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原著論文

Systemized Alternate Bearing Method for Mature Satsuma Mandarin Trees[†1]

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Summary

A new bearing method called "systemized alternate bearing method" was applied to mature satsuma mandarin trees cv. 'Aoshima unshiu', a highly alternate bearer. This method aims at achieving artificial alternate bearing by picking off all the fruits in the first year, followed by the absence of thinning in the second year. The yield per tree, number of fruits per tree, mean fruit weight, fruit quality, sprouting ratio and grouping of shoots that sprouted in the systemized alternate bearing method were compared with those in the conventional bearing method (control). The four-year experiment indicated that the application of this method to mature satsuma trees resulted in a very stable fruit production of about 153kg／tree (about 4.2t／10a) and labor-saving on fruit thinning without any influence on fruit quality. Thus the systemized alternate bearing method could be applied for stable production in satsuma mandarin.

Key words : alternate bearing prevention, cost and labor-saving

Introduction

The production area of satsuma mandarin, the most popular citrus variety in Japan, is about 64,200ha (1998) and it has gradually decreased in the last ten years (Japan fruits growers cooperative association, 1999a). As the production area decreased, the production volume also decreased, ranging from 1.2 to 1.5 million ton (Japan fruits growers cooperative association, 1999b). In addition to the decrease in production, the fluctuations in the production volume have increased since 1983. Particularly in the last five years, this problem has become more serious (Kihara and Konakahara, 2000).

Severe alternate bearing can be attributed to 1) the aging of many trees planted in the 1960s, 2) a decline in the tree vigor due to high temperature and drought damage caused by unusual weather and natural disasters such as typhoons, 3) a shift to new cultivars that easily bear alternatively and 4) a decline in grove managing techniques due to the aging of the producers. To address the problem of alternate bearing, a new method called "alternate branch fruit thinning method" was developed (Kihara et al., 1995). Its implementation, however, is so complex that the method cannot be applied practically.

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Therefore, it is necessary to develop a more convenient method that would enable to address the problems of alternate bearing. Miyata and Hashimoto (1990) reported that the systemized alternate bearing method can also contribute to stable production as in the case of the alternate branch fruit thinning method using young trees of 'Aoshima unshiu'. The systemized alternate bearing method is characterized by easy management and labor-saving. However, no results have been reported for older, less vigorous trees. Tree age and vigor may affect productivity and fruit growth. The purpose of this experiment was to analyze the productivity and ecological characteristics of the mature trees of 'Aoshima unshiu' for the implementation of the systemized alternate bearing method.

Materials and Methods

Plant materials

Satsuma mandarin trees cv. 'Aoshima unshiu' (moderately bearing, 26-year-old in 1997) which were grafted on trifoliate orange, and planted in clay loam soil from diluvial series, were used for the experiment. The planting density was 55trees／10a, tree canopy volume was 26.5 (±7.2) m^3 and each tree was completely independent.

Systemized alternate bearing method

Seventeen trees were maintained with a ratio of about 25 leaves to one fruit by fruit thinning and used as controls. Fruit thinning was performed in late July. Thirty-four trees were used in the experiment of systemized alternate bearing. All of the fruits were removed from half of the trees in the first year (resting year); these trees were used as resting trees. In the second year (production year), the fruits were not thinned. The other trees were producing fruits, and fruit thinning was limited unless the fruits were damaged or deformed. Thus, all the trees were artificially induced as strong alternate bearers.

1. Agricultural chemicals

The Pproducing trees and control trees were treated twelve times with germicides and insecticides and twice with herbicides. On the other hand, the resting trees were treated only twice with machine oil and twice with herbicides.

2. Fertilization

(7.2) kg／10a N, 6kg／10a P, and 6kg／10a K were applied in mid-March; 12kg／10a N, 8kg／10a P, and 12kg／10a K in early July; and 9.6kg／10a N, 6kg／10a P, and 8.4kg／10a P in late October.

3. Pruning

The producing trees and the control trees were pruned in the same manner. The resting trees were pruned in the same way; however, the other summer shoots, except for one or two per branch were removed.

Number of fruits borne or thinned per tree, number and yield of fruits per tree, and mean fruit weight and quality

The number of fruits thinned from the control trees and those borne in the resting trees in the systemized alternate bearing method were compared. The experiment began in 1997. Comparison of the number of fruits thinned from the control trees and those borne in the resting trees using systemized alternate bearing was made in 1998 through the end of the project in 2000.

The number of fruits per tree and yield of fruits and fruit quality were investigated over a four-year period (1997-2000). The yield and number of fruits per tree (harvest: early December) and mean fruit weight were calculated for each group and represented by the mean, based on the results of the t-test (n= 17 trees). To compare the fruit quality, ten producing trees under the systemized alternate bearing method and ten control trees were selected, and twenty fruits of moderate size (97-108g) were sampled from each tree. The Brix value and acid content of the juice mixture were determined with a sugar and acid analyzer (HORIBA NH-1000) and represented by the mean based on the results of the t-test (n=10 trees). Harvested fruits for 1998 and 1999 were classified by diameter into seven classes (<49mm ; 49-55mm ; 55-61mm ; 61-67mm ; 67-73mm ; 73-80mm ; and >80mm) and the partitioning ratio was calculated.

Sprouting ratio and grouping of shoots that sprouted in the subsequent year

Flowering and sprouting were investigated for five trees in each group, and three 3-year-old branches were selected from each tree. The number of generative, mixed, and vegetative shoots on the three branches was counted and was represented by the number per 100 nodes, based on the results obtained by Fisher's PLSD analysis.

Summer shoot and root occurrence

The degree of summer shoot occurrence was evaluated for 17 trees from 1998 to 1999 based on the shoot density above the equator of the tree and was classified into four groups (0:<25%, 1:25-50%, 2:50-75%, 3:>75%).

The degree of occurrence of new root was represented by the dry weight of newly growing roots (diameter <1mm) observed in soil (20cm square×10cm depth) after removal of the surface soil of four portions (east, south, west, north) 140cm apart from the tree trunk. Measurements were conducted monthly from 1998 to 1999 for seven defruited trees (resting trees), ten producing trees, and seven conventionally bearing trees from mid-August to mid-March. The mean value is listed, based on statistical analysis of the results obtained by the Fisher's PLSD test.

Results and Discussion

Number of fruits borne or thinned per tree, number and yield of fruits per tree, mean fruit weight and fruit quality

1. Number of fruits borne or thinned per tree

The resting trees showed a very small number of flowers and fruits, and the number of fruits was stable, less than 100 per tree (Fig. 1). On the other hand, the control trees showed large fluctuations in the number of fruits thinned, ranging from less than 100 to about 500 fruits per tree (Fig. 1).

The small number of fruits borne by the resting trees every year was ascribed to the small number of vegetative shoots in the producing trees every year as described later. This phenomenon is very common in the "on" year in highly alternate bearers, and regular bearers can produce some vegetative shoots even when they are under a severe fruit load. Another possible reason could be the reduction in the flower production of the vegetative shoots, which was caused by the heavy fruit load. Obviously, the reduction in flowering can be attributed to the small number of vegetative shoots, which are the main source of subsequent flowering. However, even though the ability of flowering of the vegetative shoots is important, there have been very few studies on this phenomenon. Okuda (1995) and Okuda et al. (1996) have focused on the flowering ability of vegetative shoots and have shown that flowering of the vegetative shoots under a heavy fruit load is lower in the following year and that removal of the nearby fruits improves the flowering ability. Therefore, when this method is applied to highly alternate bearers, they bear few fruits in the resting year because there are few vegetative shoots with a lower ability of flowering in the production year.

In the systemized alternate bearing method, half of the field was used for the resting trees. All the fruits in the resting trees were assumed to be thinned; however, in fact, it was almost not necessary to thin the fruits because the resting trees bore negligible amounts of fruits except in the first year. Moreover, application of chemical thinning (Kamuro and Hirai, 1982; Suetsugu and Nogata, 1985) to the resting trees would be the most suitable method to use. Chemical

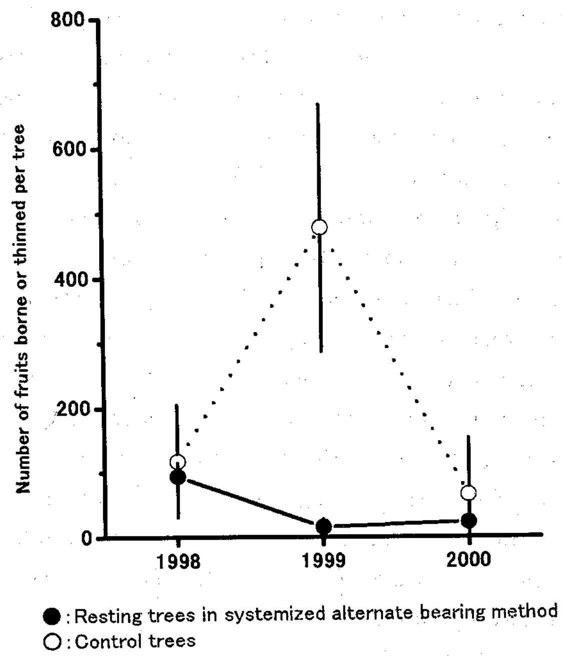

Fig. 1. Comparison of the number of fruits thinned from the control trees (○) and borne on the resting trees in the systemized alternate bearing method (●). Values represent the mean ± S.D. (n=17).

thinning agents used for this bearing method may save the labor cost. In addition, the producing trees may not require fruit thinning, resulting in considerable labor-saving on fruit thinning.

2. *Yield per tree*

Mean fruit yield per tree in the four-year experiments was 153kg for the systemized alternate bearing method, a value about 1.6 times as high as that for the control trees (95kg) (Fig. 2a). The fluctuations in the yield per tree were less pronounced for the systemized alternate bearing method (coefficient of variance: 4.2) than for the control trees (coefficient of variance: 35.1) (Fig. 2a).

3. *Number of fruits per tree*

The fluctuations in the number of fruits per tree were negligible (coefficient of variance: 12.3), ranging from 1,449 to 1,932, while the control trees showed remarkable alternate bearing with large fluctuations (coefficient of variance: 42.4), ranging from 432 to 1,020 (Fig. 2b).

The mean fruit yield of the producing trees in the systemized alternate bearing method was 153kg with negligible fluctuations (coefficient of variance: 4.2) (Fig.2a). Compared with the control trees, the producing trees bore more than twice the number of fruits with some fluctuations because of the lack of fruit thinning. However, the fruit yield per tree was almost stable for four years, corresponding to about 8.4t/10a (planting density: 55 trees/10a), a value about 4.1 times higher than the mean yield in the last decade (2027kg/10a (1989-1998) (Japan fruits growers cooperative association, 1999a, b), in Japan. Tachibana (1987) reported that younger satsuma mandarin trees 'Miyagawa wase' can yield about 6.8t/10a fruits at an optimum planting density. These reports and findings suggested that the maximum production was about 150kg/tree (5.7kg/m²) under these growing conditions, and that in the systemized alternate bearing method a yield of about 4.2t/10a could be continuously maintained.

4. *Mean fruit weight*

Mean fruit weight for the 4-year period was 93g for the systemized alternate bearing method, 30% less than for the control trees (132g) (Fig. 2c).

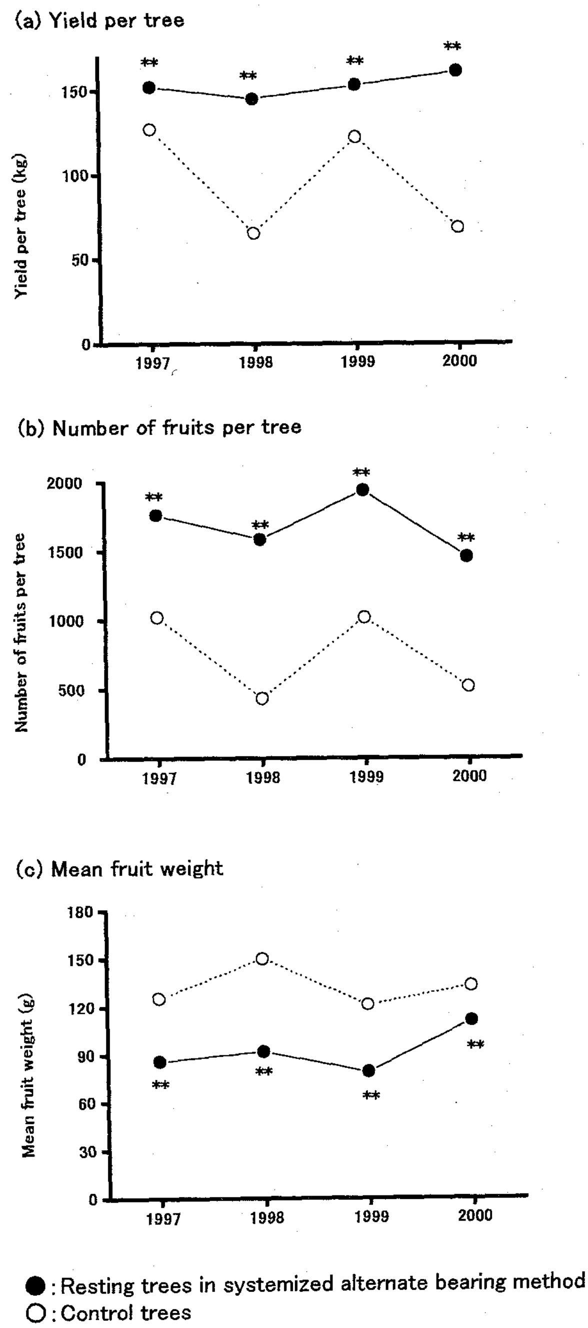

Fig. 2. Changes in yield per tree (a), number of fruits per tree (b) and mean fruit weight (c) in the systemized alternate bearing trees (●) and control trees (○).
The results represent mean (n=17) and the asterisk denotes a significant difference at 5% (*) or 1% (**) level by T-test.
C.V. : coefficient of variance.

5. *Distribution of fruit diameter*

The diameter of about 75% of the fruits in the control trees ranged from 61-80mm, and the peak class was 67-73mm (about 28%), while the fruits in the alternate bearing method were smaller, the diameter ranging from 49-67mm (about 75%), with the peak class in the range of 55-61mm (about 33%) (Fig. 3).

Miyata and Hashimoto (1990) reported that systemized alternate bearing led to the production of fruits with a more moderate size (61-73mm), which fetched a higher unit price when younger trees (nine-year-old) of 'Aoshima unshiu' that tended to bear relatively larger fruits were used. However, the mature trees such as those used in this experiment did not necessarily produce larger fruits (>73mm). The systemized alternate bearing method strongly reduced fruit growth and the average fruit in the producing trees weighed 80g or less (< about 55mm) as in 1999, when the trees produced the largest amount of fruits (Fig. 2). To compensate for the poor fruit growth, it is necessary to improve the methods of fertilization and pruning to preserve new shoots and leaves.

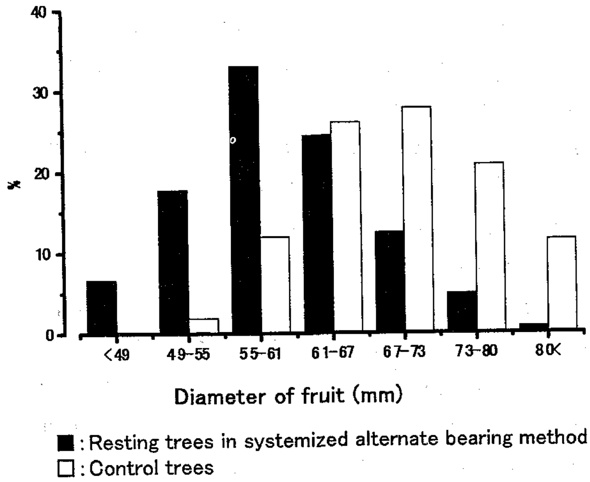

Fig. 3. Distribution of fruit diameter.

6. Fruit quality

There was no significant difference in the Brix value or acid content of the fruits between the trees in the systemized alternate bearing method and the control trees (Table 1).

As for the fruit quality, the systemized alternate bearing method did not appear to affect the Brix value or acid content. There have been many reports (Nishida, 1978; Shimizu et al., 1976; Yukawa et al., 1956) on the relationship between the bearing density and fruit quality, but the fruit size and related factors such as bearing density were not taken into account. However, a detailed analysis by Morioka (1987, 1988) showed that the bearing density did not influence the Brix value or acid content unless the fruits were thinned out. Thus, the present findings are in agreement with these reports.

Sprouting ratio and grouping of shoots that sprouted in the subsequent year

In the "off" year (1998) and in the "on" year (1999) of the production in satsuma mandarin, the sprouting ratio and the component ratio of shoots were compared between the producing and resting trees in the systemized alternate bearing method and the control trees. Most of the new shoots from the control trees in the "on" year and the producing trees were generative or mixed, while those from the control trees in the "off" year and the resting trees were vegetative (Table 2).

Whether new shoots from highly alternate bearers such as the 'Aoshima unshiu' would be either reproductive or vegetative tended to depend on the fruit load in the previous year. To identify the factors involved in the bearing or absence of bearing, investigations on the nutrient contents and organic

Table 1. Comparison of fruit quality.

		1997	1998	1999	2000	Mean	C.V.
Brix value	Systemized alternate bearing method	12.3	9.7	11.1	9.7	10.7	11.7
	Control	12.0	10.0	11.3	9.7	10.8	10.1
	Significance	ns	ns	ns	ns	ns	ns
Acid content	Systemized alternate bearing method	1.03	0.93	1.18	0.90	1.01	12.5
	Control	1.01	0.93	1.15	0.90	1.00	11.2
	Significance	ns	ns	ns	ns	ns	ns

Mean for 10 trees (20 fruits from each).
C.V. : coefficient of variance.

substances of the trees, plant growth regulators, etc. should be carried out. Okuda (1995) and Okuda et al. (1996) reported that changes occurred in the leaves on the vegetative shoots near the areas where fruits had been removed. In other words, the amount of leafy free ABA decreased, stomatal conductance increased, and photosynthesis and transpiration increased. The increase in photosynthesis and transpiration could be attributed to the storage of carbohydrates that are related to flowering. Furthermore, when ABA was exogenously applied to buds during the floral induction period, there was a reduction in flowering in the following year (Okuda, 1996). These findings suggest that the fruit load alters the flowering function of the vegetative shoots by regulating the free ABA concentration in the leaves or buds. Thus, the fruit load might regulate flowering of vegetative shoots. Furthermore, this mechanism of direct and indirect control of flowering by leafy ABA was remarkably effective in the trees with highly alternate bearing.

The producing trees showed a 78-82% sprouting ratio, and 23-32% of the sprouts were mixed shoots. The mixed shoot ratio was higher than that of the control trees, because, in the resting year, the trees do not bear fruits and their activities are centered on nutrient storage and increase of tree vigor for subsequent flowering.

In the resting trees, the sprouting ratio in the "off" year (19%) was lower than that in the "on" year (39%). Regardless of the sprouting ratio, the resting trees bore more than 1,500 fruits and fruit production was about 150kg/tree in the subsequent year.

Summer shoot and root occurrence

1. Summer shoots

Resting trees grew summer shoots in late July to August. Generally, summer shoots were more abundant in the "off" year (1998) than in the "on" year (1999), and the resting trees grew more shoots (score: 2.2 for 1998, 1.6 for 1999) than the control trees (0.9 for 1998, 0.2 for 1999) in both years (Fig. 4a). In the producing trees almost no summer shoots grew in either year (Fig. 4a).

2. Roots

The resting trees had more new roots than the producing trees in both years (Fig. 4b). The volume of the new roots in the resting trees was higher in 1998 than in 1999 in accordance with the volume of summer shoots, while the producing trees did not show annual differences (Fig. 4b). As for the control trees, they produced 1.7gdw of roots in 1998, an intermediate value between that of the resting trees and producing trees, and 0.9gdw of roots in 1999, a value equal to that of the producing trees (Fig. 4 b).

For the most part, the producing trees used the absorbed minerals and/or organic nutrients for the current growth of fruit, whereas the resting trees stored them for subsequent flowering. With systemized alternate bearing, the resting trees required more nutrients than the control trees because they were expected to bear about twice as many fruits. Of the above nutrients or minerals, carbohydrates appeared to be the best indicators of flowering. Garcia-Luis et al. (1989) demonstrated that more carbohydrates are required for flowering than for the development of vegetative shoots. Many studies (Goldschmidt and Golomb, 1982; Lovatt et al., 1988; Ogaki et al.,

Table 2 . Comparison of the sprouting nodes and types of shoots in the 2 groups.

Bearing method		Number of nodes	Number of shnots/100 nodes	Type of shoots		
				Generative		
Systemized alternate bearing						
Producing trees	1998 ("off" year)	78c	134c	65b	32c	3a
	1999 ("on" year)	82c	199d	76b	23c	1a
Resting trees	1998 ("off" year)	19a	21a	0a	0a	100b
	1999 ("on" year)	39b	45b	1a	0a	99b
Control	1998 ("off" year)	35b	37b	1a	1a	98b
	1999 ("on" year)	71c	120c	82b	14b	4a

Mean (n=5) followed by different letters is significantly different at 5% level in Fisher's PLSD test.

1963) also showed that in healthy trees flowering would be stimulated with a higher carbohydrate level although no direct relationship was demonstrated. During the resting year, fruit load was minimal (Fig. 1) and the trees showed a remarkable occurrence of summer shoots with new leaves displaying a high photosynthetic activity and fibrous roots that could actively take up water and nutrients. Consequently, the resting trees seemed to be able to store a large amount of nutrients for the subsequent production year. Producing trees also need tree vigor to prevent excessive fruit growth reduction induced by the heavy fruit load. For the improvement of fruit growth, pruning at a relatively strong density might be required to produce new shoots and/or to restrict the number of fruits.

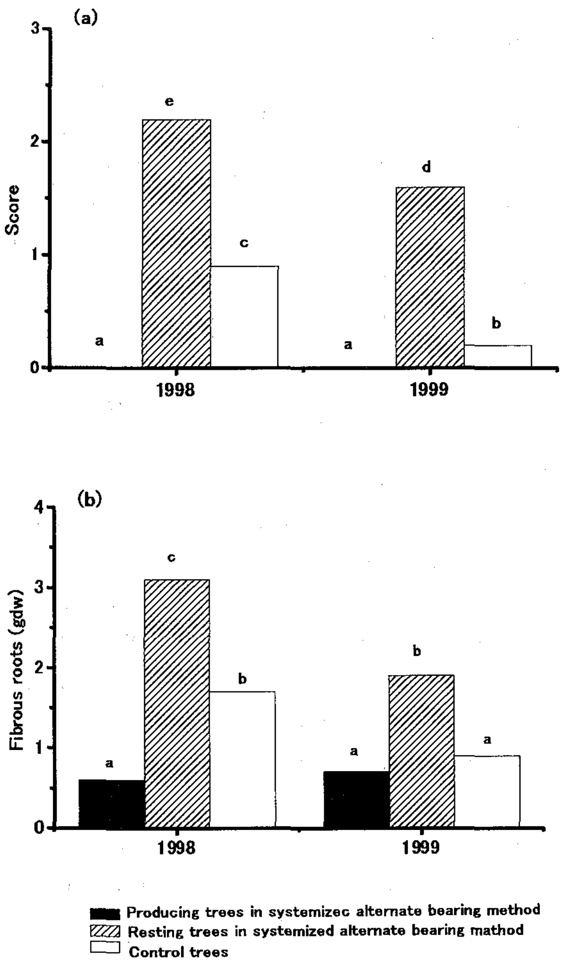

Fig. 4 Comparison of the occurrence of summer shoots (a) and fibrous roots (<2mm) (b).
(a)Mean of 17 trees.
(b)Mean of 7 trees for resting trees and control trees, respectively, and 10 trees for producing trees. Different letters represent significant difference at 5% level by Fisher' s PLSD test.

At any rate, during the experimental period, the trees grown under the systemized alternate bearing method maintained a certain degree of tree vigor in spite of the alternate heavy fruit load. However, after a few years, excessive fruit load that accumulated alternatively may result in a sudden decrease in tree vigor. Therefore, a sufficient amount of new shoots and roots is indispensable for the increase of the tree vigor. To achieve this objective, pruning should be improved and a suitable method of fertilizer application should be developed in the systemized alternate bearing method.

The application of this method to mature satsuma mandarin tree, 'Aoshima unshiu', led to a very stable fruit production of about 153kg/tree (about 4.2 t/10a). Moreover, this bearing method contributed to the reduction of working hours for chemical control and fruit thinning. The disadvantage of this method is that heavy fruit load results in fruit growth reduction. This shortcoming, however, could be easily alleviated by improved management such as pruning at a relatively strong density for whole tree canopy above the equator of the tree.

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隔年交互結実法の温州ミカン成木樹への適応

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摘　要

新結実管理法"隔年交互結実法"を隔年結果性の強い'青島温州'の成木に適用した．この結実管理法は，初年度に全摘果，次年度は無摘果のサイクルを繰り返すことで，隔年結果が体系的に生じることを利用している．本結実管理法による樹別収量・果数，平均果重，果実品質，発芽率ならびに新梢のタイプを慣行の結実管理法と４年間比較した結果，樹別収量は153kg（4.2t／10a，55樹／10a）で安定し，果実品質に影響することなく摘果労力を節減できることが示唆された．このことから，隔年交互結実法は温州ミカンの安定生産に寄与できるものと考えられた．