MANAGEMENT FOR REDUCED IRRIGATION DIVERSIONS

Freddie R. Lamm
Research Agricultural Engineer
Northwest Research-Extension Center
Colby, Kansas
Voice: 785-462-6281
Email: flamm@ksu.edu

QUICK FACTS

- *Irrigation scheduling should be the first tool selected and used when reducing irrigation diversions.*
- *Irrigation micromanagement decisions about season initiation and termination are important ways to reduce irrigation diversions.*
- *Cultural practices can affect the success of reduced irrigation diversions.*
- *Irrigation diversions vary widely between years.*
- *Common conditions within the Central Great Plains affect the ability to reduce irrigation diversions.*

INTRODUCTION

Irrigation water is diverted to augment natural precipitation and soil water reserves for the provision of crop water needs. In the Central Great Plains region, these diversions are coming into increased scrutiny as both ground and surface water supplies are becoming increasingly stressed. These stresses can be entirely hydrologic in nature (i.e., the flow rate of the diversion is decreasing over the years or in some cases even within the season), institutional (i.e., a governmental entity imposes an additional restriction on the amount or rate of diversion) or a combination of the two. Often the appropriate management strategy to deal with the reduction in irrigation diversions will be affected by what is causing the stresses on the water resources.

There is a myriad of scenarios that can be considered for management for reduced irrigation diversions, many more than can be considered in the scope of this paper. For that reason, this paper will limit discussion to *common conditions* in the Central Great Plains region. The discussion will focus on irrigated corn production on the deep silt loam soils with a semi-arid climate with a summer-dominant precipitation pattern. The discussion will also focus primarily on corn production under center pivot sprinkler irrigation, although subsurface drip irrigation may be used to emphasize some specific concepts. The title connotes that the discussion will also be centered on scenarios where irrigation is being reduced, possibly subjecting the corn crop to deficit irrigation. All these limitations to the discussion are necessary to keep a reasonable scope to the paper, but they do not always match the conditions for an individual producer. A broader listing of management tools for deficit irrigation of grain and oil seed crops was provided by Lamm et al., 2014, but that publication chose to limit the discussion more-or-less to the listing of tools. In this paper, a more thorough discussion on the use of some of those tools will be provided, particularly those appropriate for the aforementioned *common conditions*.

THE NEED FOR IRRIGATION SCHEDULING

The most common definition of irrigation scheduling is simply the determination of when and how much water to apply (Martin et. al 1990; Howell and Meron, 2007; Hengeller et al. 2011). Modern scientific irrigation scheduling uses a single approach or combination of weather-, soil- or plant-based approaches. Science-based irrigation scheduling has existed for approximately 65 years with one of the earlier discussions of the topic made by van Bavel (1956) of using evapotranspiration to estimate soil water conditions and for timing of irrigation. Modern scientific irrigation scheduling uses a single approach or combination of weather-, soil- or plant-based approaches. All of these approaches are acceptable and greatly enhance the ability of the irrigator to manage reduced irrigation diversions. ***In fact, few if any of the following management approaches discussed in this paper will have much merit when attempted without using scientifically-based, season-long, day-to-day irrigation scheduling.*** The rationale for the previous statement will be discussed in the following paragraphs condensed from Lamm and Rogers, 2015.

Although there is a wide body of literature on irrigation scheduling in reference books, journal articles, symposium proceedings, and extension publications, effective methods have not been well adopted by irrigators. When the accuracy of irrigation scheduling is perceived to be an issue, there is a great impediment to adoption since the economic penalty of over-applying water is usually many times less than that of under-applying water (Fig. 1). Lack of confidence by the irrigator can be the result of changes in cultural practices that affect the field water budget or introduction of new drought resistant varieties or hybrids that seem to indicate a change in the water use of the crop. An example is drought resistance corn, which is often misinterpreted by irrigators as a corn that needs less water, while actually it may just mean the hybrid may tolerate water stress better.

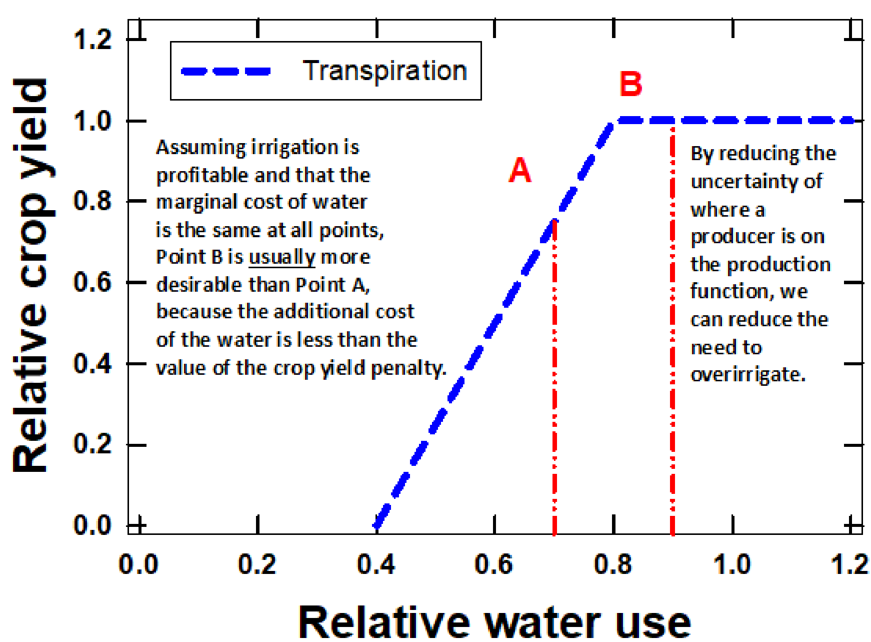

Figure 1. Effect of irrigation inaccuracy on crop production points. Adapted from discussion and graph in Lamm (1997) and provided here after Lamm and Rogers (2015).

Additionally, irrigators, economists, and water planners often want to simplify the question of "How much irrigation water do I need?" to a single annual value when in reality there is no single answer (Fig. 2). Furthermore, as indicated in Fig. 2, averaging several years of data will result in a smooth yield/water response curve that has very little basis for obtaining good yields in a given year***. Fortunately, with science-based irrigation scheduling, irrigators do not need to use average values.*** The Kansas USDA-NRCS officially adopted KanSched, developed at Kansas State University, as an approved ET-based irrigation scheduling program and has offered cost share incentives to encourage irrigator adoption of ET- based scheduling and have required adoption as an eligibility requirement for other irrigation improvement cost-share programs.

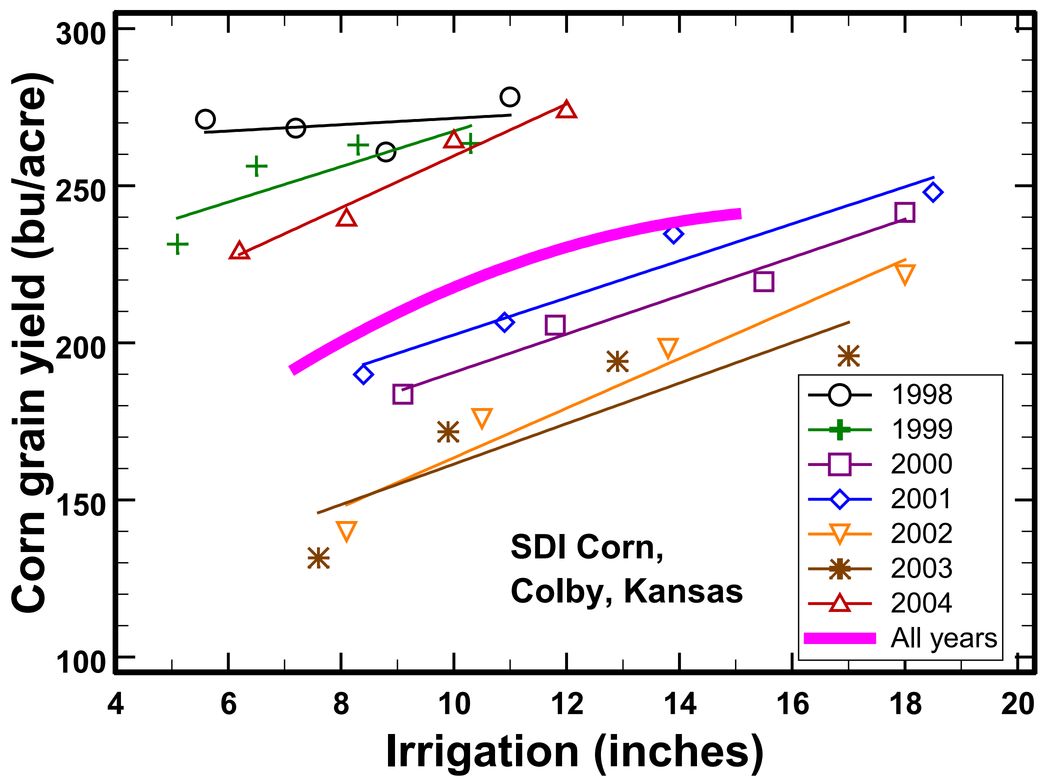

Figure 2. Corn yield response to subsurface drip irrigation (SDI) amount in seven different years, KSU Northwest Research-Extension Center, Colby, Kansas (data from Lamm, 2004). The boldface curve is the average of all seven years emphasizing that average values are insufficient for irrigation management in an individual season. All years were scheduled according to daily ET-based water budget with individual data points representing differences in available irrigation capacity (i.e., volume of water/time). After Lamm and Rogers (2015).

Many irrigators have been unwilling to set aside much time to manage water. They often feel that if their irrigation capacity is appreciably less than crop water needs, they need to operate their irrigation systems continuously during the growing season. Although, there are a large number of marginal capacity irrigation systems in the region, there remains opportunities to delay unnecessary irrigations by using ET-based irrigation scheduling (Rogers, 2009, Lamm and Rogers, 2015). Simulation modeling has indicated adoption of ET-based irrigation scheduling with an initial soil water condition of 85% of field capacity and 95% application efficiency potentially could save on average 8.34 inches water for a 1 inch/4 days irrigation capacity (i.e., essentially full irrigation in this region) and 2.80 inches for a severely deficit 1 inch/8 day irrigation capacity (Lamm and Rogers, 2015). ***Irrigators with marginal capacity systems should adopt science-based irrigation scheduling to make best use of their limited irrigation and should not discount their opportunity to save irrigation water even when their system restrictions are severe.***

A greater portion of the potential irrigation savings occurs during the early part of the irrigation season and after that period, irrigation water savings are incrementally increased as the season progresses, increasing during cooler, more humid periods and decreasing during warmer and drier periods with a *saw-tooth* pattern as irrigation events occur (Figure 3). ***This emphasizes the need to use season long, day-to-day irrigation scheduling.***

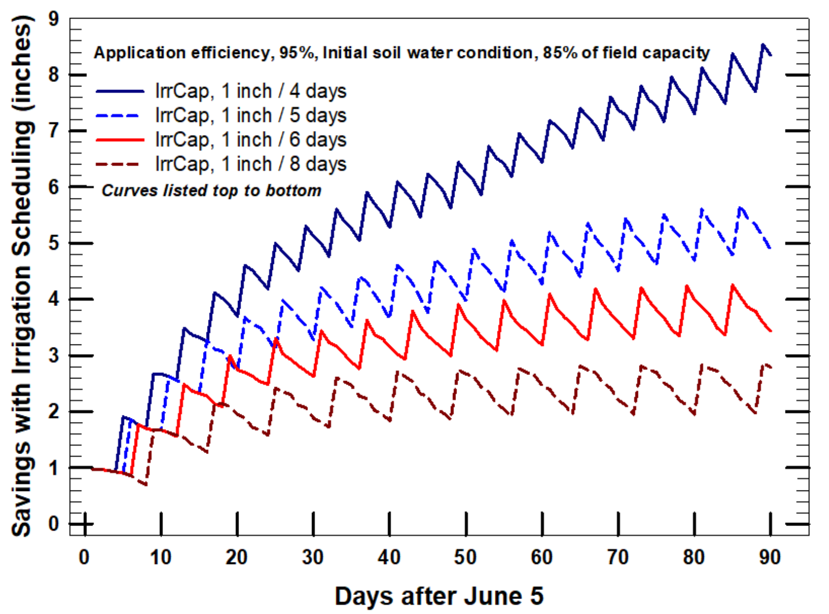

Figure 3. Average savings of irrigation that could be obtained with ET-based irrigation scheduling as compared to maximum seasonal applications possible with various irrigation capacities for an application efficiency of 95% and an initial soil water condition of 85% of field capacity as determined in simulation modeling for 43 years of weather data (1972-2014), Colby, Kansas. After Lamm and Rogers (2015).

IRRIGATION MACROMANAGEMENT ASPECTS OF SEASON INITIATION AND SEASON TERMINATION

There are larger irrigation management decisions [i.e., irrigation macromanagement (Lamm et al., 1996)] that can be considered separately from the step-by-step, periodic scheduling procedures. Two important macromanagement decisions occur at the seasonal boundaries, the initiation and termination of the irrigation season. Irrigators sometimes make these seasonal boundary determinations based on a traditional time-of-year rather than with sound rationale or science-based procedures. However, a single, inappropriate, macromanagement decision can easily have a larger effect on total irrigation water use and/or crop production than the cumulative errors that might occur due to small, systematic errors in science-based, day-to-day irrigation scheduling procedures.

INITIATION OF THE IRRIGATION SEASON

The corn vegetative stage is often considered the least-sensitive stage to water stress and could provide the opportunity to limit irrigation water applications without severe yield reductions. The vegetative stage begins at crop emergence and ends at tasseling, which immediately precedes the beginning of the reproductive period when the silks start to emerge. Important yield components such as the ears/plant and the potential number of kernels/ear are established during this period. Stresses during the 10 to 14 days after silking will reduce the potential kernels/ear to the final or actual number of kernels/ear. Therefore, in research studies designed to examine water stresses during the first one-half of the corn crop season, both ears/plant and kernels/ear are critical factors. Additionally, there could be permanent damaging effects from the vegetative and early-reproductive period water stress that may affect grain filling (kernel mass). Often, irrigators in the Central Great Plains, start their corn irrigation season after early season cultural practices are completed. Crop evapotranspiration is beginning to increase rapidly and drier weather periods are approaching, so often there is soil water storage that can be replenished by timely irrigation during this period for use later in the summer. However, this does not always mean that the corn crop required the irrigation at that point-in-time (Lamm and Aboukheira, 2009).

Numerous years of research has indicated that when considering early season crop water stress, the number of kernels/area (i.e., multiplication of plants/area x ears/plant x kernels/ear) is a good surrogate for correlation with the final grain yield (Lamm and Aboukheira, 2009). In other words, the number of kernels per unit area has to be maximized to ensure that grain yield can be maximized. Maximizing the relative kernels/area was found to be related to the minimum plant available soil water (ASW) occurring in the month of July at Colby, Kansas in long term studies.

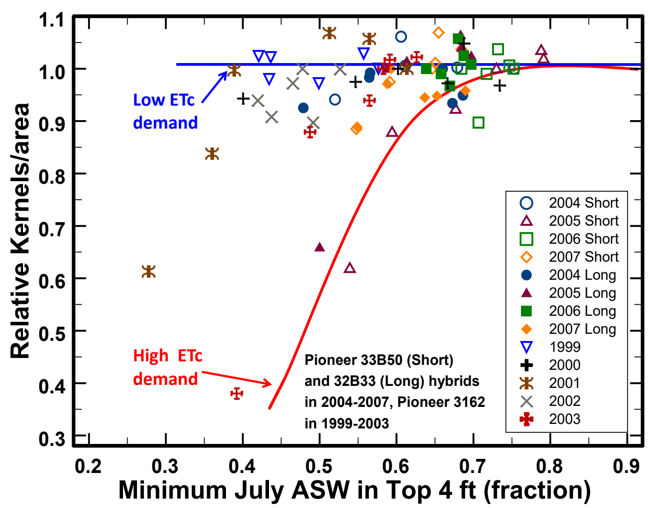

Figure 4. Relative kernels/area as affected by July minimum available soil water in the top 4 ft of soil in an early-season corn water stress study, KSU-NWREC, Colby, Kansas, 1999-2007. The upper (red) and lower (blue) lines are manually drawn to illustrate years with larger and smaller July evaporative demand. After Lamm and Aboukheira (2009).

In some years, ASW in the top 4 feet could be depleted as much as perhaps 60% without an effect on relative kernels/area (i.e, ultimately grain yield), while in other years reductions began to occur at 30 to 40% reduction in ASW. When crop evapotranspiration (ETc) was greater, a higher level of soil water (ASW) was required. These results would match known theories of water stress and water flow through plants (Denmead and Shaw, 1962). ***These results once again emphasize the need for science-based, season long, day-to day irrigation scheduling so that the producer has information about whether crop water stress might be affecting the kernels/area (i.e ultimately the grain yield).*** It should be noted the data in Figure 4 are from subsurface drip irrigation studies where the water stress after silking was alleviated with daily irrigation amounts of 0.4 inches/day until such time that the ASW was restored to near field capacity. Alleviating the water stress in this manner is not practical with other types of irrigation systems as irrigation runoff from heavy, frequent irrigation will result in excessive runoff.

The deep silt loam soil profiles of the Central Great Plains region will store considerable amounts of ASW for later usage. Using ET-Based irrigation scheduling and /or soil water measurements for scheduling, the producer can manage this soil water "bank", sometimes banking water in the vegetative period before the critical reproductive (silking and pollination) period. This runs a bit counter to the earlier statements in this section and that are widely held in older publications about the vegetative period being an opportunity to cut back on water. However, the criticality of establishing the maximum kernels/area expressed in Figure 4, the common presence of deep silt loam soil profiles, and the discussion in the following paragraphs strongly challenge those older assumptions.

Sprinkler irrigation does not allow for large amounts of water to be timed to a specific growth stage without incurring runoff, so strategies must be employed that can slowly restrict or slowly increase water available to the crop and to soil water storage for later usage. Preliminary computer simulation indicated that on average, approximately 40% of the seasonal irrigation amount is required prior to silking (Figure 5), so a study was conducted to determine if an imposed reduction of 50% during the pre-silking period might be acceptable most years, yet not be excessive in the drier years. However, this does not fully reflect the ability of the soil profile to be a "bank," so examining a higher irrigation regime was also warranted.

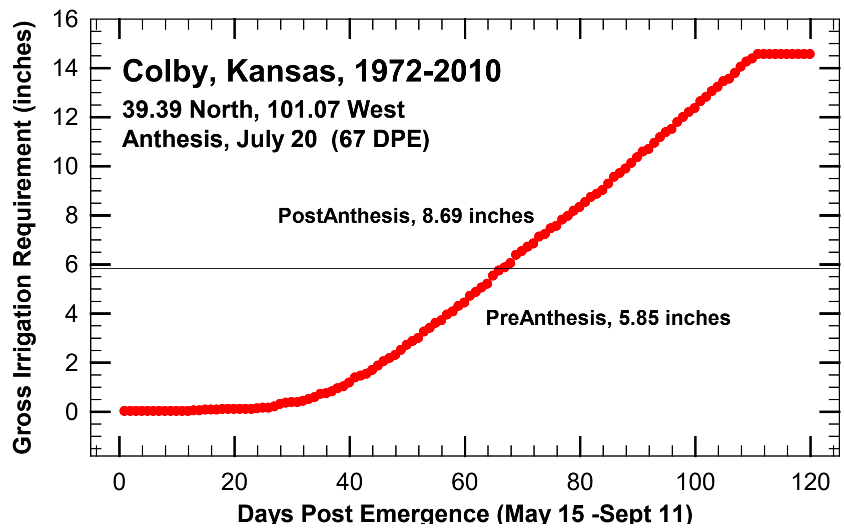

Figure 5. Seasonal gross irrigation requirements for field corn at Colby, Kansas for the pre- and post anthesis (silking) periods. After Lamm (2017).

Corn production was compared under five different irrigation regimes in a three-year (2013-2015) field study on a deep silt loam at the KSU Northwest Research-Extension Center at Colby, Kansas (Lamm, 2017).

The irrigation regimes were:

1) Full irrigation (100% ET) with no restriction on total irrigation
2) Irrigation restricted pre-silking to 50% of ET, 100% of ET thereafter with 11.5 inches total restriction
3) Irrigation restricted pre-silking to 75% of ET, 100% of ET thereafter with 11.5 inches total restriction
4) Irrigation restricted post-silking to 50% of ET with 11.5 inches total restriction
5) Irrigation restricted post-silking to 75% of ET with 11.5 inches total restriction

Irrigation amounts of 1 inch/event were scheduled according to water budget weather-based irrigation scheduling procedures only as needed subject to the specific treatment limitations. As an example, during the pre-silking stage Irrigation Trt 3 would only receive 75% ET, but after silking would receive irrigation at 100% until such time that the total irrigation is 11.5 inches.

Full irrigation amounts varied from 12.48 inches in 2014 to 15.36 inches in 2013 (Figure 6). The irrigation treatments with pre-silking water restrictions (Irr 2, 50% ET pre-silking and Irr 3, 75% ET pre-silking) reached their water limitation (11.5 inches) in two of the three years (2013 and 2015) as did the post-silking deficit irrigated treatment that was irrigated with 75% of ET during the post-silking period. The irrigation treatment using the least amount of water during the three years of the study was the treatment where irrigation was restricted to 50% of ET during post-silking period (Irr 4).

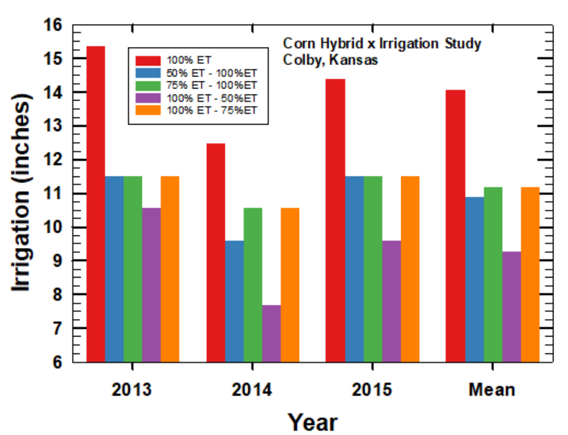

Figure 6. Irrigation amounts for the five irrigated corn treatments during the three years of the study. After Lamm (2017).

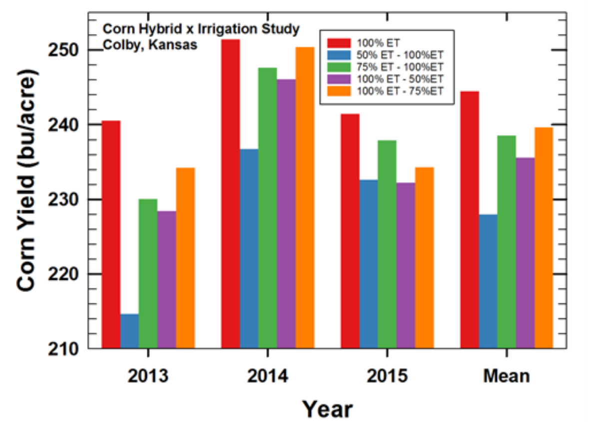

Figure 7. Corn yields for the five irrigation treatments during the three years of the study. After Lamm (2017)/

Fully irrigated corn grain yields ranged annually from 241 to 251 bushels/acre with the deficit-irrigated lowest yields ranging from 215 to 237 bushels/acre (Figure 7). Corn yield was greatest for unrestricted irrigation (Irr 1) but required 30 to 36% more irrigation, but was still very efficient with only a 2 to 4% reduction in crop water productivity (data not shown, see Lamm, 2017). Lower yields occurred for pre-silking water restrictions (Irr 2 and 3) than for similar post-silking restrictions (Irr 4 and 5). These results suggest that obtaining sufficient kernel set (i.e., kernels/ear) was more important than saving irrigation for grain filling (i.e., kernel mass) in this study. ***When irrigation is greatly restricted, a 50% reduction post-silking appears as a promising alternative, relying more heavily on stored soil water and precipitation for grain filling.***

Summarizing this study (i.e., Lamm 2017), it appears that ***if water is limited, there are better opportunities to save water during the post-silking period by relying on stored soil water (ASW), occasional precipitation, while moderately reducing the irrigation during this period.*** This conclusion relies heavily on the *common conditions* typically occurring in the Central Great Plains that were expressed in the Introduction.

TERMINATION OF THE IRRIGATION SEASON

Similarly to the initiation of the irrigation season, the termination of the irrigation season is considered to present opportunities to reduce irrigation diversions. Plant water stress can cause kernel abortion if it occurs early enough in the post-silking period but is more often associated with poor grain filling and thus reduced kernel mass. Grain kernel mass is termed as a very loosely restricted yield component (Yoshida, 1972; Shaw, 1988), meaning that it can be manipulated by a number of factors. The final value is also set quite late, essentially only a few days before physiological maturity. The rate of grain filling is linear for a relatively long period of time from around blister kernel to near physiological maturity. Yield increases of over 4 bushels/acre for each day are possible during this period, so a premature termination of the irrigation season can be quite costly. Providing good management during the period can help to provide a high grain filling rate and, in some cases, may extend the grain filling period a few days thereby increasing yields. Availability of water for crop growth and health is the largest single controllable factor during this period. However, the rate of grain filling remains remarkably linear unless severe crop stress occurs (Rhoads and Bennett, 1990). This is attributed to remobilization of photosynthate from other plant parts when conditions are unfavorable for making new photosynthate.

Four separate studies were conducted at the KSU Northwest Research-Extension Center at Colby, Kansas over the years 1993 through 2008 to examine the effects of post-silking water stress on corn (Lamm and Aboukheira, 2009). Prior to silking, all treatments in each of the studies were fully irrigated according to their need. Results from the studies indicate that silking for corn in Northwest Kansas varies from July 12 to July 24 with an average date of July 19 (Table 1). Physiological maturity ranged from September 14 through October 10 with an average date of September 27. The average length of the post-silking period was approximately 70 days. Using the corn grain yield results from the studies and the individual treatment irrigation termination dates responsible for those yields, Table 1 was created to indicate the problems with using inflexible dates for determining the irrigation season termination date. Additionally, the corn grain yield results and the treatment irrigation dates were used to estimate the date when a specified percentage of maximum grain yield would occur. Because there was not an unlimited number of irrigation treatment dates, there are years when the date required for a specified percentage of maximum grain yield was the same as the date for the next higher percentage. The average estimated termination date to achieve 80, 90, and 100% of maximum corn grain yield was August 2, 13, and 28, respectively, but the earliest dates were July 17, July 17 and August 12, respectively, while the latest dates were September 14, 21, and 21, respectively. ***Irrigators that use average or fixed dates to terminate the corn irrigation season are not realistically considering the irrigation needs of the corn that may be greater or smaller in a particular year, and thus, often will neither optimize corn production, nor minimize water pumping costs. These results once again emphasize the need for science-based, season long, day-to day irrigation scheduling so that the producer has information about when he can safely end the irrigation season.***

Table 1. Anthesis and physiological maturity dates and estimated irrigation season termination dates* to achieve specified percentage of maximum corn grain yield from studies examining post-anthesis corn water stress, KSU Northwest Research-Extension Center, Colby, Kansas, 1993-2008. Note: This table was created to show the fallacy of using a specific date to terminate the irrigation season. Note: Because there was not an unlimited number of irrigation treatment dates, there are years when the date required for a specified percentage of maximum grain yield was the same as the date for the next higher percentage. Adapted from Lamm and Aboukheira (2009).

Year	Date of Anthesis	Date of Maturity	Irrigation Season Termination Date For		
			80% Max Yield	90% Max Yield	MaxYield
Average	19-Jul	27-Sep	2-Aug	13-Aug	28-Aug
Standard Dev.	3 days	6 days	13 days	19 days	13 days
Earliest	12-Jul	14-Sep	17-Jul	17-Jul	12-Aug
Latest	24-Jul	10-Oct	14-Sep	21-Sep	21-Sep

* *Estimated dates are based on the individual irrigation treatment dates from each of the different studies when the specified percentage of yield was exceeded.*

When termination of the irrigation season allowed the minimum soil water (ASW) fraction to fall below approximately 65% of field capacity, there was a tendency for decreased yields (Figure 8).

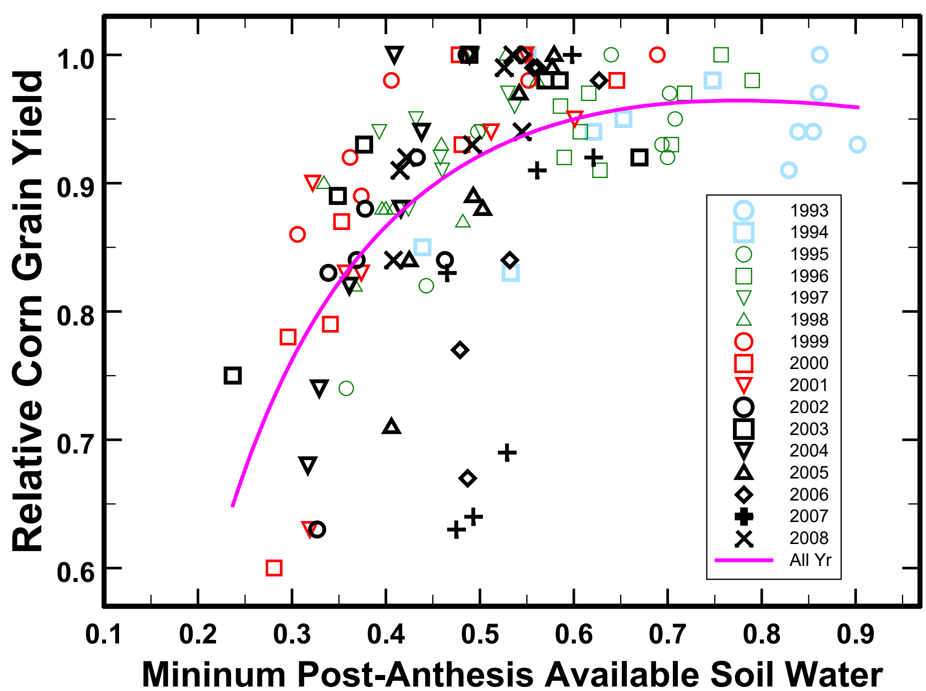

Figure 8. Relative corn grain yield as affected by the minimum value of available soil water (fraction) within the 8 ft soil profile occurring during the post-anthesis (post sillking) period. Data are from various studies examining the effect of post-silking corn water stress, KSU Northwest Research-Extension Center, Colby, Kansas, 1993-2008. After Lamm and Aboukheira (2009).

Producers in the Central Great Plains should plan for post-silking water use needs of approximately 17 inches and that water use during the last 30 and 15 days of the season might average nearly 5 and 2 inches, respectively. This water use would need to come from the sum of available soil water reserves, precipitation, and irrigation. When irrigation losses are minimized, a percentage decrease in post-silking water use will result in nearly a one-to-one percentage decrease in corn grain yield(data not shown, see Lamm and Aboukheira, 2009). Producers growing corn on deep silt loam soils in the Central Great Plains should attempt to limit management allowable depletion (MAD) of available soil water in the top 8 ft of the soil profile to approximately 35%.

CORN RESPONSE TO TILLAGE, PLANT DENSITY AND IRRIGATION REQUIREMENTS AND IRRIGATION CAPACITY

Tillage management strategies that leave greater amounts of residue on the soil surface are beneficial in sprinkler-irrigated corn production in terms of improving infiltration of both irrigation and rainfall, and in reduction of soil evaporative losses early in the growing season. Additionally, sometimes early season crop growth is delayed under higher residue conditions and this can result in the shifting of crop evapotranspiration to later in the season for higher residue treatments. Irrigation requirements and corn water use are typically not affected by plant density (aka plant population) changes in the range of typical economical corn production in the Central Great Plains region.

A four-year study was conducted at KSU Northwest Research-Extension Center, Colby, Kansas to evaluate corn production as affected by tillage management (Conventional, Strip-Tillage and No-Tillage), plant density (26,000, 30,000, and 34,000 plants/acre) and irrigation capacity (limited to 1 inch every 4, 6 or 8 days (Lamm, 2018).

For brevity data in Figure 9 and 10 are averaged across the experimental factors. The reader is referred to Lamm et al. (2009) for a more detailed examination of the study results. ***Reduced or no-tillage increased corn grain yields over conventional tillage and increased plant density was also beneficial. As anticipated there was some yield reduction with decreased irrigation capacity.***

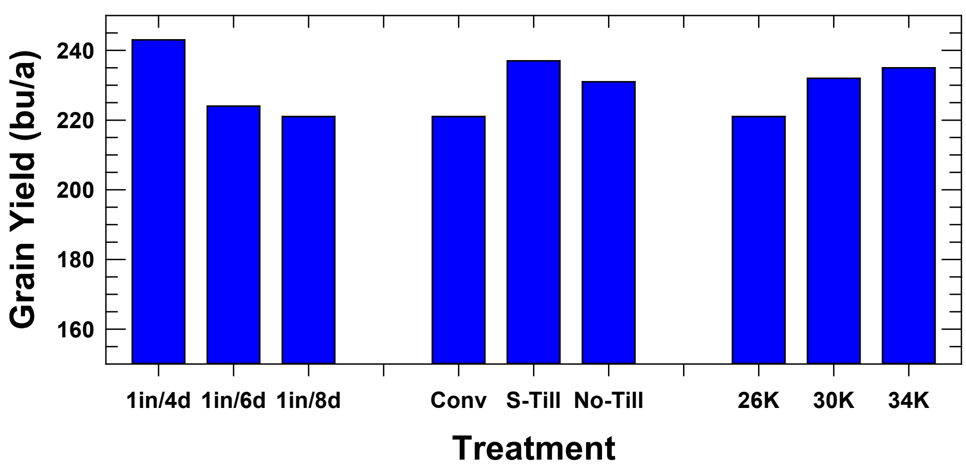

Figure 9. Corn grain yield as affected by irrigation capacity, tillage treatment and target plant density in a sprinkler-irrigated research study, KSU Northwest Research-Extension Center, Colby, Kansas, 2004-2007. After Lamm (2018).

Crop water use was greater with strip tillage and no-tillage probably because their plants did not senesce as early in the season as the conventional treatment***. Plant density did not affect corn water use as would be anticipated at these plant densities.*** *Plant density would likely need to be decreased to 20,000 to 24,000 plants/acre or less before crop water use would decrease.* However, lower plant densities can sometimes help under extreme drought conditions to ensure pollination, though crop water use is unaffected. Crop water use was affected by irrigation capacity as would be anticipated.

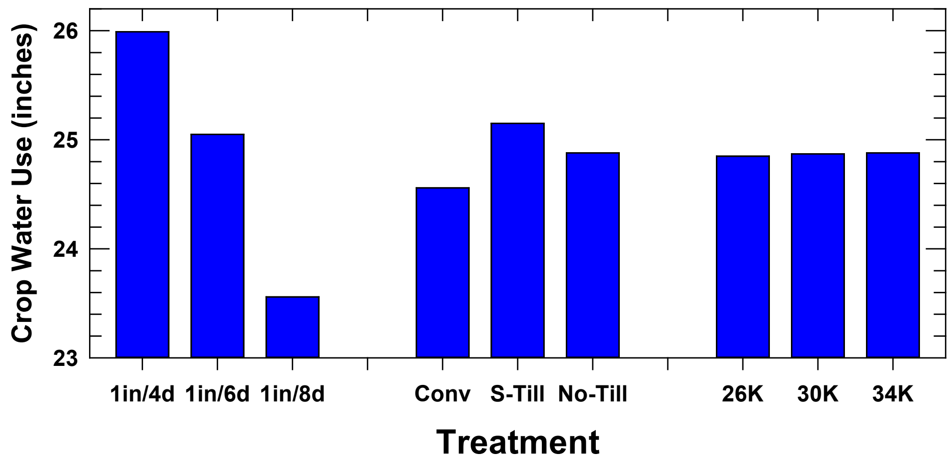

Figure 10 Corn water use as affected by irrigation capacity, tillage treatment and target plant density in a sprinkler-irrigated research study, KSU Northwest Research-Extension Center, Colby, Kansas, 2004-2007. After Lamm (2018).

IRRIGATION REQUIREMENTS AND IRRIGATION CAPACITY

Corn grain yields are obviously sensitive to reductions in irrigation below a criticial threshold. It is common for the slope of the water production function for corn under deficit irrigation to be 12 to 15 bushels/inch and values of nearly 20 bushels/inch have been reported, so it is imperative that deficit irrigation not be too severe to remain in profitable production.

Corn yields were simulated for 42 years (1972-2013) of weather data from Colby, Kansas (Lamm et al., 2014). Well-watered corn ETc ranged from 17.6 to 27.1 inches with average of 23.1 inches for these 42 years of record. In-season precipitation ranged from 3.1 to 21.2 inches with average of 11.8 inches. Full irrigation ranged from 6 to 22 inches with average of 15.7 inches. The marginal WP (slope) was 17 bu/acre-in, which might result in an economic benefit of 65 to $85/acre-in. The yield threshold was 10.9 inches of ETc. Yields were simulated for irrigation capacities of full irrigation, 1 inch every 4, 6, 8, or 10 days and also for dryland conditions. As irrigation capacity decreases (Figure 11 and Table 5), corn yields decrease from the fully irrigated yields for some years and the variability in yields also increases. Typically, crop yields increase with increasing ETc, although this response in not a direct cause and effect. Rather in many cases, increased ETc is also reflecting better growing conditions (e.g., increased sunlight, warmer temperatures). As irrigation capacity decreases, the positive aspects of greater ETc on yield begins to disappear and the slope is relatively flat for an irrigation capacity of 1 inch/10 days (Figure 11). Under dryland conditions, corn yields typically decreased over the entire range of increasing ETc experienced at Colby, Kansas during this 42-year period.

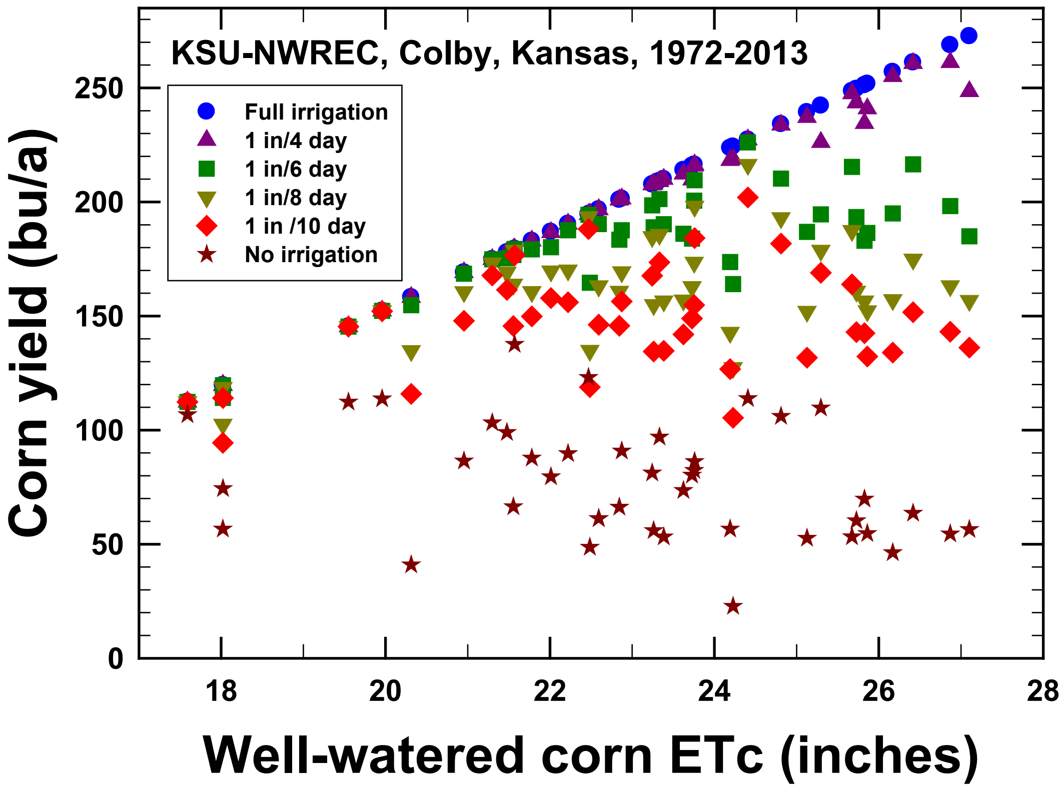

Figure 11. Simulated corn yields as a function of the calculated well-watered corn evapotranspiration for the 42-year period, 1972-2013, Colby, Kansas as affected by irrigation capacity.

Table 2. Effect of irrigation capacity on simulated corn yields for the 42-year period, 1972-2013, Colby, Kansas.

Irrigation capacity	Maximum yield	Mean Yield	Minimum Yield	Yield variation from full irrigation for maximum yield at maximum well-watered ETc
Full	273	204	112	-
1 inch/4 day	261	202	112	-4.4%
1 inch/6 day	226	181	112	-17.2%
1 inch/8 day	216	162	103	-20.9%
1 inch/10 day	202	148	94	-26.0%
Dryland	138	77	23	-49.5%

When irrigation is carefully managed with efficient irrigation systems, such as subsurface drip irrigation (SDI), corn grain yield and crop water productivity both often begin to plateau with irrigation levels (Figure 12 and 13) in the range of 80% of full irrigation (Lamm, 2005). The aspect of maximum water productivity with irrigation levels of 80% was also reported by Howell (2001).

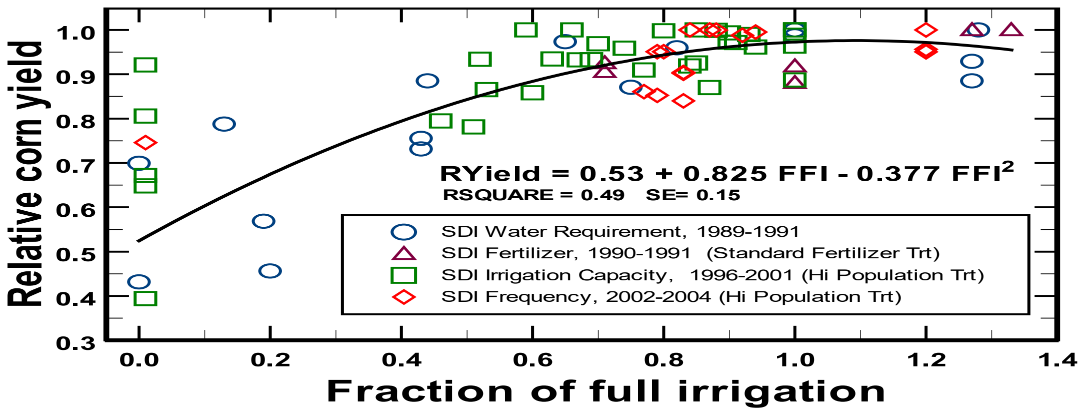

Figure 12. Relative corn grain yield for a given SDI research study and year as related to the fraction of full irrigation, KSU Northwest Research-Extension Center, Colby, Kansas. After Lamm (2005).

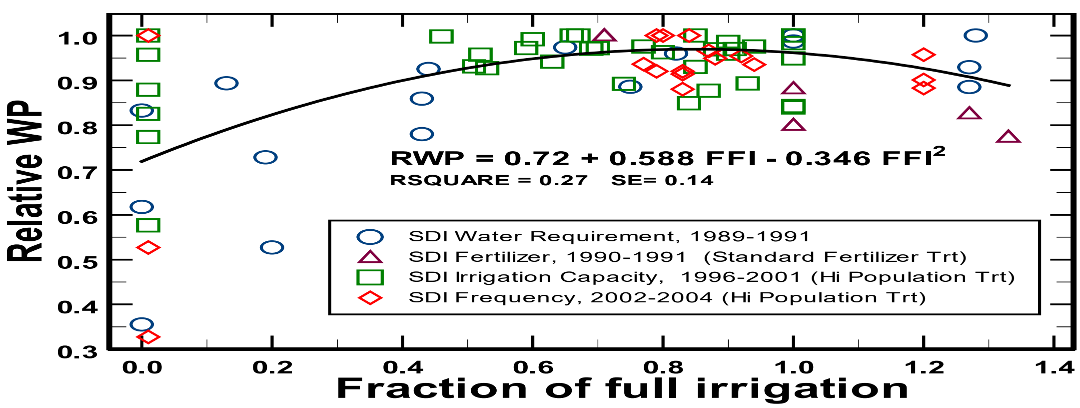

Figure 13. Relative water productivity (WP) of corn for a given SDI research study and year as related to the fraction of full irrigation, Colby, Kansas. After Lamm (2005).

This suggests that both water- and economically-efficient production potentially can be obtained with irrigation levels of approximately 80% of full irrigation across a wide range of weather conditions in many years on the soils in this region.

The weather conditions in the individual years can have a large effect on corn grain yield as affected by irrigation system type and irrigation capacity.

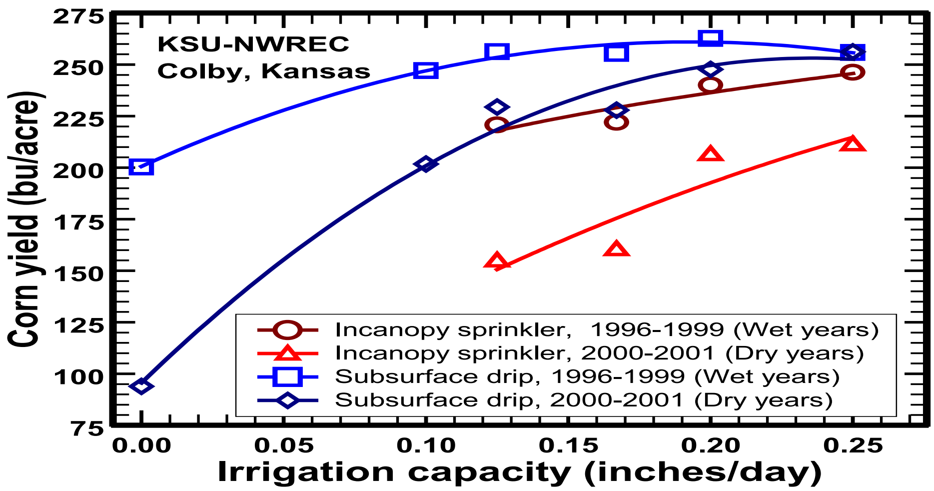

Figure 4. Corn yields for SDI and mid elevation spray application (MESA) sprinkler irrigation in wet years and dry years at Colby, Kansas. Note: Results are from different but similar studies, so these are not statistical differences.

CONCLUDING STATEMENTS

- Science-based, season long, day-to-day irrigation scheduling is a prerequisite to obtaining appropriate reductions in irrigation diversions.
- Irrigation scheduling and the data associated with its implementation inform many of the other techniques to potentially reduce irrigation diversions.
- Irrigation micromanagement decisions about irrigation season initiation and termination present large opportunities to reduce irrigation diversions, but they must be carefully determined using science-based information.
- Cultural practices such as tillage management and selection of appropriate plant density can affect crop yield and water productivity under reduced irrigation diversions.
- Irrigation requirements and the necessary irrigation capacity are quite variable between years.
- Common conditions or characteristics of the Central Great Plains affect selection of water saving techniques.

ACKNOWLEDGEMENTS

This paper was first presented at the Central Plains Irrigation Conference, Feb. 18-19, 2019, Burlington, Colorado.

REFERENCES

Denmead, O. T. and R.H. Shaw. 1962. Availability of soil water to plants as affected by soil moisture and meteorological conditions. Agron J. 45:385-390.

Hengeller, J. C., M. D. Dukes,and B. Q. Mecham. 2011. Irrigation scheduling. In Irrigation. Sixth Ed. (pp. 491-564). Falls Church, Virginia: The Irrigation Association.

Howell, T. A. 2001. Enhancing water use efficiency in irrigated agriculture. Agron J. 93(2):281-289.

Howell, T. A. and M. Meron. (2007) Irrigation scheduling. In: Microirrigation for Crop Production – Design, Operation, and Management. (pp. 61-130). Amsterdam, The Netherlands: Elsevier.

Lamm, F. R. 1997. Improvements in irrigation efficiency. In Proc. Central Plains Irrigation Short Course, Colby, KS, Feb. 4, 1997. Available from CPIA, 760 N. Thompson, Colby, KS. pp. 49-52. Also available at https://www.ksre.k-state.edu/irrigate/reports/Lamm_ImprovIrrigEff.pdf

Lamm, F. R. 2004. Comparison of SDI and Simulated LEPA Sprinkler Irrigation for Corn. In Proc. Irrigation Assn. Int'l. Irrigation Technical Conf., November 14-16, 2004, Tampa, FL. Available from Irrigation Assn., Falls Church VA. IA Paper No. IA04-1098. pp 475-485. Also available at http://www.ksre.ksu.edu/sdi/reports/2004/LS100104.pdf

Lamm, F. R. 2005. SDI for conserving water in corn production. In Proc. ASCE-EWRI Water Congress, May 15-19, 2005, Anchorage, AK. 12 pp. Also available at: http://www.ksre.ksu.edu/sdi/reports/2005/ASC000557.pdf

Lamm, F. R. 2017. Sprinkler irrigation management of modern corn hybrids under institutional constraints. In: Proc. 29th annual Central Plains Irrigation Conference, Feb. 21-22, 2017, Burlington, Colorado. Available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 53-65. Also available at: https://www.ksre.k-state.edu/irrigate/reports/r17/LammModCorn17.pdf

Lamm, F. R. 2018. Tillage management and sprinkler-irrigated corn production. In: Proc. 2018 Irrigation Association Technical Conference, Dec 4-6, Long Beach, CA. 7 pp. Also available at https://www.ksre.k-state.edu/irrigate/reports/r18/Lamm18TMforCP.pdf

Lamm, F. R. and A. A. Aboukheira. 2009. Corn irrigation macromanagement at the seasonal boundaries – Initiating and terminating the irrigation season. In: Proc. Central Plains Irrigation Conference, Colby, KS., Feb. 24-25, 2009. Available from CPIA, 760 N. Thompson, Colby, KS. pp. 40-60. Also available at https://www.ksre.k-state.edu/irrigate/oow/p09/Lamm09SB.pdf

Lamm, F. R. and D. H. Rogers. 2015. Irrigation scheduling remains important for low capacity systems. In: Proc. 27th annual Central Plains Irrigation Conference, Feb. 17-18, 2015, Colby, Kansas. Available from CPIA, 760 N. Thompson, Colby, Kansas. pp. 35-43. Also available at: https://www.ksre.k-state.edu/irrigate/reports/r15/Lamm15_IrrSched.pdf

Lamm, F. R., R. M. Aiken, and A. A. Aboukheira. 2009. Corn yield and water use characteristics as affected by tillage, plant density and irrigation. Trans ASAE: 52(1):133-143. Also available at https://www.ksre.k-state.edu/irrigate/reports/LammTIC09.pdf

Lamm, F. R., D. H. Rogers, and G. A. Clark. 1996. Irrigation Scheduling for Corn: Macromanagement. In: Proc. Evapotranspiration and Irrigation Scheduling Conf., San Antonio, TX, Nov. 3-6, 1996. pp. 741-748. ASAE. Also available at http://www.ksre.ksu.edu/irrigate/reports/macro.pdf

Lamm, F. R., D. H. Rogers, J.P. Aguilar and I. Kisekka. 2014. Deficit irrigation of grain and oilseed crops. In: Proc. 2014 Irrigation Association Technical Conference, Nov. 19-20, Phoenix, AZ. CD-Rom. 18 pp. Also at https://www.ksre.k-state.edu/irrigate/reports/LammDI_IASeminar14.pdf

Martin, D. L., E. C. Stegman, and E. Fereres. 1990. Irrigation scheduling principles. In Management of Irrigation Systems, (pp. 155-203). St. Joseph, Michigan: ASABE.

Rogers, D. H. (2009) Irrigation scheduling using KanSched for a range of weather conditions. In Proc. Central Plains Irrigation Conference, Colby, KS, Feb. 24-25, 2009. Available from CPIA, 760 N. Thompson, Colby, KS. pp. 66-73. Also available at: https://www.ksre.k-state.edu/irrigate/oow/p09/Rogers09KS.pdf

Rhoads F. M. and J. M. Bennett. 1990. Corn. Chapter 19 in Irrigation of Agricultural Crops. pp. 569-596. ASA-CSSA-SSSA, Mono No. 30, B. A. Stewart and D. R. Nielsen (Eds.). 1218 pp.

Shaw, R. H. 1988. Climate requirement. Chapter 10 in Corn and Corn Improvement. Third Edition. pp. 609-638. ASA-CSSA-SSSA, Mono No. 18, G. F. Sprague and J. W. Dudley (Eds.). 986 pp.

van Bavel, C. H. M. (1956) Estimating Soil Moisture Conditions and Time for Irrigation with the Evapotranspiration Method. USDA-ARS 41-11, Raleigh, North Carolina. 16 pp.

Yoshida, S. 1972. Physiological aspects of grain yield. Annu. Rev. Plant Physiol. 23:437-464.