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Corn Irrigation Management Under Water-Limiting Conditions

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This article discusses irrigation management under water-limiting conditions, including deficit and limited irrigation strategies as they relate to corn production. Some of the basics of deficit and limited irrigation management, in relation to full irrigation, are presented.

Overview

Crop irrigation demand is commonly measured as evapotranspiration (ET), which is a combination of evaporation at the soil and plant surfaces and transpiration through the plant's stomata that transfer water vapor from the plant into the surrounding atmosphere. Crop ET is highly dependent on crop type, development and growth stage as well as micrometeorological conditions, including temperature (T), solar radiation (Rs), relative humidity (RH), and wind speed (u). When effective rainfall and soil water storage in the crop root zone cannot supply the root system with enough water to meet crop ET demand, irrigation is required. Without irrigation, crop water stress will ensue, which often leads to a reduction in biomass, grain yield, and grain quality.

Managing irrigation to prevent crop water stress during the entire growing season at any plant growth and development stage is usually referred to as full irrigation management. Under full irrigation management, the timing and amount of irrigation applied will depend on several factors, including crop type and growth stage, soil moisture conditions, micrometeorological conditions, soil physical and chemical properties, irrigation system and efficiency, nutrient and land management practices, topography, economic considerations, etc. Unfortunately, full irrigation management is not always an option due to the effects of drought, declining water table depths, reduced stream flow, water allocations, irrigation system design capacity, etc. Therefore, less irrigation than what is required to meet the crop ET demand is applied, which has led to the development of limited and deficit irrigation management practices.

Crop Water Demand

Temporal and spatial variability in crop water demand exists and should be accounted for when scheduling irrigation. Early in the growing season, corn plants are small with minimal rooting depth and low leaf area, which results in low crop water demand. However, irrigation may still be required to meet the low crop water demand as soil evaporation can dominate ET early in the growing season due to limited canopy cover. As the crop and canopy develop (i.e., greater leaf area and plant height), an increase in crop water demand occurs, but also greater soil water availability exists due to root development (i.e., greater

IANR

root mass and rooting depth). Consequently, it is important for agricultural producers to have knowledge of temporal changes in effective rooting depth as well as changes in crop water demand to properly schedule irrigation over the growing season. Furthermore, this becomes even more challenging when managing a field spatially (e.g., variable rate irrigation), since one must account for temporal and spatial factors that impact crop growth and ET, to develop a proper spatial irrigation prescription. NebGuide G2245, *Corn Soil-Water Extraction and Effective Rooting Depth in a Silt-Loam Soil* addresses temporal and spatial (lateral and vertical) soil water extraction as well as temporal changes in effective rooting depth, as they relate to irrigation and nutrient management of corn.

One method for estimating crop water use is the two-step approach of using reference (potential) ET and crop-specific coefficients:

$$ET_a = ET_{ref} \times K_c \qquad \text{(Equation 1)}$$

in which ET_a is actual crop evapotranspiration, ET_{ref} is evapotranspiration of a reference crop (alfalfa or grass), and K_c is an adjustment factor, referred to as crop coefficient, that relates a given crop's ET to that of a reference crop. NebGuide G1994, *Estimating Crop Evapotranspiration from Reference Evapotranspiration and Crop Coefficients* explains the use of the two-step approach for irrigation management of different crops, including corn, soybean, alfalfa, wheat, sorghum, and dry beans. Reference (potential) ET can be calculated using different empirical-based equations or estimated using atmometers (ETgages). Information about using ETgages to estimate ET_{ref} for irrigation management is described in detail in the NebGuide G1579, *Using Modified Atmometers (ETgage) for Irrigation Management*.

Crop irrigation demand is not only a function of time (i.e., growth stage) and climatic factors, but also management practices, including planting population density, irrigation scheduling, fertilizer application, and tillage practices. With several influencing factors affecting crop water use, it is recommended that irrigation scheduling and management not rely solely on estimated ETa, but on both estimated ETa and soil moisture data, because there can be a difference between crop ET estimates and actual soil moisture status in the field. Therefore, it is always good practice to verify actual soil moisture conditions to determine if enough moisture exists in the soil profile to meet the crop water requirement before deciding irrigation applications. EC783, *Principles and Operational Characteristics of Watermark Granular Matrix Sensor to Measure Soil Water Status and Its Practical Applications for Irrigation Management in Various Soil Textures* addresses proper installation, maintenance, and data interpretation of an electrical resistance type soil moisture sensor for scheduling irrigation.

Full Irrigation Management

Scheduling irrigation to prevent water stress requires detailed information of the irrigation system (e.g., efficiency and system capacity) as well as frequent and accurate information on crop status and field characteristics, which includes current and forecasted crop water demands and plant soil water availability. The irrigation application amount must be adequate to meet crop water use, but yet not excessive to prevent surface runoff and percolation of water, along with nutrients, beneath the crop root zone.

Along with environmental degradation issues (e.g., nutrient leaching and runoff), excessive irrigation practices, both in amount and frequency, will drive up the operational costs associated with pumping water and the loss of applied nutrients below the crop root zone. It also could potentially damage and reduce grain yield. NebGuide G1904, *Plant Growth and Yield as Affected by Wet Soil Conditions Due to Flooding or Over-Irrigation* provides information on the potential negative impacts associated with excessive irrigation. Therefore, when scheduling an irrigation event, agricultural producers should try to minimize operational costs by taking advantage of water available in the soil profile, while at the same time starting the irrigation event early enough to ensure that the last portion of the field being irrigated does not experience water stress. Information regarding the sizing of a center pivot irrigation system in Nebraska is presented in NebGuide G1851, *Minimum Center Pivot Design Capacities in Nebraska.*

The concept of management allowable depletion (MAD, also referred to as maximum allowable depletion) was developed to aid in balancing the aforementioned conditions. Management allowable depletion is the lower limit of available soil water that the crop can use before water stress occurs. It is taken as a percent of the available water holding capacity (AWHC) of a soil, which is the difference between field capacity (FC) and permanent wilting point (PWP). Field capacity is the amount of water remaining in the soil profile after water freely drains following a wetting event; whereas, PWP is the amount of water in the soil profile that is not available for plant uptake.

EC783, *Principles and Operational Characteristics of Watermark Granular Matrix Sensor to Measure Soil Water Status and Its Practical Applications for Irrigation Management in Various Soil Textures* reports AWHC and MAD amounts for different soil textures found in Nebraska. Even though, in general, MAD for corn has been reported to be around 50 percent, with center pivots, irrigations should be triggered at 30-40 percent MAD level to prevent the last portion of the field dropping below 50 percent of AWHC. Further information on scheduling irrigation to prevent water stress can be found in NebGuide G1850, *Irrigation Management for Corn*. While the optimum MAD level is a strong function of crop type, it is also greatly impacted by the irrigation method used, irrigation system capacity, soil textural properties, and other factors.

Corn Response to Water Stress

The effects of water stress on crop growth and development and grain yield will depend on the timing and magnitude of water stress as well as crop type, since different crops have different levels of tolerance to water stress. For example, unlike sorghum and wheat, corn does not osmotically adjust to lower soil water availability. In general, field crops are most susceptible to negative effects of water stress during the transition from vegetative to reproductive growth or from flowering to fruit setting. Critical periods of water stress for different crops, including alfalfa, corn, sorghum, soybean, and wheat, are presented in *Table 1*.

It should be noted that the critical stages to water stress presented in *Table 1* can vary substantially with the crop hybrids, cultivar, and varieties because crop genetics can play a critical role in crops' physiological response to water stress. Usually, for corn, the most critical period with the greatest reduction in grain yield is between tasseling (VT) and blister (R2) growth stages. It has been reported that a single water stress event during this time period can result in a 30-40 percent yield reduction in a dry year. If water stress occurs during this time period, the following may result: delay in silk growth or elongation, drying of silks, and delay in tassel emergence, which can all lead to reduced pollination.

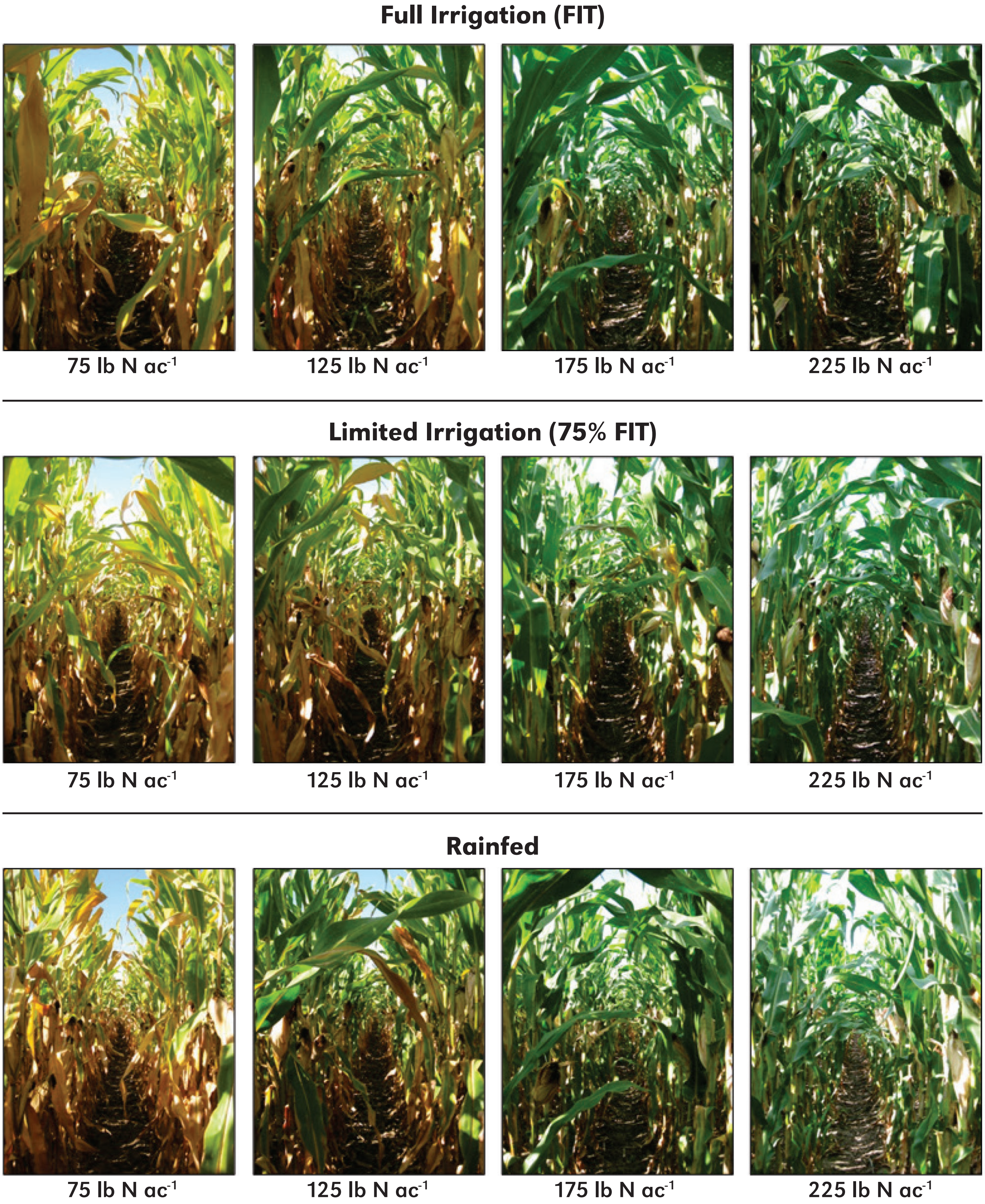
In addition, water stress during this period can lead to kernel abortion, which is most susceptible within two weeks following pollination. This time period also usually coincides with rapid nutrient (e.g., nitrogen) uptake. With the exception of fertigation through sub-surface drip irrigation systems, nitrogen (N) fertilizer is applied at the surface, which typically dries up first during periods of water stress. This can result in combined water and N stress if water and N are unavailable lower in the soil profile (Wolfe et al., 1988). To illustrate this, visual differences among N fertilizer application amounts under full irrigation, limited irrigation (75 percent of full irrigation), and rainfed settings in 2011 at the University of Nebraska–Lincoln South Central Agricultural Laboratory (SCAL), located near Clay Center, Nebraska, are presented in *Figure 1*.

Prior to silking (R1 growth stage), water stress can reduce the final size of leaves and stem internode elongation as well as lower stomatal conductance,

Table 1. Critical periods of soil water stress for different crops (Source: Doorenbos and Pruitt, 1977).

Crop Type	Critical Periods to Water Stress
Alfalfa	**Hay:** Following cutting **Seed Production:** Start of flowering
Corn[a]	**Most Critical:** Pollination period from tasseling (VT) to blister kernel (R2) stages **Mid – Critical:** Prior to tasseling **Less Critical:** Grain filling period
Sorghum	**Most Critical:** Secondary rooting and tillering to boot stage **Mid – Critical:** Heading, flowering, and grain formation **Less Critical:** Grain filling period
Soybean	Flowering and fruiting stage and possibly period of maximum vegetative growth
Wheat	Possibly during booting and heading and two weeks before pollination

[a] Pollination period very critical if no prior water stress.



Full Irrigation (FIT)

75 lb N ac^{-1} 125 lb N ac^{-1} 175 lb N ac^{-1} 225 lb N ac^{-1}

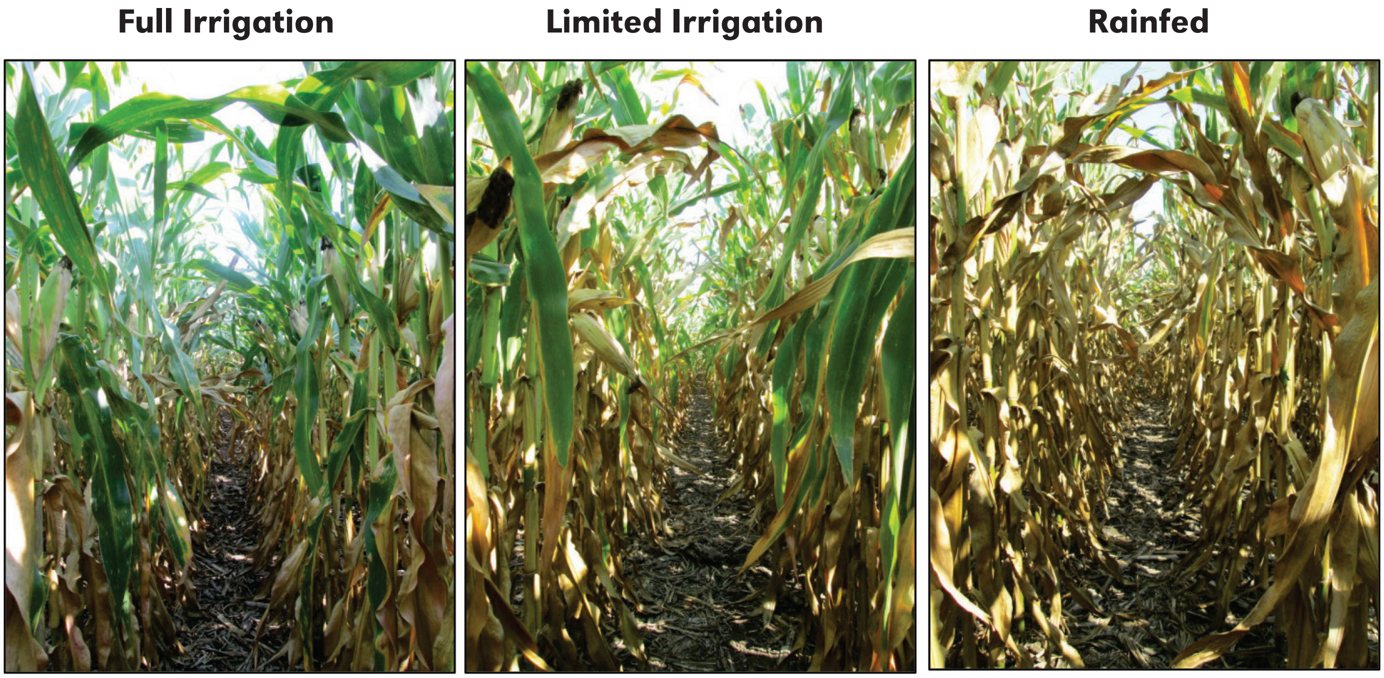
Limited Irrigation (75% FIT)

75 lb N ac^{-1} 125 lb N ac^{-1} 175 lb N ac^{-1} 225 lb N ac^{-1}

Rainfed

75 lb N ac^{-1} 125 lb N ac^{-1} 175 lb N ac^{-1} 225 lb N ac^{-1}

Figure 1. Visual differences among irrigation and nitrogen (N) fertilizer application amounts captured on September 8, 2011, at the University of Nebraska–Lincoln South Central Agricultural Laboratory near Clay Center, Nebraska (Source: Rudnick and Irmak, 2013).



Full Irrigation

Limited Irrigation

Rainfed

Figure 2. Visual differences in crop senescence at the dent growth stage (R5) between full irrigation, limited irrigation (75 percent of full irrigation), and rainfed management in 2012 at SCAL.

which usually results in reduced transpiration and, in turn, reduced biomass and yield production. The reduction in leaf size or area has a lasting effect on grain yield, due to a reduction in carbon assimilation (i.e., photosynthesis) throughout the growing season. At or following blister (R2 growth stage), referred to as the grain filling period, water stress can accelerate senescence of older leaves (i.e., less green leaf area), which will decrease carbon uptake. Furthermore, an increased rate of senescence will shorten the grain filling period, further reducing grain yield.

Visual differences in leaf senescence during the dent growth stage (R5), which is during the grain filling period, between full irrigation, limited irrigation (75 percent of full irrigation), and rainfed management at SCAL in 2012 are presented in *Figure 2.* As shown, earlier leaf aging and senescence occurred under rainfed as compared to limited and/or full irrigation management as a result of severe water stress. Refer to NebGuide G1865, *The Use and Pricing of Drought-Stressed Corn* for further information on the effects of water stress on corn grain yield as well as alternative harvest options and pricing of forage made from drought-stressed corn.

As indicated in *Table 1,* water stress prior to tasseling is more critical than the grain filling period; however, other researchers have reported greater yield reduction occurs when water stress exists during the grain filling than the vegetative period. Depending on micrometeorological conditions throughout the growing season as well as the potential impact of water stress on nutrient (e.g., nitrogen) uptake, either case has the potential to be more severe. Regardless of which period is more critical than the other, a producer should try to avoid long durations of water stress to maintain healthy crop growth and development to achieve high yield.

Deficit and Limited Irrigation Management Practices

As mentioned earlier, there are times when full irrigation management is not an option and less water than what the crop is requiring is applied. As a result, researchers have developed deficit and/or limited irrigation management strategies to try and maximize or optimize yield per unit of water applied. Deficit irrigation consists of withholding water at crop growth stages that are less sensitive to water stress than others; whereas, limited irrigation distributes the total seasonal available water with fixed amounts throughout the growing season independent of crop growth stage. Therefore, the main difference between deficit and limited irrigation practices is that deficit irrigation management accounts for crop growth stages and limited irrigation management does not.

Deficit irrigation is mainly practiced under a water allocation or severe water shortage condition. Under situations when a fixed amount of water is available, producers should apply water at the most critical period(s) to prevent drastic yield reduction. As an example, when managing corn under a water allocation, producers should target the VT to R2 growth stages *(Table 1),* and if water is still available, it should be managed to prevent major periods (length) of water stress. However, under drought conditions, irrigation prior to VT may be necessary to prevent severe lasting effects of water and/or nutrient stress on crop growth and canopy development.

One approach for triggering irrigation prior to VT under a water allocation would be applying the MAD procedure, with an increased tolerance; for example, increasing the full irrigation management MAD during VT stages from 30-40 percent to 40-50 percent, which will result in moderate water stress but prevent severe water stress. All of these practices are a strong function of precipitation amount and distribution as well as soil moisture conditions during the growing season. The success of deficit or limited irrigation practices in relation to MAD levels depends on how accurately these MAD values are determined.

Limited irrigation management is the strategy of applying less water than crop ETa and requires that water be available at the time of irrigation. There are several reasons why limited irrigation management is practiced. These include insufficient irrigation system capacity to meet crop water demands, water allocations, irrigation scheduling delays, and operational savings of pumping water. Depending on the precipitation amount and distribution, the level of limited irrigation can result in different levels of water stress. Thus, developing local-specific deficit or limited irrigation strategies is extremely important for the success of these practices due to the extreme variability of precipitation timing and amount from one location to another. In long-term research conducted at SCAL, near Clay Center, Neb., from 2005 to 2010 (Irmak, 2014a, b), it was found that corn response to water was similar between full and limited irrigation of 60 and 75 percent of full irrigation. It was observed that in most cases, the limited irrigation strategy of 75 percent of full irrigation resulted in statistically the same crop yield and crop water productivity as the full irrigation strategy, and that 75 percent of full irrigation is a viable and robust strategy for south central Nebraska climatic, soil, and crop management conditions.

As mentioned previously, when limited or deficit irrigation strategies are practiced, the crop yield productivity is solely dependent upon the precipitation timing and amount during the growing season and the early season soil-water storage from winter precipitation. Both limited and deficit irrigation strategies can exhibit substantial year-to-year variability, in that one strategy of applying water at critical stages of corn that works effectively may not always be the best option due to uncertainty and nonuniform distribution of in-season precipitation. Extensive data and information on year-to-year variability of crop yield and water productivity response to irrigation and evapotranspiration for full and limited irrigation as well as rainfed settings for corn through long-term field research have been presented and discussed by Irmak (2014a, and b).

Also, in research conducted in North Platte, Neb., in 2005 and 2006, to develop best management practices for a 6 inch seasonal irrigation water allocation for corn grown in Cozad silt loam soil, Payero et al. (2009) observed that irrigations applied in July had the highest positive correlation with yield. This high positive correlation decreased considerably for irrigation applied in August, and became negative for irrigation applied in September. The best positive correlation between the soil water deficit factor and yield occurred during weeks 12–14 from crop emergence during the "milk" and "dough" growth stages. Yield was poorly correlated to stress during weeks 15 and 16, and the correlation became negative after week 17. Dividing the 6 inch water allocation fairly even among July, August, and September was a good strategy, resulting in the highest yields in 2005, but not in 2006. Applying a larger proportion of the allocation in July was a good strategy during both years, and the opposite resulted when applying a large proportion of the allocation in September. The different results obtained between years indicate that flexible irrigation scheduling techniques should be adopted, rather than relying on fixed timing strategies.

The magnitude of limited irrigation (i.e., percent reduction from full irrigation) should be based off of the overall objective of the producer. For example, if a system's capacity is inadequate to meet crop ET, a producer might choose to speed up the irrigation system, consequently reducing irrigation depth (i.e., limited irrigation), to prevent severe water stress in the last portion of the field to be irrigated. Whereas, if a producer wants to limit irrigation for the purpose of operational savings, he/she must account for the increase in yield per unit of irrigation to better determine whether a reduction in irrigation, and a potential reduction in grain yield, is more economical than full irrigation management. As stated in NebGuide G1850, *Irrigation Management for Corn,* grain yield response to irrigation water follows a diminishing return. In other words, when the crop approaches maximum grain yield, the last few irrigation events will result in less grain yield per unit of water compared to prior irrigation events.

Another option for managing irrigation under water-limiting conditions is practicing a combination of limited and deficit irrigation management. This can be accomplished by limiting irrigation amounts early and late in the growing season and applying full irrigation requirement amounts during the most critical time period (VT – R2). This will ensure the crop receives adequate water during the most critical time period as well as prevent extreme or long-lasting water stress during the less critical periods. In research conducted in central and south central Nebraska in 2007 and 2008 (Irmak et al., 2012), a combination of limited and deficit irrigation management for corn resulted in 34 percent and 32 percent less irrigation application, respectively, compared with farmer-managed full irrigation practices. Furthermore, the reduction in irrigation did not statistically impact grain yield, and increased irrigation water use efficiency by 38 percent and 30 percent in 2007 and 2008, respectively.

Summary

Full irrigation management is not always an option due to the effects of drought, declining water table depths, reduced stream flow, water allocations, irrigation system design capacity, economic considerations, etc. Therefore, less irrigation than what is required to meet crop evapotranspiration is applied, which has led to limited and deficit irrigation management practices. When managing corn under water-limiting conditions, it is important for agricultural producers to have knowledge of temporal changes in crop water use and plant water availability, as well as knowing the critical periods or growth stages during which the crop is most sensitive to water stress, to try to maximize yield per unit of water applied.

Resources

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