Journal of Bio-Environment Control, 17(4):306~311, (2008)

Proper Tree Vigor and Crop Load in High Density Planting System for 'Fuji'/M.9 Apple Trees

Moo-Yong Park[1], Jeong-Kwan Park[1], Sang-Jin Yang[1], Hyun-Hee Han[1], In-Kyu Kang[2]*, and Jae Kyun Byun[3]

[1]*Apple Experiment Station, National Institute of Horticultural & Herbal Science, R.D.A., Gunwi 716-810, Korea*
[2]*Dept. of Environmental Horticulture, Kyungpook National University, Sangju 742-711, Korea*
[3]*College of Natural Resources, Yeongnam University, Gyeongsan 712-749, Korea*

Abstract. Proper tree vigor and crop load were determined for 'Fuji'/M.9 apple trees in high density planting system from 2001 to 2003. Leaf/fruit ratio was highly correlated to mean fruit weight ($y=1.715x+205.02$, $R^2=0.66^{**}$) and yield ($y=-35.156x+5963.7$, $R^2=0.44^{**}$). In addition, there was a significant correlation between the number of leaves per tree and mean fruit weight. However, crop load did not affect tree growth, soluble solids content of fruit, and Hunter a value. To harvest the fruits heavier than 300 g without biennial bearing, it was appropriate to crop 55 to 64 fruits in a tree with 55 leaves per fruit of adult tree. The good indices for proper tree vigor could be 20 to 25 cm of mean shoot length and above 95% of shoot termination rate. Moreover, no secondary growth and 20 to 30% of spur formation could be the indices for highly productive tree vigor.

Key words : biennial bearing, shoot growth, leaf/fruit ratio, fruit quality

Introduction

Since 1995, the high density planting system using M.9 rootstocks has been employed for enhancing competitiveness of apple industry in Korea (Park, 1999). This system has proved early and high productivity with labor-saving. As a result, this system has increasingly been applied to more cultivation area in Korea.

In high density planting system, 'Fuji' has been a main cultivar so far in Korea. Oh and Jang (1987) reported that 'Fuji' in growing season produced long shoots with less medium bearing branches (20 cm). Poor fruit quality of 'Fuji' apple trees has been a major problem in the high density planting system with more than 1,900 trees/ha because of excessive shoots growth and poor light penetration. Especially, this phenomenon in highly productive age causes many problems including low yield, poor fruit quality, and biennial bearing.

Therefore, management methods for stabilizing tree vigor and ensuring effective fruiting of 'Fuji' apple trees are required.

This study was carried out to establish the high quality fruit production technique in high density planting system of 'Fuji' cultivar grafted on M.9 rootstock by adjusting tree vigor and crop load for preventing biennial bearing and stabilizing tree vigor.

Materials and Methods

Establishment of proper tree vigor

Five apple producing districts, Suwon, Chungju, Andong, Gunwi, and Jangsu, were selected for establishing proper tree vigor in high density planting systems in 'Fuji'/M.9 planted with the distance of 3.5×1.5 m (1,900 trees/ha) in each orchard. Tree ages were various from 2- to 7-years-old per each three orchards at the same district and ten trees were randomly selected from each orchard for this study. The orchards were grouped into proper tree vigor orchard without biennial bearing and poor tree vigor orchard according to the report of Park (2004). Tree growth characteristics such as mean shoot length and shoot termination were measured on July 10, and secondary growth was measured on August 10.

*Corresponding author: kangik@knu.ac.kr
Received September 9, 2008; Accepted December 10, 2008

Establishment of proper crop load

This experiment was performed from 2001 to 2003 in five apple producing districts as Suwon, Chungju, Andong, Gunwi, and Jangsu planted in March 1999 with 3.2×1.2 m (2,600 trees/ha) using even quality of 'Fuji' nursery.

In order to set the number of appropriate fruiting and yield, each tree was controlled as 40, 60, and 80 of the number of fruitings. Leaf/fruit ratio was calculated by the number of total leaves on mid-July, and the tree growth was performed by the same method as in the above.

Fruit quality was investigated with 20 fruits per tree. The soluble solids content in the fruit juice including the fruit skin was measured using a digital refract meter (model PR-100, Atago Co., Tokyo, Japan). Fruit coloring skin coloration was indicated by Hunter value using a color difference meter (model JX-777, Conica Minolta, Japan). All experiments were employed in a randomized block design with three replications as one tree by one block.

Results and Discussion

Establishment of proper tree vigor

To establish proper tree vigor during growing season for 'Fuji'/M.9 in a high density planting system, tree growth characteristics were investigated (Table 1). The mean shoot lengths in the proper orchards from 2- to 7-years-old tree were 17.4~25.5 cm, whereas those of the contrastive orchards were 24.6~38.2 cm. Shoot terminations on July 10 within whole tree ages were 97~98% of the proper orchards and at 90% of the contrastive orchards. Secondary growths in the proper orchards were 1.2~7.4% and those of non-proper orchards were 8.8~22.2% at whole tree ages.

Distribution of shoot length in proper tree vigor orchard on 'Fuji'/M.9 was shown in Table 2. Less than 5 cm of shoot length in 2-years-old tree showed higher than others. The frequency of the shoots with the length of 6 to 10 cm was high in the trees of 2-years-old and low in those of 7-years-old. Shoot length from 11 to 20 cm showed over 35% from 2- to 6-years-old trees and 29% in 7-years-old trees. Distribution over 31 cm was higher in 5- to 7-years-old trees which approached in the adult tree period than 2- to 4-years-old trees which were young trees. Distributions of shoot length at entire tree ages were in order of 11~20 cm>21~30 cm>the others.

For the production of 30~33 kg/tree and 300 g of

Table 1. Tree growth with different ages and tree vigors in 'Fuji'/M.9 apple trees.

Tree age	Shoot length (cm)		Shoot termination (%)[z]		Secondary growth (%)[y]	
	Proper orchard	Non-proper orchard	Proper orchard	Non-proper orchard	Proper orchard	Non-proper orchard
2	17.4±1.0[x]	24.6±2.3	98.3±0.4	91.9±3.0	3.4±1.2	22.2±7.1
3	21.4±1.2	26.5±1.7	98.4±1.2	92.2±1.1	2.1±1.4	16.3±4.2
4	20.3±0.5	28.2±0.5	99.0±0.6	95.7±1.5	1.2±0.2	16.8±2.4
5	22.2±0.6	30.8±1.7	97.8±0.8	94.7±2.2	4.6±0.9	8.8±1.1
6	22.5±0.6	27.9±2.7	98.4±0.9	92.5±5.1	4.1±1.2	12.5±1.6
7	25.5±0.3	38.2±2.8	97.6±1.3	91.3±0.8	7.4±0.8	15.3±3.2

[z]Measured on July 10., [y]Measured on August 10. [x]Mean±SE.

Table 2. Distribution of shoot length on tree age in proper tree vigor of 'Fuji'/M.9 apple trees.

Tree age	Distribution of shoot length (%)					
	≤5 cm	6~10	11~20	21~30	31~40	≥41 cm
2	6.1±1.5[z]	24.0±2.7	38.2±2.3	20.8±3.6	8.3±2.1	2.7±0.7
3	2.3±0.4	12.9±1.9	38.7±1.8	28.9±2.0	11.9±2.1	5.3±3.3
4	2.4±0.3	16.6±3.7	39.7±0.3	27.3±4.3	10.7±0.5	3.3±0.9
5	5.7±0.9	15.3±2.1	33.6±2.1	23.1±2.3	11.6±0.5	10.0±2.6
6	4.4±1.7	14.9±3.3	40.4±2.5	26.3±4.3	9.5±1.0	11.0±2.2
7	1.3±0.4	8.4±1.2	29.0±1.5	35.9±0.7	15.6±1.1	9.6±1.4

[z]Mean±SE.

Table 3. Yield on tree age and different tree vigor in 'Fuji'/M.9 orchards.

Tree age	No. of fruiting (No./tree)		Fruit weight (g)		Yield (kg/10a)[z]	
	Proper orchard	Non-proper orchard	Proper orchard	Non-proper orchard	Proper orchard	Non-proper orchard
2	18.7±2.2[y]	16.8±4.4	301.7±4.0z	319.3±6.2	1,068±125.3	999±255.0
3	40.0±4.7	20.3±3.2	313.3±4.4	320.0±2.9	2,386±294.8	1,239±204.7
4	73.0±8.2	70.0±8.7	326.0±4.2	319.0±3.8	4,535±559.7	4,226±543.9
5	66.0±4.6	60.3±6.3	323.0±2.1	283.0±8.1	4,039±273.0	3,232±299.6
6	79.0±2.6	66.0±3.6	285.0±2.9	271.7±6.0	4,412±83.9	3,415±258.4
7	94.3±3.2	75.7±2.2	305.0±5.8	294.0±5.9	5,463±152.8	4,231±202.9

[z]Calculated by 3.5 × 1.5 m planting density,
[y]Mean±SE

Table 4. Fruit quality on tree age and different tree vigor in 'Fuji'/M.9 orchards.

Tree age	Soluble solids (°Brix)		Hunter a value	
	Proper orchard	Non-proper orchard	Proper orchard	Non-proper orchard
2	14.4±0.07[z]	13.1±0.15	26.7±0.27	24.9±0.38
3	14.4±0.12	13.5±0.17	25.6±0.49	24.3±0.76
4	14.7±0.14	14.2±0.08	25.8±0.37	22.6±0.38
5	14.8±0.20	13.9±0.17	27.5±0.51	23.5±0.40
6	14.2±0.18	13.1±0.31	24.3±0.26	21.1±0.49
7	13.8±0.20	13.2±0.29	23.9±0.93	21.9±0.76

[z]Mean±SE

average fruit weight in 'Fuji' apple with high density planting system, they must planted at the rate of 1,250~1,670 trees/ha, and the growth index reported for mean shoot length was around 20 cm and shoot terminations on mid-June were 90~95% in Nagano province in Japan (Byun, 1997). In addition, Kim *et al.* (1996) reported that high productive tree showed 15~30 cm of mean shoot length. On the other hand, low productive tree produced over 40 cm of mean shoot length and many water-sprout shoots in 'Fuji'/M.26. MAF (2002) reported that suitable tree vigor for apple production of 3.3±0.5 tons/10a between 2- to 4-years-old trees in 'Fuji'/M.9 were 19±4 cm of over 5 cm of shoot length, 23±3 cm of terminal shoot length and less 14% of shoot re-growth on 2-years-old branches.

The number of fruitings, mean fruit weight, and yield according to different tree ages and tree vigor were shown in Table 3. The number of fruitings in 2-years-old tree had no significant difference, but it was remarkably differed as to elapsing of tree age. Fruit weight of entire tree ages in the proper orchards produced around 300 g. On the other hand, in case of improper orchard produced around 320 g in young tree age (2- to 4-years-old tree) and 270~290 g in adult tree age (5- to 7-years-old tree). Yield per 10 a showed similar tendency with the number of fruitings.

The soluble solids content of the proper orchards was about 1.3°Brix higher than that of non-proper orchard through the entire investigated tree ages. Similarly, Hunter a value of proper orchard was about 2.5 higher than that of improper orchard from 2- to 7-years-old tree (Table 4). Generally, strong tree vigor has high nitrogen content (Rapp and Ibrahim, 1995), insufficient light penetration (Barritt *et al.*, 1987), and poor net productivity because of increasing shoot growth (Koike *et al.*, 1990). To prevent poor tree growth and fruit quality, the suitable fertilizing, pruning, and fruiting management has to be considered. Park (2003) reported that incase of strong vigor tree produced vigorous growth in shoot growth, leaf area, and internodes length than those of poor vigor tree. Moreover, it requires higher water content in branches or leaves. Additionally, Hong *et al.* (1997)

Table 5. Effect of leaf/fruit ratio on leaf area and mean shoot length in 'Fuji'/M.9 apple trees from the 4th to 6th year after planting.

No. of fruiting (No./tree)	Leaf/fruit ratio	Shoot length (cm)		
		Year after planting		
		4th	5th	6th
40	66±2.2[z]	17.4a[y]	15.4a	25.1a
60	55±1.7	16.5a	13.3a	19.7ab
80	31±1.4	15.9a	11.7a	18.2b

[z]Mean±SE,
[y]Mean separation within columns by Duncan's multiple range test at 5% level.

Table 6. Effect of leaf/fruit ratio on terminal bud on spur formation in 'Fuji'/M.9 apple trees from the 4th to 6th year after planting.

No. of fruiting (No./tree)	The number of terminal buds on spur (No./tree)[z]		
	Year after planting		
	4th	5th	6th
40	134.8a[y]	149.5a	215.7a
60	130.6a	147.3a	201.0a
80	126.3a	126.0b	217.5a

[z]Mean separation within columns by Duncan's multiple range test at 5% level,
[y]Mean±SE

Table 7. Effect of leaf/fruit ratio on fruit weight and fruit quality in 'Fuji'/M.9 apples trees from the 4th to 6th year after planting.

No. of fruiting (No./tree)	Fruit weight (g)			Soluble solids (°Brix)			Hunter a value		
	Year after planting								
	4th	5th	6th	4th	5th	6th	4th	5th	6th
40	288.0a[z]	328.0a	337.1a	15.3a	13.4a	14.5a	24.1a	21.3a	23.7a
60	271.0ab	315.0ab	316.4ab	14.8a	12.8a	13.9a	21.9a	21.3a	24.0a
80	252.0b	296.0b	274.9b	14.6a	13.0a	14.0a	23.1a	18.8a	24.1a

[z]Mean separation within columns by Duncan's multiple range test at 5% level.

reported that strong lateral shoot growth required high water content in leaf and water condition was related to tree growth. Tree vigor in same fertilizing and soil condition considers rather absorption and transfer amount of saps by water condition in soil and activity of roots than nitrogen concentration in sap related to growth. In this study, proper tree vigor orchard maintained good soil air and water permeability and provided good light penetration, but excessive water supply and insufficient light penetration cause strong tree vigor orchard (data not shown). When trying to synthesize the result of above, proper tree vigor during adult season in 'Fuji'/M.9 high density planting system involves 20~25 cm of mean shoot length, 95% of shoot termination, cessation of second growth, and 20~30% of spur ratio.

Establishment of proper crop load

To establish proper crop load in 'Fuji'/M.9, the number of fruitings per tree was controlled as 40, 60, 80 and leaf/fruit ratio was in the order of 66±2.2, 55±1.7, and 31±1.4 (Table 5). Mean shoot length in the block of 40 fruits per bearing tree was longer than that of 80 fruits when we compared at sixth year after planting. The number of terminal bud on spur was higher in the trees with 40 or 60 fruits than in 80's (Table 6).

When we compared the fruit yield and quality among the different number of fruitings (Table 7), the fruit weight was heavier in the block of 40 fruits per tree than

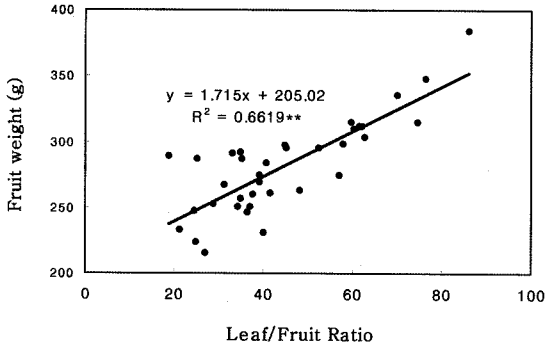

Fig. 1. Correlation between leaf/fruit ratio and mean fruit weight in 'Fuji'/M.9 apple trees from the 4th to 6th years after planting.

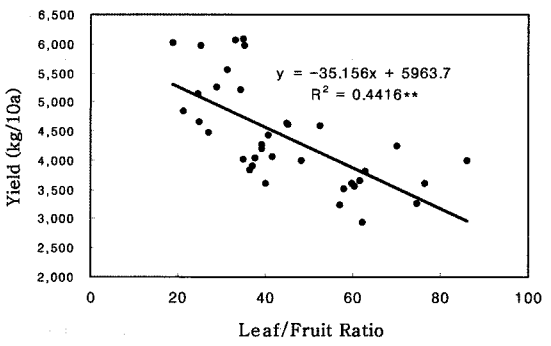

Fig. 2. Correlation between leaf/fruit ratio and yield in 'Fuji'/M.9 apple trees from the 4th to 6th year after planting.

in that of 80 fruit's. Soluble solids content and Hunter a value were not significantly different.

In the relationship between leaf/fruit ratio and the mean fruit weight (Fig. 1), leaf/fruit ratio and mean fruit weight showed highly positive relation as each 80, 55, and 30 of leaf/fruit ratios were 340, 300, and 260~270 g of mean fruit weight. Fig. 2 showed the correlation between leaf/fruit ratio and yield. Increasing leaf/fruit ratio caused decreasing yield as negative relation. As a result, increasing leaf/fruit ratio caused increase of fruit weight but decrease of mean yield.

Although, Magness *et al.* (1939) reported that minimum leaves to increase fruit size in 'Delicious', 'Rome Beauty', 'Jonathan', and 'Wine shop' cultivar with seedling stock were 30~40, in the case of our study, it needed about 50 leaves for 'Fuji'/M.9. Meanwhile, Koike *et al.* (1990) reported that the proper number of fruitings could be considered by leaf/fruit ratio, mean fruit weight, shoot dry weight, yields, and the number of apical buds of spur. Decreasing yield was related to increases in fruit weight, leaf/fruit ratio, and the number of apical buds of spur. In addition, for the production of 300~350 g of fruit in 'Fuji'/M.26, the leaf/fruit ratio needed 50~60 fruits per tree in adult tree age. However, it was not accordance when using M.9 rootstock. Fruit size among various factors of fruit quality was affected by rather changing of fruiting loads than leaf area and maximum yield with high fruit quality conflicts the proper number of fruitings as explained by Grappadelli *et al.* (1997). Especially, 'Fuji' cultivar, which showing strong biannual bearing, has to be controlled tree vigor, the number of flowerings and fruitings for improving fruit quality and yields (Barritt, 1997). There were many studies about the proper number of fruitings and leaves, and one of that accomplished by Myers and Ferree (1990). They performed that proper tree vigor and management for fruiting needs to prevent poor yield because of decreasing terminal bud formation when shoot length was over 25 cm. Leaf area of 500 cm^2 per fruit transfers 35~45% of total carbohydrate to fruit and the rest of them transfers branch for increasing branch volume, while those of 300 cm^2 transfers 55~75% of total carbohydrate to fruit (Hansen, 1978).

This study also performed that 66 of leaf/fruit ratio was longer shoot length and heavier fruit weight than others, on the other hand, in case of 31 of leaf/fruit ratio showed shorter shoot length and lighter fruit weight than others. This result was due to transfer assimilation products rather branch than fruit. Chalmers *et al.* (1983) insisted that fruiting set tree in peach may affect amount of water consumption because it produced low transpiration rate during slow fruit increment and high transpiration rate during rapid fruit increment compared with non-fruiting set tree. Finally, sap flow in non-fruiting set tree may be increased by many shoot growth volumes whereas those of fruiting set tree may be decreased by fruiting. Although many studies concerning correlations between fruit increment and the number of leaves and between fruit development and shoot growth had done, our experiment recorded different leaf/fruit ratio in M.9 rootstock. When considering the better quality of fruit and the maximum yield in high density orchard system with 'Fuji'/M.9, appropriate leaf/fruit ratio was thought to be 55.

Literature Cited

1. Barritt, B.H., C.R. Rom, K.R. Gvelich, S.R. Drake, and M.A. Dilley. 1987. Canopy position and light effects on spur, leaf, and fruit characteristics of 'Delicious' apple. HortScience 22:402-405.
2. Barritt, B.H., M.A. Dilley, and B.S. Konish. 1997. Selecting intensive orchard systems for apples. Compact Fruit Tree 30:37-39.
3. Byun, J.K. 1997. Nitrogen management in high density apple orchard. Kor. J. Hort. Ind. Sci. 1:49-62.
4. Chalmers, D.J., K.A. Olsson, and T.R. Jones. 1983. Water deficits and plant growth. p. 197-232. In: T.T. Kozlowski (ed.). Vol. 7, Academic Press, New York, USA.
5. Corelli, L. and S. Sansavini. 1989. Light management and photosynthesis related to planting density and canopy management in apple. Acta Hort. 243:159-174.
6. Grappadelli, L.C., S. Sansavini, and A.N. Lakso. 1997. The efficiency of the apple canopy in high density systems. Compact Fruit Tree 30:18-24.
7. Hansen, P. 1987. Blatt-Fruitverhaltnisse, Assimilateverteilung und Fruchtenwicklung. Erwerbs-Obstbau. 20:228-231.
8. Hong, J.S., J.Y. Lee, J.K. Kim, J.G. Park, J.B. Kim, and C.J. Yun. 1997. Comparative studies on the effects of shoot training angles on flower bud formation and fruiting for young 'Fuji' apple trees on M.26 rootstocks. RDA J. Hort. Sci. 39:112-116.
9. Kim, J.K., J.S. Hong., S.B. Kim, C.J. Cheon, and G.C. Song. 1996. Comparison of growth characteristics by different productivity in 'Fuji' apple trees grafted on M.26. RDA J. Agr. Sci. 38:660-666.
10. Koike, H., S. Yoshizawa, and K. Tsukahara. 1990. Optimum crop load and dry weight partitioning in 'Fuji' apple trees. J. Jpn. Soc. Hort. Sci. 58:827-834.
11. MAF. 2002. Study on suitable tree growth and standard levels of leaf mineral nutrient for the best fruit production in high density orchard. In: I. M. Yaol. Nutritional diagnosis at early cropping stage of super high-density orchard M.9 rootstock (Sub-project 1).
12. Magness, J.R., L.P. Batjer, and L.O. Regeimbal. 1939. Correlation of fruit color in apples to nitrogen content of leaves. Proc. Amer. Soc. Hort. Sci. 37:39-42.
13. Myers, S.C. and D.C. Ferree. 1990. Influence of summer pruning on the growth pattern of vigorous 'Delicious' apple limb. HortScience 21:252-253.
14. Oh, S.D. and J.T. Jang. 1987. Relationship between the development of two years old apple tree and number of spur and shoot growth. Res. Rep. Chonbuk Natl. Univ. 30:225-232.
15. Park, J.G. 2003. Effect of transportation and composition of xylem sap on lateral branch development in 'Fuji'/M.9 apple trees. Ph.D. Diss., Chungbuk Natl. Univ., Cheongju, Korea.
16. Park, M.Y. 2004. Studies on establishment of high density orchard system with slender spindle form 'Fuji'/M.9 apple trees. PhD Diss., Yeungnam Univ., Gyeongsan, Korea.
17. Rapp, J. and Z.I. Ibrahim. 1995. Distribution of some N compounds in shoots and fruits of the apple cv. Jonathan after soil and foliar application of nitrogen. Kerteszeti-Tudimany 27:43-49.

사과 '후지'/M.9 밀식 사과원의 성과기 적정 결실 및 수세 기준

박무용[1] · 박정관[1] · 양상진[1] · 한현희[1] · 강인규[2]* · 변재균[3]

국립원예특작과학원 사과시험장[1], 경북대학교 환경원예학과[2], 영남대학교 원예학과[3]

적 요. 본 연구는 2001년부터 2003년까지 '후지'/M.9가 재식된 밀식사과원에서 적정 수세와 적정 착과량을 조사하였다. 엽과비는 평균 과중($y=1.715x+205.02$, $R^2=0.66^{**}$)과 수량($y=-35.156x+5963.7$, $R^2=0.44^{**}$)에서 고도로 유의한 상관이 있는 것으로 나타났고, 주당엽수와 평균 과중 또한 상관이 있었다. 그러나 착과량에 따른 수체생육, 과실품질 요인중 당도 및 착색도에서는 처리간 차이가 없었다. 격년결실이 발생하지 않으면서 300g 이상의 과실을 생산하는 기준은 엽과비는 55 수준에서 착과량이 주당 약 55~64개의 수준이 적합하였다.

'후지'/M.9 밀식재배시 성목기의 안정된 수세 기준은 평균 신초장이 20~25cm, 신초 정지율이 95% 이상 수준을 보여야 되는 것으로 판단되며, 보다 세부적으로는 2차 생장이 거의 발생되지 않으며 과대지 비율은 적어도 20~30% 정도 되어야 할 것으로 판단되었다.

주제어 : 가지생장, 격년결실, 과실품질, 엽과비