EARLY SEASON IRRIGATION INFLUENCE ON SOIL TEMPERATURE AND COTTON YIELD

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Abstract

A two-year cotton field study investigated the effect of initiation time of irrigation for a high frequency irrigation scheduling method on soil temperature, plant growth, and final yield using bare soil and polyethylene film covered beds to expand the range of soil temperatures. An Early Irrigation (EI) treatment started automated irrigation when seedlings had 3 to 4 main stem nodes. The other treatment, Delayed Irrigation (DI), treatment was delayed until squaring began (7 to 9 main stem nodes). The period when only the EI treatment was irrigating was designated as the early irrigation period (EIP) and following this was the late irrigation (LIP) when both the EI and DI treatments were irrigated. Clear, white, and black polyethylene film was installed in the plots immediately before the EI treatment started and was removed after first bloom. Soil temperature was measured in the center of the bed with thermocouples placed at 50, 100, 200, and 500 mm below the surface. Soil temperatures in bare soil were consistently higher at all depths in the DI treatment than the EI treatment during the EIP of both years. This was caused by cooling from evaporation since the soil surface moisture of the EI treatment was higher than the DI treatment. Soil temperatures under clear polyethylene were higher than under the white and black film. In the EI treatment average soil temperatures under polyethylene films were greater than those in bare soil (1 °C to 5 °C during the EIP and 4 °C during the LIP). Plants were tallest in the EI treatment for bare soil and the polyethylene films for all measurement dates during the early and late irrigation periods. At first bloom in both years plants growing in the polyethylene film were taller than in bare soil in both irrigation treatments. In 1993 and 1994 average yield produced with polyethylene film were similar in both irrigation treatments. Lint yields in bare soil were the same in both irrigation treatments in 1993 but in 1994 the EI treatment produced higher yield than the DI treatment.

Introduction

Cotton, a plant of tropical origin, has a root system that grows optimally in a temperature range from 28 °C to 33 °C (McMichael and Quisenberry, 1993). Suboptimal soil temperatures increase cotton root susceptibility to soil borne diseases in addition to reducing plant growth. Based on an analysis of the temperature dependence of enzyme kinetics Burke et al. (1988) defined a thermal kinetic window for cotton as being from 23.5 °C to 32 °C.

Soil temperature and soil water are important edaphic factors that determine early cotton seedling growth and development. Irrigation can maintain adequate soil moisture but when it is applied soon after crop emergence soil temperatures at shallow depths are lowered by the cooling effect of evaporation. Under irrigation management where a well watered soil condition is maintained with frequent small applications of irrigation the possibility of creating cool soil temperatures by initiating irrigation early is increased compared to delaying irrigation.

A field experiment was conducted to investigate the effect of applying high frequency irrigation beginning soon after stand establishment. In addition to the normal practice of planting in bare soil beds, polyethylene film was used to eliminate soil evaporation and modify soil temperature. The objective was to evaluate the effect of early season irrigation initiation time on soil temperature, plant growth, and cotton yield where polyethylene film was used to extend the range of soil temperature from that of bare soil.

Materials and Methods

Irrigation studies using cotton (Gossypium hirsutum L.) were conducted at the Texas Agricultural Experiment Station near Lubbock,TX in 1993 and 1994. The soil is classified in the Olton series (fine, mixed, thermic Aridic Paleustoll). Furrow irrigation approximately one month prior to planting in each year, filled the soil rooting zone to field capacity. Subsequent irrigations were applied through drip tubing placed on the surface of each planted bed. Irrigation was controlled by canopy temperature measured with infrared thermometers. Whenever the average canopy temperature for a 15-minute period exceeded 28 °C the plot was irrigated through the drip irrigation system during the next 15-minute cycle. Additional details and results from using continuously measured canopy temperature to control irrigation can be found in Wanjura et al. (1992).

The experiments included two irrigation initiation time treatments. In the Early Irrigation (EI) treatment automated irrigation was started as soon as the irrigation system and data logging equipment could be installed following emergence 3 to 4 main stem node growth stage). The other treatment, Delayed Irrigation (DI), irrigation was delayed until squaring began (7 to 9 main stem node growth stage).

Before irrigation began in 1993 and 1994 in the EI treatment clear, white, and black polyethylene film treatments were superimposed on each plot. The clear mulch was a smooth surface film of 1.5 mil thickness, the

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white mulch film was smooth surface of 1.0 mil thickness, and the black mulch film was an embossed surface of 1.0 mil thickness. Each polyethylene mulch film was four feet wide and treatments were installed across 4 rows in lengths of 10 feet.

The mulch film was manually installed in 1993 beginning on 1 June (DOY 152) and completed on 7 June (DOY 158). The irrigation system, which was controlled by measuring plant canopy temperature, was activated on DOY 158 in the EI treatment plots. Irrigation of the DI treatment was delayed until DOY 182. Beginning on DOY 182 the EI and DI treatments were automatically irrigated when ever the 15-minute average canopy temperature exceeded 28 °C. In 1994 the mulch film was manually installed on 25 and 26 May (DOYs 145 and 146). The irrigation system was activated on 1 June (DOY 152) in the EI treatment. Irrigation of the DI treatment was delayed until 20 June (DOY 173). Irrigation was applied at an average rate of 1.2 mm/hr through 16 mm diameter polyethylene dripline with 610 mm spacing between emitters. Nitrogen was injected into the irrigation system at the rate of 900 g/ha-cm water.

Canopy temperature was measured by an infrared thermometer (Model 4000 LCS, Everest Inter science, Inc., Fullerton, CA) located directly above a row in each irrigation plot. Atmospheric environmental measurements included total radiation, net radiation, dry bulb air temperature, wet bulb air temperature, and wind speed which were measured at 2 m above ground level. Daily rainfall was measured at a weather station 0.2 km south of the study site.

Soil temperatures were measured at 1-minute intervals and 15-minute averages were recorded for 50, 100, 200, and 500 mm depths in one replication of the EI and DI treatments. One thermocouple was placed in the center of the bed at each depth and the vertical position was measured from the soil surface. Temperature data were inspected daily to ensure thermocouples were operating properly. Soil temperatures were measured from the initiation of irrigation in the EI treatment and continued until the occurrence of first bloom. Average soil temperatures were calculated by depth for each day and then for all days within the EIP when only the EI treatment was irrigated and the LIP when both the EI and DI treatments were irrigated. Average soil temperature in the top 500 mm was computed as the mean of the five depths.

The studies were arranged in a randomized complete block design with three replications. Each plot consisted of 18 rows 31 m long. Row spacing was 76 cm and orientation was East-West in all years. The cotton cultivar Paymaster HS 26 (Delta and Pine Land Co., Scott, MS) was grown in both years. Agronomic and irrigation period data are given in Table 1. Early season soil temperatures, plant height, and lint yield was compared among bare soil and the three polyethylene mulches in the EI and DI treatments.

Plants at first bloom were harvested from three 1 m row lengths in each plot to measure plant height and number of main stem nodes when irrigation began in the EI treatment and later when the DI treatment received its first irrigation. Lint yield was measured from hand harvests of one row from each mulch plot.

The plant measurements and yield data were analyzed as a randomized complete block experiment using analysis of variance. Daily soil temperatures averaged across depths within the EIP and the delayed irrigation period were compared. Means were compared using the Tukey-Kramer MeansTest or Fisher's Protected LSD Test.

Results and Discussion

Irrigation in the EI treatment in 1993 began on DOY 158 and a total of 138 mm was applied before irrigation began in the DI treatment on DOY 182, Fig. 1a. After starting irrigation in the DI treatment, the irrigation rate was the same in both treatments. The average total irrigations in Fig. 1a are 454 and 304 mm, respectively, for EI and DI treatments. The range in total irrigation among the three replications was 33 mm in EI treatment and 28 mm in the DI treatment. Rainfall received from DOY 158 through DOY 178 was 34 mm, followed by a 65 mm rain on DOY 181, and then until DOY 262 additional small amounts were received to a total of 171 mm.

The 1994 EI treatment began irrigating on DOY 152 and a total of 119 mm was applied before irrigation began in the DI treatment on DOY 173, Fig. 1b. Average total irrigation was 524 and 386 mm, respectively, for the EI and DI treatments. Rainfall from DOY 153 through DOY 172 was 5 mm, followed by 3 mm between DOY 173 and DOY 186, and then from DOY 187 until DOY 259, 85 mm fell for a total of 92 mm during the entire irrigation season. Total irrigation from DOY 152-259, was 520 and 390 mm, respectively, for EI and DI treatments.

Soil Temperature

Soil temperatures during 1993 which are plotted in Fig. 2a compare the effect of bare soil and the polyethylene mulches by depth during the early and late irrigation periods. The cooling effect of evaporation during the EIP due to irrigation is apparent in the bare soil where the EI treatment is about 3 °C cooler than the DI treatment down to the 200 mm depth. Under the white and clear polyethylene mulches, temperatures at the 50 and 100 mm depths are warmer in the DI treatment than the EI treatment. The coolest temperature for both irrigation treatments under all polyethylene mulches occurred at 500 mm. Temperatures during the LIP were similar in both irrigation treatments since both were irrigating. The greatest soil temperature change from the EIP to the LIP occurred in the DI treatment of bare soil which was decreased by evaporation. LIP soil temperatures were coolest in bare soil (24.5 °C) and similar under white and black polyethylene mulches (28 °C), and warmest under clear polyethylene mulch (30 °C).

Soil temperatures in 1994 during the EIP were always lower in the EI treatment than in the DI treatment for all depths in the bare soil and under the white and clear polyethylene mulches, but only at the 100 mm depth for the black polyethylene mulch, Fig. 3a. The 200 mm depth soil temperatures in the EI treatment were always highest under the polyethylene mulches but in the DI treatment the 50 and 100 mm depths were usually warmer. During the LIP soil temperatures in the bare soil were consistently higher in the DI treatment than in the EI treatment, Fig. 3b. Differences in soil temperatures between the EI and DI treatments under the polyethylene mulches were inconsistent during the LIP. Soil temperatures were generally highest under white and clear mulch in the DI treatment but EI treatment temperatures were higher under the black mulch, except at the 500 mm depth. The cooling effect of evaporation on soil temperature is apparent in bare soil during the EIP in both years where temperatures of the EI treatment were lower than in the DI treatment. The same effect under polyethylene mulch was probably the result of relatively cool irrigation water and the higher specific heat of wet soil which modulated the temperature increase from solar heating.

Daily average soil temperatures in 1993 for bare soil and the average of the three polyethylene mulches for the upper 500 mm of soil are displayed in Fig. 4a for the EI treatment and in Fig. 4b for the DI treatment. Two cool weather periods during the EIP, which were centered at DOY 160 and DOY 168, caused a temporary lowering of soil temperatures. Daily average soil temperature under the polyethylene mulches in the EI treatment ranged from 1 to 5 °C higher than bare soil during both irrigation periods. Soil temperatures under polyethylene mulch in the DI treatment, Fig. 4b, ranged from 0.5 to 2.5 °C higher than in bare soil during the EIP. Apparently evaporation was relatively low and did not severely cool the bare soil during EIP when little rainfall was received. LIP soil temperature under polyethylene mulch averaged 4 °C higher than in bare soil.

An abrupt decrease in soil temperature occurred in all treatments on DOY 182 which was the first irrigation day of the LIP when the DI treatments received their first irrigation. This also coincided with a rainfall event of 65 mm on DOY 181.

In 1994 a cool weather period occurred between DOY 159 and DOY 163, Fig. 5a and Fig. 5b. Bare soil temperatures dropped 4 °C during the cool weather period in the EI treatment and remained at a low level through the end of the LIP. Soil temperatures under the polyethylene mulch only decreased 2 °C and then recovered to their previous level by the end of the EIP and continued a gradual increase through DOY 179 of the LIP. Soil temperatures were 5 °C higher under the polyethylene mulches than in the bare soil during the LIP. In the DI treatment the soil temperature patterns in the bare soil and polyethylene mulches were similar during the EIP with bare soil temperatures being 1.5 °C lower than under the polyethylene mulches. During the LIP bare soil temperatures decreased 2 °C in the first three days in response to irrigation and then continued a slow decline. Soil temperatures under polyethylene declined about 1 °C in response to irrigation and then changed in response to aerial environmental conditions. Soil temperatures under polyethylene mulches were 4 °C higher than those in bare soil for most of the LIP.

Plant Height

Average plant height and number of main stem nodes in 1993 among polyethylene mulches were significantly greater in the EI treatment than in the DI treatment on all sampling dates, Table 2. In 1994 plant height and number of main stem nodes were equal in both irrigation treatments at the beginning of the EIP but afterwards EI treatment plants were taller and had more nodes than DI treatment plants. The increased plant height in the EI treatment compared to the DI treatment is apparently due to the irrigation in the EIP since average soil temperature differed by only 0.2 °C in 1993 and by 0.7 °C in 1994.

In both years height and main stem node number of plants in bare soil were greater in the EI treatment than the DI treatment on all sampling dates, Table 2. Average soil temperatures of bare soil were 26.7 °C and 25.1 °C in 1993, in the DI and EI treatments, respectively, and similar comparisons in 1994 were 28.0 °C and 25.5 °C. Obviously increased plant height in the EI treatment was not due to higher soil temperatures but likely the result of higher soil water content.

By DOY 201 in 1993 plants in both irrigation treatments of the polyethylene mulch plots were taller than those in bare soil. Average soil temperature under polyethylene mulch was 28.8 °C in the DI treatment compared to 26.7 °C in bare soil. For the EI treatment, soil temperature was 28.6 °C under polyethylene and 25.1 °C in bare soil. Average plant height of the polyethylene mulch treatments of the EI and DI treatment were taller than those in bare soil by DOY 193 in 1994. There were also differences in number of main stem nodes between plants in polyethylene mulch plots and those in bare soil, however, the primary cause of increased height was due to longer internode length rather than number of nodes. Average soil temperature in the DI treatment was 30.4 °C under polyethylene mulch and 28.0 °C in bare soil of the EI treatment. The same temperatures in the EI treatment were 29.6 °C and 25.4 °C, respectively. The increased height of plants in the polyethylene plots appears to be a combination of higher soil temperature and more favorable soil water content. A comparison of plant heights between polyethylene mulch and bare soil in Table 2 within irrigation treatments shows that the differences are greater in the EI treatment than the DI treatment.

Lint Yield

The 1993 lint yields among polyethylene mulch plots were not different within irrigation treatments, Table 3. Average yield for all mulch treatments were also similar between irrigation treatments. Lint yields from bare soil were also the same between the EI and DI treatments.

Lint yields from the polyethylene mulch treatments in 1994 were consistent with those in 1993. In the EI treatment all mulch yields were similar, Table 3. Yields in the black and clear polyethylene mulch treatments were 94 kg/ha lower than in the white mulch in the DI treatment. Lint yields among polyethylene mulches averaged across the irrigation treatments were not different. Lint yield from the DI treatment of bare soil was lower than in the EI treatment, a suggestion that the DI treatment may have experienced water stress during the EIP.

Summary

Soil temperatures in bare soil were consistently higher at all depths in the DI treatment than the EI treatment during the EIP of both years. This was caused by cooling from evaporation since the soil surface moisture of the EI treatment was higher than the DI treatment because of frequent irrigation. Soil temperatures under all polyethylene mulches were greater than those in bare soil. The polyethylene mulch films absorb and transmit both short and long-wave radiation but they only allow a portion of the radiant energy to reradiate as long wave radiation. In addition there was negligible loss of heat from polyethylene mulches by evaporation. Soil temperatures under clear polyethylene mulch were higher than under the white and black mulches. The color of the polyethylene mulch film affects its optical properties but the degree of thermal contact resistance between the mulch and the soil surface differentially affects the soil temperature under different color polyethylene mulches (Ham, et al., 1993; Ham and Kluitenberg, 1994). They measured higher soil temperatures under black than clear polyethylene mulch at the 100 mm depth in the center of film covered beds without plants.

Plant height was increased by the EI treatment in bare soil and the polyethylene mulches during the early and late irrigation periods. By the time of first bloom in both years plants growing in the polyethylene mulches were taller than in bare soil in the EI and DI treatments.

The yield response to both early season soil temperature and irrigation starting time (EI and DI treatments) was not consistent. In 1993 average yield of the polyethylene mulches and bare soil were not different between the EI and DI treatments. In 1994 average yield for the polyethylene mulches were similar in both irrigation treatments. However the yield from bare soil in the DI treatment was 1361 kg/ha compared to 1694 kg/ha in the EI treatment. Since yields were similar for mulches where evaporation was suppressed but higher in bare soil from the EI treatment, water stress probably occurred in the DI treatment of bare soil during the EIP. Early irrigation (EI treatment) increased plant height at first bloom in polyethylene mulch and bare soil in both years but yield was only increased in bare soil in 1994.

Disclaimer

Trade and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment by the USDA.

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Table 1. Planting and emergence dates, plant population, and irrigation data for studies in 1993 and 1994.

Data	1993	1994
Planting date	DOY 130[1] (10 May)	DOY 129 (9 May)
Emergence Date	DOY 145 (25 May)	DOY 138 (18 May)
Plant population, plants/ha	123000	186000
Polyethylene mulch installation date	DOY 152 - 158 (1 June - 7 June)	DOY 145 - 146 (25 May - 26 May)
Polyethylene mulch removal date	DOY 203 (22 July)	DOY 196 (15 July)
First bloom date	DOY 193 (12 July)	DOY 186 (5 July)
Harvest date	DOY 312 (8 Nov)	DOY 306 (2 Nov)
Preplant irrigation date	DOY 96 (6 April)	DOY 106 (16 April)
Early irrigation period	DOY 159 - 181 (8 Jun - 30 Jun)	DOY 153 - 172 (2 Jun - 21 Jun)
Late irrigation period	DOY 182 - 193 (1 Jul - 12 Jul)	DOY 173 - 186 (22 Jun - 5 Jul)
Irrigation amount - early period, mm	138	119

[1]DOY is day of year.

Table 2. Comparison of cotton height and number of main stem nodes under two irrigation treatments and four ground covers, 1993 and 1994.

Date, DOY	Mulch Averages		Bare Soil	
	EI	DI	EI	DI
	-----------------Plant Height, mm---------------			
1993				
168	110 a[1]	101 b	109 a	100 b
180	259 a	202 b	236 a	191 b
201	734 a	686 b	635 a	601 b
1994				
152	48 a	48 a	53 a	51 a
171	219 a	168 b	197 a	152 b
193	676 a	602 b	574 a	502 b
	-----------Nmber of Main Stem Nodes-----------			
1993				
168	6.2 a	6.0 b	5.9 a	5.7 a
180	10.9 a	9.9 b	10.3 a	9.6 b
201	--[2]	--	--	--
1994				
152	2.9 a	3.0 a	2.9 a	2.9 a
171	8.8 a	7.5 b	7.9 a	6.8 b
193	--[2]	--	--	--

[1]Values of mulch averages or bare soil in the same row followed by a common letter are staistically the same at the 0.05 level of probability according to the Tukey-Kramer means test.

[2]Main stem nodes were not measured on these dates.

Table 3. Lint yields of cotton grown with three polyethylene mulches and a bare soil treatment, 1993 and 1994.

Ground Cover	**Irrigation Treatments**		**Average of Irrigation Treatments**
	Early	**Delayed**	
	---------------lint yield, kg/ha---------------		
1993			
Black	1532 a[1]	1608 a	1571 a
White	1605 a	1665 a	1636 a
Clear	1662 a	1668 a	1665 a
Average - Mulches	1629 a	1677 a	1 653
Bare Soil	1504 a	1519 a	1539
1994			
Black	1570 a[2]	1507 a	1566 a
White	1640 a	1601 a	1620 a
Clear	1665 a	1507 a	1586 a
Average - Mulches	1654 a	1566 a	1 611
Bare Soil	1694 a	1361 b	1527

[1]Lint yields in 1993 in the same column or for bare soil in the same row followed by a common letter are statistically the same at the 0.05 level of probability according to the Tukey-Kramer means test.

[2]Lint yields in the same columnm and for bare soil in the same row for 1994 followed by a common letter are statistically the same at the 0.05 level of probability according to the Tukey-Kramer means test. Average of irrigation treatment lint yields were tested at the 0.05 level.

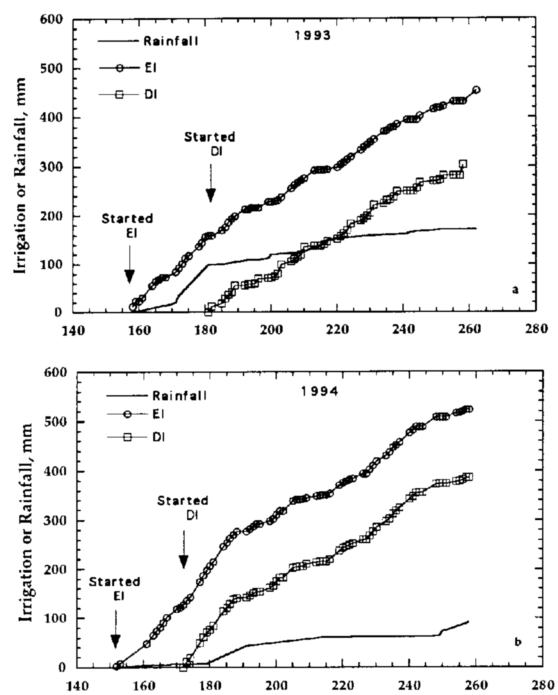

Figure 1. Cumulative irrigation and rainfall for the early irrigation treatment (EI) and the delayed irrigation treatment (DI) in 1993 and 1994.

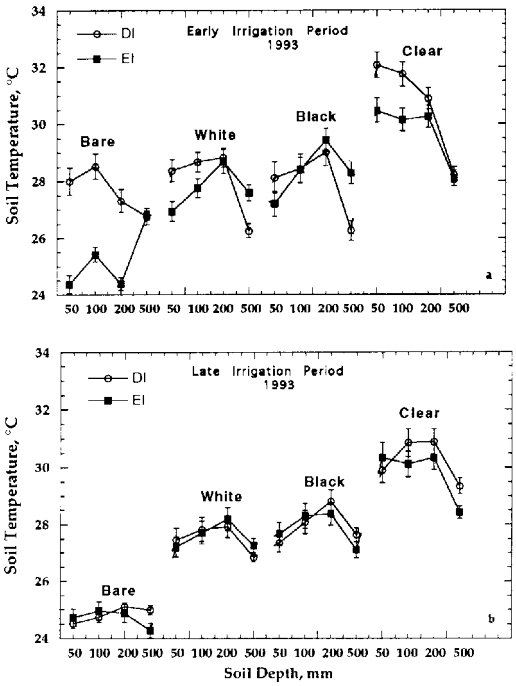

Figure 2. Soil temperatures at four depths in bare soil and white, black, and clear polyethylene mulches for the EI and DI treatments during two irrigation periods in 1993. Vertical bars through data points are standard error values ($p < 0.05$).

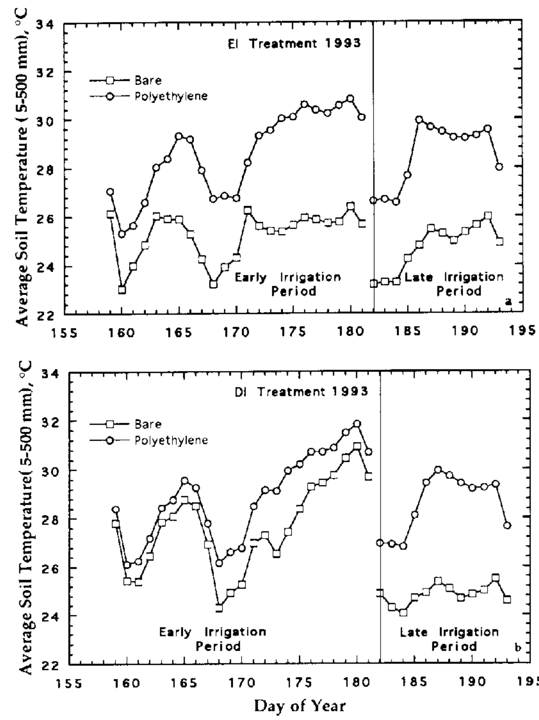

Figure 4. Average daily soil temperatures in the first 500 mm for bare soil and the average of white, black, and clear polyethylene mulches for the EI and DI treatments during two irrigation periods in 1993.

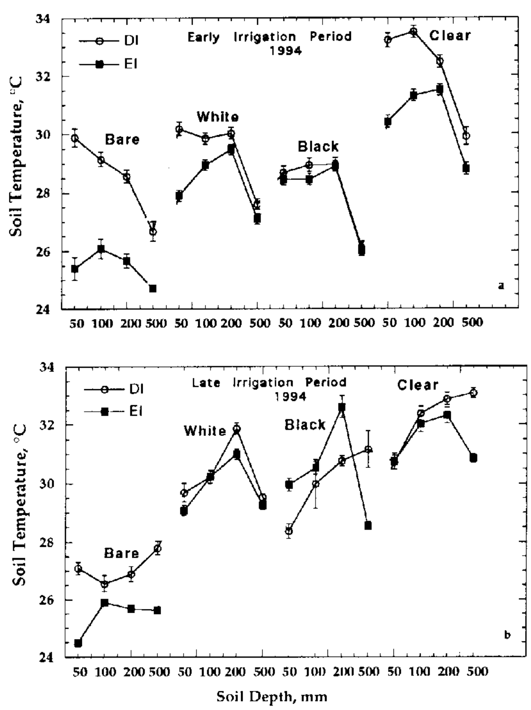

Figure 3. Soil temperatures for four depths in bare soil and white, black, and clear polyethylene mulches for the EI and DI treatments during two irrigation periods in 1994. Vertical bars through data points are standard error values ($p \leq 0.05$).

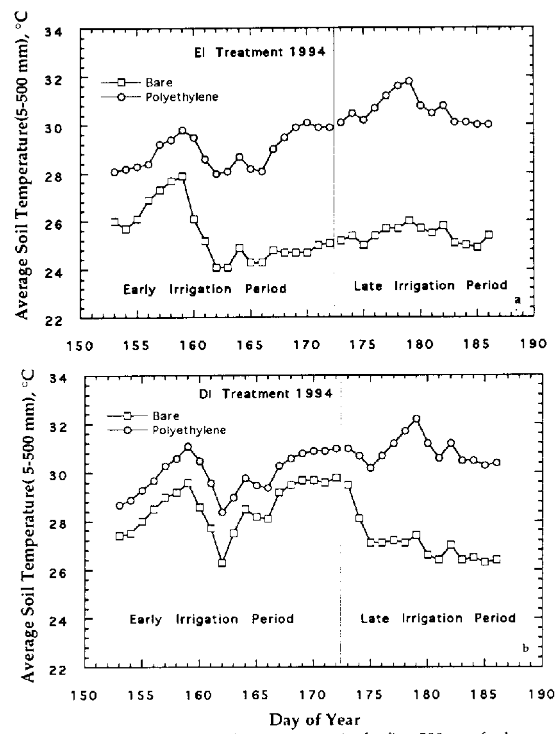

Figure 5. Average daily soil temperatures in the first 500 mm for bare soil and the average of white, black, and clear polyethylene mulches for the EI and DI treatments during two irrigation periods in 1994.