the wetting pattern is usually much more than that. This technique lets the irrigator apply water to more surface area in a given amount of time than does irrigating every furrow. Research indicates that every-other-furrow irrigation results in yields comparable to those achieved when every furrow is irrigated.

With every-other-furrow irrigation, water applications may be reduced by 20 to 30 percent. Infiltration is not reduced by one-half as compared to irrigating every furrow, because of increased lateral infiltration when watering every other furrow. Lateral water movement in the field can be checked using a soil probe in the dry rows. Figure I-3 shows the infiltration pattern for different soil textures. On coarser textured soils, the wetting pattern does not move as far laterally as it does on medium- and fine-textured soils. In this case every-other-row irrigation may be effective only on narrower row spacings. An added benefit of irrigating every other furrow is that by applying less water per irrigation, more storage space is available for rainfall after an irrigation.



a. This soil does not provide enough lateral movement for this wetted furrow spacing.

b. Lateral movement is okay for this wetted furrow spacing.

Figure I-3. Every-other irrigated furrow infiltration patterns.

Surge irrigation

Surge irrigation is the practice of applying water to a furrow intermittently in a series of on-off periods, called cycles. The wetting and drying cycles result in a reduced infiltration rate. Because there is less infiltration in the portion of the furrow that was previously wetted, two things happen. First, there is more water remaining on the surface, which will speed the advance to the end of the field. Second, this reduction in infiltration decreases the amount of deep percolation that can occur at the top end of the field when compared to conventional irrigation practices.

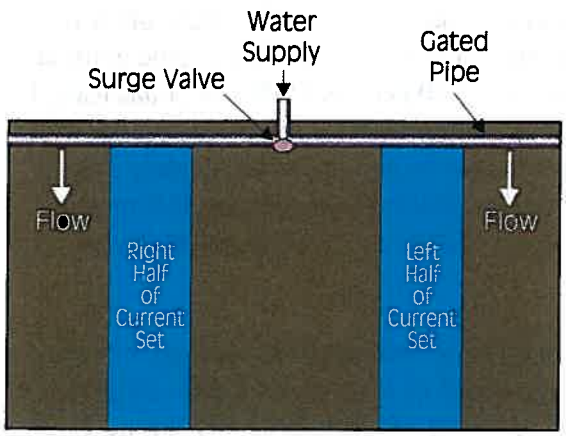


Figure I-4. Typical surge irrigation field layout.

Surge irrigation uses an automated surge valve. The surge valve diverts water to one group of furrows for a period of time and then switches the water to a different group on the other side of the valve (Fig. I-4). This sequence is repeated several times until the irrigation is completed. The length of time water is applied to a given side (the cycle time) increases during an irrigation. After water has advanced to the end of the field and the advance phase is completed, cycle times are decreased and the "soak phase" (or cutback) begins. During this phase the goal is to just fill the furrows with water and then switch to the other side. By doing this, water will continue to infiltrate into the root zone, while the amount of runoff is limited.

With surge irrigation, research has documented average reductions in advance time of 30 percent over conventional furrow irrigation, especially during the first irrigation of the season. Decreased advance times translate into improved irrigation uniformity even when using surge. The combination of decreased water advance times, less deep percolation, and improved runoff management results in better irrigation uniformity (Fig. I-5), increased irrigation efficiency, and reduced nitrate leaching during the growing season.

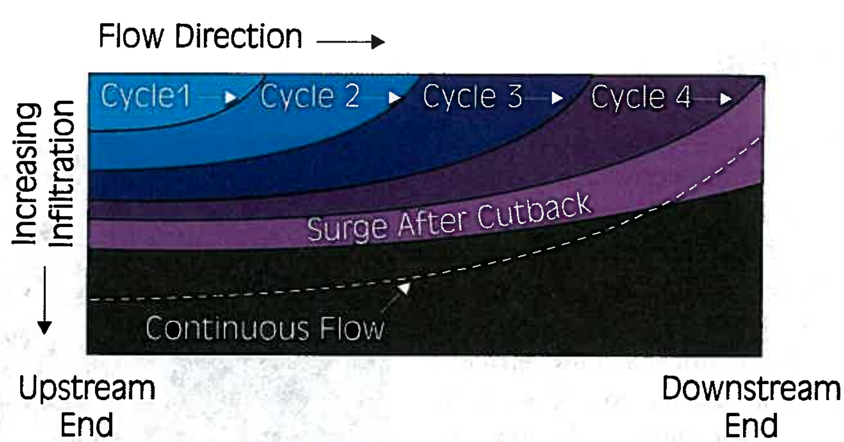


Figure I-5. Comparison of infiltration profiles for surge and continuous flow (conventional) irrigation.

Leaky gates and gaskets

Gated pipe irrigation systems with worn and/or broken gates and gaskets often leak from 10 to 30 percent of the water pumped through them. In Nebraska some extreme cases of water loss have been observed, where 40 to 60 percent of the water has leaked out before reaching the set being irrigated. Because some of the water leaving the well head does not reach the desired set, extra water must be pumped to adequately irrigate the crop. Extra water means extra pumping costs. Water losses that result from leaky gates and gaskets decrease irrigation efficiency. Crops cannot use water that never reaches the active root zone.

Another water management concern about leaky gates and gaskets is excess leaching. Some leaching will generally occur at the upper end of rows under furrow irrigation. However, leaks may worsen the problem by speeding the loss of nitrate during early irrigations. This can reduce yield at the top of the field. Whether it substantially increases the total nitrate loss for the field depends on how much leakage occurs and how far into the field it runs before it soaks into the soil.

Losses in the delivery system also decrease overall system capacity. This translates into smaller sets. For example, assume a 1000 gpm well loses 20 percent (200 gpm) through leaky gates and gaskets. If a furrow stream size of 20 gpm is needed and all 1000 gpm were available, 50 gates would be flowing. However, with a 200 gpm loss, only 800 gpm are available so only 40 gates can be opened. Smaller sets mean more sets per field. More sets per field mean more time and labor spent changing sets, and more time to get over the field. In this example, a field with 400 furrows would require two additional sets to compensate for the 20 percent leakage loss. The amount of gate and gasket loss can be checked by using a portable ultrasonic meter to measure flow on the pipeline near the pump and again just upstream of the first gate open on the most distant set from the pump.

Land grading

Land grading benefits irrigators by removing one source of variability in a field. Depressions (low spots) or up-hill sections (reverse grades) harm surface irrigation performance by increasing irrigation water advance times. In general, longer advance times mean less uniform and less efficient irrigations. If a field has low spots or reverse grades, water must fill the low spot before advancing past it. Time lost in filling the depression or building up the water level in rows to get over a high spot increases

advance time. If the reverse grade is large enough, adjacent furrow ridges may be overtopped before water advances down the furrow. This causes some furrows to be over-irrigated in the middle of the field and under-irrigated on the lower end. The result is excess leaching along part of the row and, possibly, water stress and yield reduction near the end. The area of the field where ponding occurred may also show a yield reduction because of excess leaching, oxygen deprivation in the root system, and/or denitrification.

Reverse grades and low spots can significantly harm surge irrigation performance. During surge irrigation water does not continuously flow down the furrow— it comes in surges. As a result, the furrow stream may never completely fill a depression or accumulate enough water to overtop a reverse grade and the furrow advance will never get past this point, especially in lighter soils.

Soil compaction

Soil compaction can significantly influence furrow irrigation effectiveness. The best example of this is the obvious difference in irrigation water advance rates between "soft" and "hard" rows. In "hard" furrows, those compacted by machinery traffic, infiltration is slow and advance rates are very quick. Even if the flow in the hard furrow is reduced so that water advances at the same rate as the soft furrow, infiltration in the soft row may still be 50 to 100 percent more than in the hard furrow (Fig. I-6).

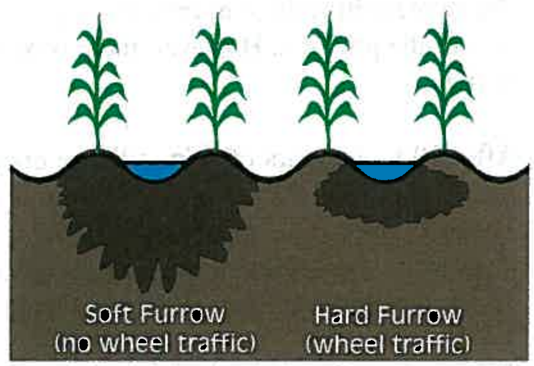


Figure I-6. Differences in infiltration patterns under "soft" and "hard" furrows.

This row-to-row difference complicates water management, especially for every-other-row irrigation. It is important to check water penetration after an irrigation to see if the hard rows got wet deep enough. If not, the "dry" furrows and "irrigated" furrows should be alternated from one irrigation to the next. Watering only soft rows may be one option to avoid the hard row problem. However, this is not an option where duals are used part of the season or where grain carts have compacted other rows under ridge-till. In those cases every other row will not be soft.

In general, extra runoff from hard rows is not a major problem if a reuse system is used. When no reuse system is in place, the extra runoff increases losses and becomes a headache with blocked-end furrows. More attention should be paid to checking rows and adjusting gates if a large build-up of runoff water behind the end-of-field dike is to be avoided.

Long-term infiltration changes under ridge-till

Many furrow irrigators have switched to ridge-till. It has many advantages in terms of doing field operations in a timely manner and in being able to plant when surface moisture is not optimum. The experience of many producers is that infiltration rates tend to go up after a few years of consistently using the ridge-till system. This has been a great improvement on soils with low infiltration rates where just getting water into the ground had been a problem. However, on soils that had moderate to good infiltration rates before ridge-till, irrigators find that it is becoming more difficult to get water through the field quickly. Some argue that the increase in residue in the furrow greatly retards water flow. That can certainly be a part of the problem. However, there is often another factor that is equally or more important.

After 10 to 12 years of ridge-till, the organic matter increases enough in the top few inches of the soil that the surface opens up and stays more open after the first irrigation. The infiltration rate may increase by 50 to 150 percent in comparison to a conventional disk-plant system. The increased infiltration slows the advance in the furrow and puts a lot more water in the soil in the upper half of the field.

There is no easy solution to this problem. The most obvious solution (up to a point) is to reduce the number of rows per irrigation set. This increases the gallons per minute per furrow and moves water through the field faster. However, if a smaller set is used, the set time must be shortened, or the entire field will still be over-irrigated. A few farmers have tried row packers. This helps some for the first irrigation, but the packing effect may not carry through the entire season. On some soils, the infiltration rate has become so high that farmers have of necessity switched to center pivots.

See these Extension publications for additional information:

G97-1338	Managing Furrow Irrigation Systems
NF94-176	Surge Irrigation
NF94-177	Nebraska Surge Irrigation Trials
NF94-178	Surge Irrigation Field Layouts
NF94-179	Surge Irrigation Management
G93-1154	Crop Residue and Irrigation Water Management

Section J

Irrigation water management for sprinkler irrigation

Well-managed sprinkler irrigation systems can apply water more uniformly and more efficiently than surface irrigation systems. In addition, center pivot irrigation systems offer the advantage of nearly complete automation that allows the manager to adjust application depths and frequencies to account for different crops, soil types, and field topographic conditions. Often this translates into a lower labor requirement. However, poor irrigation management can negate the advantages of the technology built into modern sprinkler systems.

Component selection and maintenance

Like any mechanical device, center pivot irrigation systems require proper component selection and maintenance. Nozzle wear or incorrect installation can reduce the uniformity of water application along a well-designed system. Pressure regulators may be needed to ensure that water is distributed at the designed flow rate from each nozzle/sprinkler regardless of differences in field elevation. Selection of the wrong sprinkler/nozzle package can result in surface runoff or non-uniform water application. Some of these problems could be avoided by collecting accurate field information, performing routine system maintenance, and understanding better how system management might be affected by the choice of system components.

Selecting well-matched system components will reduce installation costs while maximizing performance

The first decision is to determine what system capacity (gpm) is needed to irrigate the crop adequately. This decision incorporates soil water-holding capacity, potential for rainfall, system management, system topography, acres to be irrigated, and water application efficiency of the system. Medium- and fine-textured soils have a larger soil water reservoir when compared with a sandy soil. Consequently, the system capacity for these soils can be less than for sandy soils. Also, an electrically powered system enrolled in a load control program will require a greater system capacity than one that can be operated full time. If the system has a higher capacity than needed to meet crop needs, the potential is higher for runoff and/or infiltration problems. The sizes of the pump, motor and delivery systems are all based on the system capacity selected. In many cases, the optimum system capacity may be less than the potential pumping rate of the well. The important point is that the system should be designed to meet your management scheme.

Selecting the appropriate sprinkler package will help ensure efficient water application

Recent developments in sprinkler technology have provided a host of options when making a sprinkler package selection. The key to selecting the right package is that the water should be applied uniformly without generating runoff. Such things as sprinkler type, spacing between sprinklers/nozzles, and weather conditions can influence how uniformly the water is applied. Surface runoff depends on the water application rate, water droplet characteristics, soil texture, and field topography.

The system should be selected and managed so that water infiltrates into the soil where it lands. This means that the water application rate of the system must be less than the soil infiltration rate. As discussed in Section B, water infiltrates into a dry soil very rapidly for a short period and then the infiltration rate decreases as the application time continues. Over-irrigation can result in runoff from a system that would not otherwise produce runoff if it were managed to apply the correct amount of water. If runoff is experienced, reducing the water application time (and, therefore, the irrigation depth) is an appropriate management decision. If the irrigation depth is reduced, the irrigation frequency must be increased to keep up with crop water use. Normally, irrigation depths should be no less than 0.5 inches.

To correct cases of severe runoff, the system flow rate or sprinkler package may need to be changed. If the system was originally designed with excess capacity, reducing the system flow rate will cut runoff with no impact on production. To maintain uniform distribution when reducing the flow rate **both** the pump and the sprinkler nozzle package must be modified.

The water application rate is determined by the position of the sprinkler/nozzle along the system, the system flow rate, and the wetted diameter of the sprinkler/nozzle. These same factors determine how long any given point will receive water during an irrigation. Figure J-1 shows a typical water application pattern for a high pressure impact, low pressure impact and a low pressure spray nozzle. High pressure impact sprinklers can deliver water up to 100 ft from the pipeline. So at the **outer end** of a 1300-ft long system with a system capacity of 800 gpm, the system would irrigate a given point for nearly 1.2 hours to apply an inch of water. The same system equipped with a low pressure spray nozzle might deliver water only up to 25 ft away from the pipeline. At the outer end it would apply 1 in. of water in about 20 minutes. The low pressure impact sprinkler would require about 45 minutes to apply the same amount.

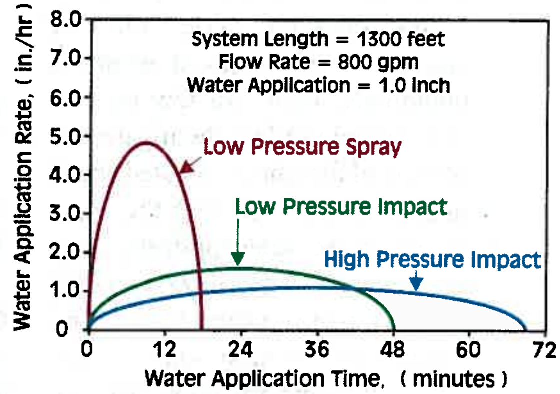


Figure J-1. Water application patterns by different types of sprinklers at the outer end of a pivot system.

Water applied at a rate greater than the soil's infiltration rate will pond on the soil surface and become runoff if the field slopes away from the application point. Since each system is applying the same depth of water, the soil under the low pressure nozzle must infiltrate water at a rate four times higher than under the high pressure impact system if ponding is to be avoided. When there is substantial runoff, additional water application may be necessary to ensure that all parts of the field are adequately irrigated. This increases cost and decreases irrigation efficiency.

Position the sprinkler/nozzle to reduce water distribution losses

Today there are many options for sprinklers, nozzles and sprinkler placement. Using different versions of the goose neck in combination with flexible or rigid tubing makes it possible to customize the nozzle position to crop and field conditions. If the system will be used to irrigate a rotation of corn and soybean, the nozzles should be positioned above tassel height for corn. If desired, a second set of drop tubes can be purchased for irrigating the bean crop.

Research at both the University of Nebraska and Kansas State University has shown that **when nozzles are positioned within the corn canopy, the uniformity of water distribution decreases**. Figure J-2 shows results from a study where nozzles were dropped into the canopy on a 12.5 ft spacing. The lower part of the chart shows the change in soil water content as a result of the irrigation. The non-uniform pattern was caused by crop leaves and stems deflecting and interrupting the water distribution pattern. Water that would normally travel to the outside edge of the pattern actually infiltrated into the soil a short distance (5 to 7.5 ft) from the nozzle. Also, there were areas between the nozzles that received almost no water.

There are several other problems with placing the nozzle within the canopy. If the irrigator wants to chemigate, there are few nozzles that can be used to chemigate that portion of the canopy located above nozzle height. Also, if the plant breaks up the water application pattern, areas near the nozzle receive several times more water and chemicals than the system average. To compensate for poor distribution, the nozzle spacing must be decreased so that the water application patterns overlap and the distribution uniformity is acceptable. This increases system installation costs since spacings may need to drop from 13-18 ft to 5 ft between nozzles.

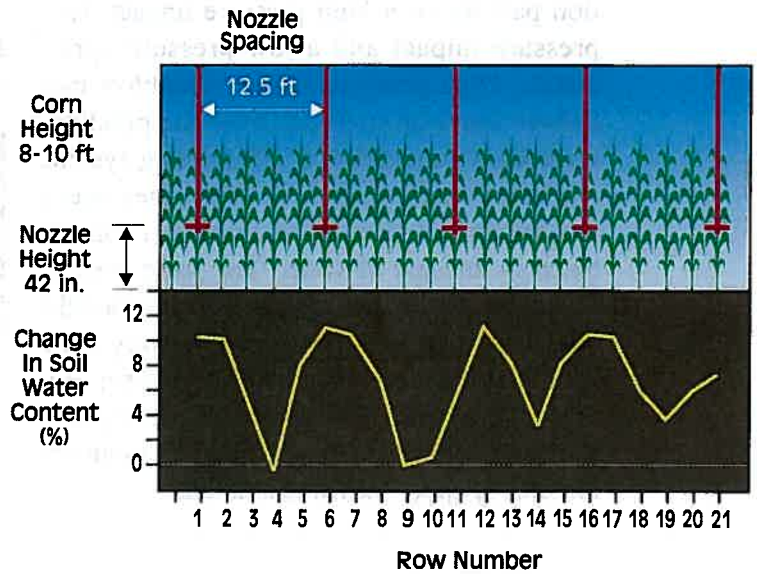


Figure J-2. Water distribution in the soil under sprinklers installed at too wide a spacing inside the crop canopy.

Some irrigators install nozzles in the canopy with the idea of reducing water application losses. Research at Bushland, Texas indicates that **even under very dry, windy conditions, the water saved by positioning the nozzles within the canopy is less than 5 percent**. The reduction in evaporation may be more than offset by reduction in uniformity. When uniformity is low, more water has to be pumped to make sure that all areas get enough.

There are additional reasons for not extending the drop tubes too far below the truss rods. For example, flexible tubes can ride up on corn leaves and stems, altering the water application pattern. The tubes can swing in the wind, potentially causing them to get hung up on the truss rods; if positioned just right, collisions between the nozzle and the truss rods can break the nozzle. These factors make it necessary for the irrigator to carefully consider the options to ensure that the system is well matched for the crop, soil, and field topography.

The general recommendation is that nozzles should be positioned above the height of the tallest crop.

LEPA systems

The **LEPA** system (Low Energy Precision Application) is a different approach to obtaining high water application efficiency with a center pivot. LEPA heads are positioned within 18 in. of the soil surface. The nozzle spacing is double the row width, so there is a nozzle above every other furrow. During irrigation the canopy is not wetted. Only part of the soil surface receives water. The water is applied at a much higher rate than the soil can absorb before runoff occurs. To avoid runoff, special tillage must be done to create storage on the soil surface to hold the water until it can soak in. In addition, planting must be done in a circle. Data from Texas show that the system can attain water application efficiencies of up to 98 percent **if all system guidelines are followed**. However, severe runoff problems have occurred at locations in Kansas, Colorado, and Nebraska, where systems were installed without following the guidelines. Farmers are not fond of planting in circles. Some have been unwilling to do the special surface tillage with a dammer-diker or similar machine. These steps are necessary to obtain efficient irigation. **If all LEPA guidelines are not followed, runoff may occur. In such case, the water application efficiency with LEPA could be less than for high pressure impact sprinklers.**

Sprinkler system application efficiency

Table J-1 shows typical water application efficiencies for different sprinkler packages. If runoff occurs, efficiencies may be much lower.

Table J-1. **Estimated water application efficiency for different sprinkler packages**

Sprinkler/Nozzle Type	Potential Application Efficiency[1] *(%)*	Runoff Potential
Low Pressure Spray (LEPA bubble mode)	95-98	High
Low Pressure Spray (3-7' off the ground)	90-95	↓
Low Pressure Spray (truss rod height)	87-92	↓
Low Pressure Spray (on top of pipeline)	85-88	↓
Low Pressure Impact	82-85	↓
High Pressure Impact	80-85	Low

[1] ***Average water application efficiency when zero runoff is produced.***

Leaving room for rainfall can reduce seasonal application amounts

Irrigation water should supplement water stored in the soil during the non-growing season and that provided by rainfall during the growing season. For rainfall to be most useful, storage space in the soil must be available when rainfall occurs. If the soil profile is near field capacity at all times, little of the rainfall received during the growing season can be used to produce a crop. Most of the rain entering the soil will pass through the root zone, carrying nitrate into the groundwater.

Modern irrigation scheduling procedures include the option to leave room in the soil for rainfall. Since rainfall is unpredictable, reserving 0.5 to 1.0 in. of soil water storage for rainfall could reduce the amount of water pumped during a growing season. Reserving some soil water storage for rainfall works well with center pivot irrigation systems because of the small water application depths per irrigation.

Small water application depths delivered by center pivots may help reduce seasonal water application. When scheduling the last irrigation of the season under center pivots, it is much easier to take the wait-and-see approach. Because an inch of water can be applied to a circle in three to four days, pivot operators can wait to see if it rains. Furrow irrigators have larger application depths and longer irrigation durations, making it more difficult to wait.

See these Extension publications for additional information:

G97-1328-A	Water Loss from Above-Canopy and In-Canopy Sprinklers
G97-1337-A	Application Uniformity of In-Canopy Sprinklers
G96-1305-A	Water Runoff from Sprinkler Irrigation—A Case Study
G92-1124-A	Converting Center Pivot Sprinkler Packages: System Considerations
G91-1043	Water Runoff Control Practices for Sprinkler Irrigation Systems
G89-932	Minimum System Design Capacities for Nebraska
G88-870	Selecting Sprinkler Packages for Center Pivots
G88-888	Flow Control Devices for Center Pivot Irrigation Systems