# WHY IRRIGATION WATER MANAGEMENT

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## INTRODUCTION

Irrigators in the Great Plains have two major challenges in addition to growing profitable crops. First, availability of water supplies for irrigation is critical to crop production. Sometimes and in some places water supplies are not adequate. Second, nitrogen and pesticides used for irrigated crop production need to stay in the crop root zones and out of the ground water if at all possible. The quality as well as the quantity of our ground water resources must be considered in irrigation water management decisions.

To meet these challenges, irrigators need to convert water to grain in the most efficient manner as possible. One of the keys for efficient conversion of water to grain is to match water available to plants with evapotranspiration (ET), also called crop water use. Since ET is directly related to yield, the goal for irrigation management is to match irrigation and rainfall with ET, unless irrigation water supply is inadequate. Irrigating below ET demand can result in yield loss. Irrigating too much can cause percolation of excess water below the root zone and into the ground water. Percolating water can carry dissolved nitrogen and other chemicals from the root zone into groundwater.

There are immediate short range operating costs to the irrigator for either excess irrigation or less than full irrigation. Excess irrigation can cost:

1. Nitrogen loss: 5 lbs. or more per acre-inch of excess irrigation
2. Yield loss or the need for extra fertilizer to compensate for leaching
3. Extra energy cost for pumping: $2.00 - $4.00 per acre-inch
4. Net cost increase: $4.00 - $17.50 per acre for each excess inch of irrigation.

Less than full irrigation can cost:

1. Reduced yield: 6-10 bu/acre per inch
2. Saves pumping cost: $2.00 - $4.00 per acre-inch
3. Net cost increase (corn at $2.30/bu): $10.00 - $21.00 for each inch of under irrigation

The long range costs of over pumping an aquifer or excessive percolation of water and chemicals are more difficult to assess. However, one of the keys to avoid these long run or short run costs is to match ET with rainfall and irrigation.

Irrigators in Nebraska and bordering states have an important information resource available to them through the area-by-area gathering of weather information that is translated along with local crop information into evapotranspiration (ET) estimates. This ET information can serve a key role in irrigation management decisions.

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WHAT IS ET?

Water from precipitation or irrigation can enter the soil where it come into contact with the crop root system. Evapotranspiration, "ET" for short, is the water lost from our soils by soil evaporation and plant transpiration. Soil evaporation occurs when the water at the soil surface changes to water vapor. Plant transpiration is evaporation of water from leaf and plant surfaces. Transpiration is the last step in a continuous water pathway from soil, into plant roots, through plant stems and leaves, and out into the atmosphere. Weather conditions "drive" the system by pulling the water "uphill" through the entire pathway. Since water in this pathway also carries the nutrients necessary to sustain plant life, transpiration is an essential process in plant life.

Soil evaporation is a direct pathway for water to move from soil to the atmosphere as water vapor. Over the course of an irrigation season, soil evaporation is 20-30% of total ET. Soil evaporation rates are highest after irrigation or rainfall. At those times the soil surface is wet and the water readily evaporates. As the soil dries the soil evaporation rates decline. Highest evaporation rates occur from wet bare soil. Lowest evaporation rates occur from shaded and mulched soil surfaces.

Both evaporation and transpiration are driven by the tremendous force that the atmosphere exerts. Figure 1 shows the relative forces that exist in water as it is drawn through the plant or directly from the soil. Water moves from high to low pressure. The "bars" noted in the figure are negative pressure, or tension, terms. Water is drawn or "pulled" by more negative tensions as it moves from the soil, through the plant and into the atmosphere.

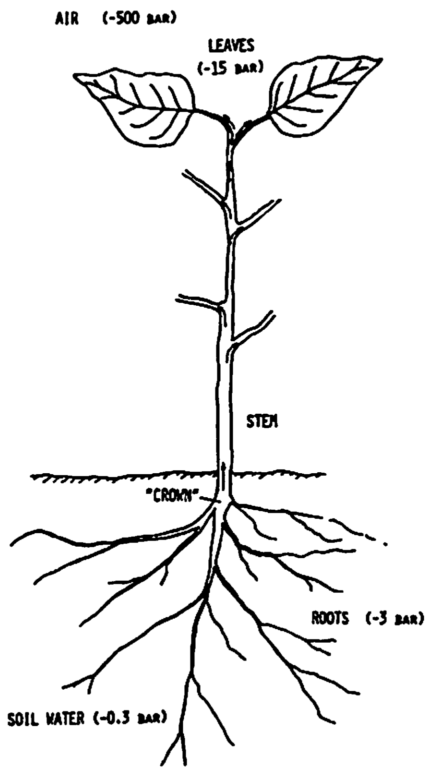


Fig. 1. The variation in water potential along the transpiration stream. (Hillel, 1980)

## ET AND CROP YIELD

ET is important to irrigation management because crop yield relates directly to ET. This linear or "straight line" relationship is shown in Figure 2. Since yield increases linearly with ET, maximum yield will not be reached unless the maximum ET level is reached. Irrigators who are working to achieve maximum yields need to apply water to meet the crop's ET demand. However, applying extra water beyond ET demand will not translate into extra yield. A particular crop variety responding to a particular climate has only so much capacity to transpire water.

ET comes from water that already is in the soil. Irrigation systems and rainfall deliver water to the soil. Not all of the water delivered by the irrigation system translates into ET and ultimately to yield. Water losses due to surface runoff and percolation beyond the root zone do not contribute to ET. The relationships between yield and irrigation are the curves in Figure 2. As more irrigation is applied more water losses occur and the irrigation-yield curves are farther from the ET-yield line. The efficiency of irrigation systems can be described as the ability of the system to supply irrigation so as to match ET and thereby maximize yield. The goal for irrigation is not only to match ET demand, but also to convert irrigation into ET as efficiently as possible.

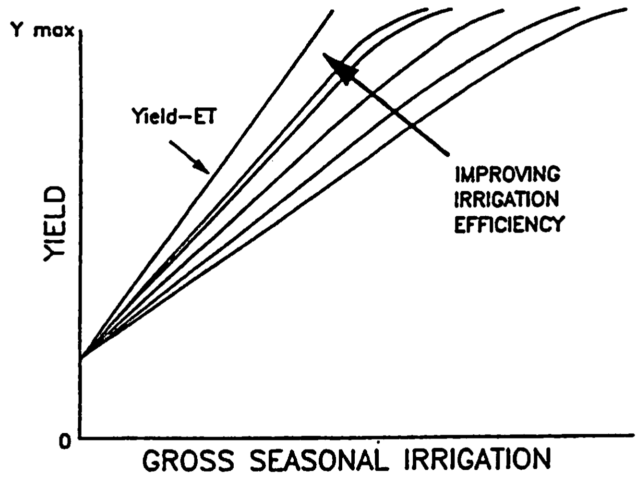


Fig. 2. Yield - ET and Yield - Irrigation relationships.

## FACTORS THAT AFFECT ET

Weather. The power of the atmosphere to evaporate water is the driving force for soil evaporation and crop transpiration. The weather factors that have major impact on this evaporative power include: air temperature, humidity, solar radiation, and wind. High air temperatures, low humidity, clear skies, and high winds cause a large evaporative demand from the atmosphere. The crop may or may not be able to satisfy the atmosphere's evaporative demand, but the weather factors set the potential for ET. This potential ET, governed by weather factors, is the starting point for estimating ET from the automated weather stations in Nebraska. These weather stations will be discussed in a later section.

Day-to-day variations in weather cause day-to-day variations in daily potential ET. Crop ET, ET actually consumed by the crop, responds to these weather variations, as illustrated in Figure 3. Crop ET can vary significantly from day-to-day.

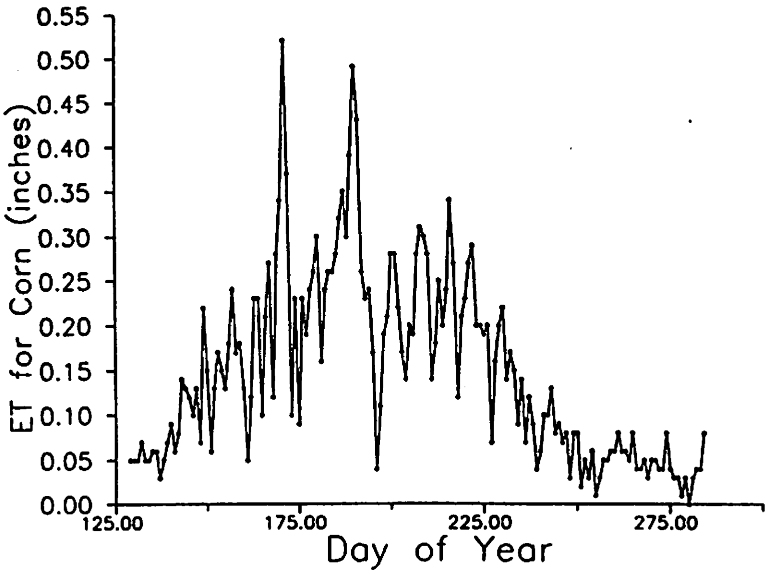


Fig. 3. Daily ET for corn at Lincoln-Havelock Station.

Crop Type. Different crops use different amounts of water over the course of the growing seasons. Table 1 shows growing season ET for corn, soybeans, sorghum, winter wheat, and alfalfa produced in eastern, western and central Nebraska. Crop planting times and water use patterns are somewhat different among the crops listed. Alfalfa is harvested 3-4 times each season and is unique since it is always in the vegetative stage. Winter wheat requires one to two inches of water in the fall and early winter. Differences in water use among corn, sorghum and soybeans are mainly due to planting time and days to maturity. The ET values in Table 1 cover a range in seasonal ET because weather patterns.

Table 1. Seasonal crop water use (ET) in Nebraska.

| Crop | Western | Central | Eastern |
|---|---|---|---|
| | inches/year | | |
| Corn | 22-25 | 24-26 | 25-28 |
| Soybeans | 20-22 | 21-23 | 22-25 |
| Sorghum | 18-20 | 19-22 | 20-23 |
| Winter Wheat | 16-18 | 16-18 | 16-18 |
| Alfalfa | 31-33 | 32-35 | 34-36 |

Crop Growth Stage. During the course of the growing season, ET from crops depends not only on the potential ET demand from the atmosphere, but also on the crop's stage of growth. When the crop is in the early vegetative stage, it cannot physically transmit all of the water that the atmosphere might take. As the crop grows and expands its vegetation, it can begin to meet potential ET.

However, due to growth patterns of different crops, maximum ET occurs at different times during the calendar year. Generally, crops grown in Nebraska reach maximum ET just prior to their reproductive growth stage. As crops start to produce and mature, Et decreases. Average crop ET data are shown in Figure 4. Weather variations are not shown in Figure 4. These lines represent the general trend in crop ET over the course of the growing season. The average maximum ET for corn, sorghum, soybeans, and wheat is 0.35 inch per day but the maximum point on the curves may occur between May and August. Individual daily ET could reach up to 0.45 - 0.50 inch per day.

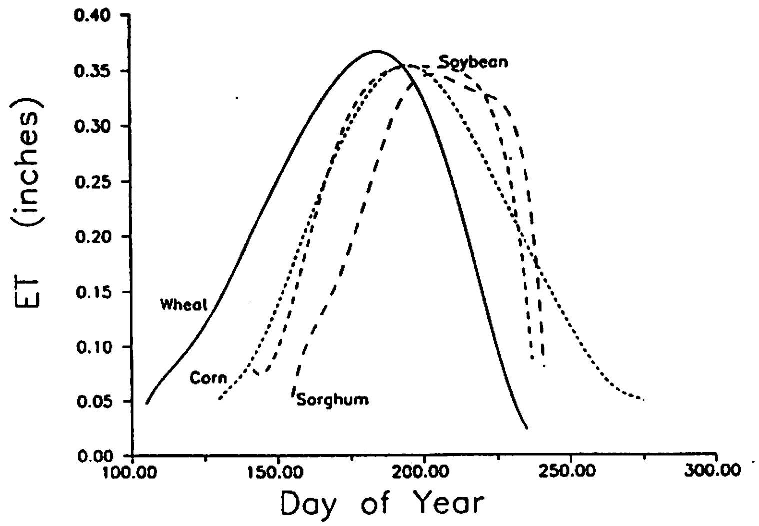


Fig. 4. Average ET values at Lincoln-Havelock, NE.

Crop Variety. The relative maturity range of a particular variety has the most impact on seasonal crop ET. At the same location, a corn variety with relative maturity of 120 days will use more water than an 85 day variety. However, if both varieties are able to mature fully, the grain produced for each inch of ET is approximately equal. Longer season corn varieties use more water, but they also produce more grain if the heat units and water supply are available.

Crop Population. Crop ET can be influenced by plant population or density in a sparsely planted crop like corn. Dryland farmers may grow 12,000-15,000 plants per acre, while a neighboring irrigator may use 25,000-30,000 plants per acre. Irrigators often wonder whether or not decreasing corn population will result in less ET and irrigation requirements. Irrigated research plots in Nebraska have shown that savings in transpiration from fewer plants per acre have been used up by increases in evaporation. Smaller populations give less shading to the soil which results in more evaporation. Irrigated corn populations which were less than 18,000 plants per acre did require less water (ET), but the grain yields were reduced at the same time. With the tradeoffs between transpiration and soil evaporation, irrigated plant populations must be reduced drastically to reduce ET.

Surface Cover and Tillage. The amount of soil surface cover influences soil evaporation. When the soil surface is wet, evaporation depends on the amount of radiant energy to reach the soil surface. Center pivots commonly irrigate a field every 3-7 days and surface irrigation commonly occurs every 7-

14 days. Crops shade more and more of the soil as they grow, but soil evaporation continues, especially after irrigation or rain. However, crop residues can reduce soil evaporation by 1-3 inches during the irrigation season.

<u>Availability of Soil Water</u>.

Research has shown that soil water content cannot be considered alone as the single factor controlling whether crop ET is reduced below its potential rate. The ability of soil to transmit water to plant roots and the actual evaporative demand for a given day are also important. For example, Figure 5 shows the results of an experiment where corn ET from one soil type was measured over a wide range of soil water and weather conditions (Denmead and Shaw, 1963). The plants were grown in 20 gallon containers. This confined the root zone and forced the plants to extract water uniformly throughout the rooting depth. The upper curve in the figure shows what happened on a warm dry day when the potential ET rate was 0.26 inch per day. Only those plants in very moist soil (88% or more available water) were able to meet the evaporative demand. For progressively drier soil, the actual crop ET fell below the demand rate. The drier soil was unable to transmit water to the roots fast enough to satisfy higher potential ET demand.

On a partly cloudy day with a lower potential ET demand of 0.17 inch per day, plants in soils with 45% or more available water were able to match evaporative demand. When the day was cloudy and humid with very low evaporative demand of 0.05 inch per day, the crop ET was equal to the demand in all cases except where available water was less than 5%. Even when the soil is very dry, plants may not experience reductions in ET, if the potential ET demand is low. The controlling factors are the potential ET demand and the soil's ability to transmit water to the roots. This transmitting ability is different for every soil and for a given soil it depends on the water content.

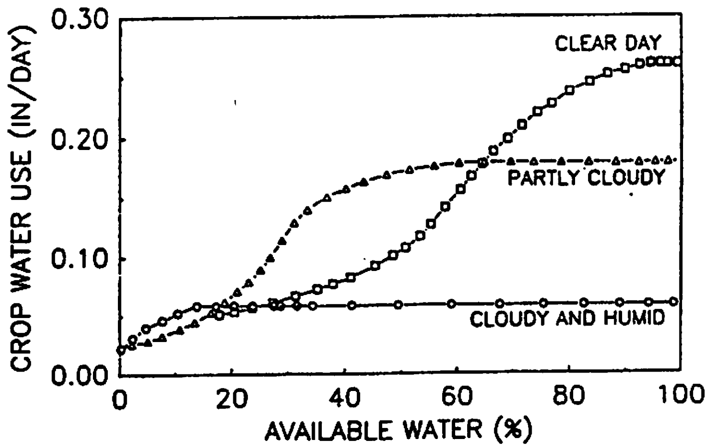


Fig. 5. ET as a function of available water for different evaporative demand rates. (Denmead and Shaw, 1963).

## ET WHEN WATER IS IN LIMITED SUPPLY

Table 2 shows the effect of reduced soil water availability on the seasonal ET for corn at North Platte, NE. Dryland crops received rainfall only, but limited irrigated crops received an additional 6 inches of irrigation. Fully irrigated crops were irrigated to replace all of the water used for ET. Crop ET and grain yields were reduced when soil moisture became limiting. However, the limited irrigation was applied to give the most benefit to grain yield. Crops including corn, winter wheat, and determinate soybeans need water during reproductive and grain filling growth stages. Indeterminate soybeans, which flower over a longer time, need water especially during grain filling. The 6 inches of limited irrigation at North Platte was targeted for these growth stages. Little or no water was applied during vegetative growth. Winter wheat did receive 1 to 2 inches of water during the fall. When crops do not receive water to meet their ET demand, grain yields can be reduced. However, limited water applications, which are targeted to critical growth stages can be very effective for grain production.

Table 2. Grain yields, water use, and irrigation water use efficiencies (IWUE) for continuous corn grown at North Plate, NE, 1985-87. (Hergert et al)

| | Dryland | Limited Irrigation | Full Irrigation |
|---|---|---|---|
| Irrigation (in) | 0.0 | 6.0 | 13.8 |
| ET (in) | 13.5 | 19.1 | 25.3 |
| Grain Yield (bu/ac) | 59.0 | 135.0 | 178.0 |
| Grain/ET (bu/ac-in) | 4.3 | 7.1 | 7.1 |
| Grain/Irrigation (bu/ac-in) | - | 22.5 | 7.0 |
| IWUE* (bu/ac-in) | - | 12.7 | 5.5 |

*IWUE = Irrigation water use efficiency

$$\text{IWUE (Limited)} = \frac{\text{Limited Irrigation Yield - Dryland Yield}}{\text{Limited Irrigation - Dryland Irrigation (0)}}$$

$$\text{IWUE (Full)} = \frac{\text{Full Irrigation Yield - Limited Irrigation Yield}}{\text{Full Irrigation - Limited Irrigation}}$$

## HOW IS ET ESTIMATED?

The University of Nebraska's Department of Agricultural Meteorology has developed a network of automated weather stations throughout Nebraska and bordering states (see Figure 6). These weather stations measure and record the air temperature, relative humidity, incoming radiation, and wind speed. This weather information from each station is collected daily by a computer in Lincoln. These data are then use to calculate potential ET which will serve as an estimate for the region around the weather station. The calculation is based on 45 years of research which has related these weather factors to evaporative demand.

The actual crop ET is calculated from potential ET. Growth stages of crops grown around the station are also calculated, based on local planting dates and accumulated growing degree days. The growth stages combined with the potential ET from the weather station give crop ET estimates. Nebraska field research has furnished the relationships between potential ET from the weather stations and crop ET throughout the growing season. However, crop ET estimates assume that soil water does not limit crop ET. Furthermore, the increased soil evaporation rates that occur immediately after rain and irrigation are not included in the estimates. These specific adjustments to crop ET vary from field to field and cannot be included in regional estimates. Therefore, regional crop ET estimates are an excellent starting point for tabulating water use from a particular irrigated field. Periodic checks of soil moisture in each irrigated field are necessary to confirm the water use from that field.

## SOURCES FOR ET INFORMATION

The University of Nebraska's Department of Agricultural Meteorology maintains ET information on a computerized "bulletin board". The bulletin board can be accessed by the public. Irrigation specialists and Extension agents also retrieve regional ET information from the bulletin board for the news media. Several newspapers, radio and television stations, and telephone recordings across Nebraska provide regional ET information. Usually, ET is reported in units of inches per day. The ET reports provide daily, 3-day, and weekly ET averages. To find the total crop ET over several days, multiply the reported ET by the number of days.

## HOW IS ET USED?

An analogy to matching irrigation and rainfall amounts to crop ET is a bank account. The soil is the bank account for water. Rainfall and irrigations are deposits to the account and ET is the withdrawal from the account. This approach has been called "checkbook" irrigation scheduling. A detailed guide for the procedure is a available through: "Irrigation scheduling Using Crop Water Use Data", NebGuide G85-753. ET estimates are a key component for tracking how much water the crops are using, when to irrigate and how much to apply.

Matching ET with rainfall and irrigation has become more important. In some areas of Nebraska groundwater is being depleted. Pumping allocations are in place or under consideration. In these area irrigators need to monitor crop ET requirements closely. In dry years, crop ET may not be met. Excess irrigation also leads to percolation of the excess water and dissolved nitrogen and chemicals to the ground water. Management to keep irrigation water in the crop root zone depends on supplying water at the right time in the right amount to fulfill crop ET.

## REFERENCES

Denmead, O. T. and R. H. Shaw. 1963. Availability of soil water to plants as affected by soil moisture content and meteorological conditions. Agronomy Journal 54:385-390.

Hergert, G.W., N.L. Klocke, P.T. Nordquist, R.T. Clark, and G.A. Wicks. 1988. Cropping Systems for Soil and Water Conservation in the Great Plains. Intl. Conf. on Dryland Farming, Amarillo, TX. p 59.


Fig 6. Weather station locations in and near Nebraska (1989).

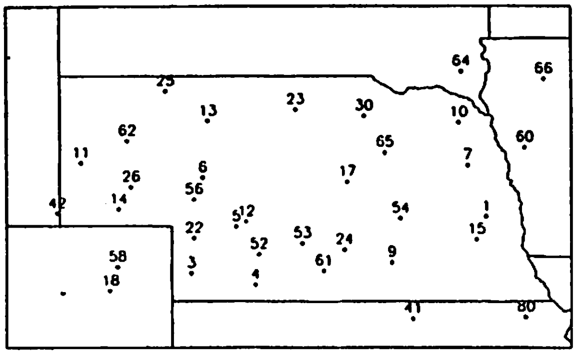


Table Weather stations in and near Nebraska (1989).

| Stations | |
|---|---|
| No. | Name |
| 1 | Mead, NE |
| 3 | Champion, NE |
| 4 | McCook, NE |
| 5 | Dickens, NE |
| 6 | Arthur, NE |
| 7 | West Point, NE |
| 9 | South Central, NE |
| 10 | North East, NE |
| 11 | Panhandle, NE |
| 12 | North Platte, NE |
| 13 | Gudmundsen's, NE |
| 14 | Sidney, NE |
| 15 | Lincoln-Havelock, NE |
| 17 | Ord, NE |
| 18 | Akron, CO |
| 22 | Grant, NE |
| 23 | Ainsworth, NE |
| 24 | Gibbon, NE |
| 25 | Gordon, NE |
| 26 | Silverthorn, NE |
| 30 | ONeill, NE |
| 41 | Scandia, KS |
| 42 | Pine Bluffs, WY |
| 46 | Rising City, NE |
| 48 | Tarnov, NE |
| 51 | Mead Turf Farm, NE (near station #1) |
| 52 | UNSTA Curtis, NE |
| 53 | Lexington, NE |
| 54 | Central City, NE |
| 55 | Lincoln IANR, NE (near station #15) |
| 56 | Arapahoe, NE |
| 58 | Sterling, CO |
| 60 | Castana, IA |
| 61 | Holdrege, NE |
| 62 | Alliance West, NE |
| 64 | Beresford, SD |
| 65 | Elgin, NE |
| 66 | Sutherland, IA |
| 80 | Powhattan, KS |