

ウンシュウミカンの栄養生長と花芽分化に及ぼす気温と地温 の影響

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Effects of Air and Soil Temperature on Vegetative Growth and Flower Bud Differentiation of Satsuma Mandarin Trees

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Summary

One-year-old satsuma mandarin (*Citrus unshiu* Marc. cv. Okitsu Wase) trees budded onto trifoliolate orange rootstocks were subjected to different soil temperature (15, 20, 25 and 30°C) and air temperature treatments (25°C in Experiment I, and 15 and 30°C in Experiment II) for 6 or 7 months. The effects of air and soil temperatures on vegetative growth and flower bud differentiation were investigated.

The number of flushes and total length of the shoots increased with rising soil temperatures. When soil temperatures were above 20°C, the number of flushes at an air temperature of 15°C was less than at 30°C. The length of spring shoots at an air temperature of 15°C was longer than at 30°C. However, due to the trees at air temperature of 30°C having more growth cycle flushes, the total length of the shoots did not differ among treatments. The dry weight of the trees increased with increases in both air and soil temperatures. Both low air and low soil temperatures affected flower induction greatly. At an air temperature of 30°C, flower buds developed only at soil temperatures of 15 and 30°C. At an air temperature of 15°C, flower buds developed even when the soil temperature was 30°C. Trees with air/soil temperatures of 25/30, 30/25 and 30/30°C did not bear any flower buds. The effects of temperature on mineral nutrient content were slight. The roles of soil and air temperature on vegetative growth and flower formation are briefly discussed.

Introduction

Flower bud differentiation in satsuma mandarin is known to be greatly affected by temperature. Cold winters have often been considered as main factor affecting flower induction, but they are not essential, as recent researches have indicated that flower initiation can occur at constant temperatures of 15 or 20°C (6, 7). On the contrary, temperatures as high as 30°C advanced only vegetative growth. Root stress may be one factor affecting flower induction, as it has been reported that drought or root pruning induces flower buds in citrus (5, 8, 15, 18, 19). Monselise (12) stated that there is a correlation between flower induction and depression of root growth. We reported

previously that both the root and shoot growth of satsuma mandarin on trifoliolate orange were markedly restricted when the trees were grown at 15°C (17). It seems likely that the physiological stress on the root system caused by cool temperatures acts on flower induction indirectly.

These studies were conducted to get basic information on the management of air and soil temperature in order to control the balance of vegetative and generative growth in satsuma mandarin.

Materials and Methods

Uniform one-year-old 'Okitsu Wase' satsuma mandarin trees budded onto trifoliolate orange rootstocks were used. The trees were planted in Wagner's pots (265 mm in diameter×300 mm in depth) filled with a mixture of granite soil and bark compost (2 : 1) in late March of 1986 and 1987. They were grown under field conditions until the experiments started.

In Experiment I, the air temperature was held constant at 25°C for all trees. Trees were

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divided into groups of three, and each group was subjected to a different soil temperature, that is, 15, 20, 25 and 30°C. In this report, these treatments will be referred to as: 25/15, 25/20, 25/25 and 25/30°C. The treatments were initiated on May 21, 1986 and were continued until November 10, 1986. The trees were fertilized with ammonium sulfate, superphosphate and potassium sulfate equivalent to 9.8 g N, 9.8 g P₂O₅ and 9.8 g K₂O per tree.

Temperature treatments in Experiment II were done from April 21 to November 30, 1987. The trees were divided as before, and some were subjected to air temperature of 15°C and others to 30°C. At each air temperature, the trees were also subjected to different soil temperatures of 15, 20, 25 and 30°C. These treatments will be referred to as 15/15, 15/20, 15/25, 15/30, 30/15, 30/20, 30/25, 30/30°C. The trees were fertilized with an 8-8-8 fertilizer (N-P-K) equivalent to 5.6 g N, 5.6 g P₂O₅ and 5.6 g K₂O per tree.

Soil temperatures were maintained by placing the pots in separate water baths (640×440×380 mm) equipped with heating and cooling devices. The surface of each bath was covered with a styrofoam plate, with only small openings for tree trunks and circulating tubes (16).

In both experiments, all the trees were defoliated and then exposed to 25°C (on November 11, 1986 in Experiment I and on December 1, 1987 in Experiment II) to observe flower bud development. At the end of the experiment, all trees were harvested. The spring leaves and fibrous roots were dried and ground for nutrient analysis.

Nitrogen content was analyzed using the Kjeldahl method. Samples were wet-digested for phosphorus and cation analysis. Phosphorus content was determined from sample stock solutions by spectrophotometry (vanadate-molybdate-yellow method), potassium content by flame photometry, and calcium, magnesium, manganese and zinc contents by atomic absorption spectrophotometry (16).

Results

Shoot Growth

The trees had three growth flushes at 25/30°C, two at 25/25 and 25/20°C and one at 25/15°C. The length of the spring shoots was not

Table 1. Effect of soil temperature on shoot length of satsuma mandarin in Experiment I (cm).

Soil temperature [†]	First growth cycle	Second growth cycle	Third growth cycle	Total growth
15°C	103.73ns [‡]	—	—	103.73c
20°C	135.43	6.93	—	142.36bc
25°C	116.23	174.13	—	290.36ab
30°C	115.70	217.93	122.40	465.07a

[‡] Different letters within columns indicate significant differences at 1% level; ns indicates non-significant at 5% level.

[†] Air temperature was 25°C.

Table 2. Effect of air and soil temperature on shoot length of satsuma mandarin in Experiment II (cm).

Air/soil temperature	First growth cycle	Second growth cycle	Third growth cycle	Total growth
15/15°C	85.53	—	—	85.52
15/20°C	172.73	—	—	172.73
15/25°C	176.03	163.50	—	339.53
15/30°C	211.13	179.13	—	423.60
30/15°C	49.13	—	—	49.13
30/20°C	100.07	39.97	51.53	187.57
30/25°C	114.63	169.60	126.33	410.57
30/30°C	147.90	165.07	106.73	419.70
Significance [‡]				
-Air	**			ns
-Soil	**			**
-Interaction	ns			ns

[‡] ns indicates non-significant at 5% level;

** significant at 1% level.

significantly different between treatments, because soil temperature treatments were initiated after the growth of spring shoots ceased. However, total shoot length was significantly different (Table 1).

The trees at 15/15, 15/20 and 30/15°C developed only spring shoots. Those at 15/25 and 15/30°C developed both spring and summer shoots, and those at 30/20, 30/25 and 30/30°C also developed autumn shoots. The length of spring shoots and the total length of the shoots increased with rising soil temperatures. Under the same soil temperature conditions, spring shoots at an air temperature of 15°C were longer than those at 30°C. However, due to the trees in the 30°C growth chamber having more growth flushes, the total length of shoots was not different (Table 2).

Dry Matter Production

The results of Experiment I showed that the dry matter of the trees increased as soil temperatures rose from 15 to 30°C (Table 3). Dry weight of the fibrous roots was lowest at 25/15°C and greatest at 25/30°C. These values were significantly different from those at 25/20 and 25/25°C (Table 4).

In Experiment II, total dry matter of the trees, and dry weight of the roots and stems increased with rising air and soil temperatures. Dry weight of the leaves increased with rising

Table 3. Effect of soil temperature on dry matter produced by satsuma mandarin in Experiment I (g).

Soil temperature ^y	Roots	Stems	Leaves	Total
15°C	32.77b ^z	33.46b	7.07c	73.30b
20°C	37.47b	39.07b	14.67bc	91.21b
25°C	43.53ab	52.37b	33.07ab	128.97a
30°C	64.23a	105.30a	54.70a	224.23a

^z The same as Table 1.

^y Air temperature was 25°C.

Table 4. Effect of soil temperature on dry weight of satsuma mandarin roots in Experiment I (g).

Soil temperature ^y	Fibrous roots ($\phi \leq 2$ mm)	Small roots ($2 < \phi \leq 5$ mm)	Large roots ($\phi > 5$ mm)	Taproots	Total
15°C	3.80c ^z	4.27ns	10.80ns	13.90b	32.77b
20°C	10.03b	3.83	11.13	12.47b	37.47b
25°C	11.60b	4.57	14.10	13.27b	43.53ab
30°C	18.07a	8.23	17.40	20.53a	64.23a

^z The same as Table 1.

^y Air temperature was 25°C.

soil temperatures, but air temperature did not significantly affect the dry weights (Table 5). Dry weight of the fibrous roots increased with both rising soil and air temperatures. At an air temperature of 30°C, the dry weight of the fibrous roots increased greatly with rising soil temperatures, but at an air temperature of 15°C there were only slight increases (Table 6).

Table 5. Effect of air and soil temperature on dry matter produced by satsuma mandarin in Experiment II (g).

Air/Soil temperature	Roots	Stems	Leaves	Total
15/15°C	19.98	18.13	10.39	48.48
15/20°C	30.51	29.85	20.64	81.00
15/25°C	34.37	34.46	48.13	116.96
15/30°C	41.04	46.04	64.47	151.55
30/15°C	33.50	25.39	11.18	70.07
30/20°C	33.28	33.31	34.21	100.80
30/25°C	42.07	50.46	48.50	141.03
30/30°C	50.99	58.30	60.47	169.76
Significance ^z				
-Air	**	**	ns	*
-Soil	**	**	**	**
-Interaction	ns	ns	**	ns

^z ns indicates non-significant at 5% level;

* significant at 5% level; ** significant at 1% level.

Flower Bud Differentiation

In Experiment I the trees at 25/15°C developed flower buds in early October of 1986 and began to blossom in mid-October. Negligible numbers of flower buds developed on the trees at 25/20 and 25/25°C in late October of 1986. At an air temperature of 25°C, raising the soil temperature from 15 to 30°C decreased the ratio of flower buds to total sprouting buds. Only negligible numbers of flower buds developed at 25/30°C (Table 7).

In Experiment II, all trees at an air temperature of 15°C developed flower buds during August and September. On the other hand, The trees at 30/15 and 30/20°C developed flower buds after they were defoliated and transferred to a 25°C growth chamber on December 1, 1987.

Table 8 shows that flower buds formed on all the trees at an air temperature of 15°C, even when the soil temperature was 30°C. The number of flower buds at 15/25 and 15/30°C, however, was significantly lower than at 15/15 and 15/20°C. At an air temperature of 30°C, flower buds formed only when soil temperatures were 15 and 20°C. The number of vegetative shoots in the 30°C growth chamber was smaller than in the 15°C growth chamber.

Table 6. Effect of air and soil temperature and dry weight of satsuma mandarin roots in Experiment II (g).

Air/Soil temprature	Fibrous roots ($\phi \leq 2$ mm)	Small roots ($2 < \phi \leq 5$ mm)	Large roots ($\phi > 5$ mm)	Taproots	Total
15/15°C	3.58	1.78	5.93	8.69	18.95
15/20°C	6.65	2.35	9.73	11.78	29.70
15/25°C	6.47	3.01	12.72	12.17	33.75
15/30°C	8.44	3.12	13.33	16.14	40.43
30/15°C	5.04	3.17	10.90	14.39	32.94
30/20°C	9.10	2.80	7.39	13.99	32.61
30/25°C	14.19	4.12	9.87	13.90	41.30
30/30°C	14.94	6.74	15.19	14.44	50.55
Significance ^a					
-Air	**	*	ns	ns	**
-Soil	**	ns	**	ns	**
-Interaction	ns	ns	**	ns	ns

^a ns indicates non-significant at 5% level; * significant at 5% level; ** significant at 1% level.

Table 7. Effect of soil temperature on bud development of satsuma mandarin in Experiment I.

Soil temperature ^y	Flower buds	Vegetative shoots	Total	Ratio of flower buds to total sprouting
15°C	48.33a ^z	41.33b	98.67ns	53.68a
20°C	25.67b	51.67b	77.33	33.24b
25°C	16.67b	95.00a	111.67	15.20c
30°C	0.67c	84.00a	84.67	0.75d

^z The same as Table 1.

^y Air temperature was 25°C.

Figure 1 illustrates that the number of sprouting buds per node, the number of flower buds per node on spring shoots, and the ratio of flower buds to total sprouting buds at an

air temperature of 30°C were smaller than at an air temperature of 15°C. At an air temperature of 30°C these numbers decreased as soil temperature increased from 15 to 25°C. They also decreased when the air temperature was 15°C and the soil temperature increased from 20 to 25°C.

Mineral Nutrient Contents

Foliar analysis of spring leaves (about 7 months old) revealed that the mineral nutrient contents were comparable to those commonly found in satsuma mandarin leaves (20). The effects of temperature on mineral nutrient content in the spring leaves were slight (data was not shown).

Table 8. Effect of air and soil temperature on bud development on each cycle of shoots of satsuma mandarin in Experiment II.

Air/soil temperature	Flower Buds					Vegetative Buds					Grand Total
	Trunk	Spring	Summer	Autumn	Total	Trunk	Spring	Summer	Autumn	Total	
15/15°C	0.00	95.33	—	—	95.33	0.67	67.67	—	—	68.33	164.67
15/20°C	0.00	143.33	—	—	143.33	1.00	65.00	—	—	66.00	209.33
15/25°C	0.00	48.00	3.67	—	51.67	0.00	31.67	39.33	—	69.67	121.33
15/30°C	0.00	38.33	3.00	—	41.33	0.00	35.00	39.33	—	74.33	115.67
30/15°C	0.00	29.67	—	—	29.67	18.67	22.00	—	—	40.67	70.33
30/20°C	0.00	12.33	0.00	0.00	12.33	5.00	21.00	6.67	7.00	39.67	52.00
30/25°C	0.00	0.00	0.00	0.00	0.00	0.33	13.33	20.67	13.33	47.67	47.67
30/30°C	0.00	0.00	0.00	0.00	0.00	0.67	19.33	25.00	17.00	62.00	62.00
Significance ^a											
-Air		**			**					*	**
-Soil		**			**					ns	*
-Interaction		**			**					ns	**

^a ns indicates non-significant at 5% level; * significant at 5% level, ** significant at 1% level.

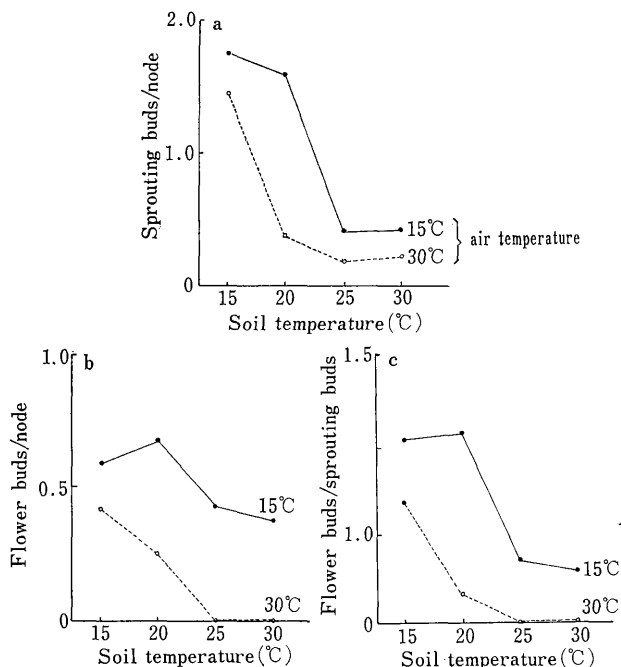


Fig. 1. Effect of air and soil temperature on the number of sprouting buds per node (a), number of flower buds on spring shoots per node (b), and the ratio of flower buds to total sprouting buds (c).

Discussion

Strong effects of soil temperature on vegetative growth and flower bud differentiation were observed. The number of flushes and the length of the shoots increased with rising soil temperatures in both experiments. These results agreed with those reported by Liebig and Chapman (11) and Khairi and Hall (9). When soil temperatures were above 20°C, the number of flushes at an air temperature of 15°C was less than at 30°C. The length of spring shoots at air temperature of 15°C was longer than at 30°C, because the duration of growth of spring shoots at 15°C was longer than at 30°C. However, the total length of the shoots did not differ between the two treatments.

Root growth of satsuma mandarin always followed shoot growth. When the spring shoots flushed, the root systems of all the trees were uniform because new roots did not develop before flushing (7, 17). It may be due to high transpiration and an imbalance between water absorption and transpiration that the growth of the spring shoots was limited at an air temperature of 30°C. Borchert (2) defined a balance between the surface of water uptake

in the root system and the surface of transpiration in the shoot system. The limitation of water absorption arrested shoot growth until enough roots were produced to achieve a balance.

At an air temperature of 30°C, flower buds developed only at soil temperatures of 15 and 20°C. At an air temperature of 15°C, flower buds developed even when the soil temperature was 30°C. Before they were defoliated and transferred to 25°C, flower buds had already developed on all trees at the low air temperature (15°C), whether the soil temperature was low (15°C) or high (30°C), and on the trees at the moderate air temperature (25°C) with low soil temperature (15°C). After defoliation, flower buds formed on trees grown at high air temperatures and low soil temperatures, or when both air and soil temperatures were moderate. No flower buds formed when high air temperatures were combined with moderate or high soil temperatures, or when moderate air temperatures were combined with high soil temperatures. It seems that low temperatures, either air or soil, induced flower bud differentiation. The effect of low air temperatures on flower induction was diminished when soil

temperatures were high. Likewise, the effect of low soil temperatures on flower induction was lessened by high air temperatures.

The trees at 30/15°C did not bear flower buds before they were defoliated and transferred to 25°C. Our defoliation technique in the warm room (25°C) was employed to force the buds to sprout. This enabled us to compare the number of buds which had potentiality to sprout among the different temperature treatments. It seems that the trees at 30/15°C had flower buds of the lower induced degree due to high air temperature. Moss (14) reported that high air temperatures inhibit flower development in sweet orange even after a period of inductive low temperature treatment. Hall *et al*(4) also reported that the number of flower buds of sweet orange developed at day air temperature of 30°C was markedly smaller than at 20°C under night air temperature conditions of 15°C.

Since vegetative growth of the trees at 15/15 and 15/20°C was greatly inhibited, greater numbers of flower buds formed at these temperatures than at 15/25 and 15/30°C. At the latter two temperatures, flushing occurred both in spring and in summer. Inoue(6) and Inoue and Harada(7) reported that all satsuma trees grown at ambient temperatures of 15 and 20°C had sprouting flushes only in the spring, and the resultant shoots produced some flower buds. At higher temperature when summer and autumn flushes occurred, flower buds were not produced. Moss(13) also reported that flowering in sweet orange trees occurs whenever shoot growth commences after the trees brought to warm condition.

Goldschmidt and Monselise(3) suggested that the flowering of citrus trees requires reduced levels of gibberellin. That trees at 15/25 and 15/30°C produced flower buds may be caused by decreasing gibberellin activity by low air temperature. And the formation of flower buds on all the trees grown at 30/15 and 30/20°C may be caused by a reduction of gibberellin export from the roots. Yamada *et al*(21) reported that gibberellin levels in the stems of citrus trees grown at 13°C soil temperature were lower than in control trees (grown in greenhouse of Kyoto University in October). Atkin *et al*(1) also found that in maize, the

export of total gibberellin and cytokinin from root to shoot increased at warm soil temperatures, while the inhibitor export decreased.

Since almost all mineral nutrient contents in the spring leaves ranged at medium levels and the effects of air and soil temperature on these contents were small, mineral nutrient content probably did not influence plant response to temperature. Labanauskas *et al*(10) reported that the nutrient contents in tops and roots of sweet orange seedlings were not affected by two soil temperature values (22.5 and 27.8°C). Khairi and Hall(9) also reported that air temperature did not have a significant effect on the status of most mineral nutrients in leaves of sweet orange. However, Inoue and Harada(6) found that mineral absorption by satsuma mandarin increased as ambient temperatures rose from 15 to 25°C, but decreased slightly at 30°C.

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ウンシュウミカンの栄養生長と花芽分化に及ぼす気温と地温の影響

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摘 要

1年生カラタチ台ウンシュウミカン '興津早生' (*Citrus unshiu* Marc. cv. Okitsu Wase) を種々の気温 (実験 I : 25°C, 実験 II : 15, 30°C) と地温 (15, 20, 25, 30°C) を組み合わせた温度条件下で4月から6または7か月間生育させ、栄養生長、花芽分化、春葉の肥料要素含量に及ぼす気温と地温の影響を調査した。

地温が高くなるほど新梢の生長周期および総伸長量は増加した。同一地温条件下では、春枝の伸長量は低気温区の15°C区で、高気温区の30°C区よりも大となったが、15°C区よりも30°C区で新梢の生長周期が多くなったため、新梢の総伸長量には差がみられなかった。乾物重は高気

温または高地温区ほど大となる傾向を示した。花芽は気温もしくは地温のどちらかが低くなれば分化した。すなわち、気温が30°Cであっても地温が15または20°Cであれば花成は促進され、地温が30°Cであっても気温が15°Cであれば花蕾の発生が認められた。気温と地温の組み合わせが25/30 (気温/地温), 30/25, 30/30°Cの場合には、花蕾の発生は全く認められなかった。春葉の肥料要素含量に及ぼす気温または地温の影響は小さかった。栄養生長ならびに生殖生長に関する気温と地温の役割について考察した。