The Effects of Colored Plastic Mulches and Row Covers on the Growth and Yield of Okra

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Summary. **Okra (*Abelmoschus esculentus* 'Clemson Spineless') was grown on an Orangeburg sandy loam soil in Shorter, AL. Okra was direct-seeded in single rows. Treatments consisted of five mulch colors: black, white, red, silver, and blue installed either with or without spun-bonded row cover. Soil temperatures were 4 to 7 °C lower than air temperatures in all treatments. The use of darker (black, blue, red) -colored plastic mulches increased early and total yield of okra compared with bare soil with and without row cover. Increased soil and air temperatures did not always correlate to an increase in yield. It can be concluded that the use of dark plastic mulch is advantageous to growers of okra in climates that do not have cool springs, but the added use of row covers to plastic mulch has no effect on growth and yield. The profit of marketable okra produced using a row cover was $1.37 versus $1.35 per pound without a cover in 2003 and $1.28 versus $1.29 per pound in 2004. Blue plastic mulch is ≈$0.08 per foot more expensive than black plastic. Our data do not show an economic advantage for blue over black mulch for okra, but the positive effect cited by other authors may be more pronounced with leafy vegetables.**

Plastic (polyethylene) mulches have been used in vegetable production in the United States since the 1950s. Black polyethylene plastic mulch is the standard plastic mulch used in vegetable production. Black plastic alters the plant's growing environment by generating warmer soil temperatures (Dodds et al., 2003; Hanna et al., 2003) and holding more soil moisture (Ham et al., 1991; Lamont, 1993) than bare soil. Researchers using black plastic instead of bare soil have recorded higher yields (Brown et al., 1995; Leib et al., 2002; Summers and Stapleton, 2002), earlier harvests (Bonanno and Lamont, 1987; Ibarra et al., 2001; Lamont, 1993), and cleaner fruit (Brown and Channell-Butcher, 2001; Loughrin and Kasperbauer, 2002), all attributed to soil temperature and moisture differences under plastic mulch. Sometimes black plastic mulches can create soil temperatures that are too high and this will cause deleterious effects on plant growth (Díaz-Péréz et al., 2000; Orzolek and Murphy, 1993). Other mulch colors besides black have been used by growers and researchers in vegetable production. White plastic mulch has been shown to generate cooler soil temperatures than black plastic (Díaz-Péréz and Batal, 2002; Lamont, 1993). White plastic is preferred during the summer growing season in warmer regions of the world compared with black plastic because it has the ability to maintain soil moisture while having cooler temperatures than black plastic. The use of silver plastic mulch has resulted in less insect-transmitted disease (Csizinszky et al., 1995; Lamont et al., 1990) in certain vegetable crops. Red plastic mulch has shown increased yield in tomato (*Solanum lycopersicum*) (Decoteau et al., 1989) and other crops (Decoteau et al., 1990; Kasperbauer, 1992).

Row covers are used to insulate a plant's growing environment to promote early yield. Floating spun-bonded polyester row covers are used with various vegetable crops (Shadbolt et al., 1962; Wells and Loy, 1985). Floating row covers have been shown to alter the plant's microenvironment by increasing temperatures for the crop during the day and into the night (Arancibia and Motsenbocker, 2002). The use of row covers with plastic mulch has shown to sometimes have a greater effect (Powell, 2000) and sometimes less effect (Lamont et al., 2000) on plant yield than the use of plastic

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
9.3540	gal/acre	$L\cdot ha^{-1}$	0.1069
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	$kg\cdot ha^{-1}$	0.8922
0.0254	mil	mm	39.3701
70.0532	oz/acre	$g\cdot ha^{-1}$	0.0143
1.1692	pt/acre	$L\cdot ha^{-1}$	0.8553
2.3385	qt/acre	$L\cdot ha^{-1}$	0.4276
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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mulch alone. The response of a plant to row covers is greatly dependent on the temperature in the region during the time the row covers are installed (Bonanno and Lamont, 1987; Contreras Magana and Sánchez del Castillo, 1990).

The use of row covers with plastic mulch has been shown to generate earlier and increased yields than row covers and plastic mulch used separately (Brown and Channell-Butcher, 1999a; Farías-Larios et al., 1998; Purser, 1993). Brown et al. (1998) observed that row covers with plastic mulch increased yield in sweetpotato (*Ipomoea batatas*). Gerber and Brown (1982) found superior and earlier yields of muskmelon (*Cucumis melo*) with the combination of row covers and plastic mulch. Cucumber (*Cucumis sativus*) exhibited a positive increase in early and total yield with the addition of row covers to plastic mulch (Wolfe et al., 1989).

Phytochrome is the photoreceptor responsible for light-regulated growth responses. The phytochrome molecule is a dissolvable chromoprotein with subunits that are made up of a linear tetrapryrrole chromophore covalently linked to a polypeptide of 120 to 127,000 molecular weight depending on the plant species (Pratt, 1982; Vierstra et al., 1984). Phytochrome receptors within plant cells have the ability to detect wavelengths from 300 to 800 nm. Red (R) light is absorbed from 660 to 680 nm and far-red (FR) light is absorbed from 730 to 740 nm (Decoteau et al., 1993; Kasperbauer, 1999; Rajapakse and Kelly, 1994). Tomato plants grown with red plastic mulch produced higher marketable yields than those grown with black plastic mulch (Decoteau et al., 1989). The researchers who conducted this study believed that their findings were related to the effects that light reflected from red plastic mulch had on the plant's phytochrome regulatory system. Orzolek et al. (2000) found silver and red plastic mulches reflected higher FR:R ratios than other mulch colors used in their study. This study also revealed an increase in marketable fruit yield in tomato using silver or red mulch as compared with standard black plastic. Bell pepper (*Capsicum annuum*) plants grew taller and were heavier when grown on red plastic, which exposed them to a greater FR:R ratio compared with other plastic mulches used in the experiment (Decoteau et al., 1990).

Plants have shown a multitude of different responses when treated with blue (wavelength 400 to 500 nm) light. Blue light treatments have shown to affect morphological, metabolic, and directional reactions in plants (Senger and Schmidt, 1994). Some of the documented findings on plant response to blue light include: phototropism (Lipson, 1980; Shropshire, 1980) enzyme synthesis (Hart, 1988; Ruyters, 1982), chloroplast development in leaves (Akoyunoglou et al., 1980), and stomatal opening (Hart, 1988). Hatt et al. (1993) and Kasperbauer and Loughrin (2004) have found white plastic mulch to reflect more blue light than the other colored mulches used in their experiments. Antonious et al. (1996) reported that turnip (*Brassica rapa*) roots grown on white plastic mulch, which reflected the largest amounts of blue light, had the least distinct or mildest flavor. Decoteau et al. (1988) reported that shorter stems and more auxiliary growth could result from the blue light reflected from the use of white plastic mulch with tomato. Field-grown cotton (*Gossypium* spp.) produced more boll fibers and seeds per plant when grown on ground covered with colored plastic mulches that reflected less blue light resulting in higher FR:R ratios (Kasperbauer and Thibodeaux, 1997).

Research on growing vegetable crops with various colored plastic mulches along with spun-bonded row covers is limited. The purpose of this study was to evaluate the effects of colored plastic mulches with and without row covers on growth and earliness of fruit production on okra.

Materials and methods

The research was conducted at the E.V. Smith Research Experiment Station in Shorter, AL. The soil type is an Orangeburg sandy loam (fine-loamy siliceous thermic Typic Kandiudult). Field plots to evaluate the effects of colored plastic mulches and row covers on the growth and production of 'Clemson Spineless' okra were established in May 2003 and Apr. 2004. The plots were 10 ft long and 5 ft wide. The colored plastic mulches and plastic drip irrigation lines were applied simultaneously on raised beds (6 inches in height) prepared with a plastic layering machine attached to a medium-sized tractor. The experimental plots were arranged in a randomized complete block design with four replications of each treatment. Each of the four replications represented a different block. Okra was direct-seeded into the field on 8 May 2003 and 28 Apr. 2004. A soil pH of 7.0 was recorded in Year 2003 and 6.2 in 2004. Treatments consisted of five mulch colors: black (BPM), white (WPM), red (RPM), silver (SPM) (all from Ken-Bar, Reading, MA), and blue [BLUPM (Pliant, Schamburg, IL)], installed either with or without spun-bonded row cover [RC (Ken-Bar)]. Drip irrigation tape applied together with the BPM was left in place for all treatments. The silver, red, white, and black plastic mulch were all 1.5 mil thick and 36 inches wide. The blue plastic mulch was 1.25 mil thick and 48 inches wide. The row cover was 1.7 × 0.77 m. The drip irrigation tape was 1 cm in diameter with 12-inch emitter

Table 1. Fertilizer and insecticide applied preplant and fertilizer, insecticide, and herbicide applied in season to okra plots with colored plastic mulch with and without row cover or bare soil in 2003 and 2004 at Shorter, AL.

	Year	
	2003	2004
Amendment	*Preplant (oz/acre)*[z]	
Phosphorus	0.14	0.29
Potassium	0.57	0.57
Magnesium	0.57	0.14
Calcium	3.14	2.14
Nitrogen	955	1012
Chloropicrin	4790	4790
	Preplant (lb/acre)[z]	
Methyl bromide	300	300
	In season (lb/acre)	
20N–8.73P–16.6K	47.7	104.8
Calcium nitrate	54.9	—
Carbaryl	4.0	1.2
	(gal/acre)[z]	
Trifluralin	0.13	0.13
Spinosad	0.007	—
Malathion	0.13	0.13
Sethoxydim	0.13	0.13
Glyphosate	0.25	0.50

[z]1 oz/acre = 70.0532 g·ha^{-1}; 1 lb/acre = 1.1209 kg·ha^{-1}; 1 gal/acre = 9.3540 L·ha^{-1}.

Table 2. Analysis of variance results for the effects of mulch color by row cover, year, block, and their interactions on okra plant height, fresh weight, stem diameter, and marketable and unmarketable yields (early and total yields) at Shorter, AL.

Treatment	Plant ht	Fresh wt	Stem diam	Early marketable yield	Early cull yield	Total marketable yield	Total cull yield	Total yield	No. branches	Soil temp	Air temp
Mulch color[z]	***	***	***	***	***	***	***	***	***	***	***
Row cover[y]	***	***	***	***	***	***	NS	***	***	**	***
Year[x]	***	NS	***	***	***	***	***	***	*	***	***
Block[w]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mulch × row cover	***	*	***	NS	NS	NS	NS	NS	NS	***	***
Mulch × row cover × year	***	*	***	**	**	NS	NS	NS	***	***	***

[z]Bare soil, black plastic, blue plastic, red plastic, silver plastic, and white plastic mulch.
[y]Plots with and without row cover.
[x]2003 and 2004.
[w]Each replication was a block.
NS = nonsignificant at the 0.05 *P* level; *, **, *** = significant at the 0.05, 0.01, and 0.001 *P* levels, respectively.

spacing. Bare soil (BS) plots with and without RC were used as controls. Six 364-ft strips of black plastic were installed over beds. Several sections in the black plastic (10 × 5 ft) were cut out, removed from the soil, and replaced with an equal size of white, blue, red, or silver plastic mulch. Uncut sections remaining in place served as the BPM treatment and cut sections left uncovered served as controls. The same day plastic mulches were installed in the field, 8 May 2003 and 28 Apr. 2004, okra was direct-seeded with three seeds for each of the 10 holes placed in the plastic mulch or bare soil treatments. The okra was thinned to one plant per hole after 14 d of growth and then 2-m-wide row cover strips were spread over designated treatments on 22 May 2003 and 12 Apr. 2004. Row cover strips were tucked into the soil around the edges of each plot and left to float loosely in an effort not to hinder plant growth as well as to prevent the loss of captured heat. The row covers were removed when okra plants developed flowers.

Soil temperature to a depth of 4 inches was measured with a soil probe thermometer (Taylor® Switchable Digital Thermometer; Taylor Precision Products, Oak Brook, IL). Air temperature was measured with Taylor® Indoor/Outdoor Thermometers (Taylor Precision Products) with sensors attached to heat-conducting wires and placed in the center of each plot at 5 inches above ground level. Temperatures were recorded for 14 d from 30 May to 15 June 2003 for air and soil temperatures. In 2004, air temperature was recorded for 12 d from 20 May to 7 June and for soil temperature 15 d from 14 May to 7 June from 1200 to 1300 HR on each day. The air temperatures were recorded during the okra vegetative stage.

The stem diameter was taken with a digital caliper (Model 500-196; Mitutoyo Digimatic, Kanagawa, Japan). Caliper measurements were taken 2 inches above ground level around the base of plants. Canopy heights were taken with a meter stick by measuring from the base of the plant to the tip of the highest leaf. Plant heights were taken from all treatments in both years on the day that the row covers were removed. The amount of branching per okra plant was determined by hand counting all branches over 3 inches in length. The okra yield was separated based on appearance (size, shape, color, and presence of insect or disease damage) into marketable and cull fruit and the weight of each group recorded. Yields for each treatment were determined by weighing marketable and cull fruit at each harvest date.

Preplant fertilizer and pesticides applied to okra plots in the years 2003 and 2004 were in accordance with soil testing recommendations from Auburn University Soil Testing Laboratory (Auburn, AL) and are given in Table 1. No limestone was added to okra plots either year. Before laying the plastic mulch, methyl bromide (67% methyl bromide + 33% chloropicrin; Soil Chemicals, Hollister, CA) was applied to the soil as a fumigant at a rate of 300 lb/acre on 17 Apr. 2003 and 27 Mar. 2004, respectively. Liquid calcium nitrate [$Ca(NO_3)_2$] fertilizer was injected into the soil through plastic drip fertigation tubes from 30 May to 28 Aug. 2003 and nitrogen (N), phosphorus (P), and potassium (K) as 20N–8.73P–16.6K from 30 May to 28 Aug. 2003. Nitrogen, P, and K as 20N–8.73P–16.6K

Table 3. Effect of row cover and plastic mulch color on early and total okra yield for marketable, cull, and the combined total of marketable plus cull fruit in 2003 at Shorter, AL.

	Early yield (lb/acre)[z]		Total yield (lb/acre)		
Treatment	Marketable	Cull	Marketable	Cull	Combined total
Row cover					
None	353 a[y]	161	9,865 b	5,435	15,300 b
Yes	186 b	127	12,630 a	6,396	19,026 a
Mulch color					
Bare soil	225	38	7,762 c	3,740 c	11,502 c
Black	311	134	13,738 a	7,662 a	21,401 a
Blue	295	229	12,084 ab	6,875 ab	18,959 ab
Red	272	187	11,275 ab	5,593 b	16,868 b
Silver	307	181	11,197 b	5,977 ab	17,174 b
White	208	97	11,429 ab	5,644 b	17,074 b

[z]First 2 weeks of harvest; 1lb/acre = 1.1209 kg·ha^{-1}.
[y]Mean separation within columns was determined by Fisher's least significant difference test. Within a column and factor, treatment means followed by the same letter are not significantly different at $P < 0.05$. Means followed by no letter were not significantly different at $P < 0.05$.

were applied to plots in 2004. Trifluralin at 1 pt/acre a.i. (Treflan; Bayer CropScience, Research Triangle Park, NC) was applied in May 2003 and 2004. In May 2003, 1 qt/acre a.i. of glyphosate (Round-Up; Monsanto, St. Louis, MO) was applied between the rows of the okra plots. In May 2004, 2 qt/acre a.i. of glyphosate was applied. Carbaryl (Sevin 80S; Bayer CropScience) was applied at a rate of 4 lb/acre a.i. in June 2003 and at 2 pt/acre a.i. in June 2004. Sethoxydim (Poast; Bayer CropScience) was applied at 1.2 $L \cdot ha^{-1}$ a.i. on 25 July 2003 and 23 June 2004. Malathion (Pestanal®; Superleco, Superleco Park, PA) and spinosad (SpinTor; Dow AgroSciences, Indianapolis, IN) were applied on 18 July and 8 Aug. 2003, respectively.

Okra was harvested from 3 July to 8 Sept. 2003 and from 21 June to 27 Aug. 2004. Fruit were picked on Monday, Wednesday, and Friday during the harvest period. Early yields were defined as okra fruit collected during the first 2 weeks of harvest, which were from 3 to 16 July 2003 and 21 June to 4 July 2004. All data were analyzed using SAS (Version 9.1; SAS Institute, Cary, NC). The effects of mulch color, row cover, replication (block), year, and their interactions on selected plant physical characteristics and yield components were tested by the analysis of variance (ANOVA) procedure. Where main effects were insignificant, those variables were dropped from the model and the ANOVA rerun. Because there were no significant block effects, the data were run in a factorial model with interaction. Temperature data were analyzed using the general linear model, repeated measures procedure of SAS (SAS Institute). Both air and soil temperatures were reported as the mean for values measured over the recording period during each year. Unless otherwise indicated, mean separation for all variables was accomplished with the Fisher's least significant difference test at $P < 0.05$.

Results and discussion

Significant differences between treatments were found for mulch color (Table 2). The row cover effect was significant for all treatments except total cull and year had a significant effect on all but fresh weight. There were significant mulch-by-cover-by-year treatment interactions for early yield components; however, by the end of harvest, these effects had vanished. All yield data are presented by year for early versus total yield comparisons. Table 3 lists yield data for 2003. Early yields, both marketable and cull, tended to be higher in plots without row covers, but this trend reversed in time. The combined total yields (marketable yield plus cull) were greater with row covers than without. Significantly lower yields were produced with bare soil than with any colored mulches used. Blue plastic mulch resulted in the highest early yield and maintained its productivity through harvest yielding the second highest combined total yield. At harvest, black plastic mulch resulted in the highest combined total yield.

There were no significant differences in early marketable and cull okra yields among the mulch color treatments in 2003. The bare soil produced the lowest marketable and combined total yields and black plastic produced the highest. On average, marketable yields were 66% of the total fruit produced with row cover

Table 4. Effect of row cover and plastic mulch color on early and total okra yield for marketable, cull, and the combined total of marketable plus cull fruit in 2004 at Shorter, AL.

	Early yield (lb/acre)[z]		Total yield (lb/acre)		
Source	Marketable	Cull	Marketable	Cull	Combined total
Row cover					
None	964 a[y]	500 a	7,579 b	3,009	10,587 a
Yes	689 b	199 b	8,897 a	3,212	12,108 a
Mulch color					
Bare soil	329 d	114 d	3,027 d	1,128 c	4,155 c
Black	1,020 ab	502 ab	10,803 a	4,423 a	15,226 a
Blue	1,081 a	648 a	10,019 ab	4,115 ab	14,133 a
Red	1,101 a	377 bc	7,668 c	2,958 b	10,626 b
Silver	754 bc	258 cd	7,932 bc	2,937 b	10,868 b
White	678 c	199 cd	9,978 ab	3,103 b	13,081 ab

[z]First 2 weeks of harvest; 1lb/acre = 1.1209 $kg \cdot ha^{-1}$.
[y]Mean separation within columns was determined by Fisher's least significant difference test. Within a column and factor, treatment means followed by the same letter are not significantly different at $P < 0.05$. Means followed by no letter were not significantly different at $P < 0.05$.

Table 5. Effect of colored plastic mulch and row cover on air and soil temperatures for okra production in 2003 and 2004 at Shorter, AL.[z]

	With row cover		Without row cover	
	Air	Soil	Air	Soil
Mulch color	*2003 temp (°C)[y]*			
Blue	38.9 ab[x]	30.3 a	34.2 ab	31.0 a
Black	38.4 ab	30.1 a	33.7 ab	30.1 b
Bare soil	36.5 c	27.9 c	33.0 c	28.8 c
Red	38.0 b	30.2 a	33.5 bc	30.5 b
Silver	39.7 a	27.5 c	33.5 bc	27.5 d
White	38.4 ab	28.9 b	34.3 a	28.5 c
	2004 temp (°C)			
Blue	34.1 bc	31.6 a	31.7	32.9 a
Black	37.5 a	31.2 a	32.2	32.2 ab
Bare soil	31.1 c	27.1 c	33.2	28.9 c
Red	34.6 ab	30.8 a	32.3	31.7 b
Silver	36.8 ab	28.6 b	33.0	28.2 c
White	36.1 ab	29.2 b	32.1	28.3 c

[z]Soil temperature to a depth of 4 inches (10.2 cm) and air temperature 5 inches (12.7 cm) above ground level were recorded daily over the time during which the row cover was present.
[y]$(1.8 \times °C) + 32 = °F$.
[x]Mean separation within columns was determined by Fisher's least significant difference test. Means with different lower case letters are significantly different at $P < 0.05$. Means followed by no letter were not significantly different at $P < 0.05$.

treatments producing a slightly higher percentage of marketable fruit than those without covers.

Okra marketable and cull yields for 2004 are shown in Table 4. Yield trends in 2004 were roughly similar to those in 2003. Early yields were greater without a row cover than with one. There was no significant difference between row cover treatments for combined total yield. This was the result of red and blue plastic mulch treatments producing greater yields without a row cover. Despite these two exceptions, by the end of harvest, plots with a row cover produced significantly more marketable yield than those without a row cover. Early marketable plus cull yields were similar for blue and black mulches and lowest with bare soil. This trend continued through to harvest. Plastic mulch has been identified for its ability to produce earlier okra yields than bare soil (Incalcaterra and Vetrano, 2000; Simone et al., 2002). In our study the results were inconsistent on this point. Bare soil always produced the lowest early yield; however, the difference was only significant in 2004.

At harvest, marketable yield was higher with row cover than without; however, the total combined yield with row cover was not significantly higher. Blue and black plastic mulches gave the highest early marketable plus

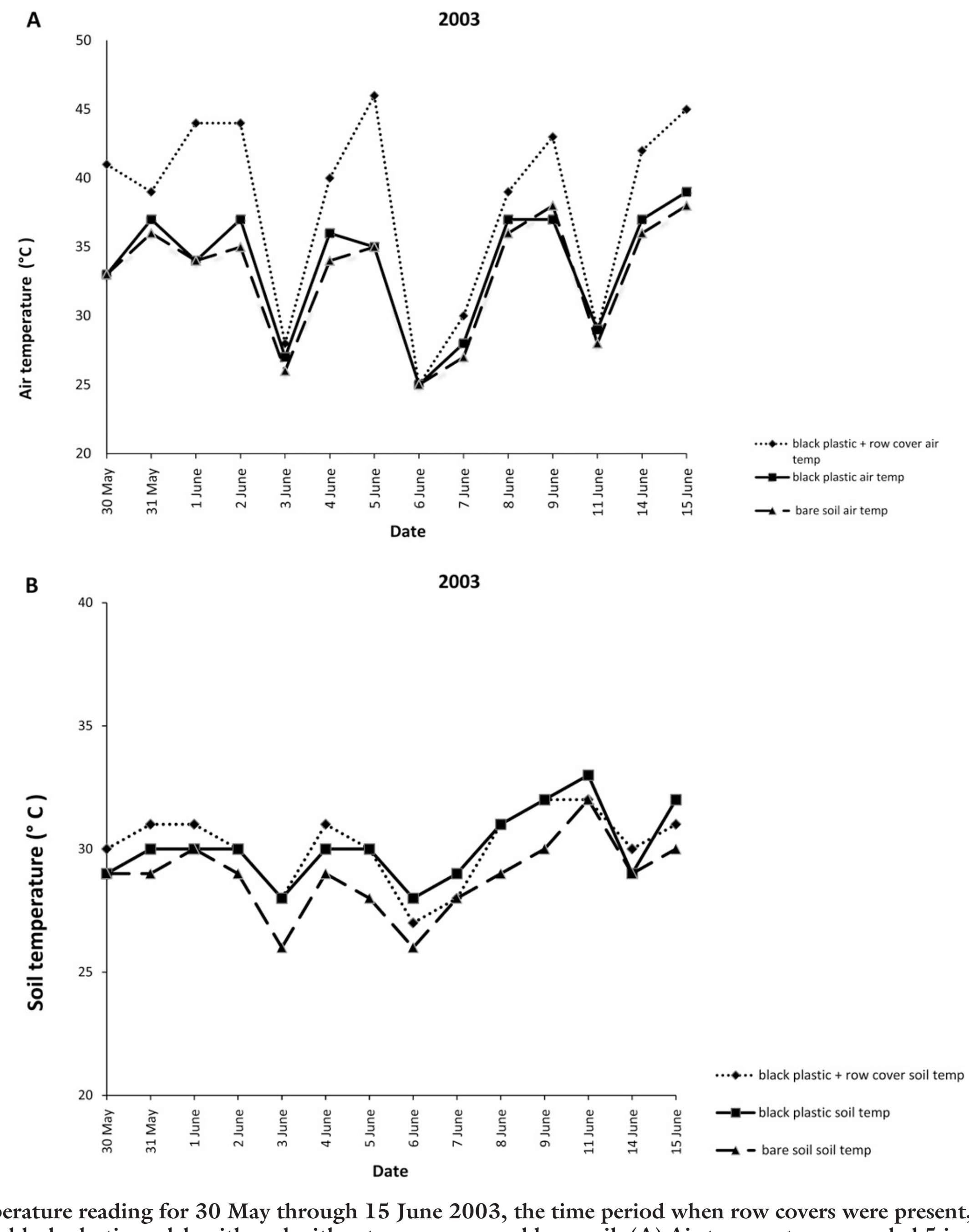

Fig. 1. Temperature reading for 30 May through 15 June 2003, the time period when row covers were present, for okra grown under black plastic mulch with and without row covers and bare soil. (A) Air temperature recorded 5 inches (12.7 cm) above each plot. (B) Soil temperature recorded 4 inches (10.2 cm) below soil surface in each plot; (1.8 × °C) + 32 = °F.

cull yield and gave the two highest total combined yields, significantly higher than all but white plastic mulch. Bare soil had the lowest total marketable yield of all treatments; this was true for BS and BS + RC. Cull yields were 26% and 28% of the combined total for treatments with and without a row cover, respectively. Combined total yield for mulch treatments for each row cover followed the order: BPM + RC ≥ WPM + RC ≥ BLUPM + RC ≥ SPM + RC ≥ RPM + RC > BS + RC and BLUPM ≥ BPM ≥ RPM = WPM = SPM > BS for treatments with and without row covers, respectively (data not shown). Brown and Lewis (1986) and Khan et al.

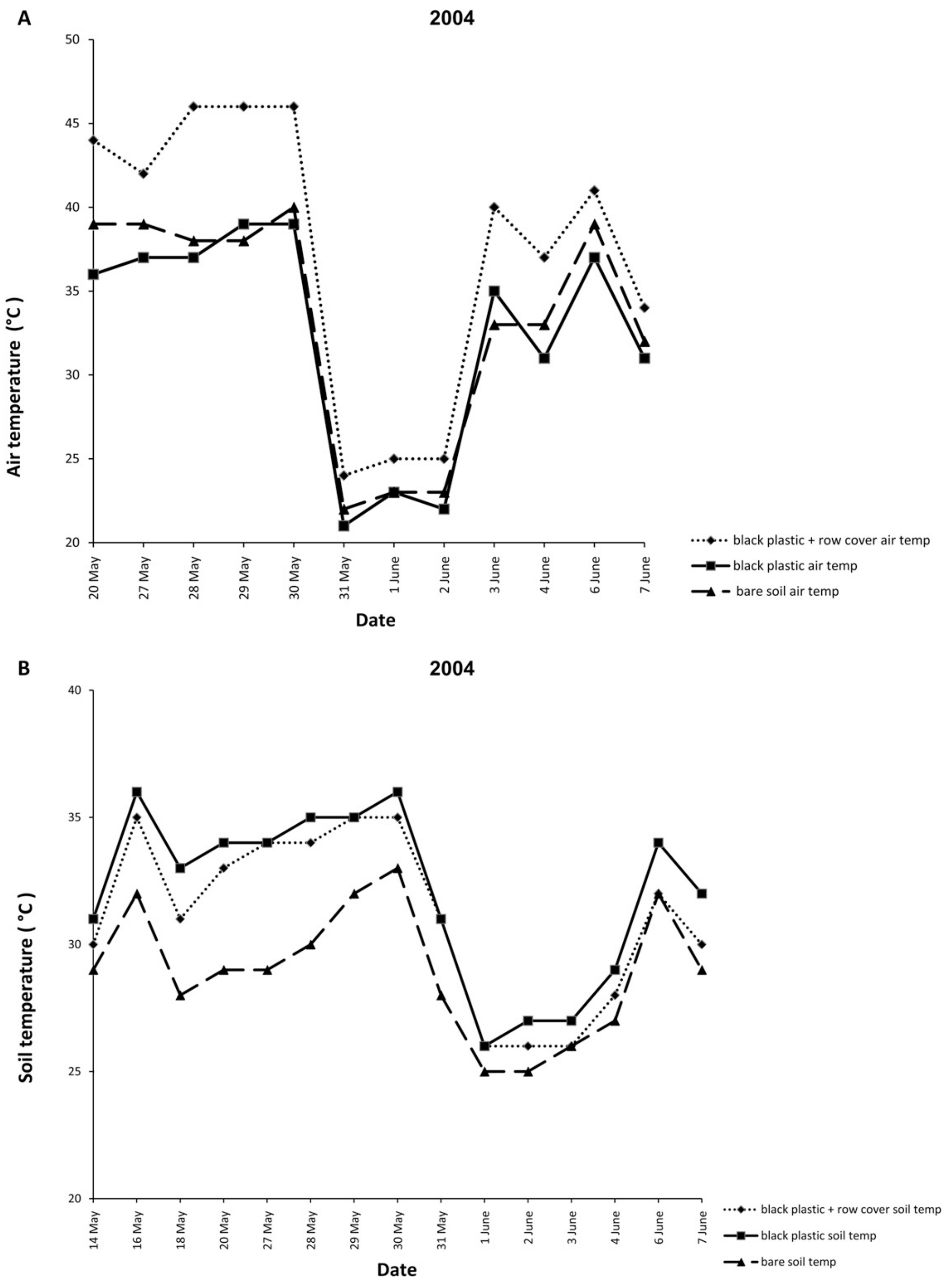

Fig. 2. Temperature reading for 20 May through 7 June 2004, the time period when row covers were present, for okra grown under black plastic mulch with and without row cover and bare soil. (A) Air temperature recorded 5 inches (12.7 cm) above each plot. (B) Soil temperature recorded 4 inches (10.2 cm) below the soil surface in each plot; (1.8 × °C) + 32 = °F.

(1990) also found black plastic mulch with a row cover produced higher okra yield than bare soil.

The data for mulch color, row cover, year, and mulch row cover interaction show significant effects on both air and soil temperature at $P < 0.01$ (Table 2). In general, plots with row cover had higher air temperatures than plots without row cover (Table 5). In 2003, row cover had no effect on soil temperature. In 2004, 1 °C higher temperatures were recorded in most plots without than with a row cover. The differences in soil temperature between plots with and without row cover were significant but not likely important. Temperature data for each year were analyzed separately.

Black plastic mulch is the standard color of mulch used in horticulture. Figure 1A shows that in 2003, black plastic mulch with row cover had a higher air temperature than black plastic mulch without row cover or bare soil. The black plastic mulch with row cover averaged 4 °C higher air temperature compared with black plastic mulch and 5 °C higher air temperature compared with bare soil. In 2004 (Fig. 2A), air temperatures were an average of 6 °C higher for black plastic mulch with row cover treatment compared with black plastic mulch and 5 °C higher compared with bare soil. Okra mean air and soil temperatures are shown in Table 5 for 2003 and 2004. In 2003, most plots with plastic mulch plus row cover had statistically similar air temperatures. However, BS + RC had a lower air temperature than other plots with a row cover. During 2004, in plots with a row cover, only BLUPM + RC failed to generate higher air temperatures than BS + RC. These findings are in agreement with other researchers who found higher air temperatures with the use of plastic mulch (Bonanno and Lamont, 1987; Brown and Channell-Butcher, 1999a; Ibarra-Jiménez et al., 2004; Khan et al., 1990). Without a row cover, WPM, BLUPM, and BPM had higher air temperatures than BS treatments in 2003. In 2004, there were no differences in treatments without row covers.

In 2003, soil temperatures were hotter under black plastic (Fig. 1B) than under black plastic with row cover or bare soil. Like 2003, soil temperatures for 2004 (Fig. 2B) were greater under black plastic mulch than black plastic mulch with row cover or bare soil. The okra soil temperatures for 2003 and 2004 were significantly higher in plots with blue, red, and black plastic mulches both with and without row covers. All of these treatments were darker colored plastic mulches. Díaz-Pérez and Batal (2002) and Rangarajan and Ingall (2001) found cooler temperatures with bare soil than under dark-colored plastic mulch. These findings also agree with Csizinszky et al. (1995) who found blue led to a higher soil temperature than orange, red, aluminum, white, or yellow-colored mulches. Gough (2001) found the warmest soil temperatures under red mulch. Soil temperature, in 2003, for plots with row cover, followed the order of BLUPM + RC = RPM + RC = BPM + RC > WPM + RC > BS + RC = SPM + RC. A similar trend was followed in 2004. Soil temperature in plots without a row cover followed the order BLUPM > RPM = BPM > BS = WPM > SPM in 2003 with a similar trend in 2004.

Air temperature was negatively correlated with early yield (Table 6). This is likely the result of above normal temperatures early in the season delaying flowering. This would lead to low early yields and the negative correlation with air temperature. Total yield and the number of branches produced by okra plants were positively correlated to air temperature. Soil temperature was positively correlated with early yield, but this relationship diminished by the end of harvest.

Mulch color, row cover, and year had significant effects on plant height, stem diameter, and the number of branches produced by okra plants; mulch color and year had significant effects on okra fresh weight (Table 7). Okra plants were taller, had greater fresh weight, and produced more branches with a row cover than without one. However, among the plastic mulch plus row cover treatments, BLUPM + RC produced significantly taller plants than WPM + RC and SPM + RC in 2003 and 2004; SPM + RC resulted in the shortest okra plants. Without a row cover, BLUPM and BPM produced taller plants than BS and WPM. Brown and Channell-Butcher (1999b) and Saikia et al. (1997) found that the use of plastic mulch with row cover generated taller okra plants than the use of just plastic mulch or bare soil. The stem diameters produced under BPM was either the largest or second largest (2004 with row cover) of any treatment.

There were no differences in okra fresh weight between treatments in 2003. In 2004, the fresh weights with blue, black, and red mulch colors were always significantly greater than with bare soil regardless of the presence of row cover.

The branch count produced by okra plants grown with a row cover followed the order BPM + RC = WPM + RC = BLUPM + RC ≥ RPM + RC ≥ SPM + RC ≥ BS + RC and BPM + RC ≥ BLUPM + RC = RPM + RC ≥ WPM + RC ≥ SPM + RC > BS + RC in 2003 and 2004, respectively. Without a row cover, the branch count was only significant in 2004 and followed the order WPM ≥ BPM = BLUPM ≥ RPM = SPM > BS. Khan et al. (1990, 1998) and Rahman and Shadeque (1999) noted that more okra branches developed with plastic mulch with or without row covers than bare soil.

Results from our study show that a row cover can increase yield; however, the presence of a row cover did not reduce the percentage of cull fruit. Black and blue mulch consistently produced plants among the

Table 6. Pearson correlation coefficient for air and soil temperatures versus okra yield components analyzed across mulch, row cover, and year combinations for experiments conducted at Shorter, AL.

Pearson correlation coefficient	Air temp (°C)	Soil temp (°C)
Early marketable yield	–0.43280	0.51026
Early unmarketable yield	–0.28249	0.58798
Total marketable yield	0.52478	0.22170
Total unmarketable yield	0.45840	0.18069
Total yield	0.51701	0.21218
No. branches	0.58546	0.20551

Table 7. Effects of colored plastic mulch and row cover on okra plant height, stem diameter, fresh weight, and branch count for each mulch by row cover combination in 2003 and 2004 at Shorter, AL.

Mulch color	Plant ht (inches)[z]	Stem diam (inches)	Fresh wt (lb/plant)[z]	Branches (no.)	Plant ht (inches)	Stem diam (inches)	Fresh wt (lb/plant)	Branches (no.)
	With row over				Without row cover			
	2003							
Blue	14.8 a[y]	0.51 a	0.62	7.1 a	11.4 ab	0.40 a	0.33	4.2
Black	14.8 a	0.50 a	0.42	7.9 a	11.9 a	0.42 a	0.35	3.7
Bare soil	11.7 c	0.40 b	0.20	4.3 c	10.1 c	0.39 ab	0.24	2.3
Red	13.4 b	0.44 b	0.35	6.8 ab	10.6 bc	0.38 ab	0.22	3.4
Silver	9.0 d	0.33 c	0.37	5.3 bc	10.5 bc	0.41 a	0.42	3.1
White	13.2 b	0.48 a	0.49	7.3 a	8.8 d	0.34 b	0.22	3.8
	2004							
Blue	17.9 ab	0.59 b	0.57 ab	6.0 ab	11.4 a	0.42 ab	0.31 abc	4.1 ab
Black	15.6 cd	0.68 a	0.73 a	6.3 a	12.4 a	0.44 a	0.44 a	4.3 ab
Bare soil	17.2 b	0.23 d	0.06 c	2.4 c	7.6 c	0.26 d	0.06 d	2.5 c
Red	18.6 a	0.67 ab	0.51 ab	5.3 ab	12.3 a	0.43 ab	0.35 ab	3.9 b
Silver	14.6 d	0.46 c	0.33 bc	4.8 b	9.1 b	0.36 bc	0.15 cd	3.6 b
White	15.9 c	0.60 b	0.71 a	5.0 ab	7.8 bc	0.30 cd	0.22 bcd	5.0 a

[z]1 inch = 2.54 cm; 1 lb = 0.4536 kg.
[y]Mean separation within columns was determined by Fisher's least significant difference test. Means with different lower case letters are significantly different at $P < 0.05$. Means followed by no letter were not significantly different at $P < 0.05$.

tallest, greatest fresh weight and most prolific branching. Early and total yields were also highest under black and blue mulches.

Conclusion

In this study, plants grown in soil under a row cover were taller and generally more robust than plants grown without row covers. Marketable yield was greater with the use of a row cover. In contrast, early yields were reduced by the presence of row cover. This is attributed to the high air temperature in late May associated with row covers. At times, air temperature surpassed 38 °F in plots containing a row cover. Soil temperatures were 5 to 7 °C lower than air temperatures. The dark colors, black, blue, and red, resulted in higher soil temperatures than silver or white-colored mulches. Warmer air and soil temperatures did not always correlate to greater yield. Early yield was generally greatest with dark mulch colors and the combined total yield greatest with black and blue plastic mulch.

Fields et al. (2004) estimated production cost of okra in Alabama without plastic mulch or row cover to be \$2834.32/acre. The price of black plastic mulch is estimated at \$252.00/acre and a row cover at \$637.00/acre. Mossler and Dunn (2005) have given a price as high as \$1.66/lb for okra. The profit of marketable okra produced using a row cover was \$1.37 versus \$1.35 per pound without a cover in 2003 and \$1.28 versus \$1.29 per pound in 2004. Combining row covers with plastic mulch did not give an advantage to the grower over plastic mulch alone. At locations where cool early-season temperatures do not occur, installing a row cover may increase yield, but the additional yield may not be sufficient to increase the return on investment. Plastic mulch did increase yield over bare soil. Even the least productive plastic mulch color (silver in 2003 and red in 2004) increased profitability over bare soil by \$0.10 and \$0.55 per pound in 2003 and 2004, respectively. Neither plastic mulch nor row cover had a great influence on the percentage of fruit lost as cull. There was no analysis of the effects of different colored mulch on insect and disease pressure.

Blue plastic mulch produced plant height, fresh weight, and early and total yield comparable to black plastic. The FR:R and blue light reflectance from the various plastic mulches was not measured during this experiment. It is possible that the FR:R and blue light reflected from the plastic mulches could have improved okra growth and yield. Decoteau et al. (1989) and Hatt et al. (1993) found the FR:R ratio had a positive effect on vegetable crops. Blue plastic mulch is ≈\$0.08 per foot more expensive than black plastic. Our data do not show an economic advantage for blue over black mulch for okra, but the positive effect cited by other authors may be more pronounced with leafy vegetables. More research needs to be done to know the effect that row covers with various colored plastic mulches have on the earliness and production of vegetable crops.

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