Mem. School. B.O.S.T. Kinki University No. 4 : 54~64 (1998)

Effects of Temperature on Growth, Dry Matter Production and Assimilate Partitioning of Japanese Persimmon (*Diospyros kaki* L.) cv.Fuyu trees

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Abstract

The effects of temperature on the growth, dry matter gain (DMG) and assimilate partitioning ratio (APR) in one-year-old Japanese persimmon (*Diospyros kaki* L.) 'Fuyu' trees grafted on 'Saijo' seedling rootstocks were investigated. The trees were grown in a growth chamber (natural daylight ; relative humidity 75%) in which the temperature was kept constant at 15, 20, 25 or 30℃, or under field conditions from 1 March to 2 September, 1997. 'Saijo' seedling trees grown in plastic pots were also examined for comparison.

The values of total shoot length, and fresh and dry weights of each organ, were the highest at 25 or 30℃ in 'Fuyu' trees, and at 30℃ in 'Saijo' seedling trees. DMG of tree was the highest at 25 - 30℃ in 'Fuyu' trees, and at 30℃ in 'Saijo' seedling trees, although DMG per unit leaf area was higher at lower temperatures. In 'Fuyu' trees, APR to shoot was similar at 25 and 30℃. However, in 'Saijo' seedling trees, APR to shoot was clearly higher at 30℃ than at 25℃.

Introduction

Since PCNA cultivars require a warm temperature to naturally remove their astringency, they are mainly cultivated in areas where the mean annual temperature is 14 - 16℃ (19). In 'Fuyu' trees, several studies on the effects of temperature have been made on fruit growth and quality (2, 3, 4), but a few on tree growth (8). To examine the effect of temperature on the growth of 'Fuyu' trees, the effect of temperature on the growth of rootstock should also be examined, because all scion cultivars are grafted on rootstocks for propagation. George et al.(8) reported the effects of day-night temperatures in the glasshouse on the growth and fruit set of 'Fuyu' trees, but not the growth of the rootstock tree. The amount of tree growth is indicated by DMG, which is largely influenced by the dry matter productivity of the leaves. However, studies on the effects of temperature on dry matter production and assimilate partitioning have not been reported in Japanese persimmon trees.

This study was conducted to reveal the effects of temperature on growth, dry matter production and assimilate partitioning in 'Fuyu' trees grafted on 'Saijo' seedling rootstocks in comparison with those in 'Saijo' seedling trees.

Materials and Methods

One-year-old Japanese persimmon (*Diospyros kaki* L.) 'Fuyu' trees grafted

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on 'Saijo' seedling rootstock and one-year-old 'Saijo' seedling trees grown at the Faculty of Biotechnology Oriented Science and Technology, Kinki University, Wakayama Prefecture, were used. They were grown in plastic pots (5 liters) filled with a mixture of vermiculite and peatmoss (1 : 1 v/v). From 1 March (before sprouting) to 2 September (end of shoot growth), 1997, these trees were placed in growth chambers (75% relative humidity, natural daylight) controlled at 15, 20, 25 or 30℃, or left in the field. Four trees were used for each temperature treatment. These trees were fertilized with a 10N-10P-10K liquid fertilizer at intervals of 1 - 2 weeks, and chemicals to control diseases and pests were applied occasionally on demand. Air temperatures under field conditions during the experimental period are shown in Fig. 1.

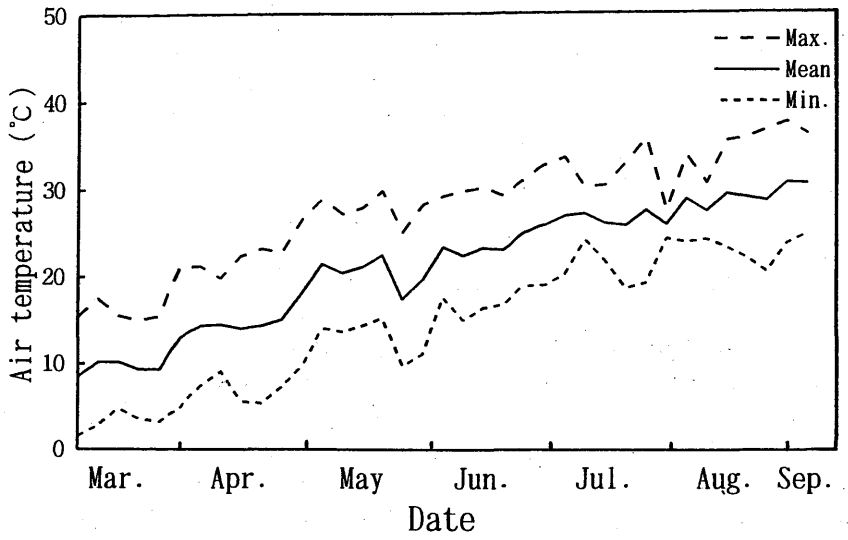

Fig. 1 Changes in air temperature under field condition during the experimental temperature treatment period.

1. Shoot elongation and dry weight of each organ

Total shoot lengths of all trees were measured at 5-day intervals from 1 March to 2 September. On 2 September, the number of leaves per tree, and leaf area were measured by automatic leaf area meter (Model AAM-7, Hayashi Denko Co.). Then, all trees were separated into trunks, branches, leaves, thick roots, (≧ 2 mm in diameter) and fine roots (< 2 mm in diameter), and their fresh weights were measured. They were then, dried in a drying oven at 75℃ until reaching constant weights to obtain dry weight.

2. Dry matter production and assimilate partitioning

DMG of trunk was estimated as follows. Diameters at the base and top of each trunk were measured at the beginning (1 March) and the end (2 September) of the temperature treatment period. Regarding the transverse section as a circle,

the areas of the transverse sections at the base and top were calculated. The ratio of the value at the base to that at the top was regarded as the trunk increment ratio, because the trunk length during the experimental period was nearly the same. Trunk fresh weight at the beginning of temperature treatment was estimated by dividing the trunk fresh weight at the end of the treatment by the trunk volume increment ratio mentioned above. Trunk dry weight was calculated by multiplying the calculated fresh weight by dry weight ratio of the trunk.

In 'Fuyu' trees, thick root dry weight is closely correlated with total dry weight of scion (7). Therefore, the thick root fresh weight at the beginning of temperature treatment (1 March) was calculated by dividing the thick root dry weight measured at the end of the treatment by the trunk dry weight increment ratio.

Dry weight increment of trunk and that of thick root during temperature treatment was calculated as the difference between the dry weight measured at the end of the treatment and the estimated initial dry weight. To obtain dry matter gain per tree during the temperature treatment period, dry weights of leaves (including fallen leaves), branches and fine roots were added to the dry weight increments of trunk and thick roots. DMG per unit leaf area was calculated by dividing DMG of tree by total leaf area per tree.

APR was shown by percentage of the dry weight increment of each organ to DMG of tree.

Results

1. Shoot elongation and dry weight of each organ

1. 1. 'Fuyu' tree grafted on 'Saijo' seedling rootstock

The higher the temperature, the earlier the sprouting in 'Fuyu' trees, in this experiment. At 30℃, the period required for sprouting from the start of temperature treatment was only 10 days, i.e., about one-third of that at 15 ℃. The trees left in the field sprouted 45 days after the start of the treatment. Total shoot length per tree was the longest at 25 or 30℃ followed by 20℃, but was short at 15℃. Leaf number and leaf area per tree were higher at 25 or 30℃, and lower at 15 or 20℃. Total shoot length and the leaf number per tree of the trees left in the field were between the values at 20 and 25℃ (Fig. 2, Table 1).

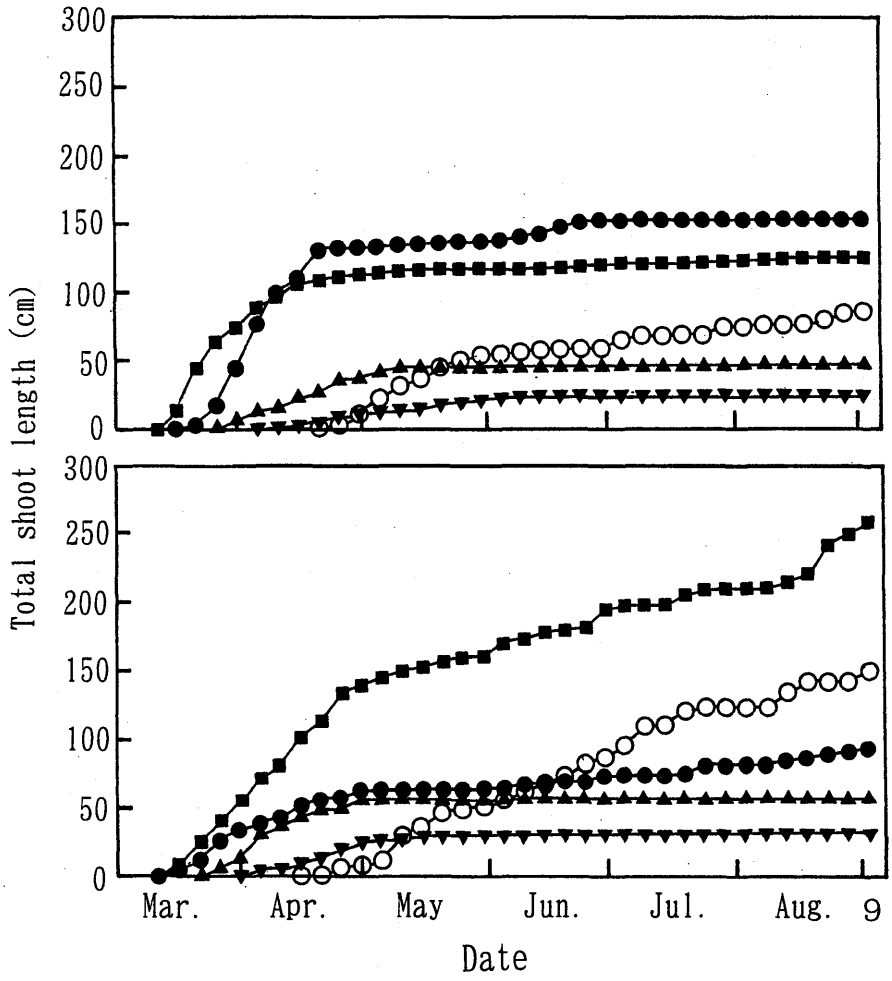

Fig. 2 Effects of temperatures on shoot lengths of 'Fuyu' trees grafted on 'Saijo' seedling rootstock (upper) and 'Saijo' seedling trees (lower).
▼ : 15℃, ▲ : 20℃, ● : 25℃, ■ : 30℃, ○ : field condition

Table 1 Effects of temperature on shoot and leaf growth of 'Fuyu' trees grafted on 'Saijo' seedling rootstock.

Temperature (℃)	Total shoot length (cm)	Leaf number (No./tree)	Leaf area (LA) (m^2/Tree)
15	24.1a[z]	32.5a	208a
20	44.0b	35.3ab	417a
25	148.9d	69.5c	1343b
30	123.0cd	55.5c	1389b
Field	84.8c	52.3bc	1334b

[z] Average values were analyzed by Duncan's multiple range test. Values in the same column followed by the same letter are not significantly different at $p=0.05$.

The values of fresh weight per tree, fresh weights of leaves, shoots and thick roots per tree, dry weight per tree, and dry weights of leaves, branches and thick roots per tree were higher at 25 or 30℃ than at 15 or 20℃. Fresh and dry weights of the trees left in the field were between the values at 20 and 25℃ (Table 2).

Table 2. Effects of temperature on fresh and dry weight of 'Fuyu' trees grafted on 'Saijo' seedling rootstock.

Temperature (℃)	Above-ground part (g)				Under-ground part (g)			Whole tree (g)
	Leaf	Shoot	Trunk	Total	Thick root (2 mm≧)	Fine root (2 mm<)	Total	
Fresh weight(g)								
15	6.5a[z]	1.9a	45.7a	54.1a	52.1a	1.9a	54.0a	108.1a
20	18.4a	5.4a	49.0a	72.8a	52.9a	4.6ab	57.5ab	130.3a
25	46.1b	20.9b	58.4a	125.4b	74.1b	9.0bc	83.1c	208.5b
30	45.2b	22.8b	50.3a	118.3b	71.9b	8.7bc	80.6c	198.9b
Field	39.0b	9.6a	52.0a	100.6b	66.2ab	10.9c	77.1bc	177.7b
Dry weight (g)								
15	2.3a	0.6a	19.9a	22.8a	23.2a	0.7a	23.9ab	46.7a
20	5.0a	2.3ab	24.6ab	31.9a	20.9a	1.6ab	22.5a	54.4a
25	13.8b	9.8c	32.9c	56.5c	34.4b	3.2b	37.6c	94.1b
30	15.7b	9.8c	26.6bc	52.1bc	27.7ab	3.0b	30.7bc	82.8b
Field	12.6b	4.3b	26.8bc	43.7b	28.1ab	3.8b	31.9bc	75.6b

[z] Average values were analyzed by Duncan's multiple range test. Values in the same column followed by the same letter are not significantly different at $p=0.05$.

1. 2. 'Saijo' seedling trees

The higher the temperature, the earlier the sprouting, as in 'Fuyu' trees grafted on 'Saijo' seedling rootstocks. The values of total shoot lengths and leaf areas per tree were the highest at 30℃ followed by 25 or 20℃, but was very low at

15℃. Leaf number per tree was the highest at 30℃ followed by 25, 20 and 15℃, in this order. Total shoot length, leaf number and leaf area of the trees left in the field were between the values at 25 and 30℃ (Fig. 2, Table 3).

Table 3 Effects of temperature on shoot and leaf growth of 'Saijo' seedling trees.

Temperature (℃)	Total shoot length (cm)	Leaf number (No./tree)	Leaf area (LA) (m^2/Tree)
15	30.6a[z]	39.8a	103a
20	55.5ab	38.3a	177ab
25	93.3b	54.3ab	1264bc
30	257.8d	105.5c	3891d
Field	149.3c	73.0b	1733c

[z] Average values were analyzed with Duncan's multiple range test. Values in the same column followed by the same letter are not significantly different at $p=0.05$.

Fresh weight per tree, fresh weights of each organ, dry weight per tree, and dry weight of each organ were the heaviest at 30℃ followed by 25℃. The values at 20 and 15℃ were very low. Fresh and dry weights of trees left in the field were between the values of 25 and 30℃ (Table 4).

Table 4 Effects of temperature on fresh and dry weight of 'Saijo' seedling trees.

Temperature (℃)	Above-ground part (g)				Under-ground part (g)			Whole tree (g)
	Leaf	Shoot	Trunk	Total	Thick root (2 mm≧)	Fine root (2 mm<)	Total	
Fresh weight (g)								
15	2.3a[z]	1.2a	18.2a	21.7a	47.2a	1.3a	48.5a	70.2a
20	4.0a	2.0a	18.4a	24.4a	37.6a	0.9a	38.5a	62.9a
25	35.4b	9.7ab	20.3a	65.4b	46.7a	7.0a	53.7a	119.1b
30	94.1c	64.0c	35.7b	193.8c	77.5b	31.4c	108.9c	302.7d
Field	44.2bc	16.9b	23.4a	84.5b	66.8b	19.7b	86.5b	171.0c
Dry weight (g)								
15	0.8a	0.4a	10.3a	11.5a	21.1bc	0.5a	21.6a	33.1a
20	1.4a	1.0a	9.6a	12.0a	14.3a	0.3a	14.6a	26.6a
25	9.9b	4.3ab	10.8a	25.0b	17.3ab	2.5a	19.8a	44.8b
30	28.4c	28.5c	18.5b	75.4d	26.2c	11.0c	37.2b	112.6d
Field	13.9b	7.5b	12.8a	34.2c	25.7c	6.9b	32.6b	66.8c

[z] Average values were analyzed by Duncan's multiple range test. Values in the same column followed by the same letter are not significantly different at $p=0.05$.

2. Dry matter production and assimilate partitioning

2. 1. 'Fuyu' tree grafted on 'Saijo' seedling rootstock

DMG of tree at 25 and 30℃ were higher than that at 15 and 20℃. On the contrary, DMG per unit leaf area was the highest at 15℃. In the trees left in the field, DMG of tree was between the values at 20 and 25℃, and DMG per unit leaf area was similar to that at 30℃ (Table 5). At 25 and 30 ℃, APR to shoot was higher and the ratios to trunk and thick root were lower than the ratio at 15℃. APRs to each organ of the trees left in the field were similar to the values at 20 and 25℃ (Table 5).

Table 5 Effects of temperature on dry matter gains and assimilate partitioning ratios of 'Fuyu' trees grafted on 'Saijo' seedling rootstock.

Temperature (℃)	Dry matter gains per tree (g/tree)						Dry matter gain per unit leaf area (g/m²) (DM/LA)
	Leaf	Shoot	Trunk	Thick root (2 mm≧)	Fine root (2 mm<)	Total (DM)	
15	2.3a[z](13.9a)[y]	0.6a (3.6a)	5.9a(35.8c)	7.0a(42.4b)	0.7a (4.3a)	16.5a (100a)	793b
20	5.0a (25.0b)	2.3ab(11.5b)	6.0a(30.0bc)	5.1a(25.5a)	1.6ab(8.0a)	20.0a (100a)	480ab
25	13.8b (23.9b)	9.8c (17.0c)	15.2c (26.3ab)	15.8c (27.4a)	3.2b (5.4a)	57.8c (100a)	430a
30	15.7b (31.5b)	9.8c (19.6c)	10.5b(21.0a)	10.9b(21.8a)	3.0b (6.1a)	49.9bc(100a)	359a
Field	12.6b (28.3b)	4.3b (9.6b)	11.6b(26.0ab)	12.3b(27.6a)	3.8b (8.5a)	44.6b (100a)	334a

[z] Average values were analyzed by Duncan's multiple range test. Values in the same column followed by the same letter are not significantly different at p=0.05.

[y] Numbers in parenthesis indicate assimilate partitioning ratios.

2. 2. 'Saijo' seedling tree

DMG of tree was the highest at 30℃ followed by 25℃, and was low at 15 or 20℃. On the other hand, DMG per unit leaf area was the highest at 15℃ followed by 20℃, and was low at 25 or 30℃. In the trees left in the field, DMG of tree was between the values at 25 and 30℃, and DMG per unit leaf area was similar to that at 25 or 30℃ (Table 6). APR to leaves was higher at 25 or 30℃ than at 15 or 20℃. At the temperature between 20 and 30℃, the higher the temperature, the higher the APRs to shoot and fine root, and lower the APRs to trunk and thick root. APRs to each organ of the trees left in the field were between the values at 25 and 30℃ (Table 6).

Table 6 Effects of temperature on dry matter gains and assimilate partitioning ratios of 'Saijo' seedling trees.

Temperature (℃)	Dry matter gains per tree (g/tree)						Dry matter gain per unit leaf area (g/m²) (DM/LA)
	Leaf	Shoot	Trunk	Thick root (2 mm≧)	Fine root (2 mm<)	Total (DM)	
15	0.8a[z](7.8a)[y]	0.4a (3.9a)	2.8a(27.5c)	5.7a(55.9d)	0.5a(4.9ab)	10.2a(100a)	990c
20	1.4a (12.5a)	1.0a (8.9a)	3.4a(30.4c)	5.1a(45.5c)	0.3a(2.7a)	11.2a(100a)	633b
25	9.9b (36.7b)	4.3ab(15.9b)	4.0a(14.8b)	6.3a(23.3b)	2.5a(9.3bc)	27.0b(100a)	214a
30	28.4c (33.8b)	28.5c (34.0c)	6.6b(7.9a)	9.5b(11.3a)	11.0c(13.0cd)	83.9d(100a)	216a
Field	13.9b (36.6b)	7.5b (19.7b)	3.2a(8.4a)	6.5a(17.1ab)	6.9b(18.2d)	38.0c(100a)	219a

[z] Average values were analyzed by Duncan's multiple range test. Values in the same column followed by the same letter are not significantly different at p=0.05.

[y] Numbers in parenthesis indicate assimilate partitioning ratios.

Discussion

Japanese persimmon cultivar 'Fuyu' require warm temperature, higher than about 25℃, for natural removal of astringency, but the optimum temperature for the growth and quality of fruit was 20 to 25℃ (2, 3). Therefore, this cultivar has been cultivated mainly in a warm climate such as Fukuoka, Gifu, Nara and Wakayama Prefectures. George et al.(8) reported that the tree growth was more vigorous at a higher temperature, and that the shoot dry weight, leaf number and leaf area were the highest at day/night temperatures of 32/27℃. Persimmon trees are highly resistant to summer heat, tolerating the high temperature up to 50℃, and have a high optimum night temperature (32℃) for vegetative growth (15). In addition, even at the temperatures higher than 30℃, cell division in the root tips continues (5). Thus, 'Fuyu' trees appear to require a relatively high temperature for vigorous tree growth. In this investigation also, a relatively high temperature stimulated tree growth of 'Fuyu' trees grafted on 'Saijo' seedling rootstocks.

The shoot elongation period in 'Fuyu' trees is about 6 - 7 weeks and the rates of shoot elongation is the greatest during a month after the sprouting, and thereafter rapidly decline (16). In this experiment, the shoot elongation of 'Fuyu' trees left in the field were the greatest during a month after sprouting, and approximately finished at 45 days after sprouting. In regard to relationship between temperature and shoot elongation, it was found that the higher the temperature, the earlier the sprouting, and that the shoot elongation period after the sprouting were 40 - 45 days except 60 days at 15℃. The shoot discontinue elongating by self pruning, however leaf primordium in the axillary bud were completed by August in the previous year (9). Consequently the shoot length was depended on the self pruning date and the internode elongation. The excellent shoot length at a relatively high temperature might be attributed to the late self pruning date and the vigorous internode elongation during shoot elongation period.

In this experiment, the temperature was kept constant, but George et al.(8)

gave the diurnal temperature fluctuation of 5 ℃ in their experiment. The effects of difference between day and night temperatures (DIF) on the growth of annual flowers have been investigated, and a positive DIF (day temperature > night temperature) promoted the increase in plant height and internode length (11). A positive DIF might also influence the growth of 'Fuyu' trees. A high soil temperature can advance bud growth break, root and shoot growth (15). In this experiment, the temperature of the under-ground part of one-year-old potted 'Fuyu' trees in growth chambers was supposed to be similar to that of the above-ground part. In the future, the effects of soil temperature on the growth of 'Fuyu' trees should be examined.

There are not many studies on the photosynthetic rate in Japanese persimmon trees (10, 12). These studies showed that the photosynthetic rate of 'fuyu' tree was the highest in early August, thereafter gradually continued to decrease until the leaf fall stage, but did not reveal the rerationship between temperature and photosynthetic rate. In this study, the photosynthetic rate was not investigated, however studied the effects of temperature on DMG of tree. As a result, DMG of tree was higher at a relatively high temperature. It is supposed that the higher DMG were caused by acceleration of the photosynthetic rate at a relatively high temperature.

There are also very few studies on the effects of rootstocks on photosynthesis in Japanese persimmon too. However, in some rootstck studies of citrus it was revealed the effects of different rootstocks on growth, photosynthesis and distribution of photosynthetic product of trees (13, 17). The effects of 'Saijo' rootstock on photosynthesis of the scion cultivar, 'Fuyu' tree is not clear from this experiment, but it is supposed that rootstock influence tree growth and response to temperature.

In 'Saijo' seedling trees, the tree growth was excellent at 30℃, and the optimum temperature for tree growth was somewhat different from that of 'Fuyu' trees grafted on 'Saijo' seedling rootstocks. Responses to temperature of 'Fuyu' trees grafted on 'Saijo' seedling rootstock may somewhat differ from that of 'Saijo' seedling trees.

DMG of tree was excellent at 25 or 30℃ in 'Fuyu' trees grafted on 'Saijo' seedling rootstocks, and at 30℃ in 'Saijo' seedling trees. In 'Fuyu' trees, APR to shoot was similar at 25 and 30 ℃. However, in 'Saijo' trees, APR to shoot was clearly higher at 30℃ than at 25℃.

DMG has been reported to be proportional to the leaf area or leaf dry weight in grapevine (18) and Japanese pear (1, 6). In this experiment, DMG of 'Fuyu' trees grafted of 'Saijo' seedling rootstocks and that of 'Saijo' seedling trees were proportional to the leaf dry weight of each tree. In addition the lower the temperature, the higher DMG per unit leaf area presumably due to reduced consumption of photosynthates at low temperatures. Morinaga et al. (14) reported that the lower the temperature, the less the respiratory rate in each organ and the gross respiratory carbon consumption in the whole 'Fuyu' tree. The high APR to shoot at relatively high temperatures (25 or 30℃) may have resulted from the accelerated shoot elongation, and the low APR to trunk or thick root at relatively high temperatures from a high APR to shoot and leaf.

'Fuyu' trees grafted on 'Saijo' seedling rootstocks grew well at a relatively high temperature, but 'Saijo' seedling trees grew vigorously at a higher temperature (30℃). The differences in the effect of temperature on the tree growth between 'Fuyu' trees grafted on 'Saijo' seedling rootstocks and 'Saijo' seedling trees might be due to genetic differnce between two cultivars, or physiological difference between the juvenile phase in the seedling tree and the adult phase in the grafted tree. Japanese persimmon is difficult to propagate by cutting. After successful growth of self-rooted 'Fuyu' trees by cutting, we will investigate the effects of temperature on the growth of the trees grafted on rootstocks in comparison with that on the growth of the self-rooted trees.

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摘　要

カキ '富有' 樹の生長、乾物生産および分配に及ぼす温度の影響

文室政彦, 井上　宏

ポット植栽の1年生 '富有'（'西条' 実生台）樹と1年生 '西条' 実生樹を供試し、3月1日より9月2日まで、15℃、20℃、25℃および30℃の恒温条件の人工気象室（自然光、相対湿度75%）を使用して、樹の生長、乾物生産および分配に及ぼす温度の影響を検討した。新梢伸長、各器官の新鮮重および乾物重は、'富有' 樹は25℃と30℃、'西条' 実生樹では30℃が最も優れた。単位葉面積当たり乾物生産量は低い温度で多かったが、1樹当たり乾物増加量は、'富有' 樹は25℃と30℃、'西条' 実生樹では30℃が最も優れた。新梢への同化産物の分配率は、'富有' 樹は25℃と30℃がほぼ同じであったが、'西条' 実生樹では25℃より30℃が明らかに高かった。