Growth and ^{14}C -Photosynthate Allocation in Citrus Nursery Trees Subjected to One of Three Bud-forcing Methods

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Abstract. Three commercially employed treatments to force scion bud growth were compared using greenhouse-grown 'Carrizo' citrange [*Citrus sinensis* (L.) Osb. × *Poncirus trifoliata* (L.) Raf.] seedlings budded with 'Hamlin' orange [*Citrus sinensis* (L.) Osb.]. Scion buds were forced either by 1) cutting off (removing the rootstock shoot above the bud union); 2) lopping (cutting half-way through the rootstock shoot above the bud union and breaking over the rootstock stem); or 3) bending (bending the rootstock shoot to its base and tying it in position). Plants were harvested, dried, and weighed at various times after scion shoot emergence. Plants on which rootstock shoots remained attached (lopping or bending) had the largest scion leaf area and gained the most scion and whole-plant dry weight. Bending rootstock shoots also resulted in a longer scion, more leaves, and higher root dry weight than did removal of rootstock shoots by cutting off. Few differences in overall growth were observed among trees retaining their rootstock shoots after two scion growth flushes. Removal of rootstock shoots after the first scion growth flush reduced leaf area and dry weight gain of the second scion growth flush; however, it did not affect total scion leaf area or dry weight. Analysis of ^{14}C -photosynthate transfer from labeled rootstock leaves showed that bending allowed the greatest movement of labeled assimilates to other plant parts during the 24 hours after $^{14}\text{CO}_2$ fixation. Radiolabeled photosynthates from rootstock leaves were partitioned primarily to shoots during scion growth flushes and to roots during periods between growth flushes.

Commonly used methods in citrus nurseries to reduce or eliminate apical dominance and force scion bud growth are cutting off, lopping, and bending (Tucker and Youtsey, 1984) and in some instances notching the rootstock seedling above the bud union (Rouse, 1988). Our survey revealed that cutting off was the most popular bud forcing method for container-grown trees followed by bending (Williamson and Castle, 1989). Lopping was preferred in field nurseries and ≈20% of both nursery types used more than one method to force buds. Bending is common in California where scions are budded relatively high on the rootstock (Newcomb and Teague, 1977; Platt and Optiz, 1973). Optiz et al. (1968) suggested that lopping or cutting off should be used in the fall, and spring buds should be forced by lopping or bending. In Florida, the scion/rootstock combination is sometimes a factor in the selection of a forcing method (Williamson and Castle, 1989).

Few quantitative comparisons have been made of bud forcing methods on citrus nursery tree growth. Moore (1978) reported generally faster, continuous growth from bending or

lopping as compared with the usual cyclic growth that occurs with cutting off. However, these observations were not supported with quantitative data. Amih (1980) found inconsistent effects of bud forcing method on scion growth with several scion/rootstock combinations under a variety of conditions. He suggested that factors such as scion, rootstock, environment, and season probably affect plant responses to bud forcing. Rouse (1988) compared cutting off, lopping, bending, and notching on growth of 'Rio Red' grapefruit (*C. paradisi* Macf.) budded to sour orange (*C. aurantium* L.) rootstock during 6 weeks following forcing. Bending resulted in a lower percentage of budbreak but more scion elongation than cutting off or lopping. Rootstock leaves left attached below the bud union significantly increased the percentage of budbreak for plants forced by bending.

Inconsistent growth responses to the various bud-forcing methods indicate that other factors influence percent budbreak and early scion growth. Boswell (1969) reported faster scion growth for 'Lisbon' and 'Eureka' lemon (*C. limon* Burro.) but not for 'Valencia' or 'Washington' orange when leaves and apical buds were removed from budwood 2 weeks before its collection. El-Hammady et al. (1976) reported better budbreak with 'Eureka' lemon but not with 'Balady' orange when defoliated or ringed budwood was used. Buds of 'Valencia' orange taken from close to the apex began growth sooner and had a higher percentage of budbreak than buds taken from the basal portions of flushes used as budwood (Halim et al., 1988). Although these findings suggest that plant hormones may influence scion budbreak and growth, treating rootstock seedlings with

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cytokinins, gibberellins, or auxin transport inhibitors had little effect on budbreak or scion growth (Samson and Bink, 1976).

Studies comparing bud forcing methods for citrus have only reported scion growth responses, i.e., percentage of budbreak, scion length, and leaf area. Little consideration has been given to underlying physiological factors responsible for rootstock shoot contributions to scion growth, or how bud-forcing methods, affect dry weight gain of scions, roots, and whole plants. Our objectives were to quantify the effects of rootstock shoots on the total dry weight gain of nursery plants and to evaluate the extent of photosynthate transfer from rootstock shoots to other plant parts at several stages of scion growth following bud forcing.

Materials and Methods

Field-grown 'Carrizo' citrange seedlings were obtained from a commercial nursery and transplanted in Aug. 1989 to 2.8-liter plastic containers using a commercial growing medium (Metro-Mix 350, Grace Horticultural Products, W.R. Grace, Cambridge, Mass.) consisting of peat moss, vermiculite, and perlite. Plants were grown in a greenhouse and irrigated as needed for 10 days following transplanting. Thereafter, a water soluble fertilizer (20N-8.8P-16.6K), (Peters Fertilizer Products, W.R. Grace, Fogelsville, Pa.), was applied at 2- to 5-day intervals with each irrigation. Fertilizer concentration was increased from 100 to 200 ppm N 14 days after transplanting and maintained at that level for the duration of the experiment. Maximum and minimum daily greenhouse temperatures ranged from 28 to 37C and 11 to 22C, respectively. At budding, rootstock seedling height and stem diameter 8 cm above the soil line ranged from 60 to 110 cm and from 5 to 8 mm, respectively. Seedlings were budded with 'Hamlin' orange, using inverted T-buds, $\approx$ 10 cm above the soil line on 5 Oct. Scion buds were forced on 30 Oct. by one of three bud forcing treatments: 1) cutting off (pruning away the rootstock top $\approx$ 4 cm above the bud union); 2) lopping (cutting half to two-thirds of the way through the rootstock stem $\approx$ 4 cm above the bud union and breaking over the stem, but leaving it still attached); or 3) bending (bending the rootstock shoot to its base and tying it in position).

Growth and dry weight partitioning. A randomized complete-block design was used with 20 single-plant replications of each bud forcing treatment in five blocks of plants with similar rootstock stem diameters. Scion stem lengths were measured for all plants at 3- to 4-day intervals throughout the experiment. Five plants per treatment (one from each block) were harvested 7, 18, 32, and 122 days after forcing. These harvest dates corresponded with the emergence of the first scion flush, midway through the first scion growth flush, between the first and second scion growth flushes, and following the completion of the second scion growth flush. Harvested plants were divided into scion stems and leaves, roots, and rootstock stems (between the bud union and roots). Scion stems and leaves were further separated by flush where more than one growth flush had occurred. All plant parts were oven-dried at 65C and weighed. The scion leaves were counted and leaf areas were measured with a model LI-300 LI-COR leaf area meter (LI-COR, Lincoln, Neb.).

Rootstock shoot removal. Following the first scion growth flush, another group of plants forced by lopping or bending was used to study the effects of rootstock shoot removal on growth of the second scion flush. Sixteen plants were arranged as four blocks of plants with similar stem diameters. Each block contained two plants forced by lopping and two plants forced by bending. Rootstock shoots were removed from a single plant

forced by lopping or bending in each block before emergence of the second scion growth flush. Scion elongation was measured at 7- to 10-day intervals during the second growth flush. Plants were harvested after the second scion growth flush and handled as described.

Rootstock photosynthate movement. Rootstock shoots of six plants forced by lopping or bending were sealed in clear polyethylene bags and exposed to 13 μ Ci (1 Ci = 37 GBq) 14 CO₂ for 24 h at 18, 32, and 89 days after bud forcing to obtain an approximation of current photosynthate distribution following export from rootstock leaves. Labeling periods corresponded with the first scion growth flush, the period between the first and second scion growth flushes, and the second scion growth flush. In addition, scions of three groups of four plants forced by cutting off were labeled with 13 μ Ci of 14 CO₂ as described. The stages of scion development when each group was labeled were: 1) elongating scion stem with the uppermost four leaves < 50% fully expanded; 2) fully elongated scion stem with the uppermost four leaves > 50% fully expanded; 3) fully elongated scion stem with all scion leaves fully expanded. After labeling, plants were harvested and divided into rootstock leaves and stems, scion leaves and stems (by growth flush), lower rootstock (below the bud union), and roots. All plant parts were oven-dried and ground in a Tecator tissue sample mill, Model TC-1093-002 (Perstort Analytical, Herndon, Vs.). Tissue subsamples (1 mg) were oxidized in a model 306 Packard oxidizer (Packard Instruments, Downer's Grove, 111.) using Carbosorb 2 (Packard Instruments) as a carbon trapping agent. Total isotopic activity was determined with a LKB scintillation counter (Pharmacia LKB, Gaithersburg, Md.) using an internal quenching curve specific for Carbosorb.

Results

Growth and dry weight partitioning. Budbreak exceeded 90% for all treatments (data not shown), but scion growth began sooner for plants forced by cutting off than by lopping (Table 1). The initial flush lasted longer for plants forced by bending than for those in which cutting off or lopping was used. No differences were observed among treatments for the initiation (78 to 80 days) or duration (18 to 23 days) of the second scion flush.

Scion stem dry weights were higher for plants subjected to bending when compared with the other treatments at 7 days after forcing, but the treatments had no effect on other measurements of growth (Table 2). Eighteen days after bud forcing, scion stem, root, and whole-plant dry weights were highest for plants forced by bending; 32 days after forcing, all growth measurements were higher for plants forced by bending than by cutting off. Additionally, scion stem and leaf dry weights, scion leaf count, and whole plant dry weight were higher for plants

Table 1. Scion growth flush timing during the first growth flush of citrus nursery trees subjected to various bud forcing treatments.

Forcing treatment	Flush	
	Initiation ^a	Duration
	Days	
Cutting	7.0 b ^a	15.4 b
Lopping	10.0 a	17.9 b
Bending	9.0 ab	24.1 a

^aDays after bud forcing.

^bMeans separation within columns by Duncan's multiple range test, $P = 0.05$.

Table 2. Growth characteristics of citrus nursery trees subjected to one of three bud forcing treatments.

Forcing treatment	Scion					Root dry Wt (g)	Total plant dry wt (g)
	Stem dry wt (g)	Leaf dry wt (g)	Total dry wt (g)	Leaf count	Leaf area (cm ²)		
	7 days after forcing						
Cutting off	0.08 W	0.07 a	0.16 a	8.8 a	---	5.35 a	7.98 a
Lopping	0.08 b	0.11 a	0.20 a	7.2 a	---	4.95 a	8.20 a
Bending	0.19 a	0.13 a	0.32 a	7.8 a	---	5.61 a	8.26 a
	18 days after forcing						
Cutting, off	0.07 b	0.31 a	0.39 a	10.5 ab	59 a	4.71 b	7.89 b
Lopping	0.09 b	0.30 a	0.38 a	9.1 b	48 a	5.24 b	8.64 b
Bending	0.27 a	0.68 a	0.95 a	10.9 a	112 a	6.12 a	10.85 a
	32 days after forcing ^w						
Cutting off	0.15 c	1.09 b	1.25 b	11.6 b	168 b	4.46 b	8.59 b
Lopping	0.27 b	1.24 b	1.50 b	11.0 b	200 ab	5.08 ab	9.73 b
Bending	0.51 a	1.94 a	2.46 a	13.7 a	267 a	5.49 a	11.49 a
	122 days after forcing ^v						
Cutting off	1.03 c	5.31 b	6.25 b	18.2 b	521 C	7.80 b	18.12 b
Lopping	2.17 b	7.56 a	9.73 a	21.7 ab	761 b	8.99 ab	23.66 a
Bending	2.82 a	8.91 a	11.81 a	24.9 a	991 a	10.08 a	26.78 a

^zCorresponds to the approximate emergence of the first scion growth flush.

^yMeans separation (within groups of three) by Duncan's multiple range test, $P = 0.05$.

^xApproximately midway through the first scion growth flush.

^wFollowing the first scion growth flush.

^vFollowing the second scion growth flush.

forced by bending than by lopping. Bending or lopping had produced higher scion stem, leaf, and whole-plant dry weights and larger leaves by 122 days after forcing than cutting off. Scion stem dry weight was higher and leaf area was larger for plants forced by bending than by lopping, but no differences were found between the two treatments for total scion, root, and whole-plant dry weights.

Plants subjected to bending had longer scions throughout both flushes than plants that had scion buds forced by cutting off (Fig. 1). Further, except during the expansion of the second scion flush, scions were longer for plants forced by bending

than by lopping. Scion length was similar for plants that had been forced by lopping or cutting off during the first scion growth flush. However, scions were longer for lopped plants than for cut off plants during the second scion growth flush.

Rootstock shoot removal. Plants previously bent or lopped responded similarly to rootstock shoot removal before the beginning of the second scion growth flush. Total scion leaf and stem dry weights and total scion length were not affected by rootstock shoot removal for either forcing treatment (data not shown). Nor did rootstock shoot removal affect scion stem dry weight of the second growth flush (Table 3). However, leaf and total shoot dry weights, leaf count, leaf area, and length of the second scion growth flush (which occurred after rootstock shoot removal) for plants with rootstock shoots attached exceeded those when they were removed.

Photosynthate movement. The extent of ¹⁴C-photosynthate exported from labeled scions forced by cutting off was not affected by the three stages of scion development examined (data not shown). About 9% to 13% of the total radiolabel recovered after 24 h was in the roots, regardless of scion growth stage.

Fig. 1. Scion length of citrus nursery trees following bud forcing by cutting off, lopping, or bending. Data points and bars represent means $\pm$ SE. (n ranged from 5 to 22, depending on measuring date).

Table 3. Growth of the second scion flush in response to rootstock shoot removal.^z

Rootstock shoot removal	Scion dry wt (g)			Leaf count	Leaf area (cm ²)	Scion length (cm)
	Stem	Leaf	Total shoot			
Intact	2.6	7.7	10.3	14.5	719	27.1
Removed	2.0	5.4	7.4	11.6	511	21.1
F test	NS	**	**	*	**	*

^zRootstock shoots removed from plants forced by bending or lopping before emergence of the second scion flush. Shoot removal $\times$ forcing method interaction was not significant.

NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

The percentage of total recovered ^{14}C -photosynthate remaining in rootstock source leaves was less in plants forced by bending than lopping during the first scion growth flush (Table 4) and a similar tendency was observed during the second scion growth flush (48.8% vs. 65.8%, $P < 0.10$). During the first scion growth flush, a larger portion of the total recovered ^{14}C -photosynthate was localized in roots of plants forced by bending than by lopping. Also, rootstock and scion stems of plants forced by bending tended to accumulate higher proportions of the recovered ^{14}C -photosynthate than plants forced by lopping (Table 4). However, the percentage of total recovered ^{14}C -photosynthate localized in scion leaves, or in entire scions (leaves + stems), did not differ between plants forced by bending or lopping.

At a point during minimal scion growth (between growth flushes, 32 days after forcing), no significant differences were noted between treatments for partitioning of labeled photosynthates in scion or root tissues (data not shown). However, regardless of forcing treatment, a higher percentage of the total radiolabel was recovered in roots than scions when the latter were not elongating (13.9% vs. 1.9%). Eighty-nine days after bud forcing (during the second scion growth flush), a higher percentage of total recovered ^{14}C -photosynthate tended to accumulate in tissues of the second scion growth flush for plants forced by bending than by lopping (27.1% vs. 10.6%, $P < 0.10$).

Discussion

Increases in nursery tree growth were obtained from leaving rootstock shoots attached during and after scion bud forcing. Dry weight gains of scions and whole plants were higher after two scion flushes for plants forced by bending and lopping than for plants in which rootstock shoots had been removed by cutting off. Some advantages in dry weight gain (scion stem, root and whole plant) were noted for the bending treatment when compared with lopping, especially during the first scion growth flush. These differences were consistent with the translocation of ^{14}C -photosynthate within nursery trees subjected to bending or lopping. Consistently lower levels of radiolabeled assimilates were recovered from rootstock shoots when trees had been subjected to bending rather than lopping. Assuming similar ^{14}C respiratory losses for the two treatments, ^{14}C -photosynthate export from rootstock source leaves was larger with bending than lopping. However, little difference in dry weight gain (only scion stems) was apparent between these two treatments after two growth flushes. Nevertheless, total scion length and leaf area for plants that were forced by bending exceeded those for

plants forced by lopping. These observations were consistent with the results of Rouse (1988), who used grapefruit budded on sour orange.

Rootstock shoots remaining on nursery plants continued to enhance growth of scions during the second scion growth flush. A significant reduction in growth of the second scion flush was observed when rootstock shoots were removed between growth flushes. Moreover, $^{14}\text{CO}_2$ assimilated by rootstock leaves in the lopping or bending treatments demonstrated substantial translocation to the second scion growth flush. However, most of the growth enhancement of scions and roots due to the presence "of rootstock leaves occurred earlier during the first flush, or between flushes one and two. Recommendations on when to remove rootstock shoots relative to scion development vary and appear to be based largely on observation (Moore, 1978; Newcomb and Teague, 1977; Platt and Opitz, 1973). Further studies are needed to determine the importance of rootstock shoots on the later stages of nursery tree growth.

Our results suggest that maximum growth of grafted citrus nursery trees will occur when rootstock shoots remain attached at least through the first scion flush. Rootstock shoots contributed to scion and root growth and provided photosynthate to scion shoots, or roots, depending on the growth phase of the nursery tree. No attempt was made to distinguish between enhanced nursery tree growth derived from current rootstock photosynthate and that derived from stored rootstock reserves. This question should be addressed in future research. However, data on translocation of ^{14}C -assimilates, together with scion dry weight gain from bending and lopping, demonstrate that rootstock photosynthate contributes significantly to nursery tree growth.

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Table 4. Localization of ^{14}C -photosynthate (percent of total radiolabel recovered) in rootstock source leaves and competing sink tissues of citrus nursery trees 18 days following bud forcing by lopping or bending.^a

Forcing treatment	Rootstock (%)			First scion growth flush (%)		
	Leaves	Stem	Roots	Leaves	Stem	Leaves + stem
Lopping	87.1	1.7	1.5	3.8	1.8	5.6
Bending	68.3	5.6	8.7	5.7	4.6	10.3
F test	*	Y	*	NS	Y	NS

^aApproximately midway through the first scion growth flush.

^b $P \leq 0.10$.

^{NS}, *Nonsignificant or significant at $P \leq 0.05$.