# Irrigation Scheduling with Planned Soil Water Depletion

F. R. Lamm, D. H. Rogers, H. L. Manges

**Abstract.** *A two-year study was initiated in the spring of 1990 on a Keith silt loam soil (Aridic Argiustoll) in northwest Kansas to determine if irrigation scheduling with planned soil water depletion could be used successfully for irrigated corn (*Zea mays *L.) as a method of conserving and protecting groundwater resources without reducing yields. The study was conducted using surface irrigation in small dead-level basins. Planned soil water depletion was attempted by allowing a small additional daily deficit (0, 1, or 2 mm/day) to accumulate in irrigation amounts as scheduled by an evapotranspiration (ET)-based water budget. The daily deficit amounts were imposed on three irrigation levels, heavy (1.25 × ET), normal (1.00 × ET), and deficit (0.75 × ET) which represented a range of management by irrigators. The plant-available soil water at physiological maturity was related linearly to irrigation amounts. However, the plant-available soil water at physiological maturity was reduced by only 25 mm for each 100 mm reduction in irrigation. Imposition of a small daily deficit of 1 mm/day after tasseling resulted in yield reductions of 7, 1, and 3% for the heavy, normal, and deficit irrigation management levels, respectively. The 1 mm/day deficit resulted in irrigation savings of approximately 12, 9, and 0% for the three respective irrigation management levels and generally resulted in slight reductions in available soil water at physiological maturity. In some cases, the imposition of the 1 mm/day deficit had little effect on the total seasonal irrigation amount, but simply shifted the irrigation event to a later date. The larger 2 mm/day daily deficit after tasseling reduced yields by 7, 9, and 15% for the three respective irrigation levels and reduced irrigation amounts by 19, 26, and 25%. Yields were related linearly to irrigation and water use with a reduction in irrigation or water use reflected by yield reductions. Water use efficiencies were similar whether planned soil water depletion was used or not. Therefore, from a water conservation standpoint, irrigation scheduling with planned soil water depletion was not justified.* **Keywords.** *Irrigation, Soil water depletion, Corn, Water use efficiency.*

Declining groundwater supplies, increased competition for available water resources, and irrigation-induced, water-quality problems have resulted in an increased need for water-conserving irrigation practices. Irrigation practices for corn production in western Kansas usually extend watering until late in the season, resulting in high levels of soil water remaining in the profile in the fall after harvest. Rogers and Lamm (1994) found in a survey of 82 producer fields in northwest Kansas that plant-available soil water contents after corn harvest averaged 70% of field capacity for a 1.5-m-depth soil profile.

One method of conserving water would be 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 root zone.

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, 1985a; Schneekloth et al., 1991). Research in Kansas by Rice (1993) found that nitrate leaching during the growing season was minimal and that the overwinter period was of greater concern because the evapotranspiration (ET) then is usually lower than the precipitation.

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.

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Mining the soil water may be possible by allowing a slight deficit in irrigation amounts to accumulate over the latter part of the season. The difficulty in this approach is that this period also coincides with the most critical crop growth stages. In simulation studies, Gilley et al. (1980) found that for several locations in Nebraska, replacing 90 and 80% of the cumulative ET during the reproductive and grain filling stages for corn, respectively, resulted in near maximum yields. Using an ET-based water budget, an irrigator may be able to avoid yield reductions by allowing a small, daily deficit in supplying ET needs to occur over a long period of time.

## Procedures

Field studies were conducted at the Kansas State University (KSU) Northwest Research-Extension Center, Colby, Kansas, during 1990 and 1991 on a deep, well-drained, loessial, Keith silt loam soil (Aridic Argiustoll). This medium-textured soil, typical of many western Kansas soils, is described in more detail by Bidwell et al. (1980). The 1.5-m soil profile will hold approximately 300 mm of available water at field capacity and has a profile bulk density of approximately 1.3 $gm/cm^3$. This corresponds to a volumetric soil water content of approximately 0.34.

The continental climate can be described as semi-arid, with an average annual precipitation of 474 mm and approximate annual lake evaporation of 1400 mm (Bark and Sunderman, 1990). Daily climatic data used to schedule irrigation were obtained from a NOAA weather station located approximately 350 m northeast of the study site.

The study was conducted each year in a different 0.6-ha, dead-level irrigation basin approximately 180 m long × 30 m wide with plots 4.6 m wide and 30 m long running perpendicular to the level basin length. The plots accommodated six corn rows spaced 76 cm apart. Small dikes were constructed around each plot to prevent runoff onto adjacent plots. The study treatments were replicated three times in a randomized complete block design. The treatments were analyzed as a single-factor design.

The reference evapotranspiration ($ET_r$) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heerman (1974). The specifics of the $ET_r$ calculations used in this study are fully described by Lamm et al. (1987). Basal crop coefficients ($K_{cb}$) were generated by equations developed by Kincaid and Heerman (1974) based on work by Jensen (1969) and Jensen et al. (1970, 1971). The basal crop coefficients were calculated for the area by assuming 70 days from emergence to full canopy for corn and physiological maturity at 130 days. This method of calculating actual evapotranspiration (AET) as the product of $K_{cb}$ and $ET_r$ has been applied in past studies at Colby, Kansas, and it has been found to estimate AET accurately (Lamm and Rogers, 1983, 1985b). In constructing the irrigation schedules, no attempt was made to modify AET with respect to soil-evaporation losses or soil-water availability as outlined by Kincaid and Heerman (1974).

Three irrigation management levels were included in the study, heavy (1.25 × ET), normal (1.00 × ET), and deficit (0.75 × ET), representing the range of management that occurs among irrigators. One of three daily deficits, 0, 1, or 2 mm/day beginning after tasseling were superimposed on the three management levels. For example, assuming a 40-day period between tasseling and the last irrigation and with no drainage below the root zone, one would expect the normal (1.00 × ET) irrigation treatment with a 2 mm/day daily deficit to have an additional 80 mm of soil water deficit at the end of the irrigation season compared to the normal treatment with the 0 mm/day daily deficit. Actual amounts would vary considerably, depending on timing and amounts of irrigation and precipitation. Summarizing the nine irrigation treatments:

Heavy irrigation (1.25 × ET) Treatments
1. Daily deficit of 0 mm/day after tasseling (DD-0)
2. Daily deficit of 1 mm/day after tasseling (DD-1)
3. Daily deficit of 2 mm/day after tasseling (DD-2)

Normal irrigation (1.00 × ET) Treatments
4. Daily deficit of 0 mm/day after tasseling (DD-0)
5. Daily deficit of 1 mm/day after tasseling (DD-1)
6. Daily deficit of 2 mm/day after tasseling (DD-2)

Deficit irrigation (0.75 × ET) Treatments
7. Daily deficit of 0 mm/day after tasseling (DD-0)
8. Daily deficit of 1 mm/day after tasseling (DD-1)
9. Daily deficit of 2 mm/day after tasseling (DD-2)

Irrigation was scheduled using a water budget to calculate the root zone depletion with precipitation and irrigation water amounts as deposits and calculated daily corn water use (AET) as a withdrawal. Irrigation efficiencies were assumed to be 100% in the small dead-level irrigation basins. Modification of the individual treatment irrigation schedules to simulate the various management levels, heavy, normal, or deficit irrigation, was accomplished by multiplying the calculated AET value by 1.25, 1.00, or 0.75, respectively. Planned soil water depletion was accomplished by reducing the calculated AET value by the daily deficit (1 or 2 mm/day) after tasseling (20 July, both years). If the root-zone depletion became negative, it was reset to zero. Treatments were irrigated to replace 100% of their calculated root-zone depletion, when the depletion was within the range of 65 to 100 mm. Most irrigations were applied at a depletion of approximately 65 mm. Irrigation water was metered separately onto each plot. All plots started the season with a nearly full soil water profile. All treatments received an initial irrigation of 64 mm after the layby furrowing was performed (19 June 1990 and 2 July 1991) to alleviate water stress caused by root pruning during the furrowing process.

A neutron probe was used to measure volumetric soil water contents in 30-cm increments to a depth of 1.5 m on an approximately weekly basis during each season. Access tubes were located near the center of each plot in-line with the corn row. The plant-available soil water was calculated from these data using wilting point values determined from long-term dryland research for the soil type. The soil water measurements were used to evaluate the treatment responses, but were not used to periodically update or adjust the irrigation schedules.

The seasonal water use for each treatment was calculated as the sum of precipitation, irrigation, and measured soil water depletion between the initial (6-06-90 and 5-28-91) and the final (9-17-90 and 9-18-91) soil water measurements. Water use, as expressed here, included any deep percolation that occurred. Water use efficiency was calculated as the corn grain yield in milligram per hectare divided by the calculated water use in millimeters.

Conventional tillage was used in corn production. The previous crop (corn) residue was shredded and double-disked in the fall for increased residue decomposition. Nitrogen (U-A-N, 32-0-0) at a rate of 245 kg/ha of N and phosphorus (10-34-0) at a rate of 45 kg/ha of $P_2O_5$ was broadcast applied as a solution in mid-October. Following fertilization, the area was furrowed to prevent overwinter wind erosion and to provide 76-cm-spaced ridges for planting in the spring.

Corn (Pioneer brand 3162) was planted at a seeding rate of 65,500 seeds/ha on 23 April 1990 and 8 May 1991. The corn emerged on 15 May each year.

An approximately 6-m length of one corn row from the center of each plot was hand harvested at physiological maturity on 18 September of each year for yield determination.

## Results and Discussion

### Effect of Climatic Conditions

Seasonal precipitations (May through September) were 309 and 332 mm for 1990 and 1991, respectively, which was very near the long-term (99-year) mean of 321 mm. However, in both years, May precipitation was significantly greater than the 99-year mean. The corn emerged on 15 May in each year so crop water use from the available May precipitation was low. In 1990, all months except May had precipitation amounts less than the long-term average (fig. 1). In 1991, both August and September had lower than average precipitation amounts. The cumulative calculated AET for the 120-day period beginning on 15 May was 592 and 600 mm for 1990 and 1991, respectively, as compared to the 20-year mean of 587 mm (fig. 2). The net irrigation requirement for corn in Thomas County of northwest Kansas is 391 mm with 80% chance precipitation (Soil Conservation Service, 1977). In 1990, extremely high AET during the mid-June to mid-July period, coupled with low precipitation, resulted in greater irrigation needs than most irrigation systems in northwest Kansas could provide. Nearly 63% of the seasonal irrigation requirement of 363 mm for the normal fully irrigated condition (Treatment 4) was applied before the corn tasseled on 20 July (table 1). Seasonal irrigation amounts for the various treatments ranged from a high of 499 mm to a low of 202 mm. Fortunately, deep soils with available water buffered the corn from excessive water stress during the period. The crop year 1991 was characterized by slightly above-normal precipitation in June and July but appreciably below-normal precipitation in August and September, resulting in 84% of the seasonal irrigation amount of 410 mm for the normal fully irrigated condition (Treatment 4) being applied after the corn tasseled on 20 July. Seasonal irrigation amounts for 1991 were relatively similar to those of 1990 ranging from a high of 530 mm to a low of 191 mm.

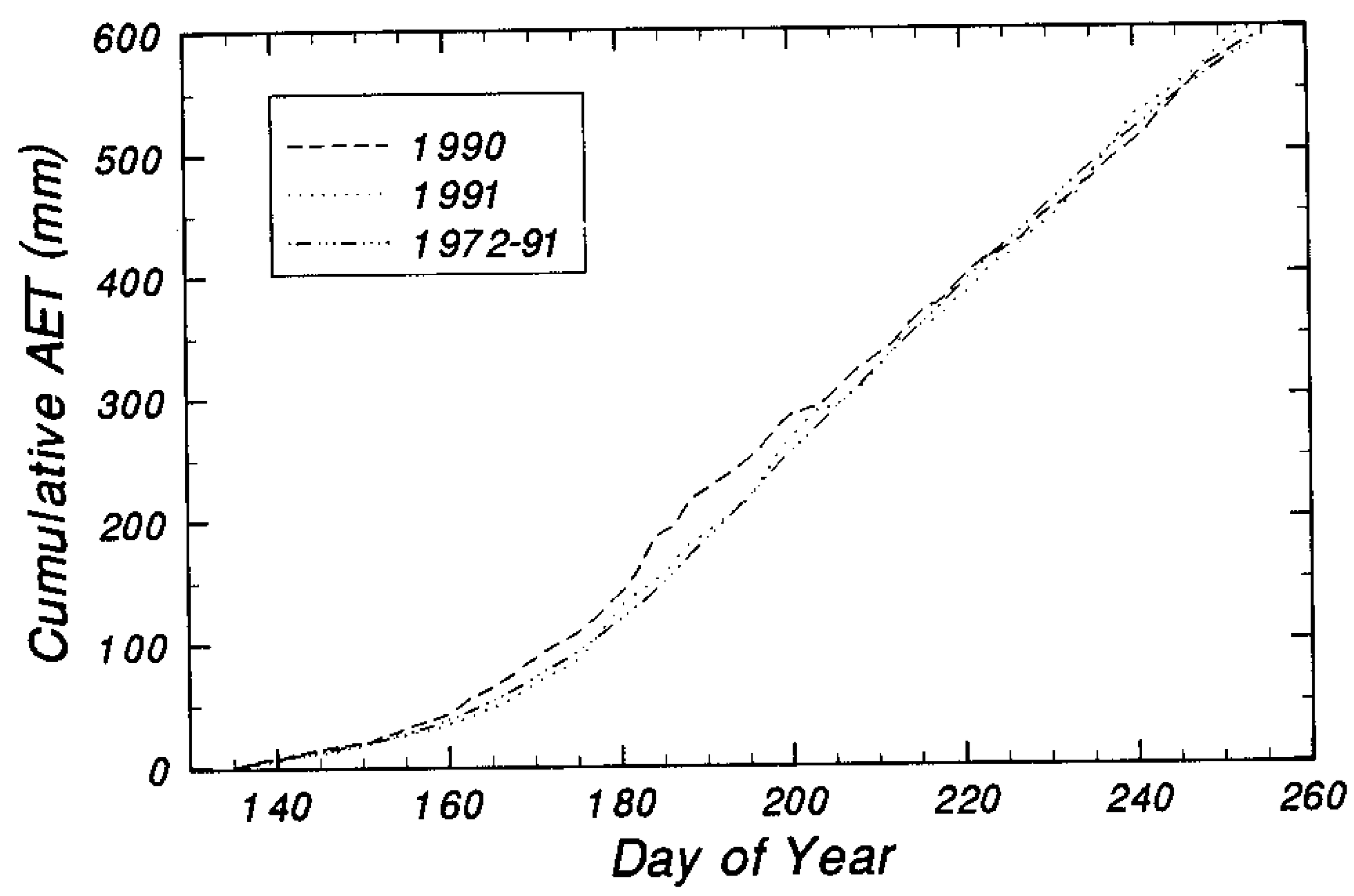


**Figure 2–Cumulative AET for corn calculated from climatic data, KSU Northwest Research-Extension Center, Colby, 1990-1991.**

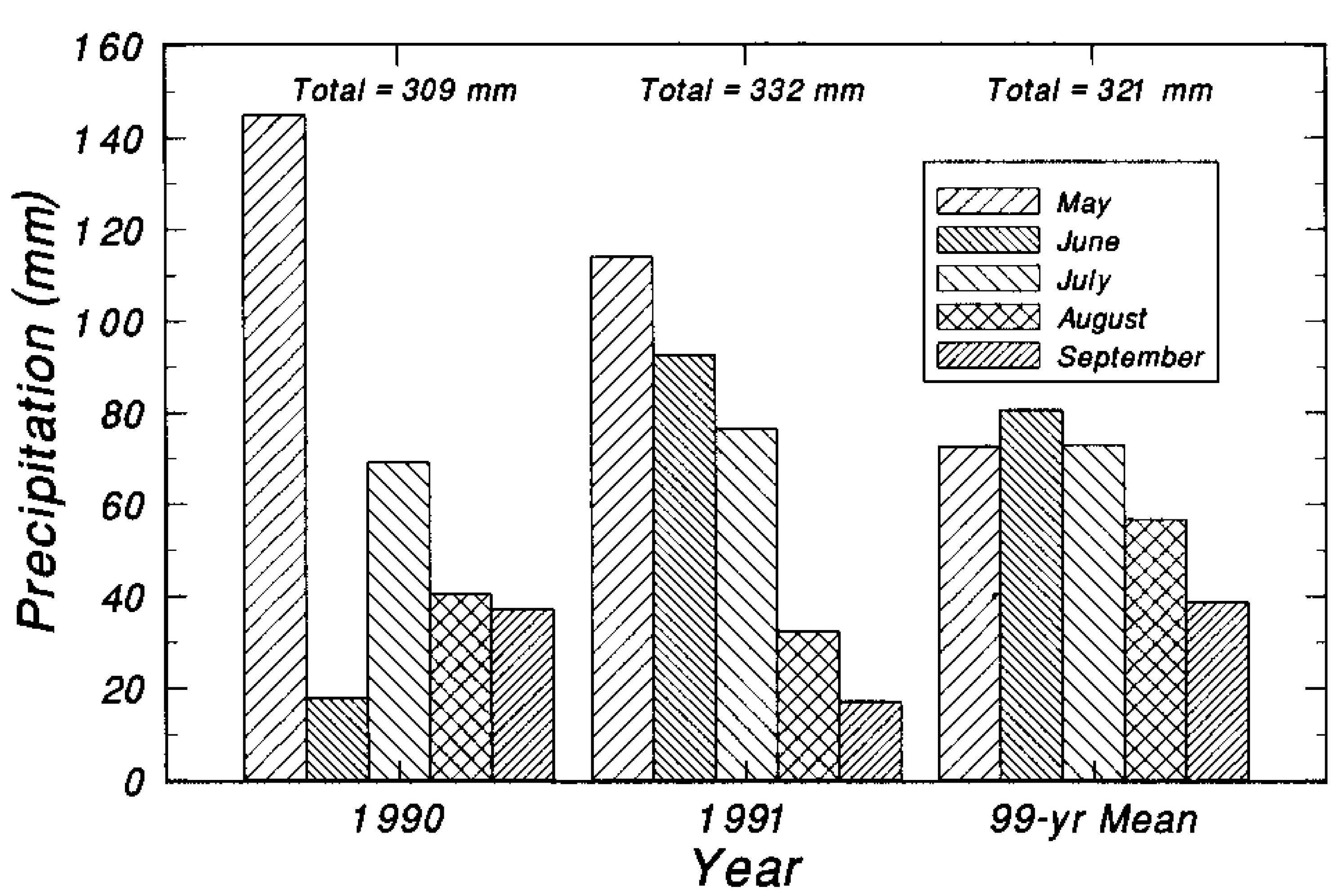


**Figure 1–Seasonal precipitation at KSU Northwest Research-Extension Center, Colby, 1990-1991.**

**Table 1. Irrigation dates and amounts (mm) for the various treatments, 1990-1991**

| Date | Trt 1 | Trt 2 | Trt 3 | Trt 4 | Trt 5 | Trt 6 | Trt 7 | Trt 8 | Trt 9 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **1990** | | | | | |
| 19 Jun | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 |
| 29 Jun | 66 | 66 | 66 | --- | --- | --- | --- | --- | --- |
| 3 Jul | --- | --- | --- | 89 | 89 | 89 | 64 | 64 | 64 |
| 9 Jul | 97 | 97 | 97 | --- | --- | --- | --- | --- | --- |
| 17 Jul | --- | --- | --- | 76 | 76 | 76 | --- | --- | --- |
| 19 Jul | 74 | 74 | 74 | --- | --- | --- | 74 | 74 | 74 |
| 8 Aug | 70 | 70 | --- | 70 | --- | --- | --- | --- | --- |
| 10 Aug | --- | --- | 64 | --- | 64 | --- | --- | --- | --- |
| 22 Aug | 64 | --- | --- | --- | --- | --- | 64 | --- | --- |
| 27 Aug | --- | 64 | --- | 64 | --- | 64 | --- | --- | --- |
| 29 Aug | --- | --- | 64 | --- | --- | --- | --- | 64 | --- |
| 30 Aug | 64 | --- | --- | --- | 64 | --- | --- | --- | --- |
| **Total** | 499 | 435 | 429 | 363 | 357 | 293 | 266 | 266 | 202 |
| | | | | **1991** | | | | | |
| 2 Jul | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 |
| 15 Jul | 83 | 83 | 83 | --- | --- | --- | --- | --- | --- |
| 18 Jul | --- | --- | --- | 84 | 84 | 84 | --- | --- | --- |
| 29 Jul | 64 | 64 | 64 | --- | --- | --- | 64 | --- | --- |
| 2 Aug | 64 | --- | --- | 64 | --- | --- | --- | 64 | 64 |
| 12 Aug | 64 | 64 | --- | --- | 64 | --- | --- | --- | --- |
| 16 Aug | --- | --- | 64 | 64 | --- | --- | --- | --- | --- |
| 21 Aug | 64 | 64 | --- | --- | --- | 64 | 64 | 64 | --- |
| 26 Aug | --- | --- | 64 | 64 | 64 | --- | --- | --- | --- |
| 28 Aug | 63 | 63 | --- | --- | --- | 63 | 63 | --- | 63 |
| 4 Sep | --- | --- | 70 | 70 | 70 | --- | --- | --- | --- |
| 6 Sep | 64 | 64 | --- | --- | --- | --- | --- | 64 | --- |
| **Total** | 530 | 466 | 409 | 410 | 346 | 274 | 255 | 256 | 191 |

The climatic conditions for the two years can be summarized overall as being near normal. Irrigation amounts were also near normal, but the seasonal distributions were very dissimilar because of the timing of precipitation and high ET periods.

### Utilization of Plant-available Soil Water

**Contribution of Various Soil Profile Layers.** The soil profile depth an irrigator manages for irrigation scheduling purposes varies with soil type and climatic conditions. In previous studies at Colby, a depth of 1.5 m has been considered adequate for fully irrigated corn (Lamm and Rogers, 1985b). The average seasonal change in plant-available soil water for the 1.5 m profile between 6 June through 17 September 1990 and 28 May through 18 September 1991 is shown in figure 3. The change in soil water as related to soil profile depth was nearly linear over the wide range of irrigation treatments, meaning that all layers contributed somewhat similar amounts of water. This contradicts the classical textbook theory of increased crop water use from the surface layers, but is indicative of the ability of this particular deep soil profile to buffer the effects of dry surface layers with water from lower depths. However, this buffering effect may not be as beneficial as frequent small irrigations of the surface layers, which should contain more nutrients for plant uptake. There were significant differences in soil water depletion among treatments (fig. 3) with a general trend towards increased depletion with decreasing amounts of irrigation. One noteworthy exception to the trend was Treatment 7 (0.75 ET, DD-0), which decreased soil water to a greater degree than Treatments 8 and 9, although not significantly. Although Treatments 7 and 8 received similar amounts of total irrigation in both years, Treatment 7 received the last irrigation early enough to be effectively used in grain production. As the irrigation treatments became more limited there was a greater reliance on the deeper parts of the soil profile for soil water utilization, as indicated by the decreasing line slopes (fig. 3).

**Time Series Progression of Plant-available Soil Water.** Analysis of the time series progression of plant-available soil water in the 1.5 m soil profile (figs. 4 and 5) shows some of the distinct climatic characteristics for the two years. In 1990, a sharp decrease in plant-available soil water occurred until about 3 July (day 183) which was reflective of the excessively high ET from mid-June through early July (fig. 2) and the low June precipitation (fig. 1). Treatments 6, 7, 8, and 9 had soil water depletions of over 100 mm on 16 July (day 196). This implies the water use model was slightly underestimating AET under the extreme climatic conditions because irrigation events should have kept depletions under 100 mm. Because over 60% of the irrigation had been applied by the time the daily deficits were initiated in 1990, less separation occurred in plant-available soil water levels for the various daily deficit treatments than in 1991. Another sharp decline began in late August 1990, following the last irrigation for the various treatments. Unusually high temperatures and winds in early September 1990 caused another high ET period, which resulted in low soil water levels at physiological maturity, even for the heavy irrigation treatments. Plant-available soil water levels for the 1.5-m profile ranged from 97 to 150 mm (fig. 4 and table 2). In 1991, relatively high irrigation needs after tasseling (20 July), when the daily deficits were initiated, resulted in appreciable separation of soil water levels for the various treatments. There were significant differences in plant-available soil water levels for the 1.5 mm profile at physiological maturity ranging from 98 to 232 mm (fig. 5 and table 2).

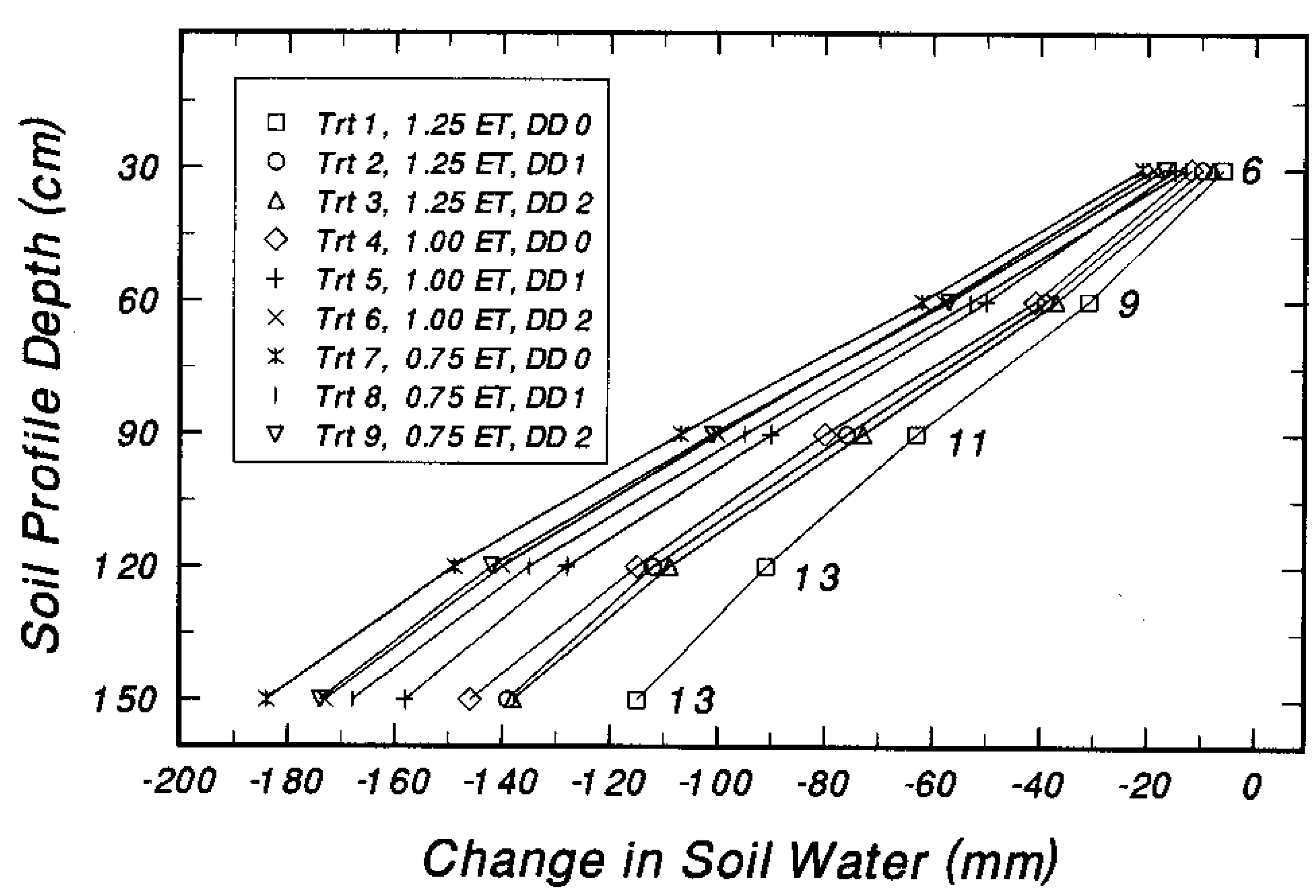

**Figure 3–Average cumulative change in soil water during the periods 6 June through 17 September 1990 and 28 May through 18 September 1991 as a function of depth in the soil profile for the various irrigation treatments. Numbers to the right of graphed lines represent the least-significant-difference for the indicated depth at P = 0.05.**

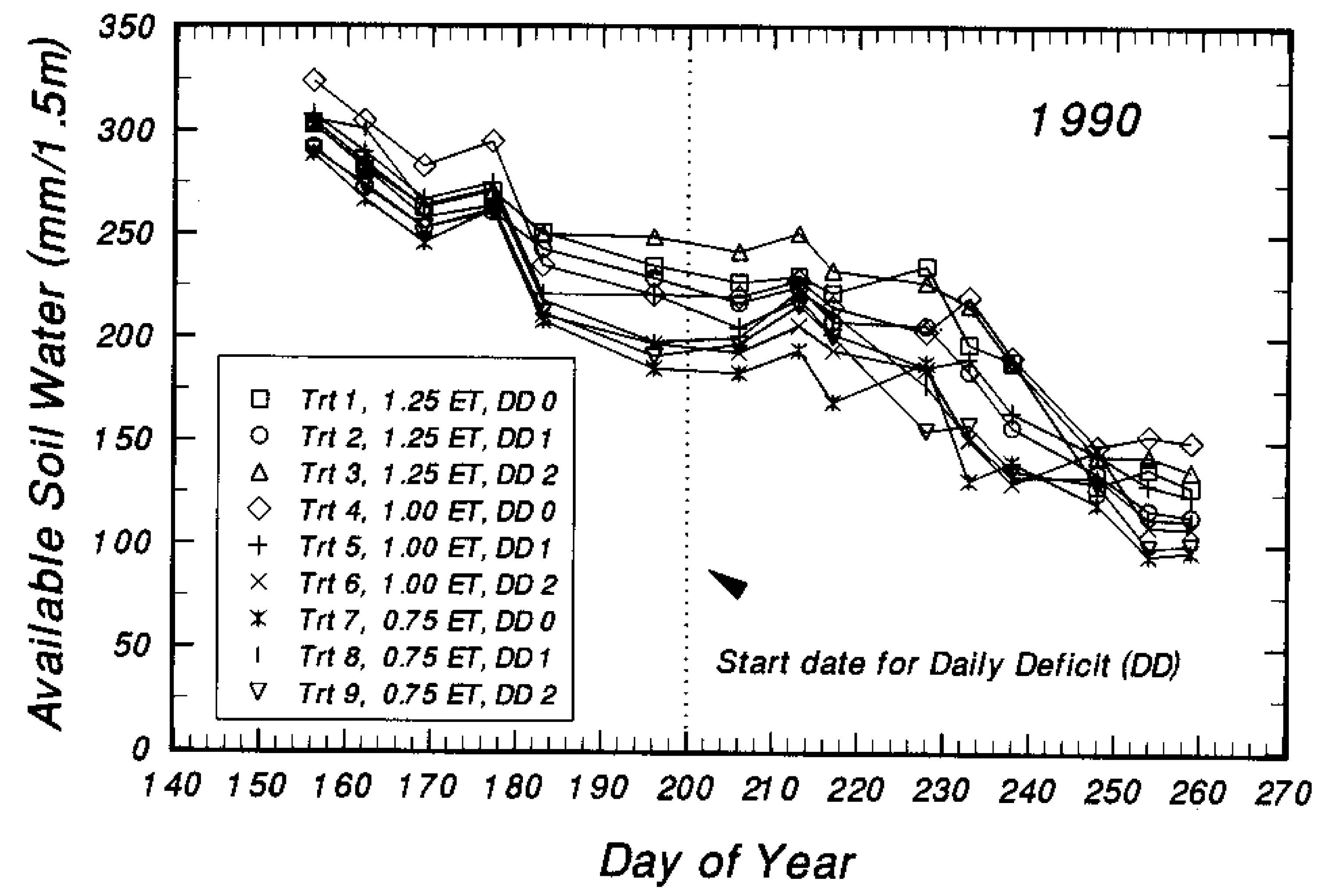

**Figure 4–Time series progression of plant-available soil water in the 1.5-m-depth soil profile for the various irrigation treatments, 1990.**

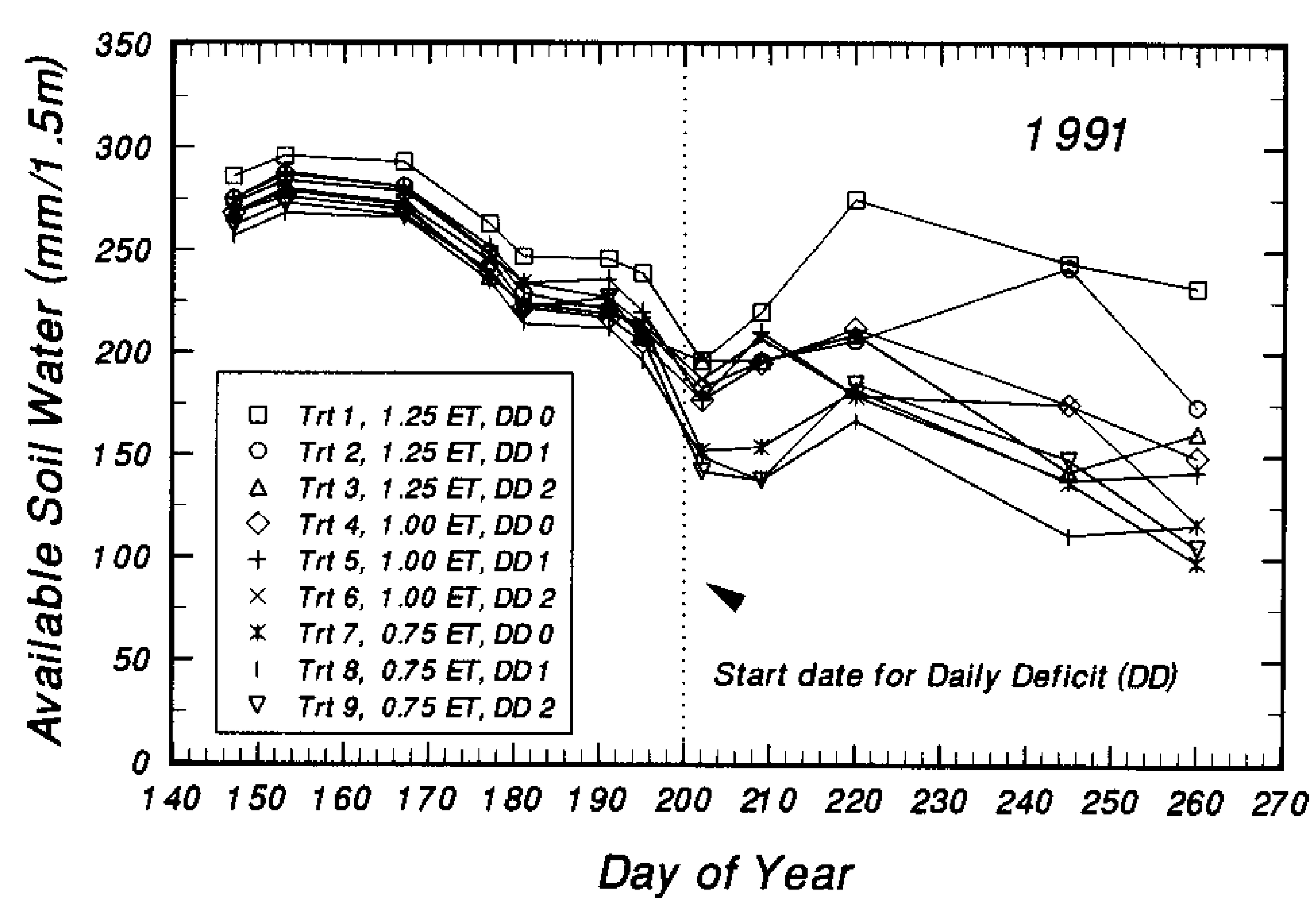

**Figure 5–Time series progression of plant-available soil water in the 1.5-m-depth soil profile for the various irrigation treatments, 1991.**

**Table 2. Summary of corn yield and water use data, Northwest Research-Extension Center, 1990**

| ET Factor* | Daily Deficit† (mm/d) | Yield 1990 | Yield 1991 | Yield Mean | Water Use 1990 | Water Use 1991 | Water Use Mean | WUE‡ 1990 | WUE‡ 1991 | WUE‡ Mean | Soil Water§ 1990 | Soil Water§ 1991 | Soil Water§ Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (Mg/ha) | | | (mm) | | | (Mg/ha-mm) | | | (mm/1.5 m) | | |
| 1. 1.25 | 0 | 13.1a | 13.9a | 13.5a | 808a | 820a | 814a | 0.016a | 0.017a | 0.017a | 128abc | 232a | 180a |
| 2. 1.25 | 1 | 11.5ab | 13.8a | 12.6abc | 747b | 803a | 775b | 0.015a | 0.017a | 0.016a | 114bcd | 174b | 144bc |
| 3. 1.25 | 2 | 12.1ab | 13.2ab | 12.6abc | 732b | 754b | 743c | 0.017a | 0.018a | 0.017a | 136ab | 161bc | 149b |
| 4. 1.00 | 0 | 12.1ab | 13.7ab | 12.9ab | 671c | 767b | 719d | 0.018a | 0.018a | 0.018a | 150a | 149c | 150b |
| 5. 1.00 | 1 | 12.5ab | 13.0abc | 12.8abc | 676c | 716c | 696e | 0.019a | 0.018a | 0.018a | 124bc | 142c | 133c |
| 6. 1.00 | 2 | 11.2b | 12.3bcd | 11.7bcd | 622d | 665d | 644f | 0.018a | 0.018a | 0.018a | 108cd | 117d | 112d |
| 7. 0.75 | 0 | 11.2b | 11.7cde | 11.5cd | 592e | 668d | 630g | 0.019a | 0.018a | 0.018a | 97d | 98d | 97e |
| 8. 0.75 | 1 | 11.3ab | 11.2de | 11.2d | 594e | 635e | 615h | 0.019a | 0.018a | 0.018a | 112cd | 116d | 114d |
| 9. 0.75 | 2 | 9.3c | 10.4e | 9.8e | 528f | 587f | 558i | 0.018a | 0.018a | 0.018a | 100d | 105d | 102e |

* Within columns, means followed by the same letter are not significantly different according to LSD means separation at P = 0.05.
† Daily deficit amount applied to scheduling treatments after 20 July.
‡ Water use efficiency is defined as yield in Mg/ha divided by total water use in mm.
§ Plant available soil water in a 1.5-m soil profile at corn physiological maturity on 17 September 1990 and 18 September 1991.

**Irrigation and Plant-available Soil Water at Physiological Maturity.** The plant-available soil water at physiological maturity for the corn ($ASW_m$) was linearly related to the applied irrigation amount (fig. 6). Linear regression of the 18 data points from both years resulted in an equation for $ASW_m$ in mm:

$$ASW_m = 44 + (0.25 \times IRR) \qquad (1)$$

where IRR is expressed in millimeters. Overall, the equation does not have a very good fit as expressed by the relatively high standard error of the estimate (SE = 22.5 mm) and the relatively low RSQUARE ($R^2 = 0.56$). However, the results show that to leave the soil profile drier at harvest by a given amount, irrigation needs to be reduced on the average by four times that amount on this soil type. The relationship holds over a fairly broad range of irrigation levels which further implies that only slight decreases of $ASW_m$ are possible with good surface irrigation practices on this soil. Although the primary purpose of irrigation is to provide water for crop use, another purpose is to maintain a conducive soil environment for nutrient uptake. Excessive depletion of soil water also can have the effect of reducing nutrient availability. Plant-available soil water was lower than 50% of field capacity for Treatments 6 to 9. The 50% depletion level of plant-available soil water is the critical point of many soils where yields are reduced. Although the response (eq. 1) was linear over a fairly wide range of treatments for these two years, the response would approach the asymptotes of upper and lower limits of plant-available soil water as irrigation was further increased or decreased.

The imposition of the daily deficits after tasseling generally decreased plant-available soil water at maturity (fig. 7 and table 2). In many cases, these decreases were statistically significant, particularly for the heavy and normal irrigation treatments in 1991. Planned soil water depletion (DD-1 and DD-2) on the heavy irrigated treatments (1.25 × ET) resulted in plant-available soil water levels similar to those for the normal fully irrigated treatment with no daily deficit imposed. In some cases, imposition of the daily deficit had little effect on the overall irrigation amount, but simply shifted an irrigation event to a later date (table 1 and fig. 7). This occurred in both years for Treatments 7 and 8. A portion of the last

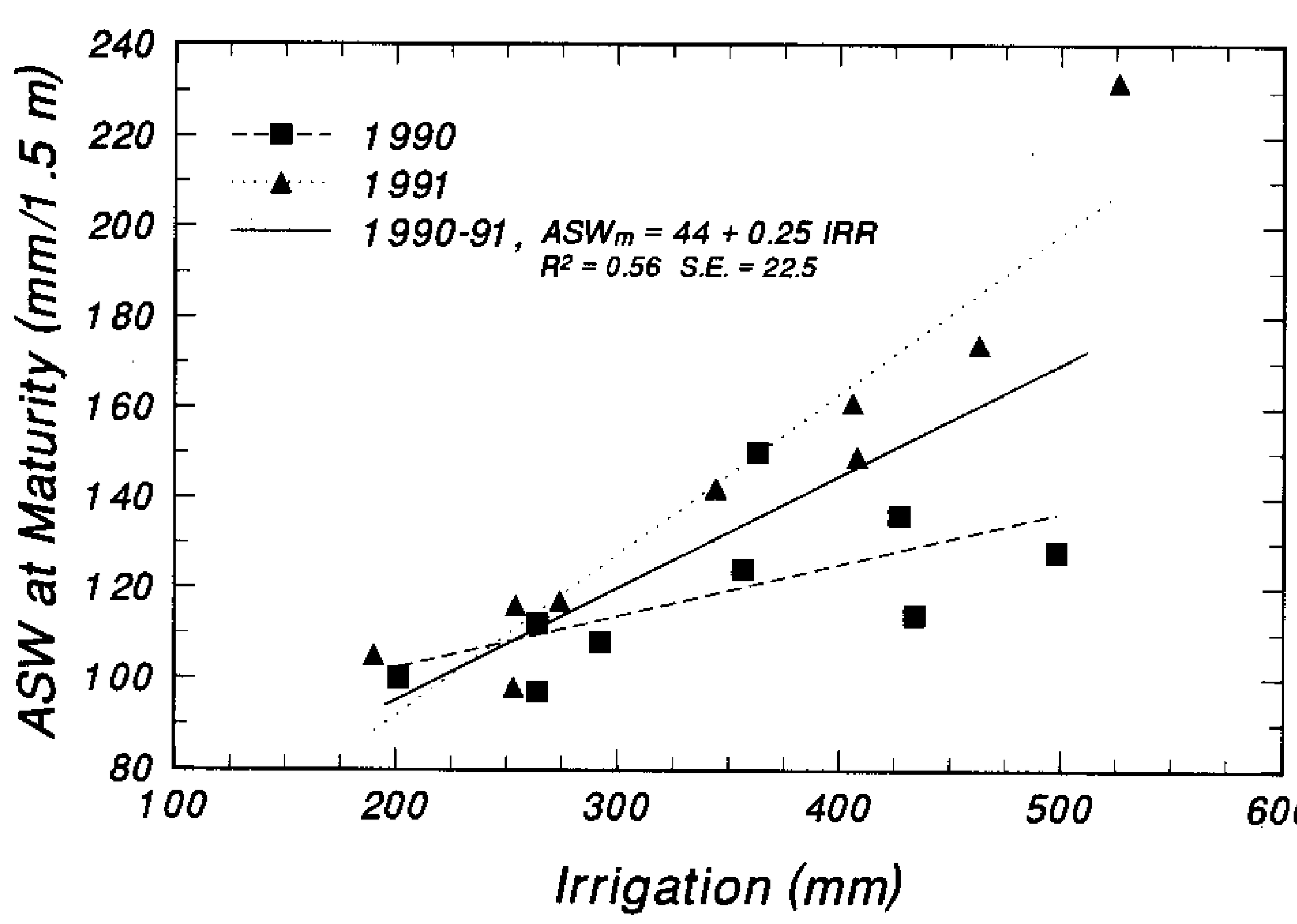


**Figure 6–Plant-available soil water, $ASW_m$, in a 1.5-m soil profile at corn physiological maturity as a function of cumulative seasonal irrigation amount, 1990-1991.**

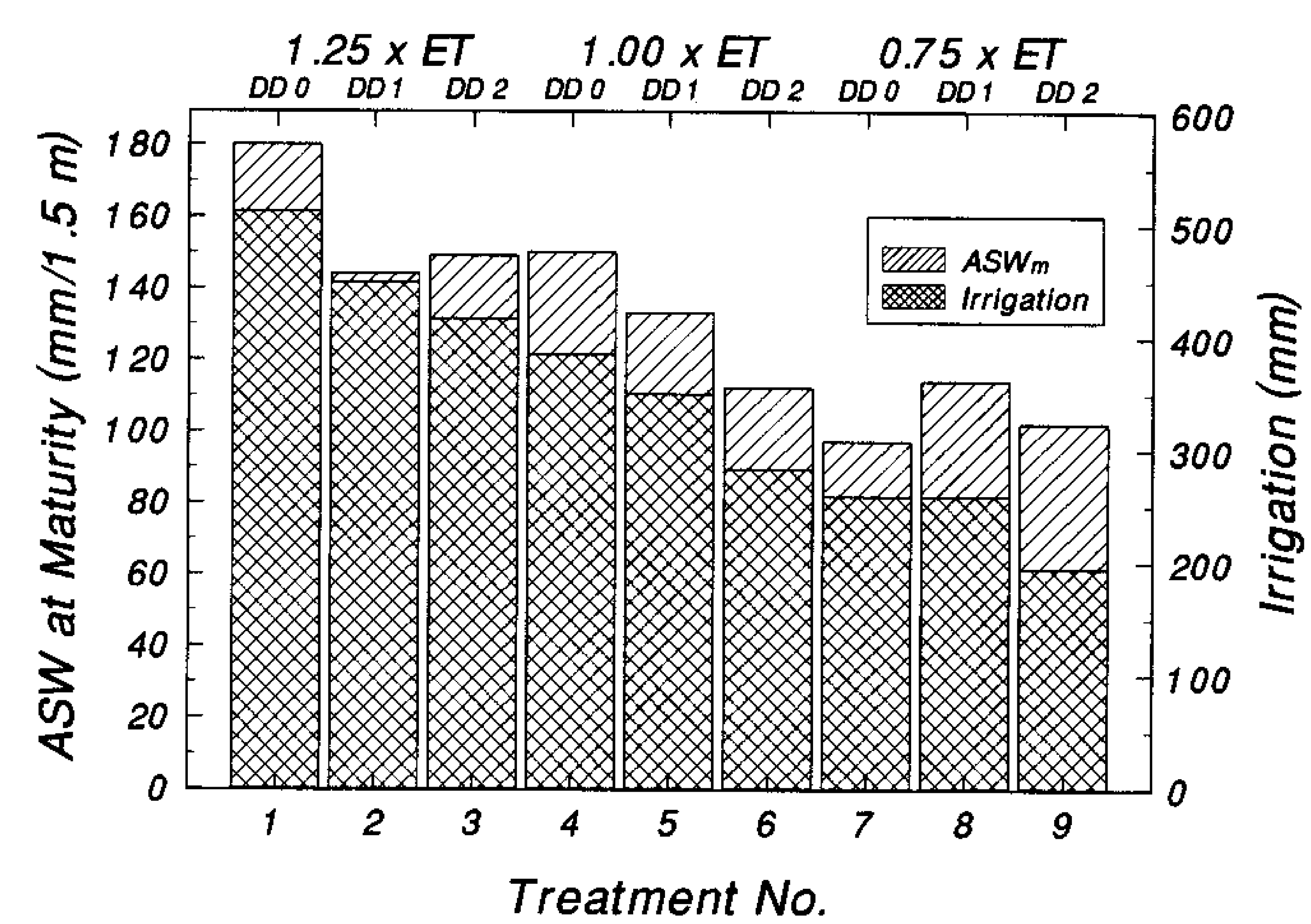


**Figure 7–Average measured plant-available soil water, $ASW_m$ in a 1.5-m soil profile at corn physiological maturity and cumulative seasonal irrigation for the various irrigation management levels and daily deficits, 1990-1991.**

irrigation amount for Treatment 8 in both years probably went to increasing plant-available soil water at maturity rather than to crop production. Use of a small, 1 mm/day deficit after tasseling reduced overall irrigation amounts for the heavy, normal, and deficit irrigation management levels by 63, 35, and 0 mm, respectively. The larger 2 mm/day deficit resulted in savings of 95, 102, and 64 mm.

### Corn Yields and Irrigation

Corn yields varied widely among treatments (table 2) for the two years of the study, ranging from a low of 9.3 Mg/ha for Treatment 9 in 1990 to a high of 13.9 Mg/ha for Treatments 1 in 1991. Although early seasonal crop water use (ET) was higher than normal in 1990, the pollination and grain filling stages of the corn occurred during periods characterized by extremely mild temperatures. These mild climatic conditions reduced plant water stress during the critical growth stages and resulted in overall excellent grain yields. Although 1991 irrigation requirements for the fully irrigated condition (Treatment 4) were higher which would generally indicate less favorable growing conditions, more consistent and less severe growing conditions resulted in higher yields in 1991 than obtained in 1990. Imposition of a small daily deficit (DD-1) after tasseling did not have a statistically significant effect on yields within a given management level (fig. 8 and table 2). However, the imposition of the larger 2 mm/day deficit did appreciably affect yields for the normal (1.00 × ET) and deficit (0.75 × ET) management levels. The deficit-irrigated treatment with a daily deficit of 2 mm/day (Treatment 9) had a significantly lower yield.

No significant differences in water use efficiencies (averaging approximately 0.018 Mg/ha-mm) occurred among treatments in either year, indicating that irrigation amounts even for the heavy irrigated treatments were relatively efficient. Reductions in irrigation imposed by the daily deficits for the deficit treatments thus would reduce yields by 0.018 Mg/ha for each millimeter reduction in irrigation. Statistically significant linear relationships for yield as a function of irrigation amount and water use were determined (fig. 9) with regression of the 18 data points

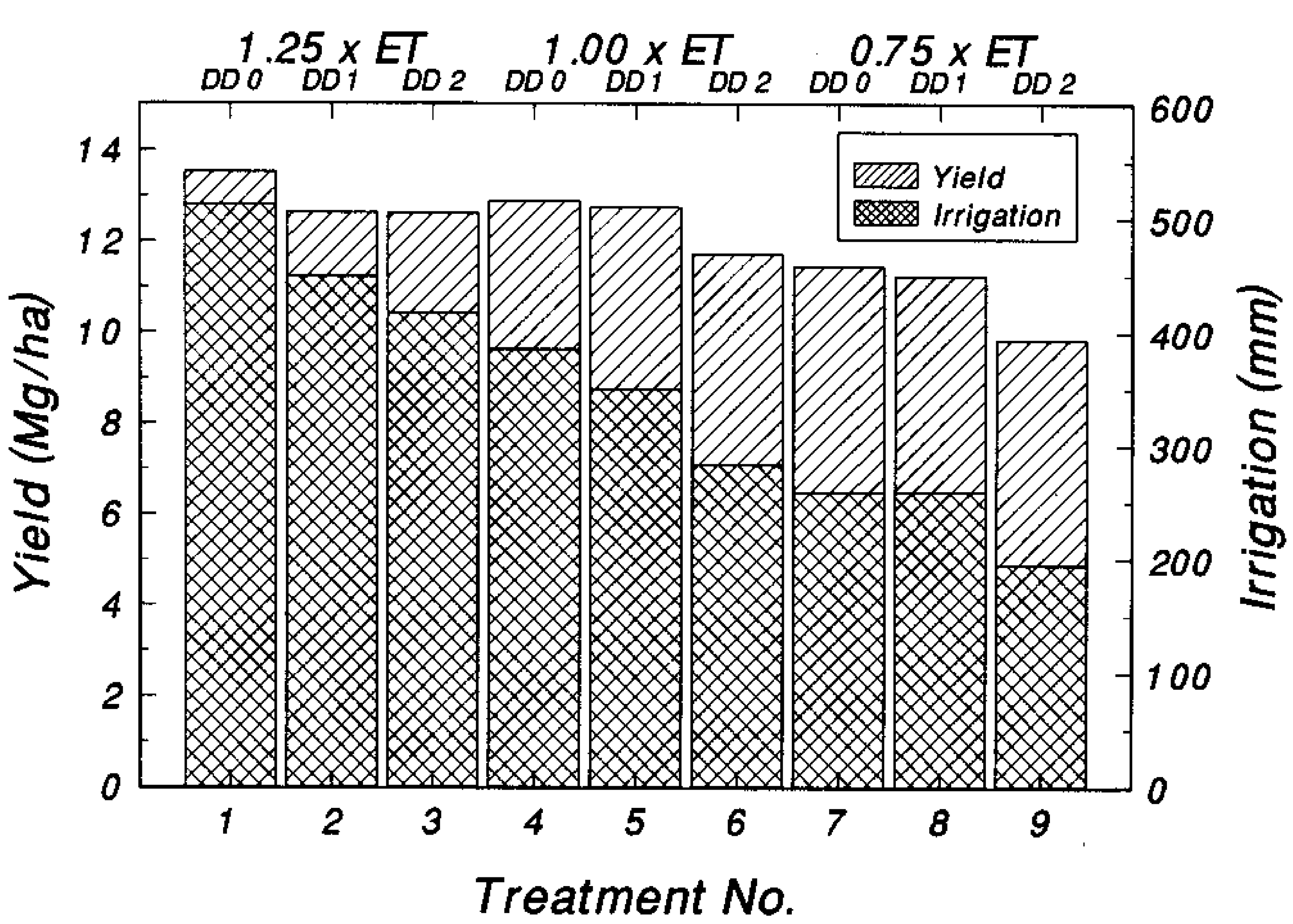


**Figure 8–Average corn yields and cumulative seasonal irrigation amounts for the various irrigation management levels and daily deficits, 1990-1991.**

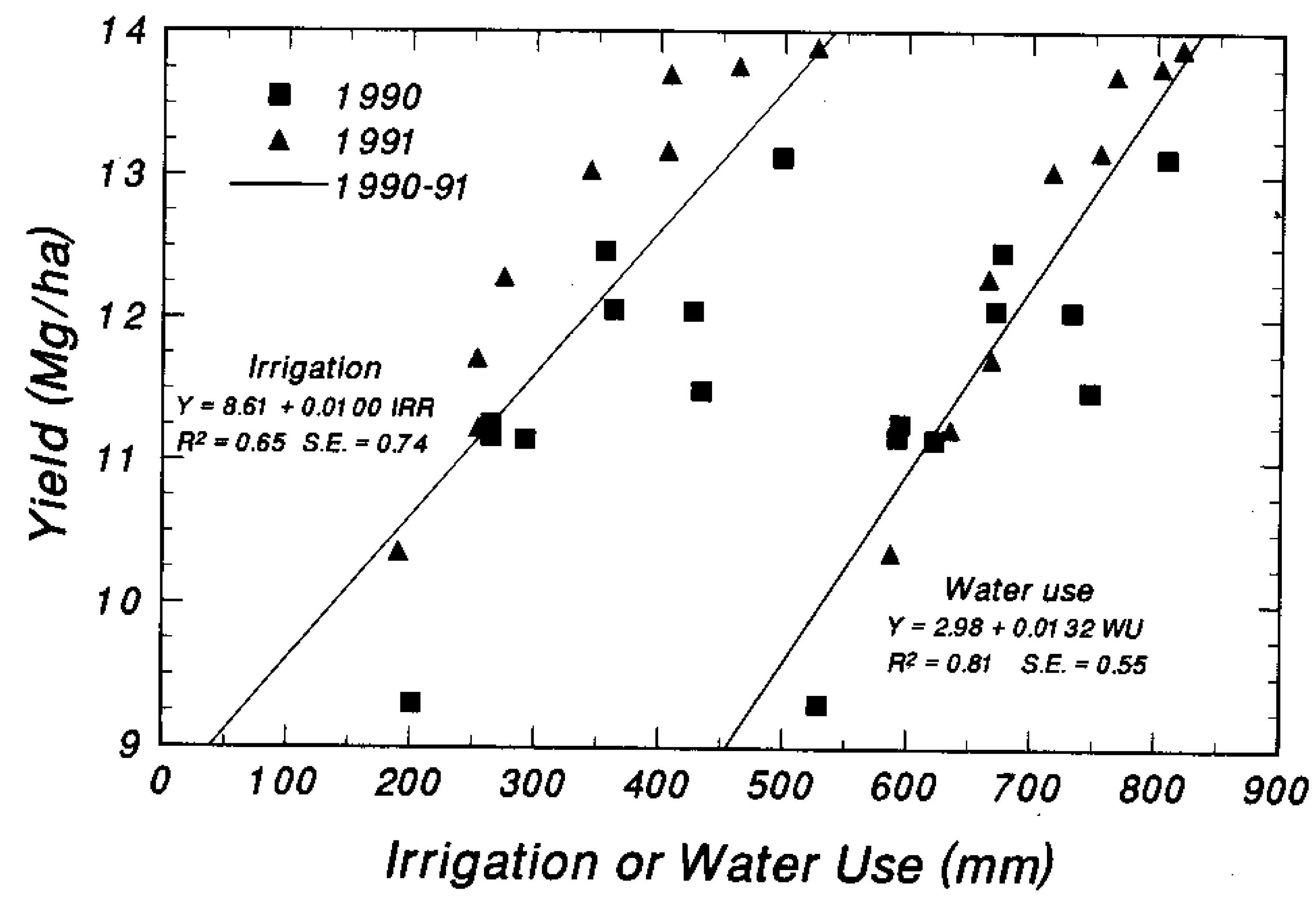


**Figure 9–Corn yield as functions of cumulative seasonal irrigation amount (IRR) and measured water use (WU), 1990-1991.**

from both years resulting in equations for yields, Y in Mg/ha:

$$Y = 8.61 + (0.0100 \times IRR) \quad (2)$$

$$Y = 2.98 + (0.0132 \times WU) \quad (3)$$

where irrigation (IRR) and water use (WU) are expressed in millimeters. The equations fit the overall data fairly well, with standard error of the estimates equal to 0.74 and 0.55 Mg/ha, respectively. The RSQUAREs of equations 2 and 3 were 0.65 and 0.81, respectively.

The absence of significant differences in water use efficiencies among treatments indicates that no benefits occurred in terms of water resource conservation by imposition of the daily deficits after tasseling. The savings in water by using planned soil water depletion were directly offset by yield reductions. Water saved in one year would have the same yield production potential in a future year. The water use efficiencies were slightly lower for the heavy irrigation treatments indicating that some deep percolation losses were occurring for these treatments. It is possible that the daily deficits would have had less effect on yields if the frequency of irrigation events had been higher. 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. Reducing the soil water level at harvest may have additional economic benefits such as reduced leaching of chemicals that traditionally have not been accounted for in analyses.

## Conclusions

Overall, the two years of this study had near normal precipitation and evapotranspiration, resulting in near normal irrigation requirements. However, the seasonal distribution of irrigation was dissimilar.

Soil water was utilized to a depth of 1.5 m in this study, and all layers contributed somewhat similar amounts of water, as evidenced by the linear relationships of seasonal soil water changes and profile depth. This characteristic of this deep soil profile would be beneficial in irrigation scheduling with planned soil water depletion, because water stress caused by dry surface layers could be buffered with water from lower depths. However, some reduction in nutrient availability could occur because of dry surface layers.

The plant-available soil water at physiological maturity was related linearly to the irrigation amount over the wide range of irrigation treatments. However, the plant-available soil water at physiological maturity was reduced by only 25 mm for each 100 mm reduction in irrigation.

Yields were related linearly to irrigation and water use with a reduction in irrigation or water use reflected by a reduction in yield. Using irrigation scheduling with planned soil water depletion resulted in yield reductions.

Water use efficiencies were similar whether planned soil water depletion was used or not. Therefore, from a water conservation standpoint, irrigation scheduling with planned soil water depletion was not justified. From a water quality standpoint, irrigation scheduling with planned soil water depletion might be advantageous. Drier soils at harvest would reduce the potential for overwinter chemical leaching. Smaller, more frequent irrigations as might be accomplished by surge, sprinkler, or drip irrigation might have helped maintain yields, while allowing planned soil water depletion.

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