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Modifying Heat Unit Accumulation with Contrasting Colors of Polyethylene Mulch

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Abstract. **Contrasting colors of plastic mulch (black and white over black) were used to modify the rate at which heat units (HU) were accumulated in four different microclimates surrounding watermelon plants during 1996 at the Texas Agricultural Experiment Station–Stephenville. Daily maximum and minimum temperatures from 25 Mar. through 4 Aug. were recorded for air 10 cm above the mulch surface, at the mulch surface, at the soil surface under mulch, and 10 cm below the soil surface under mulch. Accumulated HU were significantly higher for white than for black mulch during two of the four periods monitored; however, the reverse was true for all other points of measurements at all times. Daily mean soil surface heat gain was 3.29 HU higher under black than under white mulch in early season, 6.21 higher in late April and early May, 5.19 higher in late May and June, and 4.19 higher in late June through July. Values for soil at 10-cm depth paralleled those for soil surface.**

The effects of mulches on soil moisture, soil and air temperature, crop yield, quality, and fruiting response have been studied in a variety of crops, including tomatoes (*Lycopersicon esculentum* Mill.) (Decoteau and Friend, 1990; Decoteau et al., 1989), cowpeas (*Vigna unguiculata* L.) (Hunt et al., 1990), cassava (*Manihot esculenta* Crantz) (Mbagwu, 1991), strawberry (*Fragaria* ×*ananassa* Duch.) (Albregts and Chandler, 1993; Braud and Chesness, 1969/1970), peppers (Rivera and Goyal, 1985), squash (*Cucurbita pepo* L.) (Ghawi and Battikhi, 1988), and forage maize (*Zea mays* L.) (Singh and Sandhu, 1979). Materials used as mulch range from organic residues to plastics and petroleum products. Wheat straw in combination with opaque and transparent polyethylene was used in the study of forage maize (Singh and Sandhu, 1979), while pine straw mulch was compared to black plastic mulch in the production of strawberries (Braud and Chesness, 1969/1970). Kowsar et al. (1969) used spray-on petroleum mulch to study its effects on soil water content and temperatures.

The environmental effects of the mulch on the microclimate of the plant have also been evaluated. The effects of mulch color, as well as the quality of light reflected from different colors of mulch, have been evaluated on strawberries (Albregts and Chandler, 1993), tomatoes (Decoteau et al., 1989), and cowpeas (Hunt et al., 1990). Ham et al. (1993) reported the effects of mulch color on soil and mulch surface temperatures. Other studies have focused on the effect of mulch on soil water content (Kowsar et al., 1969; Mbagwu, 1991).

Reduced soil temperature is one of the major environmental influences of organic mulches. Bristow (1988) reported that vertical or horizontal architecture of organic mulches had little or no effect on temperature of moist soil, but vertical orientation slowed decomposition of the mulch. Straw mulch and frequent irrigation optimized soil temperature for forage maize production in the hot summer conditions of Punjab (Singh and Sandhu, 1979). In Nigeria soil temperatures were reduced by straw mulch and increased by black mulch, whereas white mulch had no effect in comparison with bare soil (Mbagwu, 1991). In the Jordan Valley, soil temperature was reduced by a transparent mulch; however, this was attributed to the more vigorous growth of plants grown with plastic mulch, which created a shading effect (Ghawi and Battikhi, 1988).

Decoteau and Friend (1990) evaluated the use of a black photo-degrading mulch laid over white mulch. As the black mulch deteriorated over the season, more white mulch was exposed and more of the sun's rays were reflected. Soil temperatures 2.5 cm below the soil surface were lower under this system through the summer season (10 July through 16 Aug.) when compared to those under black mulch.

The objective of this study was to determine the effects of black vs. white mulch on heat accumulation: 1) 10 cm below the soil surface, 2) at the soil surface under the mulch, 3) at the mulch surface, and 4) 10 cm above the mulch surface.

Materials and Methods

In Feb. 1996, a site at the Texas Agricultural Experiment Station–Stephenville was chosen for a study of the effects of 1) sequential planting and 2) color of polyethylene mulches on watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai]. The soil type was Windthorst fine sandy loam (fine, mixed, thermic Udic Paleustalf). The test area was deep plowed to a depth of 20 cm on 15 Feb. to bury winter vegetation.

On 4 Mar., fertilizer (90N–39P–74K $kg \cdot ha^{-1}$) was broadcast on this site and incorporated to a depth of 10 cm with a disc plow. The site was marked into 16 strips measuring 1.8 m wide and 24.4 m long. Strips 1, 4, 7, 10, 13, and 16 were bedded into two rows with 0.9-m centers. Each of these was planted to a single row of sweet corn for wind breaks. The remaining strips were bedded 0.9 m wide and 15 cm high on 1.8-m centers. Beds were alternately covered with black and white-on-black polyethylene mulch. Drip irrigation tape (T-Tape; T-Systems Intl., San Diego, Calif.) with 30.5-cm emitter spacings and a 17-$mL \cdot min^{-1}$ emitter flow was placed in the soil 5 cm below the polyethylene mulch. Drip tape was laid in the same operation with the mulch.

The 24.4-m-long strips were then divided into 6.1-m plots representing four sequential planting dates randomly assigned within each strip. Scheduled planting dates were 3 Apr., 23 Apr., 14 May, 3 June, and 24 June.

Three weeks prior to each scheduled planting date, 'Desert Storm' hybrid watermelon seeds were planted in Jiffy-7 peat pots (Jiffy Products, Shippagan, N.B., Canada) and placed inside a greenhouse. Greenhouse temperatures were maintained at 35 °C day and 24 °C at night. Peat pots were hand-watered daily to maintain proper moisture. These plantings produced the transplants used in the field study.

Thirty-two thermocouples, each 3 m long, were constructed from copper–constantan wire. The terminal ends of the thermocouples were twisted together and soldered, coated with Scotchkote Electrical Coating (3M Electrical Products Division, St. Paul, Minn.), and dipped in white latex paint to seal the thermocouples and reflect direct rays of sunlight from thermocouples exposed above the mulch.

Six 1.3-cm-diameter wooden dowel rods, 20 cm in length, were constructed with a 0.13-cm-wide groove cut 0.13 cm deep along one edge. Holes (0.5 cm) were drilled through the dowels 10 cm from both ends at a 90° angle to the groove.

Five of the thermocouples were grouped as a unit and taped about every 0.6 m. Four of the thermocouples were passed 10 cm through the hole of each dowel from the side opposite the groove. Two thermocouple wires were bent in opposite directions and placed in the groove of the dowel. The terminal ends were placed in the groove at the tip of each dowel and held in

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place with reinforced tape. These thermocouples measured 1) temperature 10 cm above mulch and 4) soil temperature 10 cm below soil surface. The remaining two thermocouples measured 2) mulch surface temperature and 3) soil surface temperature. The fifth thermocouple was left free of the dowel and measured 5) canopy temperature. Six units were constructed in this fashion.

Two CR21X dataloggers (Campbell Scientific, Logan, Utah) were programmed to record temperatures 1.2 m above the plots and at the five points in the microclimate described in the previous paragraph. The CR21X units were programmed to monitor temperatures once each hour and output the maximum and minimum temperatures, with the times of occurrence, every 24 hours. The thermocouple measuring air temperature 1.2 m off the ground was affixed to a section of 1.3-cm PVC pipe erected between two mulched rows. To limit artificial heating from direct sunlight, the thermocouple was protected with a white plastic drinking cup affixed to the top of the PVC post with a ring of silicone sealant. This thermocouple was also used as the reference temperature for the datalogger. The dataloggers were placed inside plastic containers with sealing lids to protect them; the containers were light in color to prevent excessive heating. Thermocouple wires entered the container through 0.6-cm holes drilled in the upper edge of the container below the sealing lid. Dataloggers and attached thermocouples were placed in the field, between two contrasting color rows of polyethylene mulch, on 25 Mar. to check the integrity of the units and record pre-plant temperature data. Two of the dowel units from datalogger-1 were placed in a row covered with black mulch and one dowel unit was placed in the white mulch row. Datalogger-2 had one dowel unit placed in a black mulch row and two dowel units placed in the white mulch row.

Each dowel unit was placed in the center of the mulched row located between two watermelon seedlings planted 0.75 m apart. The end of the wooden dowel with thermocouple-4 was inserted vertically through the polyethylene mulch and into the soil to a depth of 10 cm. Thermocouple-3 was placed between the mulch and the soil surface and thermocouple-2 was secured to the top surface of the mulch. Thermocouple-1 remained attached to the wooden dowel 10 cm above the mulch surface. Thermocouple-5, which was free of the dowel, was affixed over a location where a seedling was to be transplanted.

Dataloggers and thermocouple units were left to record data at these locations through the 3-week period of the first melon planting, which took place on 3 Apr. A late-season frost on 4 and 5 Apr. killed all plants in the 3 Apr. planting, resulting in temperature measurements being taken from mulched rows with no vegetation.

Planting date-2 melons were transplanted to the field on 24 Apr. The dataloggers and thermocouple units were moved into this location on the same day. The same sequence was used to install the units at this location and the remaining locations throughout the study. Temperatures were monitored at this location for a period of 3 weeks. Planting date-3 transplants were set in the field and dataloggers with thermocouple units were moved on 14 May. During this planting sequence the monitoring period was extended to 6 weeks instead of 3. This was done to accumulate temperatures as the canopy reached maximum density, resulting in more complete shading of the mulched surface. Transplants for planting date-5 were set in the field on 24 June. Dataloggers with thermocouple units were relocated the same day. Data were collected from planting date-5 for a period of 6 weeks.

Data were collected weekly from the dataloggers. Maximum and minimum temperatures were converted to Heat Units (HU) with a base of 12.8 °C using the formula: $HU_{12.8}$ = [(maximum temp + minimum temp)/2] – 12.78 (Maynard and Hochmuth, 1997). Data were statistically analyzed using SAS 6.03 (SAS Institute, Cary, N.C.) with analysis of variance (ANOVA) procedure. Individual means were separated using the least significant difference (LSD) procedure at $P \leq 0.05$.

Results

Heat units above the mulch. Black polyethylene mulched rows had accumulated 130 HU

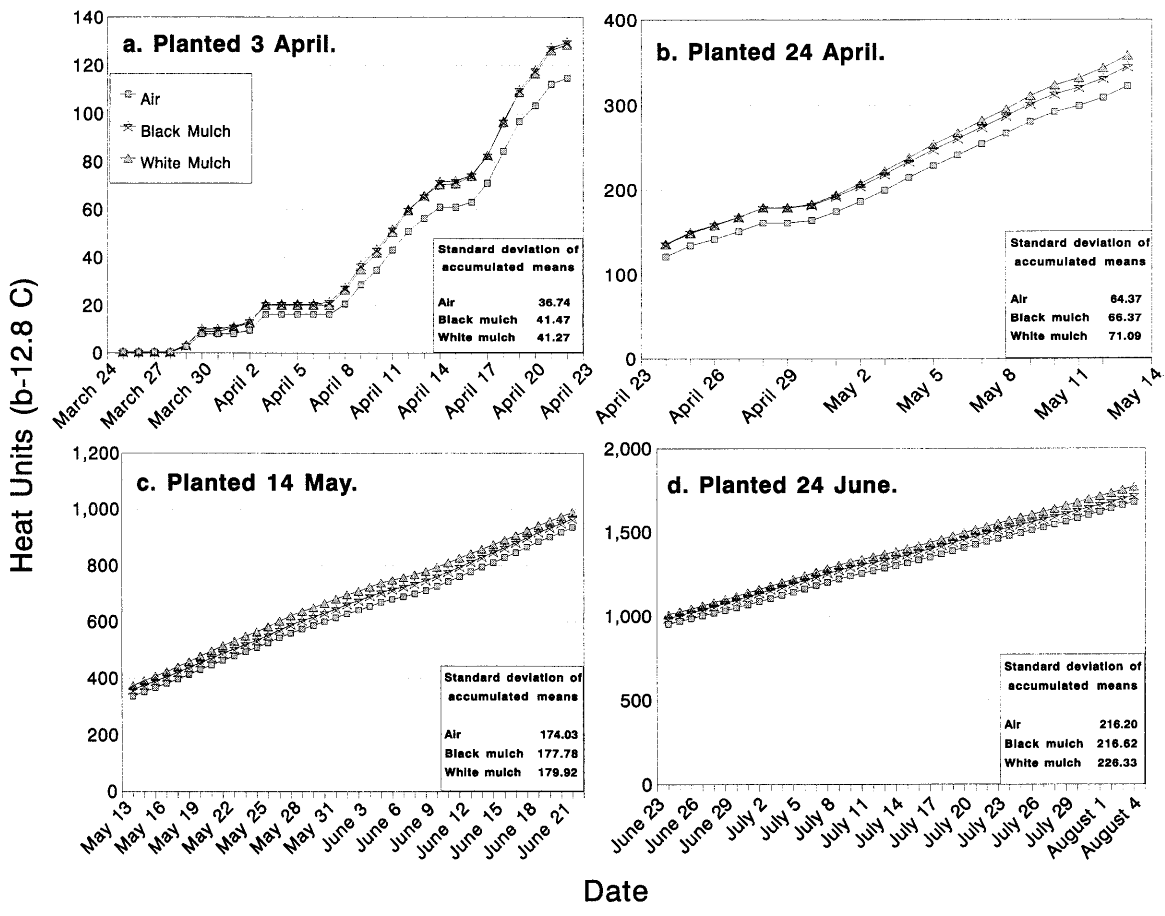

Fig. 1. Accumulated heat units 10 cm above the mulch surface and 1.2 m above the soil surface measured in watermelons transplanted in black and in white polyethylene mulch on four dates in 1996. Stephenville, Texas.

10 cm above the mulch by 22 Apr., compared with 128 HU for white-mulched rows and 115 HU for the air 1.2 m above the soil surface (Fig. 1a). Average daily accumulation of HU above black-mulched rows (4.50) was not significantly different from that above white-mulched rows (4.44 HU) (Table 1).

By 13 May the white-mulched rows (358 HU) had surpassed the black-mulched rows (345 HU), while the atmosphere had attained 322 HU (Fig. 1b). Average daily increase in HU was significantly greater above white-mulched rows (11.16 HU) than above black-mulched rows (10.45 HU) (Table 1).

Accumulated HU had increased approximately two and one-half times by the end of the monitoring period of 14 May through 22 June. White-mulched rows had acquired 989 HU, compared with 966 HU for black-mulched rows and 935 HU for air (Fig. 1c). Average daily increases in HU accumulation were not significantly affected by color of the mulch (Table 1).

The final measuring period extended from 24 June through 4 Aug. During this period total accumulated HU for white-mulched rows, black-mulched rows, and the atmosphere were 1770, 1716, and 1679, respectively (Fig. 1d). Average daily increases in HU accumulation during this period were significantly greater above white mulch than above black mulch (Table 1).

Significant differences in heat unit accumulation 10 cm above the mulched rows were detected only in the 23 Apr. and 24 June measurement periods. However, white-mulched rows had higher average daily increases of HU and total accumulated HU in all but the first measuring period.

Heat units at the mulch surface. Early season low temperatures prevented HU accumulation on the mulch surface until 28 Mar., when temperatures began to warm. Accumulation of HU on the mulch surface was greater for black-mulched rows than for white-mulched rows (Table 1). Black-mulched surfaces accumulated a total of 240 HU by 22 Apr., white-mulched rows 192 HU (Fig. 2a).

By 13 May, the black-mulch surface accumulated 596 HU vs. 481 HU for the white-mulch surface (Fig. 2b). Black-mulched rows acquired significantly more HU per day than did white-mulched rows (Table 1).

Accumulation of HU on the mulch surface during the period of 14 May through 22 June was significantly greater for black-mulched rows than for white-mulched rows (Table 1). By 22 June, black-mulched rows had accumulated a total of 1391 HU and white-mulched rows 1217 HU (Fig. 2c).

Table 1. Influence of mulch color (black or white) on average daily increase in heat unit accumulation around watermelon plants. Stephenville, Texas, 1996.

		Mean daily heat unit accumulation			
Planting date	Mulch color	Above mulch (10 cm)	Mulch surface	Soil surface (under mulch)	Soil below mulch (10 cm)
3 Apr.	Black	4.50	8.27	9.11	4.59
	White	4.44	6.57	5.82	3.66
	$LSD_{0.05}$	NS	1.66	1.50	0.91
23 Apr.	Black	10.45	17.69	19.57	10.77
	White	11.16	14.40	13.36	9.48
	$LSD_{0.05}$	1.47	1.46	1.35	0.87
14 May	Black	15.48	19.90	22.71	16.93
	White	15.75	18.33	17.52	14.76
	$LSD_{0.05}$	NS	0.93	0.89	0.42
24 June	Black	17.87	24.13	25.19	19.01
	White	18.60	22.10	21.00	17.06
	$LSD_{0.05}$	0.47	1.04	1.17	0.43

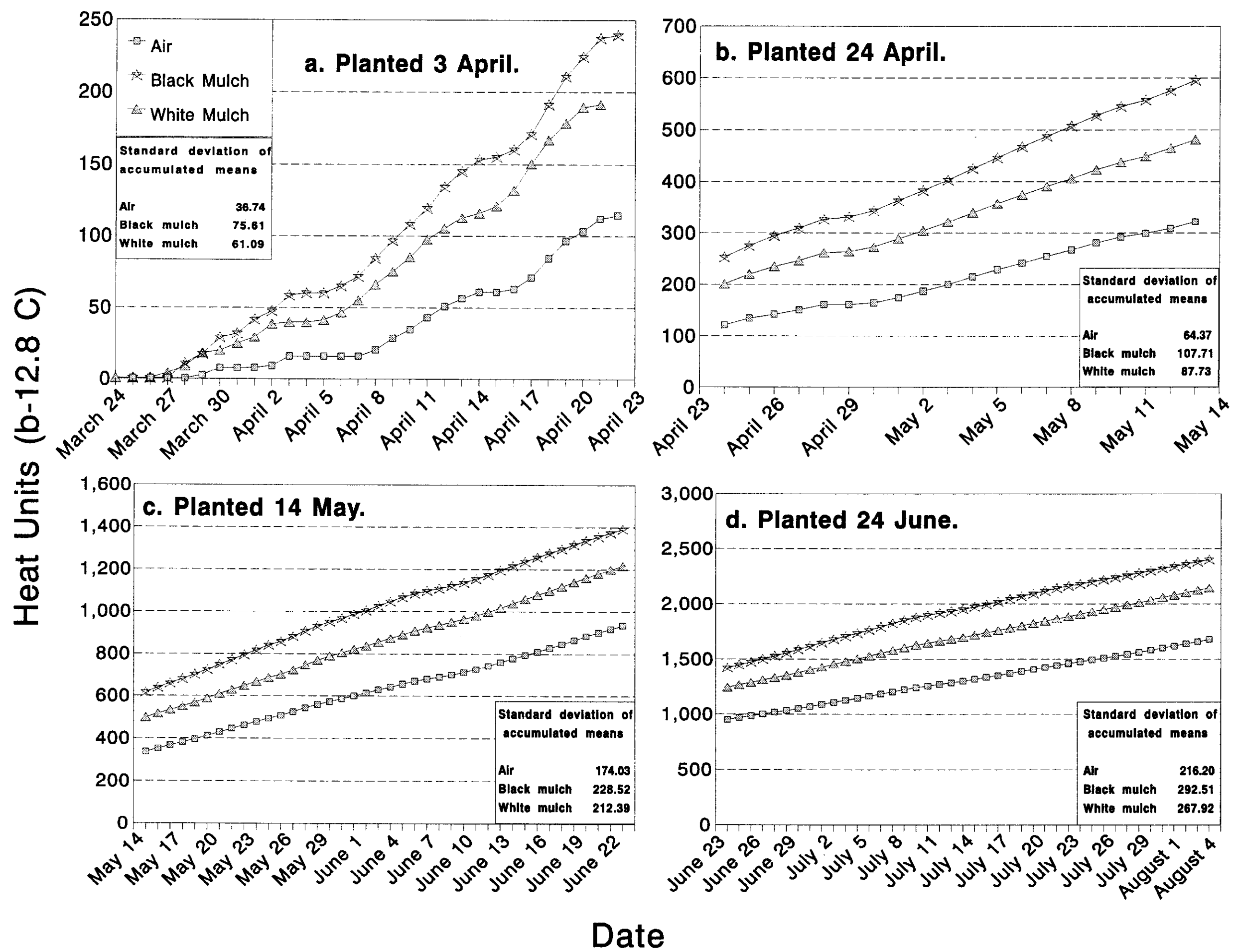

Fig. 2. Accumulated heat units on the mulch surface and the atmosphere 1.2 m above the soil surface in watermelons transplanted in black and in white polyethylene mulch on four dates in 1996. Stephenville, Texas.

During the period of 24 June through 4 Aug., black-mulched rows acquired significantly more HU on the mulch surface (24.13 HU per day) than did white-mulched rows (22.10 HU per day) (Table 1). Black-mulched rows had accumulated 2404 HU by 4 Aug. compared with 2145 units by white-mulched rows (Fig. 2d).

Heat units at the soil surface. Rows covered with black mulch accumulated significantly more HU on the soil surface during the period of 25 Mar. through 22 Apr. (9.11 HU per day) than did white-mulched rows (5.82 HU per day) (Table 1). Soil under black-mulched rows accumulated a total of 264 HU, soil under white-mulched rows 170 HU (Fig. 3a).

Temperatures increased more uniformly from 24 Apr. through 13 May. Heat accumulation on the soil surface was significantly greater for black- than for white-mulched rows (19.57 vs. 13.36 HU per day) (Table 1). Total accumulated HU reached 657 units under black mulch and 440 units under white mulch (Fig. 3b).

Heat accumulation during 14 May through 22 June was significantly greater for black-mulched rows than for white-mulched rows (Table 1). Total accumulation for black-mulched and white-mulched rows was 1568 and 1140 HU, respectively (Fig. 3c).

In the fourth monitoring period (23 June through 4 Aug.), total accumulated HU for the black-mulched rows was not significantly different from that of white-mulched rows (2626 vs. 2022 accumulated HU) (Fig. 3d). Black-mulched soil surfaces gained significantly more HU per day than did white-mulched soil surfaces (Table 1).

Heat units in soil. Average daily increases in HU, measured 10 cm below the soil surface, were significantly greater under black- than under white-mulched rows for each of the four monitoring periods (Table 1). The differences during the four periods were 0.93, 1.29, 2.17, and 1.95, respectively (Table 1).

Mulch color did not significantly affect total accumulated HU 10 cm below the surface in any of the four periods (Fig. 4).

Conclusions

Our results support the use of polyethylene mulch to modify temperature at selected microclimate locations. Accumulation of HU at 10 cm above the mulch surface was greater above white than above black mulch during 2 of 4 comparisons. This contradicts the results reported by Ham et al. (1993), who in a short-duration study concluded that air temperatures at heights >5 cm were not related to mulch color.

Accumulation of HU was reduced more by white than by black mulch at the mulch surface, at the soil surface, and at a soil depth of 10 cm in plantings that began in early April and extended through July. Effects at the mulch surface agree with results reported by Ham et al. (1993), but the soil surface data conflicts with those of Rivera and Goyal (1985).

At a depth of 10 cm in the soil, modification of accumulated HU was measured into the month of August. Soil accumulation rate is lower in the early season but increases later in the season. Lower soil temperatures under white mulch support the data of Albregts and Chandler (1993), Decoteau and Friend (1990), Decoteau et al. (1989), Ham et al. (1993), and Mbagwu (1991).

Lighter colored mulches can be used to slow the accumulation of HU. This may permit extension of the planting date of crops that are sensitive to heat. In contrast, dark mulches may be used to increase the accumulation of HU, resulting in earlier planting of crops that require more heat.

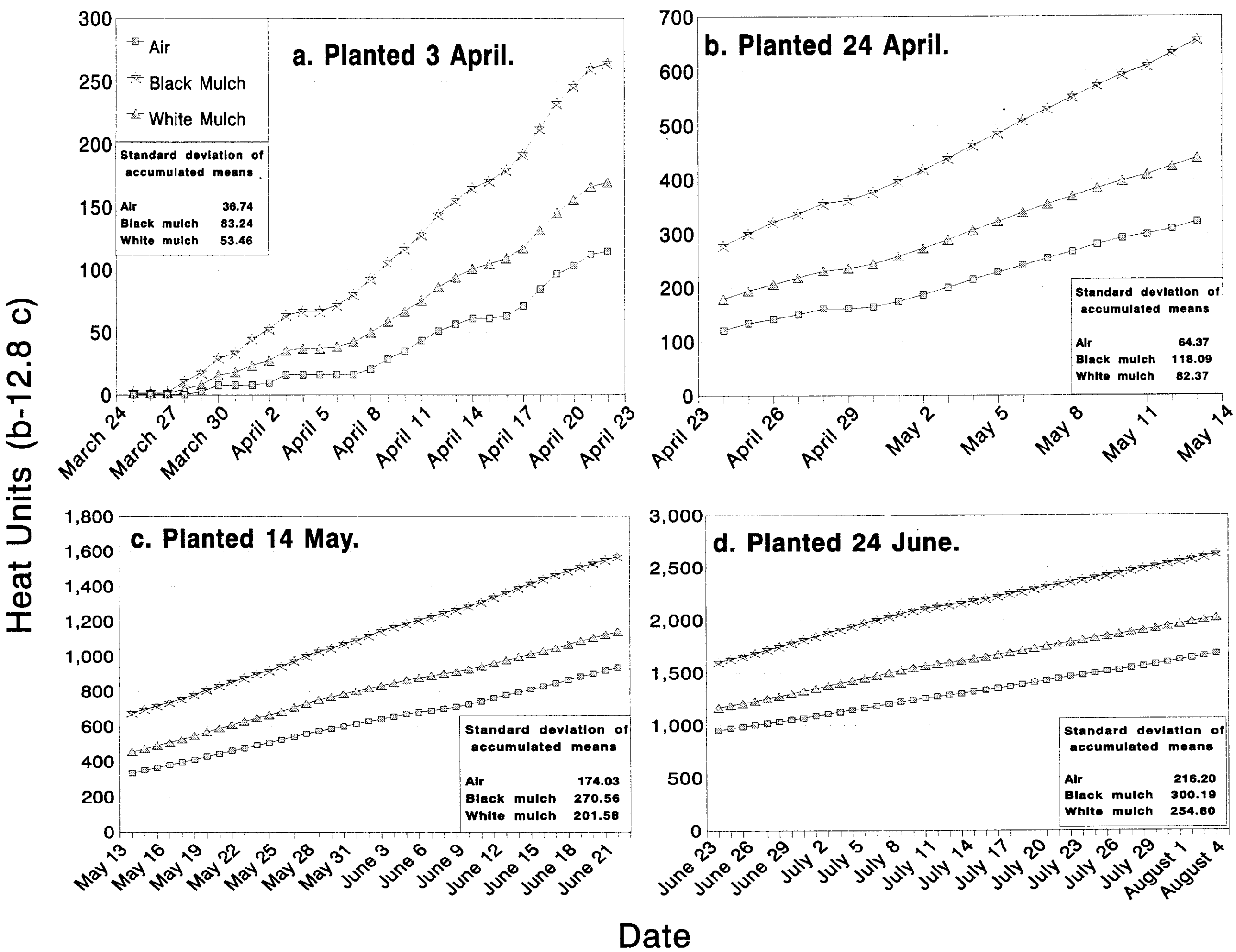

Fig. 3. Accumulated heat units on the soil surface under mulch and the atmosphere 1.2 m above the soil surface measured in watermelons transplanted in black and in white polyethylene mulch on four dates in 1996. Stephenville, Texas.

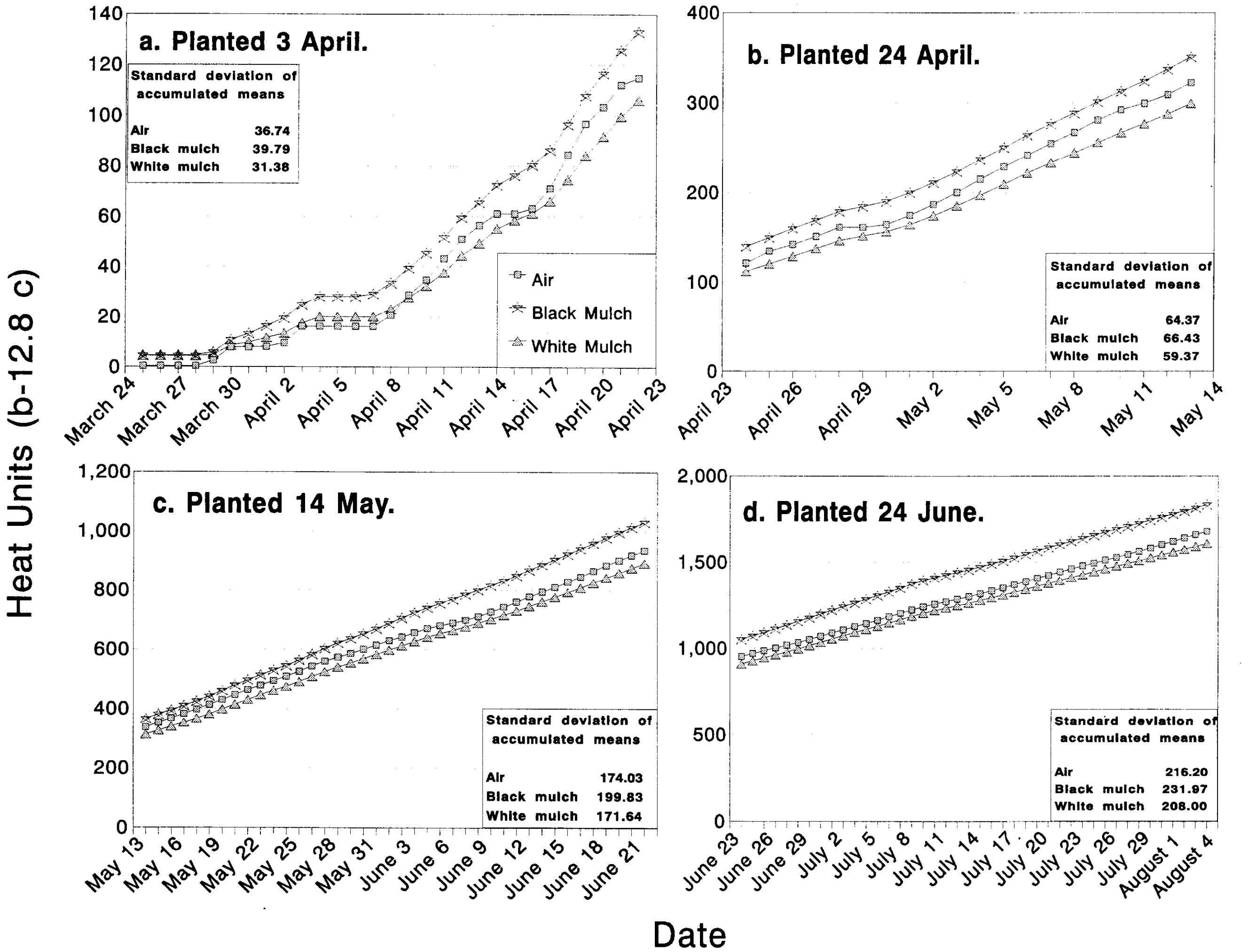

Fig. 4. Accumulated heat units 10 cm deep in the soil under mulch and the atmosphere 1.2 m above the soil surface measured in watermelons transplanted in black and in white polyethylene mulch on four dates in 1996. Stephenville, Texas.

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