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Influence of Water Stress in Autumn on Flower Induction and Fruiting in Young Pomelo Trees (*Citrus grandis* (L.) Osbeck)

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Summary

Young pomelo trees grown in concrete pots in a plastic house were water-stressed for different durations from early September to late December, 1990. The cyclical stress treatments were established by withholding water from the potted trees until the leaf water potentials reached -24 to -28 bars (7 to 13 days after irrigation) at which time they were re-irrigated. Maximum day and minimum night temperatures in the plastic house were adjusted to about 25° and 10°C, respectively, from early December, 1990, to early April of the following year.

1. Trees, subjected to water stress from early September hardly grew in the fall, whereas those stressed from early October and the control trees sent forth several shoots per tree. The number and length of the spring shoots which sprouted in the following year were not significantly different among the treatments.
2. The number of inflorescences, flower buds, and flowers which opened, increased as the duration of water stress was extended. Anthesis was advanced in trees from which fall shoots failed to sprout but not in trees that produced fall shoots. The stress treatments had no effect on the % fruit set which ranged from 0.1 to 1.1 for leafless flowers and 4.8 to 6.0 for leafly ones.
3. Comparison of analyses made in late December between leaves of stressed trees with and without fall shoots revealed that leaf sugar content increased while starch content decreased, the magnitude of the difference being proportional to the duration of the stress period. Leaf N content was significantly higher in stressed trees compared to unstressed ones. No significant difference in C : N ratio in leaves was observed in late December among the treatments.

Introduction

We observed during our several trips to Southeast Asia that many pomelo trees cultivated in those regions had relatively poor production as compared wiht those in a subtropical region. The low yield was attributed to the relatively high temperatures which inhibited flower bud induction and fruit set in pomelo trees. Flowering was retarded in young pomelo trees when adequately watered and kept at 25°/20°C (day/night) during winter (Susanto et al., 1992). In other citrus species kept at 30°/25°C (day/night), flowering was strongly inhibited, whereas vegetative growth was promoted (Inoue, 1989a; Lenz, 1969; Moss, 1969). On the contrary, long duration of exposure to 20°/5～10°C (Susanto et al., 1992), and 15°/5°C (Nakajima et al., 1992) day/night during winter induced much flowering in young pomelo trees. Likewise, flowering in citrus can be induced by water stress (Nir et al., 1972; Inoue, 1989b). Therefore, flowering of citrus trees in the coastal region of the tropics appears to be associated with water stress in the dry season of the year (Reuther and Rio-Castano, 1969). In this trial, the effect of water stress late in the vegetative growth cycle of unchilled pomelo trees with respect to shoot growth and flowering was investigated.

Materials and methods

Non-bearing young 'Tosa Buntan' pomelo (*Citrus grandis* (L.) Osbeck) trees on trifoliate orange (*Poncirus trifoliata* Raf.) rootstocks were transplanted to concrete pots in late March 1990, and grown in

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an uncovered plastic house. The planting medium in the pot was a mixture of soil, sand, and bark compost (1:1:1). Organic fertilizer was applied on the surface in late April and mid-July 1990. The house was covered with a clear film from mid-November 1990 until the following summer. Maximum day and minimum night temperatures in the plastic house were adjusted to about 25° and 10°C, respectively, from early December 1990 to early April 1991. The potted trees were subjected to different durations of water stress from early September to late December 1990. The cyclical water stress was established by withholding water from potted trees until leaf water potential from −24 to −28 bars were achieved. This required 7 to 13 days at which time the trees were re-watered. Water was again withheld and the cycle repeated during the treatment. All trees, before and after each treatment, were watered every other day. The pot surface was sealed to prevent rain water from infiltrating the soil before the plastic house was covered. Leaf xylem pressure potentials were measured at mid-day by the pressure bomb technique (Machida and Maotani, 1974, Scholander et al., 1965). Measurements were made 2～3 times during the day when slightly withering symptoms such as curling appeared on leaf margin. The range between −24 and −28 bars was attained, depending on the stress duration. Only one medium-sized leaf per tree from the water stress regimes was used for the measurement. In trial 1, 3-year-old trees grown in 100 liter pots were subjected to having water withheld from 1 September for the duration of 0, 1, 2, 3 and 4 months. In trial 2, 2-year-old trees grown in 70 liter pots were subjected to water stress from 1 September, 1 October, 1 November, and 1 December to 31 December. Unstressed trees as a control plot were maintained. Each treatment was replicated 4 times. The spring leaves were collected in late December for the carbohydrate and nitrogen analyses. Starch was hydrolyzed with perchloric acid and the resulting sugar was determined by a Somogyi-Nelson's method. Nitrogen content was analyzed using a Micro-Kjeldahl method.

Results

The average diurnal maximum and minimum temperatures were about 30° and 22°C in the field in September 1990; they gradually decreased to about 23° and 10°C in the plastic house during winter (Fig. 1). The trees subjected to water stress from early September produced few shoots in the fall in both trials. However, trees subjected to water stress from early October in trial 2 and the control trees in both trials produced 7 to 9 fall shoots per tree during mid- to late-September (Table 1). The 3-year-old trees in trial 1 produced 54 to 62 spring shoots, whereas the 2-year-old trees in trial 2 had 36 to 49 spring shoots per tree during the ensuing February (Table 1). There were no significant differences in the number and length of shoots among the treatments in both trials. The length of spring shoots was relatively shorter than that of fall shoots (Table 1). The inflorescences, flower buds, and flowers which opened were more numerous on trees exposed to longer periods of water stress, such as the 2 to 4 month-treatments from early September in trials 1, 2, and the 3-month-treatment from early October in trial 2 (Table 2). On the contrary, the one month-treatment from early September in trial 1 and early December in trial 2, and the two-month treatment from early November in trial 2 were not effective in inducing flowering in the following spring. The percentages of leafless inflorescences and flower buds from the total leafless and leafy ones were in the range of 79 to 91% in trial 1 and 68 to 84% in trial 2. Their percentages were higher with the longer duration of treatments in trial 1 but no consistency was evident among treatments in trial 2 (Table 2). Anthesis occurred from early March to early May in both trials in 1991. The

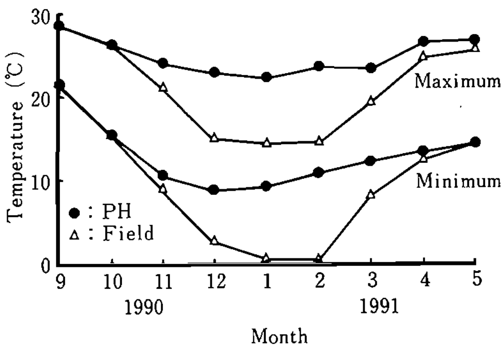

Fig. 1. Monthly maximum and minimum temperatures in the plastic house (PH) and field during the experimental period.

Table 1. Effect of water stress on shoot growth of 'Tosa Buntan' pomelo trees[z].

Treatment period	No. of shoots/tree		Shoot length/tree (cm)		Length/shoot (cm)	
	Fall[y]	Spring[y]	Fall[y]	Spring[y]	Fall[y]	Spring[y]
			Trial 1			
Sep.~Dec.	0 b[x]	56.8 a	0 b	914.8 a	0 b	16.1 a
Sep.~Nov.	1.4 b	60.7 a	22.3 b	831.6 a	20.9 a	13.7 a
Sep.~Oct.	2.2 b	54.0 a	43.6 b	820.8 a	19.8 a	15.2 a
Sep.	0 b	62.3 a	0 b	928.3 a	0 b	14.9 a
Control	12.3 a	53.8 a	363.2 a	866.2 a	21.4 a	16.1 a
			Trial 2			
Sep.~Dec.	0 b	43.4 a	0 b	594.6 a	0 b	13.7 a
Oct.~Dec.	8.6 a	49.2 a	150.5 a	629.8 a	17.5 a	12.8 a
Nov.~Dec.	7.2 a	35.6 a	139.0 a	498.4 a	19.3 a	14.0 a
Dec.	6.8 a	40.3 a	130.6 a	640.8 a	19.2 a	15.9 a
Control	7.9 a	38.4 a	140.6 a	522.2 a	17.8 a	13.6 a

z The treated trees were fully watered after leaf water potential achieved −24~−28bar, whereas the control trees were fully watered every other day. Each treatment was replicated 4 times for both trials.
y Sprouting time: 17~25 September 1990 for fall shoots and 3~24 February 1991 for spring shoots.
x Different letters within columns indicate significance at 5% level using Duncan's multiple range test.

Table 2. Effect of water stress[z] on inflorescence and flower counts of 'Tosa Buntan' pomelo trees.

Treatment duration	Inflorescences/node			Flower buds/node				Flowers opened/node			
	Ll.[y]	Lf.[y]	Total	Ll.	Lf.	Total	Ll./Total(%)	Ll.	Lf.	Total	Ll./Total(%)
						Trial 1					
Sep.~Dec.	0.58 a[x]	0.07 a	0.65 a	3.18 a	0.37 a	3.55 a	90	2.74 a	0.35 a	3.09 a	90
Sep.~Nov.	0.50 ab	0.05 a	0.55 ab	2.88 a	0.29 a	3.17 a	91	2.60 a	0.29 a	2.89 a	90
Sep.~Oct.	0.44 ab	0.07 a	0.51 ab	2.52 ab	0.40 a	2.92 ab	86	2.28 ab	0.37 a	2.65 ab	86
Sep.	0.27 b	0.06 a	0.33 b	1.78 b	0.39 a	2.17 b	82	1.59 b	0.36 a	1.95 b	82
Control	0.29 b	0.08 a	0.37 b	1.86 b	0.48 a	2.34 b	79	1.68 b	0.46 a	2.14 b	79
						Trial 2					
Sep.~Dec.	0.45 a	0.09 a	0.54 a	2.52 a	0.51 a	3.03 a	83	2.25 a	0.46 a	2.71 a	83
Oct.~Dec.	0.37 ab	0.08 a	0.45 ab	2.15 ab	0.42 a	2.57 ab	84	1.96 ab	0.42 a	2.38 ab	82
Nov.~Dec.	0.26 b	0.11 a	0.37 b	1.67 b	0.66 a	2.33 b	72	1.54 b	0.62 a	2.16 b	71
Dec.	0.28 b	0.10 a	0.38 b	1.49 b	0.66 a	2.15 b	69	1.37 b	0.65 a	2.02 b	68
Control	0.31 b	0.09 a	0.40 b	1.77 b	0.52 a	2.29 b	77	1.62 b	0.48 a	2.10 b	77

z, x The same as Table 1.
Number of nodes : 339.9~378.3/tree in trial 1 and 185.2~219.7/tree in trial 2.
y Ll. : leafless, Lf. : leafy.

flowers opened about 10 days later in trees which produced fall shoots in the previous year compared with trees whose buds did not emerge in both trials (Fig. 2). Fruit set percentages after June drop ranged from 0.8 to 1.1% in leafless flowers and 4.8 to 6.0% in leafy ones; there were no significant differences among treatments in both trials (Table 3). Analyses made in late December showed that leaf sugar content increased while starch content decreased on trees exposed to long periods of water stress. N content of the same leaves was significantly higher in stressed trees than in unstressed ones. C-N ratio of leaves ranged from 4.26 to 5.05 in trial 1 and 4.75 to 5.10 in trial 2; there were no significant differences among the treatments in both trials (Table 4).

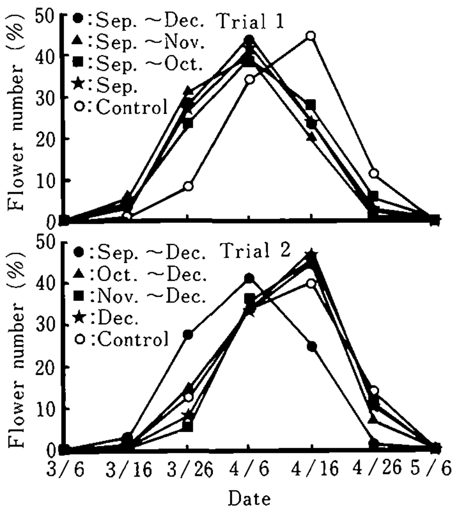

Fig. 2. Flower opening period of 'Tosa Buntan' pomelo trees as influenced by water stress.

Table 3. Effect of water stress[z] on fruit set of leafless and leafy inflorescences in 'Tosa Buntan' pomelo trees.

Treatment period	Fruit set[y] (%)		
	Leafless infl.	Leafy infl.	Total
		Trial 1	
Sep.~Dec.	0.8 a[x]	5.9 a	1.4 a
Sep.~Nov.	1.1 a	5.6 a	1.6 a
Sep.~Oct.	0.9 a	5.7 a	1.6 a
Sep.	1.0 a	6.0 a	1.9 a
Control	0.9 a	5.3 a	1.8 a
		Trial 2	
Sep.~Dec.	0.9 a	5.5 a	1.7 a
Oct.~Dec.	1.0 a	5.9 a	1.9 a
Nov.~Dec.	0.8 a	4.9 a	2.0 a
Dec.	1.0 a	4.8 a	2.2 a
Control	1.0 a	5.5 a	2.0 a

z, x The same as Table 1.
y Based on the number of flowers which opened.

Table 4. Effect of water stress[z] on carbohydrate and nitrogen contents in spring leaves of 'Tosa Buntan' pomelo trees.

Treatment	Sugar (%)	Starch (%)	Total carbo-hydrate (%)	Nitrogen (%)	C-N ratio
			Trial 1		
Sep.~Dec.	8.69 a[y]	4.63 b	13.32 a	2.69 a	4.95 a
Sep.~Nov.	7.19 ab	5.25 ab	12.44 a	2.73 a	4.54 a
Sep.~Oct.	8.00 a	5.38 ab	13.38 a	2.73 a	4.90 a
Sep.	6.51 ab	5.32 ab	11.83 a	2.78 a	4.26 a
Control	5.75 b	6.88 a	12.63 a	2.50 b	5.05 a
			Trial 2		
Sep.~Dec.	8.63 a	4.38 b	13.01 a	2.71 a	4.80 a
Oct.~Dec.	7.88 a	4.94 ab	12.82 a	2.52 b	5.09 a
Nov.~Dec.	7.42 ab	5.28 ab	12.70 a	2.49 b	5.10 a
Dec.	6.50 ab	5.32 ab	11.82 a	2.49 b	4.75 a
Control	5.44 b	6.69 a	12.13 a	2.48 b	4.89 a

z, y The same as Table 1.
Leaf samples were collected on 31 December 1990.

Discussion

Variations of 7 to 13 days among plants to attain leaf water potentials of −24 to −28 bars, after water was withheld, are attributed to weather conditions during the treatments. These cyclical intervals which are considerably shorter than those under field condition without rainfall may be due to the small soil volume in the concrete pots in relation to tree sizes. In our previous trial, young pomelo trees planted in a plastic house took over 3 weeks to reach leaf water potentials of −24 to −28 bars during the growing season (unpublished data). The trees, subjected to water stress from early September, were forced into dormancy and did not produce fall shoots during this period.

These trees bloomed earlier the following spring. Therefore, we conclude that the early dormant condition in young pomelo trees in the late growing season promoted flower induction. Similarly, flower buds of coffee were released from dormancy by water stress (Astegiano et al., 1988). Severe water stress such as −3.5 megapascals induced flowering of 'Tahiti' lime trees more than did moderate water stress of −2.25 megapascals (Southwick and Davenport, 1986). Leaf water potential below −25 bar during the growing season strongly affected the photosynthetic rate and fruit enlargement in satsuma mandarin (Ogawa et al., 1991). Water potentials ranging from −30 to −35 bars are excessive for young pomelo trees as judged by severe wilting symptoms of leaves. However, the photosynthetic rate of satsuma mandarin leaves recovered after 20 day-duration of water stress at −30 to −35 bar levels (Morinaga and Ikeda, 1990). In this trial, leaf water potentials of −24 to −28 bars were attained cyclically within one to two weeks. This condition lasted for a few days. These levels in the late growing season had a promotive effect on flower induction, insofar as many flowers appeared in the following spring without severe defoliation during winter. Relatively low levels of fruit set percentages in the water-stressed trees may have resulted because most flowers were of the leafless type; they have the reputation of poor setting parthenocarpically, compared with leafy flowers from a large number of flowers which mainly consisted of leafless flowers (Susanto et al., 1991). Moreover, lack of cross pollination probably decreased fruit set, as 'Tosa Buntan' pomelo tree is strongly self-incompatible. The sugar content and C-N ratio in pomelo leaves were increased by the winter-chilling treatment which was accompanied by an increase in flowering (Nakajima et al., 1992). Yelenosky (1978) found that sugar content in citrus leaves was increased by withholding water from the trees. Thus, the increase in flowers on plants exposed to longer water stress may be attributed to the accumulation of sugars in leaves, whereas there were no significant differences in C : N ratio in the leaves of unchilled trees subjected to water stress treatments late in the growing season.

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ブンタン幼樹の開花と結実に及ぼす秋季の水ストレスの影響

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摘　要

ハウス栽培のポット植えブンタン幼樹に，1990年9月上旬から同年12月下旬まで処理期間を変えて水ストレス処理を行った．樹の水ストレスは自然乾燥によって与え，葉の水ポテンシャルがかん水停止後7日から13日目に，－24から－28バールに達した時点で充分にかん水した．同年12月上旬から翌年4月上旬まで，ビニルハウスの最高温度を約25 °C，最低温度を10 °Cに調節した．

1. 9月上旬から水ストレスを受けた樹では，ほとんど秋枝が発生しなかったが，10月上旬からの樹および無処理樹では1樹当たり数本の秋枝が発生した．翌年の春枝の発生数とその長さには処理間に有意差が認められなかった．

2. 花房数，花らい数および開花数は水ストレス処理の期間が長くなるにつれて増加した．開花期は前年に秋枝の発生した樹よりも発生しなかった樹で早くなった．結実率は直花で0.1～1.1%，有葉花で4.8～6.0%であったが，それぞれ処理間に有意差を示さなかった．

3. 12月下旬の葉分析では，水ストレスの期間が長くなるにつれて，糖含量が増加したが，でんぷん含量は逆に減少した．同葉の窒素含量は無処理樹よりも水ストレス処理樹で有意的に高くなった．12月下旬の葉のC-N率は処理間に有意差を示さなかった．