EC2008

Irrigation and Nitrogen Management

User Education/Certification Program

Extension is a Division of the Institute of Agriculture and Natural Resources at the University of Nebraska–Lincoln cooperating with the Counties and the United States Department of Agriculture.

EDITOR

William L. Kranz	Extension Irrigation Specialist Nebraska Association of Natural Resources Districts

CONTRIBUTING AUTHORS

Department of Agronomy and Horticulture

Bhupinder S. Farmaha	Post-Doctoral Research Associate
Patricio Grassini	Cropping Systems Agronomist
Gary W. Hergert	Soil and Nutrient Management Specialist
Timothy Shaver	Nutrient Management Specialist
Charles A. Shapiro	Soil Scientist/Crop Nutrition

Department of Biological Systems Engineering

Suat Irmak	Soil and Water Resources and Irrigation Engineer
Derrel Martin	Water Resource and Irrigation Engineer

Extension Educators

Chuck Burr	Water and Cropping Systems
Aaron Nygren	Water and Cropping Systems
Gary Zoubek	Water and Cropping Systems

PROJECT COORDINATORS

Leslie J. Johnson
Mary K. Jarvi

LAYOUT AND GRAPHICS

C. Alberts	Editor
S.A. Smith	Illustrator
A.M. Moore	Layout

Acknowledgments

The authors gratefully acknowledge the support of the Natural Resources Districts who collaborated in this project. In particular, we wish to recognize the following personnel who contributed significant time and effort to developing the training materials:

Daryl Anderson, Sheri Daniels, Rod DeBuhr, Nolan Little, Mike Lorenz, Don Ogle, Brian Bruckner and Jennifer Swanson.

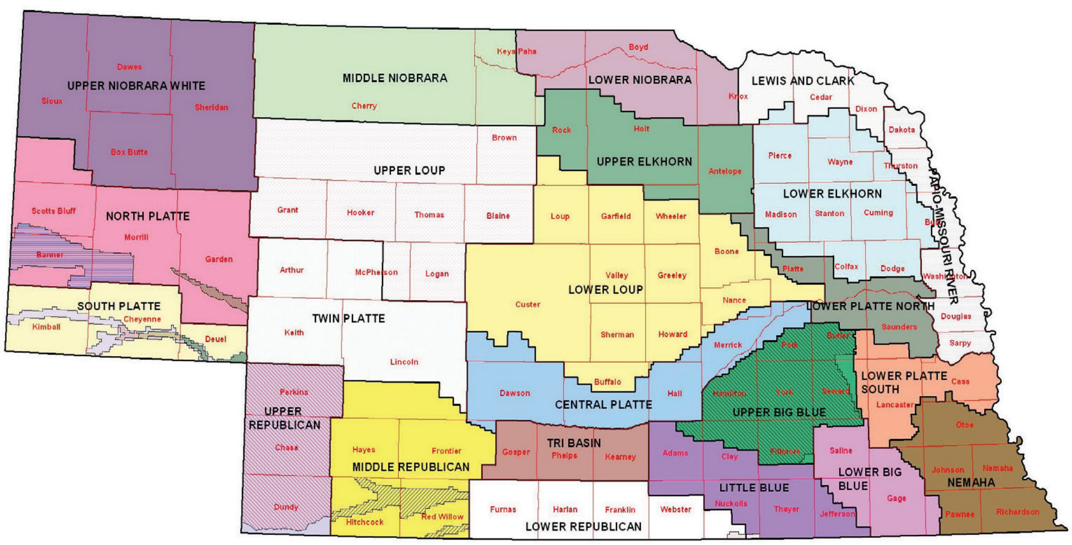
Partial funding for this manual has been provided by: The U.S. Environmental Protection Agency (EPA) Region 7 under the 319 Nonpoint Source Program through the Nebraska Department of Environmental Quality (Project Number 56-1099).

Table of Contents

Related videos and presentations can be found at: *water.unl.edu/waternmgt*

Foreword

Nonpoint source contamination of groundwater by nitrate-nitrogen is a problem across Nebraska. Each Natural Resources District (NRD) has developed and is implementing a groundwater quality and quantity management plan that outlines actions to be taken to address nitrate contamination and conserve groundwater. The map below shows the locations of each of the 23 NRDs in Nebraska. For information about NRD programs in your area go to: *nrdnet.org/find-your-nrd.php*. An annual summary report of activities in each water basin may be accessed at: *nrdnet.org/water.php.*



Producer education is a key component of all NRD Groundwater Management Plans. Nebraska Extension developed the original edition of this manual in 1998. This version of the manual outlines the knowledge base needed by producers to manage both nitrogen and irrigation in a manner that will reduce nonpoint source nitrogen contamination and be profitable.

The end of each section in this manual has a list of publications for getting additional information on topics discussed in that section. These publications are from various sources and include web addresses where appropriate. Many listed publications are only available electronically at: *tinyurl.com/n2lls9u*.

Guidelines

Effective nitrogen management to protect water quality and irrigation management to conserve water

Good management of both nitrogen and water is necessary to reduce nitrate contamination of groundwater. Below are key nitrogen and irrigation water management practices needed to protect water quality and conserve water. Individual sections of this manual will expand upon these key practices.

Keys for nitrogen management:

- Understand the nitrogen cycle to manage fertilizer more effectively
- Set realistic expected yield goals
- Use deep soil samples to determine residual nitrate-nitrogen
- Give proper credit for non-fertilizer nitrogen sources
- Time nitrogen applications to match crop uptake needs
- Consider potential N losses, and manage to minimize them
- Use some in-season N sensing technology to fine tune N applications
- Apply only the amount of nitrogen required to achieve expected yield

Keys for irrigation water management:

- Use soil water sensors to know the current soil water content
- Use crop ET information to check soil water sensors
- Know how much water you apply by using a water meter
- Manage pivot irrigation so there is always some room left in the root zone for capturing possible precipitation
- Under furrow irrigation adjust both set times and furrow flow rates to apply water uniformly
- Use surge valves to increase furrow irrigation water application uniformity
- Schedule last irrigation to leave space for off-season precipitation
- Maintain center pivot water application uniformity by selecting and maintaining sprinkler packages suitable for the field soils and topography
- Install, maintain, and manage subsurface drip irrigation system components to ensure that deep percolation does not occur

Section A

The nitrate contamination concern

In 1974, the U.S. Congress passed the Safe Drinking Water Act (SDWA). This law required the Environmental Protection Agency (EPA) to determine the level of contaminants in drinking water at which no adverse health effects were likely to occur. Contaminants were defined as any physical, chemical, biological, or radiological substances or matter in water. One of the **contaminants** on the EPA list is nitrate (NO_3). The EPA has set the enforceable regulation for nitrate, referred to as the **maximum contaminant level** (MCL) at **10 mg/L or 10 ppm NO_3-N**.

Contaminants are any physical, chemical, matter, biological, or radiological substances in water.

Maximum Contaminant Level (MCL) is an enforceable regulation that establishes the level of a contaminant at which no adverse health effects are likely to occur.

Nitrate (NO_3) is a naturally occurring inorganic ion and a **nitrogen**-oxygen combination which readily reacts with various organic and inorganic compounds.

Groundwater is water contained in pores of geologic materials that make up the earth's crust.

Methemoglobinemia or "blue baby syndrome" is caused when water or food containing nitrates are ingested and bacteria in the human digestive system convert the nitrate to nitrite. Nitrite reacts with iron in hemoglobin to form methemoglobin which has a reduced oxygen carrying capacity.

Nitrate is a naturally occurring form of nitrogen found in most soils. Nitrate is a colorless, odorless, and tasteless compound and is also one of the most common groundwater contaminants in Nebraska. Though nitrate occurs naturally in some **groundwater**, in most cases levels above 3 ppm result from human activities. Nitrates form when microorganisms break down ammonium fertilizers, decaying plants, manures, or other organic residues involved in crop production systems. Sources of nitrate in water include fertilizers, septic systems, wastewater treatment effluent, animal wastes, mineralization of organic matter, industrial wastes, and food processing wastes. Usually plants take up these nitrates, but sometimes precipitation or irrigation water can leach nitrates out of the crop root zone and into the groundwater.

Health concerns

Several health concerns may be related to the consumption of high nitrate water. The acute health hazard associated with drinking water having elevated levels of nitrate occurs when bacteria in the human digestive system transform nitrate to nitrite. The nitrite reacts with iron in the hemoglobin of red blood cells to form methemoglobin, which lacks the oxygen-carrying ability of hemoglobin. This creates the condition known as **methemoglobinemia** (sometimes referred to as "blue baby syndrome"), in which blood lacks the ability to carry sufficient oxygen to individual body cells.

The current 10 ppm standard was set to prevent the occurrence of methemoglobinemia in infants under six months of age. Infants are particularly susceptible if fed formula, due to the volume of water intake relative to their body weight. A much greater question is whether consuming water with various levels of nitrate can have chronic health impacts for adults. While research is limited, correlations have been found between long-term ingestion of water with nitrate and increased incidence of certain diseases and cancers.

Figure A-1 shows the location of wells where nitrate-nitrogen concentrations were documented 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.

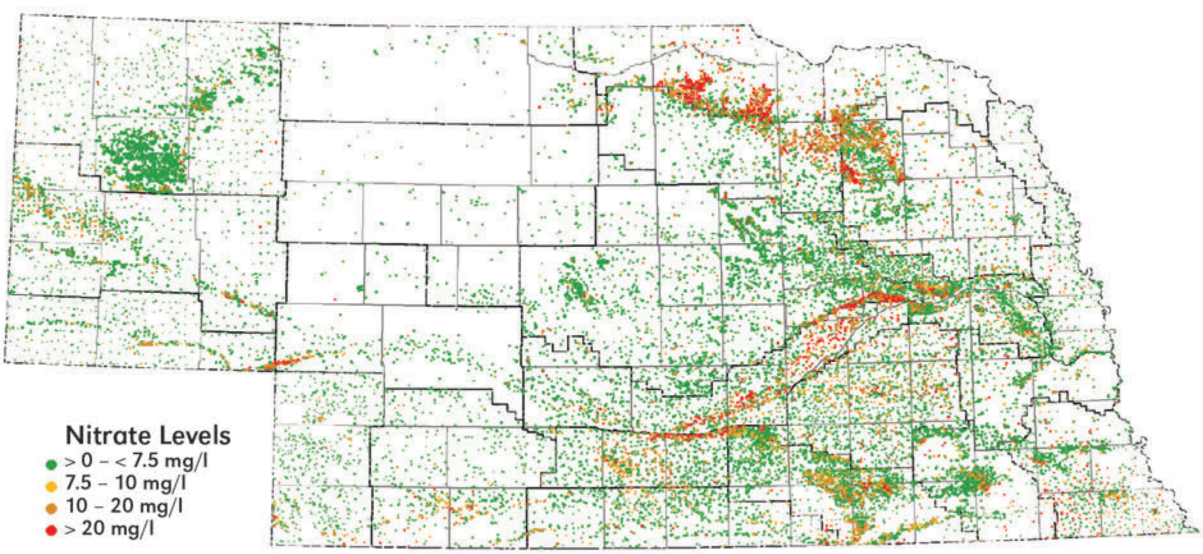


Figure A-1. **Nebraska map presenting recorded concentration of nitrate from 1974 - 2012. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2013). Empty areas indicate no data reported, not the absence of nitrate in groundwater.**

Groundwater sampling programs conducted by local NRDs across the state indicate that groundwater nitrate concentrations continue to rise (*Figure A-2*). However, data for the last 30 years of using nitrogen and irrigation best management practices show signs that some areas in the Platte Valley are seeing nitrate levels plateau or beginning to decline.

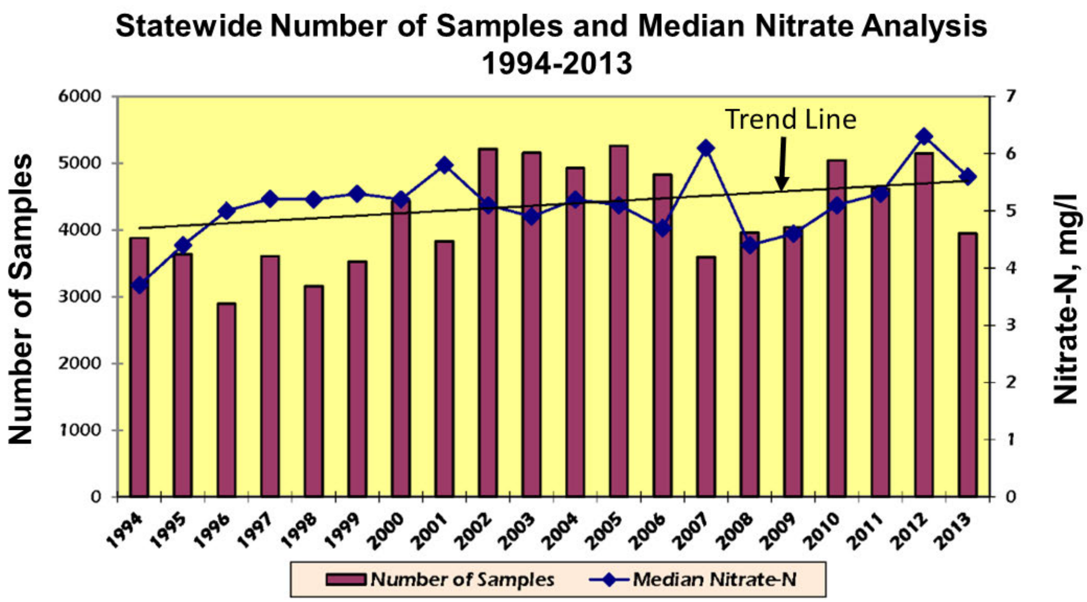


Figure A-2. Water laboratory analyses and median **nitrate-nitrogen** levels for 102,386 samples collected across Nebraska between 1994 and 2013. (See 2014 Nebraska Groundwater Quality Monitoring Report, NDEQ.)

Impacts on town and rural water supplies

Today, residents of cities, small towns, and rural areas 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 increased by excessive applications of irrigation water. With improper management of nitrogen sources, non-irrigated crop production can also contribute to the problem. In some cases urban sources of contamination, including **nitrate leaching** from areas such as lawns and golf courses, contribute to the nitrate contamination levels. *Figure A-3* depicts the number of cities and towns that have issues with nitrate contamination of their water supplies.

Nitrate-nitrogen (NO_3-N) is one chemical formulation used by the EPA to establish the U.S. drinking water maximum contaminant level for nitrates. 1.0 ppm NO_3-N = 4.5 ppm NO_3.

Nonpoint Source Contamination (NPS) is contamination discharged over a wide land area. Typically the exact source of the contamination is difficult to identify. Leaching of fertilizer from a corn field or surface runoff from a large land area are examples of NPS.

Nitrogen leaching is the passage of nitrogen vertically through the soil to a position where the nitrogen effectively becomes unavailable to the crop.

Figure A-3 shows that at least 12 small towns and villages had to find alternative drinking water supplies and are treating their water to meet the 10 ppm standard. Although the users of private wells are not required to meet the EPA nitrate MCL, they should monitor nitrate levels in the water supply. If nitrate levels are excessive, they should identify an alternative water supply or treat their water to assure it is safe to drink especially if babies will be present.

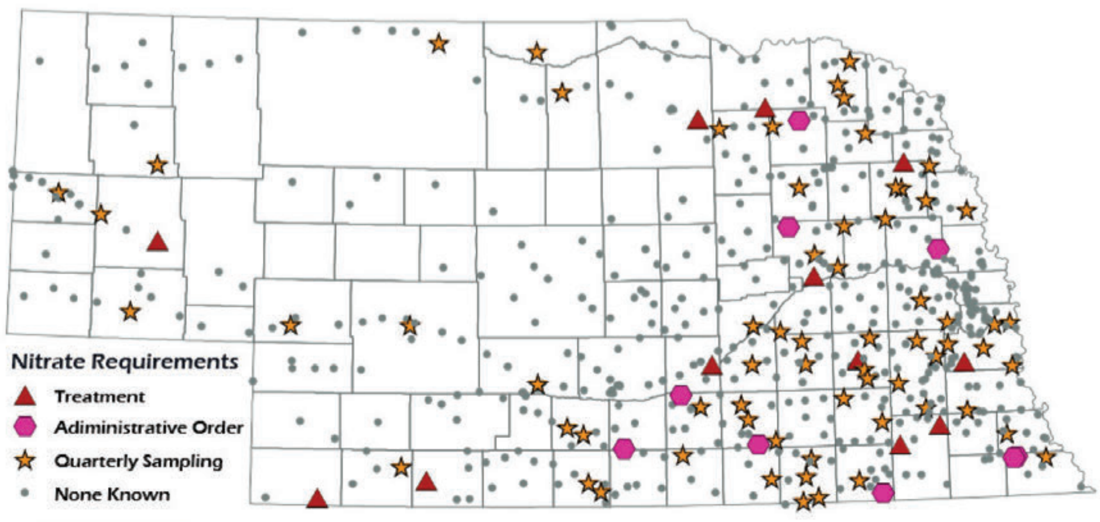


Figure A-3. 2013 map of community and public water supply systems with nitrate contamination issues. (Source: Department of Health and Human Services).

How does nitrate contamination of groundwater happen?

Nitrate contamination happens when water moves through the soil profile that contains excess nitrate (*Figure A-4*). 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-nitrogen is highly soluble in water and since soil is a porous system, water passing through the soil will carry some nitrate with it to the groundwater.

One factor is that crops are unable to remove all available nitrogen from the root zone. Even if the crop is under-fertilized, there will be some residual nitrate-nitrogen in the root zone at the end of the growing season. During the off-season, part of the excess nitrate-nitrogen can be leached by excess precipitation. Similarly, early spring precipitation events can move available nitrate-nitrogen from the root zone.

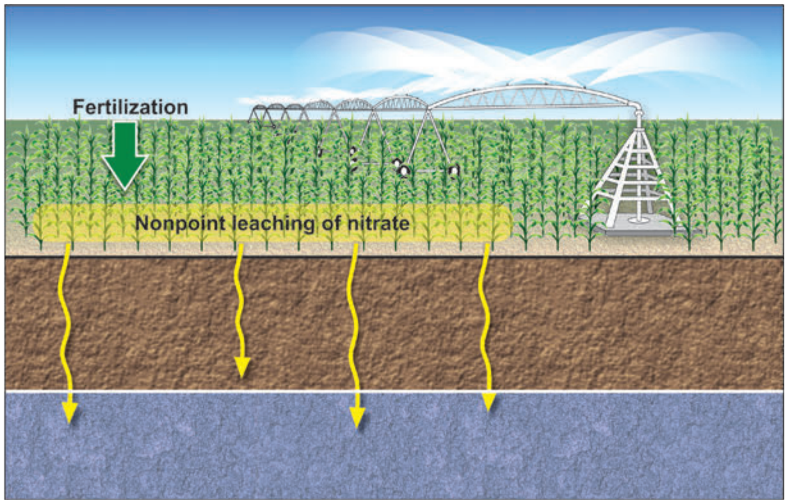


Figure A-4. Nonpoint source nitrate contamination of groundwater can come from intensive production of irrigated corn.

At some point, **nitrate leaching** occurs under all corn fields that receive nitrogen fertilizer whether the field is irrigated or not. However, *Figure A-5* shows significant difference in nitrogen leaching potential due to the type of system used to apply irrigation water. *Figure A-5* also shows that nitrate loss cannot be entirely stopped, but it can be reduced with good management. Two major advantages of the surge and sprinkler irrigation systems are that the depth and uniformity of water applied can be more precisely controlled by the irrigator. Center pivots provide the greatest level of control of these two factors. For a traditional furrow irrigation system, the field conditions such as soil texture, cropping practices, and furrow length can contribute greatly to how much water infiltrates into the soil, and thus how uniform the water can be applied along the furrow length.

Nitrate leaching loss rates range from 5 to 10 lb/ac-in of deep percolation or drainage, which is why over-irrigation needs to be avoided.

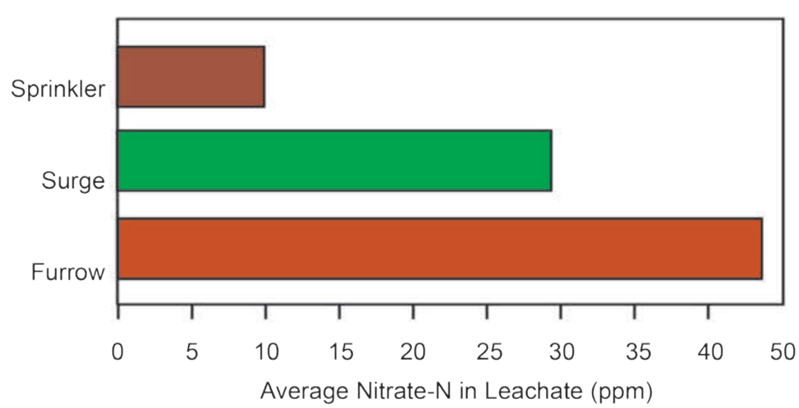


Figure A-5. Average nitrate-nitrogen concentrations in leachate water below corn fields irrigated by sprinkler, surge flow, and traditional furrow irrigated fields in the Platte Valley. (See Spalding, et al., 2001).

Annual nitrate leaching losses

University of Nebraska researchers measured water and nitrogen loss from the root zone in a deep, silt loam soils, and sandy soils. Yearly average concentrations of nitrate-nitrogen in the drainage often ranged from 22 to 44 ppm. They found annual nitrate-nitrogen losses ranging from 40 to 80 lb/acre. 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 drainage. This rate of drainage is typical under continuous corn production, when following recommended nitrogen and irrigation water management programs. Thus, losses are greater where irrigation and nitrogen applications are not well managed during the growing season.

Aquifer is a water-bearing geological formation capable of yielding water in sufficient quantity to support a well.

Transit time is the length of time required for contaminants to move from the bottom of the root zone to groundwater. Transit times range between a few weeks to decades depending on the depth and texture of the soil.

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

The time it takes soil nitrate to reach the groundwater **aquifer** after it moves below the root zone is called the **transit time**. Depending on the geology of the area and the depth of drainage loss, nitrate-nitrogen can reach the top of a shallow aquifer in a matter of weeks, or at most, a few months. Today the nitrate problem is appearing in areas where the water table is 100 ft or more below the surface and is covered almost entirely with fine-textured soil material. Some people thought that the depth to groundwater conditions would prevent aquifer contamination. However, nitrate-nitrogen moves slowly in such materials, too. In this case the travel time from the root zone to the water table may be more than 30 years. Some areas in Nebraska have subsoil conditions that greatly limit the movement of nitrate to the aquifer. Groundwater in these areas is not significantly affected by farming practices.

See these publications for additional information:

EC91-735, The impact of nitrogen and irrigation management and vadose zone conditions on groundwater contamination by nitrate-nitrogen (archived publication)

RP189, Agricultural nitrogen management for water quality protection in the midwest

For More Information

Nebraska Department of Environmental Quality. 2014. 2014 Nebraska groundwater quality monitoring report. Prepared Pursuant to Nebraska Rev. Stat. §46-1304.

Spalding, R. F., D. G. Watts, J.S. Schepers, M. E. Burbach, and M. E. Exner. 2001. Controlling nitrate leaching in irrigated agriculture. Journal of Environmental Quality 30: 1184-1194.

Section B

Recent trends in nitrogen fertilizer and water use in irrigated corn

Water, nitrogen, and corn yields

Water plays a crucial role in the life of plants. Of all the resources that plants need to grow and function, water is typically the most limiting for agricultural productivity. The fact that water is limiting is the reason for applying irrigation. In turn, nitrogen (N) is the mineral element that plants require in the greatest amounts. Water and N deficiency reduce leaf area expansion, hasten leaf senescence, and reduce photosynthetic rates, which ultimately reduces corn yield.

This section summarizes historical trends in corn yield and N fertilizer use in Nebraska and presents the current status of on-farm N and irrigation water use based on data collected by the Natural Resources Districts (NRDs).

Figure B-1 shows some general relationships between grain yield, N uptake, and water use for corn in Nebraska. The response of corn yield to N uptake follows a curvilinear shape (yield increase slows with increasing N uptake and gradually approaches a plateau) (*Figure B-1A*). The level of the plateau is determined by the site-specific yield potential. On the contrary, the relationship between corn grain yield and crop water use is fairly linear (*Figure B-1B*), thus each additional inch of crop water use produces essentially the same amount of grain yield.

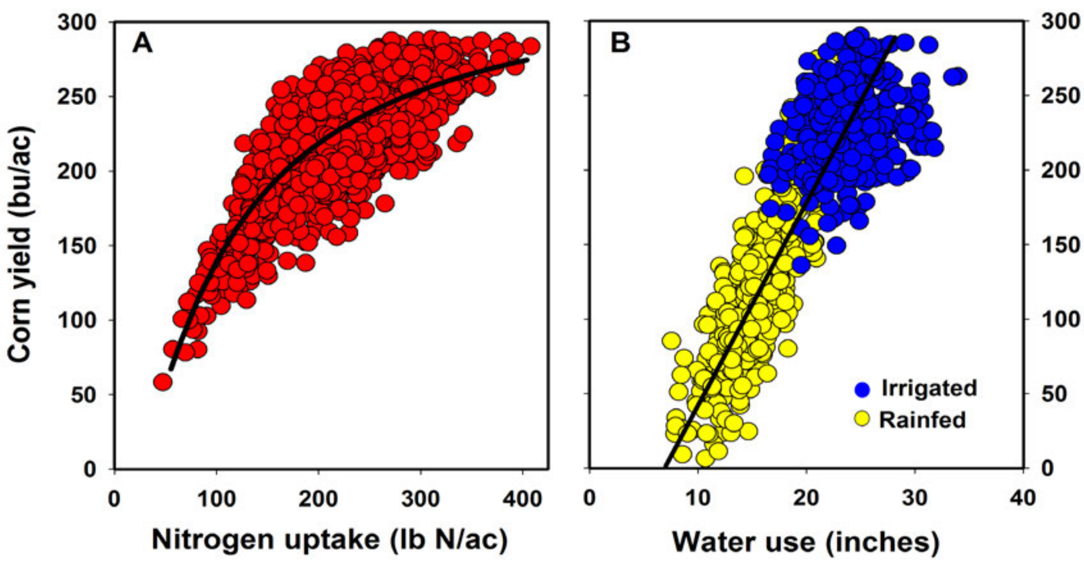


Figure B-1. Relationship between corn yield and corn N uptake (A) and corn yield and water use or crop ET (B). (Adapted from Grassini et al. 2009 and Setiyono et al. 2010).

Producers in Nebraska apply N fertilizer and irrigation water because N supplied by mineralization of soil organic matter and water supplied by precipitation are not enough to satisfy crop N and water requirements for high yields. At low N fertilizer or irrigation rates, increases in these inputs produce parallel increases in crop N uptake and water use, resulting in large yield increases. However, as input rates increase and yields approach their yield potential, it becomes more difficult to achieve the same yield increase per unit of applied N or irrigation water. This is because factors other than N and water become more limiting and less of the applied N fertilizer and irrigation water is recovered by the crops and more is prone to be lost into the environment. Hence, the challenge in crop production is to optimize, for a given field, the applied N fertilizer and irrigation water in relation to crop requirements to ensure high yields while minimizing the environmental impact. Later in this manual, methods for obtaining more grain yield for each pound of N and for each inch of water will be discussed with the goal of protecting groundwater quality.

Historical trends in yield and N fertilizer use and efficiency

Nitrogen Use Efficiency, NUE_F: refers to the amount of yield produced per unit of N fertilizer applied and is calculated by dividing the total grain or forage yield by pounds of N applied.

Water Use Efficiency (WUE) is the amount of yield produced per water applied and is calculated by dividing the unit of total grain or forage yield by inches of water applied.

Corn yields and N fertilizer and water use efficiencies have increased steadily in Nebraska during the past four decades (*Figure B-2*). Irrigated yield has increased at an annual rate of 2.0 bu/ac and rainfed yields have increased 1.6 bu/ac from 1965 to 2010 (*Figure B-2A*). However, N fertilizer rates have been relatively stable since the early 1970s with an average rate of 138 lb N/ac (*Figure B-2B*). The increase in corn grain yields without any significant increase in N rate over the same time translates into an increase in the yield produced per unit of N fertilizer (NUE_F) from 0.6 bu/lb N in the early ’70s to 1.1 bu/lb N in the 2000s. *Figure B-2C* presents the increase in **N use efficiency** based on the average corn yield for both rainfed and irrigated fields. Likewise**, the amount of yield produced per unit of in-season water (precipitation plus irrigation**) in both dryland and irrigated corn has increased during the same time period (*Figure B-2D*).

The increase in yield and use efficiencies of N fertilizer and water to produce grain are explained by genetic and agronomic management improvements, as well as the interactions between them. The important improvements are: hybrids more tolerant to high plant densities, earlier planting dates, adoption of reduced tillage and corn-soybean rotations, shift from a single large N fertilizer application in the fall to one or more applications during the growing season, replacement of surface irrigation systems with more efficient center pivots, and better control of weeds, insect pests, and diseases.

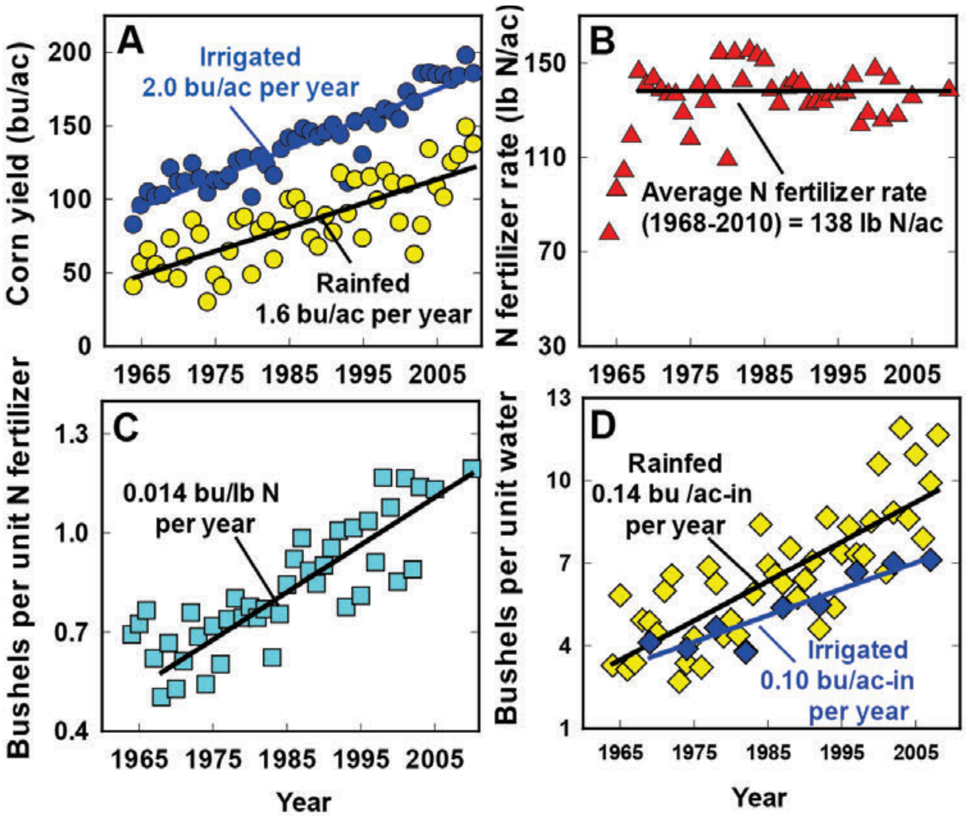


Figure B-2. Trends in corn grain yield (A), N fertilizer rate (B), grain yield produced per unit of N fertilizer (NUE_F) (C), and per unit of in-season water (WUE) (D) for the period from *1965-2010*. Separate trends are shown for rainfed (yellow) and irrigated crops (blue) in (A) and (D). In-season (May-Aug.) water includes rainfall and irrigation. Rainfall data (D) were retrieved from five representative locations in Nebraska. Yield, N fertilizer, and irrigation water data were retrieved from USDA-NASS.

Nitrogen fertilizer use and use efficiency for irrigated corn

Data from Natural Resources Districts nitrogen management areas

Many Nebraska NRDs have implemented Nitrogen Management Areas during the past few decades. Producers with fields located in Nitrogen Management Areas report field-specific information on corn yield, N fertilizer rate, and irrigation water applied every year. The number of fields reporting data and type of data varies among NRDs. In this section, we use data from six regions of Nebraska with NRD-collected data from 2006 to 2011 on yield, N fertilizer, and irrigation (*Figure B-3*). These six regions cover a range in climate, soils, and management practices for the major corn producing regions in Nebraska. In addition to yield, N fertilizer rate, and irrigation, the NRD data also include residual soil N (in the upper 3 ft.), irrigation water N amount, and recommended N fertilizer application rates based on the UNL N algorithm (explained in later sections of this manual). This information is presented as averages in *Tables B-1, B-2,* and *B-3*.

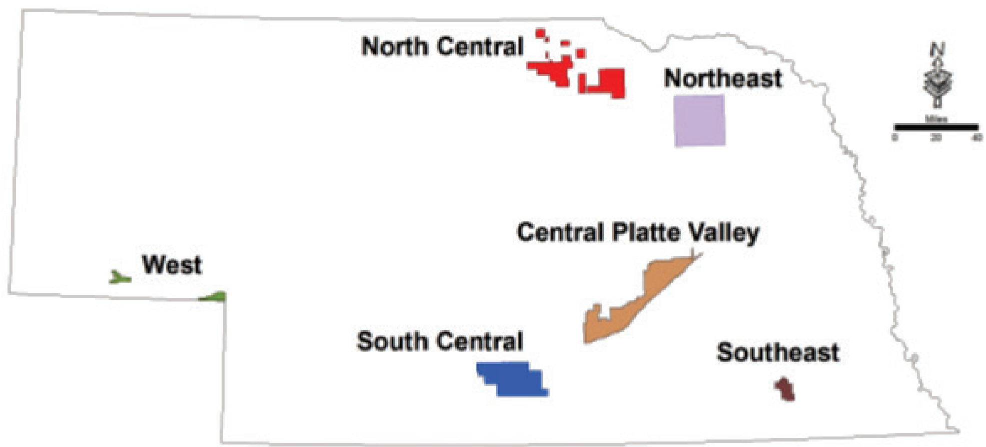


Figure B-3. Map of Nebraska indicating the six regions in Nebraska with available yield, N fertilizer rates, and irrigation data collected from NRD Nitrogen Management Areas and used in this section.

The average number of reporting fields in each year, as well as some key characteristics such as average irrigation, annual precipitation, and soil texture, are shown for each region in *Table B-1*. We used this information to calculate fertilizer N use and its efficiency for each region. Fertilizer NUE calculations were performed for corn fields either under continuous-corn or under corn-soybean rotation but did not receive manure application. Though it can be locally important, the average N applied from manure in Nebraska is very small (7 lb N/ac).

Table B-1. Average number of annual reporting fields, annual precipitation, proportion of pivot- and surface-irrigated fields, topography, and soil texture of dominant soils in the six data-reporting regions in Nebraska shown in *Figure B-3.*

Region of Nebraska	Reporting Fields	Precipitation (inches)	Irrigation System	Topography	Dominant Soil Textures
South Central	360	23	Pivot (67%), Surface (33%)	Flat to gently rolling plains	Silt loam
Central Platte Valley	3718	22	Pivot (50%), Surface (50%)	Flat, wide alluvial valley	Highly variable (Silt loam, loam, sandy loam)
Southeast	36	25	Pivot (50%), Surface (50%)	Flat to gently rolling plains	Loam, silty clay loam
Northeast	332	27	Pivot (≈100%)	Level to rolling plains or low hills	Highly variable (from silty clay loam to loamy sand)
North Central	578	21	Pivot (≈100%)	Tablelands with dissect slopes	Loam to loamy sand
West	84	9	Pivot (≈100%)	Alluvial valley	Sandy loam

On-farm corn yields, N inputs, and use efficiencies

Average (2006-2011) irrigated corn yields in Nebraska were well above the average U.S. corn yield of 150 bu/ac during the same time period, ranging from 165 bu/ac in the West Region to 207 bu/ac in the South Central Nebraska Region (*Table B-2*). Lower irrigated yields in the West Region were expected due to a shorter growing season. Across regions, average corn yield was 35% (Southeast) to 185% (west) greater in irrigated versus rainfed conditions and much less variable among years. Irrigation averaged 11 inches per year, ranging from 8 inches in the Southeast Region to 18 inches in the West Region. These differences were due to the east-west gradient in precipitation and evapotranspiration, though soil texture also explained part of the variation in irrigation totals among regions (for example, sandy soils in North Central Nebraska). In addition to geographic location, the high proportion of surface-irrigated fields in the Central Platte Valley increased the average irrigation inches within this region.

Irrigation Water Use Efficiency (IWUE) is the amount of yield produced per inch of irrigation water applied. It is calculated by subtracting the dryland grain yield from the irrigated grain yield and dividing by the inches of irrigation water applied.

Irrigation water use efficiency (IWUE) indicates how many extra bushels of grain were produced per unit of irrigation compared to the yield under rainfed conditions. On average, irrigated producers obtained an extra 7 bu/ac for every inch of water applied. However, the overall IWUE varied from nearly 10 bu/ac-in in the South Central Region to less than 6 bu/ac-in in the Central Platte Valley (*Table B-2*).

Table B-2. Average (2006-2011) irrigated and dryland corn yield, coefficients of variation (CVs[1]), total irrigation, and irrigation water use efficiency[2] in each of the six data-reporting regions in Nebraska.

Region of Nebraska	Irrigated Corn		Rainfed Corn		Total Irrigation	Irrigation-Water Use Efficiency
	Yield (bu/ac)	CV (%)	Yield (bu/ac)	CV (%)	(inches)	(bu/ac-in)
South Central	207	6	123	18	9.0	9.6
Central Platte Valley	180	7	116	15	11.4	5.5
Southeast	185	4	136	16	7.6	7.7
Northeast	197	3	132	16	8.7	6.7
North Central	197	4	96	27	13.1	6.3
West	165	6	58	30	18.0	6.1
Average	189	5	110	20	11.6	7. 1

[1]The CV is a measure of the year-to-year variation in yields; the greater the CV, the greater the yield variation among years.
[2]Irrigation water use efficiency was estimated as the difference between irrigated and dryland yields, divided by the total irrigation, in each region and in each year.

Coefficient of Variation is a measure of the relative year-to-year variation in yields; the greater the CV, the greater the yield variation among years.

Average (2006-2011) total N supply and its components (fertilizer, residual soil N, and irrigation water N), and nitrogen-use efficiency are shown in *Table B-3*. Total N supply through fertilizer, residual soil N, and groundwater N added via irrigation ranged from 243 to 317 lb N/ac across regions. On average, N fertilizer, residual soil N, and groundwater N accounted for 65, 20, and 15% of the total N supply (*Table B-3*). The greatest N supplied to corn was observed in the North Central Region where dominant soils are sandy and spring weather is typically cooler than in the rest of Nebraska.

Average fertilizer N rates for irrigated corn in Nebraska (172 lb N/ac) was 27% greater than the national average N fertilizer rate (135 lb N/ac), which is mostly based on rainfed corn production. However, because yields in Nebraska were 25% greater than the national average, fertilizer NUE_F in irrigated corn in Nebraska was equal to the national average NUE for corn (1.10 bu/lb N). ***In summary, irrigated producers in Nebraska are achieving corn yields much greater than the national average without sacrificing N fertilizer use efficiency.***

Total Nitrogen Use Efficiency
NUE_T is the grain or forage yield per unit of total nitrogen available to the crop including soil residual N, groundwater N added via irrigation, and fertilizer N.

Average N application rates of 172 lb N/ac (*Table B-3*) are greater than the 138 lb N/ac average N rate in Nebraska shown in *Figure B-2* for the 1968-2010 time period. This is because the long-term average includes rainfed corn that received much lower N rates but also achieved much lower yields. When other non-fertilizer N sources are accounted for in the calculation of NUE (irrigation water N and soil residual N), the **total nitrogen-use efficiency** (NUE_T) for irrigated corn averaged 0.72 bu/lb N. Greatest N use efficiencies were calculated for the South Central and Southeast Regions (0.85 and 0.76 bu/lb N) while the least NUE_T was observed in the North Central and West Regions (0.62 and 0.67 bu/lb N). Interestingly, the two least NUE_T corresponded to regions where: 1) soil residual N plus groundwater irrigation N was greatest; and 2) the difference between actual N application rates compared to the recommended N application rates were greatest. In the other four regions, actual average N fertilizer application rates were similar, or even below the recommended N rate. However, use of average values masks the overall variability among fields, with many of them receiving N rates much less or greater than needed, resulting in large field-to-field variability in NUE_F and NUE_T.

Table B-3. **Average N fertilizer, residual soil N in the upper 3 feet, groundwater irrigation water N, and total N supply (sum of fertilizer, residual soil and groundwater irrigation N) in irrigated corn fields in each of the six data-reporting regions in Nebraska for the 2006-2011 time period.**

Region of Nebraska	Fertilizer N Applied (lb N/ac)	Soil Residual N (lb N/ac)	Groundwater N Added via Irrigation (lb N/ac)	Total N Supply (lb N/ac)	Fertilizer Nitrogen Use Efficiency NUE_F (bu/lb N)	Total Nitrogen Use Efficiency NUE_T (bu/lb N)	Recommended Fertilizer N Application (lb N/ac)
South Central	177	43	24	244	1.17	0.85	201
Central Platte Valley	160	49	45	254	1.13	0.71	150
Southeast	184	38	21	243	1.01	0.76	177
Northeast	181	67	24	272	1.09	0.72	190
North Central	182	58[1]	77	317	1.08	0.62	137
West	149	62	37	248	1.11	0.67	129
Average	172	52	38	263	1.10	0.72	164

[1]Residual soil N in the North Central Region was reported for the upper 2 ft. Nitrogen use efficiency (bu/lb N) is based on yields reported in *Table B-2* and N fertilizer applied (N fertilizer use efficiency, NUE_F) and total N supply (total N use efficiency, NUE_T). Recommended N fertilizer application is based on the UNL algorithm and accounts for all field-specific sources of N (residual soil N, irrigation water N, N credit from previous crop) and yield goal. **Manured fields were not included in this analysis**. The data were averaged for both corn following corn and corn following soybean (see next section for an assessment of rotation impact on yield, N fertilizer use, and N use efficiency).

Field-to-field variation in applied inputs and use efficiencies

Averages may be deceiving since most field managers are interested in specific fields and not NRD wide averages. Box plots are one way to display the range of values, for a given variable, in a single graph. To illustrate the variability in input use efficiency among fields, *Figure B-4* shows box plots of field NUE_F and irrigation amounts in 2009 for the six regions in Nebraska. Horizontal lines inside each box represent the median value. The box represents the range of NUE_F and irrigation amounts in 50% of the fields whereas the top and bottom box bars indicate the range in 80% of the fields, and the upper and lower dots indicate the range in 90% of the fields. The box plots in *Figure B-4* show that variability in NUE_F and irrigation among individual fields is several times larger than observed for the same two variables among regions. Even though the regions were relatively small and soils were similar within most of the regions (except for the Central Platte Valley and Northeast Regions), NUE_F and irrigation amounts varied widely within each region, ranging from 0.7 to 2.0 bu/lb N for NUE_F and 5 to 30 inches of applied irrigation water. Based on the results in *Figure B-4*, field managers have a great opportunity to improve the N and irrigation water use efficiency in Nebraska.

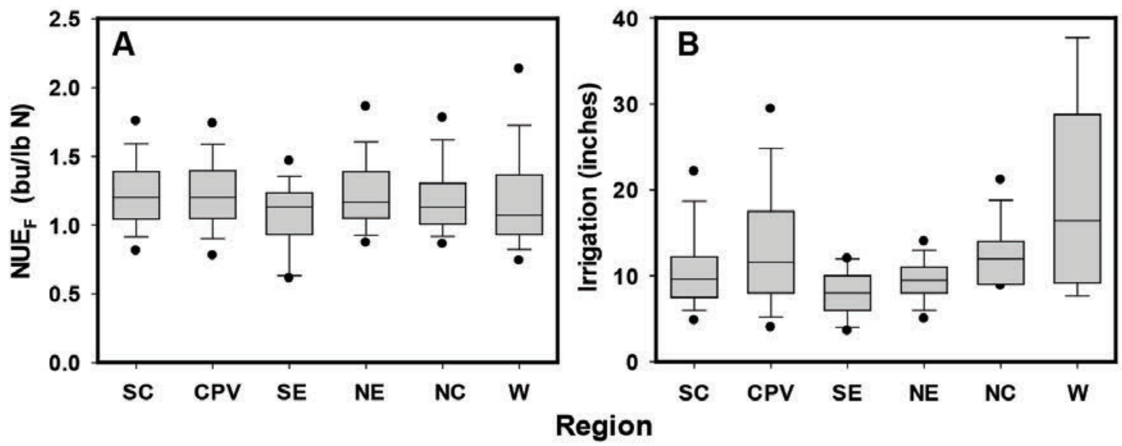


Figure B-4. Box plots for field N use efficiency (NUE_F) and total irrigation showing the variation across irrigated corn fields in the six regions in Nebraska for the 2009 crop season (SC: South Central; CPV: Central Platte Valley; SE: Southeast; NE: Northeast; NC: North Central; W: West).

One factor that influences NUE_F is crop rotation. *Figure B-5* shows average irrigated yield, N fertilizer rate, and NUE_F in irrigated corn in fields in the South Central region under corn-soybean rotation and continuous corn. Average irrigated corn yield in corn-soybean rotation was 6 bu/ac greater than continuous-corn yield, while the N fertilizer rate was 23 lb N/ac less. This resulted in an increase in NUE_F when using a corn-soybean rotation. The rotation effect on corn yield may be associated with a range of factors including crop establishment issues, greater plant-to-plant variation, and greater N immobilization by corn residue produced in continuous corn fields. These findings should not be extrapolated to other regions of Nebraska where the rotation effect has not been rigorously evaluated.

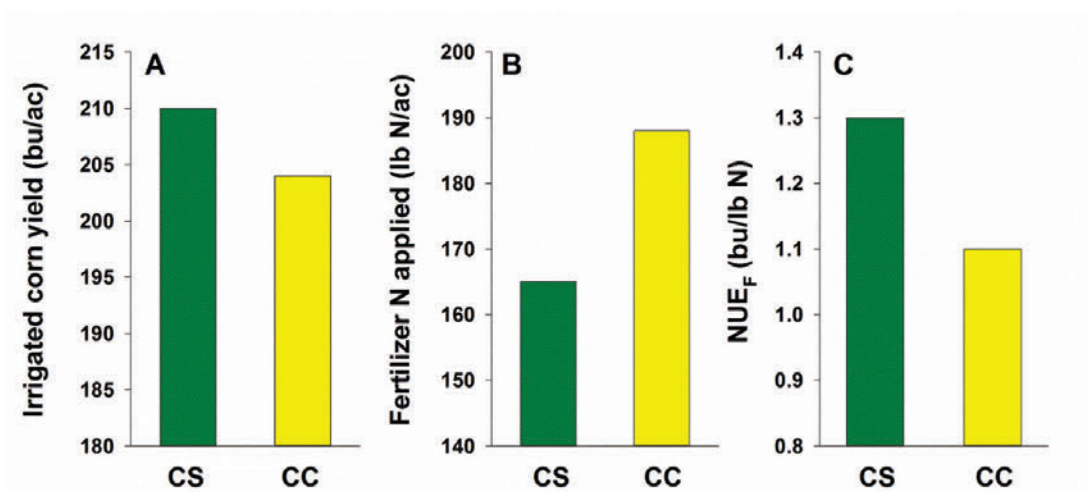


Figure B-5. Average (2006-2011) yield (A), fertilizer N (B), and fertilizer nitrogen use efficiency NUE_F (C) in irrigated corn grown in corn-soybean rotations (CS) versus continuous corn (CC) in the South Central region.

The type of irrigation system (pivot or furrow) greatly influences the ability to control the water applied with each irrigation event and IWUE. *Figure B-6* shows average irrigated corn yields (A), irrigation water applied (B), and IWUE (C) in the South Central Region for furrow- and pivot-irrigated fields. Average yields were identical in fields irrigated with either type of irrigation system; however, irrigation application depth was just over half for pivot- vs surface-irrigated fields. Given that grain yields were the same, IWUE was about 4 bu/ac-in greater in pivot irrigated fields than for furrow-irrigated fields.

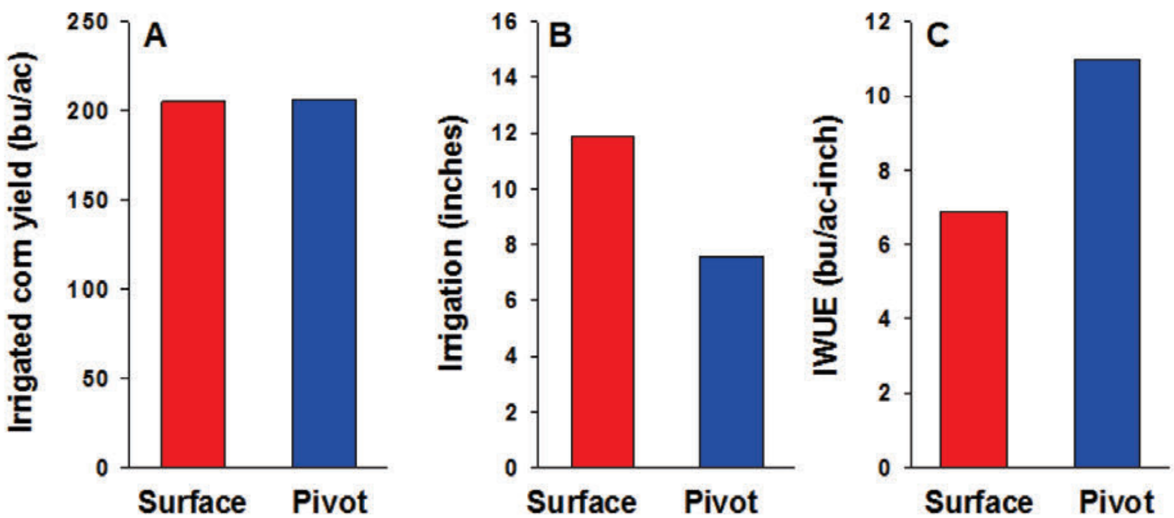


Figure B-6. Average (2006-2011) irrigated yield (A), irrigation inches applied (B), and irrigation water use efficiency (IWUE) (C) in surface- and pivot-irrigated corn fields in the South Central region.

Conclusions

Irrigated producers in Nebraska are achieving corn yields much greater and with much lower year-to-year variability than the national U.S. corn yield average, without sacrificing efficiency in the use of water and N. There is a wide range of fertilizer-N and irrigation water use efficiency across fields within the same year and region of Nebraska, highlighting the potential for further improvement in efficiencies through increased adoption of BMPs related to N and irrigation water management. Improvement is possible especially in fields that exhibit lower use efficiencies or greater N or irrigation applications in relation to the average for the respective region.

For More Information

Grassini, P., H.S. Yang, and K.G. Cassman. 2009. Limits to maize productivity in the Western Corn-Belt: A simulation analysis for fully irrigated and rainfed conditions. Agricultural and Forest Meteorology 149:1254-1265.

Grassini, P., H.S. Yang, S. Irmak, J. Thorburn, C. Burr, and K.G. Cassman. 2011. High-yield irrigated maize in the Western U.S. Corn Belt: II. Irrigation management and crop water productivity. Field Crops Research 120:133-144.

Grassini, P., J. Specht, T. Tollenaar, I. Ciampitti, and K.G. Cassman. 2014. High-yield maize-soybean cropping systems in the U.S. Corn Belt. In: Crop Physiology- Applications for genetic improvement and agronomy (2nd edition), Sadras VO, Calderini DF (Eds). Elsevier, The Netherlands.

Setiyono, T.D., D.T. Walters, K.G. Cassman, C. Witt, and A. Dobermann. 2010. Estimating maize nutrient uptake requirements. Field Crops Research 118:158-168.

Section C

Soil characteristics that influence nitrogen and water management

Soil characteristics vary across the landscape

Soils vary 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 must 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 inches, pH, and the thickness and density of the clay accumulation horizon.

Organic Matter is that fraction of the soil composed of anything that once lived, including microbes, and plant and animal remains.

Parent Material is the geologic material from which soil horizons form. As an example: wind-blown loess over glacial till.

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 (*Figure C-1*).

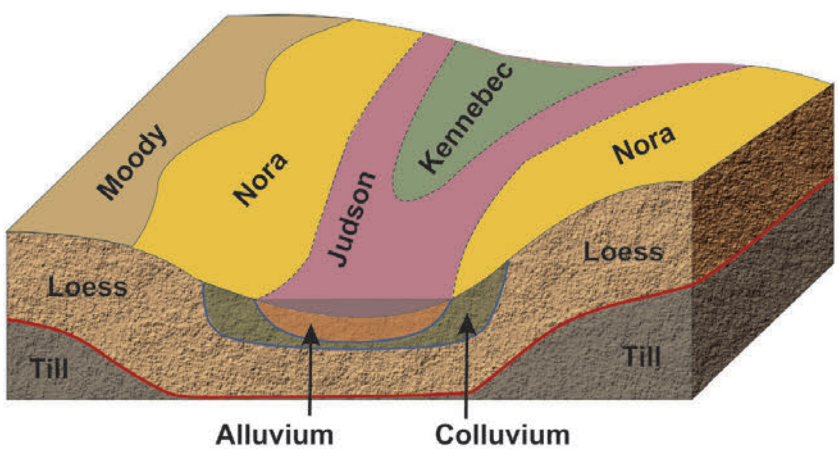


Figure C-1. Different soil series form based on their position on field topography. Note that the soil series changes from the top of the hill to the bottom land areas.

Some important features of a soil profile are shown in *Figure C-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 surface horizon, holds many nutrients essential for plant growth. The amount of organic matter in the surface horizon also greatly improves the soil structure and 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.

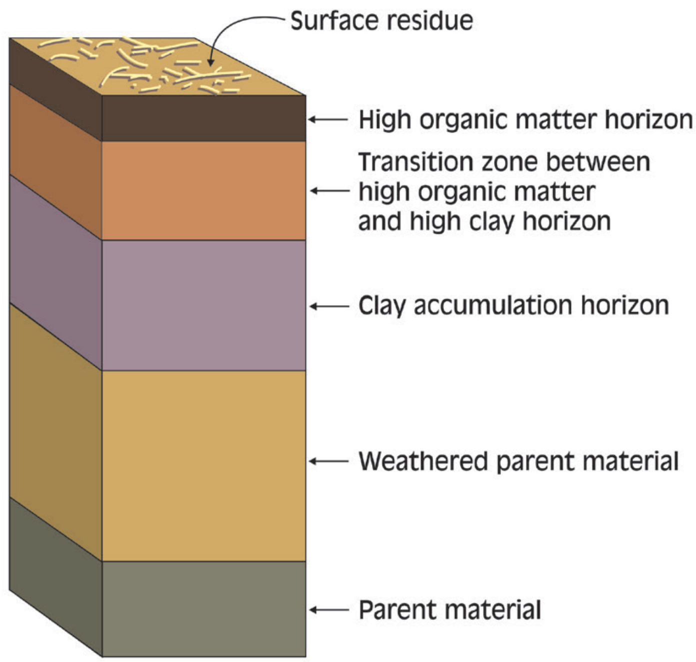


Figure C-2. **A typical soil profile depicting important textural features.**

Soils vary dramatically from east to west across Nebraska due to the wide range in parent materials and precipitation levels. Thus, not all soils show the characteristics shown in *Figure C-2* to the same degree. Even within the same county, parent material and soil age often require different management practices to reduce nitrate leaching. For example, a silty clay loam formed from fine-textured, wind-deposited material has a thick, high organic matter horizon, and a thick dense clay accumulation horizon. This means that a silty clay loam soil has slow internal drainage, thus nitrate leaching occurs slowly. The high organic matter means that a silty clay loam provides substantial amounts of nitrate from mineralization of organic matter over the growing season.

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 very short distances. If nitrate leaching losses from the root zone are to be held to a minimum, the characteristics of different soils and soil variability within fields have to be considered when planning fertilizer and water management programs.

Soil water content

Figure C-3 illustrates a volume of soil that is composed of three major components: soil particles, air, and water. The pie-chart on the lower right provides a visual indication of the relative volumes for each component. The fractions of water and air are contained in the voids between soil particles. The amount of water in a soil can be expressed in many ways, including percent water on a dry soil basis (mass water content), percent water on a volumetric basis (volumetric water content), percent of the available water remaining or percent of the available water depleted. However, the most useful methods of expressing soil water content are volumetric soil water content and percent of available water remaining.

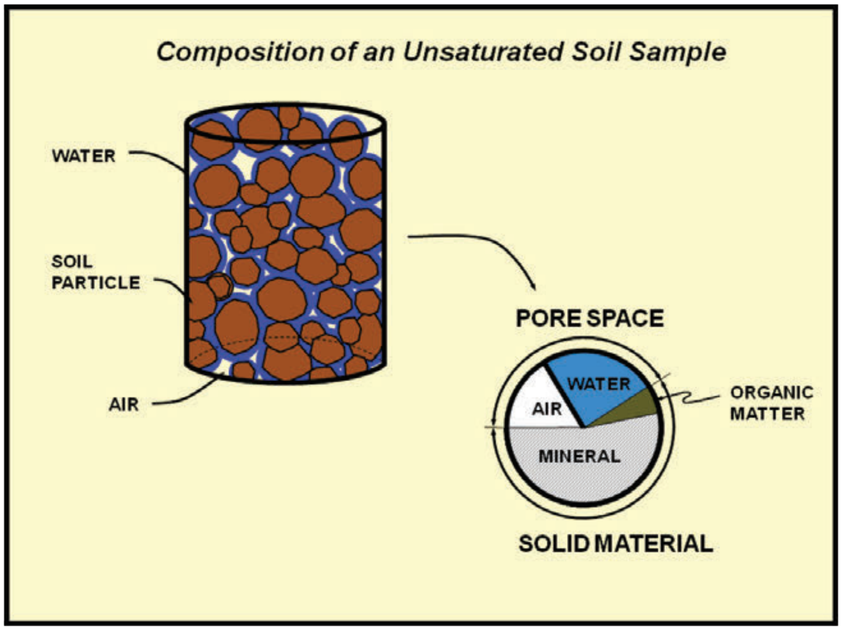


Figure C-3. Composition of an unsaturated soil core.

The *volumetric water content* represents the volume of water contained in a volume of soil. *Figure C-4* illustrates the components needed to estimate the volumetric water content. The process includes obtaining a known volume of wet soil, weighing the sample wet, drying the soil in an oven or microwave, and weighing the soil volume dry. The equation uses an equivalent value for water volume and mass of 1 gram per cubic centimeter of water. The change in weight of the soil sample between wet and dry is the water weight, which is converted to volume before dividing by the volume of the soil sample.

When thinking about water amounts per unit of land area, it is more convenient to speak in equivalent depths of water rather than volumetric water content. The relationship between volumetric water content and the equivalent depth of water in a soil layer is determined by multiplying the volumetric water content times the soil depth. For example, if soil sample is determined to have a volumetric water content of 30% water in a foot of soil sample, the equivalent depth of water in the soil is 3.6 inches per foot (0.30 x 12).

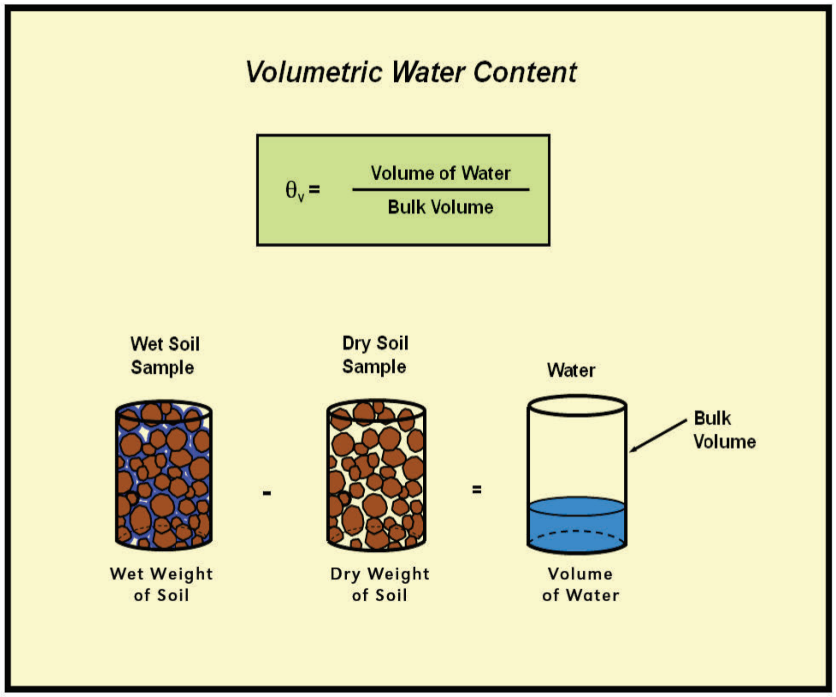


Figure C-4. Concept of how volumetric soil water content is determined

Plant available soil water

Plant available water is the amount held by the soil between two limits: **field capacity** (the upper limit) and **permanent wilting point** (the lower limit) (*Figure C-5*). Plant available water is determined primarily by soil texture, although soil structure is also important in fine-textured soils. Right after irrigation or precipitation, the soil water content may be temporarily above field capacity (very temporary storage in *Figure C-5*). If this water is not used by the plant or allowed

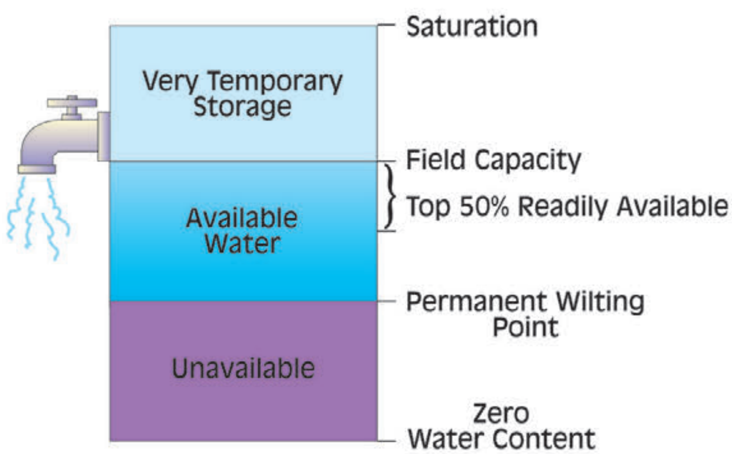


Figure C-5. Schematic drawing of a water tank analogy to depict key plant available soil water availability factors.

Field Capacity represents the amount of water remaining in the soil after drainage due to gravitational forces has ceased.

Permanent Wilting Point is the water content of a soil when most plants growing in the soil wilt and fail to recover.

Plant Available Water is the portion of water contained in the soil that can be absorbed by plant roots.

to drain, the soil will remain saturated. However, in most Nebraska soils the excess water drains in two or three days due to the pull of gravity. Once the excess water has drained, soil water content is at field capacity.

Between field capacity and the permanent wilting point, plants are able to remove soil water to meet crop demand. As the **plant available water** approaches the permanent wilting point, the water content of the soil becomes so dry that plants wilt and do not recover. About half the water held between field capacity and permanent wilting is considered to be readily available water. In general, if a plant is irrigated by the time the readily available water in the root zone has been used, there will be no crop stress. Note that below the wilting point there is still some water held in the smallest pores, but it not available to plants.

Soil Water Potential or **Matric Potential** is an indicator or measure of soil water content expressed in kilopascals, bars, or centibars.

Soil Water Retention Curve is a graph displaying the change in water content in response to the application of tension.

Soil water potential is an indicator or measure of the soil water content and is often expressed in units of kilopascals (kPa), bars, or centibars. The component that dominates the release of water from the soil to plants is the ***matric potential***. The strength of the matric force depends on the distribution of the soil pore sizes. Large pores will freely give up pore water to plants or to drainage due to the gravitational forces. The magnitude of the matric potential is expressed as soil water tension and is the basis for monitoring soil water content that will be discussed in a future section of this manual. A curve representing the relationship between the soil water tension and volumetric water content is known as a ***soil water retention curve*** *(Figure C-6)*. Soil-water retention curves are often used to define the amount of soil water available to plants. *Figure C-6* depicts the three important levels of soil matric potential, including the wilting point.

The academic definition of wilting point is the soil water content corresponding to a soil matric potential of -15 bars. The volumetric water content at wilting point is given in *Figure C-6* for three soil types. Similarly field capacity is often defined as the soil water content at a soil water potential of -0.33 bars. **Note:** the volumetric water contents for the wilting point and field capacity designations for three soil textures shown in *Figure C-6*. The plant available water capacity of a soil is often expressed in units of depth of available water per unit depth of soil, i.e., inches of water per foot of soil. For the sandy loam soil, the volumetric water content at field capacity is 0.23 inches of water per inch of soil depth or 23%, and the volumetric water content at wilting point is about 0.10 or 10%. Using these two numbers we can estimate the plant available water capacity for that sandy loam soil as 0.13 (0.23-0.10). In this example, the plant available water content is 0.13 in/in or 1.56 inches of water per foot of soil.

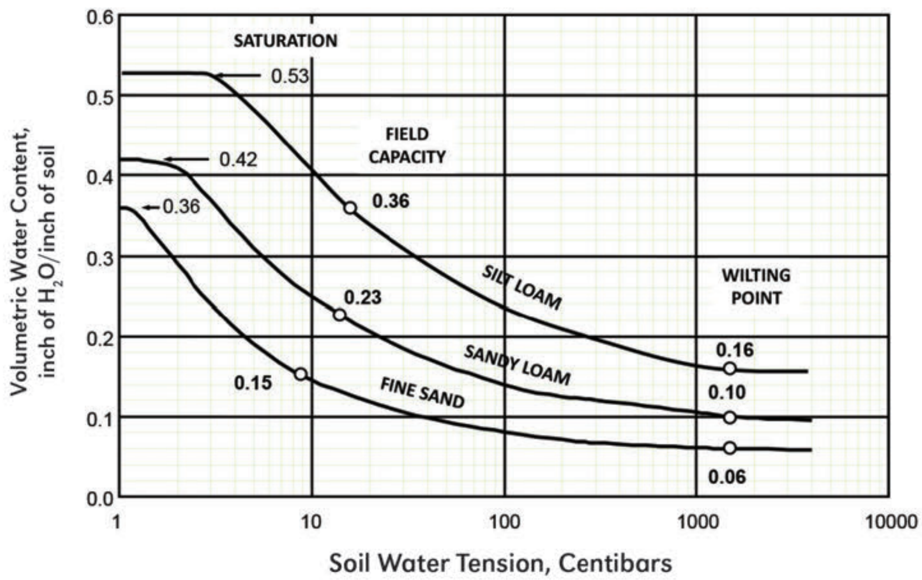


Figure C-6. Soil water retention curves for three soil textures.

> The soil water retention curve and the volumetric water content at saturation, field capacity, and permanent wilting point are specific to each soil texture classification.

Data for soil water holding properties are available from various sources. County Soil Survey Reports and the Web Soil Survey from the USDA-NRCS normally list these data. Ranges of values for available water holding capacity for some typical soil texture classes are listed in *Table C-1*.

Infiltration

> **Infiltration** is the passage of water through the air-soil interface and into the soil.
>
> **Infiltration rate** is the rate water enters into the soil in inches per hour.

Soil water is replenished by the process called ***infiltration***, the entry of water into the soil. Infiltration is described in terms of the rate water enters the soil (i.e., the depth that infiltrates per unit of time). Infiltration is very important in irrigation since the goal is to supply water to the root zone to meet plant needs. The goal is that all of the applied irrigation water and precipitation enters the soil, thereby minimizing the amount of water that runs off the soil surface.

The curves shown in *Figure C-7* illustrate changes in **infiltration rate** for three soil textures. The curves show that initially the infiltration rate is very high but as infiltration time progresses, or more correctly, as the amount of water that has infiltrated increases, the rate of infiltration decreases. **If water application continues long enough the infiltration rate gradually approaches a constant or steady rate, sometimes called basic infiltration rate.**

Research has shown that coarser-textured (sandy) soils have greater infiltration rates than fine- (clay) and medium-textured (loam) soils. Thus, typically more precipitation and irrigation will infiltrate into a sandy soil before runoff begins. Remember from earlier in this section that sandy soils also have relatively lower soil water-holding capacities. Hence the combination of greater infiltration rates and lower water-holding capacities results in a greater potential for deep percolation and nitrate-nitrogen leaching.

The combination of greater infiltration rates and lower soil water holding capacity results in a greater potential for deep percolation and nitrate-nitrogen leaching.

Table C-1. Available soil water holding capacity of representative soil textural classes in inches of water per foot of soil depth (inch of H_2O/inch of soil).

	Soil Layer and Depth Interval		
Soil Textural Class	**Surface Soil 0-12 inches**	**Subsoil 12-36 inches**	**Lower Horizon 36-60 inches**
Coarse sand and gravel	0.48 - 0.72	0.36 - 0.60	0.25 - 0.50
Sands	0.84 - 1.08	0.72 - 0.96	0.60 - 0.84
Loamy sands	1.20 - 1.44	1.08 - 1.32	0.96 - 1.20
Sandy loams	1.56 - 1.80	1.44 - 1.68	1.32 - 1.56
Fine sandy loams	1.92 - 2.16	1.80 - 2.04	1.44 - 1.92
Very fine sandy loam	2.04 - 2.28	1.92 - 2.16	1.92 - 2.16
Loam	2.40 - 2.64	2.04 - 2.28	2.04 - 2.28
Silt loams	2.40 - 2.76	2.16 - 2.40	2.16 - 2.40
Silty clay loams (<35% clay)	2.52 - 2.76	2.16 - 2.40	2.16 - 2.40
Silty clay loams (>35% clay)	2.04 - 2.40	1.92 - 2.16	1.92 - 2.16
Sandy clay loams	2.16 - 2.40	1.92 - 2.16	1.80 - 2.04
Clay loams (<35% clay)	2.28 - 2.64	2.04 - 2.28	1.92 - 2.16
Clay loams (>35% clay)	1.92 - 2.28	1.80 - 2.04	1.68 - 1.92
Silty clays (<50% clay)	1.56 - 2.04	1.32 - 1.92	1.20 - 1.56
Silty clays (>50% clay)	1.20 -1.68	1.20 - 1.44	0.96 - 1.44
Clays (<50% clay)	1.44 - 1.92	1.20 - 1.80	1.20 - 1.44
Clays (>50% clay)	1.20 - 1.68	0.96 - 1.44	0.96 - 1.44

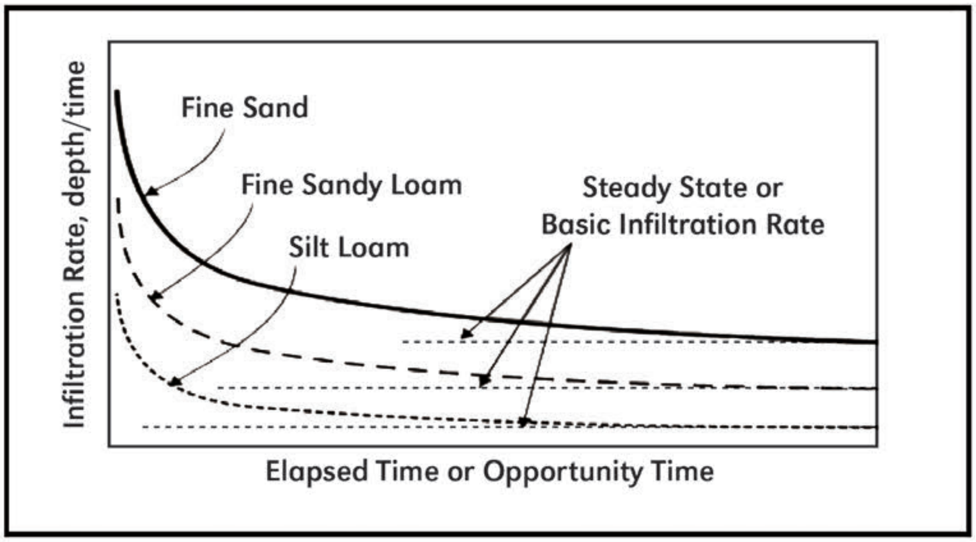


Figure C-7. Infiltration rate vs. infiltration opportunity time graph for a fine sand, fine sandy loam, and silt loam soil.

Intake family

Intake Family is a means of classifying or grouping of soil mapping units based on similarities of soil infiltration rates.

The USDA-NRCS has rated soils for their ability to infiltrate water. Soils are assigned to representative infiltration classes called the **Intake Family** based upon extensive field measurements across the nation. Soils classified in the Intake Families of 0.1, 0.3, 0.5, and 1.0 are generally those that are well suited for irrigation but that have potential for runoff. Some sandy soils are classified as Intake Family 1.5 but these soils rarely have runoff problems and are not very well-suited for furrow irrigation. Intake Family classifications are available from the Natural Resources Conservation Service. Field managers should note that the Intake Family is a general classification system for soils. Actual infiltration rates can vary considerably due to tillage, residue, and other cultural practices.

For More Information

USDA-NRCS. 1999. KS652.0204 State supplement-soils. Chapter 2 in USDA-NRCS National Engineering Handbook- Part 652. *http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_031591.pdf*

Section D

What happens when nitrogen is applied to the soil?

Soil nitrogen processes

Nitrogen Cycle: All nitrogen in or added to the soil is subject to the processes of the nitrogen cycle (*Figure D-1*). Some processes are beneficial to plant nutrition while others provide no benefit or are detrimental to plant growth. For example, nitrogen can be converted from forms that are not available to plants, to available forms (and vice versa) by soil bacteria. Nitrogen can be moved by leaching out of the reach of plant roots or can escape into the atmosphere through gaseous loss known as denitrification. Understanding the basic nitrogen cycle provides insight into plant nutrient relationships and can provide the basis of nutrient management decisions on how much and when to apply supplemental nitrogen. The following paragraphs will introduce and provide detail on nitrogen cycle processes as they affect nutrient management.

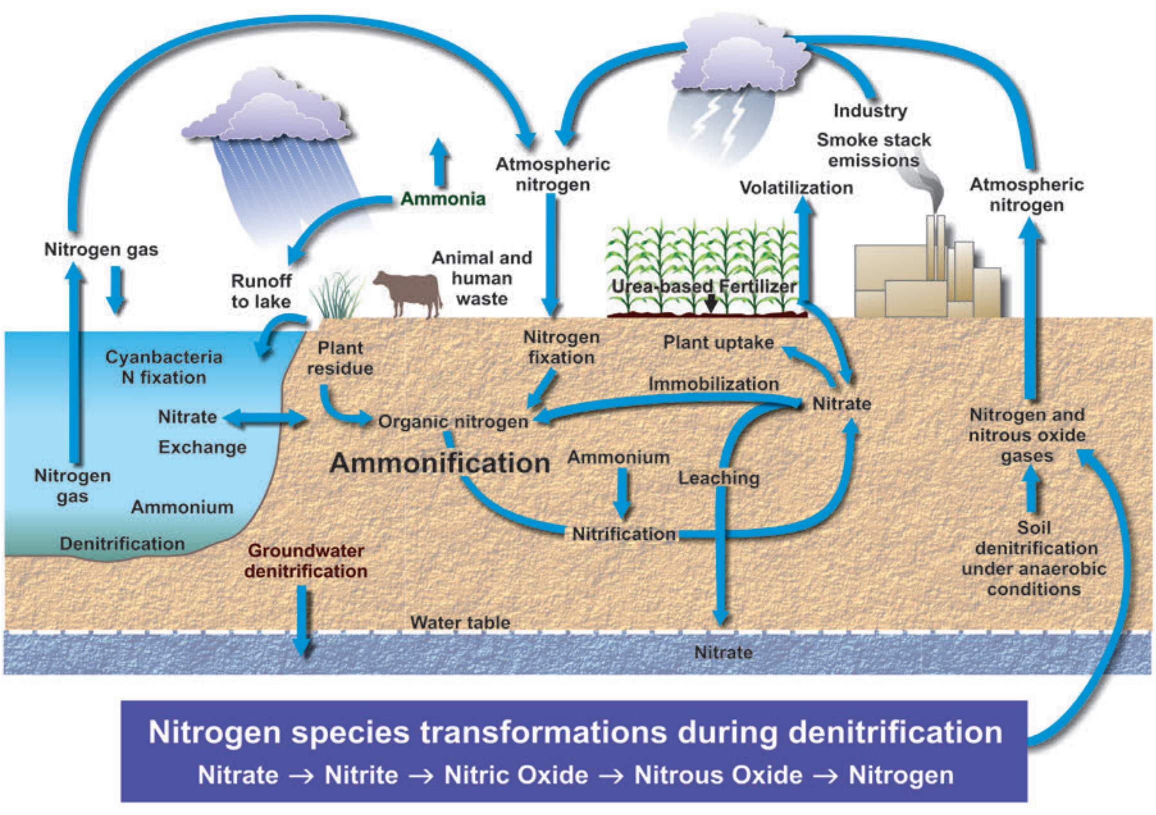


Figure D-1. Generalized nitrogen cycle within water, soil and in the air.

Mineralization: Mineralization is the process by which organic nitrogen (N) is converted to inorganic, or plant available N (*Figure D-2*)**.** Specifically, mineralization is the conversion of organic N to NH_4^+(ammonium). This process is very important for plant growth as organic N is not available for plant use, while NH_4^+ is. Mineralization is composed of two processes: aminization and ammonification. Both aminization and ammonification are carried out primarily by bacteria through the process of organic matter (OM) decomposition. The rate at which the bacteria work depends on soil temperature, soil moisture, and the amount of OM in the soil. As soils warm up in the spring, bacteria become increasingly active and use OM as an energy source. Bacteria decompose proteins in the OM, releasing amino acids, amines, and urea. This step is called aminization. The amino acids, amines, and urea are then further decomposed by bacteria releasing ammonium (NH_4^+) that is available for plant use. This step is called ammonification. Ammonium is relatively unstable and is therefore susceptible to multiple fates in the soil. These include; plant uptake; nitrification (explained below), fixation by clay minerals, and conversion to NH_3 (ammonia), which can be lost to the atmosphere through volatilization.

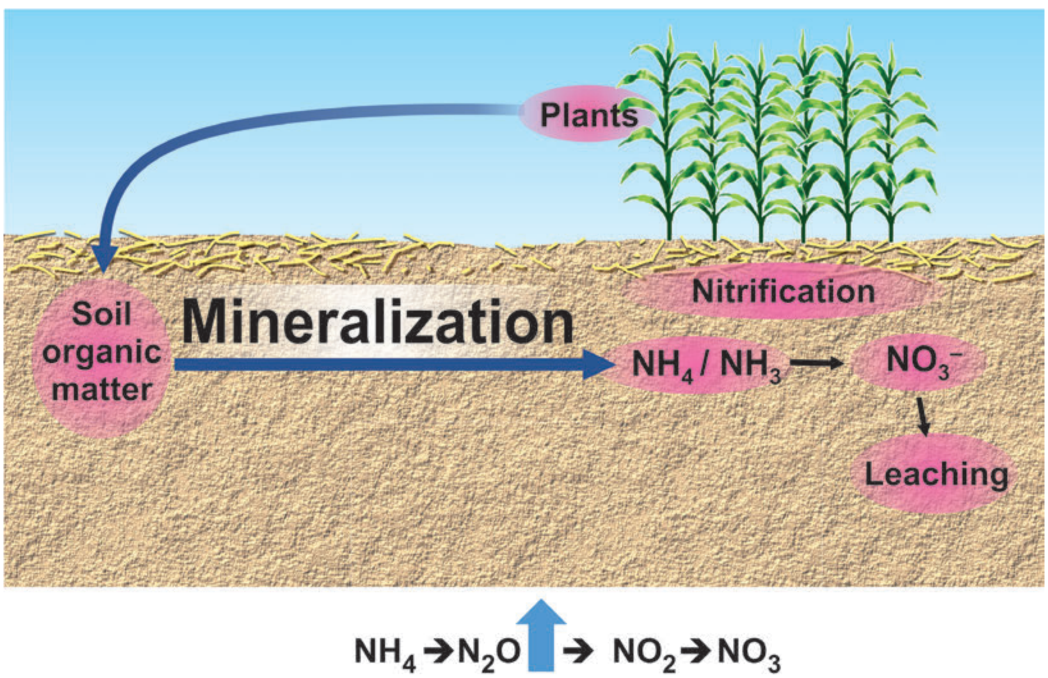


Figure D-2. The conversion of soil organic matter to ammonium and then to nitrate.

Nitrification: Nitrification is the process by which ammonium (NH_4^+) is converted to nitrate (NO_3^-) (*Figure D-3*). Both NH_4^+ and NO_3^- are inorganic forms of N and both are plant available. Both N sources can be used by corn and other agronomic crops, nitrate is preferred. Ammonium will nitrify to nitrate over time (usually less than three weeks during the growing season). As with mineralization, nitrification is carried out by soil bacteria.

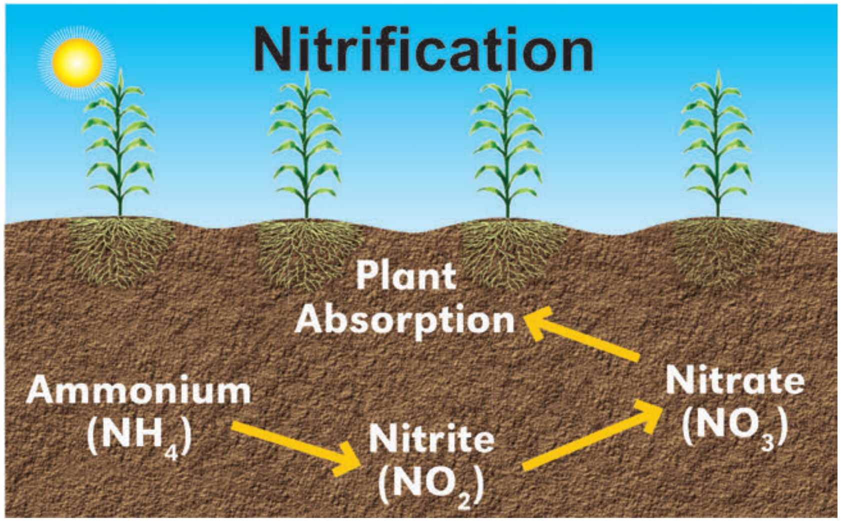


Figure D-3. Detail of the conversion of ammonium to plant available nitrate.

Immobilization: Immobilization is the process by which plant available inorganic forms of N (NH_4^+ and NO_3^-) are converted to plant unavailable organic forms of N (*Figure D-4*). This process is essentially the reverse of mineralization and is driven by soil bacteria and soil carbon and N levels. Immobilization usually occurs when high levels of residue with a high carbon (C) to nitrogen (N) ratio are added to the soil, such as wheat stubble or corn stalks. The carbon residue is an energy source for microbes and they need nitrogen in the soil solution to grow. The N is sequestered in the microbe's body until they die and it is released back to the soil solution. Bacteria can reduce NH_4^+ and NO_3^- levels quite dramatically and can out-compete plants for the N source, thereby immobilizing or tying up the N. In most production situations, N needs to be applied in sufficient quantities early in the season to overcome this effect, or placed below the residue so as not to be near the carbon source. Late season release of immobilized N may have water quality implications.

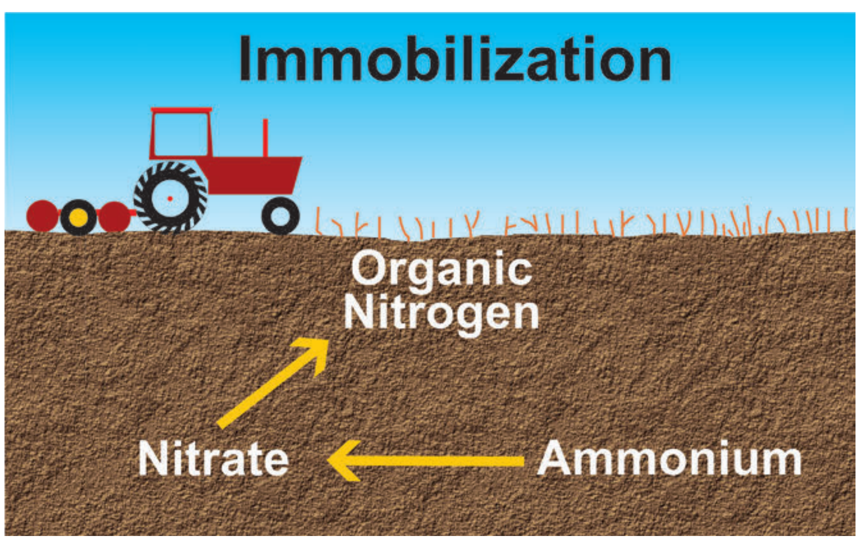


Figure D-4. Immobilization temporarily removes nitrates from the soil solution.

Denitrification: Denitrification is the process by which nitrate in the soil is converted to gaseous forms of nitrogen that can escape from the soil into the atmosphere (*Figure D-5*). The process is dependent on soil bacteria and almost all denitrification takes place in saturated or compacted soils that have a limited oxygen supply. When oxygen is not available, certain bacteria are capable of using the oxygen from nitrate as a substitute energy source. As oxygen is removed from nitrate gaseous forms of N are created (NO, N_2O, and N_2). These forms of nitrogen can then escape into the atmosphere. Denitrification occurs where water is ponded for a significant amount of time and is common during flooded conditions.

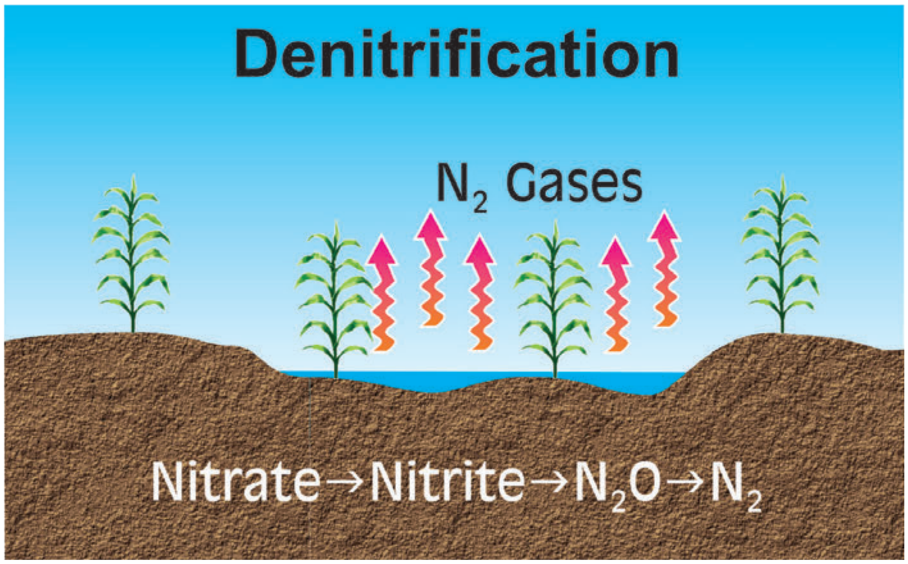


Figure D-5. Denitrification occurs in low-oxygen conditions and removes nitrates from the soil solution.

Volatilization: Volatilization is the process by which ammonia (NH_3) is lost into the atmosphere (*Figure D-6*). Volatilization occurs naturally in soils but losses are usually small. There are two ways nitrogen can volatilize. The first is through the direct loss of ammonia from either fertilizer or animal manures. The second is through the breakdown (hydrolysis) of urea. Both primarily occur when applied fertilizers are placed on the soil surface and not incorporated following application. Fertilizers placed below the soil surface or incorporated by precipitation or sprinkler irrigation of at least 0.5 inches will move urea into the soil and minimize volatilization.

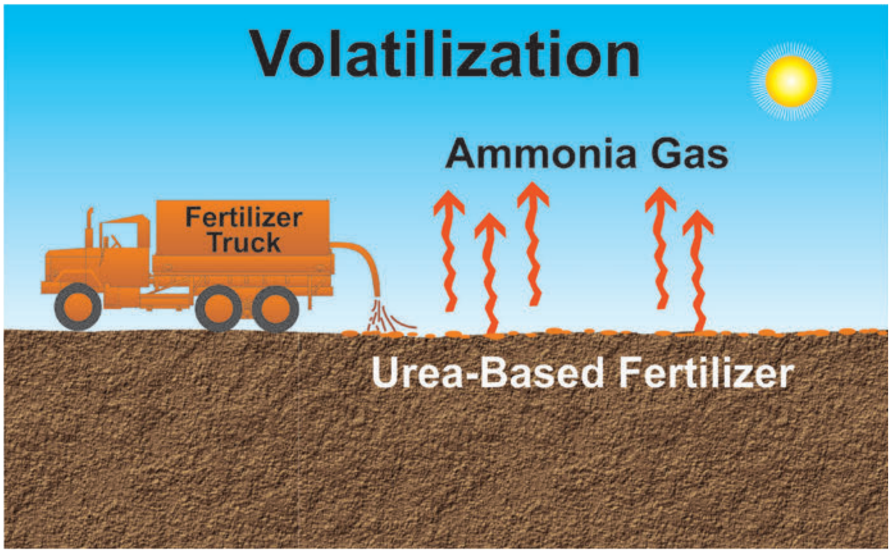


Figure D-6. Volatilization occurs when manures or ammonia containing fertilizers are on the soil surface.

Fixation: Nitrogen gas (N_2) in the atmosphere is converted into plant available forms through the process of fixation (*Figure D-7*). Nitrogen gas is converted into nitrate through two processes. First it occurs through lightning (combustion) and precipitation; and secondly it occurs naturally through symbiotic fixation involving bacteria in association with legumes such as soybean. Non-symbiotic fixation is also possible, involving free-living soil organisms. Industrial fixation (Haber-Bosch process), is the process by which atmospheric N_2 and hydrogen from natural gas are reacted under pressure to produce ammonia that is the basis for all other N fertilizers.

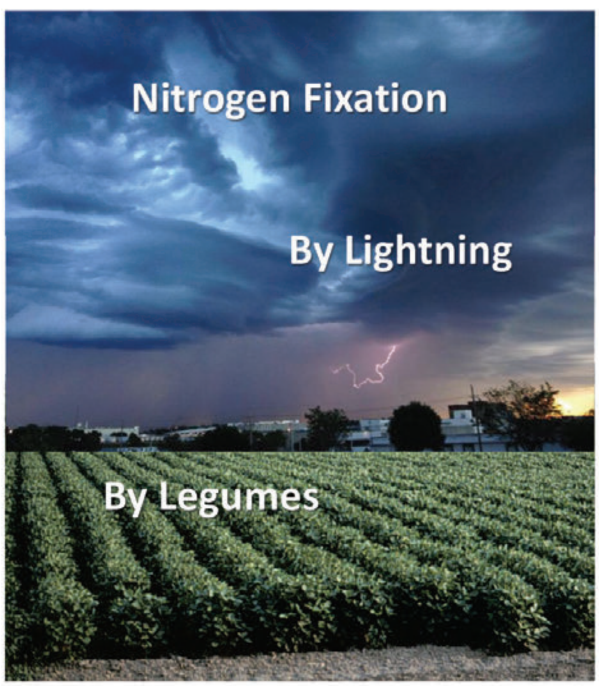


Figure D-7. Examples of ways in which nitrogen can be converted from nitrogen gas into nitrate via the fixation process.

Nitrate Leaching: Nitrogen Leaching is the passage of nitrogen through the soil profile and downward beyond where crop roots can access the nitrogen (*Figure D-8*). When making the decision on when and how to apply N fertilizers, consider the **4Rs** of nutrient management; **R**ight time of application, **R**ight fertilizer type, **R**ight placement, and **R**ight application rate. Research has shown that fall applications of N fertilizer are less efficient than applications during the growing season. Corn uses N more efficiently when applied as close as possible to when the plant needs it. As stated previously N is a very mobile nutrient that is easily lost from the soil through leaching and denitrification. Significant quantities of N applied in the fall can be lost during the off-season.

Residual N is the N remaining in the soil at the end of a cropping season. This is the leftover N that was not used by the crop during the growing season. The amount of residual N is related to nitrogen fertilizer management practices, irrigation management practices, crop yield (plant N uptake), and environmental conditions such as precipitation and temperature that affect mineralization. The majority of residual N is dissolved in water held in the pore space between the soil particles. Nitrate is very mobile and when the water moves in the soil, the N moves as well (*Figure D-8*).

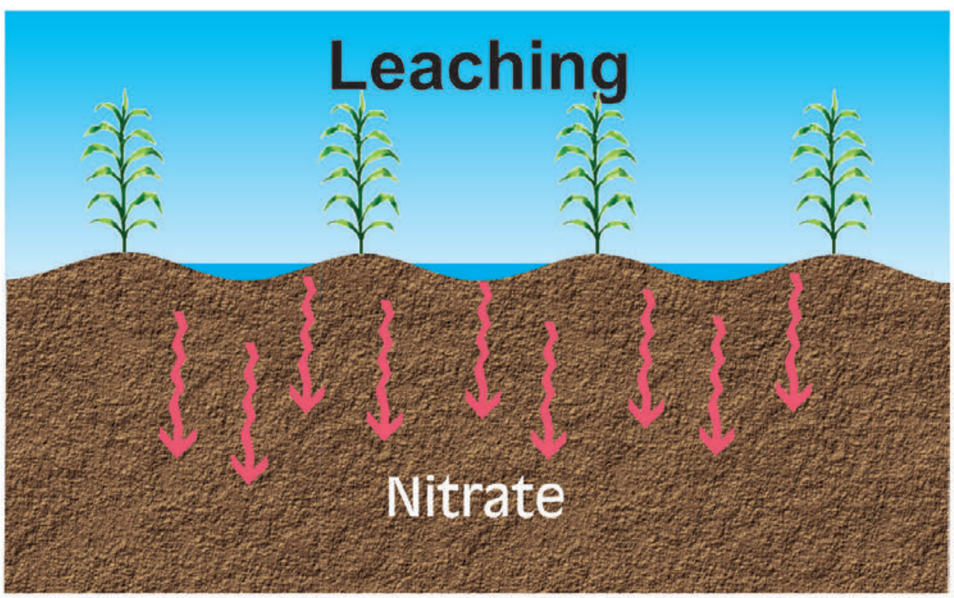


Figure D-8. Depiction of nitrate-nitrogen being leached due to excessive water application via irrigation or precipitation.

In the fall, if the distribution of residual N looks like the graph shown in *Figure D-9A*, there either was a crop failure due to insufficient water or storm damage, or the N application rate was too high for the grain yield level. The relatively high concentration of N in the surface 24 inches of soil leaves a lot of N in a high-leaching potential. If excess precipitation is recorded, the nitrate will move deeper in the soil during the offseason.

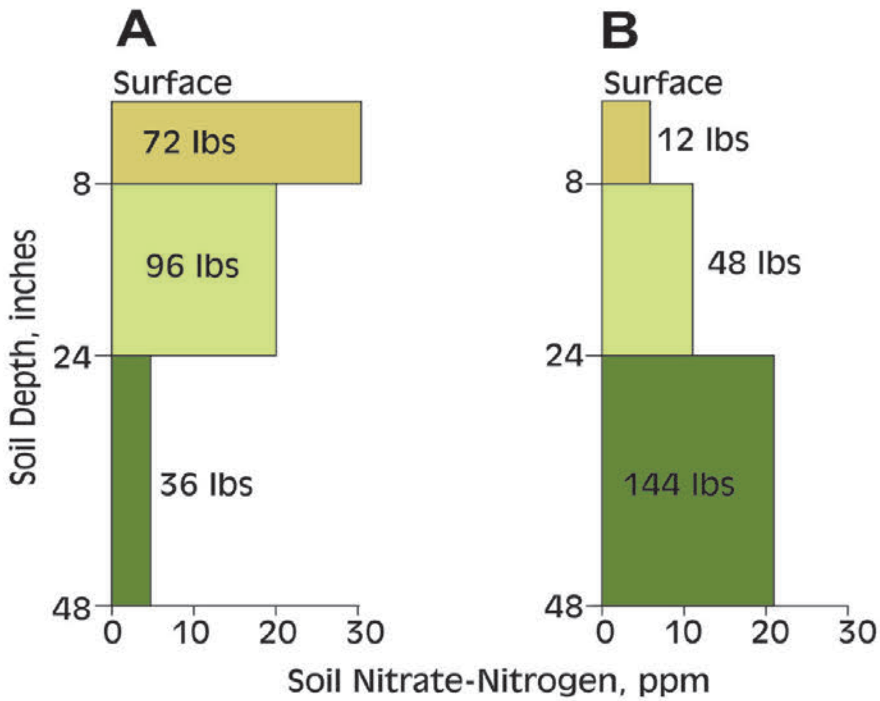


Figure D-9. Summary of two sets of soil samples: A) taken from soil that was sprinkler irrigated; and B) taken from soil that was irrigated by a furrow irrigation system.

The distribution of residual N in the soil profile at harvest depends greatly on the method of irrigation (furrow, drip, or sprinkler) and the care taken to manage the water correctly during the growing season. Under furrow irrigation, it is likely that N will be moved deeper in the profile during the growing season because the depth of water applied with each irrigation is typically more than is required to refill the root zone. So the scenario depicted in *Figure D-9B* may represent the position of soil N at the end of the season. With a furrow system that is well-designed, well-maintained, and well-managed, there is a chance that the N will remain in the crop root zone and accessible to crop roots.

Well-managed sprinkler irrigation systems should result in zero deep percolation so that most of the N applied remains in the crop root zone. Under sub-surface drip irrigation, the dynamics of N movement changes depending on the N application method. Surface applied N can create high N levels near the soil surface because N movement will be controlled by amount of precipitation and the soil's water holding capacity. If N is injected into the sub-surface drip system it is possible to move N much deeper into the profile as the nitrate will move with the water.

The way water is applied affects how both water and nitrate move down through the soil. When the application rate is less than the soil intake rate (such as from a gentle rain or a well-managed sprinkler system), water tends to move downward in a relatively uniform manner. For example, *Figure D-10* shows a band of nitrate that has formed from a previous application of anhydrous ammonia. A wetting front is moving down under precipitation. When the wetting front reaches the band, the nitrate tends to spread mainly downward (*Figure D-11*).

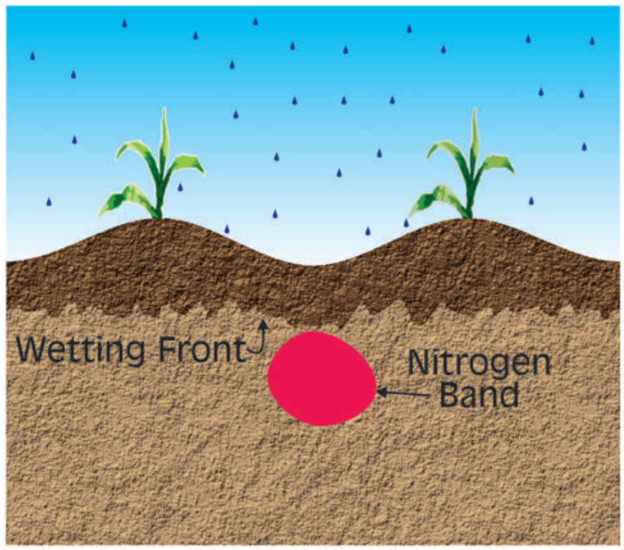


Figure D-10. Depiction of a nitrate band resulting from application of liquid urea ammonium nitrate or anhydrous ammonia using a knife applicator.

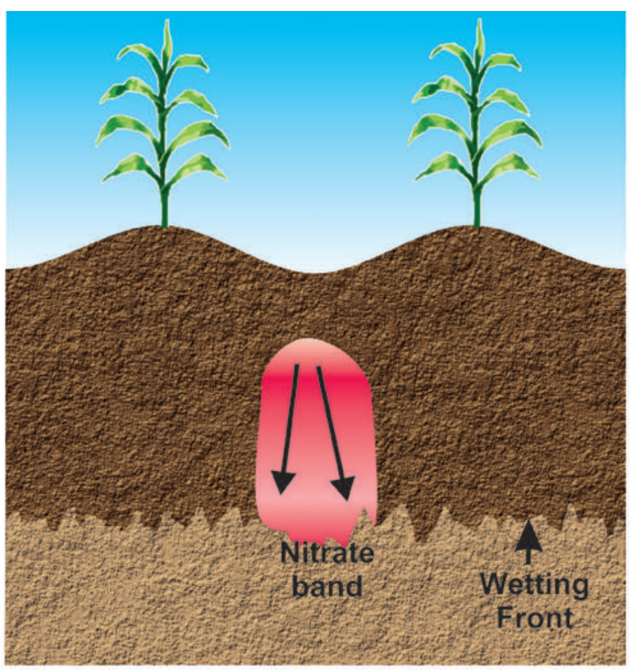


Figure D-11. Depiction of the downward vertical movement from a concentrated band of nitrogen application following excessive precipitation or sprinkler irrigation.

Under furrow irrigation, only 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 with each irrigation event is greater than under sprinkler irrigation. Under these conditions, a nitrate band will tend to spread further, both vertically and horizontally (*Figure D-12*). Excess irrigation will move the nitrate even deeper.

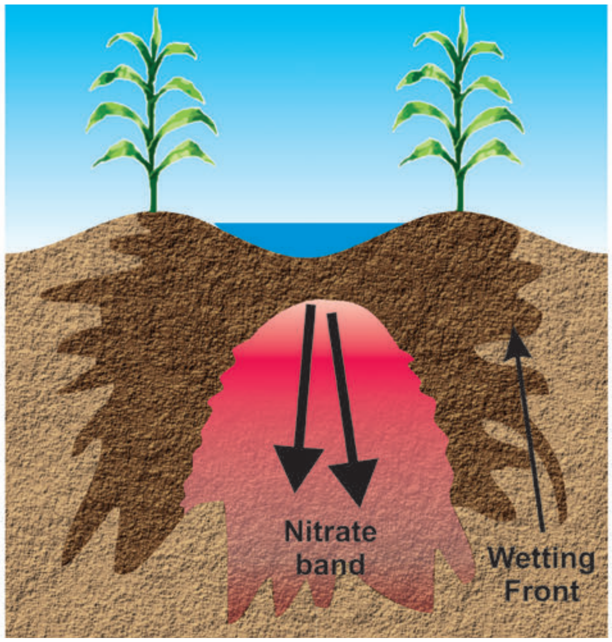


Figure D-12. Impact of furrow irrigation on a concentrated band of nitrogen applied below the soil surface.

Surface runoff

Whenever water runs off the 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 the 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. Management practices that reduce sediment transfer or soil erosion such as no-till will also greatly decrease the potential for nitrogen movement through runoff.

More Extension Publications (available at ianrpubs.unl.edu)

EC91-735, The impact of nitrogen and irrigation management and vadose zone conditions on groundwater contamination by nitrate-nitrogen (archived publication)

G1338, Managing Furrow Irrigation Systems

G91-1043, Water runoff control practices for sprinkler irrigation systems (archived publication)

Section E

How to determine the optimum rate of nitrogen fertilizer

A general strategy for developing a nutrient management program is the **4Rs system:** the **R**ight rate, the **R**ight source, the **R**ight placement, and the **R**ight timing. These 4Rs are interrelated and have to be adjusted based on some choices, but the major first step is the right rate. The University of Nebraska–Lincoln (UNL) has developed its nitrogen recommendation procedure over the last 50 years based on research and the experience of the soils faculty. More detail on the procedures and other nutrients can be found in the references at the end of this chapter.

Since corn under irrigation is by far the major user of nitrogen this chapter will focus on developing a nitrogen recommendation for corn. The UNL provides a web-based digital N tool where you can enter the information of soil type, soil test values, organic matter, nutrient availability, residual nitrate, timing of application, and price of fertilizer and corn to get an economically optimum nitrogen rate for corn grain. The link for the digital N tool is available here: https://cropwatch.unl.edu/nitrogen-tool.

UNL'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. In addition to the agronomic credits, we adjust the recommendations for economics and for timing.

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. Managers 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. As described in Section B, the result is often a greater-than-necessary nitrogen fertilizer application, which increases costs and negatively impacts water quality.

Because of unknown weather throughout the growing season and all the transformations discussed in Section D, the optimum N fertilizer rate for any field in any year cannot be determined with absolute certainty. However, enough is known or can be estimated to arrive at a rate that is reasonable. An N rate lower than optimum will increase the risk of lower yields. Selecting an N rate above optimum will cost more, may offer no additional yield, and may be lost to the groundwater. UNL has developed a procedure to help determine the N application rate that will meet crop needs and minimize the risk of N losses. When nitrogen losses are known to occur after application, the rate needs to be adjusted, and the management plan refined, so future nitrogen loss is minimized.

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 UNL 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%. The UNL digital N tool provides options for estimating yield goal based on five-year yields. An unusually bad year can be omitted.

Example: Calculation of realistic corn yield for an irrigated corn field

Irrigated corn

5 years of yields (bu/acre)

208, 221, 215, 170 (hail), 205

Average all years= 203 bu/acre

Average with 170 bu/acre omitted = 212 bu/acre

Expected yield (EY) in this case is 212 x 1.05 = **223 bu/acre**

Caution: Do not over-estimate crop yields for nitrogen use decisions. Increasing the average yields by 5% will provide enough increase in the nitrogen recommendation to account for the increasing yield potential provided by advancing technology. If yield is unsatisfactory, several factors can contribute to grain yield so just increasing the yield goal is unlikely to increase yields. Examine the complete cropping system to determine what the limiting factor is and address this directly.

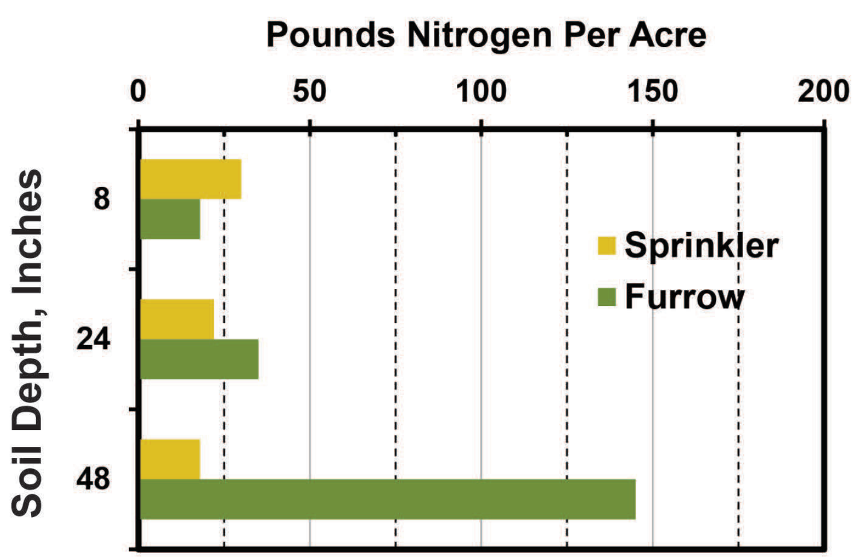


Figure E-1. Summary of two sets of soil samples: 1) taken from a soil that was sprinkler irrigated; and 2) taken from a soil that was irrigated by a furrow irrigation system.

Soil sampling: Proper sampling for soil testing is a critical step in making a realistic estimate of available soil nitrates. Because nitrate is very soluble and moves with the water in the soil profile, 1-foot deep samples have very little value except when doing the pre-sidedress nitrate test. For the preplant nitrogen rate determination deep samples are necessary.

Sampling depth: The 0- to 8-in depth increment is important since it is used for general fertility (organic matter, pH, phosphorus, potassium, zinc) as well as N, while deeper increments should be analyzed for nitrate-nitrogen only. In order to assess soil nitrate availability, the ideal sampling depth should be as deep as the effective rooting depth for the crop. However, recommended soil sampling programs must also be practical. Samples taken to a depth of 3 ft or greater are generally acceptable for corn, wheat, and sugar beet. However, the estimate of available soil residual N will be more accurate by using a greater sampling depth. Samples collected to a depth of 4 ft are more time consuming and labor-intensive, but provide a better estimate of residual N than 2- or 3-ft samples.

Deeper soil samples are desirable because it is possible for residual N to have a greater concentration in the lower part of the root zone than in the top foot. For example, *Figure E-1* shows the amount of N distributed in a 4-ft profile collected from sprinkler and furrow irrigated fields. Collection of cores in depth increments can identify unusual situations and allow the field manager to develop a management plan to address the N distribution issues. High levels of N in the 2- to 4-ft depth presents problems for the manager. Nitrogen is needed early in the growing season but drainage could decrease N available to the growing crop. Without taking samples at various depths, this situation would not be discovered and the field manager may have incorrectly adjusted the N application rate upward. With the preseason samples in hand, the manager can resample the field and adjust with a sidedress and/or fertigation nitrogen application.

Figure E-1 also depicts a sample profile from a center pivot irrigated field where most of the nitrogen has been removed by the previous crop. Even if substantial precipitation is recorded early in the growing season, little additional nitrogen would be leached out of the root zone. In this case, taking samples from deeper depths appears to add little information to the manager. However, if the samples had not been collected, the field manager may have applied too little nitrogen.

Number of cores to be collected: Because of natural variability, a better estimate of a field's fertility can be obtained by taking more individual soil cores per sample and more samples per field. UNL has two publications on soil sampling, one for traditional soil sampling and one for precision agriculture. For the traditional approach areas need to be no larger than 40 acres. Divide fields according to patterns of cropping history, topography, soil type, or any reason where differences are expected. 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 cores collected to represent the deeper portion of the crop root zone give a better estimate of nitrates. ***Multiple soil cores will improve the estimate of nitrates in the soil, but check with your NRD for specific requirements.***

Using the soil nitrate-nitrogen values from the soil test

The amount of N 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 amount of commercial N fertilizer applied,
- Application of biosolids (manure, sludge, compost, etc.),
- Previous crop: some crops remove more soil nitrogen than others,
- Precipitation: 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, and
- Soil organic matter

How much nitrogen is credited from the soil test is an important question that will affect the final nitrogen recommendation. Normally, agricultural soil testing laboratories report soil nitrate-nitrogen in parts per million (ppm) and pounds N per acre (lb/acre). The challenge is how to use the soil nitrate numbers taken from a soil sample from only part of the root zone and accurately adjust the recommended nitrogen fertilizer rate. UNL nitrogen fertilizer recommendations use the weighted-average nitrate-nitrogen concentration in ppm in the sampled horizons. Therefore, regardless of the number of depths sampled, 1.0 ppm value is entered into the equation. The example on the next page presents the procedure using example calculations made to determine the weighted-average N concentration from samples collected from three depth increments.

Example: Weighted average soil nitrate-nitrogen concentration based on sample analysis results from three sampling depth increments.

Depth Increment (in)	Core Sample Length (in)	x	Nitrate-Nitrogen (ppm)	=	Length x ppm
0-8	8		11		88
8-24	16		7		112
24-48	24		5		120
				Total	320

$$\text{Average ppm nitrate-nitrogen} = \frac{\text{Total}}{\text{inch of depth}} = \frac{320}{48} = 6.7 \text{ average ppm nitrate-nitrogen}$$

Calculation of the weighted-average soil nitrate-nitrogen concentration has been incorporated into an algorithm where the ppm is multiplied by 8 to get the residual soil nitrate credit. *Table E-2* shows values of residual soil nitrogen for a range of soil nitrate-nitrogen contents. Questions may arise: *Where does the 8 come from?* and *Is all the soil nitrate available to the crop?* One way to answer these questions is to consider how much 10 ppm nitrate-nitrogen would be in pounds of nitrogen if it were the weighted-average concentration in the top 48 inches. The calculations would go like this: there are about 3.6 million pounds of soil in an acre-foot (1 acre of surface area, 1 ft deep), 4 ft would weigh 14.4 million pounds (4 x 3.6 = 14.4 million pounds and this is an estimate). If we multiply 10 ppm nitrate-nitrogen by 14.4, we get 144 lb of nitrogen in the top 4 ft of soil.

However, our equation uses 8, so we are not accounting for all the nitrogen that is really contained in the top 4 feet. If we divide 80 by 144 we find we are only accounting for 55% of the nitrogen that may be contained in the soil. The use of only 55% of the nitrogen that may be available covers some uncertainty about whether the nitrogen will remain at a specific soil depth or will it be leached out of the root zone during the growing season. In addition, use of 55% of the potential nitrogen available helps to account for the inability of roots to remove all the nitrogen, especially deeper in the profile.

Table E-2. Nitrogen fertilizer rate reduction for residual soil nitrate.

Residual Soil Nitrate-Nitrogen* (ppm)	Reduction in Nitrogen Fertilizer Needed by Crop** (lb/acre of nitrogen)
3	24
9	72
15	120
21	168
27	216

**Average ppm in at least the top two feet. Deeper samples are better.*
***Not the total nitrate N, but the N credited.*

Determining nitrogen fertilizer needs for corn

UNL developed an **algorithm or a set of steps that are followed in order to solve a problem,** which is used to estimate corn nitrogen fertilizer needs. The original research was conducted in the early 1980s from 81 nitrogen rate experiments on Nebraska soils over a range of organic matters, soil textures, and residual nitrate levels. The algorithm was developed from statistical analysis of the data and is a mathematical model. The output is an N recommendation and the algorithm should be viewed as a whole, not according to the individual parts. However, the terms and coefficients do make practical sense. Additional N experiments done across Nebraska in the early 2000s with 34 sites with much greater yield levels (+260 bu) were added to the data set. The algorithm has been verified with the new set of data and by on-farm testing. The N rate calculation through the algorithm is available through a recently developed UNL digital N tool, which is available on the following link: https://cropwatch.unl.edu/nitrogen-tool.

More Extension Publications (available at ianrpubs.unl.edu)

EC117, Fertilizer suggestions for corn

EC154, Soil sampling for precision agriculture

EC155, Nutrient management for agronomic crops in Nebraska

EC168, N rate calculator for corn

G1740, Guidelines for soil sampling

Section F

Giving credit for non-fertilizer nitrogen sources

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.

Soils in Nebraska typically range from 0.5 to 3.0% organic matter and occasionally higher. A soil with 2% organic matter has almost 20 tons/acre of organic matter in the top 6 inches. This much organic matter contains roughly 2,000 lb of nitrogen in organic form. About 70 to 80% of the total organic matter decays very slowly. The remaining 20 to 30%, the humus, is in a stable advanced state of decay. Thus, only 1 to 2% of the organic N (20-40 lb N/ac) is mineralized per year. *Table F-1* shows the minimum estimated amount of N made available annually by mineralization, according to the organic matter content of the soil.

Table F-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	20 - 30
2	40 - 55
3	60 - 70

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 E 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 N fertilizer need algorithm discussed in Section E.

Figure F-1. Large round bale in an alfalfa field. Alfalfa is a legume that provides soil N due to the decay of plant roots, stems, and leaves.

Legume nitrogen starts with the formation of a root nodule. Each nodule represents an invasion by specific soil bacteria into 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 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 soil nitrates are 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 F-2* shows the expected nitrogen credit when a grain crop follows a legume.

Table F-2. Estimated nitrogen credit when the previous crop is a legume.

Legume Crop	Medium and Fine Textured Soils	Sandy Soils
	(lb/acre nitrogen credit)	
Alfalfa 70 - 100% stand (More than 4 plants per sq ft)	180	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 and red clover	80% of credit allowed for alfalfa	
Soybean	45	35
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 N/ac to the soil with each 12-inches of irrigation water applied (or 0.23 lb N/acre with each inch of irrigation water applied).

When irrigation water contains 10 or more ppm of nitrate-nitrogen, the amount of N fertilizer added to a crop should be reduced to credit the nitrogen coming from irrigation water. *Table F-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 F-3. Crop available nitrogen in irrigation water.

Water Applied (inches)	Nitrate-Nitrogen concentration (ppm or mg/l)								
	5	10	15	20	25	30	35	40	45
	(lb of nitrogen added per acre)								
6	7	14	20	27	34	41	48	54	61
9	10	20	30	41	51	61	72	82	92
12	14	27	41	54	68	81	95	109	122
15	17	34	51	68	85	102	119	136	153
20	23	45	68	91	114	136	159	182	204
25	28	57	85	114	142	170	199	227	255

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 to that year's crop. Rapid N uptake is illustrated in *Figure G-1* and extends from about V6 to after pollination, but N is taken up all season. 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. Care must be taken to reduce drainage below the root zone since nitrogen will leach with the water. The sections on irrigation scheduling are critical to reduce these losses.

Due of the uncertainty of precipitation during the growing season, we suggest that the nitrogen contained in 80% of the 5-year average irrigation depth be used when calculating the N contribution by irrigation water. If your field site is within an NRD with an annual water allocation, use the annual allocation in place of the 5-year average. An example will show how to calculate the N provided by irrigation water containing N.

Example: Calculating the irrigation water N credit

Irrigation water contains 15 ppm nitrate-nitrogen. The 5-year average irrigation water application depth is 10 inches per year. Using 80% of the 5-year average, how much crop available N is in the irrigation water?

(ppm) x (0.2267) x (in. of water) = lb of nitrogen/acre in the water

0.8 x 15 ppm x 0.227 x 10 in. = 34 lb of nitrogen/acre

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 micro-organisms. 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 F-4*). 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 always collect samples of organic resources and have the samples analyzed to determine a more accurate credit. Manure sampling procedures are presented in NebGuide G1450 at: *www.ianrpubs.unl.edu/sendIt/g1450.pdf.*

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 that can also be beneficial in subsequent crop years.

Long-term use of organic resources to fully meet nitrogen requirements usually results in excessive buildup of available phosphorus and potassium in the soil. To avoid this problem, organic material application should be based on replacing the phosphorus removed in the crop. Applying organic resources to meet the crop's needs for phosphorus instead of nitrogen will require three to seven times more land area. 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.

Table F-4. Typical available nitrogen expected from application of organic resources.	
Organic 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 numbers will vary widely depending on storage, handling, application methods, and conditions after application.

More Extension Publications (available at ianrpubs.unl.edu)

G1335, Determining Crop Available Nutrients from Manure

G1450, Manure Testing for Nutrient Content.

G1519, Calculating the Value of Manure for Crop Production

G1563, Manure Incorporation and Crop Residue Cover - Part I: Reducation of Cover

G1564, Manure Incorporation and Crop Residue Cover - Part II: Fine-Tuning the System

G1939, Sewage Sludge Utilization for Crop Production

For More Information

More information can also be found at: *manure.unl.edu*

Section G

How to properly apply nitrogen fertilizer

How to properly apply nitrogen fertilizer

As previously discussed, implementation of the 4**R**s of nitrogen management is essential for protecting groundwater quality. Proper nitrogen management includes applying the **R**ight nitrogen rate, the **R**ight source, at the **R**ight time, and the **R**ight placement. The primary goal of nitrogen best management practices is attaining high nitrogen use efficiency (greatest yield with least amount of nitrogen). This assures the most effective use of nitrogen fertilizer.

Good nitrogen management requires an understanding of:

- How nitrogen is used by the crop
- When nitrogen is used by the crop
- What environmental influences affect nitrogen use by the growing crop
- How management of nitrogen and irrigation water affect the leaching of residual nitrate

Corn nitrogen uptake across the growing season

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

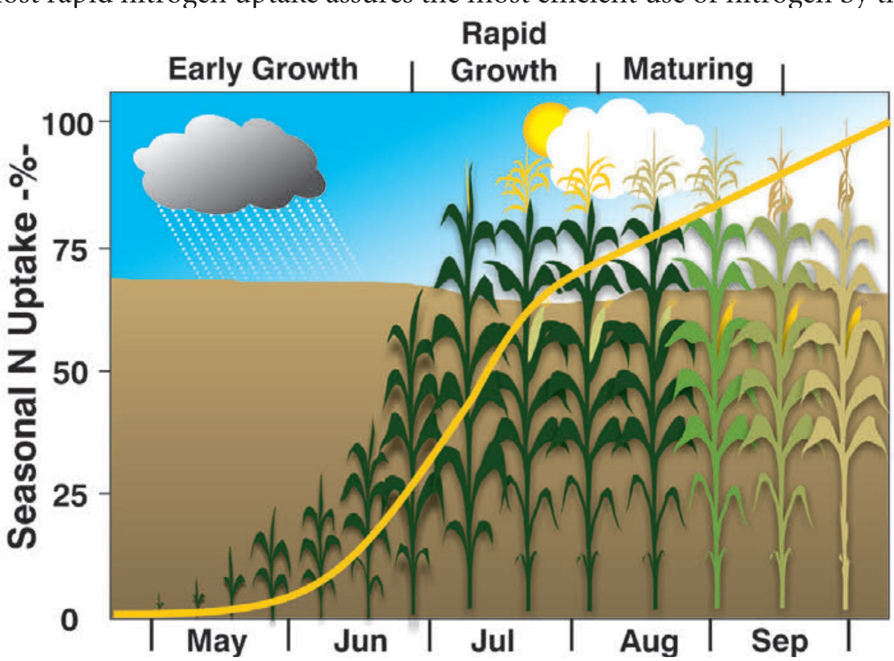


Figure G-1. Cumulative nitrogen uptake curve for a growing season.

The potential for leaching of nitrate by precipitation is greatest in the spring before the crops start growing rapidly (*Figure G-2*). On average, the highest precipitation in Nebraska occurs in May and June. During this time crop water use is low and very little nitrogen uptake occurs. If the water content of the root zone is 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 fertilizer type and timing of application. When the nitrogen fertilizer rate is below optimum, yield is lost. When the rate it is above optimum, excess residual nitrogen can remain and be leached before the next growing season. Such losses contribute to groundwater contamination.

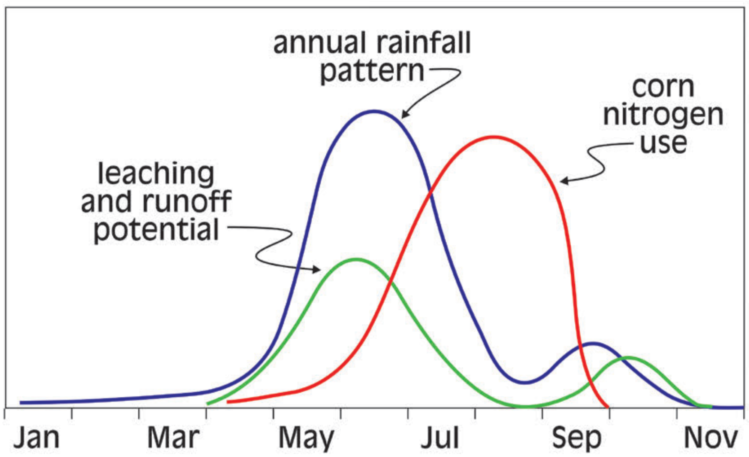


Figure G-2. Depiction of typical nitrogen uptake and the potential for nitrate leaching and runoff caused by precipitation during the growing season.

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. **Nitrogen use efficiency is described in Section B as the bushel of grain harvested per pound of nitrogen applied**. High nitrogen use efficiency 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. Low nitrogen use efficiency can result when nitrogen applications are applied well before the crop needs it and/or are excessive.

Figure G-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 and will leach if water passes through the soil.

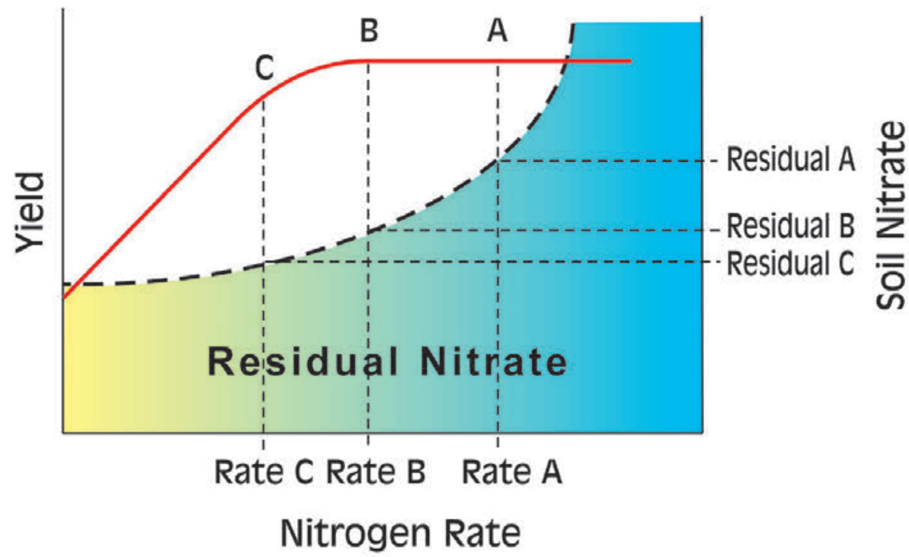


Figure G-3. Impact of excessive nitrogen application rate on soil residual nitrogen.

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	176	104

In this example presented above, the yield for the 90 lb/acre average nitrogen application corresponds to point C in *Figure G-3* with a yield of 168 bu/ac and residual nitrate-nitrogen was 73 lb/ac. When the nitrogen application was increased from 90 to 140 lb/ac, the grain yield increased by 8 bu/acre and the residual nitrate-nitrogen increased by 3 lb/ac. This corresponds to point B in *Figure G-3*. A further increase in nitrogen applied resulted in no additional yield, but the residual nitrate-nitrogen went up. This corresponds to point A in *Figure G-3*.

Timing

Crops have their greatest daily nitrogen use rate between the V6 and VT growth stages (*Figure G-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 precipitation or irrigation. The relative ranking of nitrogen use efficiency for different application timings is summarized in *Table G-1*. These rankings are correct for irrigated production. In rainfed areas that lack 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 G-1. Nitrogen use efficiency according to timing of application.

Highest	Sprinkler applied during rapid growth
↓	Sidedress just before rapid growth
	Postplant incorporated
	Preplant 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.

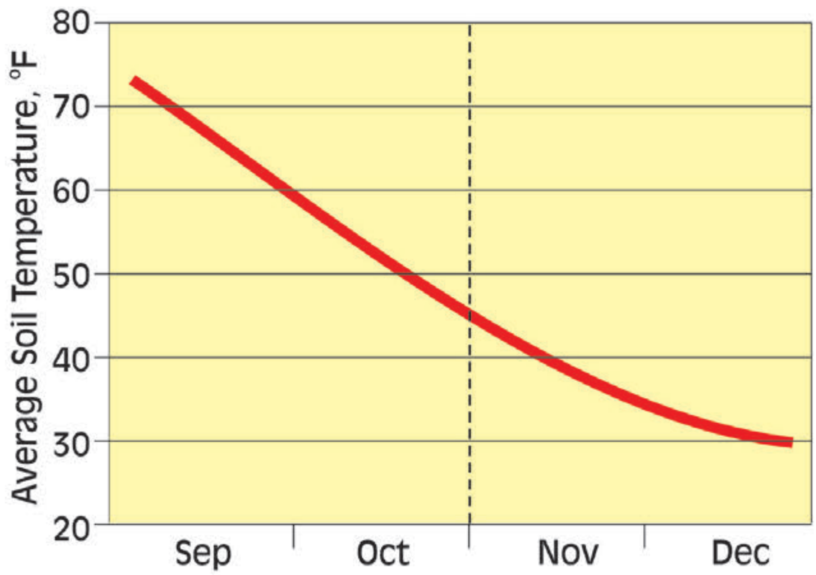


Figure G-4. Average soil temperature in the fall at Clay Center, NE.

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% of its maximum rate in a warm soil. As long as the soil stays cold, only a limited amount of the ammonium will nitrify and be subject to leaching. Figure G-4 shows that, on average, a soil temperature of 50° F is reached around Oct. 15 in South Central Nebraska. For this reason, it is recommended that fall applications of anhydrous ammonia wait until after Oct. 15. However, it is best to check local soil temperatures first. Check the UNL

CropWatch site for soil temperature progression in your area (*cropwatch.unl.edu/web/cropwatch/cropwatchsoiltemperature*). Of course, as the soil warms in the spring, nitrification rate increases again so fall applied nitrogen is subject to leaching by spring precipitation and therefore it is best to avoid fall applications if possible.

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 as 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.
- Surface-applied fertilizer should be incorporated with irrigation to reduce surface runoff and volatilization.
- If nitrogen is surface applied, banding reduces potential volatilization loss. Using a 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 potential nitrate loss to groundwater will 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 that passes through the root zone. Ammonium sources will attach to soil and organic matter and resist leaching. However, nitrification will change ammonium forms to nitrate quite rapidly. Some leaching potential can be overcome by the use of nitrification inhibitors. Inhibitors are substances added to nitrogen fertilizer that 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 reduced or prevented if a heavy precipitation event occurs close to application. Inhibitors will not prevent the leaching of residual nitrate that is already in the soil at the time fertilizer is applied.

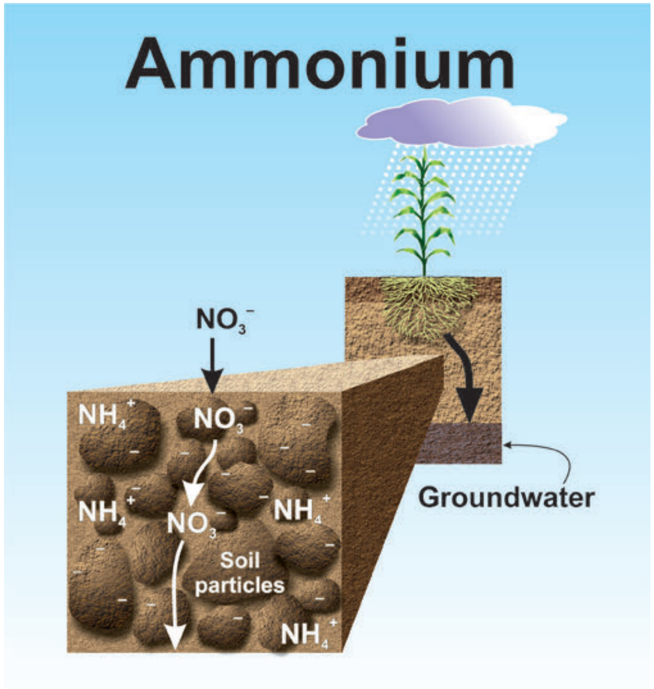


Figure G-5. Depiction of the attachment of positively charged ammonium molecules to negatively charged soil particles, which prevents leaching of N in the ammonium form while allowing leaching in the nitrate form.

Both the ammonium and nitrate forms of nitrogen are available to the crop. However, anhydrous ammonia is the only form of nitrogen fertilizer that is totally nonleachable immediately after application. Urea and nitrate can leach right after application but urea will be converted to ammonium in a very few days. A potential for volatilization loss exists from surface applied nitrogen and runoff from heavy rains can transport nitrogen that has not been mixed into the soil. Incorporation of nitrogen and timely applications will provide good crop nutrition from all nitrogen sources. (Details in Section D.)

Enhanced efficiency fertilizers

Decisions on which fertilizer to use, when to apply it, and how much to apply interact with which nitrogen source is chosen. Making a nitrogen management plan to reduce risks that threaten the nitrogen use efficiency will contribute to profit and environmental protection. The choices for a nitrogen source have expanded over the last few years because of several technologies designed to improve nitrogen use efficiency by addressing various sources of potential nitrogen losses. These are collectively called Enhanced Efficiency Fertilizers (EEF). However, many of them have different modes of action so it is important that they be understood so they can be used under the appropriate situations.

As discussed several times in this publication, nitrate is the form of nitrogen that has the most potential for loss in the soil, and urea on the surface of the soil has the potential for volatilization with ammonia being lost to the atmosphere. Most of the products available address the need to slow the availability of nitrate, or protect urea from the process called hydrolysis, which frees the ammonia molecule from the urea compound.

Table G-2 lists the many compounds and the nitrogen process affected by the use of the chemical. Section D discusses these processes in detail. The major concept critical for effective use of these products is that there has to be risk of loss. Split applications and timing when corn needs the nitrogen are excellent management strategies. *Table G-3* lists some of the situations that might benefit from the use of the materials in *Table G-2*.

Table G-2. Enhanced efficiency fertilizers available in the United States.

Nitrogen Products*	Common Product Names	Process Affected
Dicyandiamide (DCD)	Guardian®	Nitrification
2-chloro-6 (trichloromethyl) pyridine (Nitrapyrin)	N-Serve®, Instinct®	Nitrification
N-butyl-thiophosphoric triamide (NBPT)	Agrotain®	N volatilization
NBPT + DCD	Agrotain®Plus, SuperU®	Nitrification, N volatilization
Triazone + NBPT	N-Pact®	N release, volatilization
Malic+ itaconic acid co-polymer with urea	Nutrisphere®,	Nitrification, N volatilization
Polymer-coated urea (PCU)	ESN®, Polyon®, Duration®	N release
Sulfur-coated urea (SCU)	SCU	N release
Polymer + SCU	Tricote, Poly-S®	N release
Urea formaldehyde	Nitroform®	N release
Methylene urea	Nutralene®, CoRoN®, NFusion®	N release
Triazone	N-Sure®	N release
Methylene urea + triazone	Nitamin®, Nfusion®	N release

Table G-3. Risk assessment for N fertilizer management.

Situation	Risk	Approaches
Fall application to silt loam or clay loam soil	Denitrification, leaching	NH_3 injection with nitrapyrin
Preplant application to silt loam or clay loam soil	Denitrification, leaching, runoff, volatilization	NH_3 with nitrapyrin; PCU; Urea with NBPT; Methylene urea; UAN knife in
At-planting surface application with no-till	Volatilization, runoff, denitrification	Urea with NBPT; PCU; Methylene urea; UAN with NBPT
Sidedress application or fertigation	Wet weather preventing timely application	Preplant or at-planting knife application, using inhibitors or slow/controlled release formulation

Real time N adjustments

It is well known that improving N use efficiency reduces the amount of N that can potentially leach into groundwater supplies. However, management of N is a major challenge because of the unknown factors related to weather such as air temperature and precipitation levels. To minimize the risk associated with having the necessary amount of N available to the crop, researchers have worked to develop tools that can be used to help make N management decisions during the growing season. Handheld chlorophyll meters and multispectral sensors mounted in aircraft or on high clearance equipment can provide in-season measures of N sufficiency. These tools provide the potential to fine-tune N management decisions by reacting to changing crop and weather conditions during the growing season.

Leaf chlorophyll meters

Research over the past decade indicates a close link between leaf chlorophyll content and leaf N content in corn, which makes sense because the majority of leaf N is contained in chlorophyll molecules. Chlorophyll meters (*Figure G-6*) enable field managers to quickly and easily measure potential photosynthetic activity, which is closely linked to leaf chlorophyll content, crop N status, and leaf greenness. Essentially, the meter exposes a small portion of the leaf to abundant light and measures how much was reflected by chlorophyll in the leaf. The chlorophyll meter records the reflection of light in the photosynthetically active waveband of plant leaves and can be used to monitor crop N status and potentially increase N use efficiency.

Figure G-6. Handheld chlorophyll meter used to monitor nitrogen status of corn plants.

The chlorophyll meter has several advantages over other tissue testing methods. Samples don't need to be sent to a laboratory for analysis, saving time and money. The use of the chlorophyll meter is nondestructive and permits repeated measurements throughout the growing season. Plants produce as much chlorophyll as possible until something else becomes limiting. As such, luxury consumption of N does not increase leaf chlorophyll content. This causes meter readings to reach a plateau when N availability is adequate, regardless of how much extra N is taken up by the plant. Using a chlorophyll meter to monitor leaf greenness throughout the growing season can signal the approach of a potential N deficiency early enough to correct it without reducing yields. This approach makes chlorophyll meters especially useful where additional N can be applied through sprinkler irrigation systems (fertigation) or with high-clearance equipment such as a sprayer.

Many factors affect chlorophyll meter readings. Variety or hybrid differences can greatly affect meter readings in that some adequately fertilized corn and sorghum hybrids are darker green than others. The stage of growth can affect leaf greenness, as can recent environmental conditions such as temperature, moisture stress, and sunlight. Plant diseases, nutrient deficiencies, and nearly any other kind of plant stress can affect the plant's ability to produce chlorophyll, thus affecting leaf greenness. Because the chlorophyll meter is affected by so many things, it is impossible to say that a given meter reading indicates sufficient N. Meter readings mean very little by themselves and must be calibrated for each field, soil, hybrid, and environment to make use of the readings. The best way to calibrate the meter is to create a set of adequately fertilized reference strips in each field every year.

The chlorophyll meter enhances a producer's ability to make N management decisions but does not replace other aspects of good N management. Environmentally and economically sound N management must begin with a representative soil sample and a realistic value for expected yield. It is suggested that at least one-half to three-quarters of the total N fertilizer be applied to the entire field prior to the six-leaf stage to ensure the chlorophyll meter technique is effective. If a corn plant experiences moderate to severe N stress in the early growth stages, the size of the ear and number of kernels may be limited, so additional N fertilizer applied later will not allow full recovery of grain yield.

The chlorophyll meter technique allows fine-tuning N management to field conditions and reduces the risk of yield limiting N deficiencies. The meters can also help prevent the over-application of N fertilizers, thereby reducing potential leaching. Producers should recognize this as another tool that may complement, but does not replace, other aspects of sound N management.

Additional information on how to specifically use chlorophyll meters use can be found in UNL NebGuide G1632, Using a Chlorophyll Meter to Improve N Management.

Crop canopy sensors

Recent advances in precision agriculture technology have led to the development of ground-based remote sensors (or crop canopy sensors). These sensors essentially measure the amount of light reflected off of the crop canopy. Light reflectance has been used for some time to gauge crop status in terms of nutrient and water stress. However, ground-based sensors are novel in that they have their own light source (active sensor) instead of relying on sunlight (passive sensor). Previously reflectance was collected via airborne or satellite sensors. These had several limitations, including expense and weather-related issues such as cloud cover that could greatly limit the effectiveness of these sensing techniques. Active sensors have their own source of light energy and allow for the determination of reflectance measurements at specific times and locations throughout the growing season without need for ambient illumination or flight concerns.

Figure G-7. Onboard plant chlorophyll sensors used to adjust nitrogen fertilizer application.

Crop canopy sensors are relatively small in size and operate by directing sensor produced visible light (VIS) as well as near infrared (NIR) light at the plant canopy of interest (some sensors are configurable allowing for other wavelengths of light to be used as well). The amount of VIS and NIR light that is reflected off the plant canopy is measured and specific indices can be calculated depending on the variable of interest (i.e. N stress). The visible light reflectance is primarily dependent on the chlorophyll contained in the palisade layer of the leaf and the NIR reflectance depends on the structure of the mesophyll cells and the cavities between these cells.

A strong relationship exists between leaf chlorophyll concentration and leaf nitrogen (N) concentration. Therefore, greater leaf area and green plant biomass levels result in higher reflectance and higher subsequent sensor readings. Because these variables are directly related to the N content of the plant, higher values relate with higher plant N content. These properties allow sensors to be a valuable tool in determining the relative plant N status by comparing the plants with sufficient N to plants with an N deficiency.

Crop canopy sensors are used much in the same way as the aforementioned chlorophyll meters. However, the crop canopy sensors do not need to be directly attached to the leaf. The crop canopy sensors are placed approximately 2 feet above the canopy (depending on manufacturer recommendations) and collect data as the sensor moves through the corn (usually attached to a high clearance tractor). This allows the crop canopy sensors to cover a lot of ground in a short amount of time, thus recommendations for supplemental N fertilizer can be made on a field scale in relatively short order.

Generally the sensors would be used at the V10-V12 corn growth stages (high clearance equipment is needed for effective crop canopy sensor use). Readings would first be collected on an area of the field where crops exhibit no visual deficiencies due to N. This is called the reference strip and is set up by the producer early in the growing season by applying N in quantities that will not be limiting to the corn by the V10-V12 growth stages. Next, sensor readings are collected on the area of the field where side-dress is needed (usually called the target area). Sensor readings from the reference area and target area are then put into an algorithm (several are available depending on sensor type, use, etc.) that calculates a recommended N rate. This process can be done on the fly where sensor readings and calculations are made rapidly and variable rate N fertilizer is applied all in the same pass.

Research has shown that crop canopy sensors can significantly reduce the amount of N that is applied while still maintaining yields. This can greatly increase nitrogen use efficiency and has the potential to greatly reduce potential leaching of N into groundwater. Unfortunately, the process has been shown to be site-specific and the sensors are still relatively expensive. However, there are several co-ops and custom applicators now offering this method of N application to farmers. It is expected that the use of crop canopy sensors will increase as they become more cost effective over time. As with the chlorophyll meters, producers should recognize crop canopy sensors as a tool that can complement sound N management.

Nitrogen fertilizer cost

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 (prices continually change, numbers given are just an example).

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

82-0-0, anhydrous ammonia (82% nitrogen) costs $315/ton

82% x 2000 = 1640 lb nitrogen/ton of anhydrous

$315 ÷ 1640 lb = $0.19/lb

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

28% x 2000 = 560 lb nitrogen/ton

$135 + 560 lb = $0.24/lb

**The most profitable nitrogen application rate is dependent on the price of corn and cost of nitrogen. Adustments based on these prices are descibed in EC117, Fertilizer Suggestions for Corn*

More Extension Publications (available at ianrpubs.unl.edu)

EC117, Fertilizer suggestions for corn

EC163, Site-specific nitrogen management for irrigated corn

G1632, Using a chlorophyll meter to improve N management

For More Information

Hergert, G.W., R. Ferguson, C. Wortmann, C. Shapiro, and T. Shaver. 2011. Enhanced efficiency fertilizers: Will they enhance my fertilizer efficiency? *In*: 2011 Crop Production Clinics Proceedings. Pg. 145-148.

Section H

Nebraska irrigation water resources management

Nebraska is one of eight states that have access to portions of the High Plains Aquifer that extends from Texas to South Dakota. *Figure H-1* shows the saturated thickness of the aquifer, with Nebraska having a substantial area with blue colors on the map that indicates over 600 feet of saturated thickness. In total, over 65% of the water stored in the aquifer is located inside the Nebraska borders. Some areas of the Sandhills can reach saturated thickness of 1,200 feet or more. The High Plains Aquifer supplies irrigation water to over 8.9 million acres of Nebraska farmland. However, as the map indicates the saturated thickness varies greatly across the state and water mining has lowered groundwater levels in excess of 100 feet in some areas of the state.

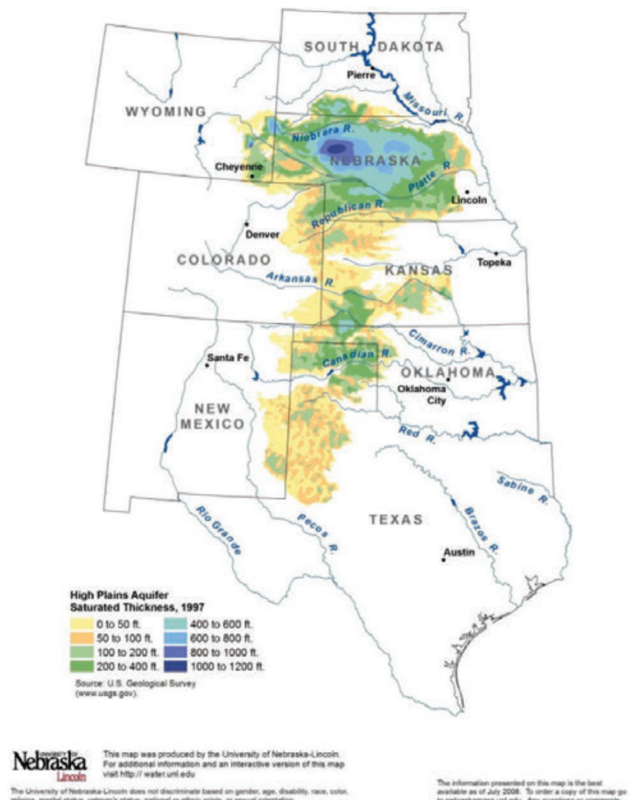


Figure H-1. Map of the saturated thickness in the High Plains Aquifer formation across eight states ranging from Texas to South Dakota.

Nebraska experiences a broad range of annual precipitation, from over 34 inches in the far southeast to less than 15 inches in the far west (*Figure H-2*). In general, annual precipitation decreases 1.0 inch for every 25 miles traveled from east to west. This range in precipitation places the state in climatic zones ranging from subhumid in the east to semiarid in the west. As a result, the need for irrigation increases substantially as one travels west across the state. Of the over 8.9 million irrigated acres of cropland, over 80% of the irrigation water is applied using center pivot irrigation systems.

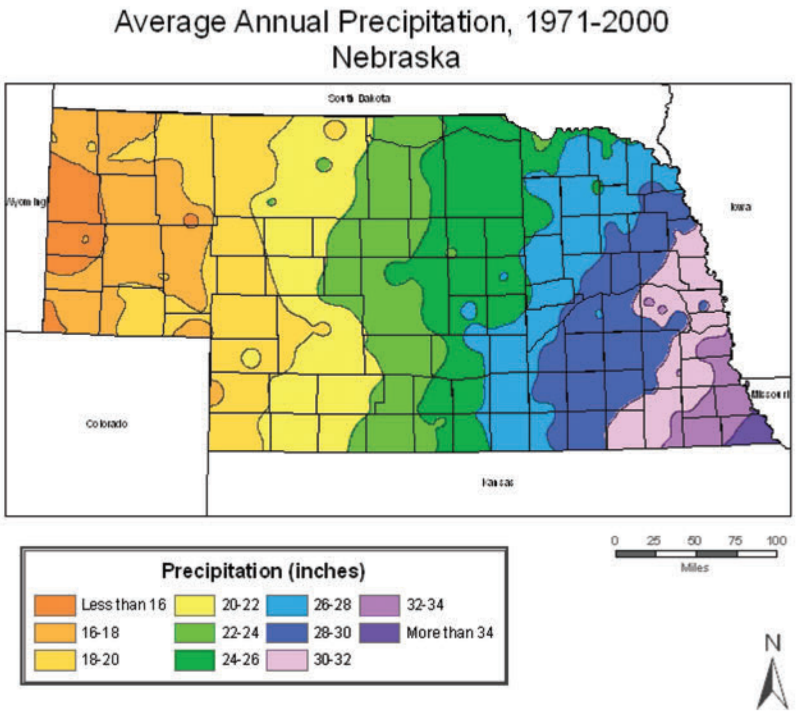


Figure H-2. Range in long-term average precipitation across Nebraska.

To understand water use it is helpful to consider the fate of water as depicted in the hydrologic cycle (*Figure H-3*). Within the earth's atmosphere there is a constant amount of water; however, the supply of water is continuously recycled when viewed from a global perspective. Precipitation that reaches the earth's surface either infiltrates into plant root zone, runs off to streams and rivers, or is intercepted by plants. Some of the water that infiltrates is used to supply water that evaporates from the soil or that transpires through plant leaves. When more water infiltrates into the soil than plant root zones can store, the excess infiltration flows through the soil toward the groundwater aquifer. Water that reaches the groundwater is usually called recharge. Recharge causes the local groundwater level to rise, which can develop a gradient resulting in groundwater flow away from the recharge area. Groundwater may flow toward streams, lakes, and rivers if groundwater aquifers are connected to the stream. In other cases the elevation of the stream may be higher than the groundwater surface and water may flow from the stream to the groundwater. Water also reaches streams and lakes by direct overland runoff.

Water in streams and lakes can come from either surface runoff or groundwater (*Figure H-3*). The contribution of flow due to groundwater is frequently called base flow. Energy from the sun and dry winds causes water in streams, lakes, and the ocean to evaporate into the atmosphere. Similarly, water evaporates from soil and/or transpires from plant leaves. The return of water to the atmosphere as water vapor is referred to as evapotranspiration, abbreviated as ET. Water vapor in the atmosphere condenses as it cools and returns to the earth as precipitation. **The hydrologic cycle is the continuous process of converting water into different states and transporting from one location to another.**

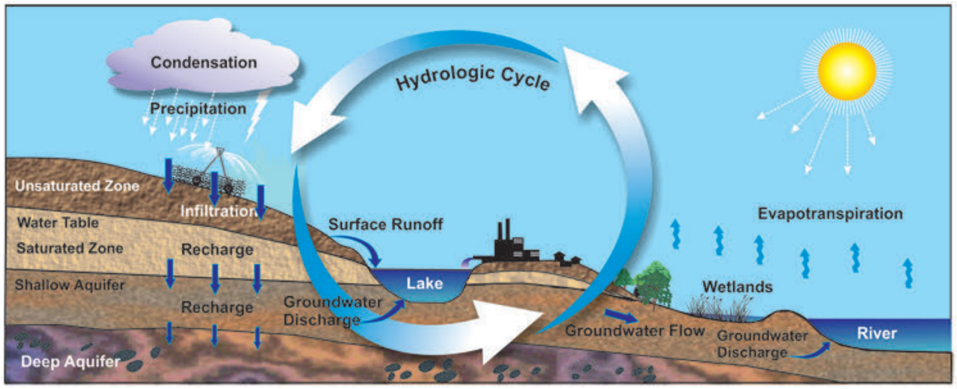


Figure H-3. Diagram of the hydrologic cycle (source *www.sws.uiuc.edu/docs/watercycle*).

The approximate water balance for Nebraska is depicted in *Figure H-4*. On average the state is a net exporter of surface water with 1.4 inches per year more exiting the state than enters. Annual precipitation averages 22.6 inches of which soil evaporation and plant transpiration deliver nearly 20 inches back into the atmosphere. Electric power plants and other relatively small water uses return approximately 1.3 inches of water to the atmosphere per year.

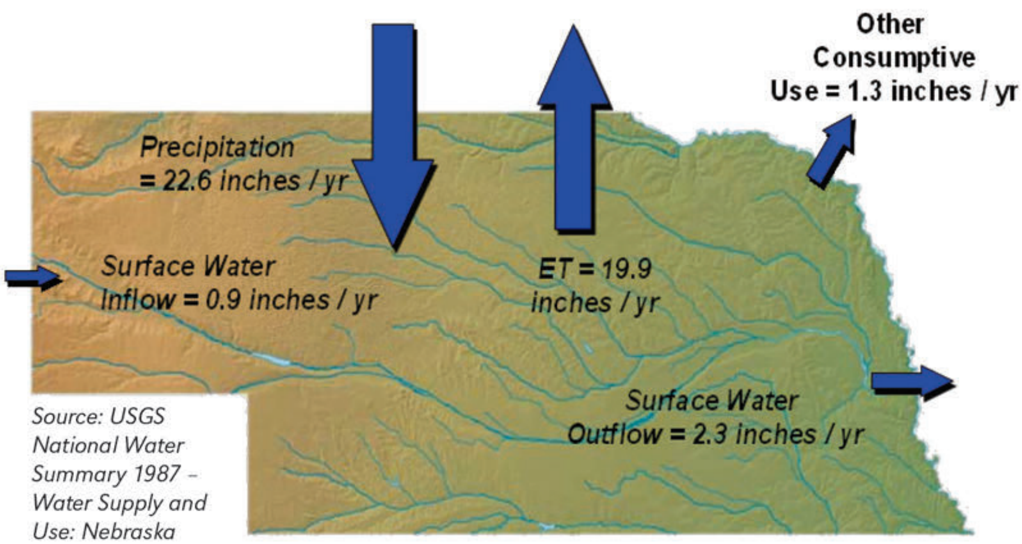


Figure H-4. Approximate statewide water balance for Nebraska.

Watersheds

Though most people think of watersheds on a local scale**, a watershed is the land whose runoff drains into a particular stream** (*Figure H-5*). All land uses in a watershed affect the overall water balance of the watershed and surrounding regions. Many processes included in the hydrologic cycle also apply to the watershed. The primary difference is that water vapor as evapotranspiration generally does not return to the same watershed where the ET occurred. Thus, evapotranspiration represents a loss for the watershed. In the Great Plains, the jet stream transports air from more arid regions into the watershed, and the evapotranspiration that occurs is often transported toward more humid regions.

Precipitation is the primary source of renewable water supplies for most watersheds in the Great Plains. Some watersheds benefit from inflow from surface water in streams and rivers from upstream regions. Groundwater may also flow into the watershed area. Precipitation and inflow to the watershed produces outflow (streamflow or groundwater discharge) or evapotranspiration within the watershed. Some water is also temporarily stored within the watershed as water in reservoirs or groundwater aquifers. Water is also stored in the unsaturated soil (i.e. the root zone and the vadose zone) above the groundwater aquifer. Water in storage can increase or decrease over time depending on the balance between inflow, outflow, and evapotranspiration.

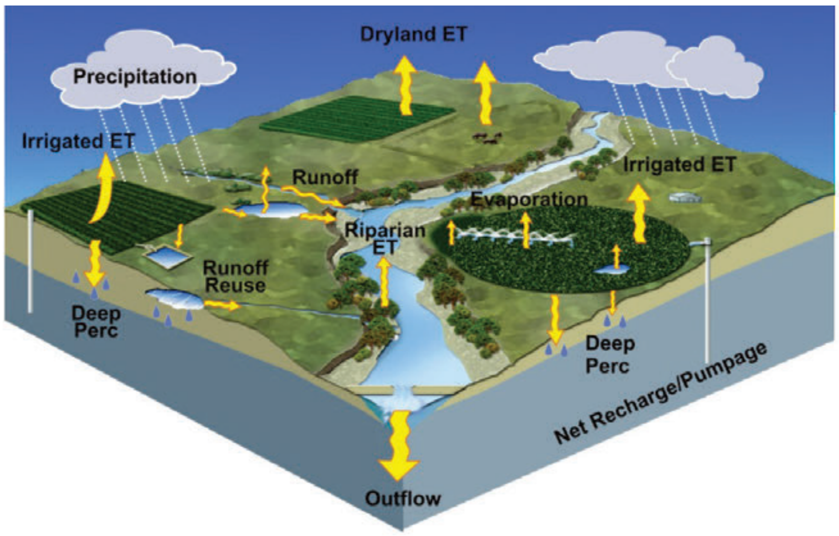


Figure H-5. Diagram of the major water balance components of a typical agricultural watershed.

Man can affect the hydrologic cycle and the water balance of a watershed by diverting surface water from lakes or streams, and by pumping groundwater. Some applications, such as irrigating crops, increase evapotranspiration. The increase in evapotranspiration due to irrigation is the called the consumptive use of irrigation water and represents a conversion of liquid water to water vapor that ultimately leaves the watershed. Some of the water diverted from streams or pumped from groundwater for irrigation may percolate through root zones of irrigated fields or seep from water delivery systems. Seepage and drainage usually recharge the groundwater aquifer. Some water may run off irrigated fields or may be spilled from delivery systems. If the runoff and/or spills flow to a stream or lake, the water is usually referred to as return flow because it becomes available downstream.

Water use

We generally think of diverting water from streams or reservoirs, or pumping from groundwater, to supply an intentional use. Evapotranspiration that occurs due to natural activities is not generally considered to be a "use." Thus, evapotranspiration from native range or evaporation of natural lakes would not normally be referred to as a use. The act of moving water from its original location to a different location or time (i.e., "using the water") has an intended purpose. For example we irrigate to reduce water stress during dry periods to sustain crop yields. We might also use streamflow or groundwater to cool electrical power generation systems or to produce ethanol. When we "use" water, we generally increase evapotranspiration.

Not all of the water "used" is consumed (i.e., converted from a liquid to water vapor). For example, consider the sprinkler and surface irrigation examples shown in *Figure H-5*. Water supplied to the irrigated field as either precipitation or irrigation furnishes water for crop evapotranspiration, but may also result in runoff that may return to the streams of the watershed or may percolate through the crop root zone and recharge the groundwater aquifer. Thus, the amount of water pumped for irrigation is not all consumptively used. Data from the USGS (2005) lists the relative consumptive use of water by major sectors in Nebraska. The data show that up to 90% of the water consumed in the state is for irrigation. Cooling of power plants represents approximately 8% of the total consumptive use in the state. The USGS report indicates that, in Nebraska, relatively little water (<10%) is consumed for domestic or municipal uses.

Consumptive use

The meaning of consumptive use is often different among individuals, especially those that are new to hydrologic processes. Various scientific and engineering organizations have developed definitions for **consumptive use** that vary slightly, but that usually have a consistent message. The United States Geological Survey defines consumptive use as **"that part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment."**

Consumptive use is more subtle if we alter the land use and/or agricultural production practices. For example, it is widely recognized that reduced tillage contributes to higher infiltration rates that supply water for crop evapotranspiration and groundwater recharge. The increased evapotranspiration diminishes the amount of runoff that contributes to streamflow leaving the watershed. So, as one compares practices from earlier times, the changes in farming practices could represent an increase in consumptive use. However, the individual producer did not intentionally move water from one location to another in this process, so in that sense there may not be an increase in consumptive use even though it results in an increase in evapotranspiration.

Some consumptive use may be beneficial in that it increases crop yields and profitability, allows for production of electrical energy or provide for increased recreation at lakes, or provides for some other purpose. In other cases consumptive use may be nonbeneficial. Examples of nonbeneficial uses would be evapotranspiration from weeds in road ditches that are wetted due to uncontrolled runoff from irrigated lands, evapotranspiration from artificially wetted areas adjacent to irrigation canals, or evaporation of water from agricultural fields, water surfaces, streets, and pavements. The fate of an irrigation water withdrawal relative to these considerations is illustrated in *Figure H-6.* Identification and reduction of non-beneficial uses of water offers potential to enhance water supplies with little loss of economic or environmental impact.

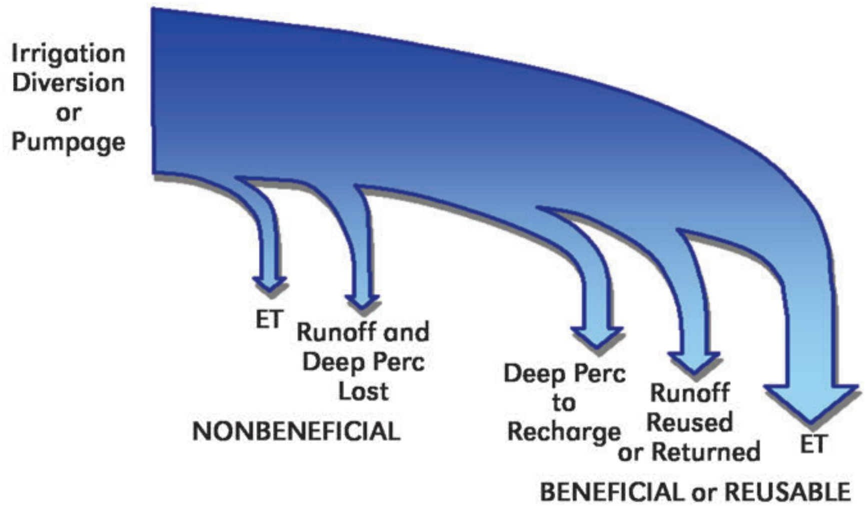


Figure H-6. Schematic drawing of the possible fate of water used for irrigation.

Farm scale

Water use at the farm or field scale differs slightly from considerations at the watershed scale. The fate of water for an irrigated field located in a watershed is illustrated in *Figure H-7*. The rectangular dashed line represents the water balance for an irrigator. Additions to the field water balance include precipitation, and irrigation water from ground or surface water sources. In some cases a high groundwater table can be considered as a water addition to the field water balance. Losses of water from the field are represented by surface runoff, deep percolation and evapotranspiration from the field, and evaporation from on-farm storage or water conveyance systems. Lateral flow of groundwater leaving the watershed can also be a loss. Farmers profit by increasing efficiency to obtain as much evapotranspiration by irrigated crops as possible. Thus, runoff, deep percolation, and evaporation from storage are seen as losses of water. Water that percolates from the field or that runs off and returns to the stream would not be seen as a loss to the watershed as the water is still in the system for use elsewhere.

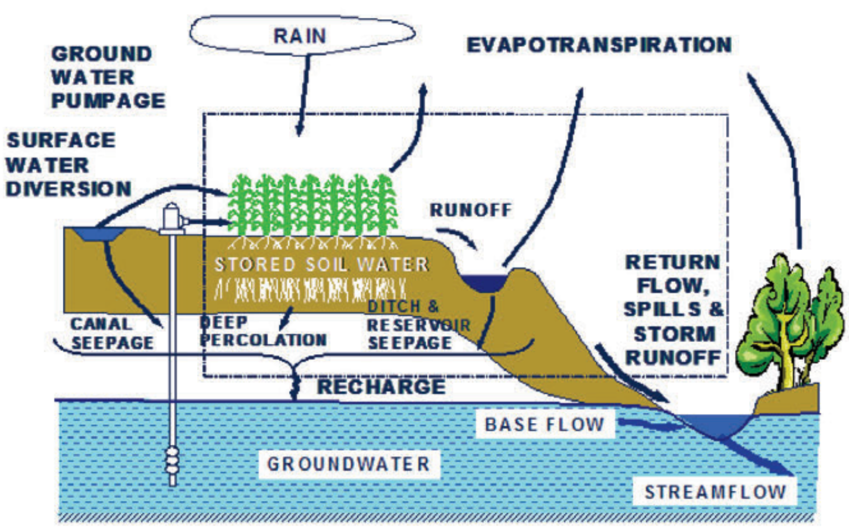


Figure H-7. Diagram of water balance for an irrigated field supplied with ground and surface water for irrigation.

Application of water from an irrigation system can result in several outcomes as illustrated in *Figure H-8*. The goal of the irrigator is to produce the maximum of crop ET from the irrigation as it is generally linearly related to crop yield as shown in *Figure H-9*. Irrigators can improve their efficiency by a range of activities and management practice changes. Actually, the only truly beneficial use of water for the field manager is transpiration from crop leaves. However, it is difficult to separate the transpiration from soil evaporation, so evaporation is included with transpiration as a beneficial use. Reduced tillage and other practices that reduce evaporation from the soil reduce consumptive use without reducing transpiration. This can reduce the amount of water that must be extracted from the source to fully irrigate the field.

Improving irrigation efficiency can reduce the other surface water losses and recharge and/or return flow to streams as shown in *Figure H-8*. Practices that reduce surface losses will reduce nonbeneficial consumptive use. Irrigation water that goes to recharge and/or return flow represents losses to the producer, but not to the watershed per se. Thus, improving irrigation efficiency will usually leave more water at the ground or surface water source, and may reduce nonbeneficial use. Extracted (pumped or diverted) water that is recycled back to the aquifer or stream is not a loss to the watershed, thus improving irrigation efficiency will not "save" all of the reduction in extraction that was accomplished through improved irrigation efficiency.

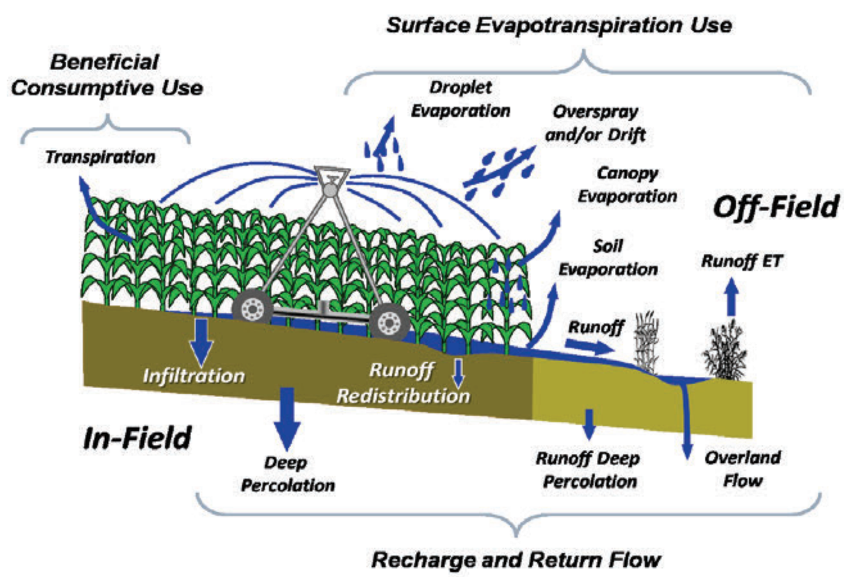


Figure H-8. **Water balance components for irrigated cropland.**

Deficit irrigation can also affect crop water use and yield. Deficit irrigation is the intentional stressing of the crop at certain crop growth stages to reduce water use while minimizing yield reduction. The process of deficit irrigation is illustrated in *Figure H-9.* We normally find a linear relationship between crop yield and evapotranspiration (ET) from the crop for most crops that are raised in the Great Plains. The relationship between irrigation and yield for an efficient and inefficient irrigation system is also shown in *Figure H-9.* The curves show that a portion of the irrigation water is consumed for ET while the rest goes to other surface losses, recharge, or return flow. If the yield is the same for an efficient and inefficient irrigation system the crop water use will be the same but the nonconsumptive uses will be larger for the inefficient system. If the amount of irrigation water is limited an efficient irrigation system will generally produce more yield and will result in more in-field consumptive use than a less efficient system. *Figure H-9* also illustrates that irrigation systems become more efficient, i.e. a larger portion of the applied water will go to ET, when deficit irrigation is employed.

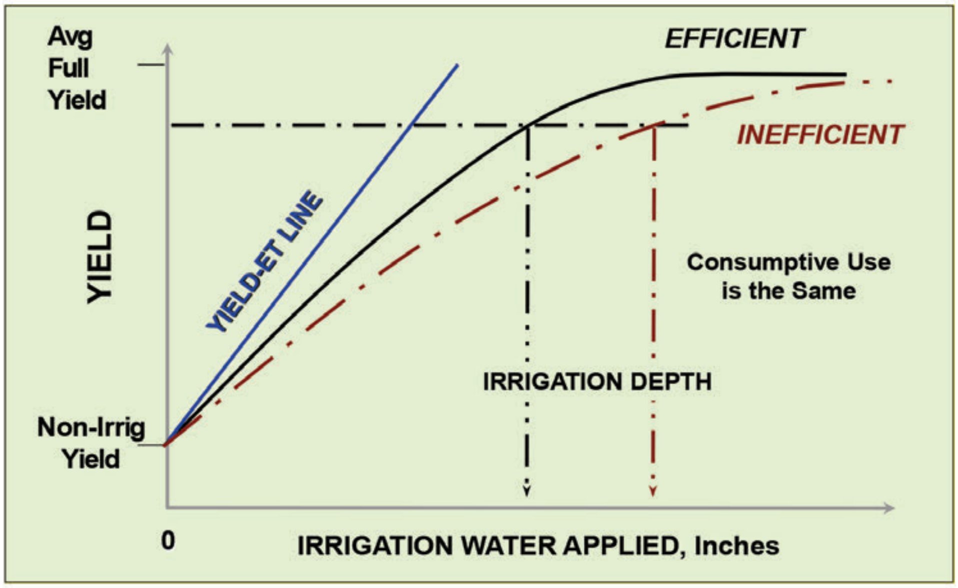


Figure H-9. Effect of improved irrigation efficiency on in-field water use and yield.

More Extension Publications (available at ianrpubs.unl.edu)

EC732, Irrigation Efficiency and Uniformity and Crop Water Use Efficiency

RP195, Targeting of Watershed Management Practices for Water Quality Protection

Section I

Understanding crop water use

When managing an irrigation system, it is important to have a good understanding of crop water use, why crops use water, and the factors that affect the rate of water use. That is because over estimating crop water use often leads to over-irrigation and nitrate leaching. Underestimating crop water use can lead to an unnecessary limitation of crop yield.

Evapotranspiration (ET)

Crop water use includes two parts: **evaporation** (E) from the soil surface and **transpiration** (**T**) from the crop leaves. It is difficult to separate transpiration from evaporation so the two components are measured or calculated together and the sum is called **evapotranspiration**, or **ET**. We will use ET and crop water use interchangeably. Over a growing season, 70% to 80% 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, thus directly contributing to producing grain. The remaining 20% to 30% of ET is direct evaporation from the soil (*Figure I-1*).

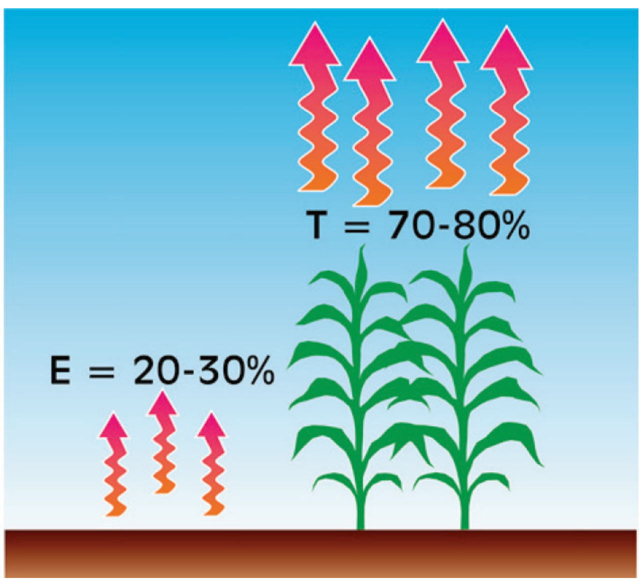


Figure I-1. Seasonal breakdown of the contribution of soil evaporation (E) and transpiration (T) for irrigated corn in Nebraska.

Evaporation is the change from liquid water to water vapor that can occur from soil and water surfaces.

Transpiration is the passage of water vapor through plant pores into the atmosphere.

Evapotranspiration is the combination of evaporation and transpiration that is often referred to as crop water use or crop ET.

The ratio of evaporation to transpiration changes as the crop grows and more of the soil surface is shaded by crop leaves. When crops are small, the portion of ET due to transpiration is minimal relative to soil evaporation. The surface area of the leaves is small and more of the soil surface is exposed. *Figure I-2* illustrates this idea with larger arrows representing more water leaving the soil through evaporation as compared to the small blue arrows representing the portion of ET transpired by the small plants.

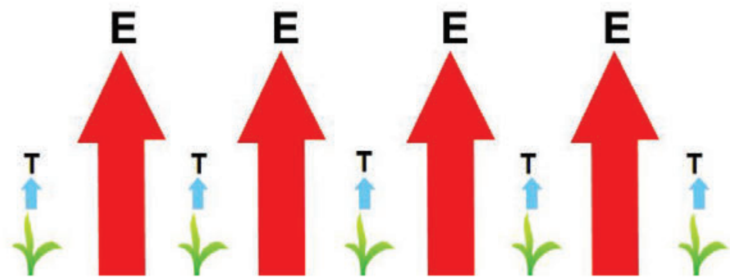


Figure I-2. **Relative magnitude of ET components early in the growing season.**

By the time that the crop reaches full canopy, the soil is mostly shaded and evaporation from the soil is minimized (*Figure I-3*). By midseason, leaf area is sufficient to cover the soil surface more than three times. Transpiration becomes the dominant component of ET and over 80% of ET is due to plant transpiration, though this varies depending on the cropping system and management practices.

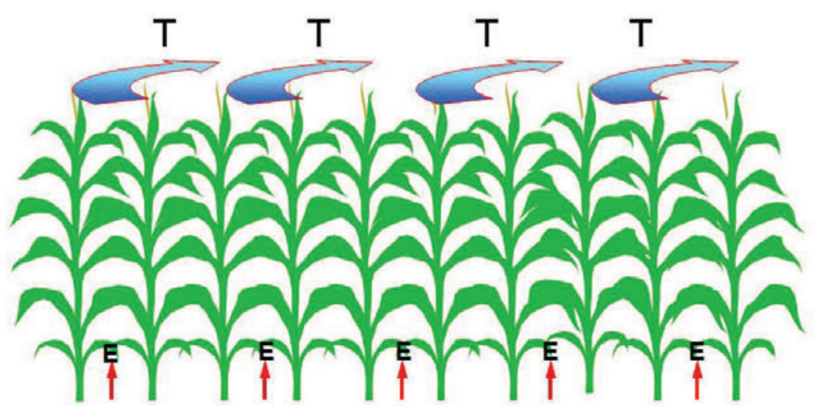


Figure I-3. **Relative magnitude of ET components in the middle of the growing season.**

Factors that affect ET

Since the primary reason for transpiration is to cool the plant, it is to be expected that climatic conditions are the driving forces behind the rate at which plants transpire. Air temperature and solar radiation are the two primary factors in the rate at which transpiration occurs. As air temperature and solar radiation increase, so does transpiration. ET will also increase with increased wind speeds to a point. When wind speeds get too high, the stomata close as a natural defense mechanism and transpiration actually decreases. Conversely, as relative humidity increases, transpiration will decrease.

Other factors that affect ET include plant species, canopy characteristics, plant population, degree of surface cover, plant growth stage, irrigation regime, tillage practices, planting date, maturity group of plant species, and soil water availability.

Crop characteristics influence water use

To demonstrate how crop characteristics influence water use, we include seasonal crop water use rate curves for corn and soybean (*Figure I-4*). At emergence most of the water use will be evaporation from the soil surface and overall ET will be less than 0.20 in/day. However, as the leaf area expands, the crop ET rate approaches 0.33 inches per day. Around beginning dent in corn or pod fill in soybean, plant leaves begin to lose their capacity to transpire at high rates; some leaves senesce and do not transpire water at all. Actual ET rates begin to fall off even though the corn and soybean crops are still at full cover. Overall, the difference in crop water use rates between corn and soybean depends of the relative maturity and planting date of the two crops.

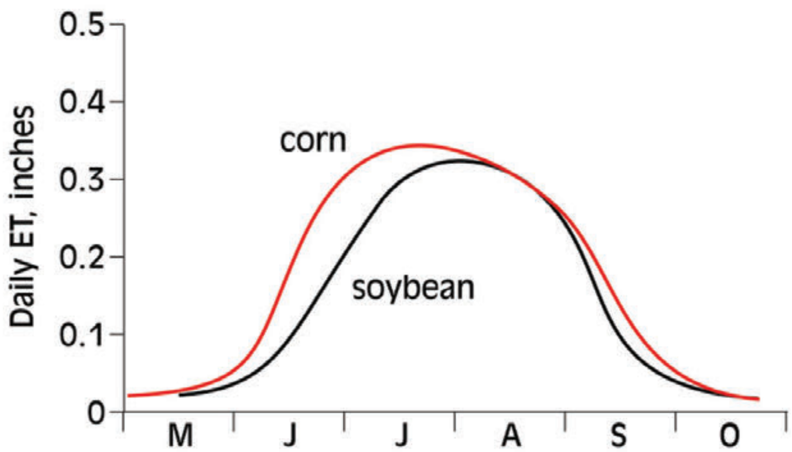


Figure I-4. **Long-term average crop water use rates for corn and soybean from emergence to maturity.**

Actual crop water use can be very different than the long-term average because of variability in the weather. This is shown in *Figure I-5*, where actual daily ET amounts across a particular growing season are compared with the long-term average for irrigated corn. In any year, long-term average values give only a rough approximation of actual crop water use and thus long-term averages do not provide an accurate estimate of the current year's crop water use rate. That's why irrigation scheduling is more accurate when using ET estimated from daily weather data rather than long-term average values.

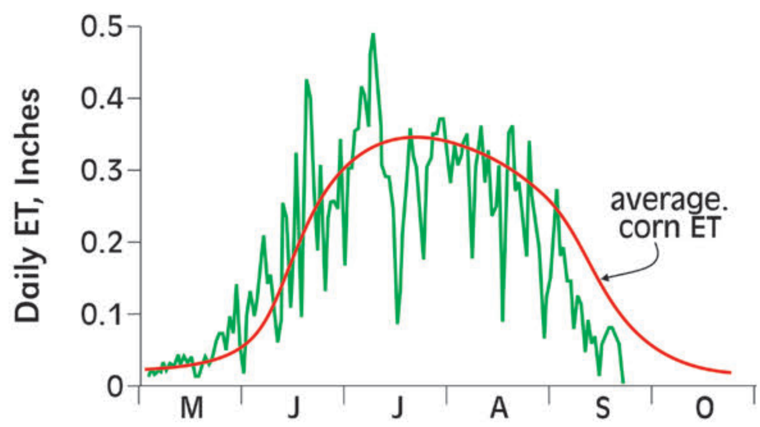


Figure I-5. Comparison of the long-term average ET rate for well-watered corn and the daily ET for a specific year.

Effect of residue

Leaving crop residue can have a significant effect on evaporation of water from the soil surface (*Figure I-6*). A University of Nebraska study found plots with residue removed would take 1.5-2.5 inches of irrigation to achieve the same yield as plots with over 80% residue cover on the soil surface. Also, at the end of the growing season, the plots with residue on the surface contained 1.5 inches more water in the top 4 feet of soil than did the bare plots. This means that the residue on the soil surface could save 3-4 inches of irrigation compared to bare soil.

Figure I-6. Crop residue cover following irrigated corn production.

Calculating ET

When irrigation is managed to meet crop water needs, the amount of water used by the crop over a given time is needed. However, water use by a crop in a specific field is difficult to estimate without collecting soil water content information. Another approach is to use a simple calculation of crop ET using estimated ET for a reference crop. Once we calculate or estimate ET for the reference crop, the ET for the any other crop can be determined using this simple equation:

$$ET_c = ET_r \times K_c$$

Reference crop ET is the water use based upon prevailing weather conditions. In Nebraska, the reference crop ET is based upon well irrigated alfalfa with at least 10 inches of growth and is estimated using the Penman-Monteith Equation

Crop Coefficient is a mathematical factor that converts reference crop ET to actual crop water use.

ET_c is the estimated crop water use, ET_r is the **reference crop water use** and K_c is the **crop coefficient**. The crop coefficient is a conversion factor that relates the ET of the reference crop to the crop of interest. The magnitude of the crop coefficient is not constant throughout the season. It changes depending on the growth stage and the relative maturity of the crop as well as some management practices.

The High Plains Regional Climate Center (HPRCC) monitors automatic recording weather stations (*Figure I-7*) throughout the region. Along with temperature and precipitation, these stations monitor solar radiation, relative humidity, and wind speed. These measurements allow HPRCC to make daily ET estimates for a reference crop at these locations. This information can be accessed online with a subscription fee at: *www.hprcc.unl.edu/*.

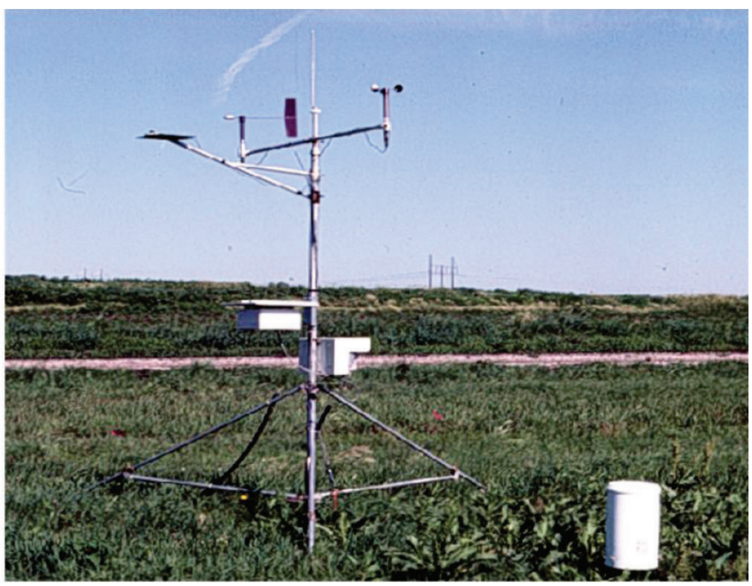


Figure I-7. Weather station used by the High Plains Climate Center to estimate crop water use.

A much more simple, but effective, method for measuring reference crop ET is with an atmometer (*Figure I-8*). Access information for Nebraska Extension publication dealing with installation and use of an atmometer is presented in the reference list for this section.

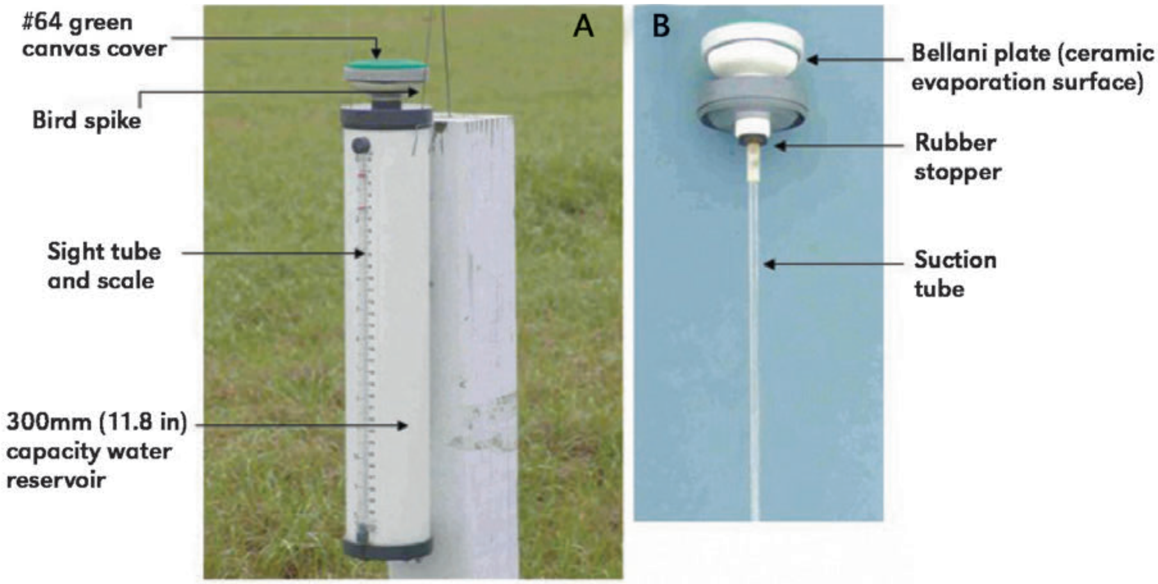


Figure I-8. ETgage used to estimate reference crop ET.

Once the math is completed to calculate the reference crop ET using the atmometer, a table of crop coefficients (K_c) is used to calculate the ET for any crop. Using the K_c found in *Table I-1*, we can use the ET_c equation. For example, if an ETgage is being used and the change in the water level in the sight gauge is 2.10 inches, and the crop is a field of soybean in the full-pod stage, the crop water use would be:

$$ET_c = 2.10 \text{ in. x } 1.10$$

$$ET_c = 2.31 \text{ inches}$$

This can be done with daily or weekly intervals, but three- to seven-day intervals provide more accurate results. *Table I-1* shows the K_c for corn, soybean, and wheat. The UNL CropWatch site has tables of calculated weekly ET_c if ET_r and the crop growth stage are known for a broader range of crops. It can be found at: *cropwatch.unl.edu/web/cropwatch/archive?articleID=1301988*.

Table I-1. Crop Coefficients for corn, soybean, and wheat used to convert reference crop ET_r to crop ET.

Stage	Corn	Kc	Soybean	Kc	Wheat	Kc
1	2 leaves	0.10	Emergence	0.10	Emergence	0.10
2	4 leaves	0.18	Cotyledon	0.10	Visible crown	0.50
3	6 leaves	0.35	First node	0.20	Leaf elongation	0.90
4	8 leaves	0.51	Second node	0.40	Jointing	1.04
5	10 leaves	0.69	Third node	0.60	Boot	1.10
6	12 leaves	0.88	Begin bloom	0.90	Heading	1.10
7	14 leaves	1.01	Full bloom	1.00	Flowering	1.10
8	16 leaves	1.10	Beginning pod	1.10	Grain fill	1.10
9	Silking	1.10	Full pod	1.10	Stiff dough	1.00
10	Blister	1.10	Beginning seed	1.10	Ripening	0.50
11	Dough	1.10	Full seed	1.10	Mature	0.10
12	Beginning dent	1.10	Begin maturity	0.90		
13	Full dent	0.98	Full maturity	0.20		
14	Black layer	0.60	Mature	0.10		
15	Full maturity	0.10				

Annual ranges in crop water use

Total ET during the growing season will vary from year to year, just as the climate varies. *Table I-2* shows a range of seasonal water use that will cover about 90% of the years in Nebraska. Extremely cool and wet or hot and dry years can produce values outside the range presented in *Table I-2*.

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

Crop	Eastern	Central	Western
	---------------- inches/year ----------------		
Corn	21-24	22-25	25-28
Soybean	20-22	21-23	22-24
Dry edible beans	—	—	15-16
Sorghum	18-20	19-22	20-23
Winter wheat	16-18	16-18	16-18
Alfalfa	31-35	33-37	35-39
Sugar beet	—	—	24-26

Effect of plant population and relative maturity on ET

Plant population can affect crop ET, however, under irrigated conditions the impact is minimal. For example, if a corn hybrid 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 plants/acre, with adequate water and fertility, one would expect considerable yield difference between the two populations. However, the manager should expect little difference in ET. Unless the leaf area does not reach three times the soil surface area, significant water savings should not be anticipated. To achieve significant water conservation, populations have to drop below 14,000 plants/acre and major water conservation comes only when populations are in the range of 8,000 to 10,000 plants/acre.

Relative maturity can impact crop water use even if planted at the same plant population. Shorter season hybrids produce fewer leaves and have shorter vegetative and reproductive stages in development. On average, corn water use changes by 1.0 inches per year for every five days of relative maturity. Grain production decreases in a similar manner.

Available soil water effects on ET rates

The amount of available water remaining in the crop root zone can affect the crop ET rate and total seasonal water use. Under average conditions a plant can use 40-50% of the available soil water without reducing the ET rate. As the plant begins to extract the last 50-60% of the available water, the actual ET rate declines in comparison to a nonstressed crop. The plant responds to water stress by taking steps to conserve what is left, including closing of stomata (pores) in the leaves to limit water vapor loss and rolling the leaves so they will intercept less sun. After irrigation the ET rate will return to normal unless the plant was severely stressed prior to the irrigation event.

More Extension Publications (available at ianrpubs.unl.edu)

G1994, Estimating Crop Evapotranspiration from Reference Evapotranspiration and Crop Coefficients

G1850, Irrigation Management for Corn

G1579, Using Modified Atmometers for Irrigation Management

G1367, Irrigating Soybean

G1778, Irrigation Management and Crop Characteristics of Alfalfa

G2000, Tillage and Crop Residue Affect Irrigation Requirements

EC731, Producing Irrigated Wheat

Section J

Irrigation management for water quality protection

Irrigation efficiency

In order to manage irrigation water, one must understand the basic concepts of irrigation system **water application efficiency**. No irrigation system is 100% 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. Note 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 available for plant use. The irrigation system application efficiency is a measure of the amount of water that is made available for crop use by an irrigation event. Irrigation system efficiency is defined as:

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

The major ways water is lost from an irrigated field are illustrated in *Figure J-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 and soil 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, 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 J-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 precipitation. 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 K.

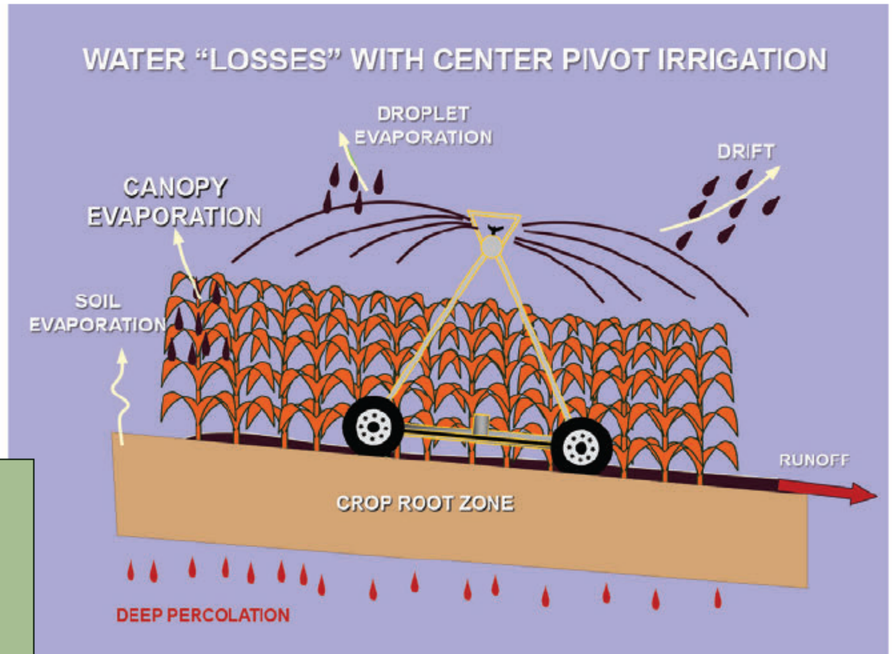


Figure J-1. Schematic drawing showing the major water losses that occur during a water application event using a center pivot irrigation system.

Water Application Efficiency is a measure of the fraction of the total volume of water that is pumped to the volume of water stored in the crop root zone and available for plant use.

Table J-1. Potential water application efficiencies of different types of irrigation water application systems (taken from EC732, Irrigation Efficiency and Uniformity and Crop Water Use Efficiency).

Irrigation System	"Potential" Application Efficiency (%)
Sprinkler Systems	
Low Energy Precision Application	80-95
Linear or Lateral Move	75-90
Center Pivot	75-92
Surface Irrigation Systems	
Conventional Furrow	45-70
Surge Flow	55-75
Furrow with tailwater reuse	60-80
Microirrigation Systems	
Bubbler (low head)	80-90
Microspray	85-90
Subsurface Drip	90-95
Surface Drip	85-95

Know how much water is applied

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 (*Figure J-2*). 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. Internet links to easy to use computer applications are available at: *water.unl.edu/cropswater/nawmdn*.

Without a water meter 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 (ac-in/hr) to make the calculation.

Typical flow-measuring devices on open ditch systems provide a flow rate measurement. For a well 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. It should be noted that flow rates may vary throughout the year and from year to year. When periodic water flow rate measurements are used to estimate total water applied during a period of time, an accurate record of irrigation time must be maintained by installing an hour meter on the power supply or irrigation system. The following example shows how the flow rate and irrigation time information is used to estimate total water pumped.

Figure J-2. Impeller flow meter commonly used to monitor the water flow rate in an irrigation pipeline.

Example: Use flow rate and time to estimate volume applied.

An ultrasonic meter indicates your pumping rate is 600 gpm (1.3 ac-in/hour). The hour meter shows you pumped for 84 hours.

The total volume pumped is 1.3 ac-in/hr x 84 hr = 109.2 ac-in.

It is highly beneficial to have a water-measuring device that provides the total volume of water delivered to the field. 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 provides the manager with the total volume of water pumped and an instantaneous flow rate. However, the most accurate estimate of the system flow rate is obtained by recording the time required for a set volume of water to be added to the accumulator box near the center of the meter dial.

Key relationships that you can use are:

453 gpm = 1 cfs = 1 acre-in/hr

1 acre-in = 27,154 gal

1 acre-ft = 325,851 gal

Since a volume of 1.0 acre-inch will cover a 1.0 acre land area with 1.0 inch of water, water from a 453 gpm pump will apply 1.0 inch of water to 1.0 acre in 1.0 hour. Similarly, a delivery of 1.0 cfs from a canal will apply 1.0 inch of water to a 1.0 acre land area in 1.0 hour. Using a measured flow rate determined by monitoring the flow meter, the average application depth may be calculated using the following equation:

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

Example: Determine the gross irrigation depth for one furrow irrigation set.

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

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

$$\text{Flow Rate} = \frac{\text{900 gpm}}{\text{453 gpm/ac-in/hr}} = \text{2.0 ac-in/hr}$$

The area irrigated is:

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

The gross depth of irrigation is:

$$\textit{Gross Irrigation Depth} = \frac{2.0\ ac - \dfrac{in}{hr} \times 12\ hr}{6\ ac} = 4\ inches$$

Example: Determine the gross irrigation depth for a center pivot?

A center pivot irrigates 128 acres and is supplied by a flow rate of 750 gpm. If the system makes a complete revolution in 75 hr, what is the gross depth of irrigation water applied?

$$\text{Flow rate} = \frac{750 \text{ gpm}}{453 \text{ gpm/acre-in/hr}} = 1.65 \text{ ac-in/hr}$$

$$\text{Gross Irrigation Depth} = \frac{1.65 \text{ acre-in/hr x 75 hr}}{128 \text{ acres}} = 0.97\ \textit{inches}$$

Irrigation management and scheduling

To manage soil water we must first measure it to verify that soil water content is within the allowable bounds, when the next water application should occur, and how much water the soil can hold without deep percolation. It's easy to see crop stress that results if irrigation is delayed too long. Unfortunately, the losses of water and nitrogen that result from irrigating too much are not nearly as visible. Therefore, field checks of soil water content and irrigation scheduling play an important role in maintaining crop yields while protecting ground and surface water.

Yield reduction and other field and environmental effects due to over irrigation can be substantial. Hence, careful scheduling of irrigation water applications help to:

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

A key input for making irrigation scheduling decisions is the amount of plant available water present in the soil. The plant available water remaining in the root zone, along with the expected ET, can be used to project the time remaining before the next irrigation begins. The crop's stage of growth must also be considered since, for most crops, water 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. As a "rule of thumb," *irrigations should be scheduled so that the plant available soil water content remains above 50% of the total available water-holding capacity.*

To develop a good estimate of the current soil water content, soil water sensors such as tensiometers, granular matrix sensors, or capacitance probes can be installed in each field and/or crop. Soil water also can be estimated by using a "checkbook" or "water balance method," which starts with a good estimate of current soil water content and then subtracts crop ET and adds an estimate for *effective precipitation* and *net irrigation water* application. This process is like balancing your checkbook (*Table J-2*). Spreadsheets for personal computers and irrigation scheduling software have made this process easier, but it still requires gathering some basic information from the field to ensure the accuracy of crop ET, effective precipitation, and net irrigation estimates.

Measuring soil water content and matric potential

Feel and appearance

The feel method uses a soil probe to take samples of soil from different depths in the crop root zone (*Figure J-3*). The soil sample is crumbled into small pieces and squeezed by hand to form a ball. The cohesiveness of the ball and whether it leaves an imprint in the palm of the hand after squeezing is an indication of the soil's wetness. The soil is then ribboned out between the thumb and the forefinger. The soil water content is estimated based on the appearance and strength of the soil ball (*Table J-3*). The USDA-NRCS developed a guide for the characteristics different soils exhibit at different moisture contents.

The feel method requires experience, self-calibration, and a great deal of judgment to provide good estimates of soil water content. Nevertheless, it is widely used by crop consultants. This method allows rapid moisture measurements at multiple locations in the field during field scout visits. The feel method is relatively inexpensive but continuous monitoring of field conditions requires significant labor at a time when producers are very busy. Thus, other methods of monitoring soil water content are encouraged for accurately scheduling irrigation events.

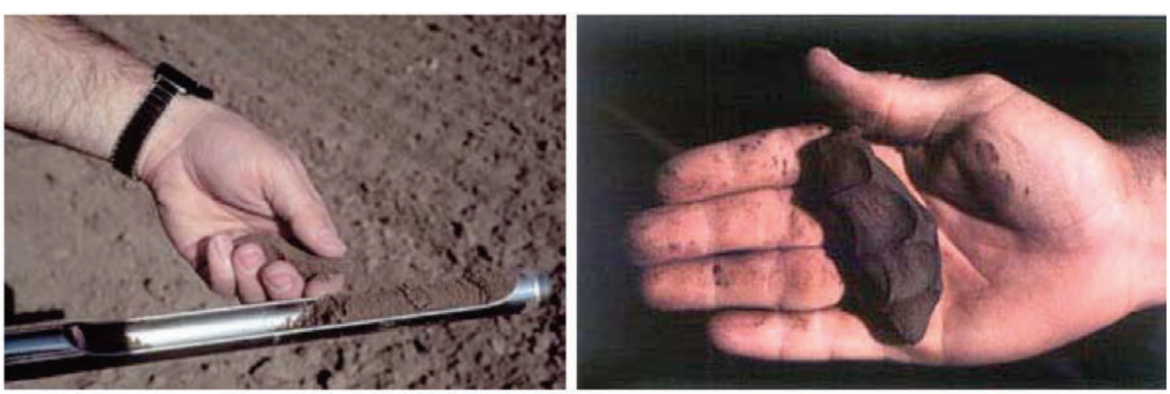


Figure J-3. Sampling and evaluation techniques for the feel method of soil water monitoring.

Table J-3. Feel and appearance for judging how much water is available for crops (taken from USDA, 1972).

Fraction of Available Soil Water Remaining	Loamy Sand or Sand	Sandy Loam	Loam and Silt Loam	Clay Loam or Silty Clay Loam
0 Wilting Point	Dry, loose, single grained, flows through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked, sometimes has loose crumbs on surface.
0.25	Appears to be dry, will not form a ball with pressure.	Appears to be dry, will not form a ball.	Somewhat crumbly but holds together from pressure.	Somewhat pliable, will ball under pressure.
0.50	Appears to be dry, will not form a ball with pressure.	Tends to ball under pressure but seldom holds together.	Forms a ball somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball, ribbons out between thumb and forefinger.
0.75	Tends to stick together slightly, sometimes forms a very weak ball under pressure.	Forms weak ball, breaks easily, will not slick.	Forms a ball, is very pliable, slicks readily, is relatively high in clay.	Easily ribbons out between fingers, has slick feeling.
At field capacity	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.

Sensing matric potential

Soil water content can be recorded by measuring the soil matric potential. There are two methods for measuring soil matric potential (*Figure J-4*). **Tensiometers** directly measure the soil matric potential. Tensiometers consist of a water-filled tube with a porous ceramic cup at one end and a reservoir and vacuum gauge at the other end (*Figure J-5*). It is installed with the ceramic cup at the desired depth below the soil surface. The cup must be in direct contact with the surrounding soil so that the water in the cup is hydraulically connected to the water in the soil. As the water content of the soil around the cup decreases, water flows through the porous cup. Since the other end of the tube is sealed, the water withdrawal creates a partial vacuum in the tube. Flow continues until there is equilibrium between the water in the tensiometer and the soil matric potential. The vacuum gauge is a direct indicator of soil matric potential. Usually the vacuum is registered in centibars and the scale reads from 0-100 centibars. As the tension or vacuum approaches 100 centibars, dissolved air in the water is released, breaking the partial vacuum. When this happens the readings are no longer reliable; thus, the practical operating range for this instrument is 0-75 centibars.

Figure J-4. Methods of measuring the soil matric potential.

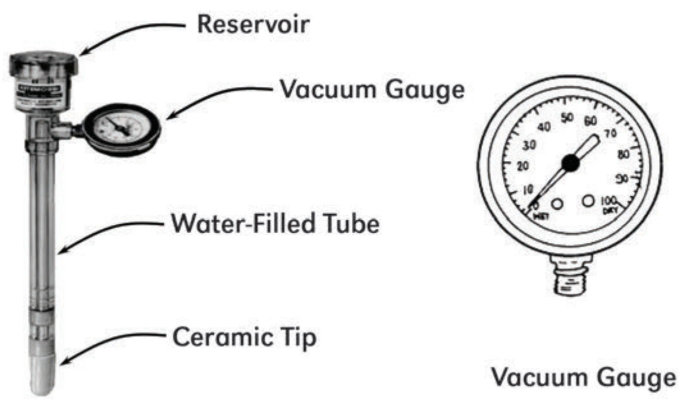


Figure J-5. Components of tensiometers used to measure soil matric potential.

Electrical resistance blocks indirectly measure the soil matric potential (*Figure J-4*). Electrical resistance blocks consist of a porous material, usually gypsum, with two embedded electrodes. The blocks are buried in the soil to the desired depth. As with tensiometers, good contact with the surrounding soil is essential. When the soil water equilibrates with the water in the block, an ohmmeter with an AC current source can be used to measure electrical resistance between the electrodes. There is a relationship between the resistance and the water content of the gypsum and therefore, the soil water potential and the resistance are related.

Electrical resistance in the soil is dependent on both soil water content and soil salinity. The gypsum buffers the effect of the salts on observed resistance in the soil. In saline soils, the effect of salts on the measured resistance cause inaccurate readings of matric potential. These sensors are inexpensive and easy to read. They work well in clayey soils but due to the particle size of gypsum, blocks are not sensitive in sandy soils.

Watermark Granular Matrix soil water sensors are another widely used version of a moisture block. Similar to gypsum blocks, these granular matrix sensors measure soil water potential indirectly through electrical resistance between two electrodes. However, Watermark Sensors use a matrix similar to fine sand with a porous ceramic external shell, surrounded with a synthetic membrane to protect against deterioration. This means that the matrix will dissolve slowly over time. The Watermark Sensors can be read by a handheld meter, or connected to a data logger (*Figure J-6*) for continuous measurement with remote access capabilities. The datalogger can set to record soil water content several times per day and the information can be downloaded to a computer using software provided by the company. Some private companies now offer the service of uploading watermark sensor readings to a Web page for easy access and viewing. *Figure J-7* presents a summary of soil water sensors recorded at a field site in 2007. Note that each sensor is displayed using a specific color so that it is easy to distinguish which depth the readings represent.

Figure J-6. Pictures of the Watermark soil water monitoring system including the sensor, hand-held readout, and automated data logger marketed by Irrometer.

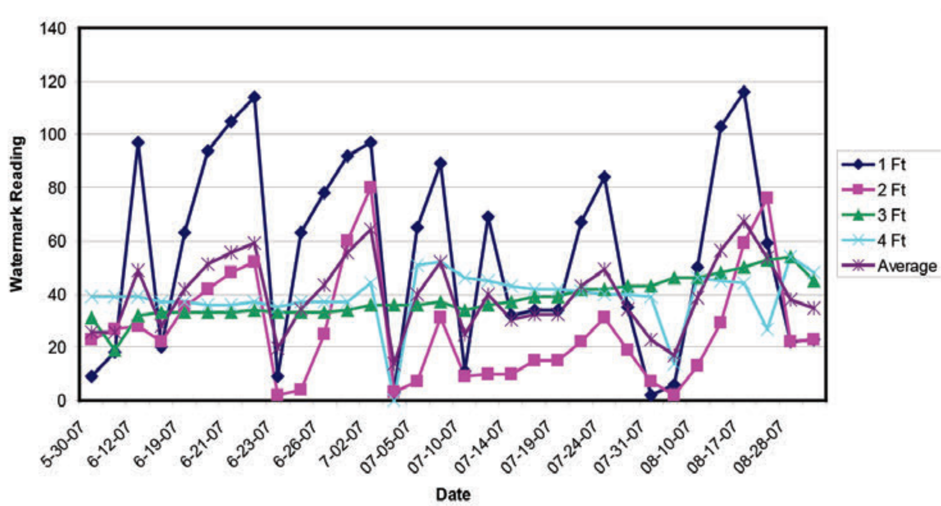


Figure J-7. Watermark record of one growing season.

Dielectric constant methods

Capacitance probes use the dielectric properties of the soil to determine the soil water content. The sensors pass a current through the soil between two electrodes. As the soil water content increases, so does the ability of the soil to transmit electrical current. *Figure J-8* shows examples of capacitance probes. Capacitance probes can be easily interfaced to a datalogger for continuous soil moisture monitoring and transfer to internet or wireless sites to allow producers to upload data without entering the field.

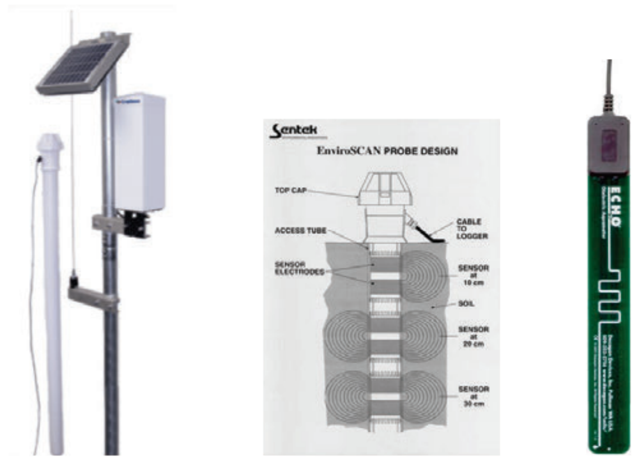


Figure J-8. **Examples of the AquaSpy, EnviroSCAN, and ECHO capacitance probes for soil water monitoring.**

Sensor placement

It is important to locate soil water monitoring equipment in locations that will give accurate and timely readings. This means that sensor locations must consider the variability in soils, the variability of water application, and the variability of plant populations within the irrigated area. The sensors should be placed under different spans of the pivot and in dominate soil textures. *Figure J-9* illustrates the concept of measuring the water content of the soil in the area of the field that has gone the longest since irrigation (start positions) and the area that was most recently irrigated (stop positions). A minimum of two depths, but preferably three or four depths are required to properly represent root zone moisture conditions.

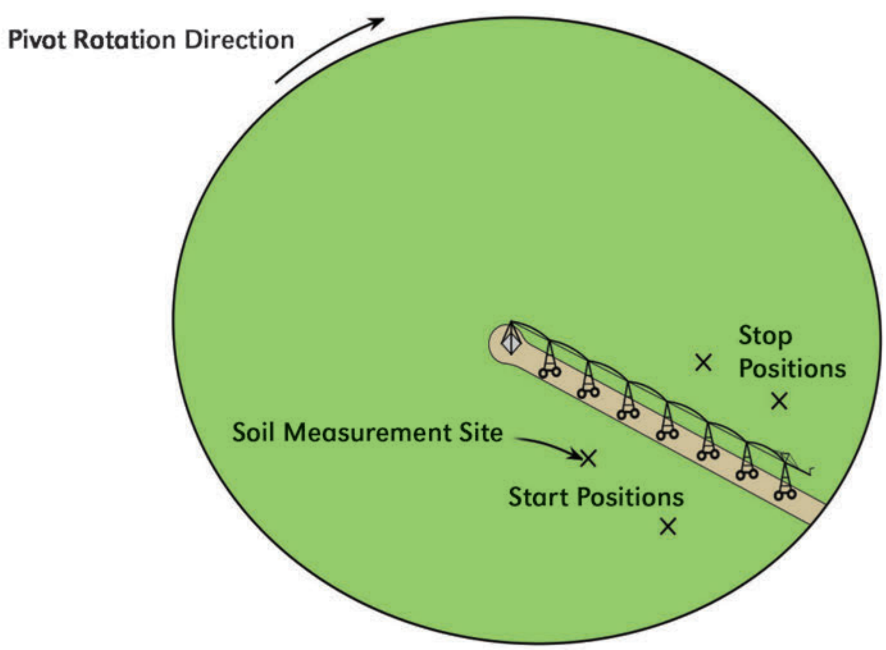


Figure J-9. **Sensor placement at starting and stopping positions in a center-pivot irrigated field.**

Web Soil Survey

A very useful tool for obtaining soil information needed for irrigation scheduling is the Web Soil Survey (WSS) (*Figure J-10*) from the Natural Resources Conservation Service (NRCS). Once WSS is launched by clicking on the Start WSS button, there are many options to locate the area to be studied, including the street address, the county, latitude and longitude, and the legal description (section, township, range). Once the area of interest (AOI) is selected the soil data is retrieved and available for viewing. The soils of a field located at the Agricultural Research and Development Center near Mead, Nebraska is illustrated in *Figure J-11*. First zoom into the field and select the area as your Area of Interest (AOI), (*Figure J-11*). Next, a soil map will be displayed when the Soil Map tab is clicked.

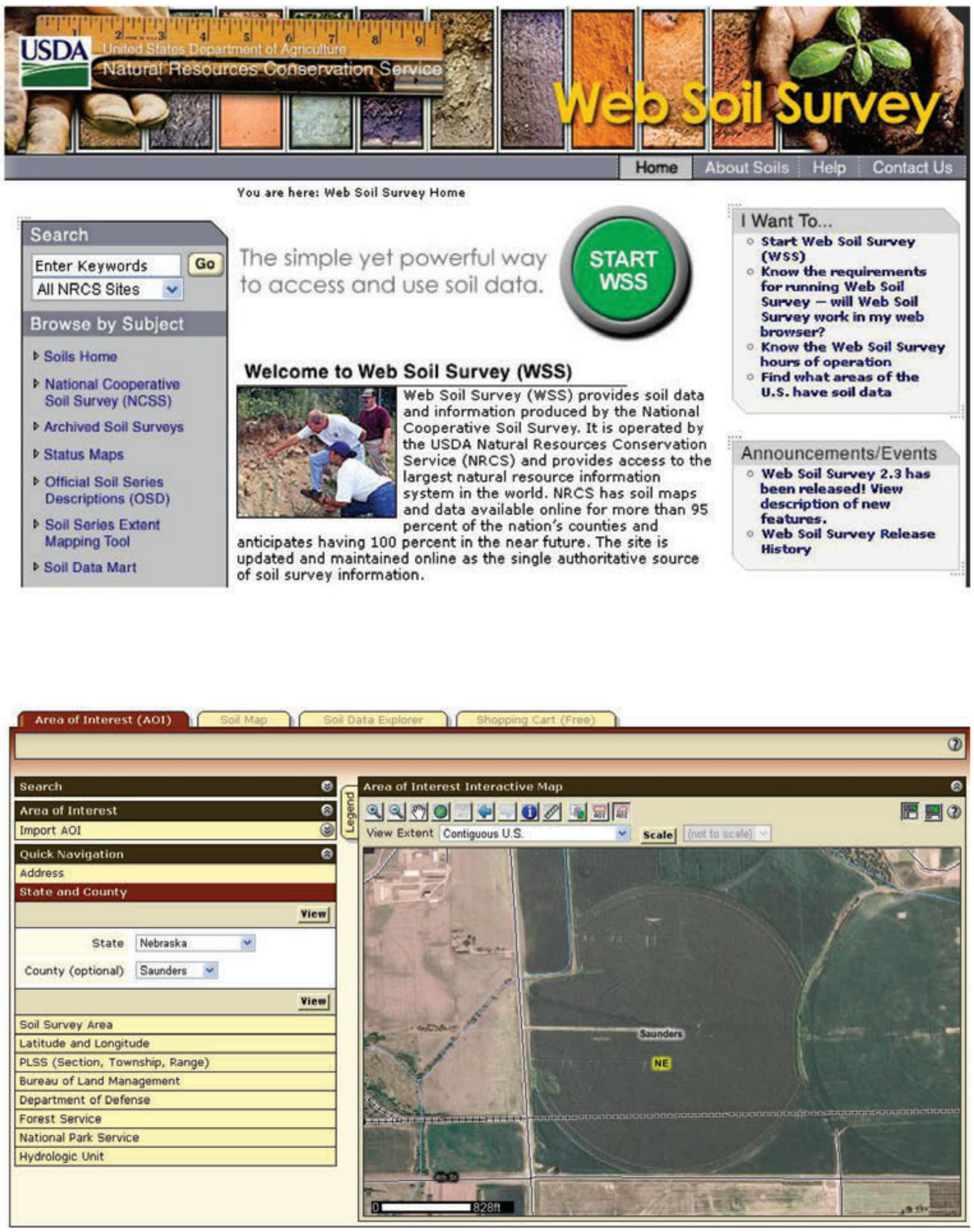


Figure J-10. Web Soil Survey webpage used to obtain soil mapping units, field slopes, and soil properties useful when scheduling irrigation events and for designing irrigation systems.

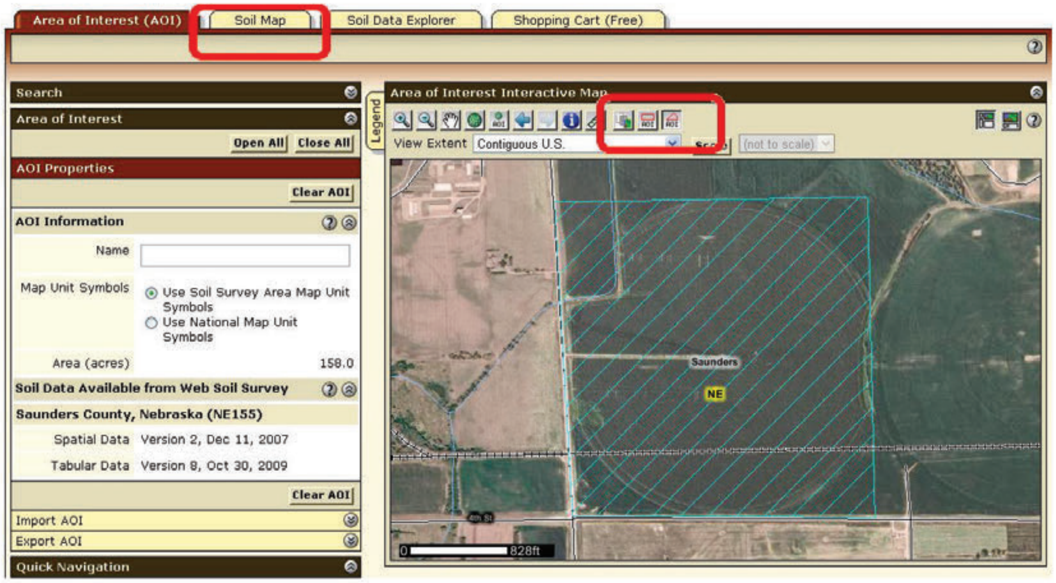


Figure J-11. **Use of Area of Interest (AOI) tool on the web soil survey to delineate field area under irrigation. Red rectangles show location of AOI and soil map icons and cross-hatched shows the AOI under consideration.**

Figure J-12 shows the soil map along with the map unit names and the areas of each map unit. Over half of this field is a Yutan silty clay loam. Another important soil is the Filbert silt loam, making up over 50 acres of this field. From the soil descriptions we can determine that the greatest slope will likely be 6%.

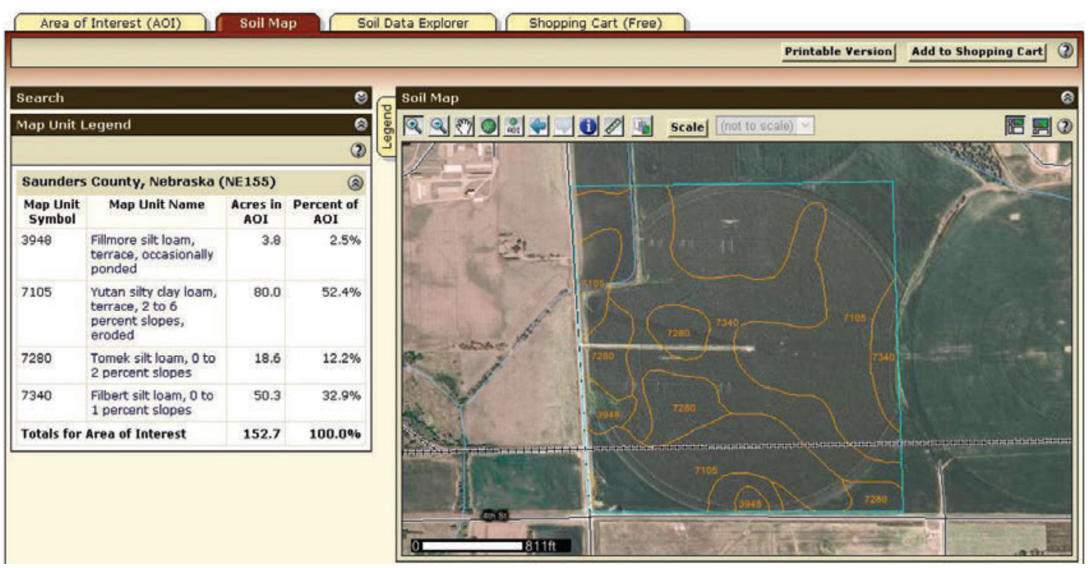


Figure J-12. **Web soil survey soils map of a field area under irrigation as delineated using the AOI tool. Yellow lines delineate different soil mapping units, and the left hand panel provides area and basic soils information for each mapping unit.**

Checkbook scheduling method

One way to schedule irrigation events is by using a "checkbook" or "water balance method." This starts with a good estimate of current soil water content, then subtracts crop ET and adds an estimate for effective rainfall and net irrigation water application. This process is like balancing your checkbook (*Table J-2*). Spreadsheets for personal computers and irrigation scheduling software have made this process easier. It still, however, requires gathering some basic information from the field to ensure the accuracy of crop ET, effective rainfall, and net irrigation estimates.

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% 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 rate will give the days remaining before the next irrigation. Start irrigation early enough so no portion of the field drops below the minimum allowable soil water balance. The calculated water balance should be periodically updated by measuring the current soil water content.

$$\text{Estimated Days Before Next Irrigation} = \frac{\text{Remaining Available Water}}{\text{Forecasted ET}}$$

Table J-2. Template for using the checkbook method of irrigation scheduling.

Basic "checkbook" soil water balance calculation		
Beginning soil water balance	___________	inches
Effective rainfall	+ ___________	inches
Net irrigation	+ ___________	inches
Crop water use	- ___________	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.

Example: Determine when irrigation should begin.

$$\text{Estimated Days} = \frac{1.0 \text{ inch}}{0.25 \text{ in/day}}$$

$$\text{Estimated Days} = 4 \text{ days}$$

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 precipitation that may occur immediately following an irrigation event.

The net irrigation amount is divided by the estimated irrigation system efficiency to obtain the gross irrigation amount required. The following examples illustrate the effect of irrigation system efficiency on the gross irrigation amount. If storage space is available in the root zone for 1.5 in. of water, and you don't reserve some storage for precipitation, the net irrigation amount will be 1.5 inches. Gross irrigation amounts for different situations are shown in *Table J-3*.

Table J-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[1], 1 inches	1.7	2.0	2.5	3.3

[1]Gross Irrigation Depth = $\frac{\text{Net Irrigation Depth}}{\text{Irrigation System Efficiency}}$

Scheduling the last irrigation

Applying a late irrigation, if not needed, 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 $5 to $15 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% of the available water remains in the crop root zone without causing yield reduction. Subtracting the remaining available 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 J-4*. Since probabilities for significant precipitation are low during the later part of the growing season, precipitation is not usually considered in the last irrigation decision. Center pivot irrigators have more flexibility to consider precipitation since they can apply an inch of water in a three- to four-day period.

Table J-4. Average water requirements for corn, grain sorghum, soybean, and dry beans for various stages of growth and maturity in Nebraska.

	Stage of growth	Approximate days to maturity	Water use to maturity (inches)
Corn			
R4	Dough	34	7.5
R4.7	Beginning dent	24	5.0
R5	1/4 milk line	19	3.75
	1/2 milk line — Full dent	13	2.25
	3/4 milk line	7	1.0
R6	Physiological maturity	0	0.0
Grain Sorghum			
Stage 6	Half bloom	34	9.0
Stage 7	Soft dough	23	5.0
Stage 8	Hard dough	12	2.0
Stage 9	Physiological maturity	0	0.0
Soybean			
R4	End of pod elongation	37	9.0
R5	Begin seed enlargement	29	6.5
R6	End of seed enlargement	18	3.5
R6.5	Leaves begin to yellow	10	1.9
R7	Beginning maturity	0	0.0
Dry beans			
R5	Early seed fill	35	7.0
R6	Mid-seed fill	25	4.2
R7	Beginning maturity	15	2.0
R8	Harvest maturity	0	0

Smart phone applications

With advances in electronics and their applications to irrigation operations, smart phone applications or apps can also be used to determine in-season irrigation schedules as well as the last irrigation event of the season. The CropWater App, which is a product of soil water content and crop water use applications, can provide reasonable estimates of the last irrigation for corn and soybean based on soil water content and predicted crop water use information. The Crop Water App, developed for iPhone and iPad, provides an easy way to estimate soil water status based on Watermark soil matric potential sensors installed at soil depths of 1, 2, and 3 feet. With these sensor readings, the app will estimate the crop water used, as well as the available soil water remaining in the profile for typical Nebraska soils. The user can also see historic sensor readings and graph the data as the season progresses. For Apple smart phones, the CropWater App can be downloaded at *https:// itunes.apple.com/us/app/crop-water/id557926049?mt=8* or for Android smart phones go to: *https://play.google.com/store/apps/details?id=edu.unl.cropwater*.

More Extension Publications (available at ianrpubs.unl.edu)

EC732, Irrigation Efficiency and Uniformity and Crop Water Use Efficiency

G1850, Irrigation Management for Corn

G1579, Using Modified Atmometers for Irrigation Management

G1367, Irrigating Soybean

G1778, Irrigation Management and Crop Characteristics of Alfalfa

G2000, Tillage and Crop Residue Affect Irrigation Requirements

EC731, Producing Irrigated Wheat

G1328, Water Loss from Above-Canopy and In-Canopy Sprinklers

G1871, Predicting the Last Irrigation of the Season

EC709, Irrigation Scheduling: Checkbook Method

For More Information

Gardner, W.H. 1986. Water Content. In: A. Klute (ed). Methods of Soil Analysis, Part I, Physical and Mineralogical Methods, Second Edition. Agronomy Number 9, American Society of Agronomy, Madison, WI. pp. 493-544; and Ley, T.W. 1994. An In-Depth Look at Soil Water Monitoring and Measurement Tools. Irrigation Journal, 44(8):8-20.

Section K

Managing furrow irrigation

The goal of every surface 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.

Figure K-1. Typical gated pipe furrow irrigation system.

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 (*Figure K-2a*). Shorter, more suitable advance times yield a more uniform infiltration profile along the length of the furrow (*Figure K-2b*).

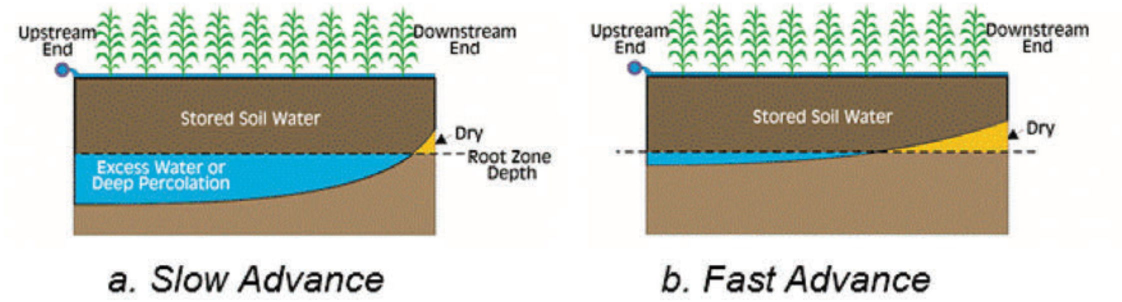


Figure K-2. Soil water infiltration pattern for furrow irrigated fields with slow (a) and fast advance (b) times.

Advance Time is the number of hours needed for water to travel from the delivery point to the lower end of a field.

Set Time is the number of hours water is delivered to the head end of the field.

Stream Size is the water flow rate distributed from each individual gate or siphon tube into an irrigation furrow and is calculated by dividing the water delivery rate (gpm) by the number of gates open.

Set Size is the number of gates or syphon tubes that are actively distributing water to furrows.

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 size (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 K-la*. To apply water uniformly and efficiently, surface irrigators must be willing to change both stream size and set time so that water advances down the field rapidly so the depth infiltrated is more uniform from one end of the field to the other (*Figure K-1b*).

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, and therefore, the nitrate leaching that 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.

Reuse System consists of a reuse pit or sump to collect runoff volume and a pump to distribute the runoff water to another portion of an irrigated field.

Systems with reuse system

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% 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.

Three-quarter-plus rule is a furrow irrigation management criterion to improve water application efficiency by setting the stream size so that water advances to the end of the furrow in three-fourths of the overall set time.

Systems without reuse system

When no runoff reuse system is available, systems should be managed to minimize runoff losses at the lower end of the field. 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 (*Figure K-3,* top). 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 (*Figure K-3* bottom).

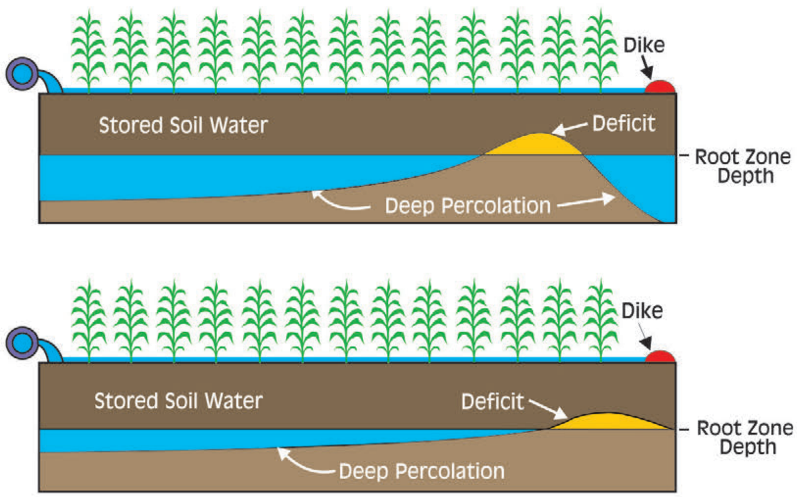


Figure K-3. Infiltration profiles under conventional furrow irrigation with blocked-end furrows (top) and three-quarter-plus advance rule (bottom).

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 two or three, 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%. 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 K-4* 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 precipitation after an irrigation event.

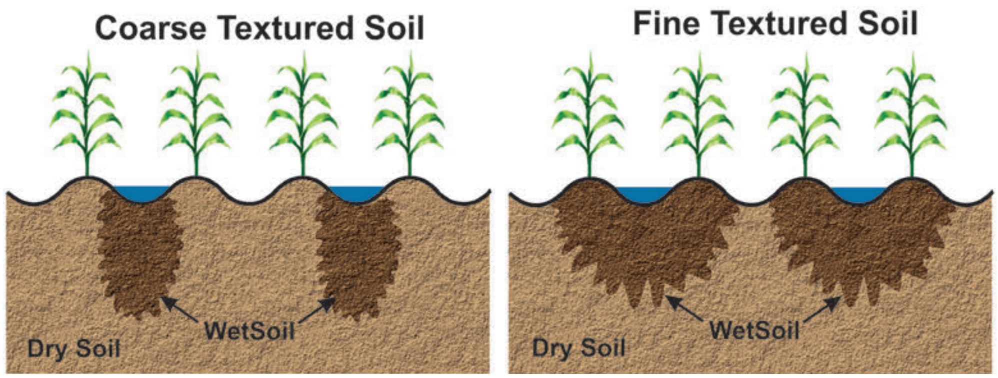


Figure K-4. Every-other irrigated furrow infiltration patterns on coarse and fine textured soils.

Surge irrigation

Surge irrigation (*Figures K-5* and *K-6*) **is the practice of applying water to two set of furrows intermittently in a series of on-off periods, called cycles.** This sequence is repeated several times until the irrigation is completed. The length of time water is applied to a set of gates (the cycle time) is increased automatically by the surge valve. After water has advanced to the end of the field and the advance phase is complete, cycle times are decreased and the "soak phase" (or cutback) begins. Research has documented average reductions in advance time of 30% when using surge valves compared to conventional continuous flow furrow irrigation, especially during the first irrigation event.

Figure K-5. Typical surge valve installation in the Platte Valley of Nebraska.

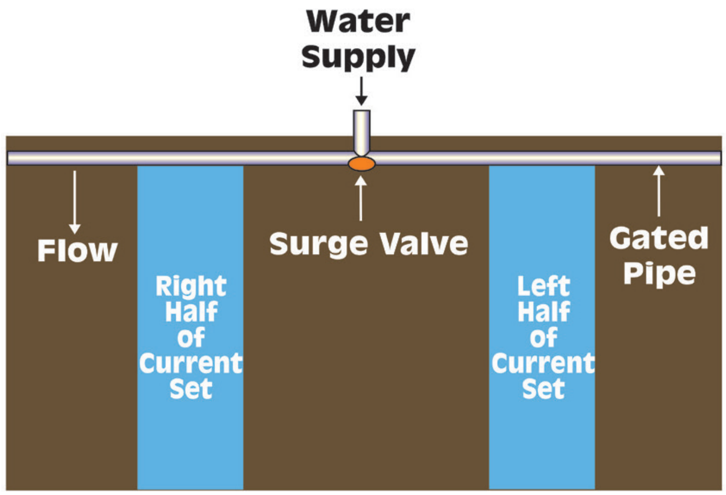


Figure K-6. Typical surge irrigation field layout.

Remember that in Section C we discussed how as the length of infiltration time increased soil infiltration rate decreased. The wetting and drying cycles take advantage of the same reduction in water infiltration rate. Because less water infiltrates 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, the reduction in infiltration decreases the amount of deep percolation that will occur at the top end of the field when compared to conventional irrigation practices (*Figure K-7*).

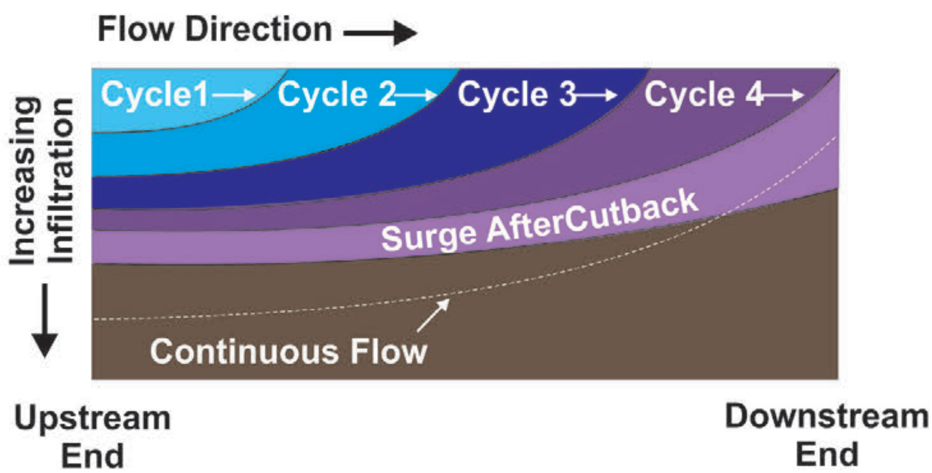


Figure K-7. Comparison of infiltration profiles for surge and continuous flow furrow irrigation systems.

Leaky gates and gaskets

Gated pipe irrigation systems with worn and/or broken gates and gaskets often leak 10 to 30% of the water pumped through them. In Nebraska, some extreme cases of water loss have been observed, where 40 to 60% 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 irrigation events. 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 1,000 gpm well loses 20% (200 gpm) through leaky gates and gaskets. If a furrow stream size of 20 gpm is needed and all 1,000 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% 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 or 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.

The land grading process typically requires moving large amounts of soil from one location to another in the field. The equipment used for this process is heavy and even though laser equipment tends to reduce the number of trips across the field, soil compaction is difficult to prevent. Thus, while the land grading process eliminates many factors that reduce water application uniformity, grading creates different levels of compaction, and could expose subsoil that will force the field manager to adjust irrigation management.

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% more than in the hard furrow (*Figure K-8*).

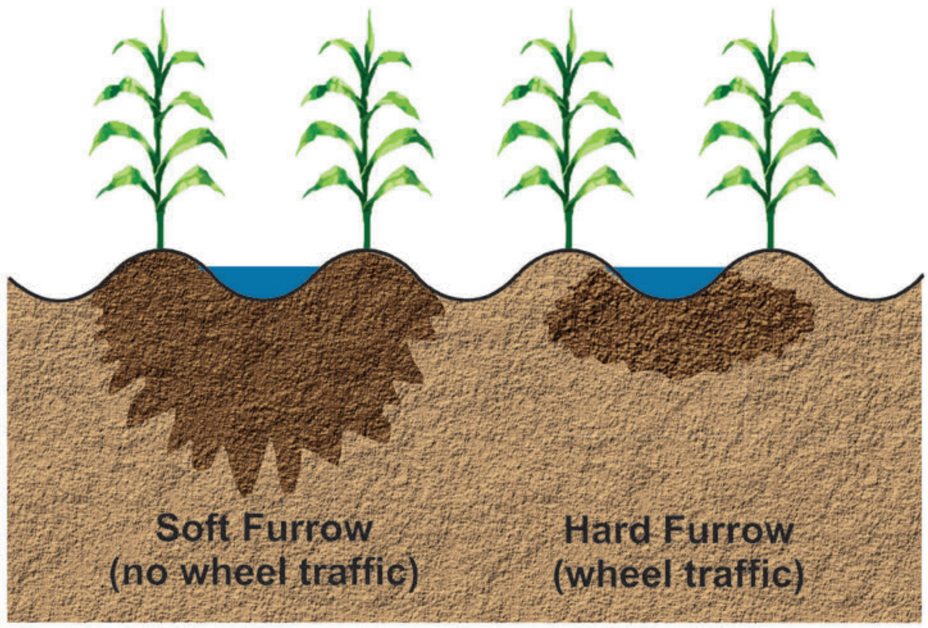


Figure K-8. Differences in water infiltration patterns under non-wheel track and wheel track furrows.

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 event to the next. Watering only soft rows may be one option to avoid the hard row problem. However, this is not an option where dual wheeled equipment is used or where grain carts have compacted rows during harvest. 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% 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.

More Extension Publications (available at ianrpubs.unl.edu)

G1720, Firming Irrigation Furrows to Improve Irrigation Performance

G1870, Fundamentals of Surge Irrigation

G1338, Managing Furrow Irrigation Systems

G1721, Management Recommendations for Blocked-end Furrow Irrigation

G1868, Surge Irrigation Management

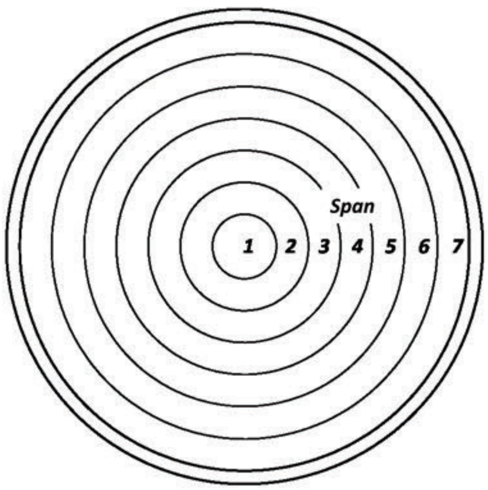
G1869, Surge Irrigation Field Layouts

G1866, Using Polyacrylamide to Reduce Soil Erosion

Section L

Managing sprinkler irrigation systems

The circular irrigation pattern of the center pivot results is illustrated in *Figure L-1*. The system is a typical seven to eight span pivot with span widths of 155-180 ft and a 50-ft overhang at the end of the pivot lateral. The pivot in *Figure L-1* irrigates 124 acres when there is no end gun. Since the spans at the outside end of the system travel much farther per revolution of the pivot, the outer spans irrigate greater areas than spans of the same length that are located at the center of the field. Consequently, sprinklers on the outer spans must discharge a greater volume of water than sprinklers located near the pivot point.



Span	Span end, ft	Area within the span, acres	Discharge from span gpm
1	180	2	14
2	360	7	42
3	549	12	71
4	720	16	99
5	900	21	127
6	1080	26	156
7	1269	39	184
O. Hang	1310	9	56
Total		124	750

Figure L-1. Characteristics of a typical center pivot. (Note that 45% of the land area is under the outer two spans while only about 7% of the land is under the first two spans.)

Proper operation of a pivot requires installation of the correct type of sprinkler and nozzle at the proper location along the pivot pipeline. The key to proper design and installation is to determine:

- The discharge needed for each sprinkler along the lateral.
- The pressure available at each sprinkler.
- The required size of nozzle needed in each successive sprinkler to meet the discharge requirement.

System capacity

The diagrams in *Figure L-2* illustrate the system capacity. **The system capacity (C_g) is the ratio of the flow into the pivot divided by the land irrigated.** System capacity relates to the ability of an irrigation system to meet crop water needs during periods of limited precipitation and high crop water use rates. Large-system capacities provide flexibility to meet high water use rates and allow for periods when the irrigation system is shutoff for repair, maintenance, and electrical load control. Large-system capacities also contribute to higher water application rates and potentially runoff. Thus, the system capacity should be large enough to meet crop water use rates most of the time, while not being so large that they contribute to runoff problems.

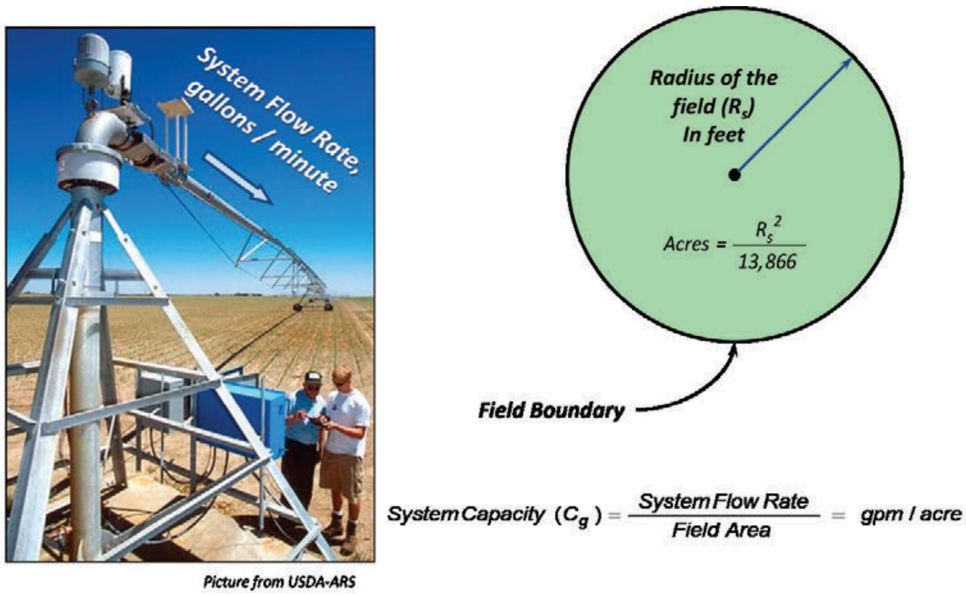


Figure L-2. Definition of system capacity for a field irrigated by a center pivot.

The recommended minimum system capacity depends on the potential for annual rainfall (*Figure L-3*) and the soil texture in the field (*Table L-1*). Typically, evapotranspiration (ET) is greater and the potential for precipitation is lower in the western region of the state than the eastern region. This means that system capacity must be greater to meet crop water requirement in the west. For example, *Table L-1* shows that the minimum net capacity on a silt loam soil in Region 2 should be 4.6 gpm/ac, while the system located in the Region 1 should only be 3.85 gpm/ac, with no down time.

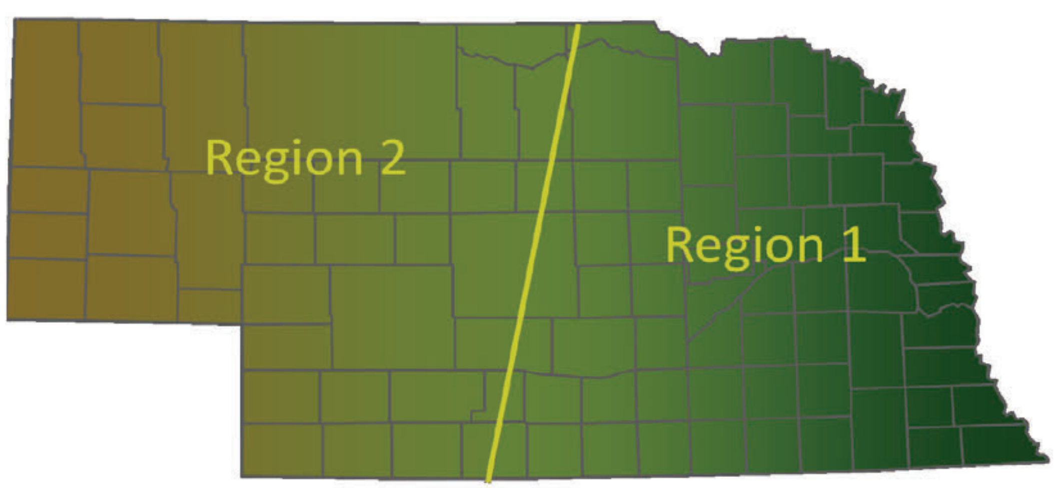


Figure L-3. Regions in Nebraska for minimum system capacity estimation.

Soil texture affects the amount of water that the soil can provide to crops during periods of high ET demand. The system capacity must be greater when less water is stored in the soil to buffer against water use during periods of high crop demand. Since sandy soil holds less water, greater system capacity is needed than for silt loam textured soil. For example, in western Nebraska the recommended minimum net capacity of 5.89 gpm/acre for sandy soil in western Nebraska compared to 4.62 gpm/acre for a silt loam soil.

The system capacity needed to match the peak ET from a crop is also listed in *Table L-1*. Peak ET is the greatest daily rate of water use that is expected by a crop over a series of three to five days. If a system has the capacity to meet this peak ET it will be able to meet the crop water needs throughout the growing season.

The values in *Table L-1* represent the net system capacity that does not account for inefficiencies or downtime for a system. The multiplier listed in *Table L-2* adjusts for the water application efficiency and the number of hours that a system does not operate during the week. For example, the net system capacity for a center pivot located on silt loam soil in eastern Nebraska is 3.85 gpm/acre. The gross or total system capacity for a system with 85% water application efficiency and 12 hours of downtime per week should be increased to 4.9 gpm/acre (1.27 × 3.85) equivalent to about 640 gpm for a traditional 130-acre field.

Table L-1. **Minimum recommended net system capacities for soil classifications and regions of Nebraska.**

	Net Capacity 9 of 10 years[1], gallons/minute/acre	
Soil Texture	**Region 1**	**Region 2**
Peak ET	**5.65**	**6.60**
Loam, Silt Loam, and		
Very Fine Sandy Loam with Silt Loam Subsoil	3.85	4.62
Sandy Clay Loam, Loam, Silt Loam, and		
Very Fine Sandy Loam with Silty Clay Subsoil	4.13	4.89
Silty Clay Loam, Clay Loam, and Fine Sandy Loam	4.24	5.07
Silty Clay	4.36	5.13
Clay and Sandy Loam	4.48	5.19
Fine Sands	4.95	5.89
Loamy Sand	4.83	5.42

[1]Flow rate per acre supplied to a field after accounting for the water application efficiency of the center pivot. The tabular values would be sufficient to meet crop water needs 9 years out of 10 or 90% of the time.

Table L-2. Multiplier for system capacity based on application efficiency and downtime.

Application Efficiency, percent	Downtime, hours/week					
	8	12	16	24	36	48
80	1.31	1.35	1.38	1.46	1.59	1.75
85	1.24	1.27	1.30	1.37	1.50	1.65
90	1.17	1.20	1.23	1.30	1.41	1.56
95	1.11	1.13	1.16	1.23	1.34	1.47

Uniformity of application

The wetted diameter of the sprinkler package is very important to the selection of sprinklers and management of a center pivot. The wetted diameter is the distance that sprinklers throw water perpendicular to the pivot lateral (*Figure L-4*). For example, wetted diameter of a Spinner low pressure spray sprinkler is 54 ft if positioned 6 ft. from the soil surface (*Figure L-4*). The wetted diameter depends on the design of the sprinkler device, the nozzle size and the pressure at the nozzle. The wetted diameter also depends on the height of the sprinkler above the surface of application when the droplets still maintain a horizontal velocity (*Figure L-7*).

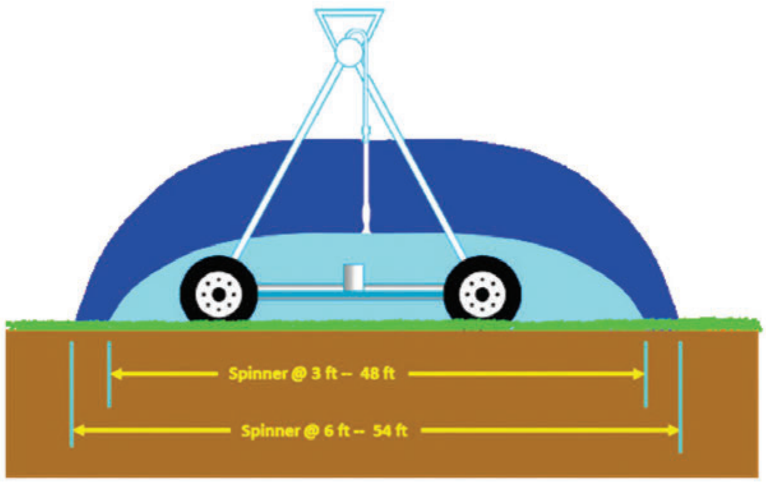


Figure L-4. Examples of the wetted diameter for Spinner devices from the Nelson Irrigation Corporation.

The efficiency of center pivots relies on maintaining high water application uniformity. The uniformity depends on the spacing of the sprinkler devices along the lateral relative to the wetted diameter of the device. Adequate sprinkler spacing provides equal opportunity to water for all crop rows. Devices placed into the canopy require a sprinkler spacing much narrower than sprinklers mounted above the canopy. However, to reduce investment costs, field managers sometimes place sprinklers too far apart and the water application uniformity declines and often the yield decreases.

The example in *Figure L-5* illustrates what can happen if the spacing is too wide. In this case, the sprinkler spacing was 17.5 feet (equal to the width of seven crop rows). The yield for rows close to the sprinkler devices was about 220 bushels of corn per acre while the yield halfway between sprinklers was only 180 bushels/acre. The yield reduction for the field averaged about 15 bushels/acre which equals about 2,000 bushels for a traditional 130-acre pivot.

Center pivots that are used for chemigation can exacerbate the yield impact and potentially lead to water quality issues. The variation in yield depicted in *Figure L-5* clearly indicates that water was not reaching the rows midway between the sprinklers. If liquid nitrogen is applied with the water, lack of nitrogen also could have been a factor in the yield reduction.

Figure L-5 also indicates that excess water was being applied to one to two rows either side of each sprinkler. If liquid nitrogen was being applied, the combination of extra water and nitrogen application creates a scenario where the potential for nitrate leaching is much greater than if the N were applied via a ground rig.

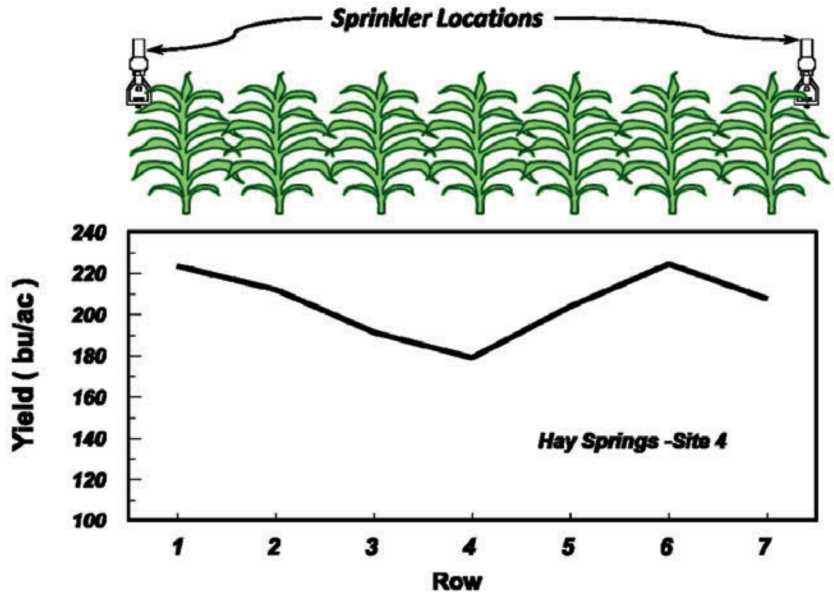


Figure L-5. Variation of yield for wide spacing of sprinklers perpendicular to rows of corn.

Runoff problems

Runoff of irrigation water occurs when the center pivot applies water at a rate that exceeds the ability of the soil to infiltrate the water. Water applied at rates that exceed the infiltration rate will initially accumulate in depressions on the soil surface. If the water applied exceeds what the soil can infiltrate or store on the surface then water will begin to flow across the field (run off) as illustrated in *Figure L-6*. The sketch on the bottom-left portion of *Figure L-6* shows that less storage is possible on steep slopes, hence the potential for runoff is greater on steeply sloped fields.

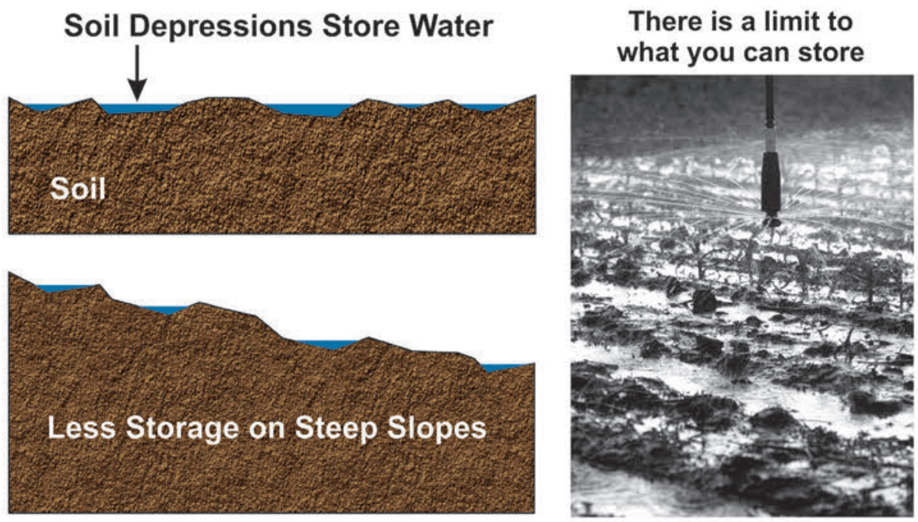


Figure L-6. Illustration of surface storage that provides detention of water application to enhance time for infiltration.

The peak application rate shown in *Figure L-7* is determined by the sprinkler package design. The duration of the irrigation controls the depth of water applied. Note that the application of 2.4 inches of water leads to a large runoff potential. As the application duration decreases, the peak application is not affected but the application depth decreases and the runoff potential drops to nearly zero when the application drops to 0.8 inches.

Control of the depth of application is about the only option available to reduce runoff during the irrigation season. Inspection of the water application at the outer end of the pivot on the steepest portion of the field can be used to determine if runoff is an issue in the field. If runoff occurs, the irrigator should consider speeding up the pivot to apply less water and reduce runoff. Long-term the best solution is to increase the wetted diameter of the sprinkler system.

Surface runoff can impact water quality and crop production in the field and offsite. Often surface runoff occurs in the field that does not leave the field boundary. This runoff finds its way to low lying areas where it infiltrates. Because it is extra water, the potential for nitrate leaching increases in these low lying areas. Runoff that leaves the field can degrade surface water streams and lakes. Thus, proper selection of sprinkler packages is critical to preventing negative water quality impacts.

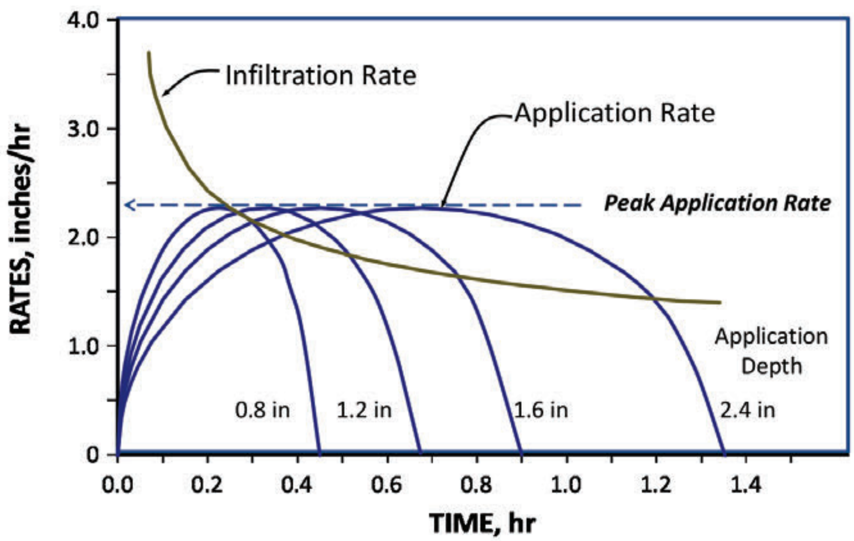


Figure L-7. Effect of water application depth per irrigation on runoff potential.

More Extension Publications (available at ianrpubs.unl.edu)

G1328, Water Loss from Above-Canopy and In-Canopy Sprinklers

G1712, Application Uniformity of ln-Canopy Sprinklers

G1124, Converting Center Pivot Sprinkler Packages: System Considerations

G1851, Minimum System Design Capacities for Nebraska

G888, Flow Control Devices for Center Pivot Irrigation Systems

G1532, Operating Characteristics of Center Pivot Sprinklers

For More Information

von Bernuth, R.D., D.L. Martin, J.R. Gilley and D.G. Watts. 1984. Irrigation System Capacities for Corn Production in Nebraska. Transactions of ASAE 27(2): 419-424, 428.

Section M

Irrigation water management for subsurface drip

Subsurface drip system

Subsurface drip irrigation (SDI) refers to an irrigation system where the water delivery occurs below the soil surface and directly to the root zone of the growing crop. Water is delivered using a series of polyethylene tubing installed at depths between 12 and 16 inches below the soil surface. The installation process includes use of a tractor equipped with an auto-steer system and a drip tape installation implement (*Figure M-1A*). When the crop is planted in 30-inch rows, the drip lines are typically installed on 60-inch spacings to provide each crop row with equal access to water (*Figure M-1B*).

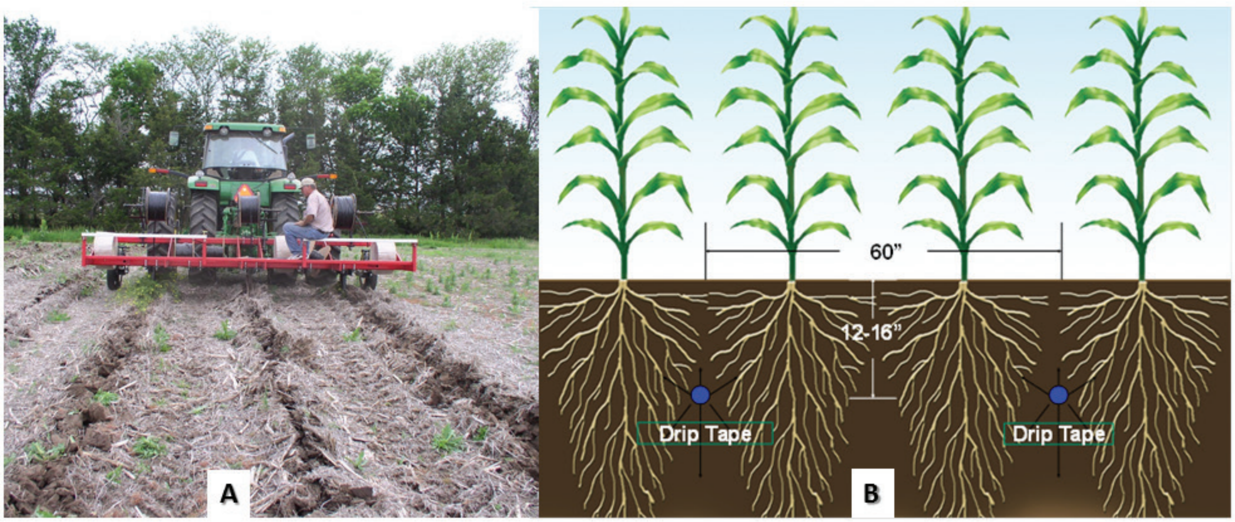


Figure M-1. Diagram showing a cross-section of a cornfield with SDI drip tape installed to provide equal access to water by each corn row.

> **Emitter or dripper** is a device used to control the discharge of water from a dripline or drip tape to plants either above or below ground level.

SDI drip tape is equipped with **emitters** spaced in equal increments along the line. Typical installations have emitters spaced at 18- or 24-inch increments. The emitters consist of a very small opening in the drip tape that allows water to exit the tape after flowing through a zig-zag like apparatus (*Figure M-2*). The combination of the spacing between drip tapes (tape spacing), the area being irrigated, the flow rate per emitter, and the spacing between emitters allows the flow rate to be calculated prior to selecting a pump.

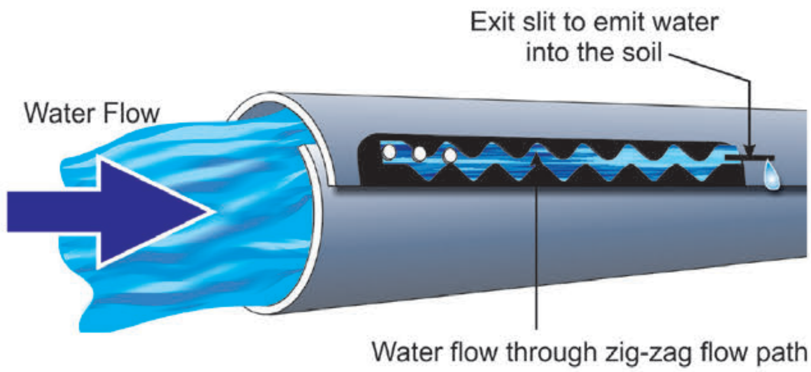


Figure M-2. Schematic drawing of a subsurface drip emitter.

SDI irrigation systems include several components that are not typically installed on other irrigation systems. *Figure M-3* shows a schematic of a field installation identifying the key components. Because SDI water application occurs below ground, it is difficult to evaluate whether water is being delivered equally by each emitter. For management purposes, the installation calls for an accurate water meter and pressure gauges positioned to provide the manager with information needed to make sure the system is operating properly.

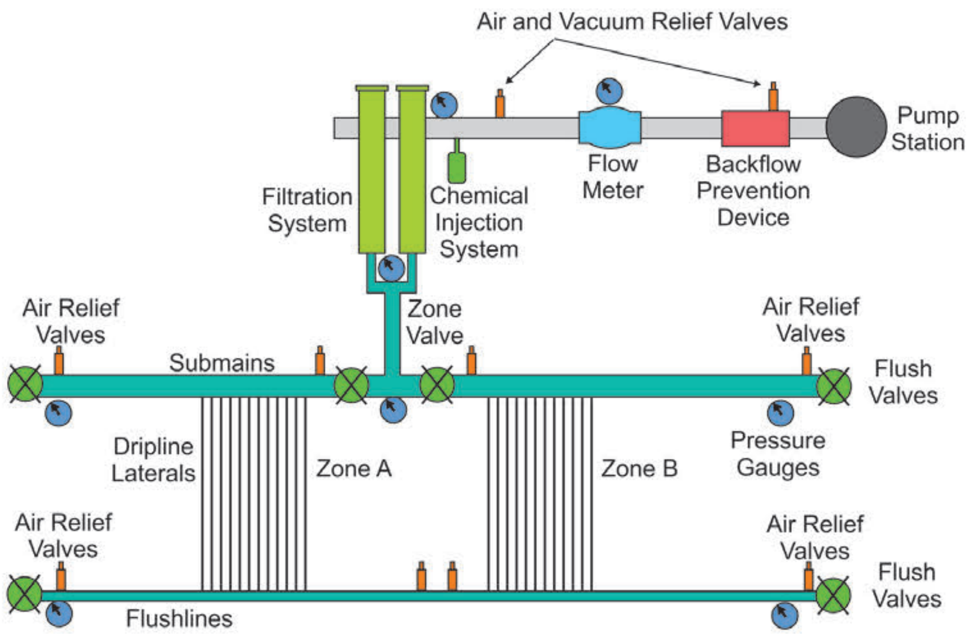


Figure M-3. Installation components recommended for an SDI system (modeled after image by Kansas State University).

Since water is delivered through small emitter openings, the emitter can become clogged with organic matter or soil particles that are contained in the water supply. To prevent clogging the installation includes a very fine filtering system (*Figure M-4*). Inclusion of the filtering system allows most any water supply (wells, canals, ponds) to be used without major issues with emitter clogging. The pressure gauges will give an indication of when the water application characteristics of the system change that requires maintenance.

It is common for various solid materials to get into the SDI drip tapes. Changes in water chemistry, rodent damage and repair procedures, and the installation process can result in unwanted solids in the drip tape. Thus at the end of each zone or combination of zones, flush valves (*Figure M-4*) are installed to allow these solids to be moved out of the drip lines. Good practices include flushing water through the drip lines at least twice per growing season (beginning and end of the season).

It is legal to apply fertilizers with irrigation water delivered using a SDI system. However, most pesticides are not labeled for application via a subsurface drip irrigation system and the Nebraska Department of Environmental Quality requires an underground injection well permit before the SDI system can be installed. In some cases where the water table is close to the soil surface, the permit may not be issued due to the near direct contact with groundwater. Once installed, similar chemigation rules apply to SDI systems as for other irrigation water delivery methods.

Figure M-4. Typical filtration system (left) and flush valve installations for SDI systems (right).

Water application efficiency

One of the major advantages of SDI is that the drip tape is installed below ground level sufficiently far that the soil surface is not wetted during each irrigation event. This conserves the water that would typically evaporate directly from the soil surface using sprinkler or furrow irrigation systems. A related benefit of the drip tape position is that only a portion of the soil is wetted, which leaves areas of drier soil to store water received as precipitation. This allows the manager to account for the precipitation and helps minimize the potential for deep percolation that often occurs with furrow irrigation systems and to a lesser extent with sprinkler application systems.

The final factor is that SDI system management is based on the ability to apply small application depths and thus SDI systems offer the potential to apply water at very high water application efficiency levels. Research indicates that water application efficiencies of over 95% are possible with good management and maintenance practices. However, like all other systems, poor irrigation management practices can reduce the water application efficiency dramatically.

Small application depths are critical to the success of SDI management because the systems rely on capillary forces to move the water horizontally from the location of the emitter. However, capillary forces are not as strong as gravity which tends to move the water vertically into the soil. Thus, small application depths keep deep percolation in check. Minimizing deep percolation loss is an absolute necessity if fertilizer is applied with irrigation water via chemigation.

Researchers in Kansas and Nebraska have reported that due to the high management potential and position of the water application system relative to the soil surface irrigation water applications can be reduced by 20-25% with SDI. On average, this allows approximately 7 inches of water to be conserved when compared to a well operated furrow irrigation system.

Finally, there is some evidence that SDI systems can produce additional grain with small, frequent irrigation water applications. This is particularly true when overall water supplies are limited to less than full irrigation management. Applying water to replace the previous day's crop water use is one management scheme that appears to have some merit.

Disadvantages

SDI is not without difficulties. For example, one of the largest issues is the control of rodent damage to the drip tape (*Figure M-5*). Small field mice, 13-lined ground squirrels, and gophers all seem to find the drip tapes and begin chewing. If field conditions are right, the leak will eventually force water to the surface where the manager can isolate the location and fix the leak. Large field areas make it difficult to isolate exactly where some of the more minor leaks are. Installation of relatively small irrigation zones will help the manager isolate the leak while large areas make it more difficult. Pressure gauges and the flow meter should be used to identify when leaks develop. If the pressure decreases and the flow rate increases, a leak needs to be fixed.

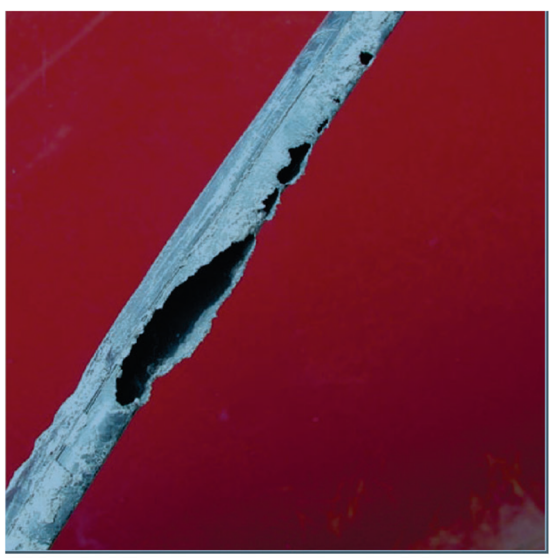


Figure M-5. Holes in SDI drip tape from rodent damage.

Small emitters can become clogged due to water quality issues even if a good filtration system is used. The flow meter and pressure gauges allow the manager to identify when the emitters are being clogged by calcium, magnesium, or iron that makes its way past the filter. Application of fertilizers can cause the water chemistry to change enough so that these salts will tend to precipitate out and clog the emitters. If the flow rate gradually decreases and the pressure rises, the manager will know that some emitters in the zone are becoming clogged by some solid or organic material. In extremely dry springs seed germination can be an issue in some portions of Nebraska.

If the crop is planted into dry soil, sprinkler irrigators could apply a small amount of water to complete the germination process. With the drip tape positioned 14-16 inches below soil surface, it may require extremely large water application depths to ensure seed germination. Thus, in the western Nebraska, it may be advisable to install the drip tape at no more than 14 inches deep. In extremely dry areas, one option is to have a backup irrigation system to apply water needed for germination.

If water is applied at a rate greater than the infiltration rate of the soil a saturated zone can develop forcing water to the soil surface. In this case it is sometimes difficult to tell whether the wet soil is due to a leak or to the "chimney" effect. Once water begins to chimney in a specific area, it is more difficult to get water to move laterally from the emitter or to eliminate the chimney. In severe cases, surface soil erosion can result in rills down to the emitter depth.

One final potential disadvantage of subsurface drip irrigation is taht the water application occurs below ground level. Despite the potential for high irrigation efficiencies, poor managment can lead to deep percolation loss and nitrate leaching. *Figure M-6* depicts a water patttern from a SDI drip tape. If excessive depths of irrigation are applied, the position of teh tape 12-16 inches below the soil surface can transport nitrate from the rootzone. Thus it is critical that irrigation water management is practiced with SDI systems.

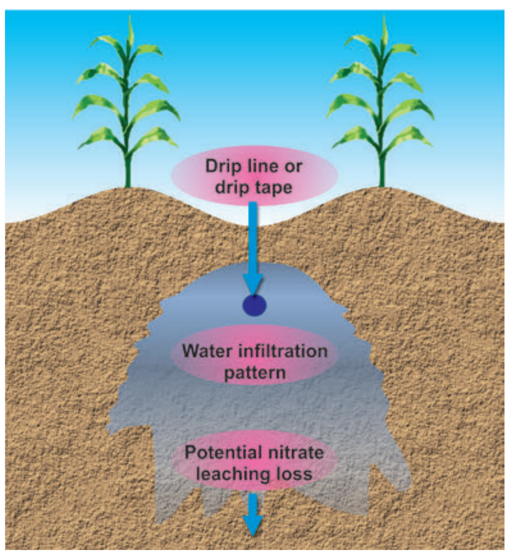


Figure M-6. Water application pattern for a subsurface drip irrigation system depicting nitrate leaching loss due to over irrigation.

More Extension Publications (available at ianrpubs.unl.edu)

EC776, Advantages and Disadvantages of Subsurface Drip Irrigation

More Extension Publications (available at *ianrpubs.unl.edu*)

EC117, Fertilizer suggestions for corn

EC154, Soil sampling for precision agriculture

EC155, Nutrient management for agronomic crops in Nebraska

EC163, Site-specific nitrogen management for irrigated corn

EC168, N rate calculator for corn

EC709, Irrigation Scheduling: Checkbook Method

EC731, Producing Irrigated Wheat

EC732, Irrigation Efficiency and Uniformity and Crop Water Use Efficiency

EC776, Advantages and Disadvantages of Subsurface Drip Irrigation

EC91-735, The impact of nitrogen and irrigation management and vadose zone conditions on groundwater contamination by nitrate-nitrogen (archived publication)

G1124, Converting Center Pivot Sprinkler Packages: System Considerations

G1328, Water Loss from Above-Canopy and In-Canopy Sprinklers

G1335, Determining Crop Available Nutrients from Manure

G1338, Managing Furrow Irrigation Systems

G1367, Irrigating Soybean

G1450, Manure Testing for Nutrient Content.

G1519, Calculating the Value of Manure for Crop Production

G1532, Operating Characteristics of Center Pivot Sprinklers

G1563, Manure Incorporation and Crop Residue Cover - Part I: Reducation of Cover

G1564, Manure Incorporation and Crop Residue Cover - Part II: Fine-Tuning the System

G1579, Using Modified Atmometers for Irrigation Management

G1632, Using a chlorophyll meter to improve N management

G1712, Application Uniformity of ln-Canopy Sprinklers

G1720, Firming Irrigation Furrows to Improve Irrigation Performance

G1721, Management Recommendations for Blocked-end Furrow Irrigation

G1740, Guidelines for soil sampling

G1778, Irrigation Management and Crop Characteristics of Alfalfa

G1850, Irrigation Management for Corn

G1851, Minimum System Design Capacities for Nebraska

G1866, Using Polyacrylamide to Reduce Soil Erosion

G1868, Surge Irrigation Management

G1869, Surge Irrigation Field Layouts

G1870, Fundamentals of Surge Irrigation

G1871, Predicting the Last Irrigation of the Season

G1939, Sewage Sludge Utilization for Crop Production

G1994, Estimating Crop Evapotranspiration from Reference Evapotranspiration and Crop Coefficients

G2000, Tillage and Crop Residue Affect Irrigation Requirements

G888, Flow Control Devices for Center Pivot Irrigation Systems

G91-1043, Water runoff control practices for sprinkler irrigation systems (archived publication)

RP189, Agricultural nitrogen management for water quality protection in the midwest

RP195, Targeting of Watershed Management Practices for Water Quality Protection

For More Information

Gardner, W.H. 1986. Water Content. In: A. Klute (ed). Methods of Soil Analysis, Part I, Physical and Mineralogical Methods, Second Edition. Agronomy Number 9, American Society of Agronomy, Madison, WI. pp. 493-544; and Ley, T.W. 1994. An In-Depth Look at Soil Water Monitoring and Measurement Tools. Irrigation Journal, 44(8):8-20.

Grassini, P., H.S. Yang, and K.G. Cassman. 2009. Limits to maize productivity in the Western Corn-Belt: A simulation analysis for fully irrigated and rainfed conditions. Agricultural and Forest Meteorology 149:1254-1265.

Grassini, P., H.S. Yang, S. Irmak, J. Thorburn, C. Burr, and K.G. Cassman. 2011. High-yield irrigated maize in the Western U.S. Corn Belt: II. Irrigation management and crop water productivity. Field Crops Research 120:133-144.

Grassini, P., J. Specht, T. Tollenaar, I. Ciampitti, and K.G. Cassman. 2014. High-yield maize-soybean cropping systems in the U.S. Corn Belt. In: Crop Physiology- Applications for genetic improvement and agronomy (2nd edition), Sadras VO, Calderini DF (Eds). Elsevier, The Netherlands.

Hergert, G.W., R. Ferguson, C. Wortmann, C. Shapiro, and T. Shaver. 2011. Enhanced efficiency fertilizers: Will they enhance my fertilizer efficiency? In: 2011 Crop Production Clinics Proceedings. Pg. 145-148.

manure.unl.edu

Nebraska Department of Environmental Quality. 2014. 2014 Nebraska groundwater quality monitoring report. Prepared Pursuant to Nebraska Rev. Stat. §46-1304.

Setiyono, T.D., D.T. Walters, K.G. Cassman, C. Witt, and A. Dobermann. 2010. Estimating maize nutrient uptake requirements. Field Crops Research 118:158-168.

Spalding, R. F., D. G. Watts, J.S. Schepers, M. E. Burbach, and M. E. Exner. 2001. Controlling nitrate leaching in irrigated agriculture. Journal of Environmental Quality 30: 1184-1194.

USDA-NRCS. 1999. KS652.0204 State supplement-soils. Chapter 2 in USDA-NRCS National Engineering Handbook- Part 652. *http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_031591.pdf*

von Bernuth, R.D., D.L. Martin, J.R. Gilley and D.G. Watts. 1984. Irrigation System Capacities for Corn Production in Nebraska. Transactions of ASAE 27(2): 419-424, 428.