CITRUS PRODUCTION IN JAPAN: NEW TRENDS IN TECHNOLOGY

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ABSTRACT

Annual citrus production in Japan has fallen from a peak of 4 million mt to 1.68 million mt (1994), of which Satsuma mandarin accounts for about 75%. To halt this decline in production and invigorate the citrus industry, growers and scientists are looking for new ways to produce high-quality fruit. Plant growth regulators have been developed to improve fruit quality and stabilize production. Porous nonwoven fabric mulches are being used in Satsuma mandarin orchards. A new fruit control system based on “alternate-branch fruit thinning” is described, and its performance discussed.

INTRODUCTION

Citrus production in Japan reached a peak of about 4 million mt in the late 1970s, but since then has decreased each year.

The very low production of 1.68 million mt (five major varieties) in 1994 cannot, however, be assumed to be the lowest possible point. Steps need to be taken to ensure that future production levels do not fall even further.

Until 1980, Satsuma mandarin accounted for more than 80% of all citrus fruit produced in Japan. Today, it accounts for about 75%. Efforts to convert from Satsuma to other varieties in order to expand the market and overcome the depression of the citrus industry have not been successful. Satsuma mandarin production in 1994 was only 1.25 million mt (Table 1), although it must be taken into account that this was an off year.

There are various opinions as to the cause of this decline in citrus production in Japan. One reason is that citrus imports have been liberalized, and about 500 thousand mt of oranges, grapefruits, and lemons are being imported annually. The importation of citrus juice was liberalized in 1992, and the amount of imported juice is rapidly increasing. At Zinno wharf in Toyohashi City, about 300 km west of Tokyo, twenty 1000 mt storage tanks were built in 1993 to hold frozen concentrated orange juice. Orange-juice tankers from Brazil fill the tanks directly with frozen juice, concentrated to one fifth its original bulk. The tanks can be rotated three times a year. The total annual capacity of the tanks is equivalent to the juice from 600 thousand mt of fresh citrus, about half the current Satsuma mandarin production in Japan.

Japanese citrus growers must also cope with various diseases because of Japan’s humid climate. Moreover, orchards are small and located on steep hillsides. It is difficult for growers to compete with overseas citrus producers, because of their high production costs.

As the standard of living in Japan has improved, dietary habits have become very diversified. Citrus fruits have strong competition from many other fruits such as apples, bananas, melons, and strawberries. The most serious trend, however, is that per capita fruit consumption is moving steadily downwards. This is probably because young people are more strongly attracted to candy, soft drinks and ice cream, which are marketed in a sophisticated way with a great deal of advertising. Consumers are even said to be unwilling to take the trouble of using a knife to peel fruit!

Keywords: Citrus, fabric mulches, Japan, plant growth regulators, Satsuma mandarin, thinning
More than 90% of growers in Japan have an orchard smaller than 1 ha in size. Faced with this reality, Japanese fruit growers have had to find ways of producing high-quality table fruit which can be sold at a high price. The production technology used to produce high-quality fruit, and the associated problems, are discussed below.

**PLANT GROWTH REGULATORS**

Certain plant growth regulators (PGRs) are used by citrus growers to regulate tree growth, control flowering and fruiting, and stabilize levels of production. PGRs are also used to improve fruit quality by controlling the physiology of maturation.

**Ethychlozate (ethyl 5-chloro-1H-3-indazolyl-acetate)**

Ethychlozate is used to thin out young fruit, accelerate maturity, and prevent fruit from developing a puffy rind. It belongs to the PGR auxin group, which also includes naphthaleneacetic acid (NAA), the main fruit-thinning agent before the registration of ethychlozate. The main reason for the fruit drop produced by this thinning agent is the development of an abscission layer by the ethylene which evolves in response to stimulation by the agent. Ethylene evolution after foliar applications of ethephon, NAA, and ethychlozate has been examined (Kamuro and Hirai 1982). The chemical ethephon evolves the greatest amount of ethylene, and has a very marked effect on fruit drop. Next in the evolution of ethylene is NAA. Ethychlozate evolves the least amount of ethylene, but its effects last for a week. These results explain the mild effect of ethychlozate as a thinning agent.

Although ethychlozate is registered for various purposes, it is mostly used as a maturity accelerator. To accelerate maturity, 67-100 ppm ethychlozate should be applied twice, the first appli-

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**Table 1. Citrus production in Japan, 1994**

<table>
<thead>
<tr>
<th>Variety</th>
<th>Production (1000 mt)</th>
<th>Major production areas (Prefecture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wase Satsuma</td>
<td>711.4</td>
<td>Ehime, Wakayama, Saga</td>
</tr>
<tr>
<td>Common Satsuma</td>
<td>535.1</td>
<td>Shizuoka, Ehime, Wakayama</td>
</tr>
<tr>
<td>Iyo (Miyauchi Iyo)</td>
<td>206.1</td>
<td>Ehime, Wakayama, Saga</td>
</tr>
<tr>
<td>Natsudaidai (Kawano natsudaidai)</td>
<td>114.0</td>
<td>Kumamoto, Ehime, Kagoshima</td>
</tr>
<tr>
<td>Hassaku</td>
<td>86.8</td>
<td>Wakayama, Hiroshima, Ehime</td>
</tr>
<tr>
<td>Ponkan</td>
<td>35.5</td>
<td>Kagoshima, Ehime, Kochi</td>
</tr>
<tr>
<td>Navel orange</td>
<td>30.1</td>
<td>Wakayama, Hiroshima, Shizuoka</td>
</tr>
<tr>
<td>Yuzu (acid fruit)</td>
<td>14.4</td>
<td>Kochi, Tokushima, Oita</td>
</tr>
<tr>
<td>Kiyomi (tangor)</td>
<td>13.8</td>
<td>Ehime, Wakayama, Kumamoto</td>
</tr>
<tr>
<td>Pummelo</td>
<td>11.8</td>
<td>Kochi, Kumamoto, Kagoshima</td>
</tr>
<tr>
<td>Total</td>
<td>1,759.0</td>
<td></td>
</tr>
</tbody>
</table>

Source: Ministry of Agriculture, Forestry and Fisheries, Japan
cation 50 - 60 days and the second 70 - 80 days after full bloom. Applying ethychlozate can be expected to advance rind coloring by 5-10 days, and produce fruit with a 0.5 - 1.0 higher Brix. It has negligible effects on the citric acid concentration.

**Gibberellic Acid**

Some citrus cultivars have too many flowers, so that the tree’s nutrients become exhausted. Too many flowers will mean that there is limited vegetative growth, and trees lose their vigor. Culture practices are often needed to reduce the number of flowers and increase the number of new leaves, especially for varieties such as “Miyauchi Iyo” (early maturing Iyo), early maturing Wase Satsuma mandarins, and navel oranges.

Gibberellic acid is often applied to “Miyauchi Iyo” in Japan, in order to maintain tree vigor. Twenty-five ppm of gibberellin sprayed in late December reduces the number of flowers. It reduces the number of both leafy and leafless inflorescences, but particularly the latter. Flower reduction is inversely proportional to the increase in new shoots and leaves. An addition of machine oil to the gibberellin solution enhances its effectiveness. Ninety-five percent machine oil emulsion diluted 50 to 100 times, or 97% machine oil emulsion diluted 100 times, with 25 ppm gibberellin has been found to be the most effective combination (Takahara et al. 1990).

**Benzylaminopurine (6-(N-benzyl amino)purine)**

There can also be a problem in some citrus varieties of too few flowers. Low yields of Satsuma mandarin occur when trees with biennial harvests fail to produce enough flowers during an off year. The effect of benzilaminopurine (BA), a cytokinin which promotes sprouting and the emergence of flower-buds, has therefore been studied, and the chemical has been registered.

In heated vinyl greenhouses, irregular sprouting and scarcity of flowers is sometimes a problem with Wase Satsuma, especially if heating is begun as early, in late November or early December. A BA application immediately after the start of heating stimulates sprouting, thereby increasing the number of flowers. The BA application guide is shown in Table 2. If tree vigor is weak, or a potential fruiting branch is not complete, too many fruits will drop. To avoid extreme stimulation on flowering, a low BA concentration is safe for use in vinyl greenhouses. Although BA is thought to affect only already differentiated axillary buds, it very effectively stimulates growth of the lower nodes of the fruiting shoot which will not sprout under normal conditions (Iwagaki 1991).

Paclobutrazole (2RS, 3RS)-1-(4-chloropenyl)-4, 4-dimethyl-2-(1H-1,2,4-triazol-1-yl) pentan-3-ol

Paclobutrazole is a triazol compound which causes growth retardation and dwarfing in a wide range of plants. When applied to Satsuma mandarin during the period from when shoots sprout until they reach a bud length of 10 mm, it shortens the length of both the internode and the shoot. Paclobutrazole does not directly affect the number of shoots and leaves, but because the tree does not have uniform growth, a reduction in the number of shoots sometimes occurs.

<table>
<thead>
<tr>
<th>Objective of application</th>
<th>Environmental conditions</th>
<th>Timing of application</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promote sprouting</td>
<td>Outdoors or in heated vinyl greenhouse</td>
<td>Immediately before, or during, sprouting (after harvesting in a heated vinyl greenhouse)</td>
<td>150 - 300 ppm</td>
</tr>
<tr>
<td>Flower-bud emergence</td>
<td>Heated vinyl greenhouse (early shipping type)</td>
<td>Immediately after heating</td>
<td>75 - 300 ppm</td>
</tr>
</tbody>
</table>
Spraying 400-800 ppm of paclobutrazole on Satsuma mandarin at the sprouting stage is recommended. When research was begun on the effects of paclobutrazole on Satsuma mandarin, dwarfing was expected (Okuda et al. 1994) but its growth-retarding effect on Satsuma mandarin in vinyl greenhouses is its most important practical use these days. Unwanted autumn-cycle shoots that sprout after maturation of the summer-cycle shoots in greenhouses managed for early harvests should be controlled.

Of the PGRs discussed, ethychlozate is the one most widely used in Japan, while benzylaminopurine is popular in vinyl greenhouse cultivation. The use of gibberellin and paclobutrazole is still limited.

### QUALITY CONTROL

**Mulching**

Sugar begins to accumulate in the juice of the Satsuma mandarin in summer. The percentage of sucrose in the total sugar then increases from September up to harvest. The acids in the juice are citric and malic acid. Citric acid rapidly decreases as the main acid after September.

Various techniques are used to increase sugar distribution to the fruit by subjecting the roots to water stress during the period of active sugar accumulation. Of these, mulching is the most useful and practical. Drying soil by covering it with an impermeable layer of vinyl or polyethylene film mulch is not new. Porous mulch materials were first used in orchards in 1989. There are two kinds of porous mulch materials. One porous film is reinforced with nonwoven fabric, and the other is made of nonwoven fabric only. Both types of material are made of polyethylene with numerous 0.1 - 1.0 micron holes, through which water vapor can pass but rainwater cannot. After the mulch has been applied, the soil gradually dries out.

The results of a trial using porous non-woven fabric mulch in an “Aoshima” Satsuma mandarin orchard are shown in Fig. 1. This was the first of many trials of this kind. Generally speaking, the use of porous mulch increased the Brix and improved the color of the rind (measured by a higher “a” value on the color difference meter). Citric acid also increased in many cases. To keep the acid level low, when producing high-quality mandarin, a small amount of irrigation water should be applied, even though this may mean some sacrifice of Brix.

There may be little or no air exchange in the soil if the mulch is applied over a wide area, but when porous mulch is used, there is no problem of an oxygen shortage. Drainage of collected rainwater in the event of sudden heavy rain must be provided. The timing of fertilizer applications is a considerable problem, because of the long mulching period during the autumn months. Trees also may lose vigor because of water stress. Despite those problems, in 1993 about 1700 ha of Satsuma mandarin orchard were covered by some kind of plastic mulching material in Japan.

### Root Confinement and Dwarf Trees

Root confinement culture is a more reliable way of controlling the water supply than mulching. Root confinement trials at the Shizuoka Prefectural Citrus Experiment Station used a system that restricts the root sphere by use of a thick nonwoven fabric which roots cannot penetrate (Plate 1). The yields per tree, and the Brix of the fruit, four “Aoshima” trees 5 to 7 years old are shown in Table 3. A higher Brix was obtained by root confinement, but tree canopies remained small, and the yield decreased. It was possible for trees with a soil

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**Table 3. Effects of root confinement on the yield and fruit quality of “Aoshima” Satsuma mandarin**

<table>
<thead>
<tr>
<th>Soil volume (L soil/tree)</th>
<th>Yield (kg/tree)</th>
<th>Brix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5-year-old</td>
<td>6-Year-old</td>
</tr>
<tr>
<td>40</td>
<td>1.8</td>
<td>0.1</td>
</tr>
<tr>
<td>75</td>
<td>3.7</td>
<td>4.1</td>
</tr>
<tr>
<td>150</td>
<td>6.3</td>
<td>8.2</td>
</tr>
<tr>
<td>300</td>
<td>10.0</td>
<td>13.5</td>
</tr>
<tr>
<td>No restriction</td>
<td>14.7</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Source: Shizuoka Prefectural Citrus Experiment Station, Japan.
Fig. 1. Effect of mulching material on the quality of "Aoshima" Satsuma mandarin

Source: Fruit Tree Research Station (Ministry of Agriculture, Forestry and Fisheries 1989), Japan.
volume of only 150 L per tree to bear fruit at a rate of 30 mt/ha. However, to shorten the period from planting until the tree bore its full crop, the results from the series of trials concluded it is better for the tree to have a soil volume of 300 L (Plate 2).

Before root confinement culture was tested, box culture was tested. However, box culture has the problems of high cost, and the high labor demand needed to control irrigation water for each box separately. Moreover, trees lose their vigor, and it is difficult to maintain their long-term productivity.

In the type of root-confined culture practiced in Shizuka prefecture, branches and twigs of “Aoshima” trees are trained on trellises to form 50 cm-wide tree hedges (Fig. 2). When new culture systems for producing high-quality fruit, such as root confinement or planting on raised ridges, are adopted, trees are grown either in hedgerows, or with only minimal training of central leaders, in order to save labor.

Citrus trees in Japan which are trained and shaped by pruning to have three primary scaffold branches are called “open-center natural-form” trees. Although the open-center type is very popular in Japan, some other types are also in use. The central leader type, sometimes called the single-stem training or Christmas tree shape, is one. These are triangular or conical trees that are comparatively small and easy to maintain. The cultural practices needed to keep these trees small, however, are not always labor-saving. If we want to make such trees even smaller, it is difficult to find suitable trifoliate rootstock.

Discussions of experiments on hedgerow or conical trees sometimes suggest that such trees promise good-quality fruit. Fruit quality, however, is closely related to other factors besides the planting system. These include plant density and tree height, the target yield, and pruning methods. The problem of quality must take into account all these factors. Rootstock studies of the dwarf trifoliate variety “Flying Dragon”, and the efficacy of adopting “Flying Dragon” as the interstock for dwarf trees, are still in progress.

### ALTERNATE-BRANCH FRUIT THINNING

“Aoshima” Satsuma mandarin is known for its biennial bearing tendency, as well as for the good quality and high sugar content of its fruit. It is not easy to achieve stable annual production with this variety, and its fruit tend to become too large during the off year if conventional fruit thinning methods are used. An improved method of fruit control is needed for “Aoshima”.

Alternate-branch fruit thinning and other control methods were studied to find ways of preventing biennial bearing and improving fruit quality. In alternate-branch fruit thinning, the young fruit are completely removed from some branches, and allowed to cluster on others. Branches stripped in one year will be allowed to bear fruit the following year.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1987</th>
<th>1988</th>
<th>1989</th>
<th>1990</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional thinning</td>
<td>68.3</td>
<td>36.7 a</td>
<td>56.8 a</td>
<td>44.2 b</td>
<td>206.0 ab a</td>
</tr>
<tr>
<td>Alternate branch thinning</td>
<td>71.9</td>
<td>68.3 a</td>
<td>64.7 a</td>
<td>69.0 a</td>
<td>273.9 a</td>
</tr>
<tr>
<td>Inside thinning</td>
<td>61.2</td>
<td>58.3 a</td>
<td>72.1 a</td>
<td>75.2 a</td>
<td>266.8 a</td>
</tr>
<tr>
<td>Unilateral thinning</td>
<td>53.6</td>
<td>49.2 a</td>
<td>52.6 a</td>
<td>45.8 b</td>
<td>201.2 ab</td>
</tr>
<tr>
<td>Alternate year thinning</td>
<td></td>
<td>64.7 a</td>
<td></td>
<td>77.8 a</td>
<td>142.5 b</td>
</tr>
</tbody>
</table>

Significance: N.S. * N.S. *

A * Significantly different at 5%. N.S.: Not significantly different
B Values within a column followed by the same letter (a and b) are not significantly different (P < 0.05)
Y Fruits uniformly removed throughout the tree canopy
Y Fruits completely removed from some branches but allowed to cluster on others:
X The alternate-branch fruit thinning method
x All fruit growing inside the tree canopy removed
w All fruit in the alternate-branch fruit thinning method
V All fruit removed on alternate years
Fig. 2. Trellised "Aoshima" trees in the root confinement trial

Source: Shizuoka Prefectural Citrus Experiment Station, Japan

Table 5. Effect of fruit removal on the flowering of vegetative shoots of the bearing branch

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of flowers or shoots per 100 nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inflorescences of leafless shoots</td>
</tr>
<tr>
<td>Fruit removed in June</td>
<td>4.8 ± 2.2</td>
</tr>
<tr>
<td>Fruit removed in September</td>
<td>3.5 ± 3.3</td>
</tr>
<tr>
<td>Control (no fruit removed)</td>
<td>3.9 ± 0.9</td>
</tr>
</tbody>
</table>

Note: Average ± standard deviation,  n = 15

This system has been called "the alternate-branch fruit cluster method" (Kihara et al. 1995).

By using alternate branch fruit thinning, it is possible to achieve a stable yield of "Aoshima" every year (Table 4). This method also produces fruit of medium size and a high Brix. Moreover, it reduces variation in fruit quality within the tree canopy.

In detail, alternate-branch fruit thinning selects 20 - 25 lateral branches 2 to 2.5 cm in diameter (500 - 600 leaves) for each fully mature 20-year-old "Aoshima" tree. Pairs of fruit-bearing and defruited branches are distributed evenly within the tree canopy. About 1.5 to 2 times as much fruit should be left on the selected fruit-bearing branches than is usual when conventional whole-tree thinning is used.

Removing the young fruit encourage the return bloom of vegetative shoots. In contrast, fruit bearing had a marked negative effect on flowering (Table 5). This may be why alternate-branch thinning stabilizes cropping better than does conventional thinning, even though the leaf number per fruit on the whole tree is almost the same (Okuda et al. 1996).

When fruit are removed early in the season, an increase in photosynthesis during the floral initiation period occurs. This increase in the photosynthesis of the non-bearing branches is also correlated with enhanced flowering. Factors that influence photosynthesis, including the levels of atmospheric carbon dioxide and solar radiation, are known to influence flowering, although a direct relationship between photosynthesis and flowering has yet to be proven.

An increase in stomatal conductance always accompanies the enhanced photosynthesis following fruit removal. This may indicate that the stomatal apertures may affect photosynthesis after fruit removal (Fig. 3). Fruit removal reduced the
Fig. 3. Effect of fruit removal on apparent photosynthesis in leaves of vegetative shoots of Satsuma mandarin. Fruit were removed in June or September. Measurements were made on the terminal three leaves of each vegetative shoot at the beginning of each month, with three replications. Each column represents the mean (± S.D. n = 3) of the measurements.

Fig. 4. Effect of fruit removal on the abscissic acid concentration in the leaves of vegetative shoots of Satsuma mandarin. Fruit were removed in June or September. Measurements were made on the terminal three leaves of each vegetative shoot at the beginning of each month. Each value represents the mean (± S.D. n = 3) of the measurements.
Plate 1. Applying a mulch of porous nonwoven fabric in a Satsuma mandarin orchard
(University Farm, Shizuoka University, Japan)

Plate 2. Confinement of roots of Satsuma mandarin in containers
(Shizuoka Prefectural Citrus Experiment Station, Japan)
ABA contents of the leaves which may cause stomatal closing. These facts suggest that the stomatal aperture, ABA level, crop load and photosynthesis are interrelated (Fig. 4).

ABA may affect flowering both by its influence on photosynthesis, and by some as yet unknown direct means.

REFERENCES


DISCUSSION

Dr. Iwagaki was asked whether the alternative branch thinning method could be applied to other varieties of citrus. He replied that he and his colleagues had also applied this system to "Silver Hill" Satsuma mandarin, but had not been able to obtain good results, probably because this variety does not have a strong biennial habit. However, the method had worked well for the variety "Aoshima", which has a strong biennial tendency. He said that more than 20 years ago, the alternate branch thinning method had been developed for use on very early Satsuma varieties. Early Satsumas tend to bear a very heavy crop on alternate years, but only poor harvests in the years in between. However, if this method is used today on early Satsumas, the branches selected for heavy bearing tend to die out. Dr. Iwagaki recommended that, while this method cannot be used for all varieties, it is well suited to "Aoshima".