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G1850

# Irrigation Management for Corn

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This NebGuide discusses corn irrigation management strategy options and objectives.

There are more than 16 million acres in harvested row crop production in Nebraska. About 8 million of these acres are irrigated. Corn occupies approximately 70 percent of the irrigated acreage, or 5.6 million acres. Consequently, improving irrigation management can have significant impact on the quantity and quality of Nebraska's most precious resource: water.

### Soil — Plant — Water Relationships

Understanding the relationships between plants and their environment is essential to effective irrigation management. Plant characteristics important to irrigation management include total seasonal water use, daily crop water use, rate of plant development, and rooting depth. Important soil characteristics include water holding capacity, water intake rate, and the presence of any restrictive soil layers that might inhibit root penetration and/or water movement. Quantity and quality of the available water supply also must be considered. The objective of irrigation management is to provide supplemental water needed by the plant while maximizing the value of water.

### Corn Water Use Characteristics

Evapotranspiration ($ET_c$), or crop water use, is the water removed from the soil by evaporation from the soil surface and transpiration by the plant. For corn, evaporation can account for 20 percent to 30 percent of growing season $ET_c$. Transpiration is the last step in a continuous water pathway from the soil, into the plant roots, through the plant stems and out through leaf surfaces and into the atmosphere. Approximately 70 percent to 80 percent of crop water use results from plant transpiration. The amount of daily corn water use varies with atmospheric conditions: air temperature, humidity, solar radiation and wind speed. High air temperatures, low humidity, clear skies and high wind speed will result in high $ET_c$ demand. High humidity, clear skies and low wind speed will result in lower $ET_c$ demand.

Atmospheric demand must be adjusted for the stage of crop development to estimate crop water use on a daily basis. A high atmospheric demand day in early May will result in little $ET_c$ because the corn plant is small with a limited root zone and little leaf area to transpire water. The same atmospheric demand day in mid-July will result in near peak crop water use because the corn roots are fully developed and the plant leaf area is sufficient to transpire water at rates equal to the atmospheric demand. This adjustment is referred to as applying a crop coefficient to the atmospheric demand or potential evapotranspiration.

Seasonal water use is affected by climatic conditions, relative maturity range, soil fertility, water availability and the interaction of these factors. Although the total amount of water used by corn will vary from season to season and location to location, it will generally follow the pattern dictated by seasonal trends in weather variables and corn development. The smooth curve in *Figure 1 (Curve A)* illustrates the long-term average water use pattern for corn. This average water use pattern shows typical daily $ET_c$ levels throughout the growing season based upon the average daily $ET_c$ over a 10 plus year period. The jagged curve in *Figure 1 (Curve B)* illustrates the fluctuation possible in daily $ET_c$ values for an individual year. Thus, irrigation managers must be familiar with the long-term trend but more importantly be able to determine what the daily $ET_c$ was over the last few days. Knowledge of the long-term trend and actual daily crop water use rates are critical to determining when to irrigate and how much water to apply.

In Nebraska, total corn water use ranges from 28 inches per year in the southwest to 24 inches in the east. Water requirement depends both on the previously mentioned atmospheric conditions and corn variety. The relative maturity range of a particular variety has the most impact on seasonal $ET_c$. For example, at the same location and in the same year, a corn hybrid with a 113-day maturity will use more water than a 100-day hybrid. Longer-season corn hybrids use more water, but they also have the potential to produce more grain if the heat units and water supply are available. If both varieties are able to mature fully, the grain produced for each inch of $ET_c$ is approximately equal. The difference in seasonal water use is due to total days of water use, and in some cases a difference in daily water use.

Due to variation in weather conditions in a given year and from year to year, the long-term average crop water use per day (Curve A) could vary by plus or inus 0.03 inches per day. Day-to-day variation within a given year (Curve B) can be more than 0.20 inches per day. Thus, for reasons described above, use of soil water sensors and accessing daily crop water use estimates based on the weather conditions during the current growing season are highly recommended. In addition, the duration of each growth stage could vary by plus or minus two days when compared to the long-term average values provided in *Table I*.

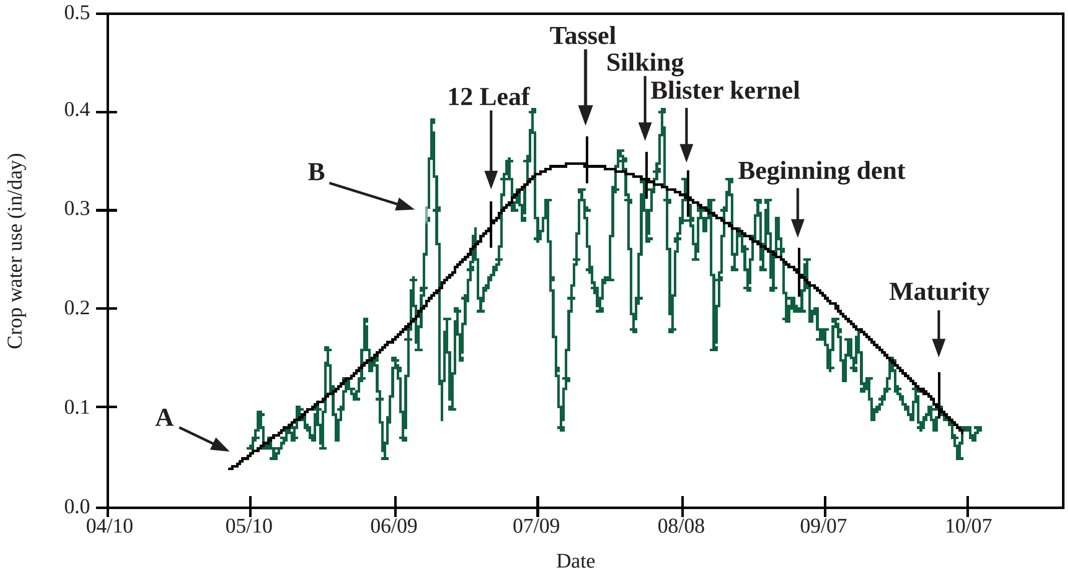


**Figure 1. Long-term daily average and individual year corn water use with select growth stages.**

4-3-2-1 rule: 40 percent of the water comes from the top 1/4 of the root zone, 30 percent comes from the second 1/4 and so on. The 4-3-2-1 rule is illustrated in *Figure 2*. Water applied using subsurface drip irrigation systems will result in more water removal from the depth where the drip lines are placed. In addition, though corn roots can reach depths of 5 to 6 feet, until late in the season conservative irrigation management assumes a 3-foot effective root zone. Later, when predicting the timing and amount of the last irrigation, the effective root zone is expanded to 4 feet.

**Table I. Average crop water use ($ET_c$) by growth stage for 113-day maturity corn grown in South Central Nebraska.**

| *Growth stage* | *Average water use rate (in/day)* | *Duration[1] (days)* | *Water needed to reach stage (inches)* | *Water needed cumulative (inches)* |
|---|---|---|---|---|
| Emergence (VE) | 0.08 | 0-10 | 0.8 | 0.8 |
| 4-leaf (V4) | 0.10 | 11-29 | 1.8 | 2.6 |
| 8-leaf (V8) | 0.18 | 30-46 | 2.9 | 5.5 |
| 12-leaf (V12) | 0.26 | 47-55 | 1.8 | 7.3 |
| Early tassel (R1) | 0.32 | 56-68 | 3.8 | 11.1 |
| Silking (R2) | 0.32 | 69-81 | 3.8 | 14.9 |
| Blister Kernel (R3) | 0.32 | 82-88 | 1.9 | 16.8 |
| Beginning Dent (R4.7) | 0.24 | 89-104 | 3.8 | 20.7 |
| Full Dent (R5.5) | 0.20 | 105-125 | 3.8 | 24.5 |
| Maturity (R6) | 0.10 | 126-140 | 1.4 | 25.9 |

[1] Long-term average number of days since planting required to progress from the previous growth stage to the next. For example, to go from the blister kernel stage to the beginning dent stage requires approximately 15 days (day 89 to day104). Days to each growth stage were determined using the Hybrid-Maize Corn Growth Model for the period 1982-2005 at Clay Center, Neb.

Corn does not extract water uniformly throughout its rooting depth. Generally, more water is extracted from shallow depths and less from deeper depths. If water is applied to the soil surface, the typical extraction pattern follows the

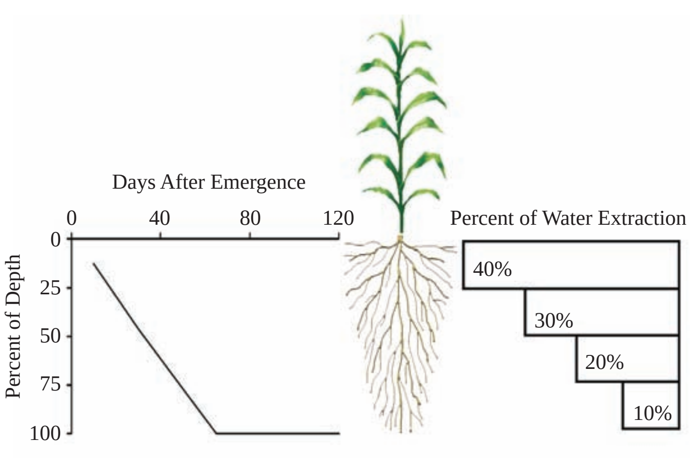


**Figure 2. Root zone soil water extraction and plant root development patterns.**

## Matching Crop Demands with Water Application

In general, irrigation water is meant to supplement water stored in the soil profile and any effective rainfall recorded during the growing season. Thus, a water balance approach for estimating the irrigation requirement would be: Effective rainfall + Soil water removed - Seasonal $ET_c$ = Irrigation requirement. On a long-term average, corn grown on a deep silt loam soil in southeast Nebraska requires about 6 inches of net irrigation, central Nebraska requires about 9 inches, and the Panhandle of Nebraska requires about 14 inches of net irrigation per year (Department of Natural Resources, 2006). These values will vary from year to year as a function of climatic conditions (rainfall, solar radiation, air temperature, wind speed and relative humidity) that impact $ET_c$ as described earlier.

When planning an irrigation system, sufficient system capacity should be available to meet the crop water use rates in column 2 of *Table I*. However, simply converting the crop water use rate to a system capacity may result in unnecessarily oversized system components. NebGuide G1851 *Minimum Center Pivot Design Capacities in Nebraska* provides a method for estimating system flow rates needed to meet crop water demand while accounting for system down time, soil water holding capacity and the potential for rainfall during the growing season. Using this approach, system capacities can be determined to meet the management scheme of the operator and minimize the installation and operating cost of the system.

The goal of irrigation management should be to provide supplemental water while considering the economic and environmental consequences. One reason is that corn yield response to irrigation water application follows the law of diminishing returns (i.e., as the crop approaches maximum yield, the last inch or two of water applied will net less additional grain yield than the first inch applied). In addition, because irrigation systems are not 100 percent efficient at delivering water, it is impossible to convert all of the applied water to $ET_c$ and ultimately to grain yield. Thus, managers need to consider the potential for increased grain yield and cost of water application when deciding whether to apply the last inch of irrigation.

Applying several inches of excess water will lower the net return for the irrigated field potentially due to depressed grain yield resulting from leaching nutrients below the active root zone and inhibiting soil aeration. In addition, the cost of pumping the extra water would add to corn production costs. Pumping costs can be estimated by multiplying the fuel use rate per acre-inch by the cost of fuel per unit. For example, the estimated fuel use to pump water from a depth of 100 feet at a pump outlet pressure of 50 psi is approximately1.97 gallons of diesel fuel per acre-inch. Thus, the pumping cost for each inch of water applied would be approximately 1.97 times the cost of diesel fuel.

In situations where irrigation water supplies and natural precipitation are not adequate to meet crop $ET_c$ demands, limited or deficit irrigation can be effective in increasing yields above dryland levels. However, applying less water than is needed by the crop will typically result in yield reductions when compared to fully irrigated corn. Under extreme water limited conditions, water applications should be targeted to critical growth stages such as between pollination and early dough, thereby making the most efficient use of the water available.

## Growth Stages

Immediately after planting, crop water use consists almost entirely of evaporation from the soil surface. Estimated $ET_c$ rates will typically be less than 0.10 inch per day unless the soil surface is wetted by a water application event. Following a rainfall event soil evaporation rate could be more than 0.20 inches per day depending on the soil texture and residue cover and the recorded amount of rainfall. Irrigation during this period is discouraged because water application via sprinkler systems could cause a crust to form on the soil surface that will reduce water infiltration and in some cases impede plant emergence. Maintaining good residue cover will limit crust development by absorbing the water droplet energy and also minimize soil evaporation by reflecting some of the incoming solar radiation.

About two weeks after emergence, the corn plant grows to a height of about 6 inches (4-leaf stage). The permanent root system begins to develop from the nodes and growing point during this time. At a plant height of about 10 to 12 inches (6-8 leaf stage), the tassel and ear are beginning to form inside the stalk. The number of kernel rows and kernels in a row are being determined at this time. Leaf area index (LAI) increases to 2.0 for fully irrigated corn. Daily corn water use averages between 0.15 and 0.20 inches per day *(Table I)*. The plant's roots are concentrated in the top 18 inches of soil if there are no soil-limiting factors such as compaction, impermeable layer, or gravel. Assuming an effective root depth of 18 inches, plant available water equals 3 inches in a silt loam soil and 1.5 inches in sandy soils. First irrigation depths should account for rainfall and be light to limit deep percolation losses.

Between the 8-leaf stage and tassel emergence corn root depth, leaf area and water use grow rapidly reaching peak daily water use rates during pollination. Root depth increases from 18 inches to 4 feet during this period doubling the amount of soil water available for plant growth. LAI increases to over 5.0 under fully irrigated corn with plant populations above 24,000 plants per acre. Water use rates grow to 0.32 inches per day when averaged over a three- to five-day period *(Table I)*. Individual day water use rates can reach over 0.40 inches per day when high air temperature, low humidity and windy conditions prevail. Due to the high water use rates, it is important to avoid water stress during the reproductive stage. Severe water stress during silking tends to desiccate the silks and pollen grains causing poor pollination. Water stress during silking will result in the greatest yield reduction. Irrigation depths should be increased to match corn $ET_c$ minus rainfall while leaving some room in the soil for future potential rainfall events (0.5 inches for a silt loam soil).

Water requirements remain high during the early reproductive stages, often remaining in the 0.30 to 0.35 inches per day range until the dough stage *(Table I)*. During this time, kernels are growing as the plant transfers dry matter to the grain. Root development begins to slow down during the blister kernel stage and remains nearly constant at 4.5 to 5 feet for the remainder of the season and plant available soil water reaches a maximum value. Bottom leaves begin dying back during this period of time but have little impact of crop water use rates or yield. Irrigation depths should match corn water use minus rainfall while continuing to leave room for future rainfall events.

Corn water use rates decline beginning with the dough stage in response to lower atmospheric demand (shorter days and cooler temperatures and lower solar radiation), loss of transpiring leaf area, and changes in plant physiology as the grain approaches maturity. Corn water use drops from 0.30 inches per day to 0.20 inches per day by full dent *(Table I)*. Lower leaf loss continues during this period as well. It is assumed that the crop root zone remains constant at approximately 4.5 feet under fully irrigated conditions. Due to reduced crop water requirements, soil water levels can be drawn down below 50 percent depleted toward the end of the dent stage without affecting grain yield. However, corn does require some water right up to physiological maturity so one should continue to monitor corn water use rates and soil water levels.

As corn approaches physiological maturity more water can be removed from the soil profile without impacting final grain yields. Determining when to stop irrigating is an important economic decision. Saving one pass with a center pivot or one irrigation event with a furrow irrigation system reduces production costs associated with pumping the irrigation water.

## Irrigation Management

Irrigation management is basically deciding when to irrigate and how much to apply. The decision must be based on the available irrigation water supply, the soil water holding capacity and water intake rate, and the corn water needs. Well-timed irrigations provide enough water to prevent corn stress while fully using water from rainfall and available in the soil. Thus, irrigation scheduling accounts for all plant sources of water to produce economic yields.

EC783 *Watermark Granular Matrix Sensor to Measure Soil Matric Potential for Irrigation Management* provides a detailed discussion about granular matrix soil water sensor field preparation and installation procedures. In addition, the publication provides information on how to convert readings recorded in the field into how much plant available water has been removed from the soil or soil water depletion. Tabular values are provided for eight general soil texture classifications. Finally, an example is provided to show how the soil water readings can be used to determine the time for the next irrigation event.

Irrigation management based upon potential crop water use estimates obtained from ETgages is discussed in detail in NebGuide G1579 *Using Modified Atmometers (ETgage) for Irrigation Management*. Estimated potential crop water use rates based on weather conditions can be obtained from the High Plains Regional Climate Center. Estimated $ET_c$ can be obtained using a subscription program directly from the Climate Center via the Internet. In this way, crop water use can be estimated for specific fields using the field location, emergence date and relative maturity. Similar information is available from radio stations and some newspapers based upon an average emergence date and crop relative maturity planted in the area.

Irrigation management also includes considering the economic and environmental consequences of each irrigation event. For example, suppose a crop production function indicates that the last 2 inches of irrigation water applied under full irrigated conditions produces 2.5 bushels of corn per inch. If the price for corn is $3.15 per bushel, the increase in income resulting from the water application is $7.88 per acre *(2.5 bu/ac x $3.15 / bu)*. If pumping cost (fixed and ownership) is less than $7.88 per acre, net income will increase as a result of applying the water. However, irrigation management must also evaluate the environmental aspects of irrigating. For example, if the plant uses 0.2 inch of the applied water, what are the potential environmental effects of the remaining 0.8 inches of water? If the extra water makes its way to the aquifer and carries 8 lbs of nitrogen with it, will the increase in net income be worth it?

## Soil Textures

Soils classified as coarse-textured include: fine sands, loamy sands and fine sandy loams. These soils generally have plant available water holding capacities less than 1.5 inches per foot. In the top 3 feet, the plant available soil water at field capacity can be between 1.5 and 2.7 inches. Some sandy soils in Nebraska also have root-restricting layers at shallow depths that can restrict root development. The combination of low plant available water capacity and shallow rooting depth results in a relatively small soil-water reservoir. Small soil-water reservoirs create challenging water management scenarios. Application depths greater than 0.75 inches could result in plant stress in the event of an unexpected system failure. Frequent irrigations of less than 0.50 inches reduce the water application efficiency due to the amount of water lost during each application event. A compromise is to apply relatively frequent light (0.50 to 0.75 in.) water applications.

Medium- and fine-textured soils generally have plant available water capacities of more than 1.8 inches per foot. In the top 3 feet, the plant available soil water at field capacity can be between 5.4 and 7.6 inches. Because these soil textures can store more water, irrigators have more scheduling flexibility. If no leaching or surface runoff occurs, water applications of 0.75 to 1.3 inches are appropriate for these soils.

## Irrigation Systems

In Nebraska, approximately 70 percent of the irrigation water is supplied by center pivot sprinkler systems and about 30 percent using furrow irrigation. An estimate of the water application efficiency is needed to determine the amount of water that might need to be pumped per season. Conventional gated pipe irrigation with no reuse pit typically has an efficiency of about 50 percent. This means if 10 inches of net irrigation is required, an irrigator using conventional gated pipe and no reuse would have to pump 20 inches of water. With a reuse system the maximum efficiency increases to near 70 percent, and the depth pumped would decrease to 14 inches. When furrow irrigating, it is important to irrigate the entire field quickly. Every-other-furrow irrigation supplies water to more area in a given amount of time and produces yield comparable to those achieved when every-furrow is irrigated. In addition to saving time, the water application depth may be reduced 20 percent to 30 percent by implementing every-other-furrow irrigation. With no reuse system, every-other-furrow irrigation is about 60 percent efficient. With a reuse system, maximum efficiency increases to near 75 percent. Surface irrigation management is discussed in detail in NebGuide G1338 *Managing Furrow Irrigation Systems*.

Properly designed and well-maintained center pivot and lateral move sprinkler irrigation systems can be 85 percent to 90 percent efficient. A sprinkler irrigation system that is 90 percent efficient would require a gross application of 11 inches to deliver a net application of 10 inches. If farming practices are changed to accommodate increased water application rates, and sprinkler spacing is less than 7.5 feet, system efficiencies can be improved by dropping the sprinkler nozzles nearer the soil surface. Center pivots also allow more precise application depths and timing than are possible with furrow irrigation systems. The ability to consistently apply only the depth of water needed allow center pivots to take full advantage of rainfall and minimize the potential for plant stress. For more information about center pivot system design and management see the University of Nebraska–Lincoln Extension publication Web site.

## Summary

Proper water management on irrigated corn can produce economic yields, conserve water supplies and preserve or enhance water quality. Use corn $ET_c$ estimates and regular soil water measurements to determine irrigation timing and amount. Consider the irrigation water supply and the system's ability to deliver the water. Work to maximize the efficiency of your irrigation system by performing regular maintenance. A critical concept of any crop production parameter is: to manage it, you must measure it. In order to manage an irrigation system effectively, irrigators need to know how much water has been pumped and where it has gone. Efficient irrigation management requires that accurate records be kept documenting the water applied and rainfall for each field.

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