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Shoot Growth and Fruit Production of the 'Masui Dauphine' Variety of Fig (*Ficus carica* L.) Undergoing Renewal Long Pruning

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Abstract

We investigated the shoot growth and fruit production of 'Masui Dauphine' fig trees (*Ficus carica* L.) with a newly devised "renewal long pruning" method and compared the results with those of conventional short pruning under straight-line training with both normal and high limb styles. This novel pruning method combines long pruning and continuous renewal pruning such that a few dormant shoots remain long and serve both as long mother shoots and as replaceable limbs. In experiments in 2009 and 2010, the shoots sprouted earlier from the renewal long pruning trees than from the short pruning trees. The number of lateral shoots was less in the renewal long pruning trees, indicating the prevention of excess vigour in bearing shoots. Renewal long pruning did not affect total percentage of fruit set; however, it slightly increased fruit set failure in the basal portion of bearing shoots. It potentially induced early maturation and greater enlargement of the fruit. Renewal long pruning was especially useful in high-limb straight-line training because it effectively compensated for disadvantage of this training, such as increasing numbers of lateral shoots and inhibition of fruit enlargement.

Discipline: Horticulture
Additional key words: high limb style, leaf-wood ratio, straight-line training.

Introduction

In the Japanese fruit industry, fig trees are cultivated mainly around city areas, and 'Masui Dauphine' ('San Piero' sensu Condit 1955) is a major fig cultivar in Japan for which straight-line training with short pruning has been successfully adapted (Kabumoto *et al.* 1985). This training is similar to bi-lateral cordon training of the grapevine in which two limbs are extended horizontally on opposing sides of the trunk. Each limb with a short pruned mother shoot (= spur) is distributed alternately across the limb at equal intervals of ca. 0.2 m. Each of the bearing shoots grows upward from the mother shoot and is pinched at ca. the 20th node position. This training system is advantageous because it reduces the labour required for shoot control and fruit harvesting, but it has some disadvantages. For example, it delays fruit maturation (Kanafusa *et al.* 1985) and can lead to discoloration of the fruit (Kabumoto *et al.* 1985). Recently, a novel straight-line training method named "high-limb straight-line training" has been adopted for fig trees (Hosomi *et al.* 2013). This training involves the use of a long trunk and a high limb position (ca. 1.8 m above ground level); and in contrast with conventional training, the bearing shoots grow downward from high position. This training compensates for the problem of fruit discoloration that can occur with normal straight-line training (Hosomi *et al.* 2013). However, this novel training method leads to a new problem: the number of superfluous lateral shoots increases and the fruit does not grow as large as it does in upward growth (Hosomi *et al.* 2013).

Here, we present a novel pruning system for fig trees as an alternative to short pruning. The system resembles "cane pruning" employed for grape vines. A few dormant shoots per tree are retained and are trained horizontally once they begin to grow so they can act both as long pruned mother shoots (= cane) and as renewed limbs for the next season. We call this method "renewal long pruning," and applied it in straight-line training with both normal and

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high limbs. Our goal was to rejuvenate even limbs that were damaged by freezing injury in the trees with normal limb position. Unexpectedly, this pruning method also compensated for the delayed fruit maturation and decreased fruit size that are disadvantages of normal or high-limb straight-line training.

Materials and methods

1. Growing the test trees

We used an experimental field belonging to the Research Institute of Environment, Agriculture and Fisheries, Osaka Prefecture, (34°32’N, 135°36’E, 68.5 m) in OSAKA, Japan. Six ‘Masui Dauphine’ fig trees were planted in 2004 at a tree spacing (= two × limb length) of 6.6 m in north-south rows, with 2.5 m between the rows. Growth commenced after normal straight-line training (NSL training) with short pruning. From 2006 to 2007, three of the trees were redirected to high-limb straight-line training (HLSL training) with short pruning, the other three continued to be managed by means of NSL training. Details of the redirection process are provided by Hosomi *et al.* (2013). Other methods of cultivation, such as irrigation, fertilization, and pest management, followed the normal schedule for fig orchard management.

The new treatment began at the end of the 2008 growing season, when we performed renewal long pruning (hereafter, long pruning) on one of the pair of limbs in each of the six trees. Figure 1 shows the pruning treatment for NSL training. One limb (the limb on the right side of the illustrated tree) acted as a control, and was managed by means of the usual short pruning. The opposite limb (on the left side of the tree) underwent long pruning. Two dormant shoots (one nearest to the trunk and one halfway to the end of the limb) were retained, and all other woody parts that were not necessary for the support of these two dormant shoots were removed. These two remaining dormant shoots were trained horizontally and acted both as long mother shoots and as the limbs for the next season. Similar pruning was undertaken on the same limbs of the trees in subsequent

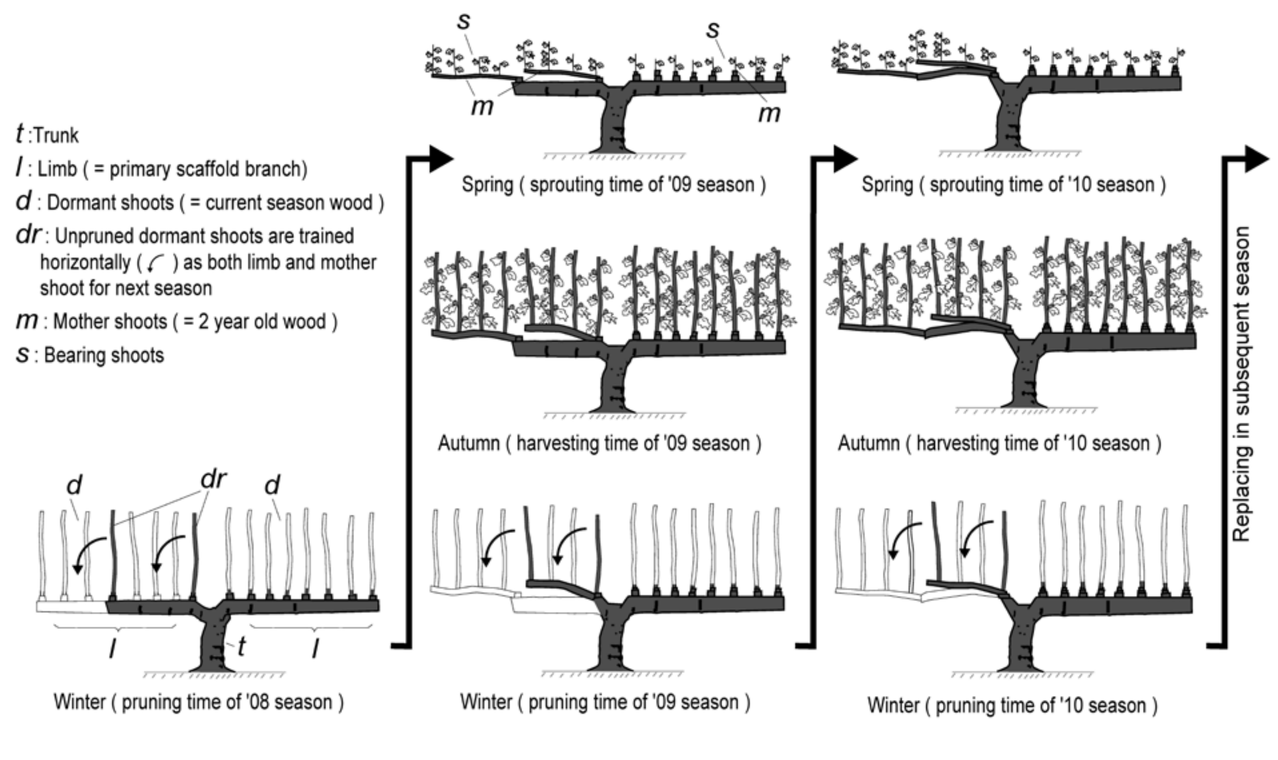

Fig. 1. Side view of the pruning patterns for normal straight-line training of the fig trees. One of the pair of limbs (on the left side of the trunk in the figure) underwent "renewal long pruning" from the end of the 2008 growing season. Two dormant shoots (*dr*) were retained and other woody parts (white parts in the figure) were removed. These two shoots were trained horizontally and acted as both the limb and the mother shoot in the next season. Similar pruning took place in the next season for the same limb so that the wood age of the limb was maintained at less than 3 years. The opposite limb acted as the control, and was managed by means of the usual short pruning. The actual shoot number was 16 or 17 per limb, although the figure shows only 8 for clarity. The high-limb straight-line training (not shown) used the inverse pattern, with a high limb position and a downward growth of the bearing shoots.

years, and the wood age of the limb was retained at three years or less by the 2010 growing season. HLSL training (not shown) employed the inverse pattern, with high limb position and downward growth of the bearing shoots. Two shoots, serving as mother shoots (i.e., limbs) for the next season, were trained horizontally in the opposite manner of NSL training at the end of the 2010 growing season. In 2009, however, the two shoots failed to grow downward and were trained horizontally from the beginning of the growing season. We used the experimental design shown in Figure 2, and observed shoot growth and fruit production in 2009 and 2010, as described later in the Methods section.

We analysed the simple main effects of the within-subject factor (pruning types) and between-subjects factor (training types) by means of two-way repeated measures ANOVA using the statistical add-in software Excel-TOUKEI 2008 (SSRI, Ltd., Tokyo, Japan) for Excel 2003 (Microsoft, Tokyo, Japan).

2. Shoot growth and fruit set

At the end of each April, shoots begin to sprout from the mother shoots. To assess the earliness of the sprouting, we counted the number of sprouted (= started leafing) shoots on 26 April 2010, counting the distal and proximal halves of the limb separately. The shoots were selected for use as bearing shoots by removing other sprouted shoots each May. In the short pruned limb, each shoot from the mother shoot elongated as a bearing shoot. In the long pruned limb, multiple bearing shoots were selected on the mother shoots. In both type of limbs, the bearing shoots were arranged on either side of the limb at equal intervals (ca. 0.2 m), for a total of 16 or 17 bearing shoots per limb. The bearing shoots were trained upward in NSL training, and downward in HLSL training. All of each bearing shoot was pinched once the apical end reached 1.7 m from the ground in NSL training or 0.5 m from the ground in HLSL training. The pinching regulated the bearing shoot length at ca. 1.3 m in both treatments and the number of bearing-shoot nodes was controlled at ca. 20. Lateral shoots that sprouted from the bearing shoots were removed weekly from May to November, and we recorded the numbers and dry weights.

For measurements described hereunder, we used all (16 or 17) of the bearing shoots on the limbs of trees in the HLSL training type in 2009 and approximately half (seven to nine) of the bearing shoots on the limbs in the HLSL training type in 2010 and for NSL training in both years. The failure of fruit set at any node of the bearing shoots was counted in July and November. The basal diameter (i.e., the diameter midway between the 2nd and 3rd nodes) and the apical diameter (i.e., diameter midway between the last two internodes before the apex) of the bearing shoots were measured in December.

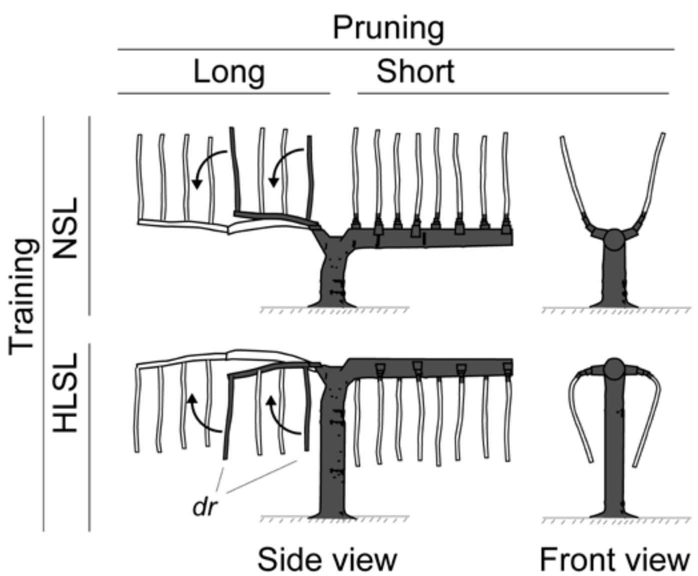

Fig. 2. Experimental design for the combinations of training (NSL, normal straight-line training; HLSL, high-limb straight-line training) and pruning (Long, renewal long pruning; Short, conventional short pruning). The patterns show the trees during the winter pruning season. In 2009; however, the two shoots of long pruning with HLSL training (*dr*) were trained horizontally from the beginning of the growing season. The white parts indicate the pruned branches. The actual bearing shoot number is 16 or 17 per limb, although the figure shows only 8 for clarity.

3. Harvesting fruit and quality

We examined mature fruit at the 3rd, 8th, 13th, and 18th nodes of the bearing shoots and used these samples to represent four ranges of nodal positions along each bearing shoot (base, 1st to 5th; semi-base, 6th to 10th; semi-apex, 11th to 15th; and apex, 16th to 20th). On the harvesting day, we recorded the skin colour, fresh weight, and soluble solids content (SSC) of the fruit juice. Fruit skin colour was categorized visually using a standardized reference that we created to make this task less subjective. This was based on the degree of colouring, into five categories, from faint (1) to complete (5). Fresh weight of the fruit was measured using a top-loading digital scale. Fruit juice was obtained by cutting the fruit in half at its equator, then filtering the expressed juice through gauze; the SSC of this juice was then measured using a digital refractometer (PR-101, Atago Co., Tokyo, Japan).

Results

1. Shoot growth

Table 1 summarizes the shoot growth results. The sprouted shoot number was investigated only in 2010. Significantly more sprouted shoots observed on 26 April had long pruning than short pruning. The tendency was similar between the distal and proximal portions of the limb. The bearing-shoot width was similar between the two pruning types, except that the apical diameters of the bearing shoots were significantly smaller in the long pruning type than in the short pruning type in HLSL training in 2009.

The number of lateral shoots tended to be less in long pruning as compared to short pruning, and the differences were significant in many case. The total dry weight of lateral shoots also tended to be less for long pruning, although the difference was not significant. The number of lateral shoots was significantly greater in HLSL training than in NSL training in September and October of both years; however, the significant differences disappeared when long pruning was employed in 2009.

2. Fruit production

Table 2 summarizes the fruit set and maturation. The percentages of failed fruit set on the bearing shoots divided into four nodal positions from the base to the apex. Percentages of failed fruit set did not differ significantly among the pruning types for the various nodal positions, and failure was only significantly higher with long pruning at the 1st to 5th nodes of HLSL in 2009. The harvesting date tended to be earlier with long pruning as compared to short pruning. An exception was the significantly later harvesting date

Table 1. Effect of pruning and training treatments on the shoot growth of 'Masui Dauphine' fig trees.

Year	Training types [z]	Pruning types [y]	Sprouted shoots [x]		Bearing shoot		Removed lateral shoots [w]								
			per distal half of limb	per proximal half of limb	Basal diameter	Apical diameter	Monthly and total number per limb								Total DW per limb
							May	Jun	Jul	Aug	Sep	Oct	Nov	Total	
			(n)	(n)	(mm)	(mm)	(n)	(n)	(n)	(n)	(n)	(n)	(n)	(n)	(g)
2009	NSL	Short	–	–	23.5	12.8	12	27	70 * [v]	91	51 **	23	3	276 *	73
		vs. Long	–	–	22.8	12.3	2	19	44	79	41	22	4	211	55
	HLSL	Short	–	–	23.9	11.2 *	4	51 *	38	86 *	150 **	67 **	4	401 **	80
		vs. Long	–	–	22.3	10.3	2	22	31	63	84	29	3	234	63
	NSL *vs.* HLSL	Short	–	–	NS	NS	NS	*	*	NS	**	**	NS	NS	NS
		Long	–	–	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2010	NSL	Short	1	0	22.8	11.3	0	16	31 **	80 **	44	11	5	188	59
		vs. Long	8 **	7 *	23.6	10.9	0	11	22	60	45	18	3	158	45
	HLSL	Short	3	3	22.6	9.7	0	37	28	40 *	127	67	7	306	52
		vs. Long	6 *	9 *	23.9	10.8	0	15	29	26	107	59	5	241	43
	NSL *vs.* HLSL	Short	NS	NS	NS	*	NS	NS	NS	NS	**	**	NS	NS	NS
		Long	NS	NS	NS	NS	NS	NS	NS	NS	*	**	NS	NS	NS

[z] High limb straight-line (HLSL) training and normal straight line (NSL) training.

[y] One-year-old shoots were pruned short (to a few nodes) or long (long enough for half of a limb).

[x] The number of shoots started leafing on distal and proximal halves of the limb, was separately counted on 26 April in 2010 (but not in 2009).

[w] The lateral shoots were removed weekly. The monthly and total numbers, and dry weight thereof are summarized per limb for 2009 and 2010.

[v] Significance of simple main effects by two-way repeated measure ANOVA are marked (*$P < 0.05$; **$P < 0.01$) on the significantly larger value in comparison between pruning type (short *vs.* long) for each training. The significance between training (NSL *vs.* HLSL) in each pruning is shown by symbols only (NS, not significant; *$P < 0.05$; **$P < 0.01$).

with long pruning at the 13th node of HLSL in 2009.

Table 3 summarizes the fruit qualities. The fresh weight of the fruit tended to be greater with long pruning than with short pruning. An exception was the significantly smaller fresh weight with long pruning at the 18th node of NSL in 2009. The fresh weight of fruit in trees with HLSL training tended to be less than in that with NSL training; however, the significant differences disappeared when the

Table 2. Effect of pruning and training treatments on the fruit set and maturation of 'Masui Dauphine' fig trees.

Year	Training types [z]	Pruning types [y]	Failure percentages of fruit set [x]					Harvesting date			
			1-5th (%)	6-10th (%)	11-15th (%)	16-20th (%)	Total (%)	3 rd (m/d)	8 th (m/d)	13 th (m/d)	18 th (m/d)
2009	NSL	Short	8.3	1.7	3.3	0.0	3.3	8/11	8/25	9/17	10/3
		vs. Long	10.5	0.8	3.6	0.0	3.7	8/10	8/26	9/18	10/11
	HLSL	Short	9.3	1.7	2.6	0.4	3.5	8/17 *[w]	8/28	9/16	10/18
		vs. Long	15.9 **	2.0	6.0	1.2	6.3	8/11	8/28	9/23 *	10/19
	NSL *vs.* HLSL	Short	NS	NS	NS	NS	NS	*	NS	NS	**
		Long	NS	NS	NS	NS	NS	NS	NS	NS	*
2010	NSL	Short	14.2	0.0	1.7	0.0	4.1	9/3	9/12 **	10/4 *	10/24
		vs. Long	13.1	0.0	1.8	0.0	3.7	8/25	9/3	9/21	10/15
	HLSL	Short	8.7	0.0	6.0	0.0	3.7	8/29	9/7 **	9/25 *	10/25
		vs. Long	17.0	0.0	4.8	1.0	5.8	8/21	9/1	9/16	10/10
	NSL *vs.* HLSL	Short	NS	NS	NS	NS	NS	NS	*	*	NS
		Long	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z, y] See Table 1.

[x] The proportion (%) of the nodes without fruit in four ranges of node order (1st to 5th, 6th to 10th, 11th to 15th, and 16th to 20th).

[w] Significance of simple main effects by two-way repeated measure ANOVA are marked (*$P < 0.05$; **$P < 0.01$) on the significantly larger value in comparison between pruning type (short *vs.* long) for each training. The significance between training (NSL *vs.* HLSL) in each pruning is shown by symbols only (NS, not significant; *$P < 0.05$; **$P < 0.01$).

Table 3. Effect of pruning and training treatments on the fruit quality of 'Masui Dauphine' fig trees.

Year	Training types [z]	Pruning types [y]	Fresh weight				Skin colour [x]				SSC [w]			
			3 rd (g)	8 th (g)	13 th (g)	18 th (g)	3 rd	8 th	13 th	18 th	3 rd (°Brix)	8 th (°Brix)	13 th (°Brix)	18 th (°Brix)
2009	NSL	Short	140	105	94	90 *[v]	3.0	2.8	3.3	4.4	13.4	13.9	14.7	16.6
		vs. Long	143	103	98	86	3.0	2.8	3.3	3.9	13.2	14.3	15.5	15.8
	HLSL	Short	124	86	84	90	3.9 **	3.4 *	3.2	3.0	14.6	14.7	15.1	14.6
		vs. Long	155 **	93 *	90	92	3.1	3.1	3.1	2.8	14.0	14.5	14.5	13.8
	NSL *vs.* HLSL	Short	*	*	NS	NS	*	**	NS	**	NS	NS	NS	NS
		Long	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS
2010	NSL	Short	127	86	76	60	2.9	2.8	3.0	3.7	15.3	15.5	15.7	17.0
		vs. Long	140	105 **	89 *	69	3.0	3.0	3.0	3.4	16.8	15.9	15.8	16.8
	HLSL	Short	112	74	64	66	3.4	3.2	3.4	2.9	17.4	16.2	16.8	16.2
		vs. Long	148 *	93 **	75 *	83 *	3.2	3.3	2.8	3.1	17.0	16.1	15.6	14.9
	NSL *vs.* HLSL	Short	NS	**	*	NS	*	NS	NS	**	*	NS	NS	NS
		Long	NS	*	*	NS	NS	NS	NS	*	NS	NS	NS	*

[z, y] See Table 1.

[x] Colouring index of fruit skin, from faintly (1) to complete (5).

[w] Soluble solids content of the fruit juice.

[v] Significance of simple main effects by two-way repeated measure ANOVA are marked (*$P < 0.05$; **$P < 0.01$) on the significantly larger value in comparison between pruning type (short *vs.* long) for each training. The significance between training (NSL *vs.* HLSL) in each pruning is shown by symbols only (NS, not significant; *$P < 0.05$; **$P < 0.01$).

long pruning was employed in 2009. The skin colour values of the fruit with long pruning were significantly lower than those with short pruning at the 3rd and 8th nodes of HLSL training in 2009. Otherwise there was no significant difference between the pruning types. When comparing the two training types, the skin colour values of the fruit with HLSL training tended to be greater than those with NSL training at the basal (3rd and 8th) nodes of the bearing shoots, but was less at the apical (18th) node. The SSC value of the flesh was not significantly influenced by the pruning treatment.

Discussion

We detected some effects of long pruning, including early shoot sprouting and a tendency towards early fruit maturation. Long pruning gave more sprouted shoots than short pruning in the sprouting season of 2010. Earlier breaking of dormancy observed in the apical nodal buds of fig trees (Kawamata *et al.* 2002) appears to be a basic characteristic of various woody plants. In our long pruning treatment, the early release from dormancy induces the production of more leafed shoots and probably induces early fruit maturation.

Although a slightly greater percentage of fruit set failure was observed with long pruning, it is unlikely to decrease the yield per tree because the failure was restricted to the basal portion of bearing shoots and did not affect the total percentage of fruit set. Furthermore, the long pruning also produced higher fruit weight. The earlier start of growth is a possible reason for the higher fruit weight in long pruning trees. The size of individual fig fruits is increased by lower temperatures during the young stage of each fruit (Hosomi 1997, Yahata & Nogata 2000). For trees undergoing pruning in this study, the fruit was exposed to longer periods of cool weather at the young stage because of the earlier start of growth, so that this fruit was larger than those of short pruning trees. The higher fruit weight in the trees with long pruning may be due to a change of shoot vigour. According to the cultivation guidance for figs (Kabumoto 1985), the type of bearing shoot for the fig trees in the present study can be classified as "succulent", and these shoots are slightly weaker than is desirable for the production of large fruit. In the trees with long pruning, the number of lateral shoots tended to be reduced, and this is evidence of weakening shoot vigour. Reduced growth of succulent shoots, which is a characteristic of straight-line training, may explain the greater fruit production in the trees with long pruning. Finally, the "intensity" of pruning, which can be defined as the proportion of the wood volume that is removed, is also important. Our long pruning represents severe pruning intensity, and some previous studies have found that high-intensity pruning can decrease the fruit yield for fig trees (Gerber *et al.* 2012, González-Rodríguez *et al.* 2010). However, it was difficult to directly relate the pruning intensity to the individual fruit size because the structure of these trees is complex, and the numbers of bearing shoots and the fruit set differs among the pruning methods. Our pruning method is equivalent to conventional pruning in terms of the arrangement of the bearing shoots and the numbers of fruit. Changing the leaf-to-wood ratio by pruning can affect the growth of individual pieces of fruit. Severe pruning increases the ratio of leaves to wood and enhances fruit production in pear (Kanato *et al.* 1968), apple (Forshey & McKee 1970), chestnut (Araki & Nakaoka 1982), and other species, and this is probably caused by an increase in net primary production by each tree. Based on a structural comparison of trainings, Kabumoto (1986) believed that increasing the leaf-to-wood ratio increased fruit production by 'Masui Dauphine' fig trees. Our pruning would also replace thick older limbs with slender younger limbs and would, therefore, increase the leaf-to-wood ratio. Accurate comparison of net production and distribution of photoassimilate was difficult because the limbs in both pruning types shared the same trees. In subsequent studies (manuscript in preparation), however, long pruning of the entire tree also promoted fruit enlargement. The increasing leaf-to-wood ratio is probably responsible for the fruit enlargement that occurs with this method of pruning. In future studies, this hypothesis should be formally tested.

Long pruning was especially useful in HLSL training. Increasing numbers of lateral shoots and inhibition of fruit enlargement are disadvantages of HLSL training (Hosomi *et al.* 2013), and these drawbacks were confirmed in the present study. However, long pruning successfully compensated for these disadvantages, especially because it resulted in remarkable fruit growth. In 2009 for HLSL training, the trees with long pruning showed less skin colouring of fruits on the basal portion of bearing shoots as compared to short pruning. This probably occurred because the two shoots, as limbs for the next season, grew along the current limbs and shaded the fruits on their basal portions. No reduction of fruit colouring occurred in HLSL trained trees in 2010, when these shoots grew downward until the horizontal training at the end of the growing season. Thus, the long pruning itself does not decrease the fruit skin coloration. Long pruning, therefore, appears to be necessary for high-limb straight-line training of fig trees.

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