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Canopy Shade and Soil Mulch Affect Yield and Solar Injury of Bell Pepper

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Abstract. **Experiments were conducted from 1989 to 1991 to compare the effectiveness of various cultural techniques in reducing solar injury (SI) and increasing yield of bell pepper *(Capsicum annuum* var. *annuum* 'California Wonder') in southern Oklahoma. Treatments included black plastic mulch, white plastic mulch, straw mulch, living rye, spunbonded polypropylene used as a plant canopy shade, and bare soil. Marketable yields from plots shaded with spunbonded polypropylene rowcovers were equal to or greater than those from other treatments each year. Two out of 3 years, plots with a black plastic soil mulch had marketable yields lower than those from other treatments. SI was reduced by rowcover shade.**

High ambient temperatures and high solar-radiation levels can limit yield and quality of horticultural crops in the southern region of the United States. Fruit set of bell pepper is impaired at temperatures >30C (Shelby et al., 1978). In southern Oklahoma, the average daily maximum temperature is ≥30C from June to September and can be >40C during July and August (U.S. Dept. of Agriculture, 1979). Production techniques are needed to produce heat-sensitive crops during hot summer months.

Plastic mulches and rowcovers are used to modify environmental conditions and improve crop yields. Plastic mulches increase soil temperatures (Ashworth and Harrison, 1983), reduce nutrient leaching (Locascio et al., 1985), and stabilize soil moisture (Sanders et al., 1986). Light reflected from the surface of plastic mulch can affect the growth of tomatoes *(Lycopersicon esculentum* Mill.) and bell pepper *(Capsicum annuum* var. *annuum* L.) (Decoteau et al., 1988, 1989, 1990). Porter and Etzel (1982) reported that bell pepper yields were increased using an aluminum-painted plastic mulch compared to bare ground or black plastic plots. They suggested that the fruit yield increase was due to increased amounts of reflected light. However, Brown et al. (1992) reported that reflective mulches had no advantage over nonmulched soils or clear plastic mulch in either early or total yield of tomatoes. The effects of mulches on foliar development may also affect crop yield. VanDerwerken and Wilcox-Lee (1988) showed that, because of the high solar injury (SI) and blossom-end rot on the nonmulched, nonirrigated plots, the percentage of marketable bell pepper fruit increased with irrigation or mulch.

Rowcovers normally are used to promote an early crop harvest. Although rowcovers reduce the amount of light reaching the plant, Wells and Loy (1985) stated that this "reduction in light transmission through spunbonded covers should not limit growth of young plants in full or partial sun, since the photon flux density of full sun is well above the light saturation point for crop plants." As the light intensity is reduced, thermal energy penetrating the rowcover presumably also would be reduced (Dubois, 1978). Thus, rowcovers could be used as shadecloth to lower the plant and soil temperature.

Vegetable crops have been grown under shade. Experiments conducted nearly a century ago in Canada and in the northeastern United States indicated that foliar development was enhanced, but fruit and root development were retarded by applying shade (U.S. Office Experiment Station, 1904). In Oklahoma and other states in the southern United States, summer days are normally sunny with minimal cloud cover, and the available light may exceed that required for maximum crop yield. When this occurs, shading could lower the plant temperature without reducing the amount of photosynthesis or crop yield.

Experiments were conducted in Lane, Okla., from 1989 to 1991 to determine the effect of soil mulches and rowcovers on yield and fruit SI damage of bell peppers. In addition to rowcovers and plastic mulches, organic mulches were included to compare the effects of various types of soil covers. Our objectives were to determine if any treatment produced higher yield and less fruit SI than did bare soil or black plastic mulch, the two standards in vegetable production today.

Materials and Methods

The experiment was conducted each year on a Bernow fine-loamy, siliceous, thermic Glossic Paleudalf soil. Raised beds 0.8 m wide × 0.2 m high were formed each spring before transplanting. All plots were 1.8 m wide × 6.1 m long and separated lengthwise by a 2.4-m alley. They contained two parallel rows of plants 0.3 m apart on a single raised bed, and plants within rows were 0.3 m apart. Guard rows surrounded the field on all sides. 'California Wonder' pepper seedlings ≈6 weeks old were transplanted to the field 1 May 1989, 13 June 1990, and 17 May 1991.

Six treatments were included every year: bare soil, maintained weed-free by hoeing; soil covered with black plastic mulch (0.038 mm thick × 1.2 m wide); soil covered with black plastic mulch painted white; soil covered with wheat straw (15 cm thick); soil seeded with living rye *(Secale cereale* L.), planted 2 weeks before pepper was transplanted at 84 $kg \cdot ha^{-1}$ and allowed to grow throughout the season; and white spunbonded polypropylene rowcover (Kimberly Farms, Roswell, Ga.) (1.5 m wide, 50 $g \cdot m^{-2}$)—hereafter referred to as rowcover—applied at transplanting time and suspended on arches of 2.5 cm × 30-m polyvinyl chloride pipe positioned above the plant foliage.

In 1991, two additional treatments were included in the experiment. Soil was covered with an open-weave, black polypropylene groundcover material (Belton, Charlotte, N.C.), and black polypropylene shadecloth (1.5 m wide) was suspended on arches identical to those of the rowcover treatment.

The mulches were applied to the soil surface just before transplanting. The rowcover and shadecloth were attached to the top portion of hoops mounted over the plant canopy (NeSmith et al., 1992). A strip parallel to the soil on each side of the hoop, ≈30 cm high, was left uncovered to allow ventilation over and through the plant canopy.

A hand-held light meter (Skye Instruments, Perkasie, Pa.) was used to monitor the light intensity under the rowcovers and the shadecloth. Readings were taken under the rowcover and shadecloth by holding the sensor ≈30 cm beneath the peak of the covers, with the sensor facing upward, at times when there was no cloud cover. Readings under the rowcover were 60% of ambient at 660 nm and 63% of ambient at 730 nm; those under black shadecloth were 33% of ambient at 660 nm and 31% of ambient at 730 nm.

Preplant fertilizers N, P, and K were applied at 56,63, and 155 $kg \cdot ha^{-1}$, respectively. Irrigation was supplied through drip irrigation lines placed on top of the soil and underneath the mulches. An additional 56 kg N/ha was

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divided into three equal amounts and injected through the drip irrigation lines on three occasions. One application was applied just after the first fruit set and the other two applications at 10-day intervals. Each year, soil moisture at 15 cm and soil temperatures at 2.5-cm depths were monitored at about 1:00 PM three times per week throughout the growing season. Water was applied through the irrigation lines as needed to keep tensiometer (Soil Moisture Equipment, Santa Barbara, Calif.) readings less than 40 kPa. The tensiometers were permanently installed, and soil temperatures were measured with hand-held thermometers (Taylor, Atlanta, Ga.) inserted into the soil at the stated depths.

Each year, fruit were harvested from the 24 plants nearest the center of each plot. Fruit were graded according to U.S. Dept. of Agriculture standards, and data were collected for the total number of fruit, weight of the marketable fruit, and the number of fruit with SI damage. The percentage of total fruit damaged by SI and the average size of all fruit were calculated. To indicate whether the rowcovers and shadecloth were shading the plants excessively, leaf chlorophyll content was measured weekly and nondestructively with a SPAD-502 meter (Minolta, Ramsey, N.J.). This technique for measuring plant chlorophyll has been shown to be highly correlated with extractable chlorophyll levels (Marquard and Tipton, 1987); thus, it is a good indicator of excessive shading.

In 1991, leaf temperatures were measured by infrared thermometry, with measurements taken between 1:00 and 2:00 PM about every 4 days from 20 June to 1 Aug. At the same time, a plant stress index was generated using a Scheduler plant stress monitor (Conservation Technologies, Irvine, Calif.). Plant stress indices based on infrared thermometry have been reviewed, and different methods exist for stress index calculation (Hatfield, 1990). The stress index calculated by the instrument in this study indicated that plants with a reading < 0 were extremely well watered, plants with a 0 - 2 reading were operating at top efficiency, and plants with readings >2 were stressed.

Each year, we used a randomized complete-block design with treatments replicated four times. We analyzed data according to analysis of variance statistical procedures of SAS (SAS Institute, 1982), with means separation by Duncan's multiple range test at $P \leq 0.05$. The percent SI data were transformed by an arcsin square-root transformation before mean separation.

Results and Discussion

Currently, standard production practices for bell pepper consist of using either bare soil or a black plastic mulch. Our results show that other treatments may be better than either of these standard practices. In 1989, the plots with black plastic mulch produced a greater number of fruit than did the plots with rowcovers, straw, or rye (Table 1). However, in 1990 and 1991, the plots with black plastic mulch produced fewer fruit than did most of the other plots. A similar response was seen with the weight of the marketable fruit. In 1989, the plants in plots with black plastic mulch produced marketable weights equal to or greater than those in any of the other plots. In 1990 and 1991, the weight of fruit produced in the plots with rowcovers, however, exceeded that of the plots with black plastic mulch. When considering all 3 years of the experiment, the magnitude of difference in marketable fruit weight between plots with rowcovers and plots with black plastic mulch was substantial: black plastic mulched plots averaged 11.4 $Mg \cdot ha^{-1}$ compared to 22.3 $Mg \cdot ha^{-1}$ for plots with rowcovers. During the last 2 years of the study, marketable weights from plots with rowcovers were from two and one-half to eight times higher than those from the plots with black or white plastic mulches.

The average weight of all fruit produced was affected by the treatments in 1990 and 1991. The heaviest fruit was produced in plots with rowcovers or shadecloth, and the lightest fruit generally were produced in the plots with black or white plastic mulch.

Not only were the weight and number of fruit affected by the treatments, but the incidence of fruit SI also was reduced using shade. In 1989, the plots with rowcovers had a smaller percentage of total fruit damaged by SI than did the plots with organic mulches (rye or straw). In 1990, the fruit from plots with rowcovers had less SI than did those of any other treatment. In 1991, fruit produced in the plots under either rowcover or shadecloth had less SI than those in any other treatment, with the exception of those from plots with straw mulch, which did not differ significantly from the two shaded treatments.

Because the rowcovers and shadecloths were suspended above the plots but were not extended to the soil, the plants were exposed to early morning and late afternoon sunlight that reached the canopy beneath the covers. At harvest, we observed that most SI that did occur was caused by sunlight entering below the rowcovers—not by sunlight that penetrated through the rowcovers.

Climatic differences during the 3-year study may be responsible for the yield inconsistency in the black plastic mulch treatments. In 1989 when the marketable weight of fruit produced with the black plastic mulch was equal to that from the rowcovers, the soil temperatures were lower than they were in 1990 or 1991. Soil temperatures in the six treatments included each year of the study averaged 29.2,32.9, and 33.7C in 1989, 1990, and 1991, respectively. The average soil temperatures beneath the black plastic mulch were 30.1, 37.0, and 39.9C in 1989, 1990, and 1991, respectively (Table 2). The low pepper yields from the black plastic mulch in the last 2 years may have been due to the higher soil temperatures.

The plots with black plastic mulch had less soil moisture (greater soil moisture tension) than did the plots with rowcovers in 1989, but the reverse was true in 1990 and 1991. Average soil moisture tension for the various treatments was < 30.9 kPa, which indicates that plots were not moisture deficient. The stress index calculated in 1991 supported this conclusion. Average stress index ratings were no greater than +1.0, indicating that limitations to crop yield were not caused by moisture deficits (Table 2). Plant stresses that did exist probably were caused by high plant or soil temperatures (Table 2) rather than by a deficit of soil moisture. In addition, the plots with black plastic mulch generally were higher in soil moisture than the other plots, but leaf temperatures were higher with black plastic mulch than with other treatments.

Dense shade materials may reduce photosynthesis and yield by reducing the amount of light reaching the plant. Because there is a close relationship between photosynthesis and the absorption spectra of chlorophyll (Noggle and Fritz, 1983), measurements were taken to determine if either rowcovers or shadecloth reduced the chlorophyll content of plants grown under shade. Numerous factors, in addition to shade, could affect the chlorophyll content of a plant, but our measurements indicate that rowcovers did not reduce the chlorophyll content of plants, compared to that of nonshaded plants (Table 2). However, plants grown under shadecloth did have a lower chlorophyll content than did most of the nonshaded plants.

The open-weave groundcover was only included in the final year of the study, but results were favorable enough to warrant further comparisons with black plastic mulch. The groundcover generally resulted in better

Table 1. Total number of fruit, marketable fruit weight, average fruit weight, and percentage of total fruit with solar injury (SI).

Treatment	Total no. fruit (1000s/ha)			Marketable wt ($Mg \cdot ha^{-1}$)			Avg fruit wt (g)			Total fruit with SI (%)		
	1989	1990	1991	1989	1990	1991	1989	1990	1991	1989	1990	1991
Black plastic	652 a[z]	120 b	185 c	28.1 a	2.6 d	3.5 c	88 a	53 cd	38 e	42 abc	46 ab	62 a
Rowcover	439 bc	288 a	225 bc	26.7 a	20.8 a	19.5 a	89 a	90 a	101 a	33 c	18 c	21 c
White plastic	583 ab	253 a	309 ab	24.4 ab	6.9 cd	7.6 bc	75 a	44 d	50 de	45 abc	53 a	53 ab
Bare soil	521 abc	278 a	313 ab	23.3 ab	10.6 bc	12.3 ab	86 a	66 bc	66 cd	36 bc	41 ab	52 ab
Straw	432 c	324 a	346 a	15.3 b	14.7 b	18.4 a	93 a	69 b	83 b	52 a	39 b	34 bc
Living rye	162 d	152 b	148 c	3.9 c	5.3 cd	5.0 bc	52 a	61 bc	58 cd	48 ab	38 b	63 a
Shadecloth	---	---	185 c	---	---	12.4 ab	--- a	---	107 a	---	---	21 c
Groundcover	---	---	228 bc	---	---	11.3 abc	--- a	---	69 bc	---	---	50 ab

[z]Mean separation between treatments (within years) by Duncan's multiple range test at $P \leq 0.05$.

Table 2. Season averages of soil moisture at a 15-cm depth, soil temperatures at a 2.5-cm depth, leaf chlorophyll content, leaf temperature, and plant stress index (PSI) taken at about 1:00 to 2:00 PM.

	Soil						Plant			
	Moisture (kPa)			Temp (°C)			Chlorophyll (SPAD 502 units)		Temp (°C)	PSI[z]
Treatment	1989	1990	1991	1989	1990	1991	1990	1991	1991	1991
Black plastic	15.9 b[y]	11.3 c	16.4 b	30.1 ab	37.0 a	39.9 a	48.9 c	64.5 a	35.1 a	+1.0 a
Rowcover	10.5 d	28.5 a	30.9 a	28.2 cd	30.8 c	31.1 e	55.7 ab	63.5 ab	31.9 d	–4.0 c
White plastic	16.5 b	18.6 b	22.9 ab	29.1 bc	33.7 b	36.2 b	53.4 b	63.8 ab	33.8 b	+0.3 a
Bare soil	17.0 ab	28.0 a	24.3 ab	30.8 a	33.2 b	34.7 c	57.5 a	63.5 ab	33.1 bc	–1.6 b
Straw	19.4 a	21.3 b	24.4 ab	27.5 d	29.9 c	30.3 e	54.7 b	61.4 abc	32.9 c	–2.2 b
Living rye	11.2 cd	30.0 a	29.2 a	29.3 bc	32.7 b	32.5 d	53.9 b	60.7 bc	33.5 bc	–1.3 b
Shadecloth	---	---	26.1 a	---	---	30.0 e	---	59.5 c	31.1 e	–5.4 d
Groundcover	---	---	27.6 a	---	---	34.7 c	---	63.2 ab	33.0 c	–2.2 b

[z]Stress ratings are unitless, with the greatest positive numbers having the most stress.
[y]Mean separation between treatments (within years) by Duncan multiple range test at $P \leq 0.05$.

plant yield than did the black plastic mulch.

Straw mulch and living rye were included in the experiment as alternative ways to provide soil mulches. Fruit count and marketable weight from the straw mulch plots were generally better than those from the plots with black plastic or rye but not better than from plots with rowcovers. The fruit yield from plots covered with rye was low each year. All treatments were fertilized with the same amount of nutrients, but it is possible that N immobilization occurred with the straw mulch plots and that the living rye competed with the pepper plants for nutrients. Our goal was to examine various cultural practices with identical soil fertilizer applications, but either of these organic mulch treatments might have responded differently if additional nutrients had been added.

Our results indicate that, in hot climates with a high solar-radiation level, rowcovers could be used as shading materials to enhance bell pepper yield and quality. Additional work is needed to determine the ideal shade rate and the climatic conditions under which shading is most feasible. Although black plastic mulch is being promoted strongly for many crops, our results indicate that it should be used with caution in areas with extended periods of hot, sunny weather. The feasibility of plastic mulch in combination with rowcover shade needs to be examined.

Economic questions also need to be addressed to determine if using rowcovers for shade is cost effective. The yield increase from rowcovers compared to bare soil was 6.9 $Mg \cdot ha^{-1}$ per year over 3 years. From 1984 to 1988, the average price for bell pepper at the Chicago, Dallas, Denver, New Orleans, and St. Louis farm markets was $9.60 per 13.6-kg carton (Henneberry and Kang, 1992). Using these prices, the yield increase from rowcovers would be worth $4866/ha per year over the three years. With bed centers 1.8 m apart, and two rows of plants per bed, the approximate cost of rowcovers would be $2000/ha, which would give a profit of $2866/ha. This does not take into consideration time of year in which the produce is sold or costs for machinery, rowcover supports, or additional labor. A complete economic analysis is needed to determine the net monetary return when rowcovers are used.

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