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# IRRIGATION SCHEDULING
# REMAINS IMPORTANT FOR LOW CAPACITY SYSTEMS

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## ABSTRACT

Many irrigators in the Central Great Plains region do not use science-based irrigation scheduling for a variety of reasons, many of which are not strongly related to the technical feasibility. Evapotranspiration (ET)-based irrigation scheduling has been shown to be an acceptable irrigation scheduling method within the region. Many irrigators have expressed the rationale that there is no need to implement irrigation scheduling because their marginal capacity irrigation must be ran continually throughout the season to meet corn irrigation needs. ET-based irrigation schedules were simulated using 43 years (1972-2014) of weather data for Colby, Kansas to determine irrigation needs as affected by irrigation capacity, center pivot sprinkler system application efficiency and the initial soil water condition at corn emergence. 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 and 2.80 inches for a severely deficit 1 inch/8 day irrigation capacity. As application efficiency was decreased from 95% to 80% these savings for similar initial soil water conditions decreased from 6.93 to 2.64 inches for the greater and smaller irrigation capacities, respectively. Potential irrigation savings using an application efficiency of 95% were reduced but still appreciable when the initial soil water condition was 60% of field capacity averaging 6.06 and 1 inches for the 1 inch every 4 or 8 days irrigation capacities, respectively. 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.

## INTRODUCTION

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 60 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. 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.

Lack of adoption was recognized many years ago as a key problem to advancing irrigation scheduling. Behavior patterns and attitudes of irrigators were identified as more significant barriers to adoption than reliability and accuracy of scheduling methods (Shearer and Vomacil, 1981). The USDA-NRCS has offered cost-sharing for implementation of ET-based scheduling in several of the US Great Plains states. 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 interpreted by irrigators as a corn that needs less water. These examples suggest that some of the reasons for non-acceptance of irrigation scheduling are cultural and not strongly related to technical feasibility.

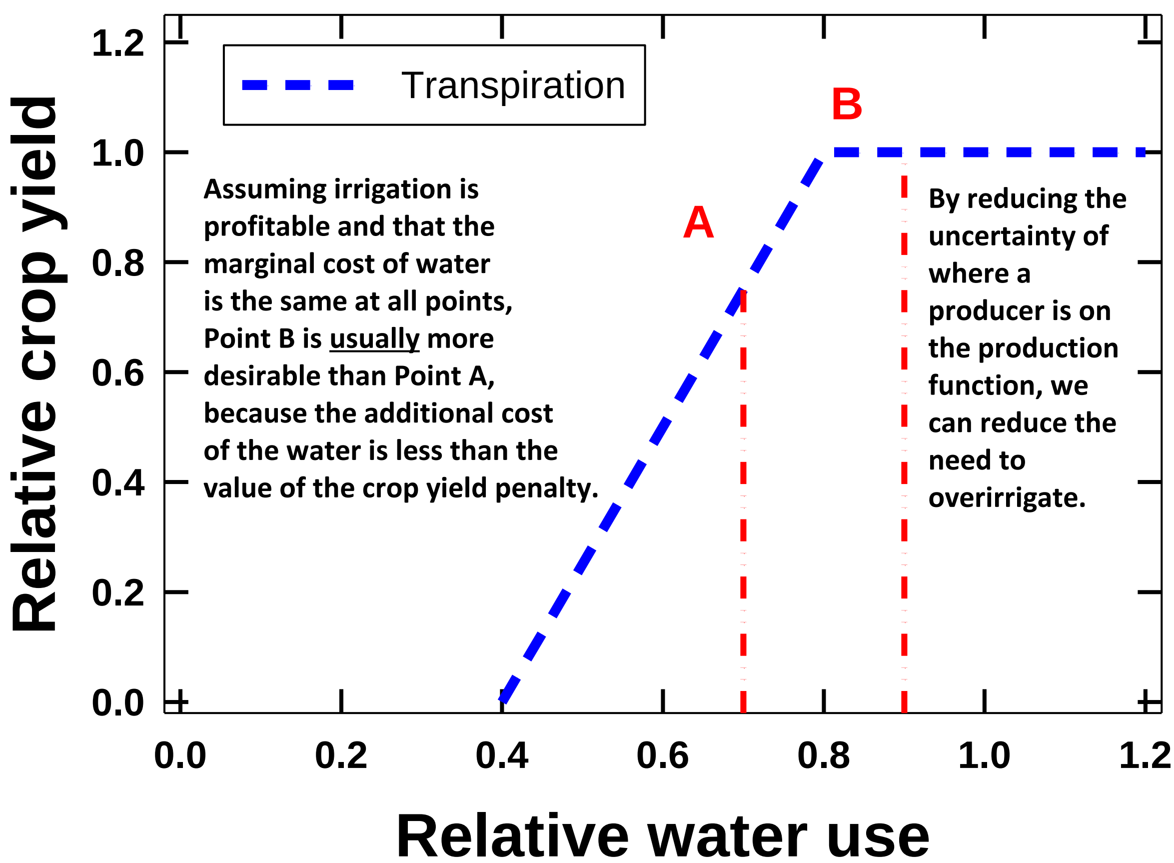


Figure 1. Effect of irrigation inaccuracy on crop production points. Adapted from discussion and graph in Lamm (1997).

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 (Rogers and Alam, 2007) 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. Since 1997, approximately 730 contracts have been issued in Kansas (Blume, 2014). Similar programs exist in other parts of the US Great Plains.

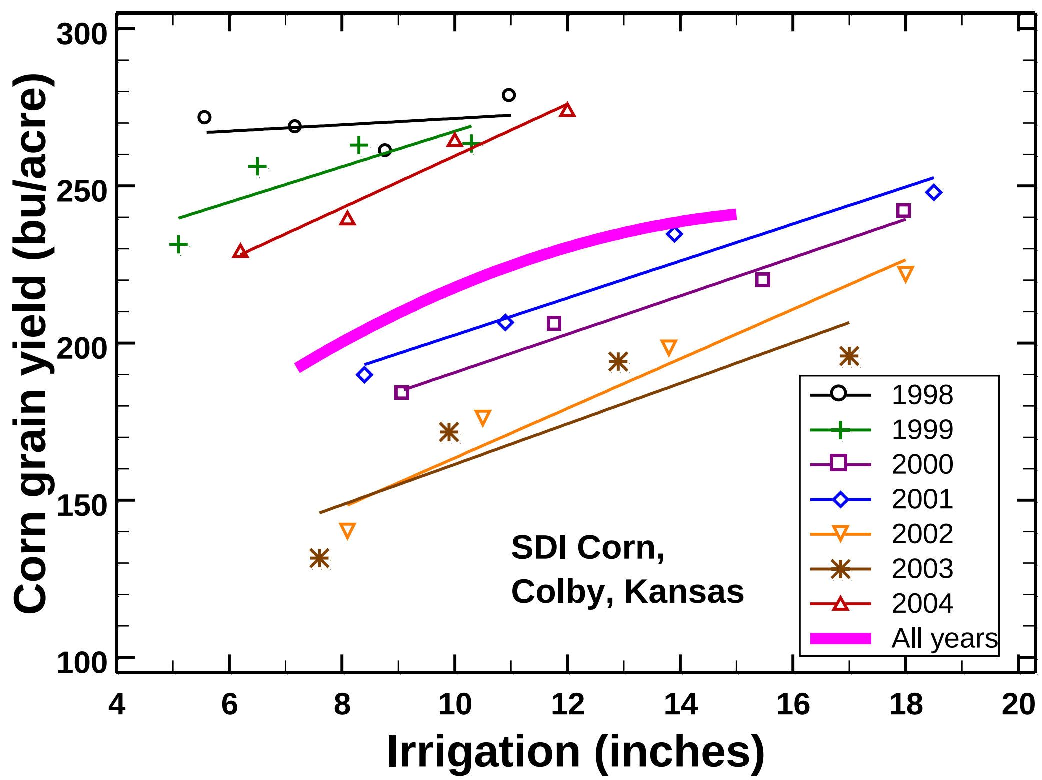


Figure 2. Corn yield response to subsurface drip irrigation (SDI) amount in seven different years, KSU Northwest Research-Extension Center, Colby, Kansas (data from Lamm, 2004). The boldface curve is the average of all seven years emphasizing that average values are insufficient for irrigation management 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).

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). The possible savings attributable to adoption of ET-based scheduling can be estimated from simulation modeling, so the goal of this paper is to more fully quantify these savings for irrigators.

# PROCEDURES

Weather data from 1972 through 2014 (43 years) for Colby, Kansas (Thomas County), collected at the Kansas State University Northwest Research-Extension Center, was used to simulate annual ET-based irrigation scheduling water budgets for corn (Zea mays L.) production. Briefly, the water budget model schedules a 1-inch irrigation event when two criteria are met. The first criterion was that there is at least 22% depletion of plant available water in the 5-ft. profile to allow storage of the irrigation event plus retaining some additional room for storage of precipitation. The 22% depletion is equivalent to approximately 3.2 inches of soil water storage. The second criterion is that there was sufficient irrigation capacity to conduct the event on that date. Irrigation capacities of 1 inch for 4, 5, 6, and 8 days were simulated at application efficiencies of 95% and 80% representing a typical range of efficiencies for center pivot sprinklers in the region (Howell, 2002). An irrigation capacity of 1 inch/4 days will typically approximate full irrigation on the deep silt loams and for the climatic conditions of this region (Lamm et al. 2007). The irrigation season was constrained to the 90-day period, June 5 through September 2 in all years which approximates the typical season for most irrigators in the region. This results in potential maximum seasonal gross irrigation applications of 23, 18, 15, and 12 inches for the irrigation capacities of 1 inch for 4, 5, 6, or 8 days, respectively. The irrigation scheduling water budget used in the simulations can be simplified to the following equation

$$S_c = S_p + P + I - R - F - ET \qquad \text{[Eq. 1]}$$

where Sc and Sp are the plant available soil water amounts in the soil profile on the current and preceding days, ET is daily crop evapotranspiration, R is irrigation runoff, P is effective precipitation, I is the irrigation water applied, and F is flux across the lower boundary of the control volume (taken as a depth well below the rooting depth), all in any consistent unit of length. Runoff was assumed to be controlled to negligible amounts by surface storage management with the exception of large rainfall events which were capped at a maximum infiltrated amount. Complete details of the model and the specific parameters used in the simulations are described in Lamm et al. (2007). Additionally, two initial soil water conditions at corn emergence were simulated, a wetter 85% of field capacity for the 5-ft soil profile and a drier 60% of field capacity.

Irrigation savings were calculated daily and accumulated throughout the season as the difference between full applications of the gross irrigation amount possible at a given capacity minus the gross irrigation amount predicted in the ET-based irrigation scheduling water budget for the same capacity. The probability of needing a given amount of irrigation was computed using a normal distribution for the mean and standard deviation values of the 43 years.

# RESULTS AND DISCUSSION

It should be reiterated that the model assumed two criteria must be satisfied before an irrigation event would be scheduled: 1) specified soil water depletion or greater is reached; and 2) irrigation capacity is sufficient to cycle the event on that day. Therefore, some of the marginal irrigation capacities examined here will not be sufficient during the greater water use periods towards the critical growth periods and crop yields would be reduced

Irrigation capacity had a great effect on the amount of irrigation that could be saved as would be anticipated. On average, the irrigation capacity of 1 inch/4 days had the potential of saving approximately 3 to 5 times more irrigation with ET-based irrigation scheduling than with the lowest 1 inch/8 day capacity for the range of application efficiencies and initial soil water scenarios evaluated (Table 1.). A greater portion of these savings for the greater capacities occurred during the early part of the irrigation season, as indicated by the increased slope on this portion of the curves (Figure 3), when irrigation capacity and increased chances for precipitation greatly exceed corn evapotranspiration. 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. This emphasizes the need to use season long day-to-day irrigation scheduling.

Table 1. Calculated seasonal gross irrigation amounts (inches) using ET-based irrigation scheduling for corn for the 90 day period (June 5-September 2) at various irrigation capacities using 43 years (1972-2014) of actual weather data from KSU Northwest Research-Extension Center, Colby, Kansas as affected by initial profile soil water conditions and sprinkler application efficiency. Sprinkler irrigation events were gross 1 inch applications. The 50% probability amount is equivalent to the actual average application due to the fact that a normal distribution was assumed in calculation of the probability.

| Irrigation capacity | Potential maximum application | Actual maximum application | Actual minimum application | 75% Probability of needing to apply less than | 50% Probability of needing to apply less than | 25% Probability of needing to apply less than |
|---|---|---|---|---|---|---|
| *Initial profile soil water condition, 85% of field capacity and sprinkler application efficiency of 95%* | | | | | | |
| 1 inch/4 d | 23.0 | 20.0 | 6.0 | 17.0 | 14.6 | 12.3 |
| 1 inch/5 d | 18.0 | 17.0 | 6.0 | 14.9 | 13.1 | 11.3 |
| 1 inch/6 d | 15.0 | 14.0 | 6.0 | 12.9 | 11.6 | 10.3 |
| 1 inch/8 d | 12.0 | 11.0 | 5.0 | 10.1 | 9.2 | 8.3 |
| *Initial profile soil water condition, 85% of field capacity and sprinkler application efficiency of 80%* | | | | | | |
| 1 inch/4 d | 23.0 | 21.0 | 7.0 | 18.3 | 16.1 | 13.8 |
| 1 inch/5 d | 18.0 | 18.0 | 6.0 | 15.4 | 13.8 | 12.2 |
| 1 inch/6 d | 15.0 | 15.0 | 6.0 | 13.4 | 12.1 | 10.8 |
| 1 inch/8 d | 12.0 | 12.0 | 6.0 | 10.2 | 9.4 | 8.5 |
| *Initial profile soil water condition, 60% of field capacity and sprinkler application efficiency of 95%* | | | | | | |
| 1 inch/4 d | 23.0 | 23.0 | 7.0 | 19.7 | 16.9 | 14.2 |
| 1 inch/5 d | 18.0 | 18.0 | 8.0 | 17.0 | 15.2 | 13.3 |
| 1 inch/6 d | 15.0 | 15.0 | 9.0 | 14.7 | 13.6 | 12.4 |
| 1 inch/8 d | 12.0 | 12.0 | 7.0 | 11.9 | 11.0 | 10.2 |
| *Initial profile soil water condition, 60% of field capacity and sprinkler application efficiency of 80%* | | | | | | |
| 1 inch/4 d | 23.0 | 23.0 | 10.0 | 21.5 | 19.2 | 16.8 |
| 1 inch/5 d | 18.0 | 18.0 | 10.0 | 17.8 | 16.4 | 14.9 |
| 1 inch/6 d | 15.0 | 15.0 | 10.0 | 15.0 | 14.0 | 13.0 |
| 1 inch/8 d | 12.0 | 12.0 | 8.0 | 12.0 | 11.3 | 10.5 |

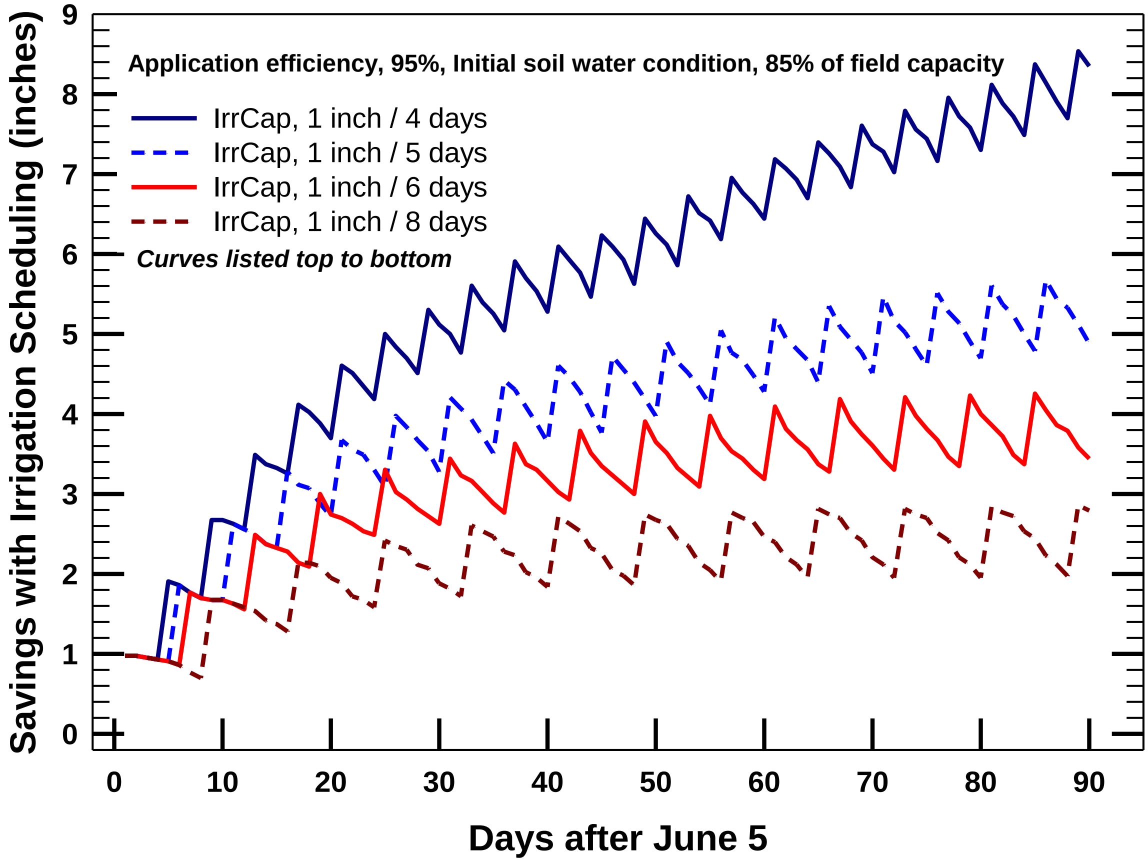


Figure 3. Average savings of irrigation that could be obtained with ET-based irrigation scheduling as compared to maximum seasonal applications possible with various irrigation capacities for an application efficiency of 95% and an initial soil water condition of 85% of field capacity as determined in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

Greater irrigation system application efficiency (Ea) increases the possibility for saving irrigation with ET-based irrigation scheduling (Table 1 and Figure 4). Potential irrigation savings for the 95% application efficiency compared to 80% at the 85% of field capacity initial soil water condition ranged from 6% for the 1 inch/8 day irrigation capacity (2.80 vs. 2.64 inches) to 20% for the 1 inch/4 day irrigation capacity (8.35 vs 6.93 inches) emphasizing the importance of increasing application efficiency whenever it is economically and technically practical to do so. The effect of increasing Ea from 80 to 95% for the drier initial soil water condition (60% of field capacity) was even greater, ranging from 31 to 58% across the range of irrigation capacities evaluated. This increase occurs because the drier initial soil water condition results in greater irrigation needs during the season (Table 1).

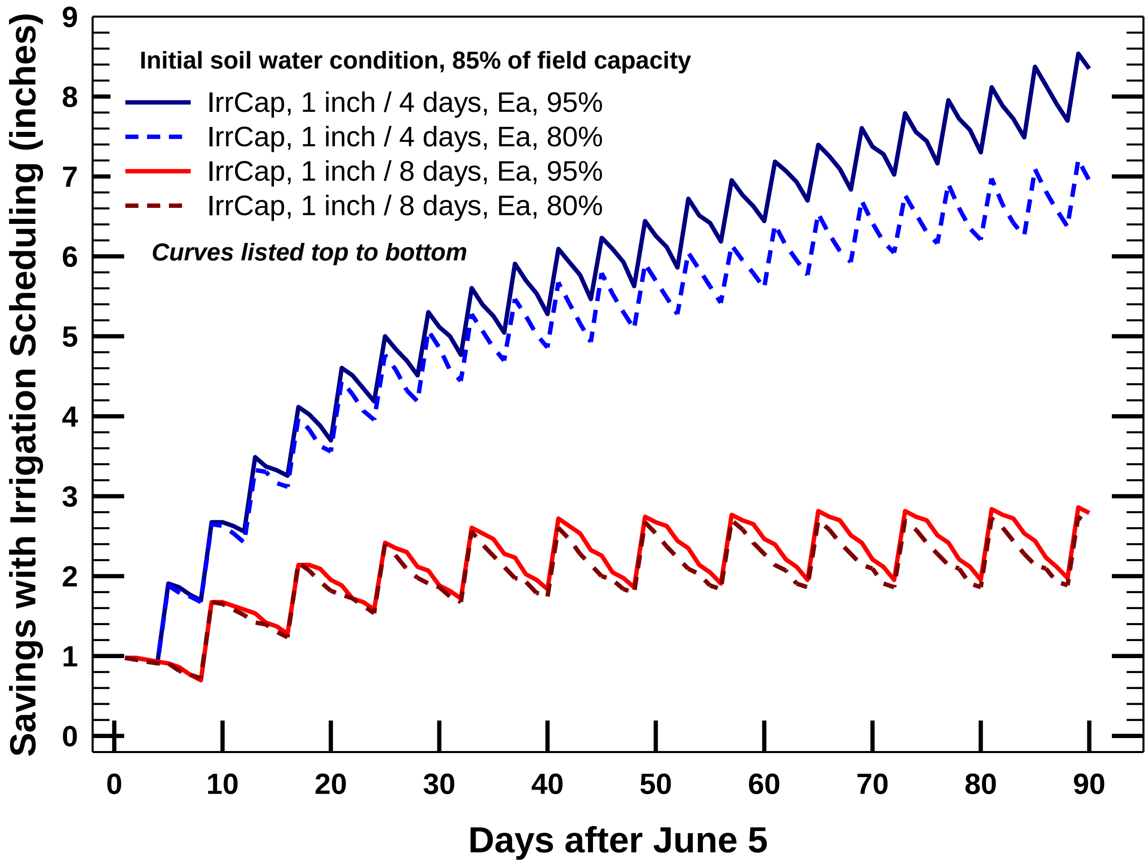


Figure 4. Average savings of irrigation that could be obtained with ET-based irrigation scheduling as compared to maximum seasonal applications possible as affected by sprinkler application efficiency, Ea, for an initial soil water condition of 85% of field capacity for irrigation capacities of 1 inch every 4 or 8 days as determined in simulation modeling for 43 years of weather data, Colby, Kansas.

Greater initial soil water greatly increased the potential savings that could be obtained with adoption of ET-based irrigation scheduling (Table 1 and Figure 5) because of the opportunity to avoid some early season irrigation events with the greater soil water reserves at a time when evapotranspiration is reduced and chances for appreciable precipitation are greater. When the initial soil water condition is only 60% of field capacity and the irrigation capacity is restricted to only 1 inch/8 days, then the average potential irrigation savings is essentially just a single 1-inch event. However, when considering the range of 43 years examined there was one year where over 4 inches could have been saved even with this severely restricted scenario. Considering the fact that most of the marginal system capacities are also related to groundwater wells with reduced and declining saturated thicknesses, saving any water in these restricted scenarios may extend the longevity of irrigation for those wells. Additionally, one nearby area in Kansas has converted their fixed water application water rights to flexible five-year accounts, where water saved in one year might be utilized in a subsequent more water-stressed year.

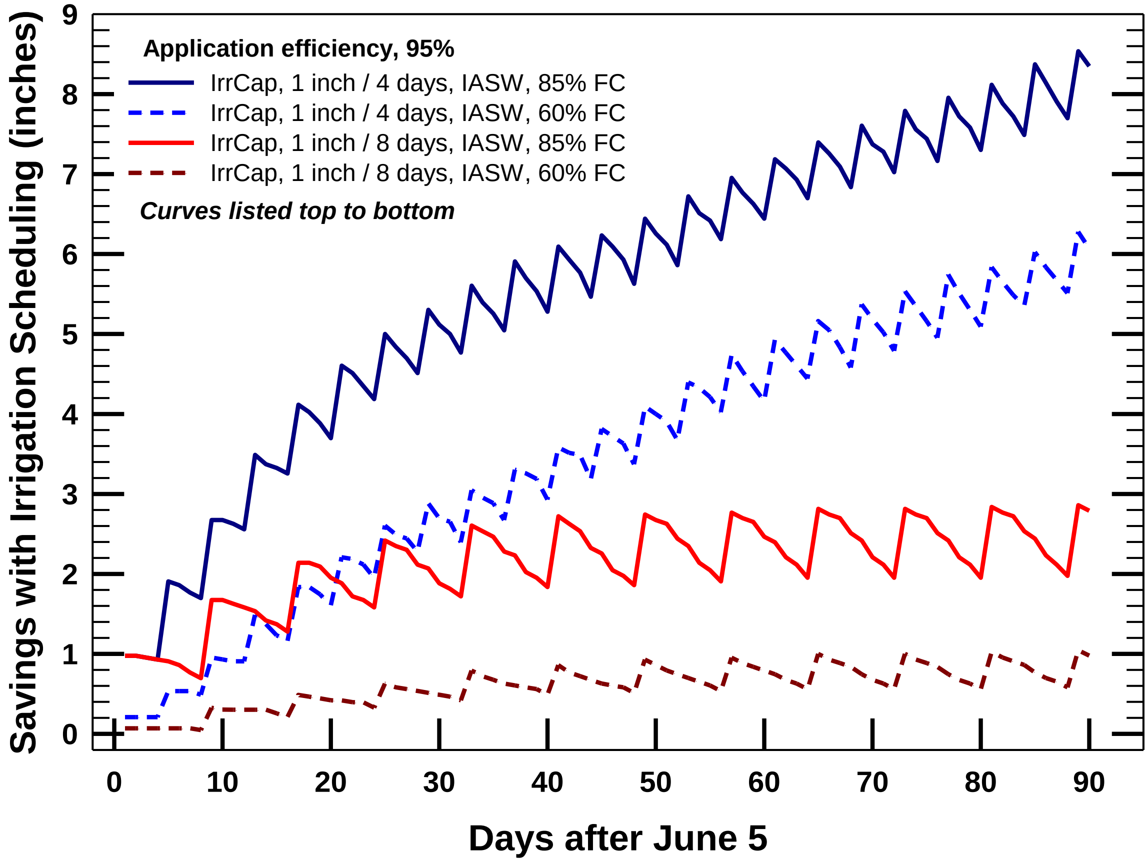


Figure 5. Average savings of irrigation that could be obtained with ET-based irrigation scheduling as compared to maximum seasonal applications possible with initial soil water conditions of 85% and 60% of field capacity for irrigation capacities of 1 inch every 4 or 8 days for an application efficiency of 95% as determined in simulation modeling for 43 years of weather data, Colby, Kansas.

## CONCLUSION

Considerable water savings are possible when ET-based irrigation scheduling is adopted for marginal capacity irrigation systems. Although these potential savings are increased for greater irrigation capacity systems, for systems with greater application efficiencies and for situations where initial soil water conditions are wetter, there are potential savings even under very restricted scenarios. The importance of science-based irrigation scheduling should not be discounted by irrigators just because they typically are operating in a deficit condition. Consistent, season-long use of science-based irrigation scheduling, such as the ET-based water budgets used in this study, can point out the opportunities and timing of when irrigation systems can be temporarily shut off.

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*Lamm, F. R. and D. H. Rogers. 2015. The importance of irrigation scheduling for marginal capacity systems growing corn. Applied Engineering in Agric. (Accepted for publication, 12-09-14).*
It is excerpted here in traditional English units.


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