# リンゴ‘ふじ'開心形樹の樹冠内における光と果実の分布特性


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# Light and Fruit Distributions within a Canopy of 'Fuji' Apple Trees Trained to a Traditional Open-Center System in Japan

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**Summary**

Light and fruit distributions within foliar canopies were measured on three 27-year-old 'Fuji'/Marubakaido (*Malus prunifolia* Borkh. var. *ringo* Asami) apple trees trained to a traditional flat open-center system developed in Japan. The canopies extended more horizontally than in depth and were interspersed with many open spaces. The percent instantaneous incident photosynthetic photon flux density (%INPPFD) was measured with quantum sensors on overcast days in mid-September and early November. Measurements were taken on four vertical plane grids placed through the center of each tree with an angle of 45 degrees made by two neighboring grids. Because of the canopy conformation, the imaginary lines connecting points of equal %INPPFD (contour lines) extended along the horizontal plane, suggesting a prevailing influence of the light from above on the within-tree environment. The canopy area receiving less than 20% INPPFD was fairly limited in depth. The depth of the main cropping zone was estimated from the contour maps at a mean height of 1.7m. More than 50% of the fruits were distributed in the canopy area receiving 40% or less INPPFD. Relatively large fruits were found in the zones receiving 20% or less INPPFD. Light measurements in early November revealed that the leaf removal practice to obtain better fruit coloration significantly improved light environment within the canopy, almost eliminating the areas receiving 20% or less INPPFD.

## Introduction

A large proportion of apple orchards in Japan are of low-density ones (150-200 trees·ha$^{-1}$), in which trees are trained to a flat open-center system developed in Japan. This tree form is suitable for very intensive orchard practices to produce high-quality fruit that the Japanese market demands. Most of these trees are grafted on Marubakaido (*Malus prunifolia* Borkh. var. *ringo* Asami) rootstock which can be classed between MM. 106 and seedling rootstocks and well adapted to rather unfavorable orchard environment such as poor soil condition, steep-sloped land, and deep snow.

The training and pruning practices for this traditional open-center trees have been developed through a long history of trial and error by innumerable apple growers so that intrinsically vigorous trees are trained to be easily manageable. It is for this reason that comprehensive studies of this traditional apple growing system have a general and contemporary significance. That is, they will contribute to the improvement of orchard system, whether in Japan or in other countries, where the use of rather vigorous rootstocks will continue to be indispensable because of unfavorable soil or some other environmental conditions.

Some features of the framework structure of the traditional open-center tree and principles underlying its training and pruning were discussed by Kikuchi and Shiozaki (1992). Shiozaki and Kikuchi (1992) investigated the per hectare yields of open-center 'Fuji' trees as related to LAI and tree vigor spanning 20 years from young to mature stages.

The present paper concerns the patterns of within-canopy distribution of light and fruit in mature open-center 'Fuji' trees. Within-canopy light status was expressed as percent instantaneous incident photosynthetic photon flux densities (%INPPFD) determined on overcast days. Campbell and Marini (1992) demonstrated that %INPPFD readings under overcast conditions after the

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canopy was fully developed had a one-to-one relationship with the percent cumulative incident photosynthetic photon density for the last 10 weeks of the growing season.

## Materials and Methods

The study was carried out in 1989 on three 27-year-old, open center 'Fuji'/Marubakaido (*Malus prunifolia* Borkh. var. *ringo* Asami) trees planted in a 9m × 9m planting distance in the experimental farm of Hirosaki University. The deep alluvial soil is classified as a clay loam. Even at this distance shoots of neighboring trees almost touched each other. The northern to eastern sides of the three trees faced an open field.

Conventional orchard practices were carried out. King flowers on spurs were hand-pollinated. Fruit thinning was carried out in early June with additional thinning done through the end of June according to the guideline for apple growers; one fruit for every four terminal buds of shoots and spurs produced in last year. In late July several wooden poles were set in every tree to prop up lateral branches according to the conventional practice. In early to late October, leaves which cast heavy shade on fruit were removed on two occasions, beginning from leaves closest to an individual fruit and then extending to more distant ones. The fruit was harvested in mid-November.

To determine the location of light measurement, four vertical plane grids (grid section: 0.5 m × 0.5 m) were placed through the center of the canopy with an angle of 45 degrees made by two neighboring grids. Photosynthetic photon flux density (PPFD) was recorded with quantum sensors (IKS-15, Koito Co. L.T.D.) at every crossing of the grids between 10 : 00 A.M. and 2 : 00 P.M. under an overcast sky on Sept. 14. Incident PPFD recorded in a spot out of the canopy simultaneously with every within-canopy PPFD measurement was used to calculate the percent instantaneous incident photon flux density (%INPPFD). Counts of fruit was made between movable guides, 0.5 m either side of the grid plane in each of the grid sections. Measurements of light were taken again in early November on one of the trees studied.

Contour lines were drawn from the %INPPFD values for the center of individual grid sections determined as the mean of the four corner values. To determine the depth of the main cropping zone, the shortest distance from 20 to 80% INPPFD contour lines were measured at horizontal intervals of 1m taking 74 measurements in total from the three trees.

At harvest one out of every 10 fruits was selected at random without regards to their origin in the canopy and weighed. The proportion of the red surface of each fruit was evaluated visually on the same samples. If the colored surface was 1/3 or less, the fruit was rejected as a cull for the fresh market.

## Results

The average annual yield of the experimental plot (0.1 ha) during the 1986～1989 period was 6.1 metric tons. This equals the highest yields from commercial apple orchards in Aomori Prefecture (Asada, 1989). The land area covered with canopy, fruit yield per tree, and the number and average weight of fruits for each tree are shown in Table 1 along with the proportion of cull fruits for the fresh market. The average fruit weighed 285 g or more; 0.2～3.5% of the fruits weighed less than 200 g. The unmarketable fruits ranged from 2.9～7.9% among the three test trees.

The test trees had very flat canopies (Fig. 1).

**Table 1.** Canopy sizes and fruit production of three 27-yr-old 'Fuji' apple trees.

| Tree | Land area covered with canopy | Fruit yield | No. of fruit | Fruit weight ($\bar{x}$±S.D.) | Rate of substandard fruit for fresh market |
|---|---|---|---|---|---|
| No.1 | 67.1 $m^2$ | 622.3 kg | 2,098 | 301 ± 54.7g | 2.9 % |
| No.2 | 65.1 | 541.2 | 1,837 | 295 ± 62.7 | 4.5 % |
| No.3 | 66.4 | 603.9 | 2,119 | 285 ± 48.8 | 7.9 % |

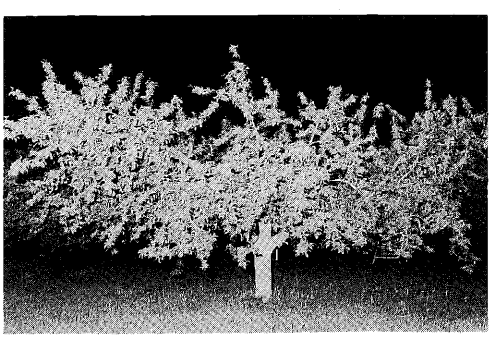


**Fig. 1.** Side view of a typical open-center tree in the experimental orchard plot.

An aerial photograph discloses the framework of those trees (Fig. 2). Horizontal distributions of canopy depth of those trees and some of vertical sections of them are shown in Fig. 3 and Fig. 4, respectively. There are many open spaces throughout the canopies.

The contour maps for %INPPFD with fruit distribution diagrams for trees No. 1 and No. 2 (Fig. 5) extend horizontally and are almost parallel to the 100% INPPFD lines which run about 4 m above the orchard floor. The canopy layer receiving less than 20% INPPFD light is fairly limited in depth judging from the bottom lines of canopy running about 1 m above ground (Fig. 4). The average depth of the main cropping zone stands at 1.7 m±0.3 m (S. E.).

Judging from the contour lines, particularly those constituting the peripheries of canopies, the influence of the open ground on the north, northeast, and east sides of canopies is not significant.

Most fruits are distributed between 1.0 m and 3.0 m above ground, with 1～2 m and 2～3 m layers sharing about the same number of fruits (Fig. 6). In relation to the light environment, more than 50% of the fruits are distributed below the 40% INPPFD line (Fig. 7).

When comparing fruit distribution in late July (Fig. 8) with Fig. 6, there is no conspicuous change in distribution pattern due to the increase in fruit weight except for a slight decrease in fruits in the 3～4 m level. This is clearly attributable to the propping up of limbs in late July.

Contour maps in Fig. 9 show the light status of No. 1 tree immediately before harvest. Leaf removing practice have almost eliminated canopy areas receiving light of 20% or less INPPFD.

## Discussion

The fruit distribution patterns showed little difference between late July and mid-September. It

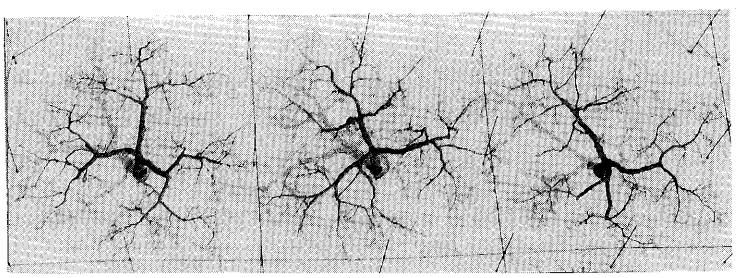


**Fig. 2.** Aerial photograph taken with a radio-controlled model helicopter showing the frameworks of three 27-yr-old 'Fuji' apple trees.

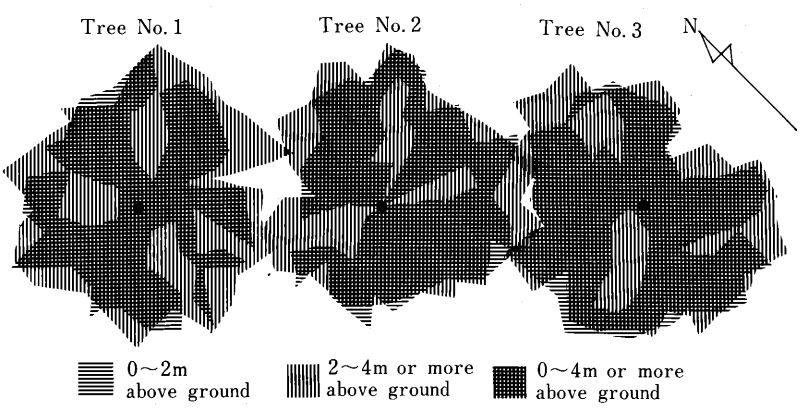



**Fig. 3.** Distributions of foliage in the trees studied as determined at 2 m intervals above ground in early July.

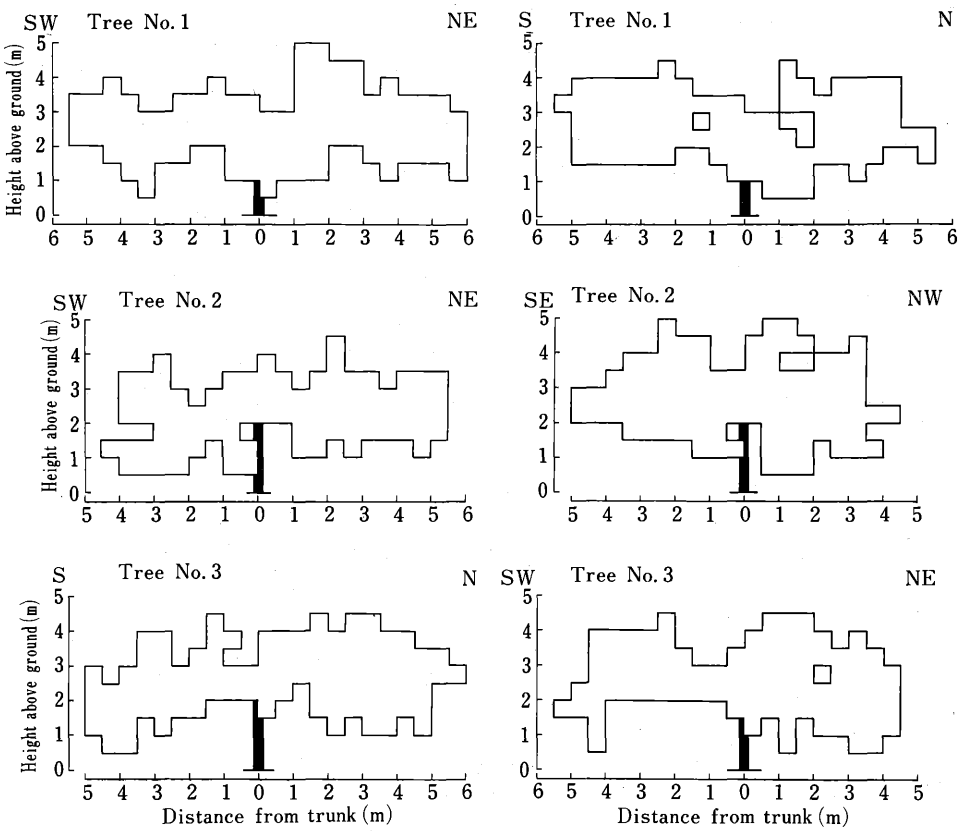



**Fig. 4.** Vertical canopy sections[z] of the trees studied in late July.
[z]The 0.5 m×0.5 m grid sections of the vertical plane grids where foliage located are presented for two orientations per tree.

can be assumed, therefore, that the within-canopy environments determined for mid-September represent those prevailing over a late growing season up to the time when leaf removal practice started.

Heinicke (1964) reported that the increase of apple canopy volume is inevitably accompanied by an increase of unproductive within-tree space. However, the situation is quite different with the open-center trees in the present study as the horizontally extended contour lines indicate; light distribution is almost independent of the distance from the sides of the canopy except in restricted peripheral areas. This suggests a prevailing influence of the light from above on the within-tree environment. This is because the flat canopy has many open spaces interspersed throughout it (Figs. 3, 4, Asada, 1990). Such canopy structure is developed on the specific framework as described by Kikuchi and Shiozaki (1992); most lateral branches are developed on secondary main branches positioned on the primary main branches 1.5 m or more away from the trunk. Thus, a considerable amount of direct or difuse light penetrates through the canopy to the lower exposed leaves and fruit.

With such a tree architecture, horizontal expansion of the canopy has little influecne on the within-tree light condition as demonstrated by Shiozaki and Kikuchi (1992) in a study with 'Fuji' trees. Their study which spanned over 20 years revealed that fruit yield per unit canopy area gradually increased until the canopy reached maximum.

The depth of the main cropping zone was determined as the shortest distance between 80% INPPFD and 20% INPPFD lines on the contour

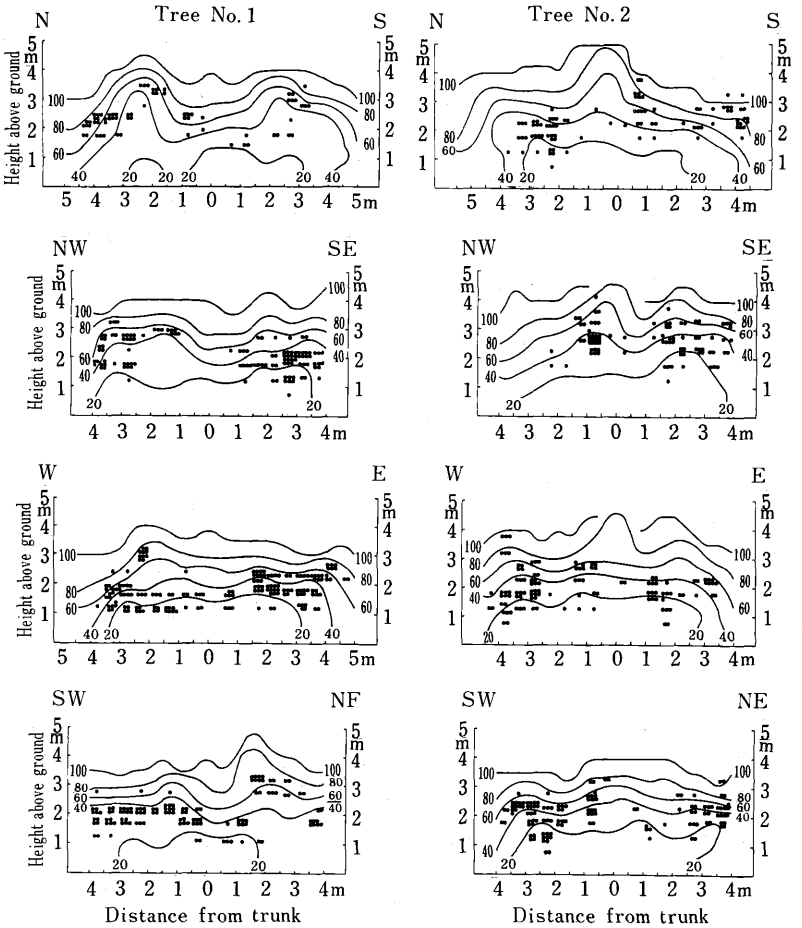



**Fig. 5.** Light and fruit distributions within canopies on Sept. 14. The numbers on the ends of contour lines represent %INPPFD. Dots represent individual fruit.

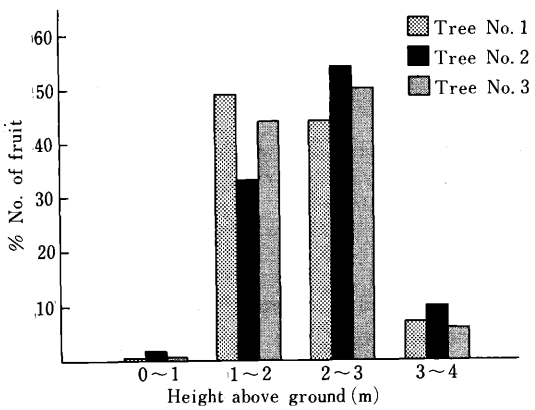



**Fig. 6.** Percentage of fruit located in different height classes above ground on Sept. 16.

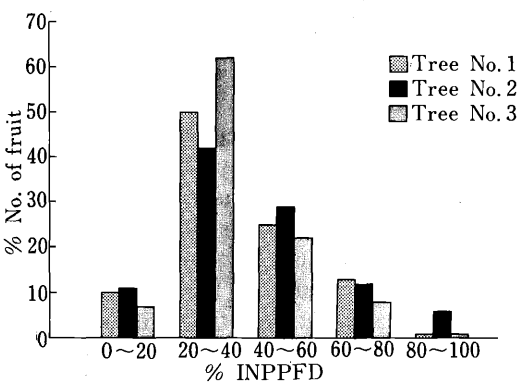



**Fig. 7.** Percentage of fruit exposed to different light intensities (%INPPFD) on Sept. 16.

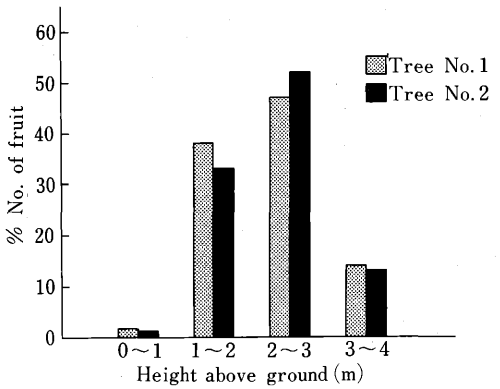



**Fig. 8.** Percentage of fruit at different heights above ground on July 22.

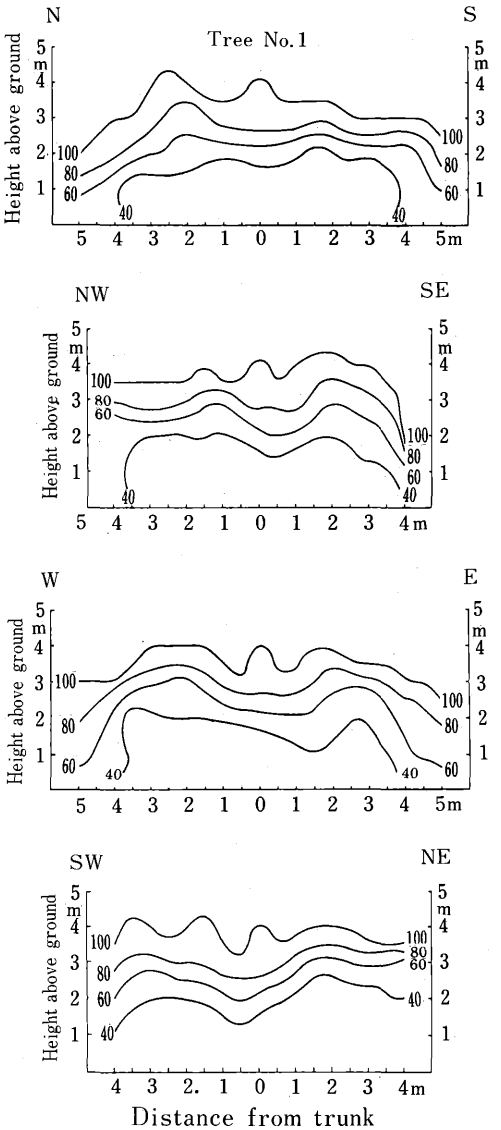



**Fig. 9.** Light distribution within canopies recorded on Nov. 4. The numbers on the ends of contour lines represent %INPPFD.

maps, since the depth of foliage masses can be greater when they face larger open spaces. It is interesting to note that this value falls into the 1.5 ~ 2.0 m range that Jackson (1980) suggested as the canopy depth of high-density orchards. This finding indicates that the canopy depth cannot exceed this range in any training and planting systems in which the orchard floor is almost completely covered with leaf canopy.

Previous studies on apple trees have demonstrated that a considerably high level of within-canopy light was required for producing marketable fruits. Jackson (1980), in his comprehensive review, cited several studies on relative light intensity within canopy as related to fruit production. It seems from these studies that relative light intensity should be more than 30 to 40% of full sunlight for securing continued flowering and production of fruits with size and color needed for fresh market. Some workers suggested much higher level: Heinicke (1966) reported that 'Red Delicious' and 'McIntosh' fruits receiving less than 50 % of full sunlight were small. In his study, the fruits in the largest size class did not exceed 170 g. In our present study, 3.5% or less of the fruits weighed less than 200 g. Therefore, most apples grown on our trees were larger than those reported by Heinicke and possibly larger than those reported from other major apple producing countries.

It is possible that in previous studies the effects of relative light intensity on fruit growth were often confounded with the effects of some tree factors carried over from previous years. Among such tree factors is the growth status of fruiting branches and spurs. It is generally known that fruits on weak twigs and spurs tend to be small (Chandler, 1957). In Japan, detailed pruning is applied to every fruiting branches, removing weak

twigs and replacing them frequently with younger ones. Lateral branches on which fruiting branches are attached are usually developed on horizontal or nearly horizontal limbs (Kikuchi and Shiozaki, 1992). This procedure facilitates renewals of fruiting branches. Such attention to minute pruning details, hand pollination, and fruit thinning may have enabled fruiting branches receiving light as low as 20% or less INPPFD to produce relatively large fruits.

Removing leaves which cast shade on fruit is an essential practice in the culture of red-colored cultivars in Japan. Leaf removal amounts to 10～40 % of the total leaves (Shiozaki and Kikuchi, 1988). It can be assumed that the within-canopy environment before leaf removal is favorable for fruit growth, but it is not sufficient for color development. To produce well colored apples under a conventional management without leaf removal practice, the LAI would have to be reduced which would lead to a lower crop yield. Therefore, the leaf removal practice not only improves red pigment formation, but it has an economic effect because the market demands that the fruits meet strict size and color standards.

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# リンゴ'ふじ'開心形樹の樹冠内における光と果実の分布特性

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## 摘　要

27年生マルバカイドウ台'ふじ'開心形樹3樹の樹冠内の光と果実の分布状態を調査した．9月中旬の曇天日に，光量子センサーを用いて樹冠内の光合成有効放射量を瞬間的に測定し，同時に樹冠外で測定した光合成有効放射量に対する百分率（%INPPFD）を求めた．樹冠内における測定は樹冠中央を通る4方向の垂直格子面に沿って行った．樹冠は扁平で深さのわりに水平方向への広がりが大きく，枝葉の存在しない多くの空所が全面に分布していた．このような樹冠構造により，%INPPFDの等高線は水平方向に長く，互いにほぼ平行に走り，樹冠内光条件に及ぼす樹冠上方からの光の重要性が示唆された．20% INPPFD以下の光を受けている樹冠部分の厚さは小さかった．果実が着生する葉層の厚さは，%INPPFD等高線図から平均1.7 mと推定された．果実はその50%以上が40% INPPFD以下の部分に分布し，20% INPPFD以下の部分にまで比較的大きい果実が着生していた．果実の着色増進のための摘葉作業は樹冠内光条件の改善に大きく寄与し，摘葉後の11月上旬の測定では20% INPPFD以下の樹冠部分はほとんど認められなかった．