Yields and Factors Affecting the Yield Fluctuation of Early Ripening Satsuma Mandarin in Greenhouse Culture

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In greenhouses heated from early December (plot A) and early January (plot B), and in an open field (plot C), early ripening satsuma mandarin ‘Miyagawa Wase’ and ‘Okitsu Wase’ trees were densely planted in sub plots in combination with organic substance application (1.5 t/10 a/year of rice straw and twice as much rice straw as normal) and fertilizer application (N: 27, P2O5: 24, K2O: 22 kg/10 a/year and 1.5 times the recommended rate). Yields and factors which affect the yield fluctuation were analyzed by employing data from 3 years old, the following year of planting, to 12 years old. There was no significant difference in the yield, leaf area index (LAI), flower-bud count, and other various parameters between organic substance treatments or between fertilizer treatments. Though plot A showed an appreciable yield fluctuation and reduction in yield due to removing filler trees, this cultivation system showed a greater potential yield compared to plot B. LAI in ‘Okitsu Wase’ was larger than that in ‘Miyagawa Wase’ until the filler trees were removed, so the initial yields of the former tended to be slightly higher. Relationships between some factors vs. yield per unit land area were determined. The results clearly indicated that LAI was the strongest factor affecting yield in different growing conditions (plots A, B, and C) and cultivars (‘Miyagawa Wase’, ‘Okitsu Wase’). The trees growing in the greenhouse heated from early December (plot A) had a small number of flower buds, but they represented high fruit set percentages and showed a comparatively strong correlation between the number of flower buds and yield.

Key Words: dense planting, greenhouse, leaf area index, satsuma mandarin, yield.

Introduction

Greenhouse cultivation of satsuma mandarin was initiated in about 1970 in Kagawa prefecture (western Japan) and has widely expanded to citrus-producing areas owing to its adequate returns with the improvement of commercial cultivation techniques (Owada, 1980). The cultivating area and fruit production of satsuma mandarin in greenhouses were estimated to be 1200 ha and 56700 t (4.7 t/10 a) in 2003, respectively (Japan Horticulture Cooperative Federation, 2004, Statistics of fruit trees) and greenhouse cultivation is regarded as important for farm management. The system calls for a kind of high investment-growing as the equipment costs much and the consumption of oil is large, and the starting time of heating and temperature control directly affect its gains (Kami et al., 1999). Therefore, many studies on temperature conditions which affect flower-bud formation and fruit set percentage were undertaken (Shimoosako et al., 1981; Susaki et al., 1993; Taniguchi, 1983; Zyuri and Kato, 1977). In greenhouse culture, cultivators came to start heating earlier to avoid competition with the growing districts and to divide harvesting labor. Subsequently, a decrease in crop production has become a problem due to poor sprouting and flower budding after heating (Susaki et al., 1993; Zyuri and Kato, 1977). Meanwhile, an observation of greenhouses which had started heating earlier indicated that trees recovered vigor and improved flower-bud formation as harvest ended sooner (Susaki et al., 1993). In regard to cultivars of early ripening satsuma mandarin to be employed in greenhouses, ‘Okitsu Wase’ is supposed to grow bigger and more vigorously than ‘Miyagawa Wase’ (Yamaguchi, 1977). The yield in greenhouses reaches 6.7 t/10 a or more (Nii et al., 1984) and these crops are fairly larger than the previously mentioned fruit statistics (4.7 t/10 a).

The above-mentioned examples summarize one or a few year’s research. Early ripening satsuma mandarins often fall into a biannual bearing habit and tree age largely affects the yield, so the experimental results are required to be considered during the long period of
growth from nursery plants to mature trees. Accordingly, densely planted ‘Miyagawa Wase’ and ‘Okitsu Wase’ trees were grown from 3 years old (1991) to 12 years old (2000) in two greenhouses, one heated earlier from the beginning of December (plot A) and another heated later from the beginning of January (plot B), and the other in an open field (plot C). Ten consecutive years of data were employed to determine crop production and factors which affect yield fluctuation. The experimental design consisted of a factorial combination of 2 levels of organic substance application and 2 levels of fertilizer application in the above 3 different growing conditions (plots A, B, and C).

**Materials and Methods**

In a field of flat clay loam, the 3 main plots with different growing conditions: greenhouses heated from early December (plot A), heated from early January (plot B), and an open field (plot C) were divided into 4 sub plots, of which 2 sub plots were assigned to a normal application of organic substance and the other 2 sub plots were assigned to larger applications of organic substances. Additionally, in each of the 2 sub plots, one was applied with a normal rate of fertilizer, and the other was applied with a larger rate of fertilizer. Early ripening satsuma mandarin trees, ‘Miyagawa Wase’ and ‘Okitsu Wase’, were planted in each of the 4 sub plots. Two year old trees grafted on trifoliate orange rootstocks were set out in May 1990 in a dense planting configuration, as seen in Figure 1. The numbers of trees employed per sub plot were 7 or 8 of each cultivar, including 2 or 3 filler trees, 2 semipermanent trees, and 3 permanent trees.

The plots with a normal application of organic substance were mulched with 1.5 t/10 a/year of rice straw, and the other plots with a larger amount of organic substance were mulched with twice as much rice straw as the normal application plots. Both plot trees were given an annual application of 50 kg/10 a dolomite and completely plowed, followed by mulching. In the plots with a normal application of fertilizer, the recommended rate of fertilizer application in Chiba prefecture, Japan (N: 27, P₂O₅: 24, K₂O: 22 kg/10 a/year) was applied by splitting it into three applications. In the plots with a larger rate of fertilizer application, 1.5 times the fertilizer application rate (40, 33, and 36 kg/10 a/year) compared to the normal plots was applied in the same manner.

Although each sub plot was not surrounded by buffer rows of trees to avoid border effects, partition walls of vinyl board were used at the borders of plots, which were 20 cm in height through 70 cm in depth. In the greenhouses, soil moisture was controlled by surface irrigation, and pF (measured at 20 cm in depth) was in the range of 1.5 to 2.8 which was regulated by irrigation and suspension. Irrigation was suspended from mid May until the end of harvest and was resumed after the harvest.

As mentioned above, the field experiments were

![Fig. 1. The planting arrangement in a dense planting system where ‘Miyagawa Wase’ and ‘Okitsu Wase’ trees were set out in 5 rows spaced 2.0 m apart and 3 rows spaced 1.4 m apart. ‘Miyagawa Wase’: 1–7 or 8. ‘Okitsu Wase’: 8 or 9–15. Filler trees: 6–10. Semipermanent trees: 2, 4, 12, and 14. Permanent trees: 1, 3, 5, 11, 13, and 15.](image)

<table>
<thead>
<tr>
<th>Growing condition (Site)</th>
<th>Depth (cm)</th>
<th>Three phase distribution</th>
<th>Hardness (mm)</th>
<th>pH (H₂O)</th>
<th>Ignition loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Solid phase (%)</td>
<td>Liquid phase (%)</td>
<td>Gaseous phase (%)</td>
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<tr>
<td>A</td>
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<tr>
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<td>50</td>
<td>33.2</td>
<td>51.6</td>
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<td>19.5</td>
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<td>Significance</td>
<td>Site (S)</td>
<td>NS</td>
<td>**</td>
<td>NS</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>Depth (D)</td>
<td>NS</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

All results presented are the average of 36 measurements.


** Determined at pF 1.5.

NS, ** indicate nonsignificant, or significant at P<0.01 by F test.
conducted on blocked split plots with 3 different growing conditions: early heated and normally heated greenhouses (plots A and B) or an open field (plot C), and involved a combination of 2 levels of organic substance application, 2 rates of fertilization application, and 2 different cultivars.

Physical and chemical properties of the soil in the experimental field are shown in Table 1, which were investigated according to the accepted method in 1990 (the year before the experiment started).

Both greenhouses (plots A and B) employed in this experiment were 10 m \times 30 m in size, roofed over with Fiberglass Reinforced Plastic (FRP) of 0.8 mm thickness, and walled off by vinyl sheets (the year round covering culture). Heating of plots A and B started in early December and January, respectively, and stopped together in late May. The greenhouses were kept in the minimum air temperature range, 18 to 22°C. When the temperature reached 28°C or more, the double layer covering was rolled up and the top ventilators were opened. At even higher temperatures, ventilating fans worked to control the temperature.

Yields and other various parameters were measured every year in all 3 year old trees in the following year of planting. Fruit was harvested from late July to mid August in plot A, from mid August to early September in plot B, and from early to late November in plot C. Fruit thinning was done in accordance with recommendations for the fruit to leaf ratio: 15 in plots A and B (Kawano, 1988) and 35 in plot C (Tachibana et al., 1987).

Leaf size and LAI were obtained using the following method. Old and new leaves of all trees were counted before and after foliation, respectively. Calculation of weight per leaf was made from all leaves on removed branches at the time of pruning after fruit harvest. Leaf sizes in each main plot were computed according to a regression equation: \( y = 28.17x^{0.3877} \), where leaf weight is \( x \) g and leaf size is \( y \) cm\(^2\) (Hirano et al., 1969). Thereafter, the total leaf area of a tree was calculated based on leaf size and the total number of leaves. LAI was obtained by the total leaf area (m\(^2\)) and given land space for canopy spread of a tree (m\(^2\)/m\(^2\)). Table 2 shows the leaf weight and leaf size used for LAI calculation.

Flower buds and young fruits were counted before and after foliation in order to calculate the fruit set percentage. The chlorophyll content was measured by a colorimeter (SPAD-502 MINOLTA, Japan) using 100 old leaves which were collected in each sub plot before fruit harvest. These measurement values were given as indices of the chlorophyll content and do not represent actual values.

In our experiment, trees were planted densely, therefore, temporary trees were removed successively to alleviate overcrowding. Filler trees of ‘Miyagawa Wase’ and ‘Okitsu Wase’ were removed at 7 years old in plots A and B, and at 10 years old in plot C. Semipermanent trees of both cultivars were removed at 9 years old in plots A and B, but were not removed in plot C because canopies spread slowly, even when observations were finished at 12 years old.

Even though an analysis of variance of annual measurements and its averages for 3 to 12 years of age was done in the organic substance and fertilizer application plots, the results of analysis indicated that no significant differences were evident at almost all tree ages. Also, no interactions between the cultural condition and cultivar were recognized. Accordingly, most results of these studies represent differences in the growing conditions and cultivars, which are the main effects.

**Results**

**Yearly change of yield and leaf area in permanent trees**

The yearly change of yield per permanent tree is displayed in Figure 2. Comparing yield among different growing conditions, the yield of plot A decreased markedly when trees were 6 and 9 years old, but progressed generally to the highest level through the experimental period. The yield of plot B was generally higher than that of plot C until 9 years old, but decreased thereafter. The yield of plot C increased linearly and slowly, with less irregular bearing than other plots.

There was no significant difference in the yields of ‘Miyagawa Wase’ and ‘Okitsu Wase’, but the yield of the latter was slightly higher during 3 to 7 years old.

As seen in Figure 3, the leaf area of permanent trees of plot A increased annually until the trees were 10 years old, and then tended to level off. It was higher than in plots B and C through the trial period. The leaf area of plot B increased continually until 7 years old, and was higher than that of plot C. But, as it declined sharply when trees were 8 years old, the difference from plot C

### Table 2. Leaf weight and leaf size used for computing LAI in the different growing conditions and cultivars.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Miyagawa</td>
<td>Okitsu</td>
<td>Miyagawa</td>
</tr>
<tr>
<td>Leaf weight(^a) (g/leaf)</td>
<td>0.687</td>
<td>0.779</td>
<td>0.691</td>
</tr>
<tr>
<td>Leaf size(^b) (cm(^2)/leaf)</td>
<td>20.2</td>
<td>28.1</td>
<td>20.3</td>
</tr>
</tbody>
</table>

\(^a\) The leaf weight was calculated by (leaf weight)/(leaf count) of the total pruned branches in all trees. The data are the averages across the ten years of the study.

\(^b\) The leaf size was calculated using the relative growth equation from the values of the leaf weight.
was not clear. The leaf area of plot C increased linearly until trees were 10 years old, and then showed a more or less stabilized value.

Comparing the leaf area per permanent tree of ‘Miyagawa Wase’ with ‘Okitsu Wase’, that of the latter was significantly larger at almost all ages.

**Yearly change of yield per unit land area and that of leaf area index (LAI)**

The annual yield per unit land area in Figure 4 was calculated by the yields of filler, semipermanent, and permanent trees, and the corresponding number of planted trees per unit land area. Parameters presented by unit land area mentioned later were obtained in the same manner. As to the yearly change of yield per unit land area, plot A showed the most remarkable increase from 3 years old toward a maximum (11.3 kg·m$^{-2}$) at 5 years old. Furthermore, plot B reached a peak (8.8 kg·m$^{-2}$) at 6 years old and plot C peaked (7.9 kg·m$^{-2}$) the following year. After that, all plots showed a tendency to decrease from 8 to 10 years old. The yield of plot A decreased to 3.8 kg·m$^{-2}$ at 9 years old, plot B to 1.8 kg·m$^{-2}$ at 10 years old, and plot C to 6.4 kg·m$^{-2}$ at 8 years old. Following the decrease, the yields of all plots tended to slightly increase or level off, and plots A and B rose to 4.5 and 3.0 kg·m$^{-2}$ at 12 years old, respectively. Although at 4 and 5 years of age the yields showed A > B > C, at 10, 11, and 12 years of age they showed C > A > B.

The yield per unit land area in ‘Okitsu Wase’ was significantly higher than that in ‘Miyagawa Wase’ at 3, 6, and 7 years old. The pattern of yearly change through 3 to 7 years old was different from that through 8 to 12 years old. The yield of ‘Okitsu Wase’ had a tendency to be slightly larger than that of ‘Miyagawa Wase’ from 3 to 7 years old.

LAI showed a similar yearly change to yield per unit land area (Fig. 5). LAI in plot A, followed by plot B, markedly increased starting from when trees were 3 years old, and peaked at 6 years old (LAI: 5.7) and at 7 years old (5.9), respectively. LAI of plot C peaked at 8 years old (LAI: 5.0). Then, LAI in each plot decreased until 8 to 10 years old and subsequently leveled off. LAI of plots A, B, and C declined to 2.7 at 10 years old, 1.9 at 8 years old, and 3.8 at 9 years old, respectively. Although at 5–6 years of age, LAI showed A > B > C, at 10–12 years of age it showed C > A > B.

Comparing LAI between the two cultivars, a pattern of yearly changes seems to be approximated. However, LAI of ‘Okitsu Wase’ was significantly larger than that
of ‘Miyagawa Wase’ through the test period. The difference in LAI between the cultivars tended to be greater with the advancement of tree age at 3–7 years old.

**Yearly change of weight of pruned material per unit land area**

Figure 6 presents the fresh weight of pruned material per unit land area plus removed filler and semipermanent trees (temporary trees) in the different growing conditions and cultivars. The pruned weight was calculated by the weight of thinned branches + leaves from all filler, semipermanent, and permanent trees, and that of removed trunks, branches, and leaves from the temporary trees.

The pruned weight in plots A and B increased abruptly from 3 years old and peaked at 7 years old when the filler trees were removed. The pruned weight the next year decreased considerably, but increased the following year when the semipermanent trees were removed. The pruned weight in plots A and B was small at 10–12 years old because pruning was applied to the permanent trees which were expected to spread their canopies. The pruned weight when trees were 7 years old was \( A < B \), but at 9 years old it was reversely \( A > B \). The pruned weight in plot C did not increase noticeably like that of plots A and B until 9 years old. It peaked at 10 years old when the filler trees were removed, and in the next year, the pruned weight showed almost the same levels in plots A and B.

Comparing the pruned weight of both cultivars, that of ‘Okitsu Wase’ was larger than that of ‘Miyagawa Wase’ at 7 and 9 years old when the filler and semipermanent trees were cut down. Generally, the former was more prone to be larger than the latter from 3 to 9 years old.

**The average of yield, LAI, flower count, and other relative growth factors through the experimental period**

Reviewing the averages over the ten years under the different growing conditions (Table 3), the yields per unit land area and LAI showed \( A > C > B \). Conversely, the yields per LAI showed \( B > A > C \). The flower count per unit land area and that per LAI were equally \( A < B < C \), but the fruit set percentage and pruned weight were reversely \( A > B > C \). The SPAD value was \( A = B < C \).

Aspects studied in either case in relation to the organic substance and fertilizer treatments showed no significant differences. As to the SPAD value, some difference between the normal application and increased application in fertilizer was seen, but it was not significant.

In the two cultivars, the yield, LAI, flower count, and
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Pruned weight which were represented per unit land area clearly indicated ‘Okitsu Wase’ > ‘Miyagawa Wase’. The yield/LAI, flower count/LAI and SPAD values conversely indicated ‘Okitsu Wase’ < ‘Miyagawa Wase’. The fruit set percentage showed no significant differences.

**Relationship between each factor vs. yield per unit land area**

Figure 7 illustrates the quadratic relationships between LAI and yield per unit land area. Data were pooled while trees were from 3 to 12 years old. Data in each plot in relation to organic substance and fertilization application were merged together for replications. The sample size was 80 each in plots A, B, and C and 120 each in both cultivars.

The relationships between LAI and yield per unit land area showed a highly significant regression in each growing condition and cultivar. Correlation coefficients \((R^2)\) between LAI and yield per unit land area summarized in Table 4 ranged from 0.474 to 0.705 in plots A–C and were about as large as 0.6 in the cultivars. With regard to the relationship between factors other than LAI such as the flower count vs. yield in Table 4, the yield per LAI showed a significant correlation in all treatment plots, but the value was as small as 0.113 in plot B. The coefficients of the flower count, fruit set

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**Table 3. Statistical analysis of the ten-year averages regarding tree performance per unit land area.**

<table>
<thead>
<tr>
<th>Growing condition</th>
<th>Organic substance application rate</th>
<th>Fertilizer application rate</th>
<th>Cultivar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A Normal (N)</td>
<td>B 2 N</td>
<td>C 1.5 N</td>
</tr>
<tr>
<td>Yield per unit land area (kg·m(^{-2}))</td>
<td>5.42b</td>
<td>4.28a</td>
<td>4.99b</td>
</tr>
<tr>
<td>LAI</td>
<td>3.34b</td>
<td>2.49a</td>
<td>3.16b</td>
</tr>
<tr>
<td>Yield per LAI (kg·m(^{-2}))</td>
<td>1.65a</td>
<td>1.77b</td>
<td>1.61a</td>
</tr>
<tr>
<td>Flower count per unit land area (flower buds/m(^2))</td>
<td>156a</td>
<td>320b</td>
<td>606c</td>
</tr>
<tr>
<td>Flower count per LAI (flower buds/m(^2))</td>
<td>48a</td>
<td>174c</td>
<td>193c</td>
</tr>
<tr>
<td>Fruit set percentage (%)</td>
<td>40.9c</td>
<td>25.5b</td>
<td>11.4a</td>
</tr>
<tr>
<td>Pruned weight per unit land area (g·m(^{-2}))</td>
<td>1185b</td>
<td>1047b</td>
<td>569a</td>
</tr>
<tr>
<td>SPAD value</td>
<td>70.3a</td>
<td>70.3a</td>
<td>74.9b</td>
</tr>
</tbody>
</table>

There was almost no significant interaction between factors in each growth and product character; therefore, the interactions are not presented. A, B, and C are the same as in Table 1.

\(^*\) Normal: rice straw mulch at 1.5 t/10 a/year.

\(^\gamma\) Normal: recommended application at a rate of 27 kg N, 22 kg P, and 24 kg K/10 a/year. N, P, and K were applied as ammonium sulphate, super phosphate of lime, and potassium chloride, respectively.

\(^\delta\) SPAD value: indices of chlorophyll content measured by a colorimeter.

NS, *, ** indicate nonsignificant, or significant at \(P<0.05\), or \(P<0.01\) by F test. Means followed by the same letter are not significantly different at \(P<0.05\) by F test.
Fig. 7. Relationships between LAI and yield per unit land area in the different growing conditions (left) and cultivars (right). Denotation of the growing conditions and significance is the same as in Figure 2.

Table 4. Correlation coefficients ($R^2$) between LAI, flower count, and other factors vs. yield per unit land area.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Growing condition</th>
<th>Cultivar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>LAI</td>
<td>0.474**, 0.568**, 0.705**</td>
<td>0.545**, 0.113**, 0.557**</td>
</tr>
<tr>
<td>Yield per LAI (kg)</td>
<td>0.545**, 0.113**, 0.557**</td>
<td>0.542**, 0.088*, 0.377**</td>
</tr>
<tr>
<td>Flower count</td>
<td>0.545**, 0.113**, 0.557**</td>
<td>0.542**, 0.088*, 0.377**</td>
</tr>
<tr>
<td>Fruit set percentage (%)</td>
<td>NS</td>
<td>0.111*</td>
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<tr>
<td>Pruned weight (kg)</td>
<td>0.284**, 0.515**, 0.363**</td>
<td>0.344**, 0.284**</td>
</tr>
<tr>
<td>SPAD value</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

* A, B, and C are the same as in Table 1.
** NS, *, ** indicate nonsignificant, or significant at $P<0.05$, or $P<0.01$ by F test.
percentage, and SPAD value were not significant or small in many cases. Exceptionally, the flower count was as large as 0.542 in plot A. The correlation coefficients for pruned weight ranged from 0.284 to 0.515. Those were comparatively larger.

**Discussion**

**Yield responding to the growing conditions**

Firstly, yields and leaf areas of the permanent trees were compared between treatments assuming that the results with permanent trees directly responded to the treatments, because in the dense planting system, the permanent trees are managed to spread their canopies, which is entirely opposite to the case of filler trees. According to the yearly change in the yield under different growing conditions (Fig. 2), plot A showed apparent off-years at 6 and 9 years old, but generally exhibited the highest sustained yield through the test period. Also, the transition at the highest levels of leaf area of the permanent trees was recognized in plot A (Fig. 3). The leaf area in plot B decreased markedly when the trees were 8 years old. This is because severe pruning was performed since the leaf amount increased owing to the off-year at 7 years old, and in the following year the trees generated less new leaves due to the large crop in the on-year. Anyhow, the leaf amount and yield in plot A are expected to be maximal in the 3 plots when the dense planting attains the final density after removing all temporary trees.

The yields per unit land area (Fig. 4) could be summarized in general as $A > B > C$ for the first 5 years. Plots A and B were inferior to plot C in the yield after 9 years old, which may be a reflection of a greater LAI reduction in plots A and B simply due to removing the filler trees at 7 years old and semipermanent trees at 9 years old. Since the yield per permanent tree of plot A was higher than that of plot C, plot A is expected to produce more fruit per unit land area than plot C in a few years provided that the filler trees are removed at an appropriate time to control overcrowding, as described later.

Nii et al. (1984) observed that mandarin trees in greenhouses may produce 6–7 t/10 a or more fruit. In our experiment, the trees in the greenhouse heated from early December (plot A) yielded more than 6 t/10 a from 4 to 8 years old, and high levels of 11.3 and 8.6 t/10 a at 5 and 7 years old, respectively. The average yield of the test period was 5.4 t/10 a, which is larger than that of the mandarin crop in 2003 in greenhouses: 4.7 t/10 a, as mentioned before.

Plot A was inferior to plot B in regard to yield per unit land area at 3, 6, and 9 years old, but was superior to it at the other tree ages (Fig. 4). The average yield per unit land area through the ten years represented A (5.42 kg·m$^{-2}$) > B (4.28 kg·m$^{-2}$). Kawano (1987) stated that a greenhouse heated from mid or late November results in an arbitrary number of flower buds, thus indicating the need to establish a technical system to stabilize the crop. The reduction of flower buds was supposed to be associated with reduced exposure to a low temperature period necessary for flower-bud initiation. In our experiment, although the trees in the greenhouse heated from early December (plot A) showed appreciable fluctuations and reductions in yield, the cultivation system showed a greater promise of yield compared to that heated from early January (plot B). As seen in Table 3, the trees in plot A maintained a necessary amount of flower buds to set, because the high fruit set percentage substituted for the actual reduction in flower buds.

**Progress of LAI and the suitable time for removing filler trees**

Both leaf area per permanent tree and leaf area per unit land area (LAI) represented $A > B > C$ in the first 4 years (3–6 years old), and LAI reached its peak at 6, 7, and 8 years old, respectively. This is elucidated by the facts that the trees in plots A and B grew more vigorously than those in plot C and leaf size was larger in plots A and B than that in plot C. Accordingly, the canopies in plots A and B were so crowded that the removal weight by pruning and cutting down was larger.

LAI of plot C did not decrease so much in the year after cutting down the filler trees (11 years old). But LAI of plots A and B decreased markedly in the year after thinning the trees (8 years old). The cause of the different degree of LAI reduction is probably as follows.

In the dense planting system in an open field, when the peripheries of canopies of the filler and permanent trees begin to touch each other, the filler trees receive normal cutting back pruning and are removed a few years later as the canopies of permanent trees spread. By this means, a small reduction in LAI occurs just after thinning the filler trees, since the canopies of the filler trees diminish inversely as those of the permanent trees spread.

Trees in greenhouses produce many long shoots compared with those in open fields. Long shoots of the filler trees touching or interlocking with canopies of the permanent trees receive training (hanging) without thinning to be used as bearing shoots next year. Consequently, the filler trees in the greenhouses do not decrease the amount of leaves even in a fully crowded state, unlike trees in an open field, so LAI in the greenhouses sharply declines after the removal of filler trees. Besides, the many trained branches in the remaining trees were pruned for renewal, which probably contributed to the appreciable decrease in LAI. To control the large decrease in LAI, in the case of using long shoots as fruit bearers, thinning-out pruning should be done in lower positions after harvest to inhibit canopy spread and maintain the amount of leaves inside the canopies.

Plot B showed a markedly decreased LAI after
thinning the filler trees at 7 years old, and then showed a retarded recovery of LAI more markedly than that of plot A. This fact is probably attributable to some observations that plot B necessitated severe pruning to alleviate excessive shading in the off-year of the existing trees, and summer and fall shoots decreased because the time of pruning of plot B was more than 3 weeks later than that of plot A.

In our experiment, the nursery stocks were planted at a distance of 2.0 m between rows and 1.4 m between plants within a row. When LAI in plot C reached a peak at 8 years old, the canopies within the rows were overshadowed, but the canopies between the rows were spreading to touch each other. LAI of plot C was 5.0 at 8 years old and 3.8 at 9 years old, not markedly large, but the pruned weight was large because the canopies within the rows were overshadowed. After removing the filler trees at 10 years old, a large reduction of LAI in the next year of plot C did not occur in the same way as in plots A and B. This may probably account for the difference in leaf amount of the existing trees, which appears to be due to the delay of spreading canopies and more compactness of tree shapes in plot C than in plots A and B. LAI in plots A and B rose to 3.9 at 5 years old and 4.1 at 6 years old, respectively. Those values approximated to LAI (3.8) at 9 years old in plot C. That is to say, the tree ages of plots A and B were just one year before LAI peaked. In the case of the dense planting system (360 trees/10 a) in greenhouses, like our experiment, to prevent a marked decrease in LAI just after removing filler trees, a suitable time is conjectured to be in the year after LAI reaches 4, or the year before LAI reaches a peak, which is observed in plot C. The spacing trial of satsuma mandarin in an open field provides convincing evidence that LAI should be 5.8, being appropriate for yield, fruit quality, and work efficiency (Tachibana and Nakai, 1989). This LAI is approximate to each peak value in plot A: 5.7, and in plot B: 5.9. Accordingly, it seems almost certain that the time to remove filler trees is the year just before this appropriate LAI is represented.

Cultivar evaluation

Comparing the yields per unit land area between the two cultivars, the yield of ‘Okitsu Wase’ was slightly higher than that of ‘Miyagawa Wase’ until the trees were 7 years old, without significance. When averaging values of the 10-year study, the yield per unit land area indicated ‘Miyagawa Wase’ (4.65 kg·m$^{-2}$) < ‘Okitsu Wase’ (5.14 kg·m$^{-2}$). This was affected by the fact that the yield of ‘Okitsu Wase’ was higher at 3–7 years old.

LAI of ‘Okitsu Wase’ was always larger than that of ‘Miyagawa Wase’ through the test period. As seen in Table 3, when averaged over the 10 years of the experiment, LAI was 2.52 in ‘Miyagawa Wase’ and 3.48 in ‘Okitsu Wase’. The overall average leaf sizes of plots A, B, and C were 19.2 cm$^2$ in ‘Miyagawa Wase’ and 26.4 cm$^2$ in ‘Okitsu Wase’ (Table 2). The number of leaves per unit land area was 1310 in the former and 1320 in the latter after calculating by each leaf size, but the difference between the two varieties seems to be small. It is worth while mentioning that the difference in LAI between the two cultivars was not due to a difference in the number of leaves per unit land area, but to a difference in leaf size. Yamaguchi (1977) stated that ‘Okitsu Wase’ trees grow more vigorously than ‘Miyagawa Wase’ trees in greenhouses. This may be true with respect to the leaf area.

Both yield per LAI and flower-bud count per LAI showed ‘Miyagawa Wase’ > ‘Okitsu Wase’, but in terms of per unit land area, the parameters were reversely ‘Miyagawa Wase’ < ‘Okitsu Wase’ (Table 3). This implies that ‘Miyagawa Wase’ is surpassed in fruit productivity by leaves, but ‘Okitsu Wase’ is superior in terms of yield and flower bud per unit land area owing to the large LAI.

The relationships between parameters vs. yields

The relationships between LAI and yield showed the largest significant correlation coefficients in the growing conditions and cultivars (Fig. 7), which is analogized with the fact that the yield was similar to LAI in the pattern of yearly changes. This means that LAI is a major factor which affects the yield regardless of different heating time and cultivars in greenhouse cultivation. The correlation coefficients between LAI and yield were $A < B < C$, which is due to some differences in the year to year fluctuations of the yields. In plot A, for instance, LAI increased or became almost constant at 5–6 and 8–9 years old (Fig. 5), but the yields decreased particularly with increasing tree age (Fig. 4). Also in plot B, LAI increased markedly at 6–7 years old, but the yields decreased at the corresponding tree ages. In plot C, each phase of the fluctuation was different, but the fluctuation was less than that in plots A and B.

In the relationships between each parameter and yield, as summarized in Table 4, flower count per unit land area and that per LAI, fruit set percentage, and SPAD value showed some significance, but the correlation coefficients were small, so these parameters were not considered to be factors strongly affecting the yield. Only flower count per unit land area in plot A presented a considerably larger correlation coefficient (0.542, $P < 0.01$). In Table 3, the flower count per unit land area and that per LAI in plot A were evidently smaller than those in plots B and C, but the fruit set percentage in plot A was conversely larger. These results further suggested that, when the number of flower buds is smaller, trees give a higher fruit set percentage. In this case, it became apparent that the yield depends on the number of flower buds with the same level of LAI. The decreased flower buds in plot A on heating from early December are considered to be a result of flower-bud differentiation being poor due to a shorter exposure to...
low temperature than plot B, which was heated from early January (Kawano, 1987; Zyuri and Kato, 1977).

The fact that the relationship between yield per LAI and yield per unit land area in plot B presented a small correlation coefficient (0.113, \( P < 0.01 \)) is explained by a reduced yield per unit land area due to the smallest LAI in spite of the largest yield per LAI (Table 3). In plots A and C, highly significant regressions existed between yield per LAI vs. yield per unit land area and between LAI vs. yield per unit land area, so an increase of yield per LAI must be associated with an increase of LAI to increase its yield. In this way, LAI is a strong factor affecting yield in greenhouse and open field cultivation, and the time to remove filler trees is important to avoid decreasing LAI, as stated before.

There were slightly larger correlation coefficients \((R^2 = 0.284–0.515)\) between the pruned weight and yield. In this case, linear coefficients were \( r = 0.370–0.544 \), showing positive regressions \((P < 0.01, \) figures not presented). Since the space for canopy spreading is remarkably limited in greenhouses, the pruned weight will increase more in trees which are vigorous, and therefore yield abundant crops.

The relationship between the SPAD value and yield showed no significance in most cases, which suggests that the SPAD value scarcely affects yield. Differences in SPAD value between the two plots pertaining to organic substance treatments was not significant. The SPAD values of the higher fertilizer application plots were slightly larger than those of the normal fertilizer plots (Table 3). Differences in yield were not significant between the two organic substance application plots and between the two fertilizer application plots. So far as these results concern yield, in dense planting in greenhouses or open fields, normal amounts of organic substance and fertilizer application are sufficiently effective.

**Literature Cited**


