Effects of Carbon Dioxide Enrichment on Tree Vigor of Citrus cv. Shiranuhi under Greenhouse Culture

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Summary

Responses of citrus 'Shiranuhi' ['Kiyomi' (*Citrus unshiu* Marc. x *C. sinensis* Osb.) x *C. reticulata* Bla.] trees growing in a greenhouse to elevated CO₂ concentration during their spring growth flush were studied. The growth of current shoots on CO₂-enriched trees was enhanced, resulting in larger, thicker leaves and prolonged shoot elongation as compared with the control. The treatment resulted in a higher fruit set and larger, heavier fruit at harvest than in those of the control trees grown in ambient CO₂ level; it had no effect on fruit quality. These findings indicate that CO₂ enrichment on 'Shiranuhi' under greenhouse culture during the spring growth flush improves the tree vigor and may lead to higher yield.

Key Words: carbon dioxide enrichment, citrus cv. Shiranuhi, fruit quality, greenhouse culture, tree vigor.

Introduction

The citrus cultivar Shiranuhi ['Kiyomi' (*Citrus unshiu* Marc. x *C. sinensis* Osb.) x *C. reticulata* Bla.] has a promising fruit quality but is weak in vigor, resulting in reduced yield when grown in the field.

CO₂-enriched grapevines grew vigorously and produced superior berries (Kurooka et al., 1990); similar responses were noted in Japanese pear (Inomata et al., 1993). In perennial evergreen trees, such as citrus, CO₂ enrichment was effective in increasing tree vigor (Downton et al., 1987). Morinaga and Ikeda (1991) reported that leaves of satsuma mandarin trees grown under CO₂-enriched greenhouse had a higher net assimilation rate (NAR) along with higher specific leaf weight. Therefore, we repeated the experiment with 'Shiranuhi' under greenhouse culture to determine the practical effects of CO₂ enrichment during spring growth flush on vegetative growth and the characteristics of its fruit.

Materials and Methods

Exp.1. An application of CO₂ enrichment to commercial greenhouse cultivation

The experiment was performed in 1997 in plastic

greenhouses located near Minamata Kumamoto Prefecture. More than 40 trees of 'Shiranuhi' in each greenhouse were grown for 7 years under commercial cultivation. CO₂ was supplemented to one of the greenhouses with kerosene burners from the middle of February to late June, 1997. The concentration was kept at 1250 $\mu\text{l} \cdot \text{liter}^{-1}$ daily from 4 to 7 AM., and except for this 3-hr period, the greenhouse was well-ventilated to keep the CO₂ level similar to the control greenhouse. The average current shoot lengths and the number of leaves and the average leaf area on these shoots were determined on 3 trees at flowering stage (April 3). The thickness of current leaves was measured on April 28. Internode length was calculated by dividing shoot length by number of nodes. Leaf color was measured using chlorophyll meter (SPAD-502, Minolta Camera Co., Ltd. Japan). The characteristics of harvested fruit were also measured on November 17, 1997 on 3 replicated trees.

Exp.2. CO₂ supplementation to potted plants in experimental greenhouse

'Shiranuhi', grafted on trifoliate orange rootstock, was grown for 2 years in 20-liter pots (35 cm on diameter). After selecting 8 trees of similar size and vigor at the end of the latest growth flush, 4 trees each for CO₂ enrichment and control were transferred into the controlled-environment rooms before the spring growth flush on March 3, 1997. The treated trees were exposed to CO₂ constantly at 1500–2000 $\mu\text{l} \cdot \text{liter}^{-1}$ with a CO₂ controller (ZFP9AB11, Fuji Electric Co., Ltd.) from a pure liquid source until May 2. The control compartment remained at ambient CO₂ concentration. In March, the chambers were kept at 20 °/15 °C (day/night) and main-

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tained at 23 °/15 °C during April and May. Leaf area, thickness, and color of young fully expanded leaves were measured and flowers, including floral buds, on the whole trees were counted during anthesis on April 8, 1997. Flower set was determined by counting the number of fruit on May 8, 1997 after the physiological fruit drop ended.

Results and Discussion

The growth of current shoots

Under commercial greenhouse cultivation, 3-hr intermittent CO₂ enrichment increased the length of newly emerging shoots by 41 %, compared with the control not owing to the number of leaves but to the elongation of internodes (Table 1). CO₂ enrichment increased the thickness of fully expanded current leaves by 8 % and 17 %, compared with controls in the commercial greenhouses (Table 1) and the experimental greenhouses (Table 2), respectively. Continuous CO₂ enrichment in the experimental greenhouses resulted in higher SPAD data of new leaves (Table 2). The leaf area of young leaves on current shoots tended to increase in the high CO₂ level in both experiments, but the differences were not significant due to variability (Table 1, 2).

Enhancements of current shoot length and leaf thickness under high CO₂ concentration were observed on deciduous fruit trees (Inomata et al., 1993; Inomata et al., 1996; Kurooka, 1990). Inomata et al. (1996) found increased leaf thickness and specific leaf area on Japanese pear trees exposed to 1000–2500 µl·liter⁻¹ CO₂ during their shoot growth period, resulting in increased total dry weight, especially in new shoots and roots. In tomato plants, leaf areas were 5.5% greater but the specific leaf weight was 33 % heavier under 900 µmol·m⁻³ CO₂

after two weeks; the CO₂-enriched plants had 43 % faster NAR than had control plants (Yelle et al., 1990).

In separate experiments, we administered ¹³C to 2-yr old 'Shiranuhi' trees for a few hours during a mid-summer growth flush and then measured the proportion of ¹³C-labeled assimilates after two days. We observed that newly developing shoots had a higher proportion of ¹³C assimilates than had shoots or leaves on older growth on non-bearing trees (Sakamoto et al., 1998). Translocation patterns of ¹⁴C-labeled assimilates have been studied on orange plants under glasshouse condition (Kriedemann, 1969). Within the actively growing shoots, currently expanding leaves were strong sinks for ¹⁴C assimilates from adjacent, fully expanded old leaves.

Commercial enrichment of CO₂ is normally carried out for the entire photoperiod. However, commercial greenhouses for citriculture are often equipped with automatic ventilators to maintain optimum temperature for the tree growth, while the time of CO₂ application without leakage is limited to a few hours in the morning.

Behboudian and Lai (1994) reported that exposing tomato plants to high CO₂ concentration for 8 hr during a 12-hr photoperiod accumulated more dry matter than did control plants growing in ambient CO₂ level. From our data, we conclude that with 'Shiranuhi' grown under greenhouse culture, CO₂ enrichment from February to June promotes the growth of developing shoots and is sufficiently invigorating even when treated intermittently for a short time.

Fruit set and fruit quality

Treated trees in the greenhouses produced more flowers and had greater fruit set, even after physiological fruit drop occurred, than had those of the control trees (Table 2). Downton et al. (1987) reported that Valencia orange trees, despite shedding fruitlets more rapidly under 800 µ bar CO₂, set 3.1 % fruit, whereas the control trees set

Table 1. Effects of CO₂ enrichment on the growth of newly emerging shoots and leaves of citrus 'Shiranuhi' grown in the commercial greenhouses.

	Enriched	Control	Ratio	Enriched Control
Length of newly emerging shoot (cm)	183.7	130.7		1.41
No. of leaves on current shoot (shoot ⁻¹)	8.2	7.8		1.06
Internode length (cm) ^z	NS	17.1		1.32
Leaf area (cm ² ·leaf ⁻¹)	22.7	29.7		1.14
Leaf color (SPAD)	33.8	54.1		1.01
Leaf thickness (mm) ^y	NS	0.34		1.08

Figures are means for 3 trees; 'NS' means not significantly different at $P=0.05$ (t -test). All other means are significantly different at this level of probability. Measured during the anthesis on April 3, 1997.

^zCalculated by dividing shoot length by number of nodes on each shoot.

^yMeasured on April 28, 1997.

Table 2. Effects of CO₂ enrichment on the growth of newly emerging leaves and flower and fruit set of citrus 'Shiranuhi' grown in the experimental greenhouses.

	Enriched	Control	Ratio	Enriched Control
Leaf area (cm ² ·leaf ⁻¹)	16.8	14.5		1.16
Leaf thickness (mm)	NS	0.33		1.17
Leaf color (SPAD)	0.39	58.2		1.15
	67.2			
No. of flowers (Plant ⁻¹)		231.3		1.66
No. of fruits (Plant ⁻¹) ^z	383.3	22.3		3.57
Fruit set (%) ^z	79.8	9.2		2.32

Figures are means for 4 trees; 'NS' means not significantly different at $P=0.05$ (t -test). All other means are significantly different at this level of probability. Measured during the anthesis on April 8, 1997.

^zMeasured after physiological fruit drop on May 8, 1997.

Table 3. Difference in fruit quality of 'Shiranuhi' between CO₂-enriched and control trees grown in the commercial greenhouses.

	Volume (cm ³)	Fresh weight (g)	Pulp proportion (%)	Peel color ^z	Soluble solids (Brix)	Acidity ^y (%)
Enriched	389 ± 15	351 ± 18	79.2 ± 1.2	5.3 ± 0.2	12.2 ± 0.5	1.50 ± 0.49
Control	322 ± 16	298 ± 14	77.7 ± 1.9	4.8 ± 0.3	13.0 ± 0.3	1.29 ± 0.02

Each value is a mean of 3 trees ± SD. Measured on November 17, 1997.

^zGraded from 1 to 10 using the color chart.

^yAcidity; % as citric acid.

only 2.4 %. The treated orange trees subsequently retained 70 % more fruit at harvest which were of equal size and quality as those of the control trees. We, likewise, found that CO₂-enriched 'Shiranuhi' trees had higher fruit set and perhaps higher yield at harvest.

There was no significant difference in fruit quality parameters, such as pulp proportion, peel color, and soluble solids content between the CO₂-enriched and control trees in the experiment in commercial greenhouses, but acidity was variable (Table 3). CO₂ enrichment sometimes increases the soluble solids content of fruit when supplemental CO₂ is given during the period of fruit development (Inomata et al., 1993; Kurooka, 1990). Our results indicate that CO₂ enrichment during spring growth flush does not influence the soluble solids content of 'Shiranuhi'.

Fruit on CO₂-enriched trees had significantly larger volume and the fresh weight than had those on the control trees (Table 3). Although CO₂-enriched trees grown in commercial greenhouses produced more fruit, even after the physiological fruit drop than non-treated trees, the yields per tree were similar in each greenhouse because of early fruit thinning (data not shown). This indicates that fruit on CO₂-enriched trees need not be thinned as much as those on the control trees and the treated trees may yet produce larger yield.

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二酸化炭素施肥による施設栽培 '不知火' の樹勢強化

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摘 要

施設栽培されているカンキツ品種 '不知火' において、発芽から新梢発育の期間のみ二酸化炭素を施用した。処理により新梢長が増大し、新葉の葉面積および葉厚が大きくなった。成熟期の果実は体積、重量が増大したが糖度等の品質には影響がみられなかった。また、人工気象室を用いて同様の時期に二酸化炭素施肥した樹は、新葉の葉面積、葉厚および葉色が向上し、生理落果後の着果数、着果率が顕著に高くなった。以上のことから、'不知火' を施設栽培する際、新梢発育期間の二酸化炭素施肥は、樹勢強化に有効であり、果実品質への影響が小さく、増収が期待できる。