

Tree Fruit Reflective Film Improves Red Skin Coloration and Advances Maturity in Peach

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SUMMARY. Replicated trials were conducted during the summers of 1998 and 1999 at commercial orchards in South Carolina to determine the influence of ground application of a metalized, high density polyethylene reflective film on fruit red skin color and maturity of peach (*Prunus persica*) cultivars that historically have poor red coloration. At each site there were two experimental treatments: 1) control and 2) reflective film (film). Film was applied 2 to 4 weeks before anticipated first harvest date by laying a 150-cm (5-ft) wide strip of plastic on either side of the tree row in the middles. Treatment areas at a given farm ranged from 0.25 to 0.5 ha (0.5 to 1.0 acre) in size and each treatment was replicated four times at each site. At harvest, two 50-fruit samples were

picked from each plot per treatment. All fruit were sized and visually sorted for color (1 = 0% to 25%, 2 = 26% to 50%, 3 = 51% to 75%, and 4 = 76% to 100% red surface, respectively). A 10-fruit subsample was selected following color sorting and evaluated for firmness and soluble solids concentration (SSC). All cultivars tested ('CVN1', 'Loring', 'Bounty', 'Summer Gold', 'Sunprince', 'Cresthaven' and 'Encore') experienced significant increases in percent red surface when film was used in 1998 and 1999. This color improvement ranged from 16% to 44% (mean = 28%). On average, fruit from film were 4.2 N (0.9 lb force) softer and had 0.3% higher SSC than control fruit. Growers harvested more fruit earlier and in fewer harvests for film. Fruit size was not affected by film. Reflected solar radiation from film was not different in quality than incident sunlight. Film resulted in an increase in canopy air temperature and a reduction in canopy relative humidity during daylight hours.

Peaches are the most important fruit crop in South Carolina (SC) with a total bearing area of 7,500 ha (16,500 acres) in 1998 and farm cash receipts of more than \$27 million dollars (South Carolina Agricultural Statistics Service (SCASS), 1999). Historically, most of the peach cultivars grown in SC were from breeding programs in the eastern and, primarily, southeastern U.S. Many of these cultivars have melting flesh, yellow background color with varying degrees of red blush at maturity, and have been recognized for their superior eating quality. California's (CA) fresh peach production is two to three times greater than that of SC, representing the single greatest market competitor for southeastern U.S. peach producers. Breeding efforts in CA have emphasized red color and firmness for cross-country shipping.

Recently, there have been shifts by the southeastern U.S. commercial peach industry in general, and in SC in particular, to increase CA cultivars such as 'O'Henry' and 'Summer Lady', known for their excellent red coloration (SCASS, 1996). These cultivars and others were bred for the arid climate of the central valley of CA. There is a Mediterranean climate and significantly greater disease pressure in the southeastern U.S. Cultivars such as

'O'Henry' and 'Summer Lady' are highly susceptible to bacterial spot (*Xanthomonas arboricola*) (Werner et al., 1986; Okie, 1998) which is a significant disease of peaches in the southeastern U.S. (Shepherd, et al., 1999). However, most of the important southeastern U.S. cultivars grown in SC (SCASS, 1996) are moderately resistant or resistant to bacterial spot (Okie, 1998). In order to grow bacterial spot susceptible cultivars in the southeastern U.S., a regular spray program is required (Univ. of Georgia, 2000) for which chemical costs can amount to more than \$600/ha (\$300/acre) to control this disease alone. Due to the inherent disadvantages noted above for growing some of the highly colored CA cultivars in the southeastern U.S., we were interested in improving red surface coloration of existing eastern peach cultivars that have excellent eating quality but often have poor red color.

As peaches ripen, the background color changes from green to yellow. Varying degrees of red over color, or blush, develop (Byrne et al., 1991; Delwiche and Baumgardner, 1983, 1985). These changes are likely due to the degradation of chlorophyll (green), unmasking of carotenoids (yellow, orange) (Cory and Schlimme, 1988) and the synthesis of anthocyanin pigments (red, purple) in the skin (Van Blaricom and Senn, 1967). Red coloration of the skin of peach and other fruit is determined by both genetic and environmental factors. The maximum capability for anthocyanin synthesis is genetically determined (Mancinelli, 1985). In apple (*Malus sylvestris* var. *domestica*) fruit, anthocyanin synthesis in the skin is both light [visible and ultraviolet (UV)] and temperature-dependent (Saure, 1990). In peach, both red skin coloration and fruit quality have been associated directly with light availability within the tree canopy (Bible and Singha, 1993; Correlli-Grappadelli and Coston, 1991; Day et al., 1989; Erez and Flore, 1986; Marini, 1985). High nitrogen fertilization has been associated with poor red coloration and fruit quality of 'Fantasia' nectarine (*Prunus persica*) (Daane et al., 1995; Crisosto et al., 1997).

To have maximum impact on red coloration and fruit quality at the time of harvest, any horticultural technique should be applied relatively near to the harvest window. A normal color break

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period, referred to as veraison for grape (*Vitis vinifera*), may occur as few as 7 to 14 d before harvest depending on the fruit species considered. Marini et al. (1991) found that light received during the second half of Stage III (final swell) of fruit development was critical for red coloration in 'Biscoe' peach. Erez and Flore (1986) and Proctor and Lougheed (1976) noted that a strong relationship existed between red coloration and fruit light exposure near the time for harvest of 'Redhaven' peach and 'McIntosh' apple, respectively. By increasing the exposure of individual fruit to sunshine, Erez and Flore (1986) suggested that increased light absorbance by fruit may actually increase fruit sink strength and thus lead to improved red coloration.

Fruit shading by foliage is reduced commercially in two ways: summer pruning and leaf stripping or pulling. Preharvest watersprout removal increased light penetration into the canopy and fruit size in 'Redskin' peach (Myers, 1993) and improved fruit color and size of 'Firebrite' nectarine (Day et al., 1989). In addition to the shading they cause, watersprouts can be competing sinks to developing fruit for water, nutrients and photosynthate. Leaf pulling or stripping, where leaves in the proximity of fruit are removed by hand 2 to 4 weeks before harvest, is also used commercially to increase red coloration of nectarines and some peaches in CA (Day, 1997) and Chile (J.W. Rushing, personal observation). The removal of source leaves that are feeding nearby fruit at a time when fruit sink strength is at an all-season high would seem counterproductive if size was the only factor affecting financial return to the grower (Flore and Layne, 1996); however, this is not the case. Market demand for red fruit is so strong that costs associated with summer pruning and leaf pulling may be offset by color improvement and increased financial return to the grower for redder fruit [i.e., \$2 to \$4 per 11-kg (25-lb) box] (Day, 1997).

One final technique that can improve light availability to fruit in the tree canopy and increase red coloration is the use of metalized reflective film mulches (Layne and Rushing, 1999). The optical properties of plastic mulches can dramatically modify the crop microclimate due to the reflection of solar radiation back into the

tree canopy (Tarara, 2000). In an early study by Moreshet et al. (1975), 'Orleans' apples from trees grown over aluminum mulch were redder, larger, and had higher SSC content than fruit from control trees. Treatment differences in their study were greatest for fruit in the lower half as opposed to the upper half of the tree canopy. Green et al. (1995) noted that photosynthetically active radiation (PAR) absorption of an apple tree canopy was increased 40% by covering the ground beneath the tree with a reflective foil sheet. Richardson et al. (1993) and Miller (1997) observed higher daily maximum and lower nightly minimum temperatures in a 'Satsuma' mandarin orange (*Citrus unshui*) canopy and a 'Hardibrite Delicious' apple canopy, respectively, where aluminum foil mulch was placed on the orchard floor. Andris and Crisosto (1996) demonstrated that 'Fuji' apple red surface color increased and the percentage of fruit harvested during the first picking increased when reflective materials (plastic or foil) were used. Toye (1995) reported that reflective mulches improved fruit color with fewer harvests required in commercial 'Fuji', 'Gala', and 'Braeburn' apple orchards in New Zealand. In the 2000 growing season, reflective mulch was used for skin color enhancement on about 60% of the commercial fresh market nectarine and 40% to 50% of the commercial fresh market peach acreage in CA (G. Van Sickle, personal communication). Today, reflective mulches are widely used in tree fruit, nut and grape production in many countries around the world (K. Williamson, personal communication).

Based on the increasing emphasis in the commercial U.S. peach market for red color, we undertook this study to address the following objectives: 1) to determine the influence of film on skin color and maturity of important commercial southeastern U.S. peach cultivars spanning the entire harvest season in SC, allowing cooperating commercial growers to choose the cultivars we tested based on past performance and history of poor red skin coloration; 2) to evaluate the influence of growing region within the state (i.e., Piedmont, Ridge, and Carolina Sandhills regions of SC), tree age, rootstock, orchard floor management practices, planting density, row orientation, and training system on the effi-

cacy of the film; 3) to conduct trials of sufficient size [0.25 to 0.5 ha (0.5 to 1 acre)] to determine the extent of microclimate alteration; and 4) to determine the influence of film on commercial harvest date based on growers' experience.

Materials and methods

FIELD PLOT DESIGN. Participating growers were contacted and cultivar blocks were surveyed to determine their suitability for trials. Maps and plot plans were prepared for each trial orchard. Specific details concerning the trials and respective orchards are presented in Table 1. In general, cultivar blocks ranged from 2 to 11 ha (5 to 25 acres) in size. A randomized complete block experimental design was used for each trial with four experimental blocks composed of the no film treatment (control) adjacent to the reflective film treatment (film). Within each trial, all four experimental blocks had an identical tree number and layout (trees / row and number of rows). However, from one trial to another, the tree number varied depending on orchard planting density and layout. For trees planted high density with the perpendicular V training system, individual treatments comprised 200 to 250 trees (7 to 8 rows wide by 25 to 30 trees long). For trees of low density conventional spacing and open center training, individual test treatments comprised 100 trees (5 rows wide $\times$ 20 trees long). Experimental blocks were oriented such that two individual film or control treatments did not reside next to each other.

FILM APPLICATION. Depending on the trial, film was laid 2 to 4 weeks before harvest. The film was a high density polyethylene material that had a highly reflective metalized surface resembling aluminum foil. It was manufactured commercially in rolls that were 150 cm (5 ft) wide and 1220 m (4000 ft) long (Sonoco RE, Sonoco Products Co., Hartsville, S.C.). If the orchard floor had a sod middle, it was mowed short by the grower before laying the film. The film was rolled out by hand for each of the designated film rows such that it was located in the middle between the tree rows. The film was secured to the ground with shovels full of soil every 2 m (6 ft) on either outside edge of the plastic. At row ends, the entire end of the plastic was covered with soil and secured to

Table 1. Research trial specifications at each commercial peach orchard used in South Carolina during 1998 and 1999.

Farm, region	Cultivar, rootstock	Tree age (years)	Density (trees/ha)	Plot area (ha ²)
1998				
Cash, Piedmont	Cresthaven, Guardian	4	996	0.25
Cash, Piedmont	Encore, Guardian	7	996	0.20
1999				
Titan, Ridge	CVN1, Lovell	5	336	0.30
McLeod, Sandhills	Loring, Lovell	8	358	0.28
McLeod, Sandhills	Bounty, Lovell	5	384	0.26
Cash, Piedmont	Summer Gold, Lovell	7	272	0.37
Titan, Ridge	Sunprince, Lovell	4	427	0.23
Cash, Piedmont	Cresthaven, Guardian	5	996	0.25
Cash, Piedmont	Encore, Guardian	8	996	0.20

²1.00 ha = 2.47 acre; 1 tree/ha = 0.405 tree/acre.

³Perp. V corresponds to perpendicular V (as in DeJong et al., 1994).

⁴Chemically mowed refers to a bare orchard floor due to application of contact herbicide.

the orchard floor. The film was maintained on the orchard floor throughout the entire harvest period and in some cases was not taken up until the fall.

LIGHT QUALITY AND QUANTITY DETERMINATION. Light quality was determined using a portable spectroradiometer (LI-1800; LI-COR, Inc., Lincoln, Nebr.) that was programmed to record data at 10-nm increments from 330 to 1100 nm. The spectroradiometric data from 330 to 400 nm comprised ultraviolet UV-A light. UV-B (280 to 320 nm) and UV-C (100-280 nm) were not measured. Light quantity was determined as PAR using a line quantum sensor (LI-190SA; LI-COR, Inc.) (light bar) attached to a data logger (LI-1000; LI-COR, Inc.). All light measurements were taken on 22 July 1999 in the 'Encore' orchard at Cash Farms (Cowpens, S.C.) (Table 1). This was 1 d following the application of the film to the orchard floor. There were diffuse clouds on this mostly sunny day. Light sensors were held at a 1-m (3-ft) height either facing the sun (sky) or ground (reflection) directly and data were collected beginning at 1200 HR and ending at 1245 HR. Light readings over film were made in the middle of the row alley directly over the center of the film strip. Light readings over the orchard floor where no plastic was present were made in the middle of the row alley also. In the latter case, the orchard floor was a living grass sod. Data were collected in the middle of each treatment for each experimental block (eight locations total). As the sun angle changed from direct over-

head, light that was previously reflected primarily to the sky was reflected back into the tree canopy. The lower foliage that was normally shaded where film was absent were bright in trees where film was present and reflecting sunlight to these leaves. Interior canopy light measurements are not presented in this study.

ORCHARD ENVIRONMENTAL MONITORING. Orchard air temperature and relative humidity data were collected in the 'Encore' orchard at Cash Farms (Table 1) over 30 d from 21 July through 20 August 1999. One data logger each was positioned in the middle of each of one film and control treatment in two different experimental blocks, respectively. Each datalogger (HOBO H8 Pro Series; Onset Computer Corp., Pocasset, Mass.) was secured within an Onset solar radiation shield and affixed to a 3-m (10-ft) long piece of aluminum conduit. The conduit was positioned vertically in the tree row immediately between two adjacent trees. The radiation shield was positioned on the conduit such that the data logger was 1.5 m (5 ft) above the orchard floor. Any shoots that were crowding the datalogger were cut back or removed at the time the dataloggers were placed in the orchard. Data were collected at 2-min intervals and after 30 d were downloaded directly to a PC using Boxcar Pro 4.0 for Windows software (Onset Computer Corp., Pocasset, Mass.). Soil temperature and tree transpiration were not monitored.

FRUIT HARVEST. Close communication was maintained with each grower by phone and personal visits to the trial

site to determine first harvest date. Commercial harvest was based on several factors: timing relative to previous year, fruit size, and skin color. In most cases, the grower allowed us to harvest our samples in the early morning of the day he began his first major harvest for that cultivar. Before each harvest, our four-person crew walked through the entire orchard and surveyed the status of the crop. At this time, several commercially acceptable fruit [≥ 64 mm (2.5 inches) diameter, except for 'CVN1'] were harvested and each harvester kept this fruit in his hand or pocket as a minimum size reference fruit. For film treatments, harvested trees were confined to the interior three rows and the two trees nearest either row end were not harvested. For control treatments, fruit was harvested at least two rows away from the nearest adjacent film treatment and typically within the middle three rows of the control treatment. Fruit were only harvested from healthy, uniform-sized trees within the orchard. Film and control treatments were harvested on the same day for each trial. We did not make multiple harvests over the 7 to 10 d harvest period for a given variety. In 1998, four 50-fruit samples (boxes) were hand-harvested randomly from trees in each treatment per block. Two boxes each were harvested at lower and upper canopy positions [lower canopy = 0.5 to 1.5 m (2 to 5 ft) and upper canopy = >1.5 m from the soil surface, respectively]. A total of thirty-two 50-fruit samples were harvested in each orchard (two samples $\times$ two canopy positions $\times$ two treatments $\times$ four blocks). Following statistical analy-

Row orientation	Training system	Orchard floor	Film application date	First harvest date
East-west	Perp. V ^y	Sod	19 June	24 July
East-west	Perp. V	Sod	1 July	6 Aug.
Northeast-southwest	Open center	Chemically mowed ^x	17 June	8 July
North-south	Open center	Chemically mowed	17 June	8 July
East-west	Open center	Chemically mowed	23 June	8 July
North-south	Open center	Sod	24 June	12 July
Northeast-southwest	Open center	Chemically mowed	25 June	26 July
East-west	Perp. V	Sod	7 July	30 July
East-west	Perp. V	Sod	21 July	16 Aug.

sis of 1998 data (not shown), it was noted that when the analysis was conducted based on only two of the four 50-fruit samples per treatment, means were not different and statistical variability of samples was no less significant than when four samples were used. In short, we did not need to evaluate so many fruit to accurately represent the treatment effects. As a result, in 1999, only two 50-fruit samples were harvested per block per treatment. Each person picked 25 fruit and then the four boxes were combined into two 50-fruit samples. In 1999, fruit harvesting was confined to a midcanopy zone, 1 to 2.5 m (3 to 8 ft) above the soil surface. Care was taken at every harvest in 1998–99 to ensure that there was uniformity among each person's fruit samples such that personal biases (i.e., more red color or larger size) were not reflected in the samples. Fruit were harvested to a minimum accepted commercial size or greater and not selected based on red surface color. Immature (green or too small) fruit were not harvested. The same four-person team conducted each harvest together over both years of the study. Boxes of fruit were numerically coded and selected at random at the time of color and maturity evaluation so that evaluators would not know what the treatment was. Fruit samples were stored in the shade in an open packinghouse at ambient air temperature until evaluated that same day.

FRUIT COLOR AND MATURITY EVALUATION. All fruit were rated for color and maturity within five hours of harvest unless indicated otherwise. For each 50-fruit sample, all fruit were visually

sorted based on their percent surface red color. The same person was responsible for color sorting fruit at each harvest. Fruit were sorted into one of four visual color ratings: 1, 2, 3, or 4 corresponding to 0% to 25%, 26% to 50%, 51% to 75%, and 76% to 100% red surface, respectively. Hence, a fruit that was entirely red (i.e., 100% red surface) would be rated 4 using this criteria. Fruit were not evaluated for ground color. The total number of fruit per color rating was determined for each sample. Immediately following color sorting, a 10-fruit subsample was selected for maturity evaluation. This subsample was a proportional representation of the 50-fruit sample based on the color categories represented. For example, a 50-fruit sample may have had 5, 15, 20 and 10 fruit in color categories 1, 2, 3, and 4, respectively. In this case, 1, 3, 4, and 2 fruit would be randomly selected from color categories 1, 2, 3, and 4, respectively, for maturity evaluations.

Fruit diameter (mm) was determined using a digital caliper. Measurements were taken at the widest point along the stem-blossom end axis at the suture and perpendicular to the suture. An average of these two measurements was calculated and used for statistical analysis. Flesh firmness was determined mid-cheek on opposite sides of the fruit (perpendicular to the suture) using an Effigi penetrometer (model FT327; McCormick Fruit Tech., Yakima, Wash.) equipped with an 8-mm (0.3-inch) stone fruit tip. The two measurements were averaged and converted from pounds force (lbf) to Newtons (N) by the formula $N = \text{lbf} \times 4.44838$.

Soluble solids concentration was determined on a fresh squeezed juice sample for each fruit using a calibrated temperature compensating refractometer (model N-20E; Atago Co., Ltd., Tokyo, Japan). The refractometer was calibrated before use with a 10% (weight:volume) sucrose solution. In between individual fruit samples, the refractometer was cleaned with distilled, deionized water.

DATA ANALYSIS. All data were subject to analysis of variance using SAS version 6.12 for the MacIntosh (SAS Institute Inc., Cary, N.C.). Correlation and linear regression analysis was also utilized to determine the relationship between fruit color and various maturity indices.

Results

LIGHT QUALITY AND QUANTITY. Incident sunlight from the sky was greater at all measured wavelengths than light reflected from the film or the orchard floor (Fig. 1). The spectral distribution of the reflected light from the film was similar to that of incident sunlight from the sky, while reflected light from the orchard floor had a very different spectral distribution. In particular, most wavelengths from 330 to 730 nm were absorbed by the orchard floor and not reflected. PAR was also significantly greater for direct sunlight from the sky than sunlight reflected from the film or the orchard floor (Table 2). This proportional reduction in light intensity of reflected light from film versus direct sunlight was uniform across the wavelengths measured (Fig. 1). Two light quality parameters were calcu-

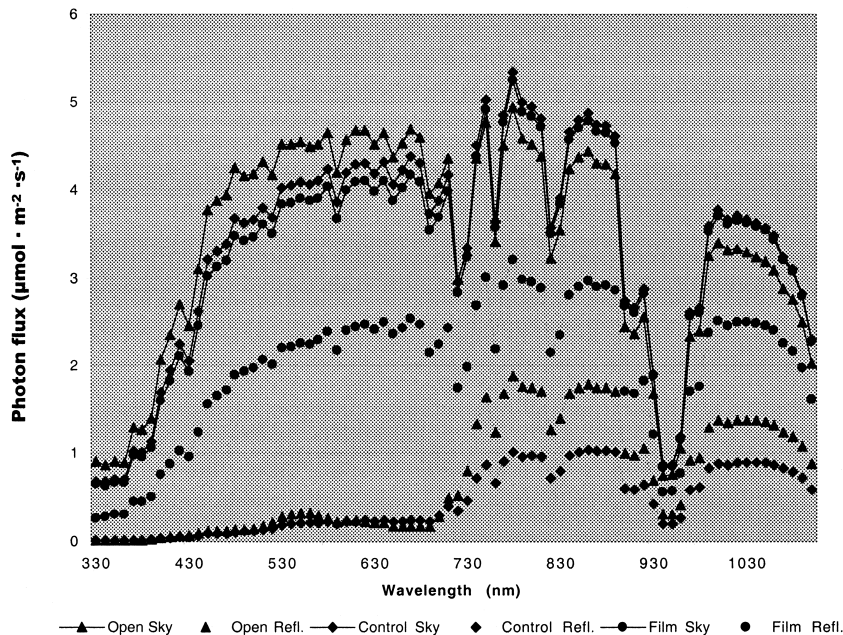


Fig. 1. Spectral distribution curves for incident and reflected (refl.) light in the 'Encore' orchard at Cash Farms, Inc. (Cowpens, S.C.) between 1200 and 1330 HR on 22 July 1999. Each point and subsequent curve represents the mean of measurements from four distinct blocks. Open corresponds to readings taken outside the orchard where there were no trees directly overhead and the floor was solid sod. Control corresponds to readings taken in the orchard in the no film control treatment. Film corresponds to readings taken in the orchard in the film treatment.

lated based on spectral distribution data (phytochrome photoequilibrium and red to far red ratio ($R/FR_{10\text{ nm}}$); Sager et al., 1988). Based on these parameters, reflected sunlight from the film was not different in quality from that of incident sunlight from the sky (Table 2). On the other hand, reflected sunlight from the orchard floor had a lower phytochrome photoequilibrium and lower $R/FR_{10\text{ nm}}$. This is not surprising since the orchard floor at the measurement site was living, photosynthetic sod. Hence, most of the incident PAR (400 to 700 nm) was absorbed by the sod foliage and not reflected. In a different trial, film that had remained on the orchard floor for

5 weeks before measuring light was 40% less reflective than new film. Old film became dirty from dust, pesticide and other deposits.

ORCHARD AIR TEMPERATURE AND RELATIVE HUMIDITY. Although data were collected over more than 30 consecutive days at 2-min intervals, a typical day is represented in Fig. 2. Film resulted in a 1 to 2 °C (3 to 6 °F) elevation of air temperature during the daylight hours when compared with the control. This difference in air temperature was greatest while the sun was near or at a direct overhead position. This increase in air temperature may have been partly due to ultraviolet light being reflected from the film. UV

reflection was significantly greater from 330 to 400 nm (range measured by spectroradiometer) for the film as compared to the sod orchard floor (Fig. 1). We did not measure UV wavelengths from 250 to 330 nm. By contrast, film resulted in a reduction of air relative humidity of 3% to 5%, especially during the daylight hours, when compared to the control. These trends of elevated air temperature and reduced relative humidity during daylight hours for film treatments relative to the control were also observed at another trial site (data not shown). However, unanticipated complications associated with Hurricane Floyd in September 1999 just before harvest prevented harvest data collection at this second site.

FRUIT COLOR AND MATURITY. Film did not significantly affect fruit size relative to control in any trial (Table 3). Film resulted in an increase in color rating of peaches in all trials during both years (Table 3). This was for trees over a broad range of geographic locations in the state, different cultivars, tree ages/sizes, rootstocks, planting densities, training systems, and orchard floor management systems. The magnitude of this increase ranged from 16 to 44% with an average value across cultivars of 28%. Position in the canopy did significantly influence the percent red surface in 1998 for 'Cresthaven' and 'Encore' peaches (Table 4). For each cultivar and both treatments, upper canopy fruit were significantly redder than lower canopy fruit (Table 4). However, lower canopy fruit in film blocks were as red or redder than upper canopy fruit in the control that had been well exposed to the sun (Table 4). In 1999, when data for fruit evaluated for maturity were pooled across cultivars, there was a dramatic shift to greater percent red surface for film compared with control fruit (Fig. 3).

Table 2. The influence of reflective film on light quality and quantity in a peach orchard^z.

Treatment	Sample size (n)	Phytochrome photoequilibrium ^y	$R/FR_{10\text{ nm}}$ ^x	PAR ^w ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)
Control—Sky	4	0.713 a	1.260 a	1313 a
Film—Sky	4	0.710 a	1.245 a	1351 a
Control—Floor reflection	4	0.573 b	0.505 b	68 c
Film—Reflection	4	0.713 a	1.215 a	646 b
LSD _(0.05)	---	0.032	0.117	144.4

^zData were collected on 22 July 1999 in 'Encore' orchard at Cash Farms, Cowpens, S.C., 1 d after film was laid.

^yPhytochrome photoequilibrium was calculated according to Sager et al. (1988).

^x $R/FR_{10\text{ nm}}$ corresponds to the ratio of red (660 nm) to far red (730 nm) light determined by spectrophotometry.

^wPAR corresponds to photosynthetically active radiation over the 400 to 700 nm range determined by ceptometry.

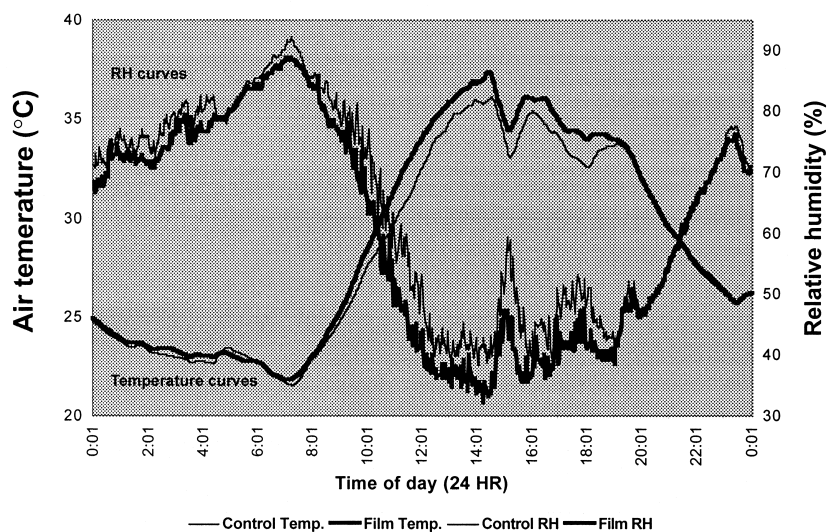


Fig. 2. The diurnal influence of reflective film on air temperature and relative humidity (RH) in the 'Encore' orchard at Cash Farms, Inc. (Cowpens, S.C.) over a 24 h period beginning at 0001 HR on 13 Aug. 1999 and ending at 0001 HR on 14 Aug. 1999 which was 4 d before first commercial harvest. Narrow and bold lines correspond to the control and film treatments, respectively; °F = 1.8(°C) + 32.

For most cultivars, fruit from the film treatment were significantly softer (lower flesh firmness) than those of the untreated control at harvest (Table 3). The magnitude of this decrease ranged from 1 to 8 N (0.2 to 1.8 lbf) with an average across cultivars of 4.2 N (0.9 lbf). For 1999 trials, correlation analysis was conducted between flesh firmness and percent red surface for film and control treatments for each cultivar, respectively. In each case, there was a significant negative relationship

between flesh firmness and percent red surface for both treatments (data not shown). In general, redder fruit were softer. Data for all cultivars tested in 1999 were pooled and an overall negative correlation between flesh firmness and percent red surface was established for control and film treatments, respectively. Regression analysis of these data revealed a statistically significant linear relationship between flesh firmness and percent red surface (Fig. 4). Although there were signifi-

cant differences in SSC between control and film treatments for some cultivars, the differences were small. When averaged across all cultivars, SSC was different by only 0.22% between control and film treatments. In some cases in 1999, there was a weak positive correlation between SSC and percent red surface but it was not always statistically significant for either the film or control treatment and it varied from one cultivar to the next (data not shown). Finally, correlation analysis was conducted between flesh firmness and SSC for fruit from control and film treatments for each cultivar in 1999, respectively. In most cases, there was a significant negative correlation where flesh firmness decreased as SSC increased (data not shown). When data were pooled across cultivars in 1999 and regression analysis was conducted, a significant linear relationship existed between flesh firmness and SSC for both the control and film treatments, respectively ($r = -0.213$ and $r = -0.201$, respectively). These relationships may be significant because n is large, but the relationship explains only 4% of the variation.

Discussion

Reflection of solar radiation by film modified the orchard microclimate (Tarara, 2000). This was particularly obvious about solar noon when convection currents could be seen above the plastic and the light was

Table 3. The influence of reflective film on color, size, flesh firmness and soluble solids concentration (SSC) of South Carolina peaches.

Farm, region	Cultivar, rootstock	Color ^z			Fruit diam		Flesh firmness		SSC	
		Control ^y	Film	Increase (%)	(mm ^x)		(N ^w)		(%)	
					Control	Film	Control	Film	Control	Film
1998										
Cash, Piedmont	Cresthaven, Guardian	1.9 b	2.2 a	16	64	65	NA ^v	NA	11.1	11.8
Cash, Piedmont	Encore, Guardian	2.3 b	3.1 a	34	70	70	82.7 a	74.7 b	12.6	12.5
1999										
Titan, Ridge	CVN1, Lovell	2.3 b	3.1 a	34	60	61	42.2 a	39.4 b	8.6 b	8.8 a
McLeod, Sandhills	Loring, Lovell	2.0 b	2.6 a	33	65	65	32.1	29.4	8.8	8.6
McLeod, Sandhills	Bounty, Lovell	2.4 b	2.9 a	20	74	73	44.3 a	39.1 b	9.9 b	10.2 a
Cash, Piedmont	Summer Gold, Lovell	2.7 b	3.1 a	16	69	69	51.8 a	44.7 b	9.9	10.1
Titan, Ridge	Sunprince, Lovell	1.9 b	2.7 a	44	80	81	56.9 a	53.0 b	8.8	8.8
Cash, Piedmont	Cresthaven, Guardian	2.5 b	3.2 a	27	67	67	30.5	27.8	10.0 b	10.6 a
Cash, Piedmont	Encore, Guardian	2.1 b	2.7 a	32	71	72	35.6	34.6	11.3	11.6

^zColor corresponds to visual rating where 1, 2, 3, and 4 represent 0% to 25%, 26% to 50%, 51% to 75%, and 76% to 100% red surface, respectively.

^yDifferent letters within rows comparing means of control versus film for a particular parameter indicate significant differences at $P \leq 0.05$ level. Separate statistical analyses were conducted for each cultivar in each of the 2 years. Absence of letters indicates a lack of significant difference.

^y25.4 mm = 1 inch.

^w1.0 N = 4.44838 pounds force (lbf).

^vNA means data were not available.

painful to unprotected eyes. Air temperature was elevated and relative humidity was reduced during the daylight hours. Richardson et al. (1993) and Miller (1997) observed a similar increase in daily maximum and reduction in nightly minimum temperatures in a 'Satsuma' mandarin orange canopy and a 'Hardibrite Delicious' apple canopy, respectively, where aluminum foil mulch was placed on the orchard floor. In CA's central valley, air temperature elevations in commercial orchards where film is used may be as much as 5 °C (10 °F) (H. Andris, personal communication). The quantity of reflected light was less than the incident light from the sun but it was not different in terms of light quality as indicated by spectral distribution, phytochrome photoequilibrium and R/FR_{10 nm}. As a result of the reflection of sunlight (including PAR) into the canopy, light absorption by the canopy and fruit probably increased significantly and fruit surface temperature likely also increased (Miller, 1997). Green et al. (1995) reported that when a reflective foil sheet was placed on the ground beneath an apple tree that PAR absorption by the canopy was increased by 40% in comparison to bare soil. We did not attempt to quantify canopy absorption in this study.

The elevation in air temperature was due to the increased heat load from the reflected light, primarily in the UV range. Higher air temperatures may have caused tree canopies to dry sooner in the day thus resulting in a reduced air relative humidity as was observed. Since sap flow, leaf or canopy transpiration rates were not measured, we cannot say that it was increased. However at one location after we collected our harvest data, the grower neglected to irrigate and dry, sunny conditions persisted for several days. We observed severe wilting and premature leaf abscission in the film rows but not in the control rows. Clearly, the increased heat load from the film could present a stress problem if inadequate rainfall occurred or if irrigation water was not available. As a precaution, we would advise any potential user (researcher, county agent, grower, etc.) to ensure that supplemental irrigation was available for very sunny, hot days. This is particularly important during the latter part of Stage III (final swell) of fruit growth. Lack of sufficient water and increased heat load

Table 4. The influence of canopy position and film on peach skin color in 1998.^z

Treatment	Canopy position	Cultivar	
		Cresthaven	Encore
Control	Upper canopy	1.87 ^y b	2.51 c
	Lower canopy	1.55 c	2.03 d
Film	Upper canopy	2.36 a	3.26 a
	Lower canopy	1.85 b	2.98 b
LSD _(0.05)		0.07	0.02

^zColor corresponds to visual rating where 1, 2, 3, and 4 represent 0% to 25%, 26% to 50%, 51% to 75%, and 76% to 100% red surface, respectively.

^yDifferent letters within rows comparing means of control versus film for a particular parameter indicate significant differences at $P \leq 0.05$ level. Each mean represents the average of 400 individual fruit.

due to the film could detrimentally affect fruit size and quality and seriously drought stress the tree. In control treatments where no film was present, daytime air temperature was lower and relative humidity was higher than film treatments. Much of the incident light was absorbed by the canopy or the sod orchard floor and very little was reflected. The light that was reflected was significantly different in quality (i.e., spectral distribution, phytochrome photoequilibrium and R/FR_{10 nm}) compared with incident sunlight or light reflected from the film. Whether this alteration in light quality impacted phytochrome-mediated anthocyanin pigment production in lower canopy fruit remains unknown but the quantity of light that

was reflected was very low.

In this study, commercial peach cultivars were selected based on their historical poor red coloration under South Carolina environmental conditions. We used reflective mulches as a solar reflector to alter the orchard microclimate (light quantity, quality, air temperature and relative humidity) and significantly increased red surface color in all peach cultivars evaluated in both 1998 and 1999. These 2 years were drier and sunnier than usual in SC. We noted improvements in red coloration for all cultivars irrespective of their geographic location in the state, tree age and planting density, rootstock, training system, row orientation, or orchard floor management system. In general, film will have its greatest ben-

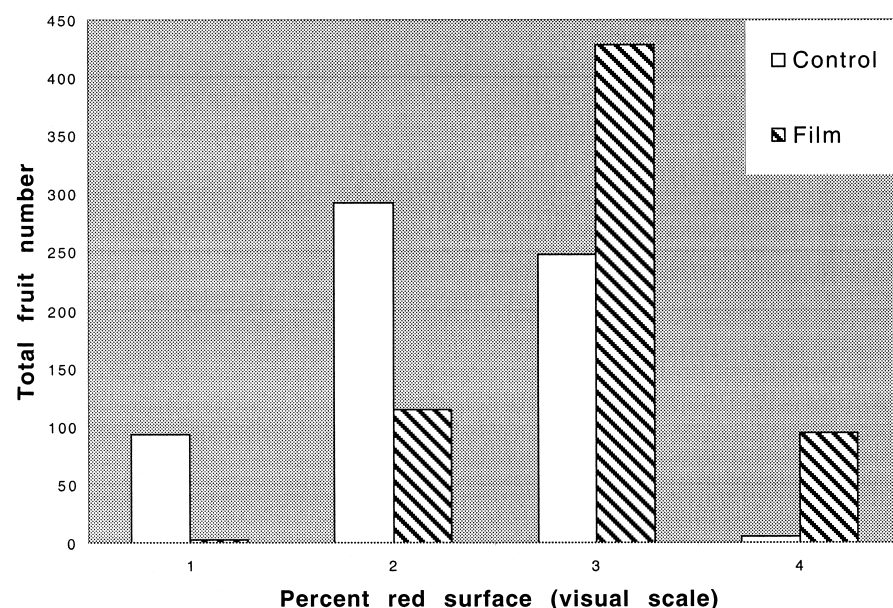


Fig. 3. The influence of reflective film on the total number of peaches distributed to different visual color categories based on percent red surface at harvest in 1999. Data for each treatment represents a pooled sample across all seven cultivars. The fruit comprising each sample were those that were specifically used for maturity evaluation only (i.e., 10-fruit subsample of 50-fruit sample).

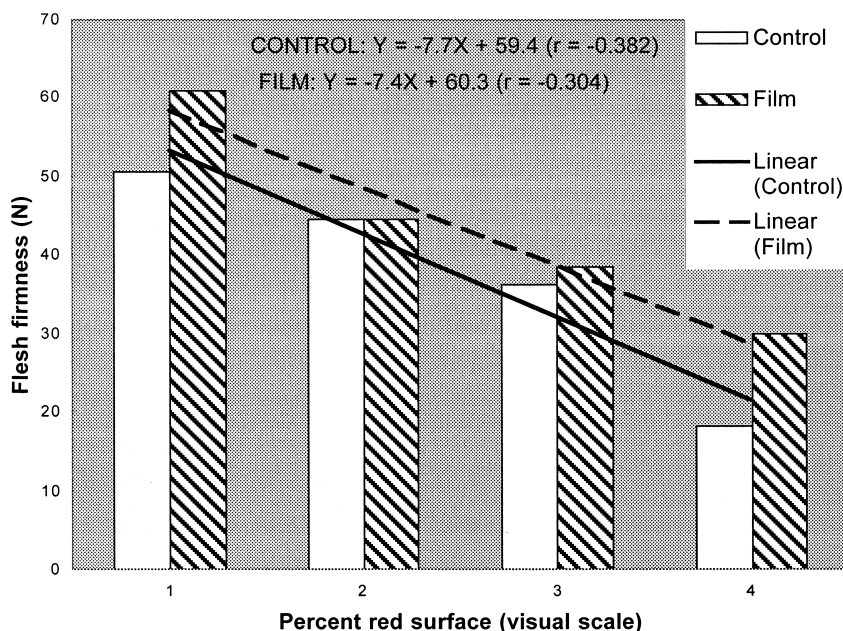


Fig. 4. The influence of reflective film on the relationship between flesh firmness and percent red surface of peaches at harvest in 1999. Correlation analysis was performed based on pooled data for all seven cultivars evaluated. The fruit comprising each treatment sample were those that were specifically used for maturity evaluation only (i.e., 10-fruit subsample of 50-fruit sample); 1 N = 4.44838 pounds force (lbf).

efit where it can maximally intercept and reflect sunlight back into the canopy. If cool, cloudy conditions had existed before harvest, the potential benefit of film may have been lost. North-south oriented rows where tree canopies did not cover the orchard row middle would be expected to have a more dramatic response to film than east-west oriented rows where the canopy of adjacent rows shaded the row middle, for example (Jackson, 1980). Further, greater responses to the film would be expected on sites with sod orchard middles as compared with to ones that were devoid of vegetation. For peaches grown on sandy soils where orchard middles are chemically mowed, film may not be necessary due to the high reflectivity of the ground surface already.

In peach, red skin coloration and fruit quality have been associated directly with light availability within the canopy (Bible and Singha, 1993; Correlli-Grappadelli and Coston, 1991; Day et al., 1989; Erez and Flore, 1986; Marini, 1985). In general, upper canopy sun-exposed peaches are typically redder than lower canopy sun-shaded fruit. This is also true with apple (Jackson, 1967). We noted this trend consistently in all of our trials. However, the improvement in color of fruit particularly in the lower canopy of trees with film present was dramatic relative to the

control. This technique might ensure that these fruit are commercially packable rather than being culled on the grading line. Reflective mulches may also be beneficial in the lower canopy of dense trees where sunlight often will not reach sufficient levels to promote flower bud development. Although we did not evaluate trees for return bloom where reflective plastic was used, flower bud production for next year's crop is also related to light level in the canopy (Jackson and Palmer, 1977). Perhaps use of film could help to maintain the lower portion of the canopy in a long-term fruitful state.

Other horticultural techniques such as summer pruning (Myers, 1993; Day et al., 1989; Marini, 1985), leaf stripping (Andris et al., 1998; Day, 1997), and fertility management (Daane, et al., 1995) can dramatically alter light levels within the tree canopy and potentially improve red skin coloration. Depending on the labor costs associated these practices, a grower may decide to use one or a combination thereof (e.g., summer pruning plus film). Ultimately, these decisions should be based on the cost of the practice versus the benefit for improved coloration of fruit and the financial gain that results to the grower (Day, 1997; Layne and Rushing, 1999). We have estimated that the grower cost for film use in 1999 was about \$220/ha

[(\$100/acre) Layne and Rushing, 1999].

Peach maturity is often determined visually by changes in background color from green to yellow/orange, red coloration of skin, tissue softening and increasing SSC (Delwiche and Baumgardner, 1983). In their study of 13 different peach cultivars, they also noted a significant negative correlation between flesh firmness and skin color. However, they measured color using a colorimeter where this strong negative correlation was associated with the "a" coordinate where the "a" scale ranges from a negative value for green to a positive value for red. Our findings conflict with those of Delwiche and Baumgardner (1983), however, where we noted significant correlations between flesh firmness and SSC and they did not. It is possible that our larger sample size enabled us to more clearly discern the relationship between these two maturity parameters. This relationship will vary with environmental conditions for the several days before harvest. Cloudy or rainy weather will lower SSC.

It is important to note that more fruit were harvested in the first pick from the film treatments than the control (data not shown). This is primarily due to the advancement in maturity of fruit in the film treatment. These results are in agreement with findings of others in apple (Andris and Crisosto, 1996; Toye, 1995). One precaution should be noted, however. Although red coloration is related to maturity, it is possible to pick red fruit that may be less mature than desired for the intended market. Further, a few extra days on the tree could increase fruit size enough such that a higher financial return would result. Our advice is for growers to judge maturity based on a subsample of fruit where skin color was assessed (both ground and red color) along with flesh firmness and SSC.

Finally, film is not a panacea for poor coloration in peach and other fruit. Neither is it a substitute for good horticultural practices such as proper pruning (winter and summer), tree training, and fertilization. However, when used properly it is a tool that can improve red coloration and advance maturity of peach, apple and other fruit. It may be of particular advantage for high quality cultivars that lack sufficient red color. Commercial peach growers in the southeastern U.S. may actually have a penalty assessed (i.e.,

\$1 per 11-kg box) in the market if there is insufficient red color of fruit in a particular load of peaches (M.E. Ferree, personal communication). Under such circumstances, color improvement by film would result in a significant increase in the monetary return to the grower. Further, access to this tool may assist southeastern growers in future decision making regarding which cultivars to plant. When faced with a market demanding red peaches and the dilemma of choosing CA-bred solid-red cultivars that may be bacterial spot susceptible (Werner et al., 1986; Okie, 1998) and may lack high eating quality, a grower may think twice. As noted previously, the cost of managing bacterial spot in the southeastern U.S. is significant. Grower choice of a bacterial spot-resistant eastern U.S. cultivar known for excellent eating quality, use of film and judicious pruning (winter and summer) to improve light penetration into the canopy and proper fertility management (especially nitrogen) to improve color, may be a more sound management decision to make.

Literature cited

- Andris, H. and C.H. Crisosto. 1996. Reflective materials enhance 'Fuji' apple color. *Calif. Agr.* 50(5):27-30.
- Andris, H., R.S. Johnson, and C.H. Crisosto. 1998. Color enhancement of stone fruit. In: 1997 Research reports for California peaches, plums and nectarines, p. 2-20. *Calif. Tree Fruit Agreement*, Reedley.
- Bible, B.B. and S. Singha. 1993. Canopy position influences CIELAB coordinates of peach color. *HortScience* 28:992-993.
- Byrne, D.H., A.N. Mikolic, and E.E. Burns. 1991. Variability in sugars, acids, firmness, and color characteristics of 12 peach genotypes. *J. Amer. Soc. Hort. Sci.* 116:1004-1006.
- Cory, K.A. and D.V. Schlimme. 1988. Relationship of rind gloss and groundspot color to flesh quality of watermelon fruit during maturation. *Scientia Hort.* 34:211-218.
- Corelli-Grappadelli, L. and D.C. Coston. 1991. Thinning pattern and light environment in peach tree canopies influences fruit quality. *HortScience* 26:1464-1466.
- Crisosto, C.H., R.S. Johnson, T.M. DeJong, and K.R. Day. 1997. Orchard factors affecting postharvest stonefruit quality. *HortScience* 32:820-823.
- Daane, K.M., R.S. Johnson, T.J. Michailides, C.H. Crisosto, J.W. Dlott, H.T. Ramirez, G.Y. Yokota, and D.P. Morgan. 1995. Excess nitrogen raises nectarine susceptibility to diseases and insects. *Calif. Agr.* 49(4):13-17.
- Day, K.R. 1997. Production practices for quality peaches. *Proc. Pa. State Hort. Assn.* 77(4):59-61.
- Day, K.R., T.M. DeJong, and A.A. Hewitt. 1989. Postharvest and preharvest summer pruning of 'Firebrite' nectarine trees. *HortScience* 24:238-240.
- DeJong, T.M., K.R. Day, J.F. Doyle, and R.S. Johnson. 1994. The Kearney Agricultural Center perpendicular "V" (KAC-V) orchard system for peaches and nectarines. *HortTechnology* 4:362-367.
- Delwiche, M.J. and R.A. Baumgardner. 1983. Ground color measurements of peach. *J. Amer. Soc. Hort. Sci.* 108:1012-1016.
- Delwiche, M.J. and R.A. Baumgardner. 1985. Ground color as a peach maturity index. *J. Amer. Soc. Hort. Sci.* 110:53-57.
- Erez, A. and J.A. Flore. 1986. The quantitative effect of solar radiation on 'Redhaven' peach fruit skin color. *HortScience* 21:1424-1426.
- Flore, J.A. and D.R. Layne. 1996. Photoassimilate distribution in *Prunus*, p. 825-849. In: E. Zamski and A.A. Schaeffer (eds.). *Photoassimilate distribution in plants and crops: Source-sink relationships*. Marcel Dekker, New York.
- Green, S.R., K.G. McNaughton, D.H. Greer, and D.J. McLeod. 1995. Measurements of increased PAR and net all-wave radiation absorption by an apple tree caused by applying a reflective ground covering. *Agr. For. Meteorol.* 76:163-183.
- Jackson, J.E. 1967. Variability in fruit size and colour within individual trees. *Rpt. East Malling Res. Sta.* 1966, p. 110-115.
- Jackson, J.E. 1980. Light interception and utilization by orchard systems. *Hort. Rev.* 2:208-267.
- Jackson, J.E. and J.W. Palmer. 1977. Effects of shade on the growth and cropping of apple trees. II. Effects on components of yield. *J. Hort. Sci.* 52:253-266.
- Layne, D.R. and J.W. Rushing. 1999. Color sells: reflective film may improve color and quality in your peaches and apples. *American Fruit Grower* May:18-19.
- Mancinelli, A.L. 1985. Light-dependent anthocyanin synthesis: A model system for the study of plant photomorphogenesis. *Bot. Rev.* 51(1):107-157.
- Marini, R.P. 1985. Vegetative growth, yield, and fruit quality of peach as influenced by dormant pruning, summer pruning, and summer topping. *J. Amer. Soc. Hort. Sci.* 110:133-139.
- Marini, R.P., D. Sowers, and M.C. Marini. 1991. Peach fruit quality is affected by shade during final swell of fruit growth. *J. Amer. Soc. Hort. Sci.* 116:383-389.
- Miller, S.S. 1997. Influence of reflective groundcover on apple color and quality. *Proc. 73rd Cumberland-Shenandoah Fruit Workers Conf.* p. 31-39.
- Moreshet, S., G. Stanhill, and M. Fuchs. 1975. Aluminum mulch increases quality and yield of 'Orleans' apples. *HortScience* 10:390-391.
- Myers, S.C. 1993. Preharvest watersprout removal influences canopy light relations, fruit quality, and flower bud formation of 'Redskin' peach trees. *J. Amer. Soc. Hort. Sci.* 118:442-445.
- Okie, W.R. 1998. Handbook of peach and nectarine varieties: performance in the southeastern United States and index of names. *USDA Agr. Hndbk.* 714.
- Proctor, J.T.A. and E.C. Loughheed. 1976. The effect of covering apples during development. *HortScience* 11:108-109.
- Richardson, A., P. Mooney, T. Dawson, P. Anderson, W.J. Killen, and M. Astill. 1993. Satsuma mandarin quality is improved using a reflective mulch. *Orchardist N.Z.* 66:36-38.
- Sager, J.C., W.O. Smith, J.L. Edwards, and K.L. Cyr. 1988. Photosynthetic efficiency and phytochrome photoequilibria determination using spectral data. *Trans. Amer. Soc. Agr. Eng.* 31(6):1882-1889.
- Saure, M.C. 1990. External control of anthocyanin formation in apple. *Sci. Hort.* 42:181-218.
- Shepherd, D.P., E.I. Zehr, and W.C. Bridges. 1999. Increased susceptibility to bacterial spot of peach trees growing in soil infested with *Criconeumella xenoplax*. *Plant Dis.* 83:961-963.
- South Carolina Agricultural Statistics Service. 1999. South Carolina agricultural statistics publication AE 489. S.C. Agr. Stat. Serv., Columbia.
- South Carolina Agricultural Statistics Service. 1996. South Carolina fruit tree survey. S.C. Agr. Stat. Serv., Columbia.
- Tarara, J.M. 2000. Microclimate modification with plastic mulches. *HortScience* 35:169-180.
- Toye, J. 1995. Reflective mulches—New Zealand leads the way. *The Orchardist* 68(8):58-60.
- University of Georgia, Athens. 2000. Southern peach, nectarine and plum pest management and culture guide. 2000. *Bul.* 1171.
- Van Blaricom, L.O. and T.L. Senn. 1967. Anthocyanin pigments in freestone peaches grown in the southeast. *Proc. Amer. Soc. Hort. Sci.* 90:541-545.
- Werner, D.J., D.F. Ritchie, D.W. Cain, and E.I. Zehr. 1986. Susceptibility of peaches and nectarines, plant introductions, and other *Prunus* species to bacterial spot. *HortScience* 21:127-130.