Irrigation Scheduling For Corn: Macromanagement

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ABSTRACT

Corn irrigation scheduling issues such as initiation and termination of the irrigation season, determining the need for dormant season irrigation, and non-crop water decisions are defined as macromanagement in this discussion. Macromanagement can have a significant effect on water conservation and production. The water conservation and crop production advantages of efficient step-by-step irrigation scheduling using the crop water balance can be greatly reduced by inappropriate macromanagement. Irrigators should use sound rationale for macromanagement. In some cases, researchers need to develop, re-evaluate or update macromanagement procedures.
Keywords: Irrigation strategies, Irrigation management, Water conservation, Zea mays L., Maximum allowable deficit (MAD)

INTRODUCTION

Corn (Zea mays L.) is a major irrigated crop in the Central Great Plains (USA). Any realistic attempt to reduce irrigation withdrawals from the Ogallala Aquifer must address this fact. A number of excellent irrigation scheduling methods for corn can be used to schedule irrigation on a real time, daily, or short-term basis throughout the season. These methods of irrigation scheduling achieve water conservation by delaying any unnecessary irrigation event with the prospect that the irrigation season might end before the next irrigation event is required. However, larger irrigation management issues can have a greater impact on water conservation than the step-by-step, periodic scheduling procedures. These include strategies for initiation and termination of the irrigation season, determining the need for dormant-season irrigation, and noncrop water issues (i.e. reducing soil water for dormant season water quality management). Macromanagement strategies can provide the potential for increased water conservation when used in conjunction with the step-by-step periodic scheduling procedures.

This paper will discuss macromanagement using research-based rationale for corn irrigated with groundwater in the semi-arid Central Great Plains, but has implications for other regions and other crops. An implicit assumption of the concepts is that efficient irrigation scheduling based on the crop water balance is used throughout the irrigation season.

INITIATION OF IRRIGATION SEASON

The date for the first irrigation can usually be effectively determined by comparing the daily calculated rootzone soil water balance to a preset maximum allowed deficit (MAD). The MAD is often assumed to be 50% of the available soil water in the active crop rootzone, but soil and climate conditions and irrigator judgment may dictate other criteria. The soil water balance is initialized with a measured or assumed initial soil water condition. The initial measurements or assumptions

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must be appropriate for the given year. For example, excessive temperatures can limit early season root growth and thus limit the rootzone available to the corn crop. Similarly, if irrigation with discrete application has been used, such as furrow or line-source drip irrigation, measurements or assumptions need to be based on the active rootzone, not the wetted portion of the soil. In some cases, additional irrigation may be required to satisfy this early-season rootzone distribution. This event can have a low application efficiency due to increased percolation and due to applications to nonrootzone areas. Furrow irrigators may initiate the first irrigation following the last cultivation or furrowing process to eliminate water stress associated with root pruning and to help seal soft furrows, rather than an irrigation need dictated by the crop water balance. Irrigators should carefully evaluate the need for these additional or early irrigations which are not dictated by the soil water balance if water conservation is important. This is particularly true in areas with a continental climate where there is a high probability of precipitation exceeding the early season corn evapotranspiration (ET).

Simulations of sprinkler irrigation schedules for corn (1972-1993) at Colby, Kansas indicate the first 25 mm irrigation event occurs between June 5 and July 5, with most years between June 10 and June 15 (Lamm et al. 1994a). Some irrigators with low capacity irrigation systems start irrigation sooner than normal. The simulations indicate that usually there is no need to start irrigating in northwest Kansas before June 10 unless the soil profile is extremely dry from the previous crop or from a dry overwinter period. Crop water stress problems associated with decreased irrigation capacity in July and August is not alleviated by the excess system capacity in June, when the soil profile is already relatively full of water. An overall point of the simulations that should not be missed is the variability in initial irrigation dates. An objective of step-by-step irrigation scheduling is to delay irrigation until necessary in hopes of replenishment by natural precipitation. Proper determination of the first irrigation date is an important step in water conservation. Irrigators should use crop water balances and/or soil water measurements to establish the first irrigation date and not rely on traditional calendar dates.

TERMINATION OF IRRIGATION SEASON

Conceptually, the irrigation season is terminated when the marginal cost of additional irrigation equals the marginal benefits of the harvested economic yield of the crop (quantity and quality). Two noteworthy points of wording in the previous statement should be made. First, in many cases, the cost of deep percolation caused by additional late-season irrigation has not been assessed. If groundwater contamination due to excessive percolation is a concern, then the marginal cost of irrigation must reflect that fact. The second point is that the marginal costs must be balanced against the harvested economic yield. For example, if the termination decision (early or late) affects harvesting, (lodging due to water stress or harvesting delays due to wet soils) then the actual economic yield could be reduced in a way not traditionally considered.

From a practical standpoint, termination of the irrigation season is most effectively determined by comparing the anticipated soil water balance at physiological maturity to the MAD. It should be noted that the MAD for the end of the season may not be the same as at other growth stages during the season. Doorenbos and Kassam (1979) indicate the MAD may approach 80% near physiological maturity for corn. The MAD point should be established according to crop sensitivity and the maximum daily ET during the period in question. They list MAD values of 0.8, 0.6 and 0.5 for maximum corn ET values of 3, 5 and 7 mm/day, respectively. Extension publications from the Central Great Plains often suggest limiting the MAD at the end of the season to 0.6 in the top 1-1.2 m (Rogers, 1995; Klocke et al., 1991). These values may need to be re-evaluated and perhaps adjusted downward (smaller MAD value). Lamm et al. (1995) found subsurface, drip-irrigated corn yields in northwest Kansas to begin to decrease rapidly when available soil water in the top 2.4 m was lower than 56-60% of field capacity for extended periods in July and August. Lamm et al., (1994b) permitted small daily deficits to accumulate on surface-irrigated corn after tasseling, and subsequent analysis of those data showed declining yields when available soil water levels approached 60% of field capacity for a 1.5-m soil profile at physiological maturity (Fig. 1). Current high corn yield levels may require greater available soil water levels than were used in earlier studies. The anticipated soil water balance at physiological maturity is projected from historical ET and precipitation data. Irrigators should time the last irrigation to ensure a reasonable probability of remaining above the chosen MAD level at physiological maturity. In the absence of good historical estimates of ET, extension publications are available that give crop water use values for the latter part of the season (Klocke et al., 1991).

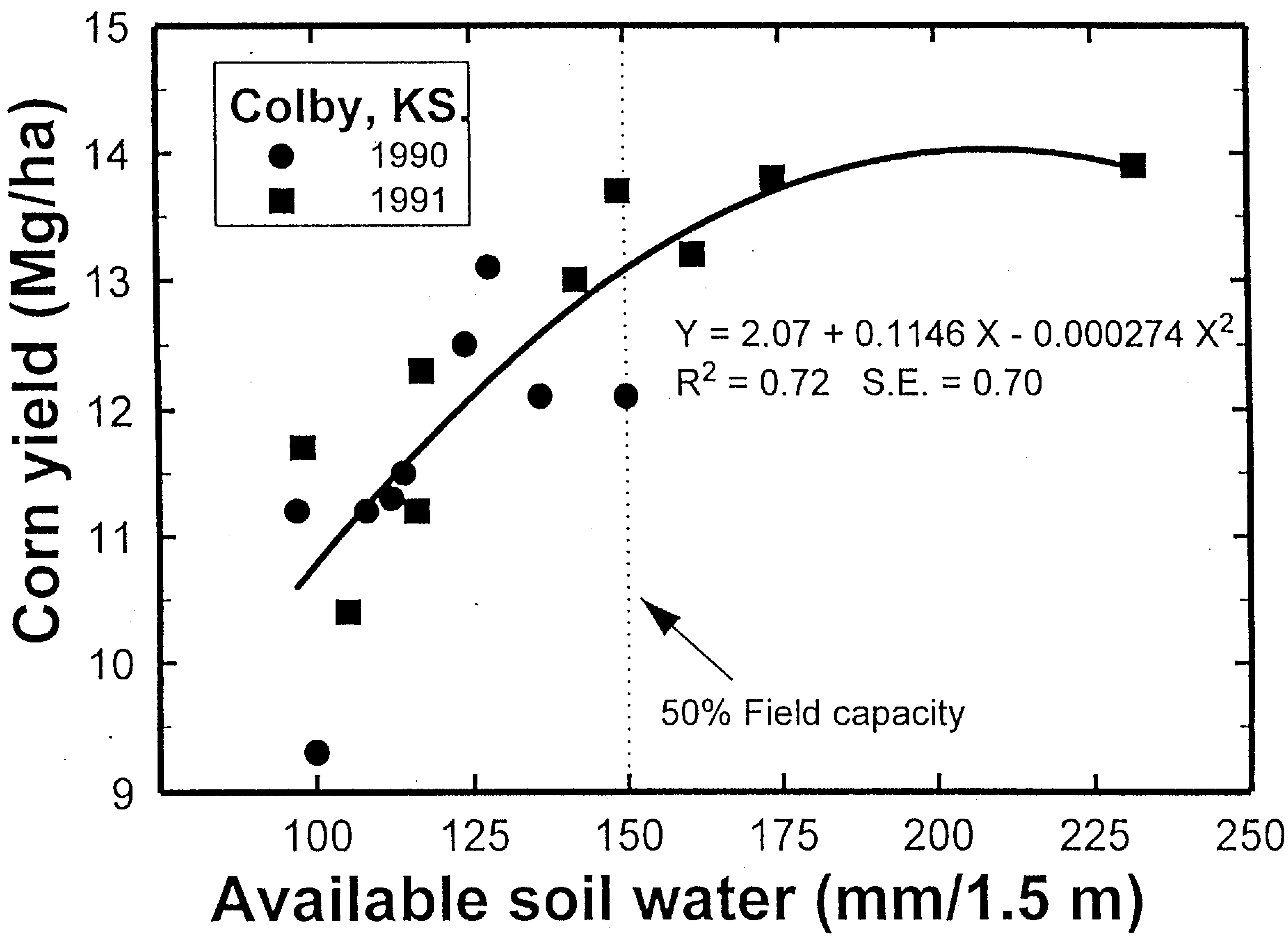

Figure 1. Corn yields as related to available soil water (ASW) in a 1.5-m soil profile at harvest in an irrigation-scheduling study where slight deficits were allowed to occur after tasseling. Data analyzed from Lamm et al., (1994b).

PRESEASON IRRIGATION

The advantages of preseason irrigation (Musick and Lamm 1990) are to 1) provide water for seed germination; 2) delay the initiation of seasonal irrigation; 3) improve tillage and cultural practices associated with crop establishment; and 4) more fully utilize marginal irrigation systems on additional land area. The disadvantages are that it may 1) increase production costs; 2) increase irrigation requirements; 3) lower overall irrigation efficiencies; and 4) lower soil temperatures. Preseason irrigation for crops such as corn has been advocated for the semi-arid Great Plains for most of the 20th century, and the practice has been debated for nearly as long. Knorr (1914) found that at Scottsbluff, Nebraska, fall irrigation normally increased corn yields. Farrell and Aune (1917) found opposite results at Belle Fourche, South Dakota. Knapp (1919) recommended winter irrigation for most of western Kansas with the exception of sandy soils. Off-season labor utilization was seen as an important factor, along with avoiding conflicts with busy summer schedules. Power et al. (1973) in a North Dakota study found that when fall irrigation was practiced, nearly all the winter precipitation was lost. On dryland plots, significant amounts of soil water were stored during the winter. Adding fall irrigation to normal seasonal irrigation did not significantly affect yields of barley or of corn silage. Hobbs and Krogman (1971), finding that storage efficiency of winter precipitation decreased as fall irrigation increased, concluded that fall irrigation to bring soil water in the profile to 50% of field capacity would be advisable. Stone et al. (1981), at Tribune, Kansas, reported that the net benefit of additional irrigation decreased linearly with increases in soil-water content in the fall. There were no significant differences in corn yields (Stone, et al. 1982) between fields irrigated in the fall and those not irrigated in the fall. They concluded that fall irrigation to bring soil water in the profile to approximately 50% of field capacity was an efficient practice. Willis et al. (1961) observed that fall irrigation subsequently increased runoff during natural precipitation, thus contributing to inefficient water storage. Stone et al. (1994) concluded irrigation water should be reserved for inseason application unless needed for stand establishment. Despite considerable controversy over preseason irrigation for corn, it remains a common practice in parts of the Great Plains. Greb (1979) advocated it as an efficient practice in much of the Central Great Plains, and Hay and Pope (1976) reported that preseason irrigation should always be considered as a management tool in corn production in western Kansas.

Elimination of unnecessary preseason irrigation could result in the largest single water savings an irrigator might obtain in a season. Musick and Lamm (1990) indicated that for surface irrigation systems the preseason irrigation is normally the largest event and may be as much as 25% of the total irrigation applied for corn. Lamm and Rogers (1985) developed an empirical model to aid in decisions concerning fall preseason irrigation for corn production in western Kansas. Available soil water at spring planting was functionally related to overwinter precipitation and initial available soil water in the fall. An extension of this simple model by incorporating precipitation probabilities is presented in Fig. 2. Using probability and the model, the irrigator can determine the need for preseason irrigation and the irrigation amount necessary to reach a desired soil-water content at planting. Procedures used to develop this model could be used in other regions, even though the coefficients are likely to be site specific. In most years, fall preseason irrigation for corn is not needed to recharge the soil profile in northwest Kansas, unless residual soil water remaining after corn harvest is excessively low. Rogers and Lamm (1994) found in a post-corn harvest survey of 82 randomly selected fields in northwest Kansas that the available soil water in the 1.5-m soil profile averaged 70% of field capacity. Available soil water was similar for center pivot sprinkler- and surface-irrigated fields, but within-field variation was higher for surface-irrigated fields. A number of low-capacity sprinkler irrigation systems exist in the Great Plains region, and many irrigators assume they must compensate with dormant-season irrigation. However, even though an irrigation system may have insufficient capacity during a critical period, an irrigator may try to catch up with irrigation later in the season, which builds soil-water reserves but may not affect yield. The survey results indicate irrigators should evaluate their conditions prior to initiating preseason irrigation.

DORMANT-SEASON SOIL WATER MANAGEMENT

Drier soil profiles at harvest result in greater opportunity for capturing winter precipitation and also reduce the potential for overwinter drainage losses and leaching of chemicals to groundwater (Lamm and Rogers, 1985; Schneekloth et al., 1991). Research in Kansas by Rice (1993) found nitrate leaching during the growing season was minimal, and the overwinter period was of greater concern because evapotranspiration is usually lower than the precipitation. One method of obtaining drier soil profiles and conserving water is to mine the plant-available soil water gradually during the irrigation season in anticipation of recharge from precipitation during the off season. This concept of irrigation scheduling with planned soil water depletion was developed by Woodruff et al. (1972) under semi-humid conditions in Missouri. Further experimental testing of the concept (Fischbach and Somerholder, 1974; Fonken et al., 1974) found it could be used successfully on deep soil profiles with high water holding capacity, provided irrigation frequency was sufficient to maintain adequate soil water in the most active zone of water and nutrient uptake. Martin et al. (1991) reported that mining of 50% of the soil water may be acceptable if off-season precipitation is sufficient to fully recharge the crop rootzone.

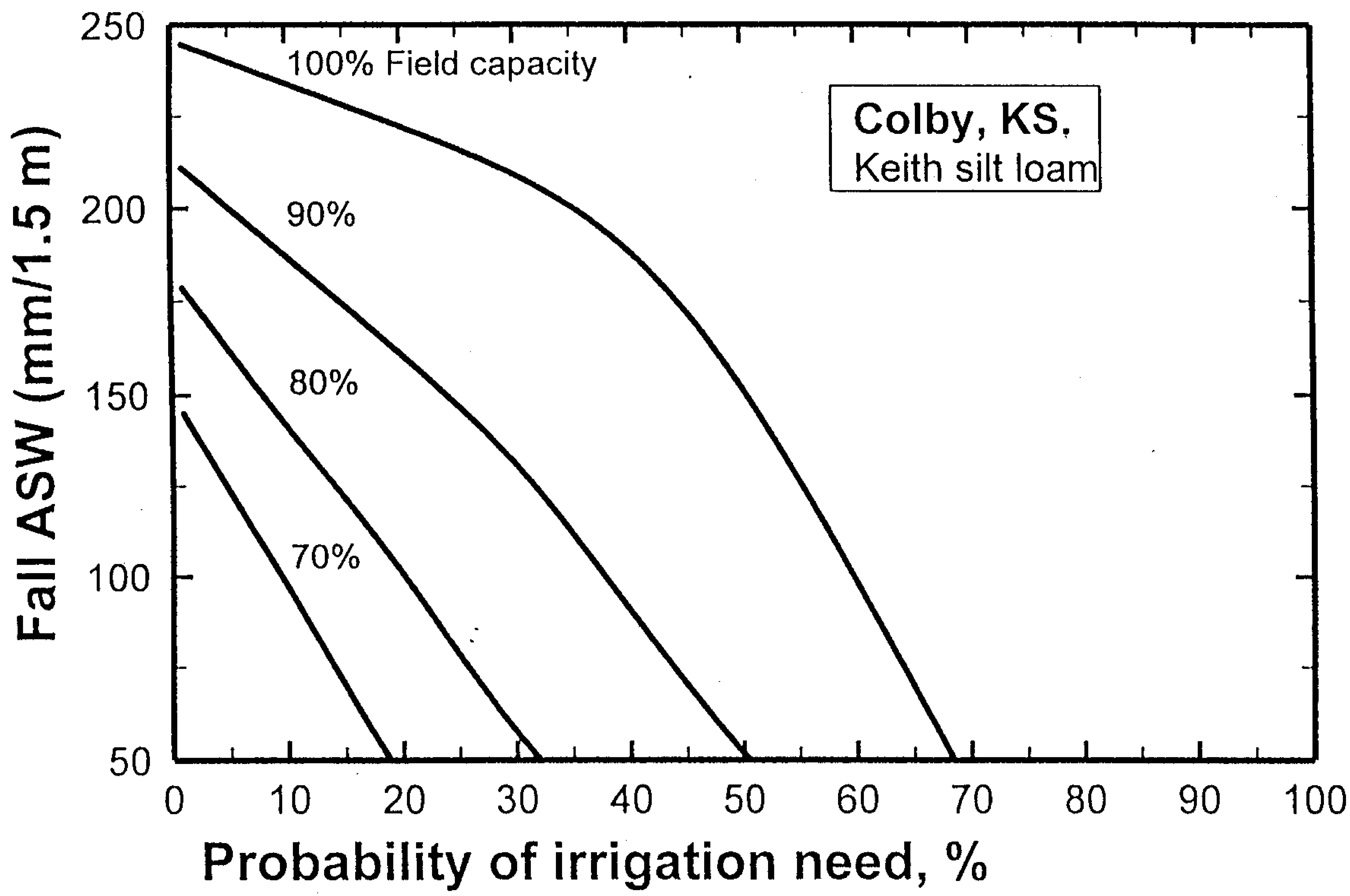

Figure 2. Probability of reaching specified percentage of field capacity by June 1 with a specified value of fall (November-December) available soil water (ASW) in the 1.5-m soil profile on a Keith silt loam soil at Colby, KS. After Lamm and Rogers (1985).

Lamm et al. (1994b) found in a surface-irrigated study that irrigation scheduling with planned soil water depletion for corn was not justified for water conservation. Reductions in soil water at harvest were accompanied by reductions in corn yields. Water use efficiencies were similar across treatments. Mining plant-available soil water to a low level would be acceptable, and even desirable, if corn yields could be maintained. However, deficit irrigation of corn is difficult to implement successfully without incurring yield reductions (Eck, 1986; Musick and Dusek, 1980; Stewart et al. 1975; Lamm et al., 1993). After reviewing numerous studies, Rhodes and Bennett (1990) reported that water stress imposed at any growth stage on corn will generally lower the efficiency of the water used in transpiration. Lamm et al. (1994b) found irrigation needed to be reduced about 4 units for each unit reduction in available soil water at harvest (Fig. 3). They concluded that irrigation scheduling with planned soil water depletion was not justified for use with surface irrigation (large, infrequent irrigation events), but might be successful with surge, sprinkler or drip irrigation (small, frequent irrigation events). Stegman et al., (1983) reported that an irrigation interval of seven days or less should be used when scheduling irrigation with planned soil water depletion.

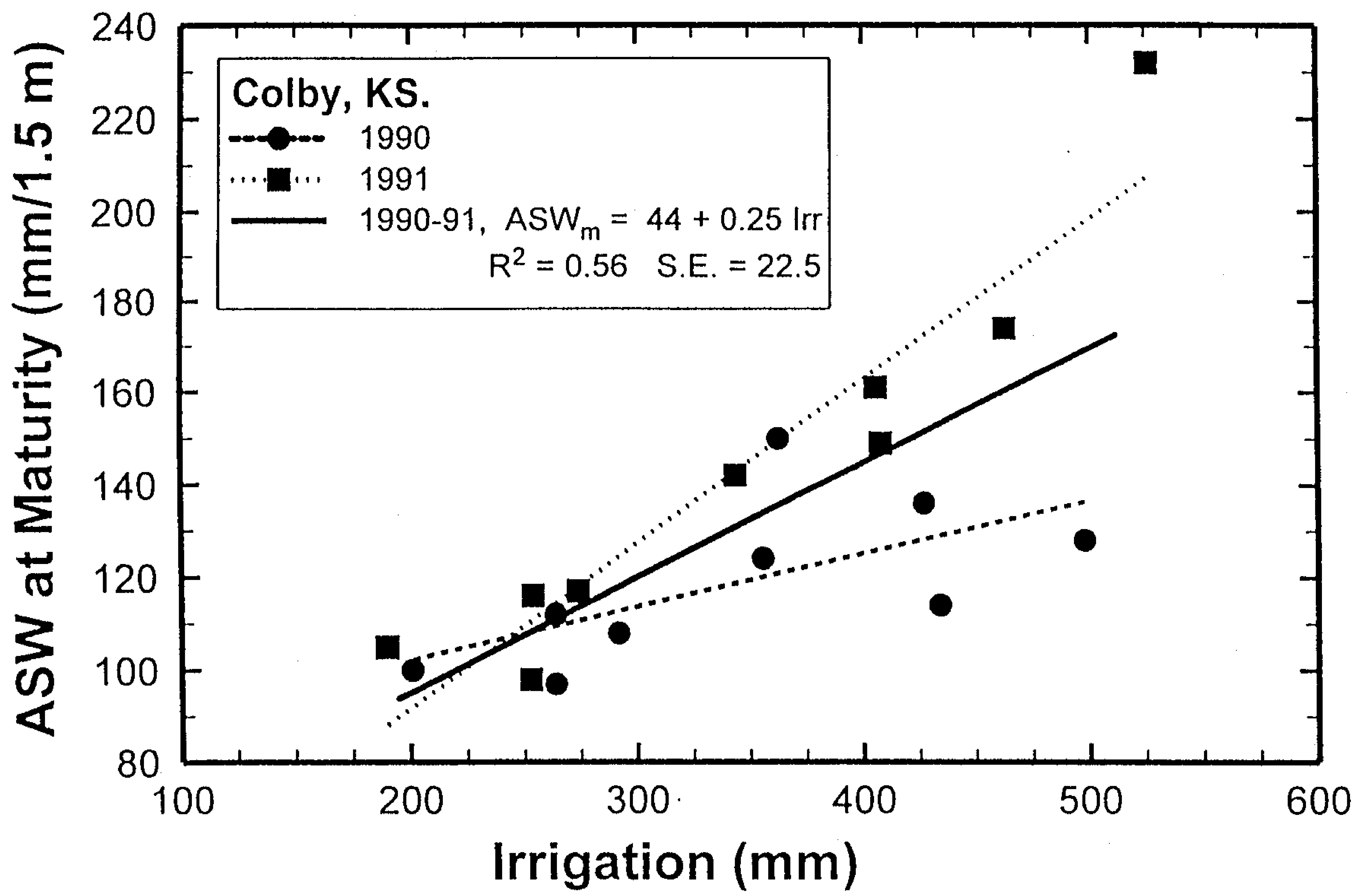

Figure 3. Available soil water (ASW) at maturity in the 1.5-m soil profile as related to seasonal irrigation on a Keith silt loam soil at Colby, KS. After Lamm et al., (1994b).

CONCLUSIONS

Traditional step-by-step, periodic irrigation scheduling using the crop water balance has been used successfully for many years. Conceptually, these methods attempt to minimize the number of irrigations and the total seasonal irrigation amount by providing irrigation "just-in-time." Macromanagement for irrigation scheduling attempts to provide the seasonal boundaries and governing parameters that provide the framework for conducting the step-by-step irrigation scheduling. The seasonal boundaries are 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 procedures. In some cases, researchers need to develop, evaluate, or update the procedures used in these determinations. Dormant-season irrigation and dormant season water quality management are governing parameters instituted by the irrigator, but will affect in-season, step-by-step irrigation scheduling. Inattention to irrigation scheduling macromanagement or practice of traditional macromanagement without adjustment for the conditions (region, climate, soil, crop parameters, etc.) can lead to inefficient use of irrigation water and/or decreased corn yields. A single, inappropriate macromanagement decision can easily have a larger effect on total irrigation water use and/or crop production than the cumulative errors in step-by-step irrigation scheduling that might occur due to small systematic errors in the crop water balance. This does not discount step-by-step irrigation scheduling. To the contrary, the use of it has been an implicit assumption of this entire discussion. Using rational macromanagement strategies and step-by-step irrigation scheduling closely together offers the best opportunities to conserve irrigation and maintain high production levels.

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