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Mulch Surface Color Affects Yield of Fresh-market Tomatoes

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Abstract. **The influence of polyethylene mulch surface color on the plant light environment and tomato (*Lycopersicon esculentum* Mill) production was investigated. White- or silver-painted mulches reflected more total light, and a lower ratio of far-red relative to red light, than mulches painted black or red. Soil temperatures were warmer under the black and red mulches. Mulch color also affected the yield and growth of tomato. Tomato plants grown with red mulch generally had the greatest early marketable yields and produced the least amount of foliage. Plants grown with a white or silver-colored mulch had lower early marketable yields but produced more foliage. These results suggest that mulch surface color can induce changes in the plant microclimate (e.g., spectral balance and quantity of light, root zone temperatures) that can act through natural regulatory systems within the growing plant and affect tomato plant growth and fruit production.**

Polyethylene mulch is widely used in the production of fresh-market tomatoes. Reported beneficial responses of tomatoes to polyethylene mulch culture include earlier production (Bhella, 1988; Schalk et al., 1979; West and Pierce, 1988), better fruit quality (Wien and Minotti, 1987), and greater total yield (Jones et al., 1977; Wien and Minotti, 1987). These responses have been attributed to enhanced soil warming (Taber, 1983), more efficient and consistent use of water (Bhella, 1988; Jones et al., 1977; Sweeney et al., 1987) and fertilizers (Bhella, 1988; Jones et al., 1977; Wien and Minotti, 1987), and better control of weeds (Smith, 1968). Management decisions on mulch color traditionally have been based on mulch effects on soil temperatures. Black or transparent polyethylene mulches are preferred for spring production because of their ability to warm normally cool soils in the early spring (Taber, 1983). A white or aluminum mulch is preferred for summer and fall production, when additional soil warming is often not beneficial for plant growth and development (Cook et al., 1982; Schalk and Robbins, 1987).

Recently, a phytoregulatory role for upwardly reflected light on tomato plant development in plastic mulch culture has been established (Decoteau et al., 1988). Morphological development of young tomato plants was altered by subtle changes in the wavelength composition of light reflected from various painted colors of polyethylene surfaces (Decoteau et al., 1986). Differences in tomato plant development can be induced in controlled environments by exposure to red (R) and far-red (FR) light, implicating phytochrome as the sensing mechanism (Decoteau et al., 1988; Tucker, 1975). Tomato plants treated with FR light at the end of the day grew taller and had fewer branches than tomato plants treated with R light. Even subtle changes in the FR:R ratio can have a major influence on plant growth (Kasperbauer, 1988; Kasperbauer et al., 1964). Nutrient uptake of tomato has also been reported to be affected by light spectral quality (Tremblay et al., 1988). Because tomato plant growth is responsive to subtle changes in the plant light environment, alternative colors of mulch that selectively reflect desired wavelengths of light into the plant canopy may have potential for improving tomato yields under field conditions. The objectives of the present study were to a) measure the influence of mulch surface color on reflected light, and b) determine the effects of various mulch surface colors on the yield of fresh-market tomatoes planted in the spring.

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Materials and Methods

Field plots evaluating mulch color effects on fresh-market tomatoes were located at the Pee Dee Research and Education Center of Clemson Univ. near Florence, S.C. in 1986 and 1987, and at the ARS/USDA Coastal Plains Soil and Water Conservation Research Center near Florence in 1987 and 1988. The field sites were ≈15 km apart. The soil at both sites was a Norfolk loamy sand (Typic Paleudults). Lime was applied at rates determined by soil tests. Fertilizer was applied at the beginning of each trial at average N, P, and K rates of 112, 160, and 310 $kg \cdot ha^{-1}$ and disked into the top 0.2 m of soil.

Black polyethylene mulch (1.5 m wide), trickle irrigation tubing, and methyl bromide fumigation were applied in all plots by machine. The polyethylene mulch covered beds 0.8 m wide and 0.1 m high. Colored mulch treatments were established by application of various colors of exterior enamel paint (Table 1) to the black plastic surfaces. The objective of using variously colored paints over the polyethylene was to obtain reflected light with a range of spectral distributions. Both black-painted and non-painted black polyethylene mulch were evaluated at the USDA site. The black mulch treatment was not painted at the Clemson site. Mulch treatments were arranged in randomized complete block design with four replicates per color treatment. Colored mulch plots were 6.1 m in length with rows 1.8 m apart.

Plants were started in a greenhouse and transplanted to the mulch treatments at the Clemson site on 15 Apr. 1986 and 17 Apr. 1987, and at the USDA site on 29 Apr. 1987 and 5 May 1988. 'Mountain Pride' was used at the Clemson site and 'Ce-

Table 1. Paints used to establish colored mulch surface treatments and the effects of mulch surface color on upwardly reflected light (20 cm above the various surface colors).

Mulch color	Paint[x]	Reflected light: Photosynthetically active radiation[z] (400–700 nm) (% of direct sunlight)	FR:R[y] (relative to direct sunlight)
Red	Vermillion (211A-119)	9.0	1.13
Black	Not painted	5.5	1.06
Black	Black (197A-105)	5.9	1.07
Silver	Silver Gray (211A-100)	24.5	0.96
White	White (211A-117)	35.5	0.97

[z]Light measurements were taken on a cloudless day at about solar noon.
[y]The far-red to red ratio of direct sunlight was assigned a value of 1.00.
[x]Ace Hardware Porch and Floor Enamel-brand paints.

lebrity' was used at the USDA site. In-row plant spacing was 0.45 m and recommended cultural practices for tomato production (Cook et al., 1982), including staking and pruning, were followed throughout the studies.

Fruit at the breaker color stage (Fahey, 1976) was harvested, two to three times a week, from plants in the center 3 m of row. Marketable yield consisted of fruit graded U.S. no. 1 or U.S. no. 2 (USDA Agricultural Marketing Service, 1976). Yields were divided into early and total marketable. Early yield consisted of marketable fruit harvested during the first 2 weeks of the harvest season and represented a typical commercial harvest period for tomato growers of South Carolina. Total marketable yields consisted of fruit harvested from the first harvest until a late harvest, when the number of nonmarketable fruit was greater than marketable. After the final harvest in 1986, plants were cut at the soil surface and dry weights of the top growth (stems and leaves) determined after complete drying at 60C.

Reflected light from each surface color of mulch was determined using a LI-COR 1800 spectroradiometer with a remote light collector on a 1.5-m fiber optic probe. Upwardly reflected light was measured at a point 20 cm above the mulch surface. Measurements were taken at 5-nm intervals from 400 to 800 nm. The reflected light was expressed as a percentage of direct sunlight at each measured wavelength to determine the shift in spectral balance due to mulch color. Spectral irradiances at 735 and 645 nm were used to calculate the FR:R ratios. These values were used because they approach the peaks for phytochrome action spectra in green plants; 645 nm was used instead of 660 nm because chlorophyll competition for light at 660 nm (the phytochrome in vitro peak) shifts the phytochrome action peak in green plants (Kasperbauer et al., 1964). Soil temperatures were measured in all plots during the growing season at the Clemson site in 1986 and at the USDA site in 1987 with a Campbell CR7 Datalogger equipped with copper–constantan fixed thermocouples.

Results and Discussion

Mulch color affected the plant light environment (Table 1). The white and silver-colored mulch surfaces reflected more total photosynthetic light, but with a lower ratio of FR:R light, which acts through the phytochrome system within a plant, than the other mulches. The FR:R ratio plays a major role in assimilate partitioning during growth and influences plant adaptation to competition from other plants (Kasperbauer, 1988). The ratio acts through the phytochrome system to regulate stem elongation, chloroplast development, and photosynthate partitioning among shoots, roots, and developing fruits (Kasperbauer, 1987). There was little difference in the amount and quality of light reflected from the black-painted polyethylene and the non-painted black polyethylene. The difference in plant light environment among the colored-mulch treatments under field conditions in the present study (Table 1) were similar to those previously reported to affect tomato seedling growth in controlled environments (Decoteau et al., 1988) and could potentially influence assimilate partitioning sufficiently to affect tomato fruit yields.

The surface color of polyethylene mulch influenced marketable yields of tomatoes (Table 2). In general, the darker-colored mulches (red and black) led to higher yields than those lighter-colored (silver and white). At the Clemson site in 1986, tomato plants grown with red mulch had the greatest early and total marketable yields. At the Clemson site in 1987, plants grown with red and black mulch had comparable early yields. For both years, early yields from the silver-colored and white mulch plots were less than from the red mulch treatment. Total yields at the Clemson site were not affected by mulch color in 1987.

Soil temperatures may have contributed to the increased early yields from the dark- (black and red) vs. light- (white and silver) colored mulch treatments (Fig. 1A). In 1986, average diurnal soil temperatures were warmest under the black mulch and coolest under the white mulch. Black and red mulch treatments produced similar diurnal temperature trends, with red having less than a 0.2C cooler hourly average temperature difference than black. Average daily maximum soil temperatures were 31.0, 30.5, 29.5, and 26.2C for black, red, silver, and white mulch, respectively. Average daily minimum soil temperatures varied <0.5C among all mulch color treatments. The early yield response with red vs. black mulch suggests that yield increases with red mulch were not entirely due to soil warming and that other environmental variables affected by the mulch, such as spectral distribution of reflected light, contributed to plant yield.

Similar early yield trends were observed with a different cultivar at the USDA site in 1987 and 1988 (Table 3). Even though plants were transplanted to field plots an average of 2 weeks later than at the Clemson site, tomato plants grown with red and black mulches had greater early marketable yields than those grown with white mulch. There was no difference in the yield response of tomatoes to the black-painted and non-painted black surface, and diurnal soil temperature trends were similar for the red and black mulches (Fig. 1B).

At the Clemson site, differences in early marketable yields in 1986 were due to increases in fruit size and number in the red and black mulch treatments (Table 4). In 1987, differences

Table 2. Effect of plastic mulch color on early and total marketable yield of 'Mountain Pride' tomato at the Clemson site near Florence, S.C.

Mulch color	Marketable yield ($t \cdot ha^{-1}$): Early[z] 1986	Early[z] 1987	Total 1986	Total 1987
Red	18.2 a[y]	15.1 a	45.3 a	45.9 a
Black, not painted	14.3 b	12.3 ab	39.5 b	44.3 a
Silver	7.9 c	12.0 b	36.7 b	43.1 a
White	4.7 c	11.2 b	33.3 c	42.1 a

[z]Comprises yield for two first weeks of harvest.
[y]Mean separation in columns by Duncan's multiple range test, P = 5%.

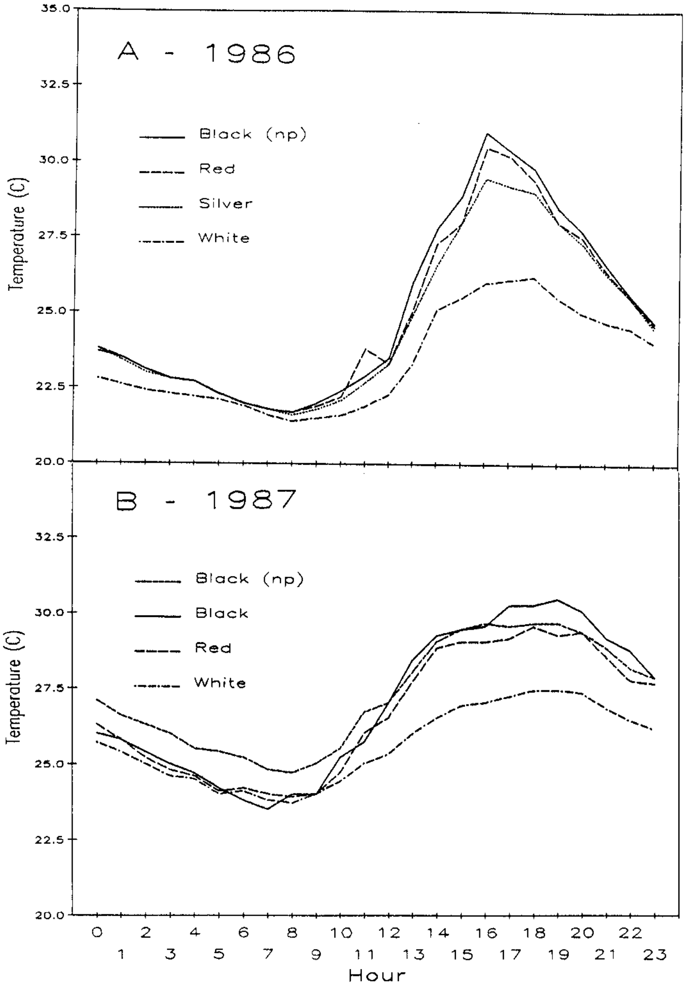

Fig. 1. Mulch color effects on root zone temperatures. Soil temperatures were measured 5 cm below the plastic mulch. Values are hourly averages over the entire growing season. The 1986 measurements (**A**) are from the Clemson site and the 1987 measurements (**B**) are from the USDA site, both near Florence, S.C.

Table 3. Effect of plastic mulch color on early and total marketable yield of 'Celebrity' tomato at the USDA site near Florence, S.C.

Mulch color	Marketable yield ($t \cdot ha^{-1}$) Early[z] 1987	Early[z] 1988	Total 1987	Total 1988
Red	42.3 a[y]	63.6 a	53.7 a	72.7 a
Black	40.8 ab	54.6 b	52.2 a	63.0 a
Black, not painted	37.5 ab	55.6 b	51.2 a	67.4 a
White	33.7 b	49.8 b	50.4 a	65.7 a

[z]Yield for two first weeks of harvest.
[y]Mean separation in columns by Duncan's multiple range test, P = 5%.

in early marketable yields were due to differences in fruit number and percentage of marketable fruit. Mulch has been shown to influence flowering of tomato (Vandenberg and Tiessen, 1972), and previous research on mulch color effects on early tomato growth (Decoteau et al., 1986) indicated that tomato plants grown with red or black mulch had more flowers at an early growth stage than tomato plants grown with white mulch. Greater and earlier flowering could contribute to increased yields observed in the present study.

Mulch surface color also affected the amount of foliage produced by the plants. Tomato plants grown over the white and silver-colored mulch had more foliage than those grown over the red and black mulch (Table 5), but tomato fruit yields were greatest over the red and black mulch (Table 2). This relationship appears to indicate that the increased yields associated with mulch color were due to allocation of photosynthate, rather than quantity of photosynthate produced. Such a response to spectral balance of upwardly reflected light from variously colored mulches is consistent with developmental responses to shifted wavelength balance of light due to reflection from competing plants (Kasperbauer, 1987) and from different-colored soils (Kasperbauer and Hunt, 1987). While the light reflected from the mulch is probably reduced or altered as the plant grows and shades the mulch, the growth-regulating effects of light or other microclimate variables may have already been perceived by the plant during its early growth stage. The plant light environment during the early vegetative growth stages has been shown to affect the subsequent flowering response of tomato (Calvert, 1959).

The results of this research show that mulch surface color can influence the plant microclimate sufficiently to affect the early yield of fresh-market tomatoes. Color of mulch affected both the plant light environment (Table 1) and soil temperatures (Fig. 1). We conclude that the beneficial effects of one mulch color as compared to another are related to its effects on spectral distribution of upwardly reflected light as well as on soil temperature. The best mulch color for a crop may vary with season and geographic area. Our present study with tomato and preliminary studies with other species (Hunt et al., 1989) strongly suggest that this approach to whole-plant photobiological regulation under field conditions has an important place in future plant–soil–water–light management systems for high-value crops.

Literature Cited

Bhella, H.S. 1988. Tomato response to trickle irrigation and black polyethylene mulch. J. Amer. Soc. Hort. Sci. 113:543–546.

Calvert, A. 1959. Effect of the early environment on the development of flowering in tomato: II. Light and temperature interactions. J. Hort. Sci. 34:154–162.

Cook, W.P., D.O. Ezell, R.P. Griffin, C.E. Drye, and P.J. Rathwell. 1982. Commercial tomato production in South Carolina. Clemson Univ. Coop. Ext. Serv. Circ. 625.

Decoteau, D.R., D.D. Daniels, M.J. Kasperbauer, and P.G. Hunt. 1986. Colored plastic mulches and tomato morphogenesis. Proc. Natl. Agr. Plastics Congr. 19:240–248.

Decoteau, D.R., M.J. Kasperbauer, D.D. Daniels, and P.G. Hunt. 1988. Plastic mulch color effects on reflected light and tomato plant growth. Scientia Hort. 34:169–175.

Fahey, J.V. 1976. How fresh tomatoes are marketed. USDA Agr. Mktg. Serv. Mktg. Bul. 59.

Hunt, P.G., M.J. Kasperbauer, and T.A. Matheny. 1989. Soybean seedling growth responses to light reflected from different colored soil surfaces. Crop Sci. 29:130–133.

Jones, T.L., U.S. Jones, and D.O. Ezell. 1977. Effect of nitrogen and plastic mulch on properties of Troup Loamy Sand and yield of "Walter" tomatoes. J. Amer. Soc. Hort. Sci. 102:273–275.

Kasperbauer, M.J. 1987. Far-red light reflection from green leaves and effects of phytochrome-mediated partitioning under field conditions. Plant Physiol. 85:350–354.

Kasperbauer, M.J. 1988. Phytochrome involvement in regulation of the photosynthetic apparatus and plant adaptation. Plant Physiol. Biochem. 26(4):519–524.

Kasperbauer, M.J. and P.G. Hunt. 1987. Soil color and surface residue effects on seedling light environment. Plant & Soil 97:295–298.

Kasperbauer, M.J., H.A. Borthwick, and S.B. Hendricks. 1964. Re-

Table 4. Plastic mulch color effects on yield components of early marketable yield of tomato at the Clemson site near Florence, S.C.

Mulch color	Fruit size (g)		No. fruit/ha (1000s)		Marketable fruit (%)	
	1986	1987	1986	1987	1986	1987
Red	222 a[z]	180 a	81.7 a	83.2 a	99.8 a	89.1 a
Black, not painted	217 a	178 a	63.4 b	72.6 ab	99.4 a	85.7 ab
Silver	195 b	172 a	40.7 c	67.5 b	100.0 a	87.0 ab
White	186 b	165 a	25.8 c	70.8 b	93.2 a	82.8 b

[z]Mean separation in columns by Duncan's multiple range test, $P = 5\%$.

Table 5. Influence of mulch color on shoot (stem plus leaf) biomass and fruit to shoot weight ratios.

Mulch color	Shoot dry wt/plant (g)	Fruit fresh wt/shoot dry wt (1000s)
Red	214 b[z]	423 a
Black, not painted	200 c	395 b
Silver	233 a	315 c
White	236 a	282 d

[z]Values are from 1986 Clemson site. Mean separation in columns by Duncan's multiple range test, $P = 5\%$.

version of phytochrome 730 (Pfr) to P660 (Pr) in *Chenopodium rubrum* L. Bot. Gaz. 125:75–90.

Schalk, J.M. and M.L. Robbins. 1987. Reflective film mulches influence plant survival, production, and insect control in fall tomatoes. HortScience 22:30–32.

Schalk, J.M., C.S. Creighton, R.L. Fery, W. Sitterly, B.W. Davis, T.L. McFadden, and A. Day. 1979. Reflective film mulches influence insect control and yield in vegetables. J. Amer. Soc. Hort. Sci. 104:759–762.

Smith, D.F. 1968. Mulching systems and techniques. Proc. Natl. Agr. Plastics Conf. 8:112–118.

Sweeney, D.W., D.A. Graetz, A.B. Bottcher, S.J. Locascio, and K.L. Campbell. 1987. Tomato yield and nitrogen recovery as influenced by irrigation method, nitrogen source, and mulch. HortScience 22:27–29.

Taber, H.G. 1983. Effects of plastic soil and plant covers on Iowa tomato and muskmelon production. Proc. Natl. Agr. Plastics Conf. 17:37–45.

Tremblay, N., M.-C. Gasia, M.-Th. Ferauge, A. Gosselin, and M.J. Trudel. 1988. Effects of light spectral quality on nutrient uptake by tomato. Can. J. Plant Sci. 68:287–289.

Tucker, D.J. 1975. Far-red light as a suppressor of side shoot growth in tomato. Plant Sci. Lett. 5:127–130.

Vandenberg, J. and H. Tiessen. 1972. Influence of wax-coated and polyethylene-coated mulch on growth and flowering of tomato. HortScience 7:464–465.

West, J. and L.C. Pierce. 1988. Yields of tomato phenotypes modified by planting density, mulch, and row covers. HortScience 23:321–324.

Wien, H.C. and P.L. Minotti. 1987. Growth yield, and nutrient uptake of transplanted fresh-market tomatoes as affected by plastic mulch and initial nitrogen rate. J. Amer. Soc. Hort. Sci. 112:759–763.

USDA Agricultural Marketing Service. 1976. U.S. Standards for grades of fresh tomatoes. USDA Agr. Mktg. Serv., Washington, D.C.