TECHNICAL NOTE:

THE IMPORTANCE OF IRRIGATION SCHEDULING FOR MARGINAL CAPACITY SYSTEMS GROWING CORN

F. R. Lamm, D. H. Rogers

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 212 mm of water for a 25.4 mm/4 days irrigation capacity and 71 mm for a severely deficit 25.4 mm/8 day irrigation capacity. As application efficiency was decreased from 95% to 80% these savings for similar initial soil water conditions decreased from 176 to 67 mm 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 154 and 25 mm for the 25.4 mm 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.*

Keywords. *Corn, Evapotranspiration, Irrigation management, Irrigation scheduling, Water budget.*

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.

Submitted for review in September 2014 as manuscript number NRES 10966; approved as a Technical Note for publication by the Natural Resources & Environmental Systems Community of ASABE in December 2014.

The authors are **Freddie R. Lamm, ASABE Member,** Professor and Research Irrigation Engineer, Northwest Research-Extension Center, Kansas State University, Colby, Kansas; and **Danny H. Rogers, ASABE Fellow,** Professor and Extension Irrigation Engineer, Biological and Agricultural Engineering, Kansas State University, Manhattan, Kansas. **Corresponding author:** Freddie Lamm, P.O. Box 505, 105 Experiment Farm Road, Colby, KS 67701; phone: 785-462-6281; e-mail: flamm@ksu.edu.

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). They further concluded it was difficult to get long-term acceptance of irrigation scheduling without continuing technical support from cooperative extension or others. Although anecdotal, it seems wise to mention some of the experiences the authors have had over the years with irrigators concerning acceptance of science-based irrigation scheduling. Several irrigators have expressed a concern for accuracy of ET estimates (either too great or too small), although often being an irrational concern about accuracy (i.e., irrigators wanting one order of magnitude greater accuracy than their control on applied irrigation amounts). The USDA-NRCS has offered cost-sharing for implementation of ET-based scheduling in several of the U.S. Great Plains states. On more than one occasion, irrigators have unsuccessfully approached the authors after the irrigation season for ex post facto assistance in creating irrigation schedules to satisfy their USDA-NRCS contract. 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

Vol. 31(2): 261-265 ISSN 0883-8542 DOI 10.13031/aea.31.10966

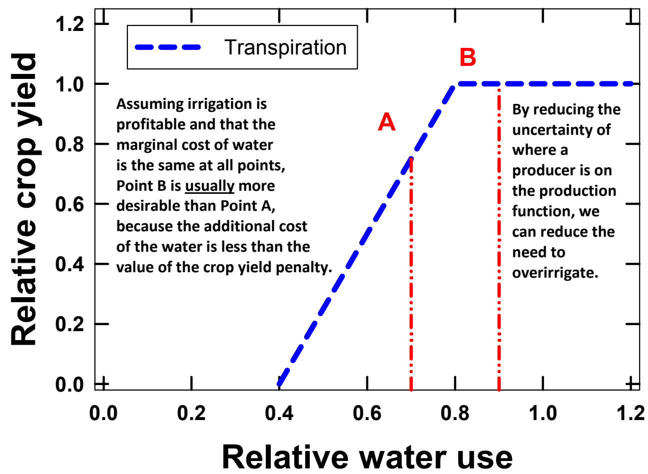

Figure 1. Effect of irrigation inaccuracy on crop production points. Adapted from discussion and graph in Lamm (1997).

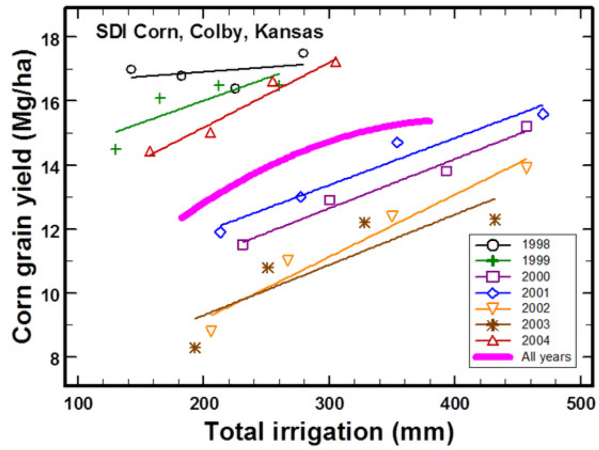

Figure 2. Corn yield response to subsurface drip irrigation (SDI) amount in seven different years, KSU Northwest Research-Extension Center, Colby, Kansas (data from Lamm, 2004). The boldface curve is the average of all seven years emphasizing that average values are insufficient for irrigation management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

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 resistant 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. Still, when asked in an extensive 1990 survey, the most strongly preferred water saving management practice indicated by High Plains irrigators was irrigation scheduling with over 53% willing to adopt this practice voluntarily (Kromm and White, 1990). They also found little to no differences in acceptance in north to south counties within the High Plains. This survey suggests that irrigators are willing to consider using irrigation scheduling.

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 figure 2, averaging several years of data will result in a smooth yield/irrigation 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. On the deep silt loam soils of western Kansas, ET-based water budget irrigation scheduling is often an easy and acceptable method. In demonstration projects in South Central Kansas, ET-based irrigation scheduling calculated from weather data was tested against ET data from atmometers (tool for measuring the rate of water evaporation to the atmosphere when equipped with the proper evaporation cover to simulate the reference ET) (Rogers et al., 1997; Clark et al., 1998). The irrigators soon developed confidence in the weather station values that matched the field atmometer readings, and they recognized that weather station values were much easier to obtain than traveling to the field and reading the atmometer. 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 (H. Blume, 2014, personal communication, USDA-NRCS, Kan.). Similar programs exist in other parts of the U.S. Great Plains.

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, opportunities remain 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 article is to more fully quantify these savings for irrigators.

PROCEDURES

The study was conducted in northwest Kansas, a semi-arid region with summer pattern rainfall and deep silt loam soils. Argiustolls-Haplustolls soils are typical to the region and are well drained and have good available soil water holding capacities of approximately 180 mm/m of profile. Annual rainfall at the location averages 481 mm with 374 mm of that occurring during the April through September period. 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

25.4 mm irrigation event when two criteria are met. The first criterion was that there is at least 22% depletion of plant available water in the 1.5 m profile to allow storage of the irrigation event plus retaining some additional room for storage of precipitation. The 22% depletion is equivalent to approximately 80 mm of soil water storage. The second criterion is that there was sufficient irrigation capacity to conduct the event on that date. Irrigation capacities of 25.4 mm 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 25.4 mm/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, 5 June through 2 September in all years which approximates the typical season for most irrigators in the region. This results in potential maximum seasonal gross irrigation applications of 584, 457, 381, and 305 mm for the irrigation capacities of 25.4 mm for 4, 5, 6, or 8 days, respectively. The irrigation scheduling water budget used in the simulations can be simplified to the following equation:

$$S_c = S_p + P + I - R - F - ET \quad (1)$$

where S_c and S_p 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 1.5 m soil profile and a drier 60% of field capacity. Irrigators in the region are typically leaving soil profiles at 60% of field capacity or greater after corn harvest even in severe drought years (Lamm et al., 2012). Overwinter and spring precipitation would typically increase the soil water reserves before emergence of the corn.

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. These constraints would describe practical operating procedures for the irrigator, avoiding irrigation when the soil profile is reasonably full and scheduling only events when they could possibly be accomplished. 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. However, conducting additional irrigation events water earlier in the season onto soil profiles with little or no depletion is inefficient and should be avoided.

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 25.4 mm/4 days had the potential of saving approximately 3 to 5 times more irrigation with ET-based irrigation scheduling than with the lowest 25.4 mm/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 (fig. 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.

Greater irrigation system application efficiency (Ea) increases the possibility for saving irrigation with ET-based irrigation scheduling (table 1 and fig. 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 25.4 mm/8 day irrigation capacity (71 vs. 67 mm) to 20% for the 25.4 mm/4 day irrigation

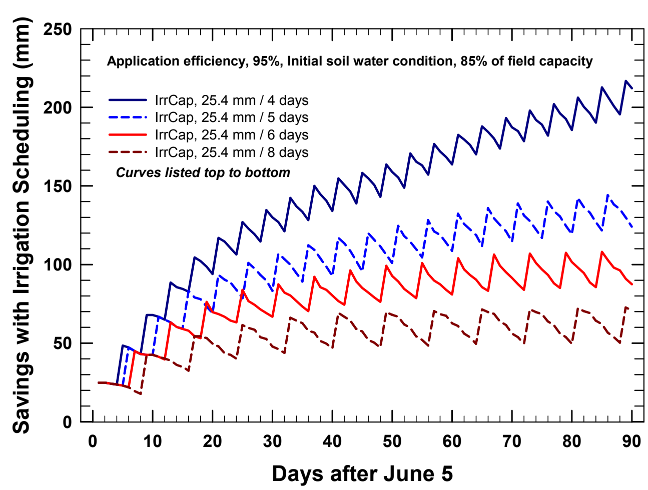

Figure 3. Average savings of irrigation that could be obtained with ET-based irrigation scheduling as compared to maximum seasonal applications possible with various irrigation capacities for an application efficiency of 95% and an initial soil water condition of 85% of field capacity as determined in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

Table 1. Calculated seasonal gross irrigation amounts (mm) using ET-based irrigation scheduling for corn for the 90 day period (5 June – 2 September) 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.[a] [b]

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%						
25.4 mm/4 d	584	508	152	431	372	313
25.4 mm/5 d	457	432	152	379	333	287
25.4 mm/6 d	381	356	152	327	294	261
25.4 mm/8 d	305	279	127	257	234	211
Initial Profile Soil Water Condition, 85% of Field Capacity and Sprinkler Application Efficiency of 80%						
25.4 mm/4 d	584	533	178	465	408	350
25.4 mm/5 d	457	457	152	392	350	309
25.4 mm/6 d	381	381	152	340	307	274
25.4 mm/8 d	305	305	152	260	238	216
Initial Profile Soil Water Condition, 60% of Field Capacity and Sprinkler Application Efficiency of 95%						
25.4 mm/4 d	584	584	178	500	430	360
25.4 mm/5 d	457	457	203	432	385	337
25.4 mm/6 d	381	381	229	374	345	316
25.4 mm/8 d	305	305	178	302	280	258
Initial Profile Soil Water Condition, 60% of Field Capacity and Sprinkler Application Efficiency of 80%						
25.4 mm/4 d	584	584	254	547	487	427
25.4 mm/5 d	457	457	254	453	416	379
25.4 mm/6 d	381	381	254	380	356	331
25.4 mm/8 d	305	305	203	305	286	267

[a] Sprinkler irrigation events were gross 25.4 mm applications.
[b] 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.

capacity (212 vs. 176 mm) 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).

Greater initial soil water greatly increased the potential savings that could be obtained with adoption of ET-based irrigation scheduling (table 1 and fig. 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 25.4 mm/8 days, then the average potential irrigation savings is essentially just one 25.4 mm event. However, when considering the range of 43 years examined there was one year where over 102 mm 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

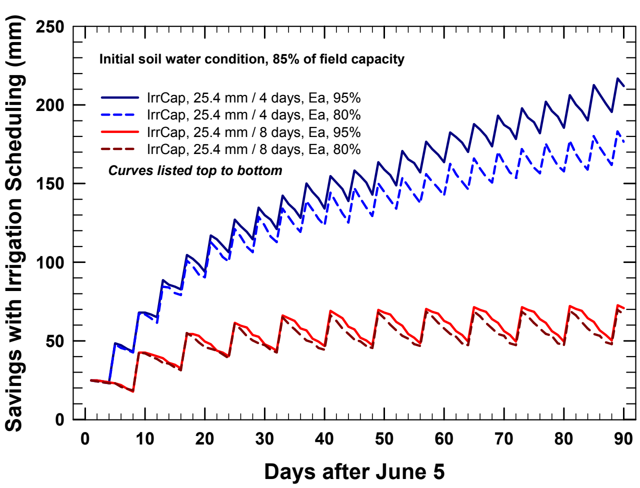

Figure 4. Average savings of irrigation that could be obtained with ET-based irrigation scheduling as compared to maximum seasonal applications possible as affected by sprinkler application efficiency, Ea, for an initial soil water condition of 85% of field capacity for irrigation capacities of 25.4 mm every 4 or 8 days as determined in simulation modeling for 43 years of weather data, Colby, Kansas.

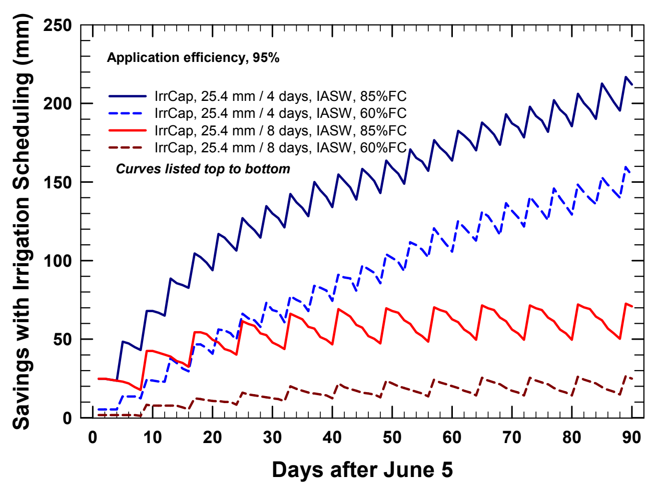

Figure 5. Average savings of irrigation that could be obtained with ET-based irrigation scheduling as compared to maximum seasonal applications possible with initial soil water conditions of 85% and 60% of field capacity for irrigation capacities of 25.4 mm every 4 or 8 days for an application efficiency of 95% as determined in simulation modeling for 43 years of weather data, Colby, Kansas.

of irrigation for those wells. Additionally, one nearby area in Kansas has converted their fixed water application water rights to flexible 5-year accounts, where water saved in one year might be utilized in a subsequent more water-stressed year.

Conclusions

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.

Acknowledgements

Contribution no. 15-209-J from the Kansas Agricultural Experiment Station, Kansas State University, Manhattan, Kansas.

References

Clark, G. A., Fjell, D. L., Martin, V., Rogers, D. H., & Stratton, R. (1998). On-farm irrigation management studies in central Kansas. ASAE Paper No.982070. St. Joseph, Mich.: ASAE.

Hengeller, J. C., Dukes, M. D., & Mecham, B. Q. (2011). Irrigation scheduling. In *Irrigation* (6th ed., pp. 491-564). Falls Church, Va.: The Irrigation Association.

Howell, T. A. (2002). Irrigation scheduling efficiencies. *Proc. Central Plains Irrigation Short Course* (pp. 80-92). Colby, Kan.: CPIA.

Howell, T. A., & Meron, M. (2007). Irrigation scheduling. In: *Microirrigation for Crop Production—Design, Operation, and Management* (pp. 61-130). Amsterdam, The Netherlands: Elsevier. http://dx.doi.org/10.1016/S0167-4137(07)80006-0.

Kromm, D. E., & White, S. E. (1990). Conserving water in the High Plains. Manhattan, Kan.: Kansas State University.

Lamm, F. R. (1997). Improvements in irrigation efficiency. *Proc. Central Plains Irrigation Short Course.* (pp. 49-52). Colby, Kan.: CPIA.

Lamm, F. R. (2004). Comparison of SDI and simulated LEPA sprinkler irrigation for corn. IA Paper No. IA04-1098. *Proc. Irrigation Assn. Intl. Irrigation Tech. Conf.* (pp. 475-485). Falls Church, Va.: Irrigation Assn.

Lamm, F. R., Rogers, D. H., Schlegel, A. J., Klocke, N. L., Stone, L. R., Aiken, R. M., & Shaw, L. K. (2012). Assessment of plant available soil water on producer fields in western Kansas. *Proc. 24th Ann. Central Plains Irrigation Conf.* (pp. 37-50). Colby, Kan.: CPIA.

Lamm, F. R., Stone, L. R., & O'Brien, D. M. (2007). Crop production and economics in northwest Kansas as related to irrigation capacity. *Appl. Eng. Agric., 23*(6), 737-745. http://dx.doi.org/10.13031/2013.24057.

Martin, D. L., Stegman, E. C., & Fereres, E. (1990). Irrigation scheduling principles. In *Management of Irrigation Systems* (pp. 155-203). St. Joseph, Mich.: ASAE.

Rogers, D. H. (2009). Irrigation scheduling using KanSched for a range of weather conditions. *Proc. Central Plains Irrigation Conf.* (pp. 66-73). Colby, Kan.: CPIA.

Rogers, D. H., & Alam, M. (2007). KanSched2—An ET-based irrigation scheduling tool users guide. Electronic Publication EP-129 (12 pp.). Kansas State Univ. Research and Extension. Retrieved from http://www.ksre.ksu.edu/library/ageng2/EP129.pdf.

Rogers, D. H., Clark, G. A., Martin, V. L., & Fjell, D. L. (1997). South Central Kansas ET scheduling and irrigation management demonstration project. ASABE Section Meeting Paper No. MC97-101. St. Joseph, Mich.: ASAE.

Shearer, M. N., & Vomacil, J. (1981). Twenty-five years of modern irrigation scheduling promotional efforts. *Proc. Irrigation Scheduling for Water and Energy Conservation in the 80's.* (pp. 208-212). St. Joseph, Mich.: ASAE.

van Bavel, C. H. M. (1956). Estimating soil moisture conditions and time for irrigation with the evapotranspiration method (16 pp). USDA-ARS 41-11. Raleigh, N.C.: USDA-ARS.