Effects of Cloudiness on Interior Diffuse Light in Apple Trees

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Abstract. Interior diffuse light readings were taken in trees of semi-dwarf ‘Wayne’ and ‘Golden Delicious’ apple (Malus domestica Borkh.) on days of varying cloudiness. Interior light to shaded spurs was found to be greatest when the total light outside the tree was 60 to 90% of maximum, due to higher diffuse light with haze or light cloudiness. Diffuse light available to a shaded site within the canopy is a function of exterior diffuse light levels and canopy density as affected by cultivar. Calculations of whole canopy photosynthetic potential from light data and photosynthetic light response, indicate that haze or cloudiness is needed to obtain maximum whole canopy rates.

Classically, studies of light penetration into deciduous fruit tree canopies have been conducted on clear, cloud-free days to provide a smooth diurnal pattern of external light (3, 4, 6, 7, 10, 12, 14, 15, 16, 18, 20). Since many of the studies took place in climates with high percentages of clear days, the light regimes were well chosen; however, in climates such as the Northeastern U.S., cloudiness is a common occurrence during the growing season. The mean July sky cover (the fraction of the sky covered by clouds) in the western New York fruit growing region is between 0.5 and 0.6 (17) with only about 8–10 clear bright days per month during June through Oct. Such weather patterns necessitate evaluations of light penetration during a range of cloudiness conditions.

Heinecke (5, 8) has stressed the importance of diffuse light and has shown that diffuse light on hazy days can reach levels high enough to saturate apple leaf photosynthesis. Thus, if a leaf or spur is shaded, but exposed to diffuse sky radiation, sufficient light may be available for photosynthesis and fruit production depending on cloud conditions. Recent work by McCree and Keener (13) has also shown that atmospheric haze affects the distribution of light between direct and diffuse much more than it affects the total amount of light. For non-linear photosynthetic response to light (as in apple leaves), they calculated only a 4% decrease in photosynthesis in response to a 20% decrease in light for exposed leaves.

When high levels of diffuse light are available, increased penetration of light into plant canopies can be expected. Liu (11) has shown this to be true in grapevine canopies. Whole canopy responses to varying levels of direct and diffuse light have been estimated by Allen et al. (1) using a computer simulation model. Their results show that whole canopy photosynthesis actually is higher under conditions of somewhat reduced total radiation but having a higher proportion of the diffuse component. This is due to the exterior canopy still receiving saturating light levels while the interior canopy receives in-
increased levels of light from the sky. These results agree with Heinecke's (8) assessment that canopy pruning and shaping may not be as critical in areas with cloudy conditions as it is in clear sky areas.

Suckling et al. (19) examined transmission of light through 4 year-old apple tree canopies to under-tree light sensors and found there was little difference between bright and cloudy conditions. Unfortunately, diffuse light data were not given. The "bright" days examined had varying cloudiness (up to 0.6 cloud cover) which would result in increased diffuse light levels, minimizing differences in canopy penetration.

Since little data is available on the effects of cloudiness, typical of different climatic regions, on the interior light available to shaded spurs and leaves, the diffuse light levels inside apple tree canopies of two varieties of contrasting growth habits were examined during varying cloud conditions.

**Materials and Methods**

Light readings were taken in 4 to 5 m tall 9-yr-old 'Golden Delicious'/M 2 and 'Wayne'/M 2 apple trees at Geneva, N.Y. representing open spreading and upright dense growth habits, respectively. The readings were taken primarily during July and August, 1975 after most of the canopy development had been completed.

All light measurements taken were of photosynthetically active radiation (PAR) with a Lambda quantum sensor meter (Model LI-185). Exterior total light readings were taken in the open at a height of 2 m with the sensor held horizontal. Diffuse light readings were obtained immediately after the total light readings by shading the sensor from direct light with an opaque shade spot, 3 cm in diameter, which shaded approximately 1–2% of the sky above the horizontal sensor.

Sampling of the interior light in the tree canopies entailed two methods: (1) recording light at 5 marked interior spurs in each tree and (2) east-west transects through the tree canopies at 1.5 m above the ground with readings taken every 25 cm. All light readings were made with the sensor held horizontally and for interior canopy readings, sunflecks were avoided.

**Results and Discussion**

Fig. 1 shows light transects taken through a single 9-year old 'Golden Delicious'/M 2 canopy on 3 days of varying cloudiness. The 3 measurements occurred within 5 days in late June so canopy light growth effects were minimal. Note that the interior light was very similar on both the clear, bright day (exterior PAR = 2000 μ E m⁻²s⁻¹) and the dull, overcast day (exterior PAR = 450 μ E m⁻²s⁻¹). However, on a partly cloudy day (exterior PAR = 1100 μ E m⁻²s⁻¹) the mean interior level of PAR was about 3 times that of either the clear or overcast day.

Interior light is not dependent solely on the total available light. The relationship between total light and mean interior light indicates that interior light is greatest when the total light is between 60 and 90% of the maximum for clear sky conditions (Fig. 2). This occurs when there is light cloudiness, or haze, or both. Under these conditions, the cloudiness is light enough to transmit and reflect high amounts of radiation giving high levels of the diffuse light component. Fig. 2 also shows the importance of canopy structure and density on the interior levels. 'Wayne' produced a dense, full canopy that not only blocked direct light but also diffuse light. In contrast, 'Golden Delicious' produced a canopy that was open with a spreading habit, allowing more of the available diffuse light to penetrate.

The direct relationship between exterior diffuse light and mean interior light (see Fig. 3) indicates the importance of cloudiness or haze for producing high levels of diffuse light which illuminate the interior, shaded spurs. Again, the effects of the 2 different canopies are obvious.
The effects of cloudiness on whole canopy photosynthesis can be estimated by applying the measured light values to published photosynthetic light responses for apple leaves. For these calculations, the photosynthetic light response measured in the field by Landsberg et al. (10) is used with the light values shown in Fig. 2 for the 'Golden Delicious' canopy. The results (Fig. 4) indicate that clear day conditions are not optimal for whole canopy photosynthesis, except for totally exposed leaf area which rarely occurs in orchards. This is a result of the non-linear photosynthetic light response of apple, as the shaded canopy responds more to the increase in diffuse light than the exposed canopy responds to the decrease in total light as cloudiness increases. As seen in Fig. 4, the lower the % sunlit foliage, the greater the response to cloudiness, although higher exposure always will give higher photosynthetic rates. These results support Heinecke's (8) conclusion that shading may be less critical in cloudy climates compared to clear climates. Although the rates of photosynthesis are only calculated, and the photosynthetic light response may be somewhat different with different varieties and growing conditions, they do suggest the beneficial effect of cloudiness on diffuse light.

Considering fruit production in relation to light available to fruit spurs, these beneficial effects of cloudiness could be very important in maintaining productivity. Cain (2) and Jackson (9) have estimated that at least 30% of full sunlight is needed to cause flower bud formation. For interior canopy locations which may not receive very much direct light, the diffuse light component may provide the extra illumination needed for fruit bud formation.

In summary, the photosynthetically active radiation available to a shaded site within an apple tree canopy is dependent not only on the density of the canopy to light penetration, but also the amount of diffuse light available to the tree. Since cloudiness can increase diffuse light over that available on a clear day, cloudy climates should allow greater efficiency of use of the available light, given a similar canopy density.

Literature Cited