The Effect of Shading on the Growth of Young 'Fuji' Apple Trees

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Summary

Young apple trees were grown for two growing seasons under 100, 52.9, 34.2, 15.8 or 5.0% natural photosynthetic photon flux density (PPFD) to assess the difference of growth on dry weight basis. Total dry weight gains of trees decreased with increasing shade, except for trees grown at 5.0% PPFD which showed a net loss at the end of the second growing season; because dry weight of the root stem, and trunk decreased. Although the growth increment in the root system was negative at 5.0% PPFD, new roots were produced in small amounts in both seasons. Shading neither decreased the photosynthetic light compensation points of leaves nor increased the initial slopes of the light response curves. Specific leaf weight declined significantly with the decrease in light level to 5.0% PPFD. In trees receiving a PPFD level above 15.8%, 42.1 to 49.5% of the total increment of dry weight was partitioned to the old trunk and branches, respectively. A high correlation between total increment and trunk thickness ($r=0.983^{**}$) was found, but not in trees under 5.0% PPFD. Therefore, the minimum light condition required to sustain a growth in dry weight increment in succeeding years appeared to be between 5.0 to 15.8% of natural sunlight in the northern part of Japan.

Key Words: *Malus*, light intensity, dry weight, photosynthesis, dry weight distribution.

Introduction

Kobayashi and Yoshimura (1953) reported that of all deciduous fruit trees examined, the apple tree had the least resistance to light stress. Kumashiro and Nishimura (1984) showed that 20% of young apple trees died when grown at 5% of full sunlight which indicates that the trees need 10% of full sunlight to maintain their growth on a dry weight basis. However, according to Priestley (1969) and Jackson and Palmer (1977), apple trees were able to maintain their growth even under 10% of full sunlight, although the amount of growth decreased. This study was carried out to determine the minimum light level that young apple trees require to sustain their growth on a dry weight basis. The photosynthetic acclimation and morphological responses of leaves, grown under reduced light conditions, were also examined.

Materials and Methods

One-year-old 'Fuji' apple trees on Marubakaido (*Malus prunifolia* Borkh. var. ringo Asami) were planted in plastic pots 30 cm in diameter in 1991 and grown in the orchard of Hirosaki University in Aomori Prefecture. Before planting, the trees were headed at a height of 60cm, and all the feathers were removed. All emerging shoots were allowed to grow to their full

length. After bud-break, five levels of shading treatments were initiated by surrounding the pots with black nets, for two growing seasons until the end of October 1992. The average percentage of light intensity (photosynthetic photon flux density, PPFD) relative to the unshaded plot (Plot 1) on overcast and sunny days was 52.9 in Plot 2 (one sheet of net), 34.2 in Plot 3 (2 sheets), 15.8 in Plot 4 (3 sheets), 5.0 in Plot 5 (5 sheets). The average monthly mean temperature and solar radiation per day from April to October in Aomori Prefecture were 15.8 °C and 13.94 MJm⁻², respectively. Each plot had 10 trees. In late October of the first and second years, half of the trees were dug up, dissected, and the dry weight of the organs was measured. The increment of dry weight gain or loss was calculated by subtracting the initial dry weight from the end-of-season dry weight. The initial dry weight was estimated by using the relationship of the volume of the trunk and root system with a predetermined volume/dry-weight ratio. In September 1992, the middle leaf of a shoot of each tree, receiving the shade treatment, was selected for net photosynthetic rate (Pn), specific leaf weight (SLW), chlorophyll determination, and observation of palisade cells and stomata. Pn and chlorophyll content were measured with an Intelligent Porometer (KIP-8510, Koito Industries, Ltd.) and the method of Mackinney (Mackinney, 1941). In 1993 and 1994, a similar experiment was repeated to measure the dry weight increment of new roots. The cultivar, age, and number of trees used were the same as those of the 1991 and 1992 experiment.

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Results and Discussion

1. Dry weight increments of the whole plant and each organ

The total dry weight increment of trees during an entire season decreased with increasing shade in the first and the second seasons (Fig. 1). The increments in trees receiving 5.0% PPFD were small in the first season and negative at the end of the second season, although no trees died. In a previous report, Asada and Ogasawara (1997) found that 80% of shoots elongated less than 5cm in trees receiving 5.0% PPFD. Our results reveal that trees receiving less than 5.0% PPFD continued to lose dry weight each consecutive year, i. e. root dry weight during the first growing season and root and trunk dry weights during the second season were lighter than the previous season. Maggs (1960), Priestley (1969), and Kobayashi and Yoshimura (1953) reported that the organ of the apple tree most severely affected by shading was the roots with which our results agree. Furthermore, shading also depressed the dry

weight increment of the trunk, but to a lesser extent than that in the roots. Thus extreme shading restricts transport of current photoassimilates to the roots, followed by trunk and branches, because of the distance they have to travel.

2. Dry weight increment in the root system

The root system of the trees examined was composed of the primary tap root, and old and newly formed lateral roots. The dry weight increment of all parts of the root system decreased with PPFD reduction (Table 1). Under 5.0% PPFD, the effect of shading on dry weight increment in the root system was extremely severe. The root stem showed negative dry weight increment at the end of the first and second growing seasons. Nevertheless, new roots were produced in both growing seasons, but the amount of new roots produced was very small so that the total increment in the root system was negative. Maggs (1960) showed that the maximum rate of loss in weight occurred between bud-break and the unfolding of new leaves and that heavy shading extended the period required to regain the

Fig. 1. Effects of shading on dry weight gains by whole plant and separate organs of young 'Fuji' apple trees for one (A) and two (B) growing seasons, 1991 and 1992.

weight in young apple trees. We also found that shading affects the replenishment period for the loss in weight of root stem during early and subsequent growth of newly formed roots. That new roots were formed in the second season in spite of the loss of dry weight in root stem in the first season suggests that the meristematic regions of fine roots are extremely strong sinks. Priestley (1969) supported the idea that excessive demands could bring about the death of some cells within tissues.

3. Characteristics of net photosynthesis and the morphology of leaves grown under reduced light conditions

The responses of leaf net photosynthesis (Pn) to increasing irradiance were hyperbolic in all the trees irrespective of shading levels (Fig. 2). The photosynthetic light saturation and the light compensation of leaves grown under full sunlight occurred at about 800 and 30 $\mu\text{mol m}^{-2}\text{s}^{-1}$, respectively, similar to the values noted by Lakso and Seeley (1978). Shading neither decreased the compensation points nor increased the initial slopes of the photosynthetic light response curves which indicates that 'Fuji' apple leaves can not acclimate photosynthetically to a low light condition as can leaves of satsuma mandarin (Ono et al., 1978). However, shading did cause saturation points to occur at lower light levels because Pn at these points decreased progressively. Pn of the leaves grown under 5.0% PPFD was assumed to be below $2.5\text{mg CO}_2\text{ dm}^{-2}\text{ hr}^{-1}$ during the experimental period, because natural PPFD at Aomori did not exceed $2000\text{ }\mu\text{mol m}^{-2}\text{s}^{-1}$. Hence, leaves with such low Pn potential as those exposed to 5.0% PPFD could not provide enough current photoassimilates to the trunk and roots.

Leaf morphology was affected by shading (Table 2, Fig. 3), notable the specific leaf weight, SLW, a most influential parameter. A significant difference in SLW existed between leaves receiving 15.8 and 5.0% PPFD of full sunlight. That shading decreased SLW and leaf thickness was reported by Barden (1978) and Jackson and Beakbane (1970), respectively; whereas it increased the space within mesophyll cells and alteration in chloroplast structure were reported by Pickett (1934) and Skene (1974), respectively. Barden (1978) pointed out that among various parameters concerning the leaf

structure, SLW might be a reasonably good index of the previous PPFD conditions and also of Pn potential. Our study seems to support Barden's opinion. Results from light microscopic observation indicated that the change of SLW with shading was due to decreases in the length and number of the palisade cells (Table 2, Fig. 3).

Fig. 2. Photosynthetic light responses of a single apple leaf grown under different light intensities.

Table 2. Effects of shading on SLW, number and depth of palisade layer, density of stomata, and chlorophyll content of 'Fuji' apple leaves, 1992.

% PPFD	SLW (mg/cm ²)	Layers of palisade		Density of stomata (No./cm ²)	Content of chlorophyll (μg/cm ²)
		Number	Depth (μm)		
100.0	9.97 a ^c	3.0 a	106.8 a	340 a	35.9 ab
52.9	9.65 b	2.7 ab	93.0 b	287 b	37.6 a
34.2	7.31 c	2.4 ab	68.9 c	243 c	32.9 ab
15.8	5.65 d	2.0 b	49.1 d	226 c	32.2 ab
5.0	4.04 e	2.0 b	42.0 d	220 c	23.8 b

^c Mean separation within columns by Duncan's multiple range test, 5% level.

Table 1. Effects of shading on dry weight gains by roots of young 'Fuji' apple trees, 1993 and 1994.

% PPFD	For 1 season			For 2 seasons		
	old	New	Total	old	1,2 years old	Total
100.0	22.5 ± 2.6 ^c	27.9 ± 3.3	50.4 ± 5.6	54.9 ± 1.0	116.7 ± 21.5	171.6 ± 35.3
52.9	15.1 ± 0.8	15.1 ± 2.7	30.2 ± 2.7	29.1 ± 9.7	71.5 ± 22.1	100.6 ± 29.5
34.2	8.4 ± 1.8	5.1 ± 3.0	16.5 ± 4.7	14.9 ± 5.2	46.0 ± 1.2	60.9 ± 14.0
15.8	2.1 ± 2.4	1.6 ± 0.9	3.7 ± 3.3	1.4 ± 0.3	8.3 ± 2.9	9.7 ± 2.9
5.0	-5.3 ± 0.5	0.2 ± 0.1	-5.1 ± 0.5	-7.9 ± 3.2	1.2 ± 1.0	-6.7 ± 3.0

Dry weight of a tree at planting, 68.4 ± 14.1 g.

^c Mean ± standard deviation.

4. Effect of shading on the distribution pattern of dry matter

Among trees under various degrees of shading, those which trees received 5.0% PPFD were not able to sustain their growth. Therefore, we investigated the inter-relationship between the growth of each organ of a tree and shading.

Maggs (1960) found that a stable proportion of dry weight increment was partitioned to stem by leaves of young apple trees exposed to 100 to 24% of full sunlight. In this study, 42.1 to 49.5% of the total tree weight gains were partitioned to the trunk and wood. Compared to leaves and roots, whose rate of increment distribution increases or decreases, respectively, with increasing shading, dry weight gains by the trunk and wood remained remarkably constant (Table 3). Under

5.0% PPFD, the organs of a tree whose dry weight increased during two growing seasons were restricted to leaves and old and new wood; the former gained 9.4g/tree, whereas the latter increased only 1.7g/tree. Consequently, the trees receiving 5.0% PPFD could not maintain the rate distributed to trunk and wood in the other four light levels.

Maggs (1960) found that the total increment in dry weight is linearly related to the increase in stem cross-sectional area, and that shading had little effect on the relationship. A linear regression between the total dry weight increment and the increase in trunk cross-sectional area was obtained in the present experiment ($r=0.983^{**}$) (Fig. 4), except for trees receiving 5.0% PPFD. Trees grown under the deepest shade treatment did not fit the regression line, in spite of a slight increase in trunk cross-sectional area. Thus, the prop-

Fig. 3. Scanning electron micrographs of transections of young 'Fuji' apple leaves exposed to full (left) and 5.0% PPFD (right). (bar=100 μ m)

Fig. 4. Relationships between total dry weight gain and increment of trunk cross-sectional area in young 'Fuji' apple trees grown under 100-15.8% (□) and 5.0% (×) of full PPFD, 1991 and 1992.

Table 3. Effects of shading on distribution of dry matter to various parts in young 'Fuji' apple trees, 1991 and 1992. (%)

% PPFD	Trunk and wood		Leaves		Roots	
	1 ²	2	1	2	1	2
100.0	43.4	49.1	20.5	23.8	36.1	27.1
52.9	47.4	49.5	25.6	26.3	27.0	24.1
34.2	42.1	45.5	31.6	31.8	26.3	22.7
15.8	49.2	45.5	32.4	37.9	18.4	16.6

² 1 : for 1 season, 2 : for 2 seasons.

ortional in the mutual relationship among organs of a tree could not be maintained at 5% PPFD.

In this study, young apple trees required at least 5.0-15.8% PPFD of natural sunlight to maintain their growth (compensation point) in northern Japan. However, Maggs (1960), Priestley (1969) and Jackson and Palmer (1977) found that at a level under 10% of full sunlight, apple trees could maintain a normal growth pattern with respect to dry weight accumulation. Considering these results, the PPFD level needed for sustainable growth of young apple trees in succeeding years lies between 5 and 10% of full sunlight.

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リンゴ幼木の生長に及ぼす遮光の影響

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摘 要

リンゴ'ふじ'幼木の持続的生長に必要な受光率を明らかにするため2年間遮光処理を行い、各器官の乾物増加量の変化と分配および光合成能力について検討した。

1. 光合成有効放射の受光率が自然条件の15.8%以上では各器官の乾物重は増加したが、受光率5.0%では、1年目に根、2年目に根と幹の乾物重が減少し、個体全体の乾物重が減少した。

2. 受光率5.0%における根の乾物重の減少は、台木部と旧根の乾物重が減少することに原因していた。新根は両年とも少量ながら発生した。

3. 遮光処理は光補償点を低下させず、光-光合成曲線の低受光下での傾きを増加させなかった。光飽和点およびその光合成速度は受光率の低下とともに減少した。光合成能力の

低下に最も密接に関係している葉の形態はSLWであった。

4. 乾物増加量の幹+旧枝+新枝への分配率は、15.8%までの受光率では約42.1~49.5%と安定した値を示したが、受光率5.0%ではその割合を維持できなかった。また、幹断面積の増加と個体乾物増加量の間には高い正の相関関係が認められたが ($r=0.983^{**}$)、受光率5.0%の木はその回帰直線に適合しなかった。

以上の結果から、東北地方の気象条件下におけるリンゴ幼木の持続的生長に必要な受光率は5.0~15.8%の間にあると推定された。

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