Research Updates

Forcing Method and Time of Rootstock Shoot Removal Affect Growth of Containerized Citrus Nursery Trees

J.G. Williamson[1]

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Summary. I conducted an experiment to determine the effects of time of rootstock shoot removal on growth of citrus nursery plants forced by bending and lopping. 'Hamlin' orange [*Citrus sinensis* (L.) Osb.] budded on Carrizo citrange [*C. sinensis* (L.) x *Poncirus trifoliata* (L.) Raf.] and Cleopatra mandarin (*C. reticulata* Blanco) seedlings were grown in 2.8-L plastic pots and forced by bending or lopping the rootstock shoots. For Carrizo plants, rootstock shoots were removed 0, 21, 36, 170, or 235 days after forcing. For Cleopatra plants, rootstock shoots were removed 0, 11, 21, 36, 170, and 235 days after forcing. Bending and lopping with rootstock shoots remaining attached for 36 days after forcing resulted in greater nursery tree growth (scion, root, and whole-plant dry masses; scion length; and leaf area) than when rootstock shoots were removed the day of forcing. Growth of scion leaves (both rootstocks) and stems (Cleopatra) was greatest at a rootstock shoot removal time (RSRT) of 36 days after forcing. However, root and whole plant dry masses increased as RSRT increased up to 235 days after forcing. These results suggest that roots continue to be a major sink for rootstock photosynthates of bent or lopped plants during periods after the first scion growth flush. Proportionally greater root growth occurred on plants forced by bending or lopping when rootstock shoots were left attached for more than the usual 4 to 5 weeks after forcing.

[1]Associate professor, Department of Horticultural Sciences, IFAS, University of Florida, Gainesville, FL 32611-0690.

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Cutting off, lopping, or bending the rootstock shoot are commonly used in citrus nurseries to force scion bud growth (Rouse, 1988; Tucker and Youtsey, 1980; Williamson and Castle, 1989). Forcing methods that leave rootstock shoots attached (i.e., lopping and bending) result in greater nursery tree growth than cutting off rootstock shoots (Amih, 1980; Rouse, 1988; Williamson et al., 1992), perhaps because of photosynthates supplied by the attached rootstock shoots. Williamson et al. (1992) found ^{14}C-labeled photosynthates from rootstock shoots in scions and roots of 'Hamlin'–Carrizo nursery trees following bud forcing by bending or lopping. Furthermore, Williamson and Maust (1995) concluded that the benefit to nursery tree growth resulted from photosynthates produced in the rootstock shoot rather than from stored carbohydrate reserves.

The major disadvantage of bending or lopping is greater production costs, which are associated with either of these methods compared to cutting off rootstock shoots. Additional labor, irrigation, fertilizer, pesticide, and space are usually required for the production of plants forced by bending or lopping than for those forced by cutting off. Some of these costs could be minimized by prompt removal of rootstock shoots after the benefits to nursery tree growth have been achieved. My purpose was to determine the effect of time of rootstock shoot removal on growth of citrus nursery plants forced by bending and lopping.

Materials and methods

The experiment was conducted in a greenhouse at the Univ. of Florida, Gainesville. Carrizo and Cleopatra seedlings were grown from validated seed and transplanted into 2.8-L plastic containers using a commercial growing medium of 1 peatmoss : 1 perlite (v/v). A completely random design with 10 replications was used. A factorial arrangement of two rootstocks × three forcing methods × six (Cleopatra) or five (Carrizo) rootstock shoot removal times was used. Plant spacing was increased periodically to minimize plant-to-plant shading. Diurnal maxima and minima temperatures ranged from 27 to 36 °C and from 14 to 22 °C, respectively. Maximum photosynthetic photon flux was 820 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Plants were irrigated every 2 to 5 d. A water-soluble fertilizer (20N–8.8P–16K) (Peters Fertilizer Products, W.R. Grace, Fogelsville, Pa.) was applied with N at 150 $mg \cdot L^{-1}$ with each irrigation after plant establishment. Eight-month-old seedlings were budded (inverted "t" bud) ≈10 cm above the medium surface with 'Hamlin' orange during July 1992. Plants were forced by bending or lopping rootstock shoots on 12 Aug. 1992. For Carrizo plants, rootstock shoots were removed 2 cm above the inserted scion bud at 0, 21 36, 170, or 235 d after forcing. For Cleopatra plants, rootstock shoots were removed 0, 11, 21, 36, 170, and 235 d after forcing. Plants with rootstock shoots removed on day 0 were considered equivalent to plants forced by cutting off. The experiment was completed after all plants that forced a scion bud had completed three scion growth flushes (235 d after forcing). Scion budbreak was recorded daily for all plants. At the conclusion of the experiment, all plants were harvested and separated into scion leaves and stems, rootstock trunks, and fine and structural roots. All plant parts were dried at 70 °C and were weighed. Leaf areas were measured with a leaf area meter (model LI-300Z; LI-COR, Lincoln, Neb.).

A three-way ANOVA was used to test for interactions among rootstock, forcing method, and rootstock shoot removal time (RSRT). SAS (SAS Institute, 1987) was used for regression analyses of the rootstock removal treatments. Duncan's multiple range tests were used to separate forcing treatment means, and F-tests from ANOVA were used to compare means between rootstocks.

Results and discussion

Scion budbreak was high (>90%) for all forcing treatment–rootstock combinations (data not reported). There were no significant interactions among rootstock, forcing method, and RSRT or between rootstock and forcing method. Significant rootstock × RSRT interactions were observed only for scion stem, rootstock trunk, and fine root dry masses (Table 1). There was a positive linear relationship between Carrizo scion stem dry mass and the length of time between forcing and rootstock shoot removal. However, Cleopatra scion stem dry mass increased as RSRT increased up to 36 d, but decreased for the later RSRTs. Fine root dry masses of both rootstocks responded curvilinearly to RSRT. However, the increase in fine root dry mass between the last two RSRTs was much greater for Carrizo than for Cleopatra. Regardless of rootstock × RSRT interactions, greater dry masses were noted for trunks and fine roots (both rootstocks) and scion stems (Carrizo) when RSRT >36 d.

Bending and lopping rootstock shoots for 36 d after bud forcing were compared to cutting off rootstock shoots at forcing because these treatments represent the typical forcing methods used in commercial nurseries. Bending or lopping with rootstock shoots remaining attached for 36 d after forcing resulted in greater nursery tree growth (scion, root, and whole plant dry masses; scion length; and leaf area) than cutting rootstock shoots off at time of forcing (Table 2). These results agree with previous reports that showed that 'Hamlin' orange budded on Carrizo (Williamson et al., 1992) or 'Hamlin' budded on Cleopatra, Swingle, and Carrizo (Williamson and Maust, 1996) grew larger when forced by bending or lopping than when cutting off the rootstock shoot was used to force scion buds. Williamson et al. (1992) also reported that ^{14}C-labeled photosynthate from rootstock shoots accumulated in developing roots and scions of citrus forced by bending or lopping. The combined results of the present and previous experiments show that bending or lopping consistently result in greater growth than forcing by cutting off, provided that scion budbreak occurs. This result was true for three major commercial rootstocks used in Florida under a variety of experimental conditions. However, bending and lopping have resulted in an unacceptably low percentage if scion budbreak in some rootstock–scion combinations such as 'Hamlin'–Swingle (Williamson and Maust, 1996). In my experiment, no differences in growth variables were noted between rootstocks, except for plant dry mass, which was greater for Cleopatra than for Carrizo.

Table 1. Interaction of rootstock and time of rootstock shoot removal on stem, trunk and root dry weights of 'Hamlin' orange nursery trees.

Rootstock shoot removal time (d)	Dry mass (g)					
	Scion stem		Scion trunk		Fine root	
	Carrizo	Cleopatra	Carrizo	Cleopatra	Carrizo	Cleopatra
0	6.3	14.0	4.6	4.2	3.2	4.4
11	---	11.0	---	4.3	---	5.3
21	13.9	16.8	6.3	5.4	5.5	6.3
36	15.2	18.4	5.9	5.3	5.9	6.6
170	18.4	14.2	9.2	5.6	8.7	8.7
235	18.5	13.1	8.7	5.9	12.0	9.4
Regression[z]						
Linear	**(0.08)	NS	***(0.12)	**(0.21)	***(0.61)	***(0.41)
Quadratic	NS	***(0.12)	NS	NS	**(0.66)	NS
Cubic	NS	NS	**(0.31)	NS	NS	NS

[z]R^2 values given in parentheses.
NS, **, ***Nonsignificant or significant at $P < 0.01$ or 0.001, respectively.

Table 2. Effect of forcing method and rootstock on growth of 'Hamlin' orange nursery trees.

Forcing method[z]	Dry mass(g)					Scion leaf area (cm²)	Scion length (cm)	Root : shoot ratio
	Scion		Root		Whole plant			
	Leaves	Stem	Structural	Total				
Treatment								
Bending[y]	22.5 a[x]	18.2 a	13.3 a	19.5 a	69.2 a	2448 a	102 a	0.47 a
Lopping	21.1 a	15.3 ab	12.7 a	19.0 a	66.0 a	2399 a	96 a	0.51 a
Cutting-off	12.0 b	10.7 b	8.3 b	12.3 b	37.5 b	1508 b	74 b	0.50 a
Rootstock[w]								
Cleopatra	18.5	15.9	10.2	15.7	58.4	2181	85	0.47
Carrizo	–16.3	11.4	11.7	16.6	50.1	1886	88	0.51
Significance	NS	NS	NS	NS	*	NS	NS	NS

[z]Averaged over both rootstocks.
[y]Rootstock shoots for bending and lopping were removed 36 d after forcing.
[x]Mean separation, within columns, by Duncan's multiple range test, $P < 0.05$.
[w]Averaged over all forcing methods.
NS,*Nonsignificant or significant at $P \leq 0.05$.

With both rootstocks, structural and total root and whole plant dry masses increased linearly as RSRT increased (Table 3). There were significant quadratic responses for scion leaf area and dry mass. These variables increased as RSRT increased from 0 to 36 d but declined as RSRT was extended to 170 and 235 d. The root : shoot ratio was lowest with RSRT at 36 d but increased substantially by 235 d (0.49 vs. 0.83, respectively). One unexpected result was that there was no significant relationship between total scion length and RSRT. However, scion length was lower with RSRT at 0 d than for any of the other treatments.

Table 3. Effect of time of rootstock shoot removal on growth of 'Hamlin' orange nursery trees.

Rootstock shoot removal time (d)	Dry mass (g)				Scion leaf area (cm^2)	Scion length (cm)	Root:shoot ratio
	Scion leaves	Root		Whole plant			
		Structural	Total				
0	12.0^z	8.3	12.3	37.5	1508	74	0.50
11	14.5	9.5	14.8	47.1	1802	91	0.53
21	18.2	13.5	19.4	62.1	2000	93	0.52
36	21.8	13.0	19.3	67.6	2425	99	0.49
170	18.9	16.3	25.0	69.3	1981	87	0.63
235	17.8	19.5	29.9	74.2	1895	89	0.83
Regression							
Linear	NS	***(0.25)	***(0.34)	***(0.20)	NS	NS	***(0.32)
Quadratic	***(0.12)	NS	NS	NS	*(0.10)	NS	***(0.42)

^{z}R^2 values given in parentheses.

NS, *, ***Nonsignificant or significant at $P < 0.05$ or 0.001, respectively.

Many nursery managers who force scion buds by bending or lopping remove the rootstock shoots after the first scion growth flush is complete and before initiating the second growth flush. In this study, that time would correspond with about the 36-d RSRT. Measurements of some scion parts, such as leaf area on both rootstocks and stem dry mass on Cleopatra, were greatest with RSRT at 36 d. These results indicate that maximum growth of some aerial plant parts can be achieved by a production system that includes rootstock shoot removal soon after the first scion growth flush is complete. However, root and whole plant dry masses were greater at the later RSRTs of 170 and 235 d. Consequently, root : shoot ratios were much greater for the later RSRTs.

There may be advantages to leaving rootstock shoots attached past the first scion flush that are not readily apparent when plants are evaluated based on size and appearance of aerial parts, especially when considering the contribution of rootstock shoot photosynthates to root growth. Alternating cycles of shoot and root growth have been reported for many perennial plants, including apple (Atkinson, 1983), peach (Williamson and Coston, 1989), Japanese holly (Mertens and Wright, 1978), and citrus nursery trees (Bevington and Castle, 1985). During periods of rapid shoot growth, developing leaves and stems usually compete more effectively than roots for current photosynthates. However, this study suggests that roots continue to be a major sink for rootstock photosynthates of bent or lopped plants after completion of the first scion growth flush. Possibly this accumulation occurred between scion growth flushes as indicated by earlier work with ^{14}C-labeled photosynthates (Williamson et al., 1992).

Well-established root systems with high fibrous root content have improved transplant establishment of field-grown citrus nursery trees (Grimm, 1956). Many other perennial crops are routinely root pruned in field nurseries to develop more compact, fibrous root systems and higher root : shoot ratios (Geisler and Ferree, 1984). In some cases (Mullin, 1966; Sutton, 1967) but not others (Janouch, 1927), this result has been correlated with higher transplant survival rates and better growth following transplanting. Retaining rootstock shoots of bent and lopped plants attached for a longer time than is usually done in commercial nurseries is beneficial if greater root growth of container-grown citrus nursery trees is desired. Whether such trees perform better when transplanted than trees with less root development and lower root : shoot ratios warrants further investigation.

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