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Soybean Water Extraction, Leaf Water Potential, and Evapotranspiration During Drought[1]

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ABSTRACT

Soil water is often the most limiting factor in soybean production in the southeastern U.S. To increase water-use efficiency in soybean production, it is necessary to characterize the plant's response to the evaporative demand and to soil water stress when the root distribution changes with depth. 'Davis' and 'McNair 800' soybean cultivars (*Glycine max* (L.) Merr.) were grown in a field experiment conducted on Norfolk sandy loam (Thermic Typic Paleudults) to evaluate the effect of irrigation on soybean yields and to determine the combined effects of soil matric potential and evaporative demand on evapotranspiration (ET) in nonirrigated and irrigated treatments. Water was applied to the irrigated treatment when the matric potential at the 15-cm depth was —0.2 bar. Leaf water potential was measured using the pressure chamber technique and ET was measured using a portable chamber during a 34-day drought. Only small differences in the midday leaf water potential were found between the two cultivars, whereas ET on the nonirrigated treatments was about two-thirds of that on the irrigated treatments 25 and 32 days into the drought. Soil matric potential data indicated significant water extraction at the 153-cm depth in the nonirrigated treatments near the end of the drought. The maximum in-canopy air temperature during the drought in the nonirrigated Davis was 6.7 C higher than in the irrigated treatment. Irrigation resulted in a 351- and 364-kg/ha increase in Davis and McNair 800, respectively. Even though the nonirrigated plants exhibited severe wilt symptoms during the drought, the results point out the importance of the root distribution and subsoil water in partially meeting the evaporative demand during drought.

***Additional index words:* *Glycine max* (L.) Merr., Xylem pressure potential water relations.**

WATER deficits can reduce plant growth by modifying physiological processes. Plant growth is controlled directly by plant water status and only indirectly by atmospheric and soil water stress. Insufficient water during the pod filling period can be a major barrier to higher soybean (*Glycine max* (L.) Merr.) yields and is an important management concern (Pendleton and Hartwig, 1973). Mederski et al. (1973) stated that soybeans may be more sensitive to a given level of or duration of stress at one stage of development than another and that growth and yield are likely affected by internal plant water stress at any stage of plant development.

Doss et al. (1974) reported soybean yields increased from 24 to 55% when irrigated at 50% of the available soil moisture during the entire season. Response was greater from water applied after full flowering than earlier. They concluded the pod-filling stage was the most critical period for adequate moisture to obtain maximum soybean yields.

Raper and Barber (1970) studied the variation in the root morphology among different soybean cultivars to an 80-cm depth. They found that 'Harosoy 63' had a more extensive root system, including a nearly two-fold greater surface area, than 'Aoda'. Both cultivars lacked a distinctive tap root development below the zone of profuse branching. Mitchell and Russell (1971), who sampled the root systems of eight soybean cultivars on four dates, found root growth and development occurred in three phases, with each phase corresponding to a specific vegetative or reproductive stage. Downward tap and shallow horizontal lateral root growth accompanied the vegetative top growth. Roots grew to the 76-cm depth during flowering and pod formation and several lateral roots penetrated deep in the profile during seed maturation.

Mayaki et al. (1976) studied soybean root depth and distribution under irrigated and nonirrigated conditions in a deep barrier-free Muir silt loam soil. They noted that the soybean roots for 'Williams' reached a depth of 160 cm in both the irrigated and nonirrigated plots. The root depth increased faster than the plant height. At physiological maturity, 67% of the soybean root dry matter was in the 0- to 15-cm layer and 89% in the 0- to 90-cm layer of the irrigated soil, as compared with 51% in the 0- to 15-cm layer and 83% in the 0- to 90-cm layer of the nonirrigated soil. Plant height correlated with rooting depth at several growth stages with the rooting depth about twice the plant height until the six-node stage.

Under ideal moisture conditions, root water extraction is related to the root distribution. However, as the surface layers dry, the pattern of water extraction shifts and a small part of the root sytsem in the subsoil is responsible for a major portion of the uptake. Allmaras et al. (1975a, b) found that maximum soybean rooting depths coincided with maximum depth of water extraction, but corn (*Zea mays* L.) rooting depths ranged from 15 to 30 cm deeper than the depth of maximum water extraction. Thus, it becomes important to characterize the plants' response to the evaporative demand and to soil water stress when there is a changing root density or root distribution with depth.

Ideally, the plant water status should be used to determine when to irrigate, and the soil should indicate how much water to apply. Several soil and plant-water measurements have been suggested as indicating soil water stress and its influence on the plants. One way of evaluating the effect of soil water stress on plant water status is by measuring the decrease in evapotranspiration (ET). The objective of this work was to evaluate the effect of irrigation on soybean production in the southeastern U. S. and to determine

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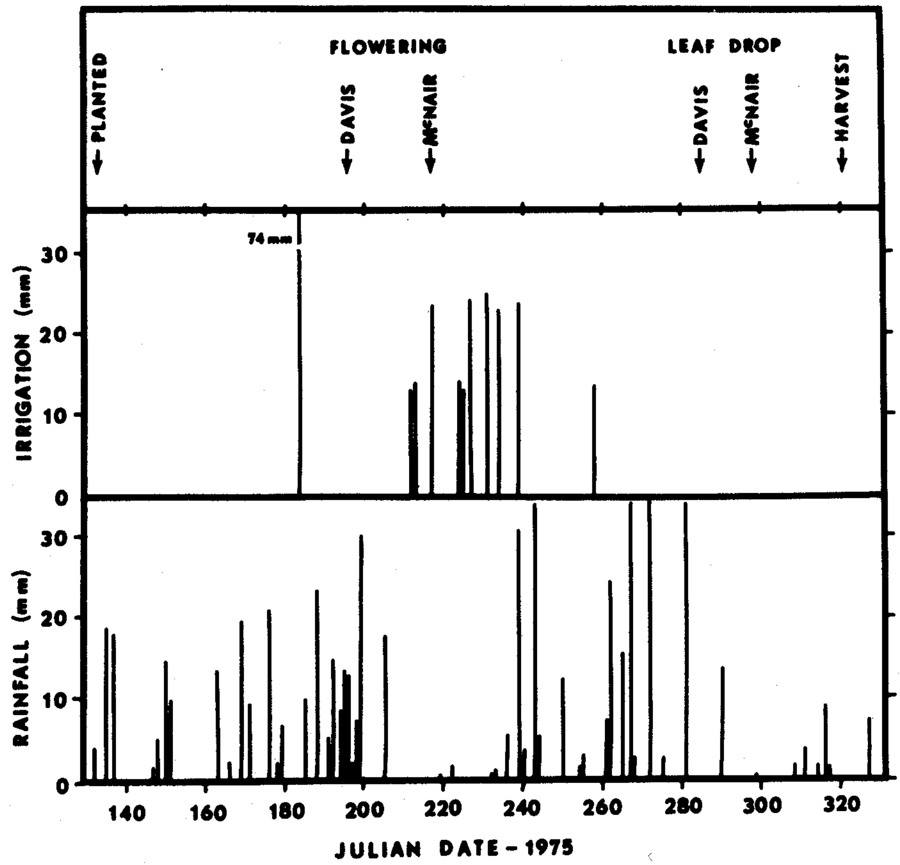

Fig. 1. Summary of the rainfall and irrigation for the 1975 growing season.

the effect of soil matric potential on ET and plant water status.

MATERIALS AND METHODS

Soybeans were grown on Norfolk fine sandy loam (Thermic Typic Paleudults) to evaluate the effect of irrigation on soybean yield. Two determinant cultivars, 'McNair 800' (Group VIII) and 'Davis' (Group VI), were planted on 13 May 1975, and harvested on 17 Nov. 1975. The soybeans were planted in eight-row plots 16.4 m long and replicated four times in a incompletely randomized block experiment. A preplant application of 511 kg/ha of 8-24-24 fertilizer was broadcast and incorporated. Preplant treatment of Trifluralin at the rate of 2.3 liters/ha was applied for weed control.

Irrigation was applied through a trickle-tube system when the matric potential at the 15-cm depth was equal to —0.2 bar. The amount of irrigation varied from 13 to 25 mm, depending upon the weather forecast for the next 2 days.

Tensiometers were installed in the plots in all four replications for both the irrigated and nonirrigated treatments at the 15-, 30-, 46-, 61-, 91-, 122-, 153-, and 183-cm depths. Tensiometers were connected to mercury manometers and read at least three times a week and more frequently during periods of rainfall. The tensiometers were flushed to eliminate air bubbles when necessary.

We made detailed measurements of leaf water potential and ET on 18 and 25 August, 25 and 32 days into the drought. Leaf water potential (xylem pressure potential) was measured using the Scholander et al. (1965) pressure chamber technique. Four to eight of the uppermost fully exposed trifoliates from each treatment were sampled in rapid succession and averaged for that sampling time.

We measured ET using the portable chamber described by Reicosky and Peters (1977). The plots were premarked to aid in positioning the chamber. Measurements were not started until late in the morning because of dew on the plants. ET was measured on two replications of the experiment. Visual observations indicated canopy development (leaf area index) was nearly the same on the irrigated and nonirrigated plots of both cultivars. Late in the drought, a few of the lower leaves in the nonirrigated plots showed signs of senescence and may have decreased the active leaf area for transpiration, but not enough to explain the measured differences in ET.

Microclimate data collected included solar radiation, net radiation over well watered grass, and open pan evaporation. Shielded temperature sensors were placed 30 cm above the soil in the canopy of irrigated and nonirrigated Davis and used to measure canopy air temperature on 25 August.

RESULTS AND DISCUSSION

Rainfall was adequate throughout most of the 1975 growing season, except for a 34-day drought during the flowering and pod-filling stages. This rainfall distribution provided an opportunity to look at the effect of drought on ET and plant water status of soybeans.

The rainfall and irrigation for the 1975 growing season is summarized in Fig. 1. The last significant rainfall before the drought was 17.3 mm on 24 July (day 205). The next significant rainfall was 35.3 mm on 27 August (day 239) that terminated the drought. The total amount of irrigation for the entire season was 262 mm.

The seasonal trends in the soil matric potential at the 30- and 122-cm depth for Davis are summarized in Fig. 2. Typically, the standard deviation about the mean for these data are ± 0.1 and ± 0.05 bar for the 30- and 122-cm depths, respectively. The results

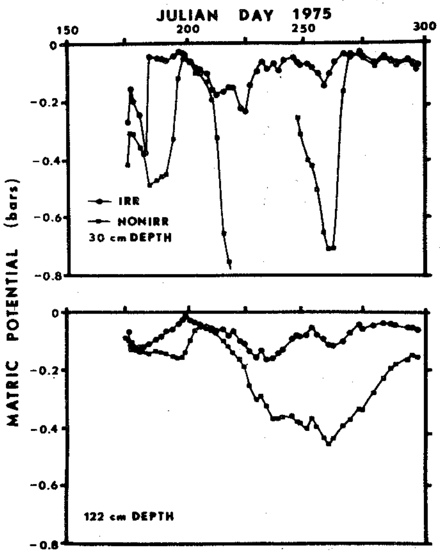

Fig. 2. Soil matric potential versus time at the 30- and 122-cm depths under Davis soybeans.

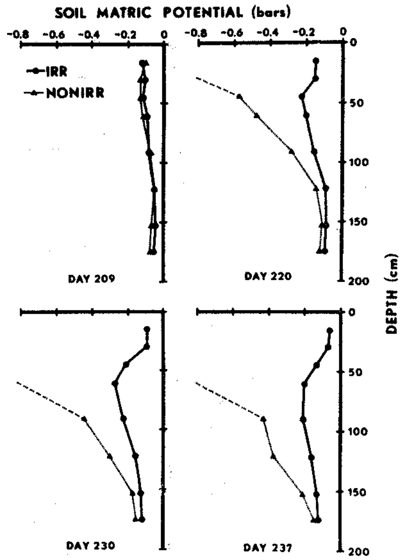

Fig. 3. Soil matric potential profiles at selected times during the drought under Davis soybeans.

for McNair 800 were essentially the same and are not shown. Throughout most of the growing season, the soil matric potential at the 30-cm depth in the irrigated plots was maintained fairly high, while that in the nonirrigated plots showed drying during the drought. Twice during the growing season, the tensiometers at the 30-cm depth exceeded the effective operating range. A similar trend is shown in the soil matric potential at the 122-cm depth with about a 7-day lag. Drying at the 122-cm depth was noted on the nonirrigated plots, while only small fluctuations were observed in the irrigated plots. The data showed a lag in the rewetting of the profile at the 122-cm depth after termination of the drought on day 239. These results suggest that even with adequate rainfall after the drought, considerable time was required to rewet the profile.

Soil matric potential profiles for Davis and McNair 800 at selected times during the growing season are summarized in Fig. 3 and 4, respectively. On day 209 both irrigated and nonirrigated treatments for both cultivars had essentially the same profile near the maximum water holding capacity. However, the profiles on subsequent dates showed progressive drying on the nonirrigated treatments as the drought continued. The irrigated treatments had some drying at the 45- and the 60-cm depths, indicating that part of the root system was extracting water, even though the surface 30 cm was maintained at —0.2 bar or higher. Even though adequate water was applied to meet the demands of the plant in the surface 30 cm, the roots were extracting some water from the subsoil. The progressive drying under the nonirrigated plots continued so that the effective range of the tensiometers was exceeded as deep as 90 cm for both cultivars. There was only a small difference on 25 August (day 237) between Davis and McNair 800. McNair 800 had a slightly lower potential for the 90- to 183-cm depths, indicating more water extraction from this depth range.

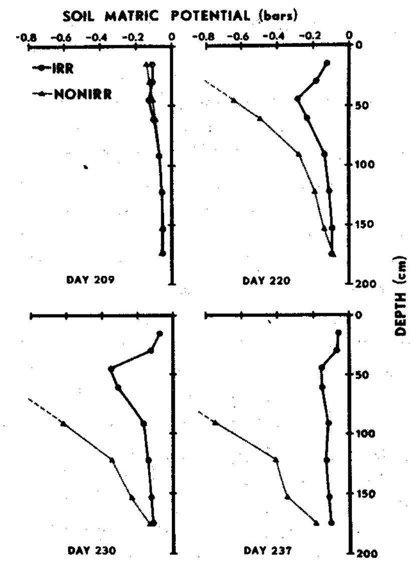

Fig. 4. Soil matric potential profiles at selected times during the drought under McNair 800 soybeans.

The results of the ET measurements on 18 August (day 230) are summarized in Fig. 5. Solar radiation changed rapidly as a result of clouds and had some effect on ET values. The irrigated plots had an ET rate that ranged from 0.6 to 0.7 mm/hour, while ET rate in the nonirrigated plots ranged from 0.2 to 0.4 mm/hour during peak radiation. The difference in ET reflects the magnitude of the plant and soil water stress at this time. Even though the surface layers were dry, a significant portion of the roots utilized subsoil water at a rate sufficient to maintain ET on the nonirrigated plots at about half that of the irrigated plots.

Leaf water potential data for both cultivars is summarized in Fig. 6. For both cultivars, the leaf water potential for the irrigated and nonirrigated treatments

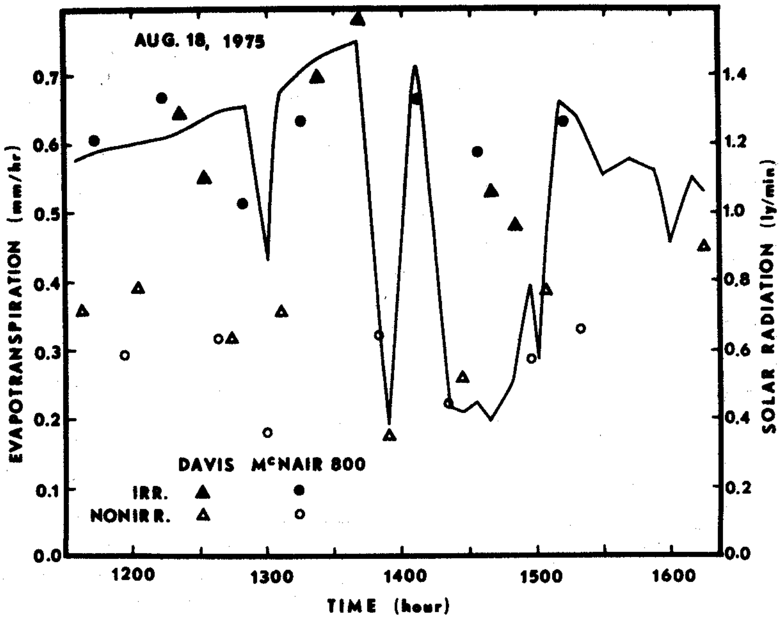

Fig. 5. Evapotranspiration (data points) and solar radiation (solid line) on 18 August, 1975.

fluctuated diurnally ranging from about —1 bar before sunrise to —18 bars near solar noon. Typical values for the standard deviation about the mean for the leaf water potential ranged from ± 0.5 bar for the predawn data to ± 2.0 bar at midday. Both the irrigated and nonirrigated treatments had essentially the same minimum leaf water potential under high radiation. Differences in leaf water potential were small in the early morning and evening, when the nonirrigated treatment was 2 to 4 bars lower than the irrigated treatment. The irrigated treatment of both cultivars showed the effect of a cloud passing over near 1500 hours, while nonirrigated Davis did not respond to the change in radiation. Nonirrigated McNair 800 slightly increased in leaf water potential when the cloud passed over. There was little difference in the minimum leaf water potential for both the irrigated and nonirrigated treatments under high solar radiation, while the ET data indicated a 50% reduction in ET on the nonirrigated treatments. This agreed with the results of Sojka et al. (1977), who did not observe large differences in leaf water potential under widely differing irrigation regimes.

The ET data for 25 August (day 237) is summarized in Fig. 7. This was a day with few clouds but generally high radiation throughout the afternoon. The difference between the irrigated and nonirrigated treatments was small around 1200 hours and increased later in the afternoon. The small difference in ET between the irrigated and nonirrigated treatments on this day, as compared with that on day 230, was probably a result of 3 mm of precipitation on the preceding day. The soil surface was slightly moist and the soil evaporation was nearly the same on both irrigated and nonirrigated treatments. However, later in the day ET on the nonirrigated treatments decreased to about 0.3 mm/hour, whereas that on the irrigated treatments was near 0.7 mm/hour for both cultivars.

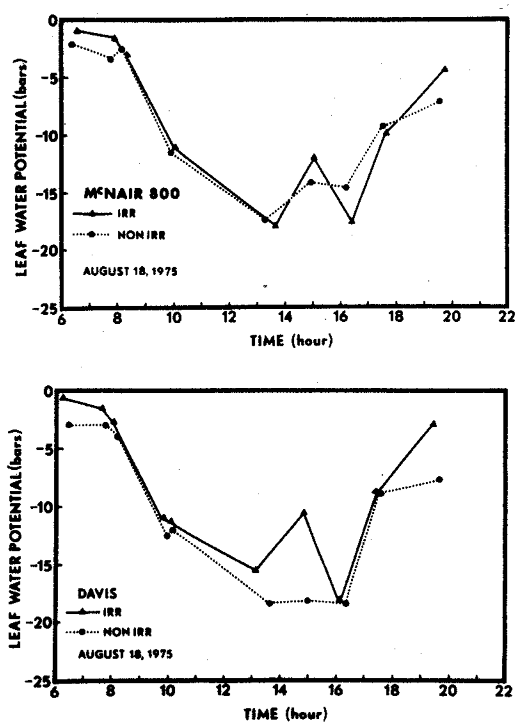

Fig. 6. Leaf water potential for the McNair 800 and Davis soybeans on 18 August, 1975.

The associated leaf water potential measurements for 25 August are summarized in Fig. 8. Both irrigated and nonirrigated treatments for both cultivars went through the same diurnal changes. McNair 800 showed a difference of about 3 bars between irrigated and nonirrigated treatment during peak radiation, whereas Davis showed no difference. The difference in leaf water potential was small for Davis early in the morning and late evening. The lag was a result of

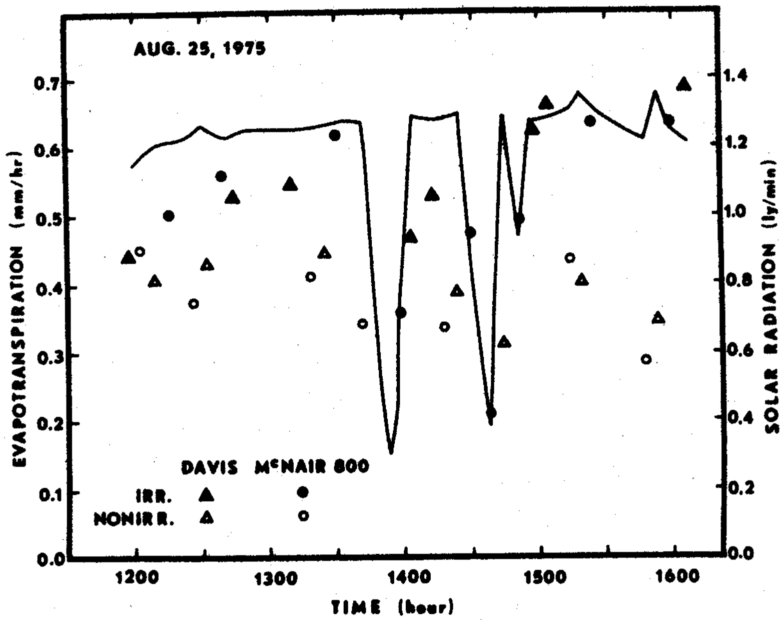

Fig. 7. Evapotranspiration (data points) and solar radiation (solid lines) on 25 August, 1975.

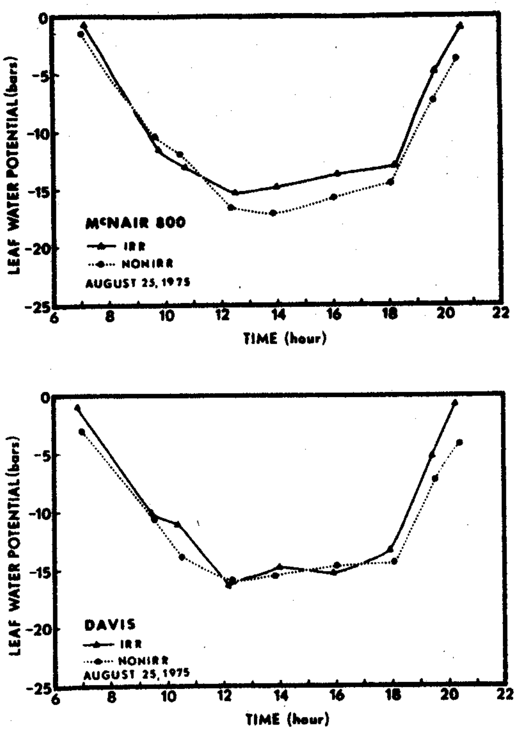

Fig. 8. Leaf water potential for the Davis and McNair 800 soybeans on 25 August, 1975.

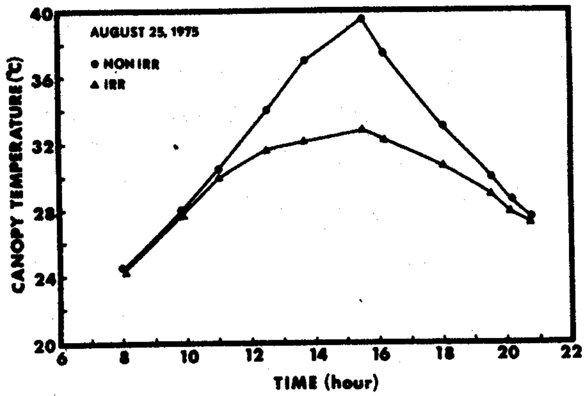

Fig. 9. The canopy air temperature at 30 cm in irrigated and nonirrigated Davis soybeans as a function of time on 25 August, 1975.

Table 1. Summary of soybean seed yields for 1975.

	1975 seed yield	
Cultivar	Nonirrigated	Irrigated
	kg/ha	
Davis	1,990 a*	2,341 a
McNair 800	2,041 a	2,405 a

* Column means followed by the same letter are not significantly different at the 0.05 level, according to Duncan's Multiple Range Test.

the soil water stress delaying the recovery of the leaf water potential as the evaporative demand decreased at sunset. Only a small difference in the minimum leaf water potential was associated with a 60% decrease in ET from the nonirrigated plots, as observed previously.

The results of the canopy air temperature measurements at 30 cm on 25 August are summarized in Fig. 9. The canopy air temperature increased from a low of 25 C before sunrise to a maximum of 39.5 C on the nonirrigated plot shortly after solar noon. The maximum on the irrigated was about 32.8 C, a difference of 6.7 C. The increase in the air temperature in the nonirrigated plot was a result of the plant water stress causing stomates to partially close limiting ET. Because ET was limited, the radiant energy was dissipated as increased sensible heat. The results indicated that part of the yield difference attributed to soil water stress may be a result of increased canopy air temperature on the nonirrigated treatment.

The yield data for the two cultivars are summarized in Table 1. The 34-day drought period during the flowering and the pod-filling stages slightly decreased the nonirrigated soybean yields. Although not significant at the 0.05 level, irrigation resulted in a 351- and 364-kg/ha increase in the seed yield for Davis and McNair 800, respectively. Differences were not as large as had been expected, based on the visible wilt symptoms of the plants. The small yield difference between the irrigated and nonirrigated plants was apparently due to the nonirrigated plants extracting water from the subsoil to a 153-cm depth. Even though the nonirrigated plants exhibited severe stress symptoms during the drought, our results indicated the importance of the root distribution and subsoil water in partially meeting the evaporative demand. The results also suggest that the plants may adapt to drought stress when it is applied slowly and progressively, so no abrupt changes in the soil water status are encountered.

ET on the nonirrigated plots after 25 and 32 days without significant rainfall ranged 40 to 60% of ET on irrigated plots. The effect of increasing soil water stress on ET and that the nonirrigated plants were able to extract water from a 153-cm depth has been demonstrated. The water extraction at this depth enabled the plants to partially meet the ET demand. Only small differences in leaf water potential were measured during the severe stress, indicating that the plants partially adjusted to the drought. Apparently, partial stomatal closure as evidenced by visible wilt symptoms, and subsoil water kept the leaf water potential of the nonirrigated plants nearly as high as that of the irrigated plants. Irrigation resulted in a 351- and 364-kg/ha increase for Davis and McNair 800, respectfully. Our results suggested a need to develop techniques for improving subsoil water utilization by the soybeans to enable them to cope with the short-term drought often encountered in the Southeast.

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