Fruiting Effects on Leaf Characteristics, Photosynthesis, and Root Growth in Peach Trees

Naosuke Nii
College of Agriculture, Meijo University, Tempaku, Nagoya 468

Summary

Effects of fruiting on leaf characteristics, photosynthesis, and root growth were assessed on small peach trees (Prunus persica (L.) Batsch. cv. Hakuto) after adjusting the number of fruits per tree.

1. Compared to leaves on non-bearing trees, those on fruiting trees were thinner, less wide, and darker green. The more intense green pigmentation indicates that the chlorophyll was more concentrated in leaves of bearing than in those from non-bearing trees. During the fruit maturation stage, former accumulated more starch in the chloroplasts than leaves of the latter as determined by the I-KI staining method, transmission electron microscopy, and starch analysis. The photosynthetic rate per unit leaf area (Pn) was faster in leaves of fruiting limbs during the fruit maturation stage; no significant difference in Pn between leaves of fruiting and defruited branches was detected during Stage II of fruit development.

2. The elongation of new roots in fruiting trees was reduced proportionately to increasing fruit number during the fruit growth period, whereas the new roots on non-bearing trees continued to elongate throughout the vegetative period. At fruit harvest, the total root volume of non-bearing trees was larger and the starch content per root dry weight was higher. On fruiting trees, renewed root growth was observed several days after harvest while the starch in the roots continued to accumulate until the leaves senesced.

Introduction

That photosynthetic rates differed between leaves of fruit trees with and without fruits is well known; fruiting actively promotes the photosynthesis of an individual leaf during the fruit maturation period (Chalmers et al., 1975; Fujii and Kennedy, 1985; De Jong, 1986; Wood, 1988). The reduction in Pn as a consequence of decreasing sink strength through fruit thinning is attributed to increased carbohydrate levels in leaves, a form of feed-back inhibition (Noel, 1970; Milford and Pearman, 1972; Thorne and Koller, 1974; Nafziger and Koller, 1976). The volume of thylakoidal systems changes readily with increased starch grain size in chloroplasts in citrus (Nii, 1987) and peach (Nii and Kuroiwa, 1988) leaves exposed to different light conditions. We found that the enlargement of starch grains led to a reduction in Pn. Similar changes were observed upon comparing activities of apple and peach leaves (Nii, 1989, 1992) on bearing and non-bearing shoots. However, some workers in this field have claimed that the correlation between photosynthetic rate and assimilate level was not definitive (Neals and Incoll, 1968; Carmi and Shomer, 1979; Daie, 1985). As for the photosynthetic activity of leaves on bearing trees over a long period, it is important to study how the starch content in the chloroplast changes in response to fruiting.

Among the various organs in a fruit tree, the fruit is the strongest sink, particularly during the late stage of the fruit development when sugars are accumulated rapidly. If the tree carries a heavy crop until the fruit maturation stage, the growth of the current shoots and new roots is inhibited accompanied by a reduction in starch accumulation by root tissues (Shimizu et al., 1978; Goldschmit and Golomb, 1982; Forney and Breen, 1985). Consequently, it is important to understand...
the relationship between reserve materials and cropping of fruit trees throughout the year because bearing in one year has a carry-over effect into the next season.

The objectives of this study were to determine the effect of fruiting in a peach tree on various leaf parameters, the CO₂ assimilation rate, and the starch accumulation in leaves and roots including new root elongation throughout the vegetative growth period.

**Materials and Methods**

**Experiment I** (1990). Five-year-old own-rooted peach trees (Prunus persica (L.) Batsch. cv. Hakuto) grown in a 30 cm basket and covered with three layers of black polypropylene shade fabric were used. Experiments were started on June 1 at the stage of fruit enlargement when the crop load was adjusted to zero (defruited treatment) and three to seven fruits per tree. Each treatment had seven plants. At harvest, the average number of current shoots per plant was 8.8 ± 2.9; the mean leaf count was 89.8 ± 18.6 on a fruiting plant and 130.0 ± 15.0 on a defruited plant.

The photosynthetic rate (as mg CO₂ • dm⁻² • hr⁻¹) was measured several times on June 6, July 7, and July 13 between 7:00 a.m. and 1:00 p.m. with the Koito portable CO₂ gas analyzer (KIP-85SC). The 5th and 7th fully expanded leaves from the shoot base were used.

**Experiment II** (1991). During the second year, similar peach trees in 30 cm root-boxes (one side with glass) were used. On May 14, the crop load on 30 uniform trees was adjusted to 0, 3, or 5 fruits per tree. Each plot had 10 trees. New lateral shoots which pushed continually were not removed. Fruit diameters on each tree were measured at weekly intervals from June 8 to July 22 (fruit harvest date). At maturity, the fruits were weighed, and their soluble solids content determined with a hand refractometer. The photosynthetic rate of the fifth and seventh basal leaves was measured several times during the season, as in Experiment I.

The average leaf area and dry weight per unit leaf area; morphological and anatomical data; chlorophyll content of the leaves were ascertained at harvest as in the previous paper (Nii and Kuroiwa, 1988). Leaf sections (1.5 μm thick) were stained with methylene blue and I-KI solution to determine starch accumulation. The ultrastructure of the chloroplast was also studied by electron microscopy. After freeze drying the leaves under a vacuum, the total sugars were extracted with 80% ethyl alcohol at 80°C. The starch in the alcohol insoluble solids was digested by glucoamylase and the resulting sugar analysed by the anthrone method.

The elongation of new roots appearing on the glass surface of the root-box was measured at weekly intervals from June until the leaf-abscission. At harvest, half of the plants in each treatment were sampled to determine root volume and starch content in the roots. Root elongation on the remaining plants was observed until leaf abscission. The root volumes of plants on July 22 (fruit harvest date) and on November 5 (leaf abscission stage) among treatments were compared via photographs. Starch and total sugar contents in the roots and microscopic observations of the root tissues were determined as above.

**Results**

**Experiment I.** The newly rising shoots were allowed to grow so that the total number of leaves per plant differed among treatments. The promotive effect of fruiting on Pn was significant, especially during the sugar accumulation stage of the fruit (Fig. 1).

**Experiment II.** At harvest, fruits of the 3-fruit treatment were larger and contained 2% more soluble solids than those of the 5-fruit treatment; the size difference persisted over the entire fruit growth period (Table 1). However, total fruit weight per tree was larger for the 5-fruit treatment.

On July 22, leaf area and leaf thickness decreased with fruiting (Table 2, Fig. 2). The chlorophyll content per unit leaf area, was significantly higher in fruiting than in defruited plants. The higher concentration is attributed to the leaves from the fruiting trees being less wide and thinner than leaves from defruited trees. The average shoot (total length per tree) was 215.0 cm on defruited plants, 183.8 cm on 3-fruit plants, and 133.3 cm on 5-fruit plants.

The distribution and the sizes of starch grains in the chloroplasts of fruiting and defruited leaves differed (Figs. 2, 3) in that starch grains in the palisade and spongy mesophyll cells of leaves from
defruited trees were readily visible, whereas they were less prominent in leaf tissues from bearing trees. The difference in starch accumulation was especially noticeable in the spongy and bundle sheath cells. These visual differences were confirmed by chemical analyses of the leaves.

The change in Pn of an individual leaf varied according to its light exposure, the Pn of leaves on the fruiting shoots being higher than that on the defruited shoots during the sugar accumulating stage of the fruit (Fig. 4). However, on June 14, there was no detectable difference on the rate of photosynthesis as related to the crop load.

New root elongation stopped during the fruit maturation stage (Fig. 5). In the 5-fruit trees new root elongation completely stopped during the fruit growth period, whereas in defruited trees the new roots continued to elongate throughout the tree growth period until the leaves abscised. The root volume of fruiting trees at fruit harvest was smal-

Table 1. Effect of varying the fruit number per tree on fruit size and soluble solids in the juice at fruit harvest date (July 22) in peach trees.

<table>
<thead>
<tr>
<th>Number of fruit per tree</th>
<th>Fruit fresh weight (g)</th>
<th>Fruit diameter (cm)</th>
<th>Soluble solids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Longitudinal</td>
<td>Transverse</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>159.6</td>
<td>6.3</td>
<td>6.5</td>
</tr>
<tr>
<td>3</td>
<td>203.5</td>
<td>6.8</td>
<td>7.0</td>
</tr>
<tr>
<td>L. S. D. 5%</td>
<td>27.3</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>1%</td>
<td>39.8</td>
<td>0.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 2. Effects of fruiting on peach leaf characteristics at harvest (July 22).

<table>
<thead>
<tr>
<th>Number of fruit per tree</th>
<th>Leaf area (cm²)</th>
<th>Total chlorophyll (µg cm⁻²)</th>
<th>Sugar content (% DW)</th>
<th>Starch content (% DW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>165.3</td>
<td>47.3</td>
<td>5.9</td>
<td>3.4</td>
</tr>
<tr>
<td>3</td>
<td>215.8</td>
<td>35.0</td>
<td>6.3</td>
<td>6.8</td>
</tr>
<tr>
<td>0</td>
<td>15.6</td>
<td>2.9</td>
<td>NS</td>
<td>1.3</td>
</tr>
<tr>
<td>L. S. D. 5%</td>
<td>22.2</td>
<td>4.2</td>
<td>NS</td>
<td>1.9</td>
</tr>
</tbody>
</table>
N. Nii

The difference in starch level between fruiting and defruited plants also appeared in the root cells at fruit harvest, the starch content in the roots of fruiting plants was less than that in the roots of defruited trees (Fig. 7A, 7B, Table 3). After fruit harvest new roots resumed growth within a week (Fig. 5) and starch deposition in the root also began to accumulate until leaf abscission (Fig. 7C, 7D). At the leaf abscission stage, the starch content of the root on a dry weight basis was greater in fruiting trees than it was in defruited trees (Table 3), even though the root volumes of fruiting trees were still a little smaller than those of defruited trees (data not shown).

Discussion

Fruiting and non-bearing peach trees displayed different morphological features; leaves of heavily cropped plants were more horizontally oriented than those of defruited ones. Fruiting promoted the photosynthetic rate of the leaves and carbohydrate partitioning, viz. the accumulation of starch in the leaves and roots, especially during the fruit maturation stage. The present data indicate that fruiting strongly influences not only Pn but also the anatomical and morphological features of the leaves, including root growth and starch accumulation.

The presence of fruits significantly influenced the chlorophyll content and starch accumulation in...
In leaves of defruited trees the chloroplasts contained an abundance of starch grains. These results were similar to a) the effects of shade on citrus (Nii, 1987) and peach (Nii and Kuroiwa, 1988) leaves and b) in leaves of fruiting and defruited on the girdled shoots in apple (Nii, 1989) and peach (Nii, 1992). These findings agree with those of Ballantine and Forde (1970), Melis and Harrey (1981), and Wilkinson and Beard (1975). In defruited
peach trees, the reduction of chloroplast compartment including thylakoid layers and increased size of starch grains in the chloroplasts may lead to reduced Pn. The percentages of the chloroplast compartment area per cross-section of a chloroplast from leaves of defruited trees were 48.8% in spongy cell and 50.5% in palisade cell, whereas the percentages were 91.4% and 83.5%, respectively, in leaves of fruiting trees. The Pn of leaves from fruiting and non-bearing trees are similar to that reported by Hansen (1970), Chalmers et al. (1975), Fujii and Kennedy (1985), De Jong (1986), and Wood (1988). However, other researchers using other plant species have questioned the effects of carbohydrate accumulation in leaves on the photosynthetic rate (Ballantine and Forde, 1970; Wilkinson and Beard, 1975; Geiger, 1976; Hariri and Brangeon, 1977; Carmi and Shomer, 1979; Melis and Harvey, 1981; Lichtenthaler et al., 1982). Daie (1985) suggested that an increase in the photosynthetic rate with increasing sink demand is not a typical response in short-term studies because there is a need for adjustment within the plant. She claims that the response of feedback inhibition, which results from a build-up of carbohydrates in the leaves, is generally observed in longer-term experiments. My finding supports that argument. Among the various mechanisms that influence the photosynthetic potential in the leaf cells of peach, the starch accumulation in the chloroplast may be considered as a principal one.

In the present study, the total growth of the new roots at the stage of fruit harvest was larger in defruited trees. Differences in starch accumulation by the roots at fruit harvest were significant among treatments. Less starch accumulated in fruiting trees than it was in non-bearing trees. Within a week after harvest, new roots appeared on the glass surface of the root-box as reported for apples (Head, 1969). Furthermore, in the 5-fruit per tree plot, the elongation rates of new roots after harvest were faster than they were on non-bearing trees.

The appearance of starch grains in the roots of plants at the leaf abscission stage was independent of treatments. The starch content per unit dry weight of roots from a bearing tree at this stage was slightly higher than it was in roots from defruited trees. In fruiting peach trees, the root

<table>
<thead>
<tr>
<th>Number of fruit per tree</th>
<th>At fruit harvest (% DW)</th>
<th>At leaf abscission (% DW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sugar content</td>
<td>Starch content</td>
</tr>
<tr>
<td>5</td>
<td>6.1</td>
<td>3.4</td>
</tr>
<tr>
<td>3</td>
<td>5.6</td>
<td>2.4</td>
</tr>
<tr>
<td>0</td>
<td>6.7</td>
<td>5.7</td>
</tr>
<tr>
<td>L. S. D. 5%</td>
<td>NS</td>
<td>1.3</td>
</tr>
<tr>
<td>1%</td>
<td>NS</td>
<td>1.9</td>
</tr>
</tbody>
</table>

![Fig. 7. Photomicrograph of peach root sections showing starch accumulation in that from a 5-fruit plot (left: A and C) and non-bearing plot (right: B and D) at fruit harvest (upper: A and B) and at leaf abscission stage (lower: C and D).](image-url)
growth and starch accumulation by roots were renewed until leaf abscission. Nevertheless, the root volume of fruiting trees was smaller than that of defruited trees. In the case of satsuma mandarin which exhibits alternate bearing, root growth and the starch accumulation in roots in fruiting trees did not resume until winter (unpublished data). This phenomenon may be related to greater tendency toward alternate bearing in satsuma mandarin than peach trees. The present study gives some insight into the problems of carbohydrate balance in alternate bearing trees, as suggested by Goldschmit and Golomb (1982).

**Literature Cited**


着果がモモの葉の形質と光合成，根の生長に及ぼす影響

新居 直祐

名城大学農学部 468 名古屋市天白区

摘　要

1樹当たりの着果数を変えたモモ樹の小さい個体を用いて，着果が葉の形質と光合成速度および根の生長に及ぼす影響を検討した。

無着果樹に比べて，着果樹では果実数が増加するにつれて，葉は薄く，着生角度もほとんど水平になるとともに，濃緑色を呈した。すなわち，葉面積当たりのクロロフィル含量は着果によって高くなった。1-KI染色法や透過型電子顕微鏡，デンプン分析などの手法から，果実成熟期における葉緑体中のデンプン蓄積は，無着果葉の方が着果葉に比べて顕著であった。果実成熟期における単位葉面積当たりの光合成速度は着果葉で高く，果実肥大の第II期ではその差異は明白でなかった。

果実の発育期間における新根の伸長は着果数の増加に対応して低下した。これに対して無着果樹では，樹の発育期間を通じて新根の伸長は顕著であった。果実の収穫期では，無着果樹の根量は着果樹に比べて大きく，根中のデンプン含量も高かった。着果樹では果実収穫後両根は伸長し，落葉期における根のデンプン含量も高くなった。