Comparison of growth between own-rooted and grafted 'Aikou' mango trees, and the effects of soil volume on the growth, yield, and fruit quality of potted own-rooted trees©

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Abstract

This study investigated the characteristics of own-rooted 'Aikou' mango trees (*Mangifera indica* L.) propagated by air layering. The own-rooted, 4-year-old trees were compared with grafted trees (Scion: 'Aikou', rootstock: 'Aikou' seedling). Growth of the own-rooted trees was significantly lower than that of grafted trees. Except for the shoots, thick branches, and fine roots, the flesh and dry weights of each own-rooted tree organ were lower than those of grafted trees. Total fresh and dry weights of the own-rooted trees were about 56% and 51% of the grafted trees, respectively. The effects of soil volume (15-, 30-, and 45-L pots) on own-rooted trees were also examined over 9 years. The differences in tree growth were not significant among soil volumes. In addition, the differences in yield, fruit number per tree, and average fruit weight among soil volumes were not significant. Fresh weights of the leaves and fine roots, as well as total fresh weights of the under-ground plant parts, increased with soil volume. There were no differences in the fresh weights of shoots, trunks, or thick roots among the soil volumes. Fresh weights of the above-ground plant parts and total tree fresh weights for the 30- and 45-L treatments were significantly greater than those of the 15-L treatment. Differences in dry weights of each organ were approximately the same as the fresh weight differences. There was no observed effect of soil volume on fruit quality.

INTRODUCTION

Mango (*Mangifera indica* L.) is a fruit tree that is difficult to propagate from cuttings. Although cuttings have been successful in rootstocks (Yamashita at al., 2006) and seedlings of cultivars (Reuveni and Castoriano, 1993; Reuveni et al., 1991), there are few reports of rooting by cuttings of cultivar (Nunez-Elisea et al., 1992). Therefore, mango propagation is usually performed by grafting using a Taiwan native strain as the rootstock source, as it is readily obtained in Japan.

Mango trees are generally tall. In Japan, however, mango trees are cultivated in greenhouses because they require warm conditions during cold weather and precautions are needed to prevent anthracnose infection. Greenhouses restrict tree height to ≤2 m by applying under-ground root restriction sheets or potting plants.

The vigor of tree grafted on a Taiwan native strain tends to become strong. Flower bud formation tends to be unstable, depending on the soil conditions. Temperatures during the autumn–winter period have increased due to global warming, which has resulted in new shoot growth during autumn. The instability of flower bud formation is becoming a serious problem in warmer regions.

Since grafting is performed relatively high above the ground (about 30 cm) to increase the survival ratio. This is particularly the case in pot culture, as pot height adds to total plant height. Fruit set position is higher and inconvenient where low tree height is preferred.

Grafted trees require 3 years to become productive. Therefore, a nursery price for mango trees is roughly 4-5 times greater than that for other fruit trees. If farmers grow

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recently planted mango, the initial cost of cultivation is higher than the price of other fruit trees, which has become an obstacle to increasing mango cultivation.

Cultivation using grafted nursery plants presents several problems for mango trees. In addition to the increased cost, the height of fruit set is increased in pot culture and flower bud formation is destabilized in response to increased tree vigor. One way to solve these problems is growing own-rooted trees. However, the cutting technique of mango trees is undeveloped, and there is very little information about own-rooted tree characteristics.

This study was performed to evaluate own-rooted nursery trees propagated using the air-layer technique (Fumuro, 2011). Own-rooted and grafted trees were compared, and the effects of container soil volume on tree growth, yield, and fruit quality in own-rooted 'Aikou' trees were investigated.

MATERIALS AND METHODS

These experiments were performed in the greenhouse (width: 7.5 m, length: 22 m; 165 m^2) at the experimental farm of Kinki University (Yuasa, Wakayama Prefecture, Japan).

Experiment 1. Comparison of tree growth between own-rooted and grafted trees

In the own-rooted nursery, the air-layer technique was performed using 'Aikou' trees planted in a greenhouse on 8 Sept. 2007. A 1-naphthaleneacetic acid (NAA) solution (2,000 ppm, 50% ethanol) was sprayed on the girdles (width: 2-3 cm) of air-layered branches and covered with polythene bottomless bags. The ends of the branches were then tied with a string. The bags were filled with moist vermiculite, and the tops of the branches were tied with a string. Subsequently, the outside was covered with aluminum foil to prevent high-temperature damage. On 11 Nov., the rooted branches (Figure 1) were removed and planted in a small pot (diameter: 13.5 cm, height: 11 cm). On 21 Aug. of the following year, the own-rooted nursery was planted in pots made of non-woven fabric (25-L pot; diameter: 30 cm, height: 30 cm) and filled with a mixture of mountain soil, perlite, compost, and vermiculite (1:1:1:1, by vol.).

Figure 1. Rooting of air-layered 'Aikou' mango.

On 15 Jun. 2008, in the grafted nursery, the 'Aikou' scion was grafted onto 2-year-old rootstock ('Aikou' seedling) planted in polythene pots (diameter: 24 cm, height: 24 cm; 9 L). On 5 Oct. they were planted in a pot made of non-woven fabric as described above. In this experiment, all inflorescences were removed during flowering. Root age of the trees used was 4 years for both the own-rooted and grafted trees.

A dissecting survey was performed 19-20 Feb. 2011. Four trees were included for each nursery tree. Trunk diameter was measured using calipers at 10 cm above the ground for the grafted tree and about 3 cm above the ground for the own-rooted tree. The total number of leaves and total shoot length per tree were measured. Thereafter, all trees were separated into leaf, branch, trunk, thick root (≥1 mm in diameter), and fine root (<1 mm in diameter) categories.

Because the scion was grafted 20-30 cm above the ground, the trunk included the stem of the rootstock seedling. After measuring their flesh weights, the extracted part of each organ was dried and the dry matter percentage was determined. The total dry weight of each organ was calculated by multiplying the dry matter percentage and the total fresh weight of each organ.

Experiment 2. Effects of pot-culture soil volume on tree growth, yield, and fruit quality in own-rooted trees

Air layer propagation was performed on 8 Sept. 2007 in the same manner as Experiment 1. On 11 Nov., the rooted branch was removed and then planted in a small pot on 7 Aug. of the following year. The own-rooted nursery was planted in three types of pots made of non-woven fabric (15-L pot: 28×28 cm; 30-L pot: 36×30 cm; 45-L pot: 42×30 cm, in diameter and height) filled with 15, 30, and 45 L of the soil mixture described above. The between-row spacing was 1.2 m and the with-in row spacings were 1, 2, and 3 m for the 15, 30, and 45-L pots, respectively. Four trees were planted for each soil volume.

The harvest dates were as follows: 13 Aug. – 27 Sept. 2011, 17 Aug. – 21 Sept. 2012, 17 Aug. – 24 Sept. 2013, 15 Aug. – 15 Sept. 2014, and 9 Aug. – 17 Sept. 2015. The fruits were covered with a bag-shaped net in advance, and harvested ones that dropped into the net naturally. After measuring fruit weight, data on the qualities of 8–9 fruits harvested in late August-early September were recorded. Peel color (Hunter's L-, a- and b-values) was measured using a color-difference meter (CR-400; Konica-Minolta, Tokyo, Japan) at the center of the equator on the side of the fruit. Flesh firmness was determined by first removing 3-cm diameter patch of peel with a sharp knife and then using a Magness-Taylor-type fruit plunger (FT011; Effegi, Alfonsine, Italy) mounted on a plunger with a 11.3-mm diameter. The maximum force was recorded after the plunger penetrated 7 mm into the flesh through the cut surface. Measurements were recorded on both sides of the fruit and the values were averaged. Flesh was collected from the center of the equator on both sides of the fruit. Juice from the fruit was then squeezed and filtered through gauze, and total soluble solids (TSS) and titratable acidity were recorded. The TSS was measured using a refractometer (PAL-1; Atago, Tokyo, Japan). Titratable acid levels were determined by titrating with 0.1 N NaOH to a phenolphthalein endpoint and converting to citric acid content. The trunk diameter, leaf number, and shoot length per tree were measured in late December.

The dissecting survey was performed during 16-21 Oct. 2015. The trees were 9 years old at the time of the dissecting survey (Figure 2). Tree height and the longer and shorter diameters of the tree crown were measured, and then the land area occupied by the tree canopy was calculated as follows: Land area occupied by the tree canopy = longer diameter × shorter diameter × $\pi/4$.

Flesh and dry weights of each organ per tree were measured in the same manner as in Experiment 1. Leaf area was measured using an automatic leaf area meter (AAM-9; Hayashi Denko, Tokyo, Japan). A total of 30 leaves were randomly sampled from each tree. The average leaf area was calculated, followed by multiplying the average leaf area and the total number of leaves per tree.

Throughout Experiments 1 and 2, the greenhouse was heated from early December to a minimum temperature of 6°C. This minimum temperature was gradually increased from mid-February, and maintained at 18-20°C from the middle of March until the late of April during the flowering period. A fan was used for ventilation to ensure the internal air temperature remained below 35°C. The plants were watered daily by automatic irrigation. Fertilization, disease control, and pest control were all performed according to conventional procedures.

Figure 2. Effects of pot culture soil volume on tree growth in nine-year-old own-rooted ‘Aikou’ mango trees. Left: 45-L pot, Middle: 30-L pot, Right: 15-L pot.

RESULTS AND DISCUSSION

Experiment 1. Comparison of tree growth between own-rooted and grafted trees

The trunk cross-sectional area, total shoot length, and total leaf number of the own-rooted tree were significantly lower than those of the grafted tree (Table 1). With the exception of shoots, thick branches, and fine roots, the flesh and dry weights of each organ in the own-rooted trees were lower than those of the grafted trees (Tables 2 and 3). In particular, the fresh weights of thick roots from the own-rooted trees were only one quarter that of the grafted trees, which was attributed to the lack of root crowns on the own-rooted trees. Total fresh and dry weights of the own-rooted trees were about 56 and 51% of the grafted trees, respectively.

Table 1. Comparison of tree growth between four-year-old own-rooted and grafted ‘Aikou’ mango trees.

	Trunk cross-sectional area (cm^2)	Total shoot length (m)	Total leaf number (No. $tree^{-1}$)
Own-rooted	8.5	486.3	299.8
Grafted	18.3	1097.2	404.3
Significance	**	*	*

*: Significant at P=0.05, **: Significant at P=0.01 by t-test, respectively.

Table 2. Comparison of fresh weight of each organ between four-year-old own-rooted and grafted 'Aikou' mango trees.

	Above-ground part fresh weight (g)					Under-ground part fresh weight (g)			Total (g)
	Leaf	Shoot	Thick branch	Trunk	Total	Thick root	Fine root	Total	
Own-rooted	769	557	407	164	1897	108	239	347	2244
Grafted	1238	782	511	689	3220	471	320	791	4011
Significance	*	NS	NS	***	*	**	NS	*	*

NS: Non-significant at *P*=0.05, *: Significant at *P*=0.05, **: Significant at *P*=0.01, ***: Significant at *P*=0.001 by t-test, respectively.

Table 3. Comparison of dry weight of each organ between four-year-old own-rooted and grafted 'Aikou' mango trees.

	Above-ground part dry weight (g)					Under-ground part dry weight (g)			Total (g)
	Leaf	Shoot	Thick branch	Trunk	Total	Thick root	Fine root	Total	
Own-rooted	359	175	136	51	721	35	51	86	807
Grafted	580	275	185	250	1290	200	81	281	1571
Significance	*	NS	NS	***	*	**	NS	**	*

NS: Non-significant at *P*=0.05, *: Significant at *P*=0.05, **: Significant at *P*=0.01, ***: Significant at *P*=0.001 by t-test, respectively.

In this study, the ages of the own-rooted and grafted trees were calibrated to the ages of the under-ground tree parts. Since it has been reported that growth of above-ground parts is consistent with growth of under-ground parts (Fumuro, 1999), it is necessary to equalize the age of the under-ground parts. When the seedling is approximately 2 years old, the root system at the time of grafting is already developed. By contrast, since an own-rooted tree is regarded as 1-year-old when an air-layered branch is rooted, it is assumed that growth of own-rooted trees is typically less than that of grafted trees. Therefore tree growth of own-rooted trees may be less than that of grafted trees because of this younger age.

The growth of own-rooted mango trees propagated by an air layer is reported to be slower than that of grafted trees (Ram, 1993). Growth of the own-rooted 'Hiratanenashi' persimmon by micropropagation is lower than that of grafted trees at 7 years after orchard planting, whereas there is no consistent trend for the 'Fuyu' tree (Tetsumura et al., 2010). In addition, comparisons between own-rooted and grafted 'Aikou' mango trees growth, fruit yield, and quality have been performed since 2009. Large differences between own-rooted and grafted trees have not been observed (data not shown). Furthermore, in Experiment 1, there were no fruits, so all photosynthetic products were used for growth. As a result, it is possibility that accelerated growth of grafted tree which the initial growth was superior to own-rooted tree.

Experiment 2. Effects of pot culture soil volume on tree growth, yield, and fruit quality in own-rooted trees

The differences in tree growth, yield, fruit number, and average fruit weight were examined for 15-, 30-, and 45-L pots over 9 years (Figure 3). There were no significant differences in tree growth, although the trunk diameter (A), total leaf number (B), and total shoot length (C) gradually increased in all soil volumes and during each year except yield and fruit number of 8-year-old trees in 45 L-pots were significantly higher than those in 15 L-pots, and average fruit weight of 9-year-old trees in 15 L-pots was significantly higher than those of 30- and 45-L pots, there were no significant differences in yield (D), fruit number (E), and average fruit weight (F) among the soil volumes.

There were no other significant differences in tree height, trunk cross-sectional area, area occupied by the tree canopy, or leaf area of 9-year-old trees among the three soil volumes (Table 4). The flesh weights of leaves, and fine roots were greater with increased soil volume. There were no differences in shoots, trunks, or thick roots among the soil volumes (Table 5). Although fresh weights of under-ground parts were greater with increased soil volume, weights of the above-ground parts, and total trees in 30- and 45-L pots were significantly greater than those of the 15-L pot.

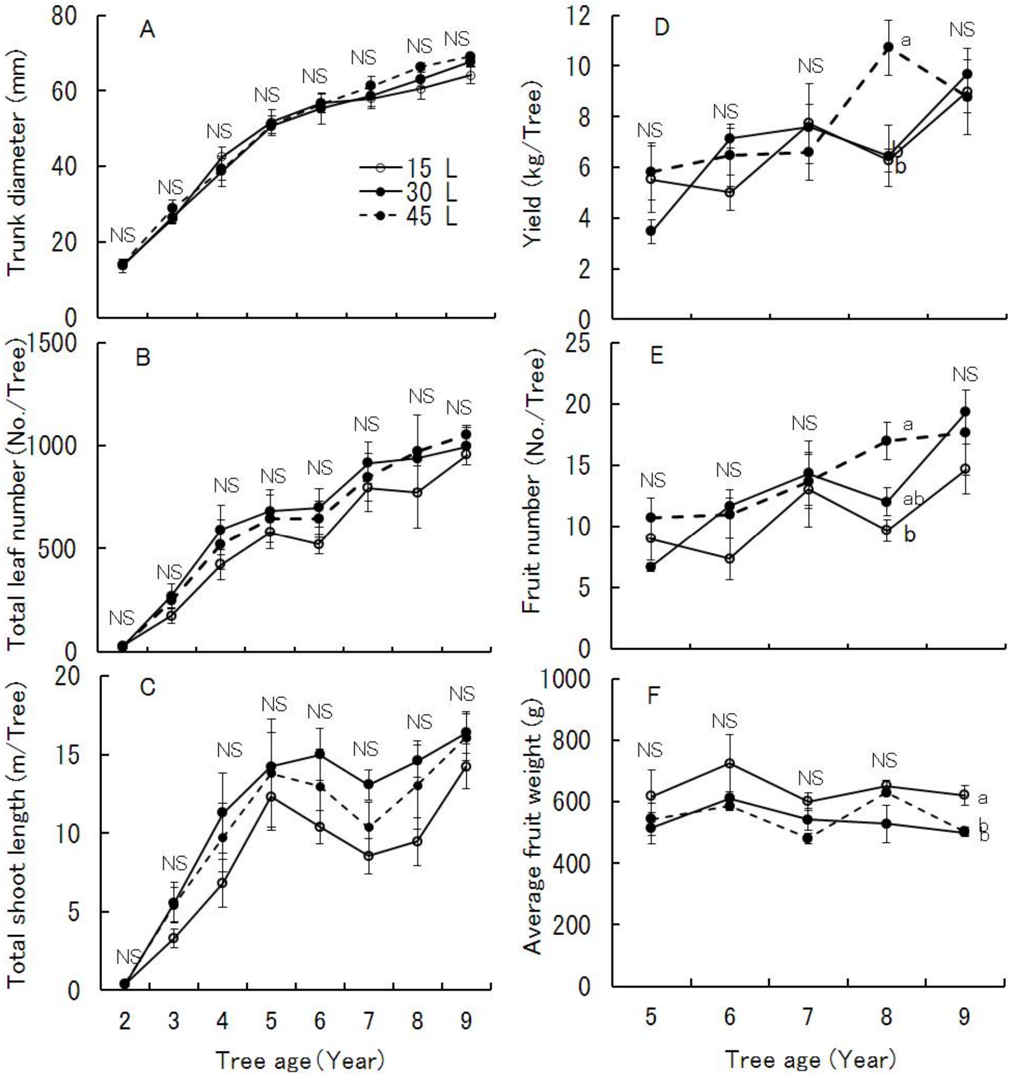

Figure 3. Effects of pot culture soil volume on trunk diameter (A), total leaf number (B), total shoot length (C), yield (D), fruit number (E), and average fruit weight (F) in nine-year-old own-rooted 'Aikou' mango trees. Vertical bars represent ± SE. Values followed by same letter and NS indicate not significantly differ (*P*<0.05) by Tukey-Kramer's multiple range test.

Table 4. Effects of pot culture soil volume on tree growth in nine-year-old own-rooted 'Aikou' mango trees.

Soil volume (L)	Tree height (m)	Trunk cross-sectional area (cm^2)	Area occupied by tree canopy (m^2)	Leaf area (m^2)
15	1.91	28.0	2.84	8.4
30	1.94	30.7	3.50	8.5
45	1.82	31.8	4.20	10.6
Significance	NS	NS	NS	NS

NS: Indicate not significantly different (*P*<0.05) by Tukey-Kramer's multiple range test.

Table 5. Effects of pot culture soil volume on fresh weight of each organ in nine-year-old own-rooted 'Aikou' mango trees.

Soil volume (L)	Above-ground part fresh weight (kg)					Under-ground part fresh weight (kg)			Total (kg)
	Leaf	Shoot	Thick branch	Trunk	Total	Thick root	Fine root	Total	
15	2.52 b[1]	1.08 a	3.84 b	0.36 a	77.80 b	1.46 a	0.49 bb	1.95 bb	99.75 b
30	2.95 ab	1.08 a	5.67 a	0.47 a	10.17 a	1.49 a	1.22 ab	2.71 ab	12.88 a
45	3.47 aa	1.35 a	5.64 a	0.42 a	10.88 a	1.49 a	1.33 aa	2.82 aa	13.70 a

[1]Values in a column followed the same letter are not significantly different (*P*<0.05) by Tukey-Kramer's multiple range test.

Furthermore, the differences in dry weights of each organ were approximately the same as the fresh weight differences, except for fine roots and total of under-ground parts in 30- and 45-L pots were significantly greater than those of 15-L pots (Table 6). There was no effect of soil volume on fruit quality (Table 7).

Table 6. Effects of pot culture soil volume on dry weight of each organ in nine-year-old own-rooted 'Aikou' mango trees.

Soil volume (L)	Above-ground part dry weight (kg)					Under-ground part dry weight (kg)			Total (kg)
	Leaf	Shoot	Thick branch	Trunk	Total	Thick root	Fine root	Total	
15	1.12 b[z]	0.33 a	1.32 b	0.13 a	2.90 b	0.52 a	0.14 b	0.66 b	3.56 b
30	1.35 ab	0.32 a	2.06 a	0.16 a	3.89 a	0.53 a	0.34 a	0.87 a	4.76 a
45	1.56 aa	0.39 a	2.06 a	0.15 a	4.16 a	0.50 a	0.36 a	0.86 a	5.02 a

[z]Values in a column followed the same letter are not significantly different (P<0.05) by Tukey-Kramer's multiple range test.

Table 7. Effects of pot culture soil volume on fruit quality in nine-year-old own-rooted 'Aikou' mango trees.

Tree age (year)	Soil volume (L)	Peel color			Flesh firmness (kg cm^{-2})	TSS (%)	Organic acid (%)
		L-value	a-value	b-value			
5	15	35.8	13.0	8.1	0.67	15.9	0.17
	30	38.5	11.3	9.5	0.64	16.0	0.14
	45	36.1	14.1	8.1	0.73	15.7	0.16
Significance		NS	NS	NS	NS	NS	NS
6	15	39.1	20.5	13.1	0.62	16.7	0.13
	30	37.8	19.8	10.4	0.75	17.4	0.14
	45	38.6	17.4	13.4	0.81	16.5	0.17
Significance		NS	NS	NS	NS	NS	NS
7	15	37.9	18.5	12.6	0.74	16.0	0.17
	30	36.8	16.0	13.4	0.73	15.8	0.19
	45	37.0	14.8	15.3	0.80	16.3	0.16
Significance		NS	NS	NS	NS	NS	NS
8	15	35.8	17.1	12.4	0.73	16.0	0.17
	30	34.7	16.1	11.6	0.75	15.6	0.18
	45	37.5	16.2	11.9	0.79	15.9	0.16
Significance		NS	NS	NS	NS	NS	NS
9	15	36.5	10.6	13.9	0.79	15.5	0.15
	30	36.6	10.3	13.7	0.76	15.1	0.17
	45	37.2	11.7	14.5	0.80	15.2	0.15
Significance		NS	NS	NS	NS	NS	NS

NS indicate not significantly different (*P*<0.05) by Tukey-Kramer's multiple range test.

Since 15-L pots were overcrowded with roots, there may have been insufficient pot volume to facilitate root expansion. By contrast, 30- and 45-L pots likely provided sufficient room to allow root growth. It was hypothesized that there was no difference in tree growth between the 30- and 45-L pots because the spacing between the 45-L pots did not allow the canopy to expand fully and match the increased potential for root growth afforded by the larger pot volume.

The own-rooted 'Dorian' had no taproot and was short-lived (Nakasone and Paull, 1997). However, based on results from this experiment, it was considered that the 15-L pot was suitable until the tree was 9-years-old, while the 30- and 45-L pots may be suitable for long-term tree cultivation.

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