Storage efficiency of preplant irrigation

L.R. Stone, A.J. Schlegel, F.R. Lamm, and W.E. Spurgeon

ABSTRACT: Drainage and water storage efficiency of preplant irrigation in the deep silt loam soils of western Kansas were evaluated. Drainage from the soil profiles was significant, even when soil water contents were less than the "field capacity" value, if extended drainage times were involved. The Ulysses (fine-silty, mixed, mesic Aridic Haplustoll), Richfield (fine, montmorillonitic, mesic Aridic Argiustoll), and Keith (fine-silty, mixed, mesic Aridic Argiustoll) soils drained 89, 61, and 69 mm (3.5, 2.4, and 2.7 in), respectively, from day 3 to day 33 following thorough wetting of the soil profiles (covered soil surfaces). From day 33 to day 63, the Richfield drained 18 mm (0.7 in) and the Keith drained 23 mm (0.9 in). For a given soil and precipitation pattern, storage efficiency of preplant irrigation was influenced largely by soil water content immediately prior to irrigation and by irrigation amount, with storage efficiency decreasing as either or both factors increased. Irrigation management during the growing season influenced soil water content after harvest and thus water storage efficiency during the off-season. If preplant irrigation is not necessary to establish a crop, irrigation water should be reserved for seasonal application.

Preplant irrigation (also referred to as off-season, dormant-season, preseason, or winter irrigation) is a water management practice in which water is applied in advance of the growing season, sometimes several months in advance. The practice is common in the central and southern High Plains of the United States (western Kansas, western Texas, eastern Colorado, eastern New Mexico, and the Oklahoma panhandle), a region with low precipitation probabilities, deep soils with large water-holding capacity, and irrigation from pumping groundwater. In a survey from the late 1980s, 64 percent of the respondents from three counties in western Kansas and 69 percent of the respondents from three counties in western Texas reported that they practice preplant irrigation *(3)*.

Although preplant irrigation is a water management option, it should not be viewed as an efficient water management practice. Stone et al. *(8)* concluded that maximum yield benefit from irrigation is achieved when water is applied during the growing season, as opposed to off-season. In a review of preplant irrigation, Musick and Lamm *(5)* stated that water use efficiency of preplant irrigation is less than that of seasonal irrigation. Lamm and Rogers *(4)* concluded that "in most years fall preseason irrigation for corn is not needed to recharge the soil profile in northwest Kansas." They added, "Preseason irrigation is a tool that should be used wisely to minimize unnecessary costs and water use." Musick and Lamm *(5)* stated, "as groundwater supplies available from the Ogallala Aquifer continue to decline, pumping energy costs remain high or further increase, and the High Plains area continues a transition to dryland agriculture, the advisability of applying large preplant irrigations to fully rewet the soil profile before planting will be increasingly questioned."

Water storage efficiency of preplant irrigation varies with conditions of precipitation, evaporative demand, soil water content, and hydraulic characteristics of the soil profile. In regions with high water-storage soils and low rainfall probabilities conducive to preplant irrigation, water storage efficiency of preplant irrigation is strongly influenced by soil water content, with efficiency decreasing as water content increases. Therefore, by considering water content of the soil profile at the time of preplant application, projected water storage efficiencies and the need for preplant irrigation can be assessed. The purpose of this paper is to examine water storage efficiencies associated with

---

L.R. Stone is a soil physicist in the Department of Agronomy, Kansas State University, Manhattan, KS, 66506; A.J. Schlegel is the agronomist-in-charge, Tribune Unit, Southwest Kansas Research-Extension Center–Tribune; F.R. Lamm is an agricultural engineer with the Northwest Kansas Research, Extension Center, Colby, KS, 67701; and W.E. Spurgeon is an agricultural engineer with the Southwest Kansas Research-Extension Center, Garden City, KS 67846. Contribution No. 92–378–J, Kansas Agricultural Experiment Station.

J. Soil and Water Cons. 49 (1): 72–76

Reprinted from the *Journal of Soil and Water Conservation*
January-February 1994, Volume 49, Number 1

preplant irrigation. With an understanding of water storage efficiencies, a producer can decide if preplant irrigation is needed, and if so, how much water should be applied.

Preplant irrigation in addition to seasonal irrigation

Research with corn (*Zea mays* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench], using irrigation schemes with or without preplant irrigation in addition to surface seasonal irrigations, has shown preplant irrigation did not influence grain yield significantly. Results from a preplant irrigation study with grain sorghum near Bushland, Texas, are summarized in Table 1 *(6)*. Although the preplant irrigation applied an additional 106 mm (4.2 in) of water, grain sorghum yield was increased by only 176 kg/ha (156 lb/acre). Results from a preplant irrigation study with corn near Tribune, Kansas are summarized in Table 2 *(8)*. The corn research plots at Tribune were level basins and all irrigations were 152 mm (6 in). Treatments having three seasonal irrigations showed no significant difference in corn grain yield, regardless of whether a fall, spring, or no preplant irrigation was added.

Table 1. Grain sorghum yield as influenced by preplant irrigation near Bushland, Texas *(6)*.

Irrigation treatment	Total irrigation	Grain yield
	mm	kg/ha
No irrigation	0	1,502
No preplant -- 2 or 3 seasonal irrigations	300	6,572
Preplant plus 2 or 3 seasonal irrigations	406	6,748

Table 2. Corn yield as influenced by irrigation treatments involving preplant and seasonal irrigations near Tribune, Kansas *(8)*.

Irrigation treatment	Total irrigation	Grain* yield
	mm	kg/ha
1. Fall preplant	152	4,749
2. Spring preplant	152	5,136
3. Fall preplant + tasseling	305	6,777
4. Spring preplant + tasseling	305	7,948
5. 12-leaf + silking + blister kernel (No preplant)	457	8,931
6. Fall preplant + 12-leaf + silking + blister kernel	610	9,513
7. Spring preplant + 12-leaf + silking + blister kernel	610	9,113

*Selected statistical comparisons involving grain yield of treatments 1 versus 2, 3 versus 4, 6 versus 7, and 5 versus 6 versus 7 found no significant difference at the 0.05 probability level.

Long-term precipitation patterns for those two locations are presented in Figure 1. The long-term mean annual precipitation for Amarillo, Texas, (24 km [15 mi] from Bushland) is 518 mm (20.4 in) and for Tribune is 415 mm (16.4 in). Both locations receive low precipitation amounts during the winter.

Studies such as these show that preplant irrigation is of no or questionable benefit under conditions where two or three surface irrigations are applied in-season to summer row crops. With seasonal irrigation adequate for relatively high yields, residual soil water going into the off-season is great enough to significantly reduce the water storage efficiency from precipitation and irrigation during the off-season. Seasonal irrigation is primarily responsible for crop yield response and the yield influence derived from off-season irrigation is low. More efficient use of water resources can be achieved by ensuring crop germination and establishment through improved soil water conditions in the upper profile by tillage and residue management practices that conserve winter and spring precipitation and by timely planting. Irrigation water then can be applied in-season, as opposed to off-season, which gives a higher yield response and greater water use efficiency.

Timing of preplant irrigation

A frequent question about preplant irrigation is the influence of timing. Research has shown timing of preplant irrigation has little influence on water storage efficiency and the resulting grain yield of summer row crops. In comparisons of all treatment pairs having spring or fall preplant irrigation, timing of preplant irrigation in the corn study near Tribune *(8)* did not influence grain yield significantly (Table 2). In the grain sorghum study near Bushland *(6)*, timing of preplant irrigation from early December through mid May had no significant influence on grain yield or on water storage efficiency of preplant irrigation and preseason rainfall (Table 3).

The preplant irrigation research at Bushland (Tables 1 and 3) involved 300 mm (11.8 in) of seasonal irrigation *(6)*. The preplant irrigation research at Tribune (Table 2) included a range of seasonal irrigation from none to 457 mm (0 to 18 in) *(8)*. Therefore, test results indicate that timing of preplant irrigation does not influence water storage and grain yield regardless of seasonal irrigation amount (i.e., relatively dry to relatively wet irrigation schemes).

Precipitation storage during winter and spring

Although many factors of weather, precipitation patterns, soil surface conditions, soil hydraulic characteristics, and soil water content influence precipitation storage efficiency, research has often found water storage during winter and spring to be in the range of 30 to 50 percent of the precipitation received. Water storage efficiency of about 40 percent of the total of preseason irrigation and rainfall was measured from late fall to mid May near Bushland (Table 3) *(6)*. When measured from late fall to late June, water storage efficiency was about 30 percent of preseason irrigation and rainfall. From a 10-day simulation of profile water storage for a loam soil with no runoff or drainage, Hillel and van Bavel *(2)* found a precipitation storage efficiency of 43 percent. Greb et al. *(1)* reported that fallow techniques using better management of stubble mulch and weed control increased precipitation storage efficiencies to the 35 to 41 percent range in the central Great Plains.

Net storage of soil water from December 1 to April 1 is presented versus percent available soil water on December 1 in Figure 2. The relationship in Figure 2 was calculated by using the water storage equation from Stone et al. *(7)* and the long-term precipitation

Table 3. Grain sorghum yield and storage efficiency of preplant irrigation and rainfall as influenced by time of preplant irrigation near Bushland, Texas *(6)*.

Average date of preplant irrigation	Water storage efficiency: Late fall to mid May	Water storage efficiency: Late fall to late June	Grain yield
	percent	percent	kg/ha
December 7	41.7	31.4	6,654
January 20	38.3	26.8	6,685
March 6	43.5	30.3	6,666
April 10	40.0	28.8	6,867
May 16	——	28.4	6,767

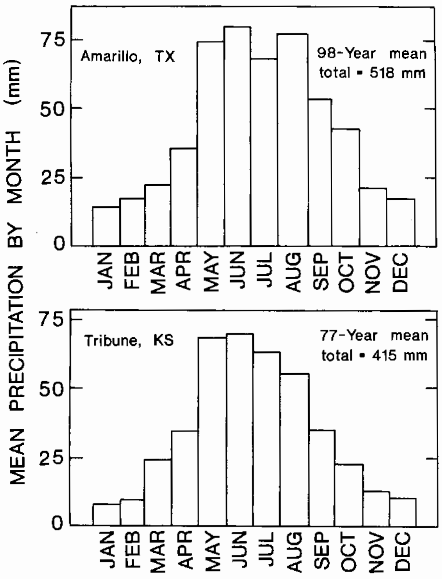

Figure 1. Mean precipitation by month from long-term records at Amarillo, Texas and Tribune, Kansas.

value for December 1 to April 1 at Tribune of 53 mm (2.1 in). The water storage equation was developed by using data from research plots with berms to prevent runoff and runon *(7)*. With 15 percent available soil water on December 1 and a mean precipitation total of 53 mm (2.1 in), net storage measured on April 1 shows a gain of 21 mm (0.84 in). Therefore, in conditions where runoff and profile drainage are not factors, the net storage of winter and early spring precipitation is about 40 percent. If precipitation is greater than the long-term mean, net storage of water will increase, but storage as a percentage of precipitation decreases. Conversely, if precipitation is less than the long-term mean, net storage of water will decrease, but storage as a percentage of precipitation increases. For example, at 15 percent available soil water on December 1 and precipitation totals of 27, 53, and 80 mm (1.05, 2.10, and 3.15 in), net storage is 18, 21, and 24 mm (0.70, 0.84, and 0.96 in), or 67, 40, and 30 percent of precipitation, respectively.

As profile water content on December 1 increases, the amount of evaporation from the soil surface and the amount of profile drainage both increase, reducing net water storage in the soil profile from December 1 to April 1. At 50 percent available soil water on December 1 and with the mean precipitation amount of 53 mm (2.1 in), net storage of water is zero. At greater than 50 percent available soil water and with mean precipitation, less water is stored in the soil profile on April 1 than on December 1 (a minus net water storage). Total water loss from the system due to evaporation and drainage is the sum of 53 mm (2.1 in) of precipitation and the reduction of profile water (the minus net storage value).

Net water storage at Tribune from December 1 to April 1 was influenced by both precipitation amount and soil profile water conditions. Of the two factors, profile water content on December 1 had more influence on net water storage during winter and early spring than did precipitation amount. Soil profile water content is an important factor that should be taken into account when projecting water storage efficiencies from precipitation or preplant irrigation.

Drainage from soil profiles

Soil profile water conditions have a dramatic impact on drainage, with drainage increasing as soil water content increases. The occurrence of drainage in soils that are above the "field capacity" water content value is well known. However, significant drainage can occur from soils having water contents less than the field capacity value. Although drainage rates will be less at water contents below field capacity than at those above, if drainage time is relatively great (as it is in many preplant irrigation programs), then total drainage can be significant. In a discussion of drainage conditions in the San Joaquin Valley of California, Tanji and Hanson *(9)* stated, "drainage water production is highest during preplant irrigation (preirrigation) in the winter months, when measured application efficiencies have been as low as 30 percent, as well as during the initial postplant irrigation—both of which have high infiltration rates."

Soil water content versus drainage time for three deep silt loam soils of western Kansas is presented in Figure 3. The soils were thoroughly wetted, covered with plastic to prevent evaporation, and allowed to drain. Typically, two to three days of drainage are allowed to reach the field capacity water content value. The Ulysses, Richfield, and Keith soils, respectively, had 683, 663, and 678 mm (26.9, 26.1, and 26.7 in) of water on day 3 and 594, 602, and 610 mm (23.4, 23.7, and 24.0 in) of water on day 33. From day 3 to day 33, 89, 61, and 69 mm (3.5, 2.4, and 2.7 in) of water drained from the Ulysses, Richfield, and Keith soils, respectively. On day 63, the Richfield and Keith soils had 584 and 587 mm (23.0 and 23.1 in) of water, respectively. From day 33 to day 63, 18 and 23 mm (0.7 and 0.9 in) of drainage occurred from those respective soils. Clearly, long-term drainage from deep soil profiles can reach significant amounts, even at water contents below the field capacity value. Soil is not a static reservoir for water, but is subject to processes of evaporation and drainage, which influence infiltration and storage of preplant irrigation and precipitation.

Water storage as influenced by available soil water

Figure 2 illustrates the significant influence soil water content in late fall has on net water storage during winter and early spring. That influence is generated primarily through the process of long-term drainage, which is illustrated in Figure 3. In Figure 4, we illustrate storage efficiency of water added to the Ulysses soil near Tribune on December 1 and measured on April 1 as a function of the amount of water added to storage on December 1. Storage efficiency patterns are shown for four values of percent available soil water on November 30 (immediately prior to water addition). Those efficiency patterns were calculated by using the water storage equation of Stone et al. *(7)* and the long-term precipitation value from December 1 to April 1 of 53 mm (2.1 in). We calculated the gain in soil water content on April 1 as a result of the water added on December 1, then expressed that gain as a percentage of the amount of water added (percent storage efficiency). The water added is that added to the water content of the soil profile and not a gross irrigation amount, which would likely involve losses through runoff, evaporation, and delivery system.

When the Ulysses soil is relatively dry in fall (10 percent available soil water), storage efficiency of water added is relatively great, decreasing from 98 percent with 25 mm (1 in) water added to 69 percent with 254 mm (10 in) water added (Figure 4). The 69 percent with 254 mm (10 in) water added is for the total amount. When the water added is increased from 229 to 254 mm (9 to 10 in), only 37 percent of that additional 25 mm (1 in) of water is realized as additional stored water on April 1. Even though the profile is relatively dry on November 30 and storage efficiency is relatively great, when application amounts increase, storage efficiency of the additional water drops off rapidly (only 50 percent efficiency from the 25 mm [1 in] of water added in going from 178 to 203 mm [7 to 8 in]). Therefore, the amount of water added needs to be carefully considered and should be kept to the minimum, thereby maintaining greater water storage efficiency.

As available soil water on November 30 increases, storage efficiency measured on April 1 decreases. Where storage efficiency from 25 mm (1 in) of water added is 98 percent with 10 percent available soil water, storage efficiencies decrease to 77, 55, and 34 percent as available soil water on November 30 increases from 30 to 50 to 70 percent, respectively. Note that these storage efficiencies occur where water added is in the soil profile (no water losses to delivery system and runoff) and where soil profile water contents are below the field capacity value (100 percent available soil water).

Storage efficiency values presented in Figure 4 are for the Ulysses soil near Tribune. We realize that different soils and different precipitation patterns likely would have somewhat different values. However, patterns exhibited in Figure 4 are reasonable and will occur (albeit with some numerical differences) on other deep silt loam soils of the central and southern High Plains. Therefore, we encourage users of preplant irrigation to consider these water storage efficiencies.

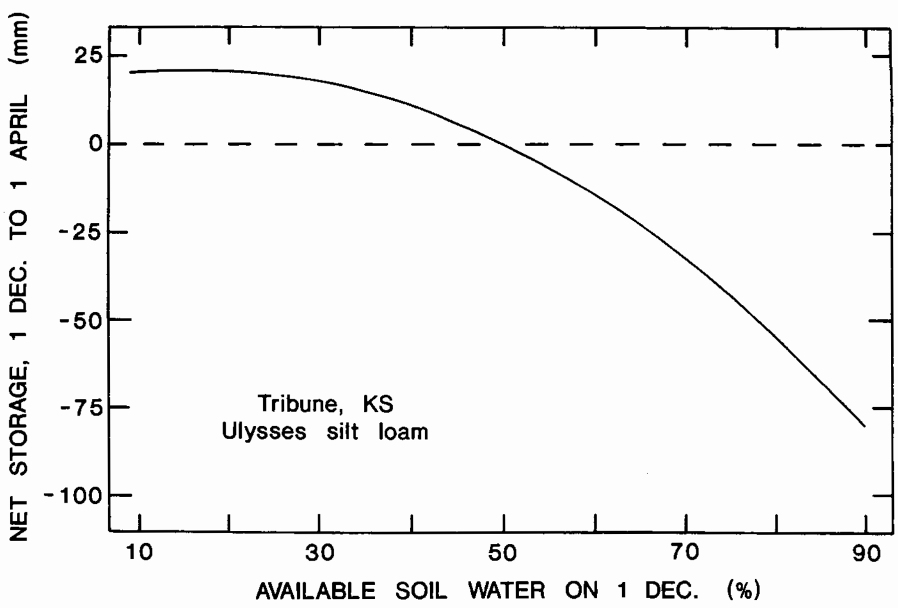

Figure 2. Net water storage from December 1 to April 1 versus amount of available water in the 1.83 m soil profile on December 1 at Tribune, Kansas.

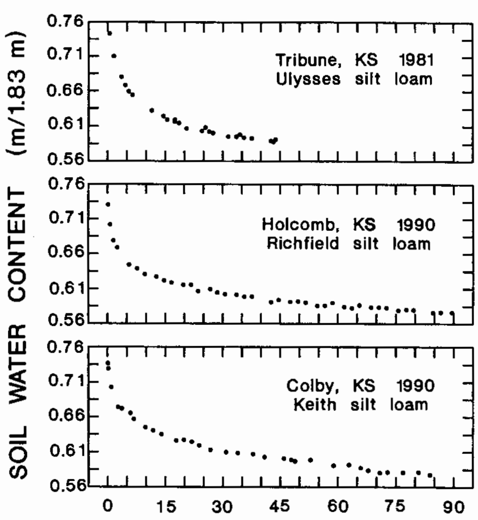

Figure 3. Water content in the 1.83 m soil profile versus drainage time at three western Kansas locations.

Available soil water in fall

Water storage efficiency of preplant irrigation is influenced to a great extent by soil water content prior to irrigation. Therefore, in projecting water storage efficiencies, one needs to assess the existing soil water conditions. Direct measurement of soil water content is the most accurate. However, long-term data are available that illustrate how available soil water is influenced by seasonal irrigation and seasonal rainfall. Use of such illustrations allows a producer to evaluate how a seasonal irrigation program influences available water at fall harvest, and how those levels of available water influence storage efficiency of water added to the soil profile.

We used multiple regression analysis, and irrigation research data from Tribune, to develop a relationship for percent available soil water shortly after harvest (AWH) as a function of seasonal irrigation (I in meters) and rainfall from July 1 to soil water sampling in fall (R in meters). Crops were corn and grain sorghum. Irrigation water was applied to level basin test plots by using gated pipe (no runoff). Soil profile depth sampled was 1.83 m (6 ft). Average date of soil water sampling was

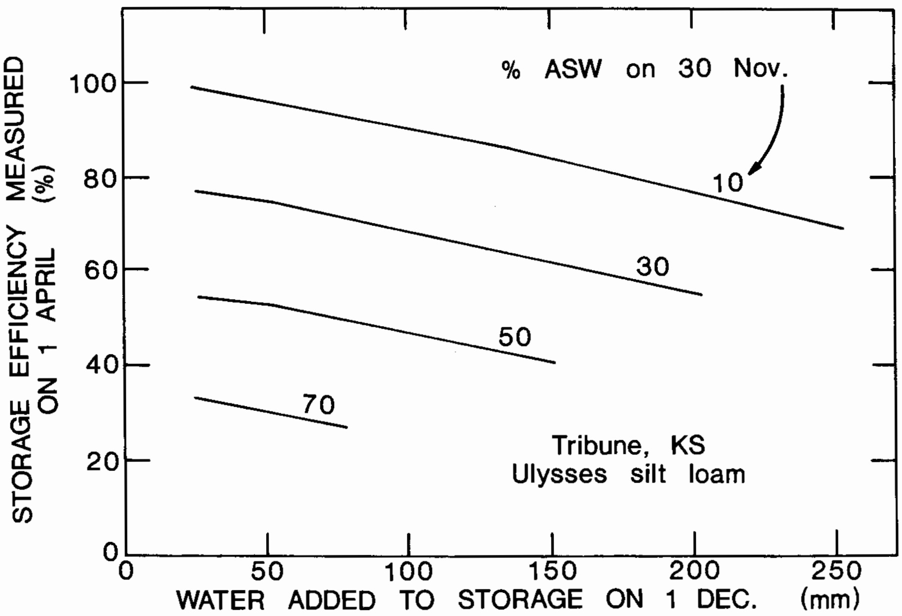

Figure 4. Storage efficiency of water added to storage on December 1 and measured on April 1 versus amount added to storage on December 1 at Tribune, Kansas. The lines give efficiency at four values of percent available soil water (percent ASW) of the 1.83 m soil profile on November 30 (immediately prior to water addition).

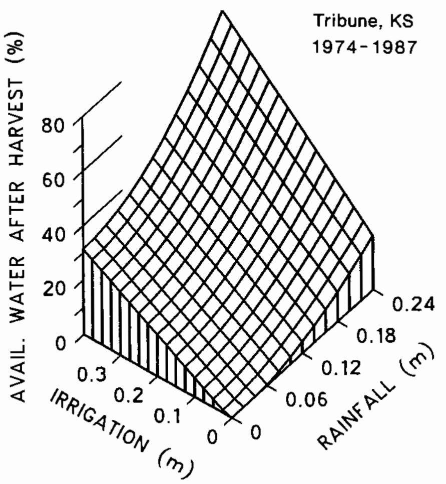

Figure 5. Available soil water of the 1.83 m soil profile shortly after harvest versus seasonal irrigation and rainfall from July 1 to soil water sampling in fall (shortly after harvest).

October 30. In the regression analysis, independent variables were I and R, the square of each (I^2 and R^2), and the interaction products of the linear and quadratic variables (IR, IR^2, I^2R, and I^2R^2). The relationship developed is:

$AWH = -1.13 + 81.31I + 366R^2 + 881R^2I$ [1] and is plotted as a three-dimensional graph in Figure 5. In model development, sample number was 104, coefficient of determination was 0.854, standard error of estimate was 7.90, and significance probability less than 0.05 was required for variable retention. Long-term mean rainfall for July 1 to November 1 at Tribune is 176 mm (6.94 in). By using equation *[1]* and mean rainfall, available soil water in late October-early November is 10, 24, 38, and 52 percent with seasonal irrigation (without delivery losses or runoff) of 0, 127, 254, and 381 mm (0, 5, 10, and 15 in), respectively. With the 52 percent available soil water in early November and long-term mean precipitation, the anticipated water storage efficiency through winter of an additional 152 mm (6 in) of profile water in late fall is only 40 percent (Figure 4).

Summary

In this article, we reviewed water storage efficiencies associated with preplant irrigation of summer row crops in the central and southern High Plains. Significant aspects are summarized as follows:

1. Maximum crop yield benefit from a given irrigation amount has been achieved with water applied in-season, as opposed to off-season as preplant irrigation. Water use efficiency is greater for seasonal than for preplant irrigation.

2. Timing of preplant irrigation has shown no significant influence on water storage efficiency and subsequent grain yield.

3. When two or three surface, seasonal irrigations were applied, preplant irrigation has not influenced grain yield significantly.

4. For a given soil and precipitation pattern, storage efficiency of preplant irrigation was influenced largely by soil water content immediately prior to irrigation and by irrigation amount, with water storage efficiency decreasing as either or both factors increased.

5. Irrigation management during the growing season influenced soil water content after harvest and thus water storage efficiencies during the off-season.

Preplant irrigation is an inefficient use of water resources. In those instances where preplant irrigation (or early season irrigation) is needed, minimum amounts of water should be applied, as opposed to large amounts for filling of the soil profile. Drainage from soils can reach significant amounts, even when soil water contents are less than the field capacity value, if extended time periods are involved. If preplant irrigation is not necessary to establish a crop, irrigation water should be reserved for seasonal application.

REFERENCES CITED

1. Greb, B.W., D.E. Smika, N.P. Woodruff, and C.J. Whitfield. 1974. *Summer fallow in the central Great Plains.* In *Summer fallow in the western United States,* Conservation Research Report No. 17, Agricultural Research Service, USDA, U.S. Government Printing Office, Washington, DC.
2. Hillel, D., and C.H.M. van Bavel. 1976. *Simulation of profile water storage as related to soil hydraulic properties.* Soil Sci. Soc. Am. J. 40: 807-815.
3. Kromm, D.E., and S.E. White. 1990. *Conserving water in the High Plains.* Dept. of Geography, Kansas State University, Manhattan, KS.
4. Lamm, F.R., and D.H. Rogers. 1985. *Soil water recharge function as a decision tool for preseason irrigation.* Trans. ASAE 28: 1521-1525.
5. Musick, J.T., and F.R. Lamm. 1990. *Preplant irrigation in the central and southern High Plains—A review.* Trans. ASAE 33: 1834-1842.
6. Musick, J.T., W.H. Sletten, and D.A. Dusek. 1971. *Preseason irrigation of grain sorghum in the Southern High Plains.* Trans. ASAE 14: 93-97.
7. Stone, L.R., C.G. Carlson, T.L. Hanson, R.E. Gwin Jr., P. Gallagher, and M.L. Horton. 1983. *Amount of profile water in early spring resulting from increased profile water in fall.* Soil Sci. Soc. Am. J. 47: 305-309.
8. Stone, L.R., R.E. Gwin Jr., P.J. Gallagher, and M.J. Hattendorf. 1987. *Dormant-season irrigation: Grain yield, water use, and water loss.* Agron. J. 79: 632-636.
9. Tanji, K.K., and B.R. Hanson. 1990. *Drainage and return flows in relation to irrigation management.* In B.A. Stewart and D.R. Nielsen (eds.) *Irrigation of agricultural crops.* Agronomy 30: 1057-1087.