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Apple Growing in Japan

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IMPORT AND CONSUMPTION OF FRUIT IN JAPAN

About 1.5 million tons of fresh fruit were imported into Japan in 1997. The main imported fruits are bananas (822,294 t), citrus (512,077 t), kiwifruits (38,301 t) and cherries (12,457 t). Apple importation was only 131 tons in 1997 (Table 1). The consumption of fruit is not so high in Japan because fruit are mainly eaten fresh as a dessert. The annual consumption of apples is approximately 5 kg per person and furthermore it has tended to decrease gradually, recently being replaced by soft drinks and snacks (Fig. 1). Japanese housewives peel and cut apples into several pieces so as to share them with their family at the dinner table.

The apple growing area reached 65,000 ha (160,600 acres) in 1965 and decreased gradually to 51,200 ha (126,500 acres) with a production of 1,000,000 metric tons in 1996 (Fig. 2). Apples are grown mainly in Aomori, Nagano, Iwate, Yamagata, Akita, Fukushima, Hokkaido, Miyagi, Gunma and some other prefectures. These main apple growing areas are located from latitudes 36˚ to 44˚ north. Two main prefectures, Aomori (50%) and Nagano (23%), produce about 73% of Japan's apples. Fuji (48%), Tsugaru (14%) and Orin (9%) are the main varieties (Fig. 3). The mean annual temperature varies from 9˚C (48˚F) in Aomori to 12˚C (54˚F) in Nagano. Fuji apples grown in Nagano mature a little earlier than those in Aomori (Table 2). Therefore, fully matured Fuji apples with enough watercore are mainly harvested in late October to November in Nagano and are quickly shipped to market.

Comparative climatic conditions between Nagano and Wenatchee, Washington, are shown in Table 3. There is a large difference in precipitation in the growing season and in temperatures from August to November.

APPLE MANAGEMENT PRACTICES

There were about 85,000 apple growers and 53,900 ha of apple orchards in 1990 and the growers are decreasing gradually now. Growers who have less than 0.5 ha orchards occupy 63% of the total growers and they do farming as a side job. The average yield of apples per ha is about 25 tons in Nagano and the recent price of apples determined by auction at the central wholesale markets is 200 to 300 yen per kg (at 125 yen/$US; .72 to 1.09 $US/lb.).

Artificial Pollination

It was essential to use artificial pollination for improving fruit set in Japan. It is necessary to collect 10,000 to 15,000 flowers at the balloon stage for the pollination of a 1-hectare orchard. Pollination is made by touching only the king flowers in blossom clusters on terminal buds by using the pollen and a pollination brush. This practice is expensive and it takes about 180 hours of labor per hectare. Recently, usage of insect pollinators such as Osmia bees is increasing in order to reduce labor.

Hand Thinning

Thinning is the most important step in achieving large, unique-sized fruit and preventing alternative bearing of Fuji apple trees. Blossom and fruitlet hand thinning has been done mainly to grow large fruits (300-350 g) which are the most important with high consumer demand in the Japanese market. This expensive practice makes up about 24% of total labor hours for apple growing in Nagano. Today, lime sulfur and carbaryl are being used as blossom and fruitlet thinners. However, hand thinning is used to thin off lateral fruits which remain in the clusters and fruitlets from axillary buds (1-year wood). Hand thinning to determine optimum crop load is necessary whether spray thinning is undertaken or not.

Bagging

Paper bagging has been developed mainly for the purpose of improving fruit color in Japan. Double bags are used for major varieties such as Fuji and Tsugaru. About 30% of Fuji apples are bagged in Nagano now, but it is decreasing because of lower prices in the market. Bags must be put on the fruit by early July. Outer bags should be removed about 35 days before harvest and inner bags should be left on until about a week before harvest to prevent sunburn of the fruit skin. The inside of the outer bag is painted black to prevent light penetration and inner bags are coated with fungicides including paraffin to reduce russet on the fruit, *alternaria* leaf spot and sooty blotch *(Gloeodes pomigena).* An average worker can bag only 3,000 fruit per day. It is thought that bagging for Fuji will decrease gradually as new red strains are introduced.

Leaf Removal and Fruit Rotation

Fruit which has a green leaf pattern and half color due to shade cannot be sold with a good return in the Japanese market. Leaf removal near the fruit, therefore, done 20 to 30 days before harvest is one of the most important practices to improve fruit color. Growers also turn the fruit (1/4 to 1/2 turn) to expose the shady side to the sunlight in order to grow unicolor fruit. About 18% of the labor time is used for this practice. It is also thought that this practice will continue in importance in the future in order to satisfy the Japanese market or consumers' demand, even with the introduction of new sorting systems equipped with an infrared analyzer.

Harvesting and Grading Apples by New Systems

Optimum harvest date for each cultivar is usually decided by the calendar day. Ground color and red surface color have been used as external maturity indices. Soluble solids and watercore, firmness, titratable acids and starch decrease are used as internal maturity indices. Fruits with watercore, especially Fuji apples, are usually sold at retail shops expensively as "honeyed (Mitsuiri) apples." Watercore is called "honey (Mitsu)" in Japan. Watercore is thought to be caused by accumulation of sorbitol promoted by low temperature (below 13˚C) just before harvest. Therefore, fruit growers in Nagano usually delay the harvest as late as possible, but it can happen that the fruit can be damaged by a sudden freeze in the late fall.

Fruits are picked by hand, collected in plastic containers holding 20 kg, and carried out of the orchard. Most fruit growers belong to cooperative associations so that the fruit is mainly graded at the packing houses of the associations. At the packing house, fruit is graded visually. Recently, many cooperative packing houses have a new sorting system with instruments for analyzing the sugar content of the fruit with infrared. For selling apples in the Japanese market, not only the appearance but also internal quality such as brix (soluble solids), crispness and juiciness are important because Japanese consumers prefer sweet, crisp apples. Apples graded automatically for brix by using optical instruments (color meters and infrared analyzers) have recently sold at higher prices. Japanese fruit growers, therefore, begin to make every effort to raise apples not only with good appearance but also with more than 15% brix (Table 4).

NEW CULTIVARS

Many new cultivars have been released in recent years from experiment stations or private farms in Japan. Akibae (Table 5), Shinano Sweet (NA-10), Shinano Red (NA-12), Shinano Gold (NA-15) are thought to be promising now. Shinano Sweet is a cross of Fuji x Tsugaru originating from Nagano Fruit Tree Experiment Station. Harvesting time is the same as Delicious and fruit are large (about 350 g) with red striped color. The flesh is slightly soft in texture, very juicy, very sweet in flavor and never mealy (Table 6). Shinano Red is a cross of Tsugaru x Vista Bella originating from Nagano Fruit Tree Experiment Station. Harvesting time is early, the same as Summerred, and it has a red striped color (Table 7). Shinano Gold is a cross of Golden Delicious x Fuji originating from Nagano Fruit Tree Experiment Station. Harvesting time is 3 weeks earlier than Fuji and the fruit is yellow. Flesh is crisp, juicy and mildly sub-acid with an excellent flavor (Table 8).

New varieties have been released recently from research stations in Japan (Table 9). Hozuri is a chance seedling of Fuji from Fukushima Fruit Tree Experiment Station with large fruit, red striped color, and acid taste. Akita-gold is a cross of Golden Delicious x Fuji originating from Akita Fruit Tree Experiment Station with medium fruit size, yellow color and somewhat acid taste. Gunmameigetsu is a cross of Akagi x Fuji originating from Gunma Horticultural Experiment Station with medium fruit size, yellow color with a pink blush and sweet taste. Kitaro is a cross of Fuji x Hatsuaki originating from Fruit Research Center of NIAFF in Morioka with medium fruit size and yellow color. Aori-9, a cross of Akane x Orin, and Aori-13, a cross of Sekaiichi x Akane, are quite new varieties originating from Aomori apple research station.

RED STRAINS OF FUJI

Recently, many strains have been founded in apple growing areas around the world but there is no clone which is superior in every country. In Japan, it was shown by collaborative work that fruit color of red sports depends on the environmental condition of each growing area. Thus, it has been recommended that growers should choose the clone which most suits their area. Nagano Fruit Tree Experiment Station recently collected many types of red strains from commercial orchards. From this study, it is clear that red strains of Fuji are classified in three types (blush, stripe and intermediate) by their coloring characteristics.

Fruit of blush types colors with 90-100% deep solid red without stripe. Nagafu-1 is a typical clone of this type. Nagafu-2 and Nagafu-6 which have been planted commercially in Japan are typical clones with stripe. Fruits of intermediate type color are deep red with unclear stripe. Nagafu-12 is a typical intermediate type and it has been recommended recently in Nagano (Table 10). Akifu-47, Mishima-Fuji, Rakuraku-Fuji and 2001-Fuji clones which color well not only with direct light but also with diffuse light are beginning to be planted now. These four clones are thought to be the same clone by recent investigation. Other new local strains originating from Nagafu-2 or Nagafu-6 are shown in Table 11. Hirosaki-Fuji and Korin, early maturing red strains, are attracting growers' attention now. They mature about 30 days earlier than Fuji and also color well.

ROOTSTOCKS AND ORCHARD SYSTEMS

The apple rootstocks actually used in old Japanese orchards were *M. prunifolia* Bork. *var. ringo* Asami (Marubakaido in Japanese) and *M. sieboldii* Mill. (Mitsubakaido in Japanese). Marubakaido has also been used as the understock with dwarfing interstems for apple trees in Japan because it is easily propagated by hardwood cuttings. The early use of M.9 as an interstem with Marubakaido resulted in severe growth retardation or death of trees because M.9

introduced into Japan was infected with the apple chlorotic leaf spot virus (ACLSV) to which Marubakaido is highly susceptible. Furthermore, Japanese nurserymen gave up propagating M.9 rootstocks by the stooling method. Thus the M.26 introduced as ACLSV virus free has been mainly used as an interstock for growing dwarfing nursery trees. M.26 has not been recommended recently for Fuji apples because deeply planted interstem trees on M.26/ Marubakaido are too big for the spacing of 2 m x 4 m (6.5 x 13 feet) to 3 m x 5 m (9.8 x 16 feet). In addition, M.26 tends to develop many burrknots and trees on M.26 with burrknots are less productive if planted with the M.26 interstem exposed above ground. Instead of M.26, M.9 has been recommended for the last 10 years. Several clones of M.9 such as M.9A, M.9 EMLA and M.9 NAGANO are commercially used in Japan and new clones such as NAKB, FL56, M.9B, Pajam 1 and Pajam 2 introduced from Europe are being tested in Nagano Fruit Tree Experiment Station.

The clone which is recommended now in Nagano is M.9 NAGANO. M.9 NAGANO which had been called M.9- (minus) is a selected ACLSV virus-free clone named by the Nagano Fruit Tree Experiment Station in 1997. It originated from M.9 which was introduced from East Malling Research Station in England before 1960. Trees on M.9 NAGANO seem to be smaller than other clones such as M.9A and M.9 EMLA in Japan. Therefore, M.9 NAGANO rootstock propagated by the stooling method has been recommended for growing small trees adapted for higher density planting. M.27, CG.10 and CG.80, which have been tested in Nagano, are not good for Fuji because fruit on M.27 is too small, trees on CG.10 produce many burrknots and fruit of trees on CG.80 is small and less juicy. It is thought from our experience that rootstocks which are more dwarfing than M.9 are suitable for Fuji planted closer than 1.5 to 2 m x 4 m (4.9 to 6.5 feet x 13 feet) spacing in hedgerow systems (Table 12). M.9 NAKB (T337), M.9 Pajam 1, P.16, M.20, G.65, JTE, JM.5, JM.7, JM.8 and some other clones of M.9 rootstocks are considered to be worthy of further trials in Japan.

ROOTSTOCK AND PLANTING STUDIES

The rootstock studies in Nagano Fruit Tree Experiment Station have been conducted to select the best dwarfing rootstocks and establish high density planting systems.

Fuji on M.26 and M.9 NAGANO

Fuji on M.9 NAGANO during 9 years showed smaller tree size and higher efficiency than those on M.26. It is concluded that fruit growers should use more dwarfing rootstocks such as M.9 NAGANO for high density planting of Fuji because M.26 is too vigorous (Table 12).

Fuji on Dwarfing Rootstocks and Interstocks

There is quite a difference in a 20-year study between shallow and deeply planted M.26 interstem trees. Shallow planted trees on M.26/Marubakaido showed weaker tree vigor. In contrast, deeply planted trees with an M.26 interstem grew too vigorously and attained a tree size too large for the 1.5 to 2 m x 4 m planting distance. Trees on M.9 NAGANO were smaller than those on M.26 and showed the best yield efficiency (Table 13). It is also observed that mean fruit size of trees on M.9 NAGANO were larger than those on others. In conclusion, we determined that M.9 NAGANO is a promising rootstock for Fuji if trees are planted at spacing of 1.5 to 2 m x 4 m.

Tree Form

Studies were carried out to determine optimum canopy structure and tree growth indices of Fuji apple trees on dwarfing rootstocks planted in 1.5 to 2.0 m x 4 m spacing. From the results, it is clear that conical-shaped smaller trees have a more efficient canopy and better light distribution. This study showed that Fuji needed at least 30% relative light intensity (% of full sun) for production of colored fruit and promotion of flower bud differentiation (Fig. 4). It is also considered that ground area covered by hedgerow canopy (hedge occupied area, HOA), leaf area index (LAI, total leaf area per orchard area), shoot length, number of shoots, ratio of growth terminated shoots (GTS) and leaf color are important indices for tree growth and high quality fruit production. Optimum HOA and LAI for producing commercially valuable fruit in Japan are thought to be about 60% for HOA and 1.8 to 2.2 for LAI in mature orchards which have been planted 1.5 to 2.0 m x 4 m spacing (Tables 14, 15). Fruit quality will be worse as LAI increases because of higher light interception and lower light penetration. Average shoot length and % of growth terminated shoots show high correlation to % of poor colored fruit and brix of fruit (Tables 16, 17).

The number of leaves per tree which shows the optimum canopy volume for 1.5 to 2.0 m x 4 m spacing is 6,000 to 8,000, when LAI is 2.0. In these conditions, trees can bear 100 to 110 fruits and a yield of 30 to 35 kg is expected. As a result, yield per hectare reaches 40 to 50 tons.

On Fuji trees in moderate vigor, optimum indices for producing quality fruit are as follows: mean shoot length of about 20 cm (8 inches) in early July, ratio of growth terminated shoots is 90 to 95% in mid-June, leaf color as determined by Minolta-SPAD50 is 29 to 31 in mid-May and 45 to 55 in mid-June (Table 18). By keeping these optimum indices, it is possible to keep optimum tree size for above spacing and quality fruit each year. For keeping good tree growth, selection of dwarf rootstocks such as M.9 NAGANO is most important. If trees are rather vigorous for the given space, removing every second tree to provide enough space is most important.

Rootstocks for High Density Plantings

In 1992, we established a trial of rootstocks including M.9 clones and JM.7 (Japan Morioka rootstock) using Fuji as a scion variety. M.9 VF157 produced the smallest tree followed by M.9 Pajam l, M.9 Pajam 2 and M.9 NAGANO. Trees on JM.7 and M.9 NAGANO/Marubakaido produced larger trees and showed lower yield efficiency than those on other rootstocks. Significant difference in tree size is not recognized among trees on other rootstocks based on these early results for 5 years (Table 19).

A trial of planting and training systems using standard Fuji and Seirin-spur Fuji on M.9 NAGANO/Marubakaido was also established in 1992. The training systems slender spindle bush and Y-trellis are compared (Table 20). Based on the results for 5 years, trees on Seirin-spur Fuji on M.9 NAGANO produced smaller trees than standard Fuji but had almost the same yield efficiency. There are large differences in shoot length and % of spurs per tree between Seirin-spur Fuji and Fuji. Total shoot length for Seirin-spur Fuji was about half that of Fuji in the slender spindle bush trees and about one-third of Fuji in Y-trellis trees. Trees trained as Y-trellis had lower bearing height than those trained as the slender spindle bush, but had similar TCA and yield efficiency for each variety (Table 20). It is observed that Seirin-spur Fuji has somewhat stronger alternative bearing habit than Fuji. In conclusion, further studies will be necessary to adequately evaluate the performance of Seirin-spur Fuji and the Y-trellis training system.

TRAINING HIGH DENSITY FUJI APPLES

During the 1970s, apple growing in Japan became more intensified. The Dutch slender spindle system was adopted at that time for mainly M.26 interstem trees on Marubakaido understock.

With slender spindle trees, it is critical to retain relatively weak growth and to keep the cone-shaped tree form within its narrow space. The system involved limb bending, a zigzag-shaped central leader, renewal of upper limbs and shortening the permanent lower scaffold limbs. Contrary to our expectation, M.26 interstem Fuji apple trees at maturity have generally grown too vigorously. Mature Fuji apple trees on M.26/Marubakaido tended to change their form naturally to the forms of a free spindle or vertical axis which have a lower layer of strong frame branches. Furthermore, removal of every second tree and tree form improvement toward the free spindle bush are recommended for almost all mature Fuji trees on M.26/Marubakaido planted at spacing of 2 m x 4 m in Nagano. Enough spacing for canopy volume and light pruning are important to maintain optimum tree growth. Training of free spindle bush, Hybrid Tree Cone, Vertical axis and Y-trellis for Fuji trees on M.9 NAGANO rootstock are now under testing in Nagano Fruit Tree Experiment Station.

There are a number of principles recommended for pruning spindle bush Fuji trees in Nagano. The most important first step to form a cone-shaped tree is planting well-feathered 1-year-old nursery trees or 2-year-old "knip" (cut) trees. Heading back or cutting the central leader has been done only in the planting year to avoid induction of greater vegetative growth of leader. Narrow crotch-angled branches which have a diameter more than half of the leader are pruned off. Branches with narrow crotch angles are bent into a horizontal or a somewhat downward position in late winter without a heading cut to promote flower bud formation or reduce the vigor. Upright strong shoots (sprouts) on limbs which have been bent to the horizontal position are removed. The strong branches on the upper part of leader are removed to maintain the conical shape. Weeping tips of the fruiting branch are cut back to the flattened position to keep the fruiting zone close to the central leader by maintaining the balance between fruiting and reproductive growth. A strong heading cut (bench cut) with a limb is not recommended because this pruning cut usually causes strong localized shoot growth and abnormal fruit growth with mineral disorders of fruit such as bitter pit (low calcium).

Summer pruning has mainly been done to improve light penetration into the tree and fruit coloring for varieties such as Fuji which have the characteristic of poor coloring. In general, Fuji apples color well at 30% or more full sun exposure in growing regions of Nagano. The size and brix of fruit are also highly related to light exposure. It is generally said that summer pruning suppresses tree vigor and causes dwarfing by reducing the leaves or rootlets. However, it is often the cause of an unexpected burst of growth from terminated spurs or axillary buds below the pruning cut, resulting in poor flower buds when it is done during early summer (Table 21). Ogata et al. (1986) have shown that flowers of secondary shoots and spurs occurring after summer pruning tend to bloom late the following spring and produce abnormal-shaped fruit. The bourse of these flower clusters showed a strange extension growth. In general, branch bending which enhances the development of vigorous upright shoots (water shoots) has been recommended in spindle bush training. These upright shoots on horizontal or downward facing limbs should be thinned out with summer pruning once or twice during the summer in Nagano.

PROPAGATION OF ROOTSTOCKS AND NURSERY TREE QUALITY

It is clear from several experiments over 20 years that mature M.26/Marubakaido interstem Fuji trees grow too large for their allotted space at 1.5 to 2 m x 4 m spacing. Therefore, stooling techniques for propagating M.9 NAGANO, which improve dwarfness and efficiency, are being recommended to permit higher density plantings of Fuji apples. Studies on stooling techniques of M.9 NAGANO undertaken at the Nagano Fruit Tree Experiment Station show that etiolation by covering with 3 to 4 cm (2 inch) layer of peat-soil mixture is effective for improving the number of well-rooted shoots (Table 22). Fruit growers in Nagano are now looking for high quality nursery trees to improve precocity. Nurserymen also recognize that the nursery tree must have at least five lateral branches (feathers) with medium length and wide angles. Two-year-old knip trees which are usually used in Europe (Nicolai, 1993) are also now recommended for planting in new orchards. The studies on the pruning of 1-year-old whip Fuji trees carried out in Nagano Experiment Station show that optimum size branches with wide angles can be obtained by heading the leaders at 60 cm above ground and thinning shoots leaving only one shoot from just below the heading cut.

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Table 1. A list of main fruit types imported into Japan in 1996 and 1997.

Fruits	1997 (t)	1996 (t)	Imported from
Banana	822,294	760,111	Philippines, Ecuador
Pineapple	88,483	89,561	Philippines
Citrus	512,077	481,893	USA
Mango	8,361	9,375	Philippines, Mexico
Avocado	5,592	6,092	Mexico, USA
Grape	6,620	6,069	Chile, USA
Papaya	4,655	5,526	USA
Kiwifruit	38,301	45,271	New Zealand
Cherry	12,467	11,309	USA, New Zealand
Apple	131	710	USA, New Zealand
Others	9,190	6,200	
Total	1,508,171	1,422,118	

Table 2. Difference in fruit quality of the new apple cultivar Shinano Gold (NA-15) depends on the site and elevation in Nagano (Nagano Fruit Tree Experiment Station).

Site	Elevation (m)	Av. fruit weight (g)	Brix	Titratable acidity (%)	Firmness (lb)	Starch index[y]	Maturity index[z]
Suzaka	360	358	16.0	0.49	14.1	4.0	4.0
Nagato	630	330	14.7	0.56	13.5	3.8	3.8
Suwa	760	336	14.6	0.49	13.7	4.0	3.8

[z]Index of ripeness (5, over-ripe; 4, fully ripe; 3, optimally ripe; 2, little ripe; 1, not ripe).
[y]Index of starch test (1, none; 5, stained the most).

Table 3. Comparison of climate (10-year average) between Nagano, Japan, and Wenatchee, WA, USA.

Site	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean temperature (˚C)												
Nagano	-1.4	-0.8	2.9	9.9	15.5	19.8	23.2	24.9	19.5	12.7	6.7	1.4
Wenatchee	-2.2	-1.8	5.8	10.8	15.6	19.6	23.1	22.4	17.6	10.5	3.8	-0.3
Precipitation (mm)												
Nagano	40	51	60	42	76	91	102	83	107	75	37	36
Wenatchee	34	20	16	16	15	14	4	18	8	15	29	36

Table 4. A grading example of Fuji apples using automatic sorting equipped with the optical instruments such as near infrared analyzers. About 23 cooperative packing houses (total of 162) have introduced this sorting system by 1997.

Grade of brix (soluble solids)[z]	Date of sorting Nov. 8-14	Nov. 20-27	Dec. 3-10
Excellent (Brix <15%)	68%	68	81
Gourmet (Brix 13-15%)	29	27	16
Non-brand (Brix 13%<)	3	5	2

[z]Data measured at a JA cooperative packing house in Nagano.

Table 5. Fruit quality and shelf life of Akibae and Senshu apples in Nagano (Nagano Agricultural Research Center).

Cultivar	Harvest date	Firmness (lb)	Brix (%)	Titratable acidity (%)	Taste score[w]
Akibae	Sep. 29[z]	14.4	15.8	0.48	5.0
	Oct. 1[y]	15.8	15.6	0.42	4.5
	Oct. 5[x]	15.5	15.6	0.38	3.5
Senshu	Sep. 29	13.8	14.1	0.43	5.0
	Oct. 1	12.6	12.6	0.38	4.5
	Oct. 5	13.9	13.9	0.45	3.5

[z]Date of harvest and fruit quality measurement.
[y]Date of measuring the quality of fruits kept 3 days under room condition.
[x]Date of measuring the quality of fruits kept 7 days under room condition.
[w]Scores of taste (5, excellent; 1, very poor).

Table 6. Fruit quality of the new apple cultivar Shinano Sweet (NA-10) in Nagano (Nagano Fruit Tree Experiment Station).

Site	Elevation (m)	Date of harvest (Oct.)	Av. fruit weight (g)	Color[z] (%)	Brix (%)	Titratable acidity (%)	Firmness (lb)	Maturity score[y]
Suzaka	360	1	332	80	15.9	0.37	13.9	3.2
Matsukawa	680	4	310	70	14.8	0.32	14.9	3.0
Azusagawa	700	8	425	71	15.5	0.35	14.1	3.3
Omi	900	15	371	66	13.9	0.37	14.4	3.8

[z]% of red color per fruit surface.
[y]Index of ripeness (5, over-ripe; 4, fully ripe; 3, optimally ripe; 2, little ripe; 1, not ripe).

Table 7. Fruit quality of Shinano Red (NA-12) apples in Suzaka, Nagano (Nagano Fruit Tree Experiment Station).

Year	Date of harvest (Aug.)	Av. fruit weight (g)	Color[y] (%)	Brix (%)	Titratable acidity (%)	Firmness (lb)
1993	23 (103)[z]	196	95	12.8	0.47	14.4
1994	12 (101)	249	70	14.5	0.42	15.7
1995	21 (110)	246	82	12.5	0.33	14.7
1996	26 (107)	221	93	12.1	0.39	14.8
1997	17 (106)	237	88	12.5	0.35	15.6

[z]Days after full bloom in parentheses.
[y]Red color percent per fruit surface.

Table 8. Fruit quality of Shinano Gold (NA-15) apples in Suzaka, Nagano (Nagano Fruit Tree Experiment Station).

Date of harvest (Oct.)	Av. fruit weight (g)	Brix (%)	Titratable acidity (%)	Firmness (lb)	Starch index[y]	Maturity index[x]
2 (153)[z]	276	14.8	0.48	15.8	2.1	2.1
8 (157)	288	15.6	0.52	15.0	3.0	3.0
20 (171)	283	16.2	0.55	15.0	4.0	4.0

[z]Days after full bloom in parentheses.
[y]Index of starch test (1, none; 5, stained the most by iodine solution).
[x]Index of ripeness (5, over-ripe; 4, fully ripe; 3, optimally ripe; 2, little ripe; 1, not ripe).

Table 9. Characteristics of recently introduced apple varieties in Japan (from report of Kanreitikajyu meeting, 1996).

Variety	Fruit harvest date	Weight[z] (g)	Brix[z] (%)	Titratable acidity[z] (%)	Firmness[z] (lb)	Color[z]	Pedigree and origin
Hozuri	Oct. 25	351	15.1	0.70	13.2	Red stripe	Seedling of Fuji. Fukushima
Akita-Gold	Oct. 15	272	13.5	0.50	16.3	Yellow	G. Delicious x Fuji. Akita Pref.
Gunmameigetsu	Nov. 7	278	13.6	0.21	12.4	Yellow	Akagi x Fuji. Gunma Pref.
Aori-9	Sep. 30	298	13.8	0.48	15.8	Red stripe	Akane x Orin. Aomori Pref.
Aori-13	Oct. 7	361	14.5	0.34	17.7	Red blush	Sekaiichi x Akane. Aomori Pref.
Kitaro	Oct. 14	250	15.4	0.42	15.1	Yellow	Fuji x Hatsuaki. Morioka

[z]Fruit quality data measured at each prefectural research station are shown.

Table 10. Comparison of notable red sports of Fuji in Nagano, Japan (Nagano Fruit Tree Experiment Station).

Red sport	Rootstock	Av. fruit weight (g)	Color[y] (%)	Color index[x]	Brix (%)	Titratable acidity (%)	Type of coloring
Akifu-47	M.26/Maruba.[z]	334	100	5.3	15.3	0.40	Stripe, colors well
Seirin-spur	Maruba.	362	82	4.2	16.1	0.30	Intermediate to blush
Nagafu-12	CG.10/Maruba.	362	99	5.8	15.5	0.37	Intermediate
Nagafu-6	M.26/Maruba.	417	94	5.5	15.4	0.40	Stripe
Nagafu-2	Maruba.	361	91	3.8	15.1	0.44	Stripe to intermediate

[z]Marubakaido (selected clone of *M. prunifolia* Bork. *var. ringo*) rootstock.
[y]% of red color per fruit surface.
[x]Coloring index (6, excellent; l, poor).

Table 11. Characteristics of recently found promising red sports of Fuji in Japan with a strong coloring characteristic.

Sport	Type of coloring	Origin	Notes
Nagafu-12	Intermediate	Selected clone	Recommended in Nagano Pref.
Mishima[z]	Stripe	Selected in Akita Pref.	Grown in some areas in Nagano Pref.
JA-Azumi	Stripe	Selected from Nagafu-2	Grown in Azumi, Nagano Pref.
Kamijo	Intermediate	Selected from Nagafu-6	Grown in Matsumoto, Nagano Pref.
Miyazakai	Stripe	Selected from Nagafu-2	Grown in Shinonoi, Nagano Pref.
Gozu	Stripe	Selected from Nagafu-2	Grown in Oomachi, Nagano Pref.
Nakata	Intermediate	Selected clone	Grown in Azusagawa, Nagano Pref.
Sheki	Stripe	Selected clone	Grown in Nagano, Nagano Pref.
Hirosaki-fuji[y]		Selected in Aomori Pref.	Start planting in Aomori Pref.
Korin[y]		Selected in Yamagata Pref.	Start planting in some Pref.

[z]Originated from Akifu-47 including Rakuraku Fuji and 2001 Fuji.
[y]Early maturing strain of Fuji.

Table 12. Comparison of 9-year-old Fuji apple trees on M.9 NAGANO and M.26 rootstocks.

Rootstock	Tree height (cm)	Trunk cross-sectional area (TCA, cm^2)	Cumulative yield/tree (kg)	Cumulative yield/TCA (kg/cm^2)	Av. fruit weight (g)
M.9 NAGANO[z]	347	33	155	4.71	335
M.26[y]	416	63	168	2.67	416
Significance[x]	*	**	NS	**	NS

[z]M.9-, a clone selected in Nagano Fruit Tree Exp. Station, was named M.9 NAGANO in 1997.
[y]Fuji trees/M.9 NAGANO (40 cm) and M.26 (40 cm) planted as rootstock half-buried.
[x]NS, not significantly different; *different at 5%, **different at 1% level.

Table 13. Comparison of 20-year-old Fuji apple trees on some interstocks and rootstocks.

Rootstock and interstock	Tree height (cm)	Tree spread (cm)	TCA (cm^2)	Cumulative yield/tree (kg)	Cumulative yield/TCA (kg/cm^2)
M.9 NAGANO[z]	388 ± 10	332 ± 7	98.8 ± 5	604.9	6.12
M. 26[y]	516 ± 16	451 ± 40	167.6 ± 21	-	-
M.26/Maruba.-D[x]	487 ± 13	424 ± 19	180.9 ± 9	599.1	3.31
M.26/Maruba.-S[w]	277 ± 11	183 ± 18	58.2 ± 10	280.2	4.82

[z]Trees/M.9 NAGANO (40 cm) planted as rootstock half-buried.
[y]Trees/M.26 (40 cm) planted as rootstock half-buried.
[x]Trees/M.26 (30 cm)/Marubakaido planted as interstem half-buried.
[w]Trees/M.26 (30 cm)/Marubakaido planted as interstem exposed above ground.

Table 14. Correlation coefficient and regression equations of % of area occupied by hedge occupied area (HOA) and yield and fruit quality of Fuji apple trees on dwarfing rootstocks.

Variable X	Y	Regression equation	Correlation coefficient[v]	Estimated Y value for X values of 50	55	60	65	70	75%
HOA[z]	Yield (kg)[y]	Y= -3.24 + 0.53X	0.707**	23.3	25.9	28.6	31.2	33.9	36.5
HOA	% PCF (%)[x]	Y= -10.27 + 0.59X	0.630**	19.2	22.2	25.1	28.1	31.0	33.9
HOA	Brix (%)[w]	Y= 18.7 - 0.04X	0.719**	16.7	16.5	16.3	16.1	15.9	15.7

[z]HOA: % of hedge occupied area in the 4 x 1.5 m spacing.
[y]Yield/tree planted at 4 x 1.5 m spacing hedge row.
[x]% of poor colored fruit which colored less than 30% of surface.
[w]Average brix of fruit.
[v]The correlation is stronger as the coefficient increases from .1 to .9; **Significant at 1% level.

Table 15. Correlation coefficient and regression equations of leaf area index (LAI) and yield, fruit quality of Fuji apple trees on dwarf rootstocks.

Variable X	Y	Regression equation	Correlation coefficient[w]	Estimated Y value for X values of 1.8	2.0	2.2	2.4	2.6
LAI[z]	Yield (kg)	$Y= 2.9 + 20.8X - 2.7X^2$	0.76**	31.6	33.7	35.6	37.3	38.7
LAI	% PCF (%)[y]	Y= 4.9 + 11.1X	0.82**	24.9	27.1	29.3	31.5	33.7
LAI	Brix (%)[x]	Y= 17.5 - 0.67X	-0.81**	16.3	16.2	16.0	15.9	15.8

[z]Leaf area index calculated in a 4 x 1.5 m spacing hedge row.
[y]% of poor colored fruit which colored less than 30% of surface.
[x]Average brix of fruit.
[w]**Significant at 1% level.

Table 16. Correlation coefficient and regression equations of average shoot length (ASL) and yield, fruit quality of Fuji apple trees on dwarfing rootstocks.

Variable X	Y	Regression equation	Correlation coefficient[w]	Estimated Y value for X values of 16	18	20	22	24	26 cm
ASL[z]	Yield (kg)	Y= 1.73 + 1.29X	0.48*	22.4	25.0	27.5	30.1	32.7	35.3
ASL	% PCF (%)[y]	Y= -29.5 + 2.61X	0.78**	12.3	17.5	22.7	27.9	33.1	38.4
ASL	Brix (%)[x]	Y= 18.9 - 0.12X	0.61**	17.0	16.7	16.5	16.3	16.0	15.8

[z]Average shoot length.
[y]% of poor colored fruit which colored less than 30% of surface.
[x]Average brix of fruit.
[w]*Significant at 5% level, ** at 1% level.

Table 17. Correlation coefficient and regression equations of % of growth terminated shoot (GTS) by July 15 and yield and fruit quality of Fuji apple trees on dwarfing rootstocks.

Variable X	Variable Y	Regression equation	Correlation coefficient[w]	Estimated Y value for X values of 88	90	92	94	96
GTS[z]	Yield (kg)	Y= 157.9 - 1.34X	-0.46**	39.9	37.3	34.6	31.9	29.3
GTS	% PCF (%)[y]	Y= 259.4 - 2.43X	-0.68**	45.6	40.7	35.8	30.9	26.1
GTS	Brix (%)[x]	Y= 1.12 + 0.157X	0.72**	14.9	15.3	15.6	15.9	16.2

[z]% of growth terminated shoot per tree on July 15.
[y]% of poor colored fruit which colored less than 30% of surface.
[x]Average brix of fruit.
[w]**Significant at 1% level.

Table 18. Optimum growth indices of Fuji apple trees with a high density hedge row for the production of high quality fruit in Nagano, Japan.

Planting system	4 x 1.5~2 m spacing of South-North hedge row
Hedge occupied area	55~60%
Canopy occupied area per tree	3.5~4.5 m^2
Crossing % of canopy occupied area	>1.5 m^2
Leaf area index (LAI) per orchard	1.8~2.2
Tree height	Less than 3.5 m (bearing height: less than 2.8 m)
Trunk cross-sectional area	45~60 cm^2 (15 cm above graft-union)
Average shoot length (except for spurs)	About 20 cm (except for spurs)
% of growth terminated shoot	90~95% (middle June), 95~100% (early July)
Leaf color (value of Minolta-SPAD50)	29~31 (middle May), 43~45 (middle June)
Fruits per tree	100~110
Yield	28~33 kg/tree, 45~55 t/ha
Average fruit weight	300~330 g
Leaf-fruit ratio	50~60 per fruit
Average brix of fruit	15.5~16.0%

Table 19. Results of apple rootstock and interstock trial during the first 5 years with Fuji in 1997.

Rootstock and interstock	Tree height (cm)	TCA (cm^2)	Yield/ tree	Cumulative yield/tree (kg)	Cumulative yield/TCA (kg/cm^2)	Av. fruit weight (g)
JM.7	412	27.2	25.8	29.8	1.11	420
M.9 NAGANO[z]	358	19.8	22.0	25.4	1.30	381
M.9 NAGANO/Maruba.[y]	398	27.5	21.7	25.4	1.02	366
M.9B	396	21.5	18.7	22.4	1.08	408
M.9 VF157[x]	339	15.0	14.7	17.4	1.21	383
M.9 Pajam 1	375	17.7	25.0	28.4	1.62	408
M.9 Pajam 2	336	17.6	19.1	23.3	1.30	394

[z]M.9- was named as M.9 NAGANO in 1997.

[y]5-year-old Fuji trees/M.9 NAGANO (40 cm) interstem on Marubakaido (*M. prunifolia* Bork. *var. ringo*) planted as interstock half-buried. Trees on other rootstocks (40 cm) are planted as rootstock half-buried.

[x]New virus-free clone of M.9 introduced in Nagano Fruit Tree Experiment Station.

Table 20. Comparison of growth and yield of 5-year-old standard growth habit Fuji apple trees and Seirin-spur Fuji apple trees on M.9 NAGANO/Marubakaido interstems with interstem half buried at 4 x 2 m spacing.

Cultivar and training	Tree height (cm)	Bearing height (cm)	TCA (cm^2)	Cumulative yield/tree (kg)	Cumulative yield/TCA (kg)	Total shoot length/tree (cm)	Flowers /spur (%)
Slender spindle bush trees							
Seirin-spur Fuji	382	221	23.9	24.3	1.02	4011	45.7
Fuji	340	266	33.8	37.8	1.12	8891	60.3
Y-trellis trees							
Seirin-spur Fuji	267	205	19.4	18.5	0.95	3039	62.9
Fuji	304	220	29.8	31.9	1.07	9653	58.7

Table 21. Effect of shortening cut (summer pruning) on the growth of current shoot of Fuji apples.

Date of pruning treatment	Total shoot length[z] (cm)	No. shoots growing after treatment[y]	Length of shoot growth from apex[x] (cm)
June 2	52	2.1	40
June 15	76	2.6	51
July 1	73	3.1	43
July 15	63	2.5	32
Aug. 15	75	1.6	27
Sept. 1	59	2.1	8
Sept. 15	54	0.7	0.6
Oct. 1	49	0.4	0.8
Oct. 15	41	0.1	0.1

[z]Growing current shoots were cut back in half and total length was measured after leaf fall including new shoot growth from axillary buds.
[y]Number of shoots growing from axillary buds after treatment.
[x]Average length of new shoots growing from terminal axillary buds after treatment.

Table 22. Effect of etiolation on rooting of M.9 NAGANO in a 2-year-old stool bed.

Treatment	No. of shoots/mother tree	No. of well-rooted shoots	Av. shoot weight (g)	Av. shoot diameter (mm)
Etiolation[z]	6.4[y]	4.9	59.0	8.7
Control	6.1	1.2	65.9	8.2
Significance	ns	**	ns	ns

[z]Shoots of stoolbed were mounded up with peat moss for shading when the shoots grew up about 3 cm.
[y]Average of 14 mother trees.

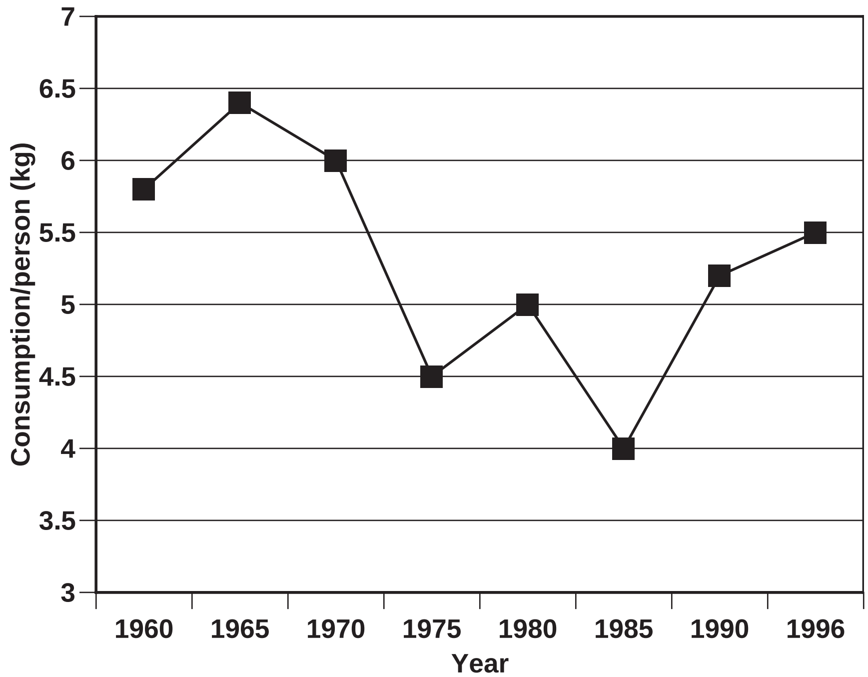

Figure 1. Changes in apple consumption in Japan.

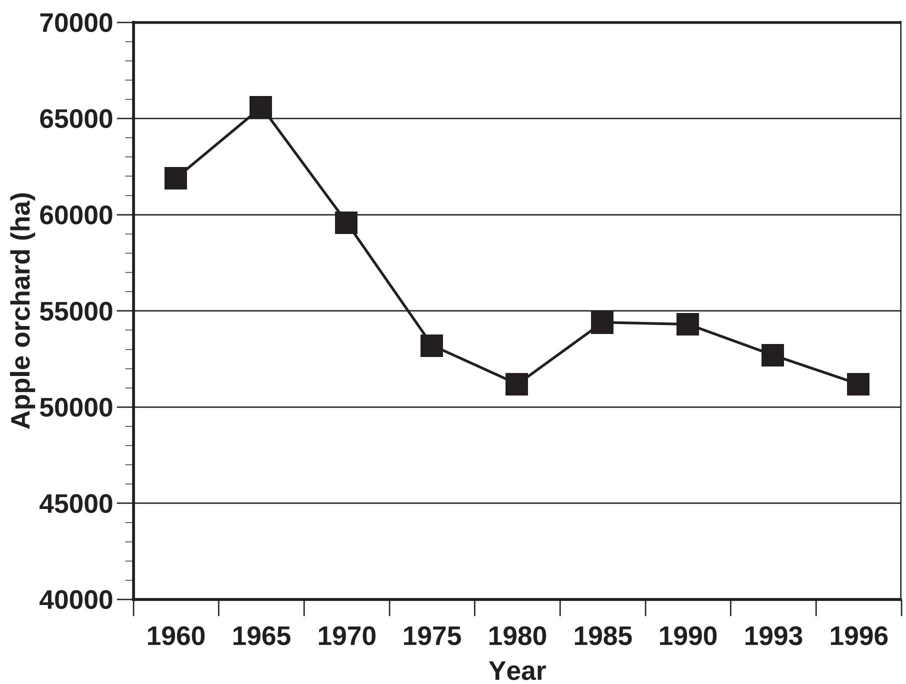

Figure 2. Changes in apple orchard area in Japan.

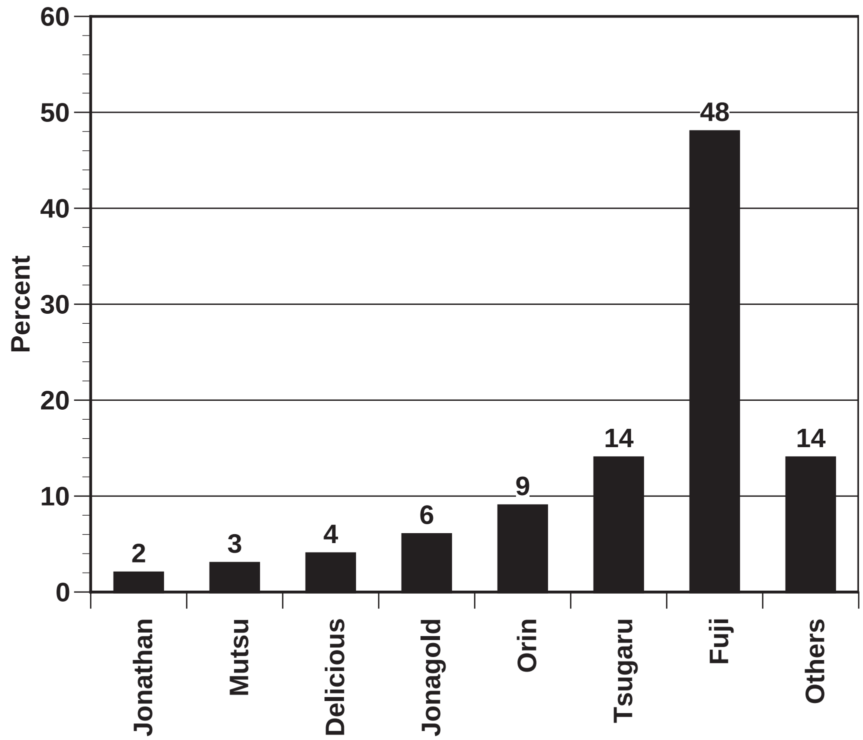

Fig. 3. Apple production by cultivars in Japan in 1997 (total production 1,048,000 tons).

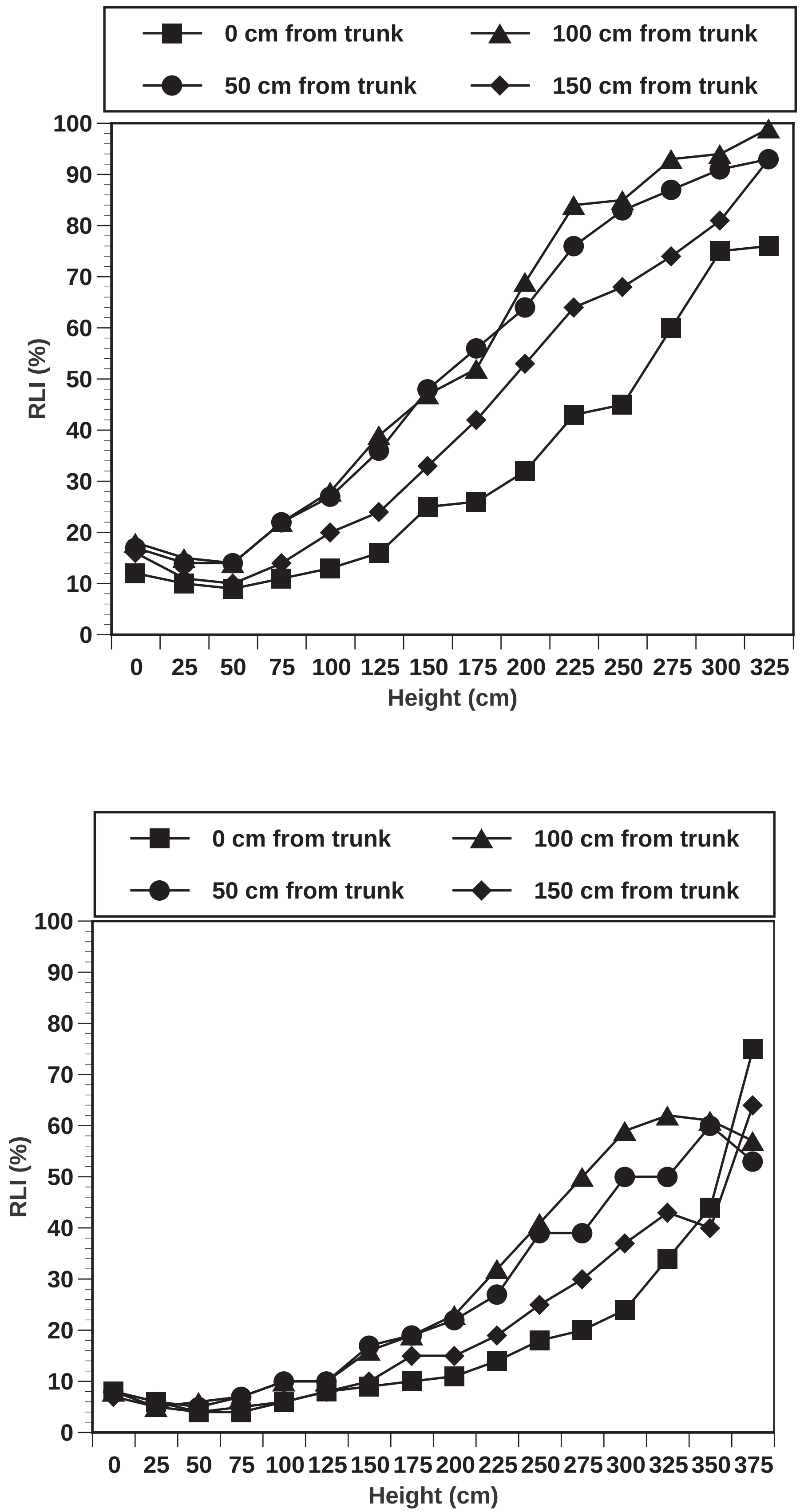

Figure 4. Relative light intensity (RLI) at four positions in canopy of 10-year-old Fuji trees planted at 1.5 x 4 m for moderately vigorous (top) and vigorous crowded trees (bottom).