Optimum Crop Load for Fuji Apples in Japan

Hiroo Koike and Takashi Ono
Nagano Fruit Tree Experiment Station
492 Ogawara Suzaka, Nagano 382, Japan

Introduction

The Japanese apple growing area reached 49,900 ha (123,300 acres) with a production of 899,200 metric tons (t) in 1996. Apples are grown in Aomori, Nagano, Iwate, Yamagata, Akita, Fukushima, Hokkaido, Miyagi, Gunma and some other prefectures. Two main prefectures, Aomori (49%) and Nagano (22%), produce about 71% of Japan's apples. The main apple varieties are Fuji (52%), Tsugaru (14%), Orin (10%) and Jonagold (8%), including red and early strains. There were about 85,000 apple growers and 51,200 ha of apple orchards in 1994. Growers who had less than 0.5 ha (1.24 acre) orchards occupy 63% of the total. However, minimum acreage per full-time grower necessary to make economic sense of the investment is estimated to be 2.0 ha (5 acres).

In the early years of the 20th century, fruit was mainly purchased by a few wealthy people and generally used as gifts in Japan. As this concept still exists, various kinds of fruit are sold, not only for food but also for gifts. You can see excellent quality fruit in gift baskets and beautifully decorated boxes not only in famous fruit shops but also supermarkets. Because of these traditional uses, apples consumed as food also should be excellent not only in taste but also in external appearance. This is why size, color and overall fruit quality are so important for the fruit trade in Japan.

It is also necessary to elevate production per unit area as well as to improve fruit quality in order to meet consumer's demand but also because of the small growing area per each household. To overcome these problems, integrated growing systems have been established based on highly developed specified technology such as artificial pollination, hand thinning, fruit bagging and coloring. Therefore, Japanese apple growing requires 2,400 to 3,000 hours of labor per hectare (Table 1).

Methods of Thinning Fuji Apples to Produce Large Fruits and Prevent Alternative Bearing in Japan

Blossom thinning. Thinning is the most important step in order to harvest large, unique-sized fruit and to prevent alternative bearing with Fuji apple trees. Reducing initial fruit set of apples by eliminating a proportion of the flowers during the bloom period is usually a highly desirable

practice for the cultivars such as Fuji which have a biannual fruiting habit. It can increase the amount of bloom that will appear the following spring (return bloom) as well as improve fruit size and crop load in the season of application.

In Japan, fruit growers usually thin off by hand the flowers of axillary buds on 1-year-old shoots prior to fruitlet thinning. Studies of chemical blossom thinning with lime-sulfur and hormone-type thinners such as NAA and Ethephon have been carried out in the past. Lime-sulfur is registered as a chemical blossom thinner but the hormone-type thinners have not been used because they cause small fruit and a decrease in the fruit length/diameter (L/D) ratio, resulting in flat-shaped fruits. Lime-sulfur (22%) spray (33 to 40 liters/4,000 liters of water/ha) at full bloom or shortly after full bloom (1 or 2 days after) has proven effective. Additional sprays of lime-sulfur 1 to 2 days later are also common. These sprays are effective to thin off the lateral flowers of spurs or terminal buds on 2-year or older branches and flowers of axillary buds on 1-year-old shoots which bloom a little later. Many growers have been afraid to use a chemical blossom thinner because of the frequent occurrence of late spring frost damage in Nagano.

Fruitlet thinning. Only Carbaryl has been used to thin fruitlets in the cluster of Fuji apples in Japan. The extent of fruit development at the time of spraying is an important consideration. When used by itself, Carbaryl results in good fruitlet thinning when the largest fruitlets, mostly originated from king flowers, are about 10 to 12 mm diameter. Carbaryl (effective, 85%) is sprayed with 4,000-5,000 liters/ha at 0.12% mixed with exclusive spray adjuvant at 0.03%. The thinning effects of Carbaryl begin to occur about 7 to 10 days after application, and the full extent of drop may be evident in 3 to 4 weeks after application in the case of Fuji apples.

Hand thinning. Whether spray thinning is undertaken or not, hand thinning is the most important step in growing quality fruits in Japan. In primary fruit thinning by hand, lateral fruitlets and fruitlets of axillary flower buds are removed, leaving only the king fruitlet or a lateral fruitlet in each cluster of spurs and terminal buds on 2-year or older branches. If spray thinning of blossoms is not done, primary thinning by hand should begin about 2 weeks after full bloom, when the sepals of flowers stand up, and it must be finished by 30 days after full bloom. For Fuji apple trees sprayed with Carbaryl, primary thinning of fruitlets by hand is carried out from 10 days after application when the thinning effect of Carbaryl can be seen.

Thinning to restrict crop load (measured as leaf number/fruit ratio) for each cultivar is the most important technique for growing the excellent quality apples that the world knows are required in the Japanese market. Crop load is usually adjusted to the optimum by hand in the secondary

thinning. Secondary thinning is considered one of the most important practices and it is recommended that it be finished within 60 days after full bloom, usually in early July in Nagano. It is clear from the studies carried out at the Nagano Fruit Tree Experiment Station that yield, mean fruit weight, shoot weight and return flowering in the following year are very sensitive to crop load. In the case of Fuji, the optimum crop load, which is effective to produce fruit of 300-350 g weight (box size 64 to 56) and to prevent alternative bearing, is shown to occur at 50 to 60 leaves per fruit, and this index is being recommended for the Fuji growing in Nagano prefecture.

These practical thinning techniques mainly for Fuji apples have been established by long-term experience and studies carried out at the Nagano Fruit Tree Experiment Station. The recommended schedule of reducing the majority of fruitlets of Fuji apples within 30 days and 60 days after full bloom (thus also reducing the number of seeds in the fruitlets) coincides with seasonal change of flower-inhibiting hormones, gibberellins, which are produced in the seeds of biannual bearing cultivars (Luckwill, 1990). The steps in thinning Fuji are outlined in Figure 1.

Experiments

This article reviews three experiments conducted at the Nagano Fruit Tree Experiment Station and reports annual changes in percentage of floral buds on spurs and terminal buds in commercial orchards at 6 sites in Nagano prefecture. These studies were designed to establish the indices (leaf number/fruit ratio) of thinning methods for producing quality fruit of Fuji suited for Japanese markets.

Optimum crop load for Fuji apples. The first experiment examined optimum crop load to produce 300 to 350 g (box size 64 to 56) fruits of high quality annually. Nine-year-old Fuji/M.26 trees (planted in 1986) and 10-year-old Fuji/M.26 trees (planted in 1987) spaced at 1.5 x 4 m (4.9 x 13 ft) in a north-south hedgerow were used for the experiments. The effects of crop load, leaf number/fruit ratio, fruit size, brix (soluble solids) of fruit, acidity of fruit, unit shoot growth and return bloom were compared. Trees were thinned to one fruitlet per cluster (on spurs or terminal buds) on 2-year or older branches, leaving king fruitlets by the primary thinning at the 30th day after full bloom. Fruitlets in the cluster of axillary buds (on 1-year-old wood) were all thinned off. The second thinning was done at the 60th day after full bloom and crop load varied from leaf number/fruit ratios of 27 to 87 in 1986 and 23 to 141 in 1987 determined by late July. All shoot length and the number of spurs were measured to estimate the total leaf number by the regression equation ($Y=8.9 + 0.176X-0.001X^2$, r=0.966**, n=200; Y, the number of leaves; X, the terminated shoot length; mean no. leaves/spur is 5). Fruit quality, shoot growth and return flowering were measured on fruits harvested in December and the following spring.

Dry weight partitioning in Fuji/M.26 apple trees. The second experiment was designed to determine the amounts of leaf photosynthate, on a dry weight basis, that accumulated during a growing season in the fruits, leaves and wood of heavily and optimally cropped Fuji apple trees. Total dry matter accumulation of heavily and moderately cropped 5-year-old Fuji/M.26 apple trees was compared for the 1994 growing seasons. The trees at 4 x 2 m (13 x 6.5 ft) spacing in north-south hedgerows were selected for uniformity on the basis of trunk cross-sectional area. The trees had been trained to a slender spindle bush. During the 1994 growing season, fruits of 5 trees per each plot were thinned to only king fruitlets in the cluster on spurs and terminal buds on 2-year or older branches at the 30th day after full bloom. Fruitlets on axillary buds on 1-year shoots were all thinned off. The second thinning was done at 60 days after full bloom. Total leaf number per trees was estimated as above. Crop load of heavily cropped trees (average leaf number/fruit ratio of 25) and normally cropped trees (average leaf number/fruit ratio of 57) was counted in late July when most shoots had set terminal buds. At thinning time, the picked fruitlets were taken for dry weight determination and included into the total dry weight. At harvest in early November, the fruit, both picked and drops, was weighed, samples were taken from each tree for dry weight determination, and the total dry weight of fruit was calculated for each tree. All trees were removed from the orchard in the dormant season and separated into leaves, 1-year to 5-year-old branches and roots for the measurement of dry matter. Annual dry weight accumulation and partitioning into each part were determined by the method of reading xylem rings of each sample.

The quality of fruit originated from king flowers and lateral flowers. The third experiment was designed to compare the quality between the fruits retained as king flowers and lateral flowers during thinning of Fuji and Tsugaru apples. Three trees each of Fuji/M.7 (18-year-old) and Tsugaru/MM.106 (13-year-old) at 5 x 3 m (16.4 x 9.8 ft) spacing in a north-south hedgerow planting were used. During the 1995 growing season, fruits of 3 trees per each plot were thinned, leaving only fruitlets originated from king flowers or only from lateral flowers in the cluster of spurs and terminal buds on 2-year or older branches at the 23rd day after full bloom. All axillary fruits on 1-year-old wood were thinned off by hand. The second hand thinning was done at the 47th day after full bloom to an index of 50 to 60 leaves per fruit for Fuji apples and 40 to 50 leaves per fruit for Tsugaru apples. Fruit quality was compared at harvest.

Results and Discussion

Optimum crop load for Fuji apples. Very good relationships (high correlation coefficients) were observed between leaf number/fruit ratio and mean fruit weight, unit shoot weight, return

flowering and yield (Table 2). Fruit size, brix, unit shoot weight and return flowering increased according to the increase of leaf number/fruit ratio, whereas yield decreased.

It is clear from the experiments that a crop load, if sufficiently heavy, will inhibit flower initiation terribly. Only 11% of the buds per spur or per terminal bud flowered the following spring on trees thinned to a 30 leaf number/fruit ratio in 1986 (Table 3). However, it is likely to be somewhat influenced by annual weather because a smaller mean fruit weight in 1987 is doubtless partly accounted for by the low temperature throughout the flowering season and summer.

In conclusion, the optimum crop load of Fuji/M.26 apple trees to harvest 300 to 350 g fruit annually and obtain enough return bloom was estimated to be at 50 to 60 leaves per fruit.

Dry weight partitioning in Fuji/M.26 apple trees. The distribution of accumulated dry matter was 73% in fruit, 9% in leaves, 15% in wood and 4% in roots in the heavily cropped trees (Table 4). In the normally cropped trees, the proportion of dry matter in fruit was 49%; the other sections were approximately 9 to 12% each. A significant reduction of dry matter partitioning into the roots was observed in the heavily cropped trees. The total dry matter per unit weight of leaves, showing photosynthetic efficiency on a dry weight basis, is 137% higher in the heavily cropped trees than the normally cropped trees.

The greatest limitation of this work is the fact that only one season of study was carried out and only 9-year-old trees were used. In spite of these limitations, the results show that the well-balanced growth of vegetation and fruiting gained by normal cropping (crop load of 57 leaves per fruit) is more important than high photosynthetic efficiency gained by heavy cropping (crop load of 25 leaves per fruit) for continuous production of large and high quality Fuji apples in Japan.

The quality of fruit originated from king flowers and lateral flowers. There were no significant differences in mean fruit weight, fruit length/diameter (L/D) ratio, brix of fruits and values of starch test in Fuji and Tsugaru apple trees when fruitlets were thinned at 23rd day after full bloom to fruitlets originating from king flowers or lateral flowers (Table 5). All clusters were on 2-year or older branches and the same crop load was established for all trees of each treatment at the 47th day after full bloom. The fruits originated from lateral flowers only with Tsugaru showed the heavy occurrence of russet around the stalk of fruits. This result shows that fruits originated from lateral flowers of Fuji are also useful in producing commercially valuable high quality fruits like those originating from king flowers.

Annual percentage of floral buds from a collected sample of 1,500 total buds (spur and terminal) of Fuji apples in commercial orchards of 6 sites in Nagano is shown in Table 6. With the percentages of floral bud less than 45%, it was still sufficient to obtain good fruit set in some sites in 1985, 1991 and 1995 by the thinning method mentioned previously in this report. This investigation shows that not only the crop load but also the weather, especially a hot or dry summer the previous year, can be considered one of the causes of lower floral bud formation of Fuji in our area. It also can be said that we have overcome the biannual bearing habit of Fuji by using our practical thinning methods, even in the years with terribly bad weather conditions.

This paper explains why we can crop Fuji apples annually in spite of its biannual bearing habit and annual variations of weather in Nagano, Japan.

Reference

Luckwill, L. C. 1990. The control of growth and fruitfulness of apple trees. pp. 237-254. L. C. Luckwill and C. V. Cutting (ed.). Physiology of Fruit Crops. Academic Press. London, New York.

Table 1. Labor requirements for management in a high density Fuji orchard in Nagano, Japan (Nagano Agri. Policy Div., 1995).

Management	Labor hours/ha	%
Training and pruning	405	16.8
Fertilizing	30	1.3
Weed control	115	4.8
Irrigation	20	0.8
Disease and pest control	235	9.8
Fruit thinning	580	24.2
Coloring (defoliating and turning fruit)	450	18.8
Harvest	500	20.8
Others	65	2.7
Total	2400	100.0

Table 2. Correlation coefficients (measuring the degree of association), regression coefficients (the slope of the relationship) and regression equations for the relationships of leaf number/fruit ratio (X variable) with flower bud formation, mean fruit weight, brix (soluble solids) of fruit, shoot weight and yield (Y variables) of Fuji apple trees on M.26 in 1986 and 1987.

Variable				
X	Y	Regression equation	Correlation coefficient[z]	Regression coefficient (slope of relationship)
		1986		
L/F[x]	Fruit weight (g)	$Y=0.027X+13.6$	0.69	4.39
L/F	Titratable acid	$Y=0.002X+0.24$	0.58	3.24
L/F	Flower buds[y]	$Y=0.02X^2+3.8X-83$	0.80	18.25
L/F	Shoot weight[w]	$Y=0.02X+0.99$	0.67	4.13
		1987		
L/F	Fruit weight (g)	$Y=-0.015X^2+3.0X+168$	0.84	19.83
L/F	Brix (%)	$Y=-0.0001X^2+0.03X+14.5$	0.78	12.23
L/F	Yield (kg)	$Y=0.001X^2-0.31X+42.5$	0.73	9.37

[z]The higher the value, the closer the association of variables; all correlations were significant (P=.01).
[y]% of flower buds that followed in the next spring.
[x]L/F: Leaf number/fruit ratio.
[w]Mean unit (basal 10 cm) shoot weight (g).

Table 3. Estimated yield, fruit quality and flower bud formation of Fuji apple trees on M.26 based on the regression equations in Table 2.

Leaf number/ fruit ratio	Fruit weight (g)	Brix (%)	Titratable acid (%)	Flower bud setting (%)[z]	Yield (kg)
		1986			
30	270	14.4	0.30	11	--
50	301	14.9	0.34	55	--
60	313	15.2	0.36	71	--
80	331	15.7	0.40	91	--
		1987			
30	246	15.5	--	--	33.8
50	283	16.0	--	--	28.9
60	297	16.2	--	--	26.6
80	316	16.6	--	--	22.6

[z]% spur and terminal buds with flower buds the following spring.

Table 4. Annual dry weight partitioning of 9-year-old Fuji apple trees on M.26 with normal (57 leaves/fruit) and heavy (25 leaves/fruit) crop loads in 1987.

	Dry weight (g) accumulated during 1987 growing season					
	Normal cropping (57 leaves/fruit)			Heavy cropping (25 leaves/fruit)		
Component	g/tree	%	g/leaf	g/tree	%	g/leaf
Leaves	1,032 ± 231[z]	12.00		735 ± 175	9.00	
Fruit	4,123 ± 916	49.00	4.534 ± 0.75	5,977 ± 1,107	73.00	8.341 ± 1.43
Current shoots	473 ± 173	5.60		190 ± 65	2.30	
Branches	1,002 ± 376	11.99		486 ± 115	5.90	
Trunk	747 ± 280	8.90		285 ± 117	3.50	
Roots	437 ± 176	5.20		183 ± 117	2.25	
Rootlets	220 ± 64	2.60		139 ± 36	1.70	
Root crown	314 ± 118	3.75		137 ± 55	1.68	
Total	8,357 ± 1,984		8.341 ± 0.82	8,132 ± 1,477		11.000 ± 4.08

[z]Mean of 5 trees ± standard deviation.

Table 5. Comparison of fruit quality between king fruit and lateral fruit when fruitlets were thinned to one per cluster with Fuji and Tsugaru apples in 1995.

Cultivar[w]	Origin of fruitlet	Mean fruit weight (g)	L/D of fruit	Coloring index[z]	Brix (%)	Starch index[y]	Russet index[x]
Fuji	king flower	303	0.894	3.3	14.1	1.1	0.0
	lateral flower	296	0.866	3.6	14.2	1.1	0.0
	t-test[v]	ns	ns	ns	ns	ns	ns
Tsugaru	king flowers	271	0.887	2.8	10.4	1.1	0.3
	lateral flowers	257	0.847	3.2	10.5	1.2	2.5
	t-test[v]	ns	ns	ns	ns	ns	*

[z]Index of color chart for Fuji apples (1 is least, 6 is most red).
[y]Index of starch test (1 is none, 5 is stained the most by iodine solution).
[x]Index of russeting (0 is none, 3 is the most).
[w]Three trees of Fuji/M.7 (18-year-old) and three trees of Tsugaru/MM.106 (13-year-old) were used.
[v]ns is not significantly different, * is significantly different.