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Influence of Reflectant and Shade Material on Light Distribution in Mature 'Delicious' Apple Trees[1]

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Abstract. **Diffuse light within the tree canopy of mature red strain of 'Delicious' apple trees (*Malus domestica* (Borkh.)) was increased throughout the 1978 growing season with under-tree reflectors and decreased by over-tree shade material. Three all season light integrating methods were well correlated (Yellow Springs total radiometer, Lambda quantum sensor, Cain integrator). The Lambda quantum sensor used at intervals showed daily quantity of light reflected was dependent on climatic conditions, time of day, and stage of tree development. Neither reflectors nor shade altered spectral quality. Leaf cross sections, as an indicator of light exposure, showed gross morphological differences between shaded and check leaves but not between reflector and check leaves.**

Adequate light within the apple tree canopy is critical to maximum fruit production per tree (8). Heinicke (7) has shown that light distribution is improved in dwarf trees. Light considerably above leaf photosynthetic saturation may occur at the tree periphery but intra-tree shading can result in inadequate light to the interior spur leaf region where fruit are set and flower buds formed (2).

Lakso and Musselman (11) reported that the amount of diffuse light in apple tree canopies (reflected from clouds, sky, or haze) was dependent on climatic conditions. A bright, hazy day (60-90% maximum total light) resulted in 3 times more diffuse light available to the canopy interior than was available on a clear day. Due to the non-linear photosynthetic response of apple leaves, a higher calculated whole tree photosynthetic rate resulted. Reflected light has been found to constitute as much as 30% of light available to a shaded lower leaf (10).

Although light levels were not monitored, Moreshet et al. (12) showed that an undertree reflectant material effectively increased fruit quality in the bottom half of the tree. Crowe (3) reported in over-tree shade or full sunlight conditions an undertree reflectant material increased the yield of large potted trees as compared to a sod cover.

This study was conducted to determine the influence in Ohio of undertree reflectant and over-tree shade material on light distribution within mature apple tree canopies as measured by various light monitoring devices. A concurrent study examined the influence of altered light levels on growth and fruiting of the trees.

Materials and Methods

Trees used were 22-year-old unknown red strain of 'Delicious' on Malling 9 in N-S oriented rows. The trees were spaced 3.9 × 5.5 m. Tree spread was about 3.0 m and height 2.7–3.0 m. Three treatments were utilized: 1) under-tree reflectors, 2) over-tree shade, 3) untreated control. Treatments were arranged as a randomized complete block with 5 replications. The reflectant material (supplied by St. Regis Paper Co., Dallas, TX) was Alure CTI – a duplex lamination of 1.00 mil LDPE/.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. Single reflective sheets were placed on the E and W sides of the trees centered on the trunk and extended to the branch tips but not into the alleyway. The reflectors were slightly sloped inward (15°) to allow rain runoff. The soil was bare beneath both shade and check treatments. Polypropylene Chicopee Lumite black shade fabric provided 63% actual shade and was placed on a wooden frame 3.0 × 3.0 × 2.4 m over the tree and extended 75 cm down all sides. Treatments were applied at pink flower bud stage and remained through harvest.

Light data were monitored by the OARDC Weather Station with a Total Radiometer Model 67 (Yellow Springs Instrument Company, Yellow Springs, Ohio). Light integrators, as designed by Cain (1), were placed in 1 tree of each treatment on May 13 and read daily with the weekly averages presented (Fig. 2). The integrators were placed at an angle of 45° facing south (1). They were located 60 cm N and 60 cm W of the tree trunk at a height of 150 cm. Heinicke (6) found the greatest concentration of vertical foliage in this area. One integrator remained exposed above the orchard during the experiment. A Lambda, Model LI-150 Integrator with a LI-190S quantum sensor was

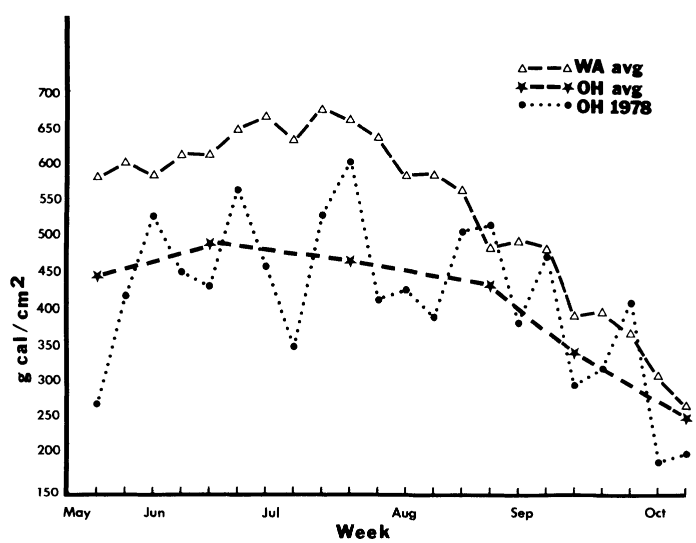

Fig. 1. Comparison of average growing season irradiance in Chelan, Douglas, and Okanogan counties of Washington (WA avg.), and in OARDC, Wooster, Ohio (OH avg.) with the irradiance in OARDC, Wooster, Ohio in 1978 (OH 1978).

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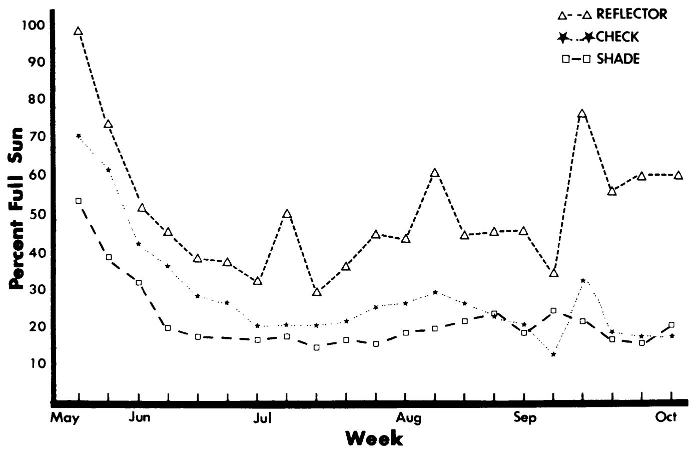

Fig. 2. Comparison of light treatments on the percent full sunlight as recorded by Cain (1) integrators (60 cm N, 60 cm W of trunk, 150 cm above soil surface) within the tree canopy during the 1978 growing season.

Table 1. Influence of light treatment on the relative distribution of light within the tree canopy of mature 'Delicious' on May 9, 1978. Figures are percent of full sunlight.

	Bloom thru terminal bud set (May 14 – July 22)		Terminal bud set thru harvest (July 23 – Oct. 14)	
	Sensor direction		Sensor direction	
Light treatment	Sky[z] (% full sun)	Soil[y] (% full sun)	Sky (% full sun)	Soil (% full sun)
Check	20.5[x]	1.5	11.4	1.3
Reflector	42.4	7.8	30.6	5.8
Shade	6.5	0.6	3.2	0.6

[z]Sensor directed skyward, 60 cm north of tree center at height of 120 cm.

[y]Sensor directed toward the soil surface, 60 cm north of tree center at height of 120 cm.

[x]Mean of 6-10 daily observations.

moved daily among trees of 1 replication. The sensor was placed 60 cm north of the tree center at a height of 120 cm and was alternately turned to face upward or downward (Table 1). A . similar sensor remained exposed above the orchard. A Lambda Model LI-185 meter with a LI-190S quantum sensor was used during the season at various growth stages of the trees in the 5 replications. An E-W transect was made through the tree 120 cm above the soil with 5 readings at 50 cm intervals along the transect. Upward and downward readings (to obtain percent full sunlight and reflectance) were taken at each interval (Table 2).

Spectral intensity distribution inside the tree canopy was measured with an ISCO Model SR spectroradiometer. It was placed 60 cm above the soil, 60 cm N and 60 cm W of the tree center with the sensor faced upward.

On August 27 (97 days postfull bloom), 5 leaves were sampled from 120 cm into the W side of the tree canopy of 1 replication and a horizontal cross section 60-90 mm wide was uniformly cut from the mid-part of each lamina. These sections were placed in a 10% Formalin solution, slides prepared and stained. Morphological differences in thickness and depth of plaisade layer were examined.

Results and Discussion

Full sunlight levels in Ohio during the 1978 growing season show that periods of low light occurred before and during both bloom (May 21) and harvest (Oct. 14) (Fig. 1) when compared with the previous 17 year Ohio average as recorded by the OARDC Weather Station. Light levels were higher than average however, during the postbloom fruit setting period. Irradiance levels in the fruit growing areas of Washington, which have less problem with fruit set and have higher yields, are considerably greater throughout the growing season (10 year average) (4). The greatest difference between regions occurs during the first half of the season when fruit is set, flower buds initiated, and vegetative growth most rapid. Heinicke and Childers (5) found an increasing net assimilation rate in apple trees with increased irradiance levels due to an increased number of light saturated leaves. Lakso and Musselman (11) however, estimated that the increased haziness present in the Eastern and Midwestern U.S. may partially compensate for lower light levels due to better light distribution within the canopy.

Table 2. Influence of light treatment on light within the apple tree canopy of mature 'Delicious' on M 9, 1978.

	100 cm West[z]		50 cm West		Tree center		50 cm East		100 cm East	
Light treatment	Sky[y] (% full sun)	Soil[x] (% full sun)	Sky (% full sun)	Soil (% full sun)	Sky (% full sun)	Soil (% full sun)	Sky (% full sun)	Soil (% full sun)	Sky (% full sun)	Soil (% full sun)
	Rainy afternoon – partial canopy (June 7)									
Check	36.4a[w]	4.1b	21.7a	2.1b	21.6a	1.8b	23.9b	1.6b	30.6a	2.7a
Reflector	25.9ab	14.9a	19.1a	16.9a	23.2a	8.3a	30.7a	9.4a	31.9a	14.8a
Shade	13.5b	1.4b	6.8b	1.2b	5.9b	0.8b	6.9b	1.0b	10.3b	1.3b
	Clear afternoon – full canopy (June 22)									
Check	28.1a	2.7b	20.4a	2.3b	22.3a	1.7b	7.4a	1.3b	9.6a	1.6b
Reflector	40.5a	16.3a	19.1a	23.0a	19.1a	25.7a	11.6a	5.6a	8.5a	5.0a
Shade	18.2a	2.2b	8.7a	1.6b	3.3b	1.1b	9.0a	0.8b	3.2a	0.9b
	Clear morning – June drop period (June 28)									
Check	25.7a	2.8a	20.7a	2.4a	5.4a	3.1a	11.2a	2.8b	12.9a	2.9b
Reflector	22.9a	4.4a	5.7a	2.8a	14.2a	5.6a	37.4a	20.0a	21.5a	37.8a
Shade	1.4b	0.8a	1.0a	0.8a	0.9b	1.1a	0.9c	1.3b	5.2a	2.5b

[z]Sensor location.

[y]Sensor directed skyward

[x]Sensor directed toward soil surface.

[w]Mean separation by date within columns with Duncan's multiple range test (5%).

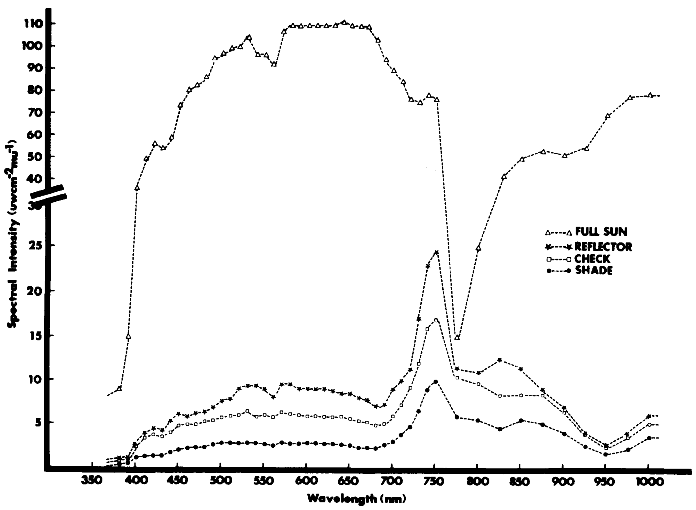

Fig. 3. Comparison of light treatments on the spectral intensity of light (60 cm N, 60 cm W of trunk, 150 cm above soil surface) within the tree canopy during mid-August, 1978.

Weather station light readings were highly correlated with both the field Lambda (r = 0.84) and Cain (1) (r = 0.80) light integrators located in the open. The exposed Lambda and Cain integrators were also well correlated (r = 0.71). Weekly the exposed correlation appeared consistent throughout the season. This would suggest that the inexpensive ($35) Cain integrators provide an acceptable option when numerous cumulative light measurements are required within trees. The Lambda integrators provide the capacity for digital accuracy, record PAR in absolute, not just comparative terms, and can remain unmonitored for long term integrations; however, the cost may be prohibitive ($500).

The percentage of full sunlight available within the tree canopy was greatest during the bloom period and decreased rapidly during canopy development in all treatments (Fig. 2). The undertree reflectors increased diffuse light within the canopy throughout the season but varied considerably. Peak light periods were associated with weeks of low full sunlight (comparison Fig. 1 and 2) which indicated reflectors increased light distribution during cloudiness. A similar pattern was observed in the check trees although light levels throughout were not as high. Over-tree shading reduced diffuse light within the tree canopy only slightly. While 63% of the direct light was blocked right below the shade fabric (at the tree periphery), diffuse light in the canopy interior was not greatly reduced by shading.

The effect of within-tree position on light availability was evident when light recorded by the Lambda LI-150 integrators (Table 1) (located in lower north area of tree) was compared with the Cain integrator measurements (Fig. 2) (located in upper west area of tree). Less light was recorded throughout the season by the Lambda integrators (Table 1). It is apparent that light reflected from beneath the tree normally accounts for a very low percentage of full sunlight available to a tree.

Climatic conditions, time of day, and stage of the tree development greatly affected light availability as determined by transect readings with a Lambda LI-185 meter with a LI-190S sensor and made successive observations difficult to compare (Table 2). In clear weather, time of day greatly affected diffuse light in the reflector treatment, being higher in the east side of the tree in the morning and the west side in the afternoon. Reflectors increased diffuse light uniformly throughout the tree in overcast conditions. Diffuse light levels in the check and shade trees were normally similar and low in all observations. Incident light levels showed much variability within each treatment due to sun flecks, wind causing leaf movement, fruit load, causing branch spreading, etc. It is suggested that in future studies attempting to correlate tree developmental stage with light level, similar time of day and weather conditions be monitored throughout the season.

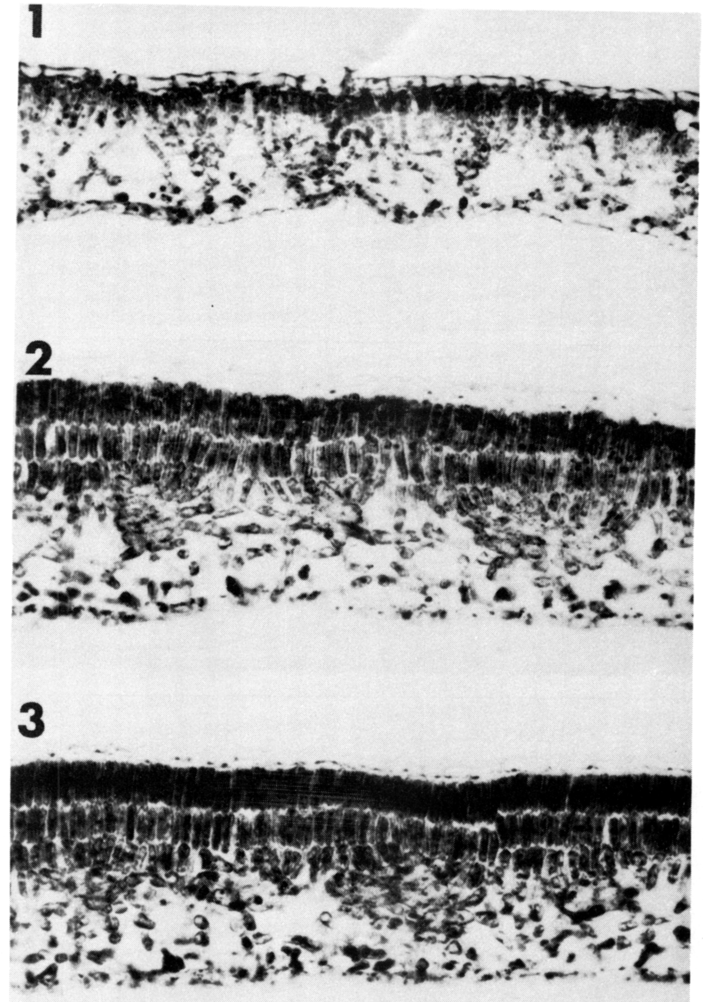

Fig. 4. Anatomical structure of leaf cross-sections of shade (1), check (2), and reflector (3) treatments, (100x magnification).

The light spectrum was determined within the tree canopy in mid-August and tended to be considerably different from the spectrum of full sunlight (Fig. 3). Light in the far red range was most available within the canopy of all treatments. Reflectors resulted in an increase in light quantity across the spectrum while shade resulted in a similar decrease. Neither treatment appeared to alter spectral quality as compared to the check.

The use of anatomical cross sections to supplement light readings was suggested by Jackson and Beakbane (9), who found that leaf thickness and depth of palisade layer was linearly related to the light level under which the leaf was grown. Cross sections of shaded leaves (Fig. 4) appear thinner and contained fewer palisade layers but check and reflector leaves appeared similar. Light increases with reflectors may have shown too much daily variability to affect leaf morphology while the more constant shading condition did cause obvious differences.

The results of the light measurements obtained in this study show that while light is increased within the tree canopy by under-tree reflectors, the increase is difficult to quantify. The reflectors do not provide a uniform source of light, being very dependent on environmental conditions such as time of day and type of day along with the characteristics of the tree such as stage of development. The over-tree shade material provided a rather uniform decrease in light due to direct blocking of light at the tree periphery. Diffuse light within the shaded trees remained at a more constant level throughout the season.

Literature Cited

1. Cain, J. C. 1969. A portable, economical instrument for measuring light and temperature intensity-time integrals. *HortScience* 4:123-125.
2. ________. 1972. Hedgerow orchard design for most efficient interception of solar radiation. Effects of tree size, shade, spacing, and row direction. *New York. Agr. Expt. Sta. Search Agr.* 2:1-14.
3. Crowe, A. D. 1976. Yield as affected by light regime. Annu. Rpt. Can. Res. Sta. Kentville, Nova Scotia. 1976. p. 6.
4. Donaldson, W. R. and C. Ruscha. 1975. Washington climate: Chelan, Douglas, Okanogan counties. Wash. State Univ. Coop. Ext. Ser. EM 3889.
5. Heinicke, A. J. and N. F. Childers. 1937. The daily rate of photosynthesis during the growing season of 1935 of a young apple tree of bearing age. Cornell Univ. Agr. Expt. Sta. Mem. 201.
6. Heinicke, D. R. 1963. The micro-climate of fruit trees. II. Foliage and light distribution patterns in apple trees. *Proc. Amer. Soc. Hort. Sci.* 83:1-11.
7. ________. 1964. The micro-climate of fruit trees. II. The effect of tree size on light penetration and leaf area in Red Delicious apple trees. *Proc. Amer. Soc. Hort. Sci.* 85:33-41.
8. ________. 1975. High-density apple orchards – planning, training, and pruning. *U.S. Dept. Agric. Handb.* 458.
9. Jackson, J. E. and A. B. Beakbane. 1970. Structure of leaves growing at different light intensities within mature apple trees. Rep. E. Malling Res. Sta. for 1969. p. 87-89.
10. Lakso, A. N. 1975. Light studies in apple trees. *New York Food & Life Sci. Quarterly.* 8(4):6-8.
11. ________ and R. C. Musselman. 1976. Effects of cloudiness on interior diffuse light in apple trees. *J. Amer. Soc. Hort. Sci.* 101: 642-644.
12. Moreshet, S., G. Stanhill, and M. Fuchs. 1975. Aluminum mulch increases quality and yield of 'Orleans' apples. *HortScience* 10:390-391.

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The Effect of Two Mycorrhizal Fungi upon Growth and Nutrition of Avocado Seedlings Grown with Six Fertilizer Treatments[1]

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Abstract. **Seedlings of 'Topa Topa' avocado (*Persea americana* Mill.) were grown in steamed loamy sand soil with no fertilizer, complete fertilizer (N, P, K, S, Ca, Mg, Cu, Zn, Mn, Fe, Mo, B), –P, –Zn, –P and –Zn, and –Zn+10 ×P (640 ppm P). Seedlings were inoculated separately with one of 2 isolates of *Glomus fasciculatus* (Thaxter) Gerd. & Trappe (GF) or were inoculated with a water filtrate of the mycorrhizal inoculum plus autoclaved mycorrhizal inoculum. Growth of mycorrhizal seedlings was 49-254% larger than nonmycorrhizal avocados except at the –Zn+10×P regime where mycorrhizal and nonmycorrhizal avocados were of similar size. Both mycorrhizal isolates increased absorption of N, P, and Cu at all fertilizer treatments and absorption of Zn was increased with all fertilizer treatments by one mycorrhizal isolate. Fertilization with P did not alter P concentrations in leaves of nonmycorrhizal plants but increased P concentrations in leaves of mycorrhizal seedlings. Fertilization with 10×P increased P concentrations in both mycorrhizal and nonmycorrhizal seedlings. One GF isolate appeared to be superior to the other based on mineral nutrition of the host avocados. Differences between the isolates apparently were related to their rate of growth or ability to infect. Poor growth of avocado seedlings in steamed or fumigated soil can be related to poor mineral nutrition due to the destruction of mycorrhizal fungi.**

Avocado seeds are normally germinated and grown in steamed or fumigated soil and are frequently transplanted to fumigated orchard sites in order to avoid root diseases. Avocado seedlings which are grown in steamed or fumigated soil frequently becomes stunted and show a reduced capacity to absorb P (11). Martin et al. (11) suggested 2 hypotheses to explain this phenomenon: 1) Microorganisms which recolonize steamed or fumigated soil may excrete chemicals which could interfere with P absorption. Other microorganisms which normally metabolize these excreted chemicals may be destroyed by steam treatment or fumigation. 2) Steam treatments or soil fumigation may destroy mycorrhizal fungi which have been associated with improved P nutrition of many plants (5, 15).

Mycorrhizal fungi are commonly associated with avocado trees in the orchard (6), but it has only recently been shown (12) that mycorrhizal fungi improve growth of avocado seedlings. Mycorrhizal fungi commonly aid their hosts by increasing host absorption of P, Zn, Cu, and other mineral nutrients. It is not known to what extent mycorrhizal fungi influence the mineral nutrition of avocado trees, nor under what fertility conditions mycorrhizal fungi improve their growth. Purposes of this study were to determine if lack of mycorrhizal fungi was

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