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Influence of Altered Light Levels on Growth and Fruiting of Mature 'Delicious' Apple Trees[1]

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Abstract. **Available light in mature apple trees (*Malus domestica* Borkh.) of an unknown red strain of 'Delicious' on Malling (M) 9 rootstocks was altered throughout the 1978 growing season by the use of reflectors, overhead lights, and shade material. Undertree reflectors increased light within the tree canopy about 20% at anthesis, 10-30% through mid-season, and 35% at harvest. Light was reduced within the canopy 20% at bloom and 10-20% the remainder of the season by over-tree shade. Shading reduced fruit set by 62% and reflectors had no effect. Red fruit color was reduced by shading and increased by reflector treatments, particularly in the lower half of the tree. Total yield and soluble solids were decreased by shading, but no significant differences were obtained by attempts to increase light. Reflectors and overhead light increased and shading reduced specific leaf weight. Shading increased levels of P, K, B and Zn and reduced Ca and Mg. None of the treatments altered total non-structural carbohydrate (CHO) levels in several tissues at bloom. However, shading reduced percent CHO in both spur and shoot leaves in June and July, but increased CHO in these tissues at harvest.**

The availability and distribution of light within the apple tree canopy is known to influence tree growth and fruit production (9). Shading reduced fruit set (1, 14, 20) and fruit quality (12, 18, 19, 20) but mixed effects have been reported for vegetative growth (1, 2, 13, 16) and tissue carbohydrate content (1, 7, 10). Gardner et al. (6) concluded that higher light and temperature during and shortly after bloom in 'Delicious' increased set but Dennis (5) re-evaluated their data and found little statistical basis for their conclusion.

Increasing light by under-tree reflectant material increased fruit set in potted trees (4) and improved fruit color and weight in mature trees (17). Lakso (15) has indicated that slight haziness increased diffuse light within the tree canopy and photosynthetic activity.

This study concerns the effectiveness of a reflectant material to increase available light to apple trees in a region of low early season irradiance and frequent cloudiness and the influence of altered light levels on growth, fruit set, fruit quality, yield, and tissue carbohydrate levels.

Materials and Methods

This 1978 field study used 22-year-old trees on an unknown strain of 'Delicious' on M 9 rootstocks in N-S oriented rows. The trees were spaced 3.0 × 5.5 m. Tree spread was about 3.0 m and height 2.7-3.0 m. Treatments were arranged as a randomized complete block with 5 replications.

The treatments applied were: 1) check (no light adjustment); 2) early reflector (tight cluster to 14 days past petal fall), 3) reflector (tight cluster to harvest); 4) reflector plus light (reflector from tight cluster to harvest plus high intensity light from tight cluster to mid-August); and 5) shade (tight cluster to harvest).

Reflectant material (supplied by St. Regis Paper Company, Dallas, Texas) was Alure CTI, a duplex lamination of 1.00 mil LDPE/0.50 mil metallized polyester/ 2.00 mil LDPE. It was 98% reflective of photosynthetically active radiation (400-700 nm) when new and was stapled to 1.2 × 2.4 m plywood sheets. Reflectors were placed on the E and W sides of the tree centered on the trunk and extended from the trunk approximately to the branch tips but not into the alleway. A 15° inward slope allowed for drainage, and reflectivity was maintained by cleaning when necessary. Shade fabric (Polypropylene Chicopee Lumite Black, rated 63% light reduction) was placed on a wooden fram 3.0 × 3.0 × 2.4 m over the tree and extended 75 cm down all sides. Overhead lights were General Electric Industrial Luminaires with Westinghouse Cermalux Lamp bulbs supported by a tripod set over the tree. The cone of light emitted covered the tree but did not extend beyond it. Lights were on during the daylight hours only.

Light integrators (3) were placed in 1 tree of each treatment on May 13 and read daily with the weekly averages presented (Fig. 1). The integrators were placed at an angle of 45° facing S. They were located 60 cm N and 60 cm W of the tree trunk at a height of 150 cm. Heinicke (8) found the greatest vertical concentration of foliage in this area. One integrator remained exposed above the orchard during the experiment. Light data were also obtained from the Weather Station at OARDC (Total Radiometer, Yellow Springs Instrument Co.) and were highly correlated with the exposed field light integrator (r = .80).

A minimum of 100 flower clusters from each of 8 tree quadrants (upper level, N, S, E, W; lower, N, S, E, W) were counted and tagged. Fruit set was determined before and after June drop. To determine if treatments had any effect on bee activity that would affect fruit set, tagged limbs of 100 clusters per tree were hand-pollinated on May 21 with 'Jonathan' pollen. The 'Jonathan' pollen had been germinated on agar media with 10% sucrose and 30 ppm boron (germination rate = 84%).

Specific leaf weight (dry weight/unit area) was obtained from a sample of 50 mid-terminal leaves taken from each upper and lower half of the tree on July 26. Leaf mineral analysis was determined using accepted analytical methods by the OARDC REAL Laboratory from a sample of 40 mid-terminal leaves taken per tree on August 13. Shoot growth was determined November 11 by measuring 32 terminal shoots picked at random from each upper and lower half of the tree.

At harvest, fruit was graded on an FMC weight sizer and divided into 4 size classes; Size 1 ⩾ 80 mm diameter (80-88 apples per box); Size 2 = 79-73 mm (100-113's); Size 3 = 72-57 mm (125-138's); Size 4 ⩽ 56 mm. The fruit was graded according to commercial standards and culled fruits were

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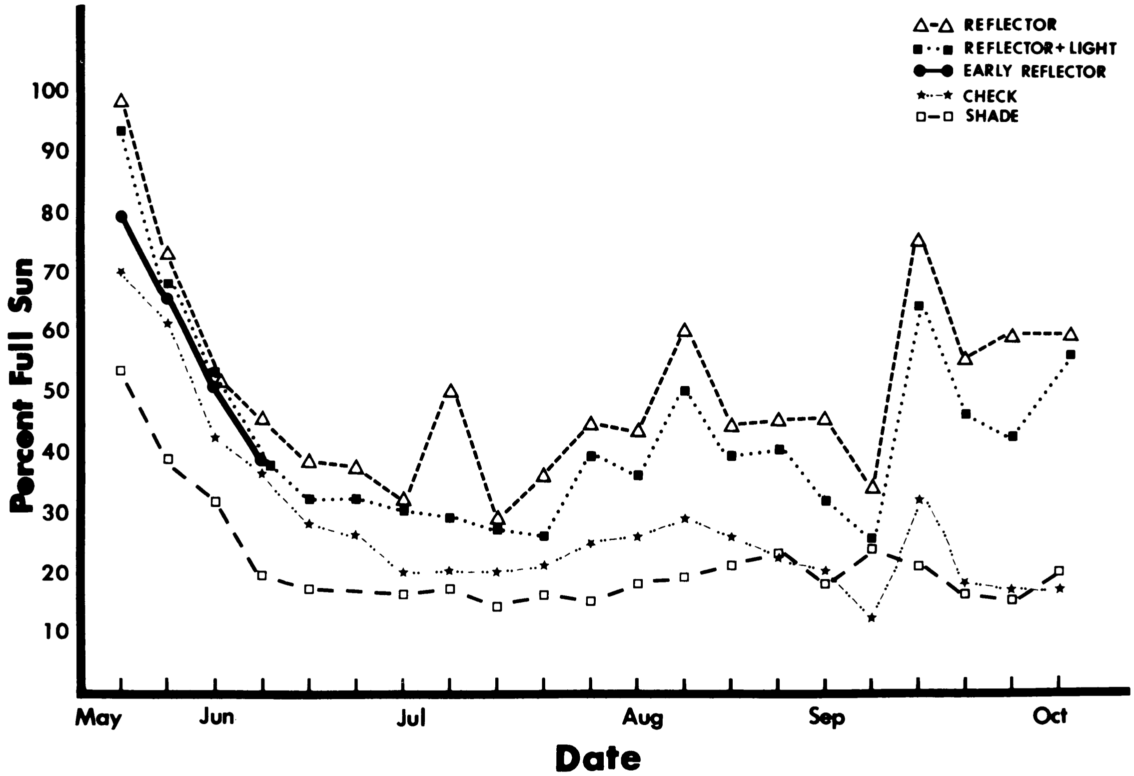

Fig. 1. Comparison of various treatments on the percent of full sunlight within the tree canopy during the 1978 growing season as recorded by light integrators positioned 60 cm N, 60 cm W and 150 cm above soil surface.

removed and counted. A sample of 30 fruit from each upper and lower tree level was taken from the 2 largest size groups during the grading and evaluated for color by assessing percent of fruit surface colored red, shade of red at stem end and shade of red at calyx end. The amount and shade of red color were rated on the following scales: 1 (< 25% red) to 4 (> 75% red); and 1 (not red) to 4 (bright, dark red). Fruit firmness (Effegi fruit tester) and soluble solids (Bausch and Lomb refractometer) were measured on 10 fruits from each tree level.

Tissues were sampled for carbohydrate (CHO) analysis at 5 ontogenetic stages during the season. Sampling times and types of tissues were: 1) April 5 – dormant spur wood; 2) May 21 (full bloom) – spur wood, spur leaves, shoot leaves, blossom clusters; 3) June 11 (June drop) – spur leaves, shoot leaves; 4) July 12 (terminal bud set) – spur leaves, shoot leaves; 5) September 8 (harvest) – spur leaves, shoot leaves; 6) November 11 – dormant spur wood. Samples were taken in the afternoon, quickly frozen and held at $-18^{o}C$ and later lyophilized and ground. Total non-structural carbohydrates were analyzed using the takadiastase method as described by Smith (21) for extraction and the ferricyanide method of Hoffman (11) for determining glucose in the extract.

Results and Discussion

The percent full sunlight available within the tree canopy was greatest during the bloom period and decreased rapidly during leaf canopy development in all treatments (Fig. 1). Reflector treatments increased light within the canopy about 20% at bloom, 10-30% through mid-season, and 35% at harvest. The reflector + light treatment did not increase light compared to the reflector alone. Apparently the artificial light was effectively attenuated by the tree canopy above the point of measurement. As leaves at the tree periphery are usually light saturated, benefit from the overhead light probably occurred only on cloudy days. Over-tree shade reduced light within the tree canopy 20% at bloom and 10-20% the remainder of the season. The greatest reduction in light within the 63% shade treatment occurred at the tree periphery as a reduction in direct light. Diffuse light in the mid- and lower canopy was not attenuated by the shading and thus the reduction of light in these areas was much less.

No significant differences were observed in quadrant or whole tree fruit set between reflector treatments and the check either before or after June drop (Table 1). However, there is a pattern of increased set with increased light due to treatments. A Spearman correlation between the light treatments ranked in order of increasing light and fruit set indicate a significant relationship ($r = .63$). The shade treatment reduced total set by 62% and resulted in lower set within most quadrants. Hand pollination did not increase fruit set in any treatment.

Shoot growth was unaffected by treatment. Specific leaf weight (SLW) was increased by the reflector + light treatment and reduced by the shade treatment (Table 2). No other reflector treatment affected SLW. Reflector treatments did not vary leaf nutrient levels from the check for any element determined (data not shown). Shading increased levels of P, K, B, and Zn while reducing levels of Ca and Mg (data not shown). No treatment affected leaf nitrogen (data not shown).

Fruit size distribution at harvest was roughly the same in all treatments with approximately 1/3 of the weight in Size 1, 1/3 in Size 2, and 1/3 in Size 3, 4 and culls (Table 2). Total fruit/tree and total fruit weight/tree were reduced about 64% by the shade treatment.

Reflector treatments increased fruit color (Table 3). In the tree lower half, percent fruit surface colored red and shade of red at the stem and calyx end were improved. In the tree upper half, only the calyx end color was increased by reflectors. Shading reduced color in all categories. Soluble solids

Table 1. Influence of light treatment on fruit set within quadrants of mature 'Delicious' trees.

Time of observation	Light treatment	Fruit set (%) North Upper	North Lower	East Upper	East Lower	South Upper	South Lower	West Upper	West Lower	Total	Hand pollinated
Pre-June	Shade	16b[z]	16c	17b	17a	22a	15a	17b	13a	15b	20b
	Check	42a	29bc	42a	32a	31a	37a	52a	24a	32a	35a
	Early reflector	48a	36ab	54a	38a	45a	30a	38ab	27a	36a	45a
	Reflector	46a	46ab	57a	38a	47a	36a	42a	24a	37a	40a
	Reflector + light	54a	52a	46a	37a	40a	31a	51a	36a	39a	49a
Post-June	Shade	15b	12c	13b	11b	15b	10b	13b	9a	10b	17b
	Check	34a	24bc	38a	26a	30ab	34a	47a	21a	25a	31a
	Early reflector	46a	28b	47a	29a	44a	25a	37a	19a	27a	32a
	Reflector	38a	39ab	51a	35a	41a	32a	41a	22a	30a	37a
	Reflector + light	49a	45a	43a	36a	40a	27a	48a	30a	32a	42a

[z]Mean separation within columns of pre-June drop and post-June drop by Duncan's multiple range test, 5% level.

Table 2. Influence of light treatment on specific leaf weight (SLW), fruit size distribution and number of fruit per tree of mature 'Delicious' trees.

Light treatment	SLW Upper	SLW Lower	SLW Total	Total no. fruit/tree	Fruit weight (kg)[z] Size 1	Size 2	Size 3	Size 4	Culls	Total
Shade	5.5c[y]	5.3b	5.4c	86b	5.4b	4.7c	2.2a	.1a	3.0a	15.4b
Check	8.6b	7.2a	7.9b	246a	14.0a	15.4b	9.3a	.1a	3.9a	42.7a
Early reflector	8.9ab	7.3a	8.1ab	324a	13.9a	23.8a	13.5a	.2a	3.3a	54.7a
Reflector	8.9ab	7.4a	8.2ab	260a	18.1a	16.7b	8.3a	.2a	2.5a	45.9a
Reflector + light	9.4a	7.5a	8.4a	300a	15.3a	18.9ab	7.2a	.2a	3.9a	45.5a

[z]Size 1 ⩾ 80 mm diameter (80-88 apples per bushel); Size 2 = 79-73 mm (100-113's); Size 3 = 72-57 mm (125-138's); Size 4 ⩽ 56 mm; culls = unmarketable quality.

[y]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 3. Influence of light treatment on color, soluble solid content, and firmness at harvest of 'Delicious' apples.

Light treatment	Fruit color rating: Fruit surface[z] Tree level Upper	Fruit surface Lower	Red shade[y]: Stem end Tree level Upper	Stem end Lower	Calyx end Tree level Upper	Calyx end Lower	Soluble solids (%)	Fruit firmness (kg)
Shade	2.5d[x]	2.7cd	2.4d	2.5d	2.1f	2.3ef	13.4b	6.7a
Check	3.6a	3.1a	3.7ab	3.1c	3.4bc	2.7d	15.6a	6.4b
Early reflector[w]	3.6a	3.0bc	3.6b	3.1c	3.4bc	2.6de	15.4a	6.7a
Reflector	3.8a	3.5a	3.9a	3.5b	3.9a	3.8ab	15.6a	6.5ab
Reflector + light[v]	3.7a	3.5a	3.8ab	3.6b	3.7abc	3.7abc	15.5a	6.5ab

[z]Scale: 1 = 25% red; 2 = 25-50% red; 3 = 50-75% red; 4 = 75% red.

[y]Scale: 1 = not red; 2 = pale red; 3 = red; 4 = bright, dark red.

[x]Mean separation within color measurements by Duncan's multiple range test, 5% level.

[w]Reflectors removed June 6.

[v]Light removed August 15 – reflectors remaned through harvest.

and fruit firmness were not altered by reflectors while shading reduced soluble solids. Moreshet et al. (17) increased not only color but also total yield, fruit weight, and soluble solids in the lower tree half by the use of a reflectant material.

The treatments had no effect on total non-structural CHO in any tissue sampled in May or November (Table 4). Reflector treatments had no apparent influence on CHO level at any of the sampling dates. Shading reduced percent CHO in both spur and shoot leaves sampled in June and July At harvest, however, leaf CHO levels were higher in the shade treatment.

While periods of low light occurred at both bloom and harvest, light during the 10-14 day post-bloom fruit setting

Table 4. Influence of light treatment on total non-structural carbohydrate levels of various tissues of 'Delicious' apple at 5 ontogenetic stages.

	Total non-structural carbohydrates (% dry wt)											
	Dormant	Full bloom				June drop		Terminal bud set		Harvest		Dormant
Light treatment	April 5, 1978 Spur wood	Spur Wood	Blossom cluster	Spur leaf	Shoot leaf	Spur leaf	Shoot leaf	Spur leaf	Shoot leaf	Spur leaf	Shoot leaf	Nov. 11, 1978 Spur wood
Shade	0.68a	0.93a	1.46a	2.54a	1.82a	2.27b	1.82b	2.20b	2.28c	2.81a	2.97a	1.22a
Check	0.72a	0.91a	1.48a	2.57a	1.81a	2.46a	2.02a	2.58a	2.48b	2.76ab	2.88b	1.16a
Early reflector	0.72a	0.93a	1.47a	2.58a	1.73a	2.48a	2.03a	2.58a	2.57ab	2.75ab	2.84b	1.18a
Reflector	0.66a	0.91a	1.43a	2.53a	1.78a	2.54a	2.07a	2.54a	2.66a	2.71b	2.84b	1.17a
Reflector + light	0.70a	0.93a	1.47a	2.55a	1.74a	2.41a	2.06a	2.55a	2.59ab	2.73b	2.87b	1.18a

[z]Mean separation within columns by Duncan's multiple range test, 5% level.

period in 1978 was higher than average as recorded by the OARDC Weather Station. The available light in Ohio in 1978 did not appear to be limiting to 'Delicious' fruit set. Several observations, however, suggest that light is important to fruit set: 1) in all treatments fruit set was consistently higher in the S and W (both upper and lower) tree quadrants than their corresponding N and E quadrants. In N-S oriented rows in Ohio, the S and W sides of the tree would receive the most irradiance. 2) Fruit set in all treatments was also consistently greater in the upper tree quadrant than its corresponding lower quadrant. The shading effect a tree has upon itself is well documented (9). 3) Fruit set was reduced by the shading treatment even though pollination was not limiting. 4) Light levels were higher in 1978 during the fruit setting period than normal and 'Delicious' fruit set across the state was better than usual. We conclude that a reflectant material added to the orchard floor to increase available light might increase fruit set during a year of low irradiance during bloom.

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