Axillary Shoot Growth, Rooting and Overwinter Survival in Stem Cuttings of *Viburnum dentatum* 'Chicago Luster'[1]

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Abstract

The effects of stock plant and cutting manipulation on propagation success of *Viburnum dentatum* 'Chicago Luster' were studied. One-node semi-hardwood stem cuttings were harvested from greenhouse-grown stock plants. Cuttings from plants decapitated 21 days before harvest (compared to non-decapitated plants), and one-leaf (compared to two-leaf) cuttings, had relatively high rooting potential and a high initial percentage of axillary shoot flushing. However, subsequent shoot growth, and overwinter survival, were less. A second stock plant decapitation resulted in the flushing and initial growth of all axillary shoots by the time cuttings were stuck. These cuttings all survived the propagation phase and soon resumed shoot growth, even after transplanting, and the plants all survived the following winter. In cuttings with actively growing axillary shoots, shoot extension growth was greatest in cuttings reduced at sticking to one leaf and one shoot in the leafless axil, but the radial distribution of roots was not uniform, being concentrated in the same 180° sector of the stem as the shoot. Incorporating controlled-release fertilizer (CRF) in the rooting substrate during the propagation phase tended to reduce initial survival but promoted rooting and shoot growth among the survivors, even after transplanting and increased overwinter survival.

Index words: asexual propagation, single-node cuttings, arrowwood viburnum.

Significance to the Nursery Industry

Some taxa are easy-to-root from stem cuttings, but die during the winter. We found that treatments which promoted early axillary shoot flushing during propagation in one-node cuttings of 'Chicago Luster' viburnum (stock plant shoot decapitation prior to cutting collection and reducing two-leaf cuttings to one leaf at sticking), reduced subsequent shoot growth and overwinter survival. However, decapitating stock plant shoots so that axillary shoots were in active growth at the time of cutting harvest was beneficial: the axillary shoots continued to grow during the propagation phase, and the rooted cuttings survived late-season transplanting and had high overwinter survival. In cuttings of conventional form (without growing axillary shoots), incorporating controlled release fertilizer in the rooting substrate increased the rate of shoot flushing, subsequent shoot growth and overwinter survival.

Introduction

Leafy cuttings of some temperate woody taxa root in high percentages in the season of propagation, but are prone to die during the winter or shortly after the onset of growth the following spring. Genera susceptible to overwinter mortality include *Viburnum*, as well as *Acer*, *Berberis*, *Betula*, *Cornus*, *Corylopsis*, *Fothergilla*, *Hamamelis*, *Magnolia*, *Rhododendron* and *Stewartia* (7), *Prunus* (1), *Quercus* (4), *Fagus* and *Syringa* (5). Susceptible cuttings have low winter cold hardiness, due either to insufficient reserves of non-structural carbohydrates or to the continuation of growth excessively late into the autumn (7). The importance of non-structural carbohydrates reserves to overwintering success is species dependent; *Hamamelis vernalis* and *H. virginiana* cuttings with low levels overwintered in lower percentages than those with higher levels, but in *Acer rubrum* 'Red Sunset' and *Stewartia pseudocamellia* cuttings the level of non-structural carbohydrate was not related to overwintering success (6).

Axillary shoot extension growth in the season of propagation generally increases the overwinter survival of cuttings (7), although in some species it is not critical to overwintering success (4). New shoot growth, whether extension growth or radial growth, creates carbohydrate storage capacity in the cutting, allows the vascular traces of the roots and shoots to develop (necessary before the form of the cutting approximates that of an entire plant), and may increase the resilience of the underground stem (13).

Smalley and Dirr (7) reviewed numerous treatments and cultural practices for promoting shoot growth of cuttings, including the taking of cuttings early in the season (facilitated by growing the stock plants in a greenhouse), extending photoperiod within an appropriate temperature range, fertilization of rooted cuttings with soluble fertilizer, sprays of growth regulators (mainly gibberellins), leaf removal from cuttings and the avoidance of transplanting in the season of propagation.

Alternatively, stock plant manipulation such as decapitation of the intact shoots prior to the harvest of cuttings to induce axillary bud growth prior to cutting collection or cutting manipulation such as removing axillary buds/shoots (as well as leaves) from cuttings at sticking, and/or pre-fertilization of the rooting medium of cuttings with controlled-release fertilizer (CRF) can be used to increase propagation success (12). Root constriction may also help to promote shoot development when rooting is profuse (9). These stock plant or cutting manipulations or rooting medium fertility treatments are easy to apply in practice, and were tested for their effect on the rooting response, incidence of shoot flushing and overwinter survival in stem cuttings of *Viburnum dentatum* 'Chicago Luster'.

[1]Received for publication January 12, 2005; in revised form October 5, 2005. Manuscript No. HCS 05-01 of the Ohio Agricultural Research and Development Center. This work was done while the senior author was the Victor Ries Visiting Scholar in the Department of Horticulture and Crop Science of The Ohio State University.

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Materials and Methods

General procedures: Propagation. The work was done from April to July 2002 in the propagation facilities of Ohio State University, Columbus, OH. Stock plants of *Viburnum dentatum* 'Chicago Luster' were grown in No. 3 nursery containers (Classic 1000, Nursery Supplies, Fairless Hills, PA) with a net volume of 8.6 liters (2.3 gal). The substrate was 4:1 (by vol) composted pine bark:Comtil (composted municipal sewage sludge, City of Columbus, OH), which was watered daily and fertilized weekly with 100 mg/liter N from 20N:9P:17K soluble fertilizer (20–20–20 Peters fertilizer, O.M. Scotts, Marysville OH). The plants had been overwintered in an unheated polyhouse and were moved into an unshaded glasshouse in mid-February, where they grew prior to providing cuttings for propagation. Evaporative pads and fans cooled the glasshouse. Over the four months of these experiments, temperatures varied between 13C (56F; night) and 33C (92F; day); weekly mean temperature varied from 22C (71F) to 25C (77F). Weekly mean relative humidity varied from 25 to 50% (day) and 35 to 75% (night). Weekly mean outdoor irradiance during daylight hours varied from 150 Wm^{-2} to 300 Wm^{-2}, with weekly maxima of 800–900 Wm^{-2}.

Cuttings were treated at the base with 1000 ppm indole butyric acid (IBA) in talc (Horomdin #1, Olympic Horticultural Products, Mainland, PA). Where stated, the rooting substrate was pre-fertilized with 3 kg/m (0.2 lb/cu ft). 15N:3.8P:7.9K (15–9–12 Osmocote® Plus O.M. Scotts, Marysville, OH) controlled-release fertilizer (CRF), releasing over 8–9 months at 20C (70F). Pre-fertilized flats were left under intermittent mist for at least two weeks before cuttings were stuck.

Propagation density was about 400 cuttings/m^2 (37/ft^2). Propagation containers were flats 52 × 38 × 10 cm (21 × 15 × 3 in) with a total rooting volume of 14820 cm^3 (709 in^3) and, in Trial 4 only, trays had square-section plugs 1.2 × 1.2 × 1.2 cm (0.5 × 0.5 × 0.5 in); individual cell rooting volume was 1.5 cm^3 (0.1 in^3). Cuttings were stuck in 1:1 (by vol) peat:perlite propagation substrate in an unshaded mist house with glass walls and a cellular polycarbonate roof. The house was cooled by evaporative pad and fan. The mist regime was 5 seconds on every 5 minutes during the day. Over the four months, temperature in the mist house varied within the overall extremes of 17C (63F) and 37C (98F), and weekly mean temperature varied from 22C (72F) to 27C (81F). Weekly mean relative humidity varied from 30 to 76% (day) and from 60 to 91% (night).

The basic form of the cuttings, further modified in some trials, consisted of one pair of mature opposite leaves reduced to less than half the original leaf area per leaf, the associated axillary buds/shoots and the single internode below. Axillary buds/shoots were classified as flushed if at least one leaf had begun to unfurl. The percentage of buds/shoots flushed was the number flushed (one or two per cutting) divided by the total number of buds/shoots (two per cutting). The percentage of cuttings flushed was the number of cuttings with at least one bud/shoot flushed divided by the number of cuttings.

Trials were enumerated by lifting the cuttings 45–55 days after sticking (the end of the propagation phase). Cuttings were counted as 'dead' if they had no surviving stem below the level of the substrate or no remaining foliar area. The number of cuttings surviving the propagation phase (calculated as a percentage of the original number of cuttings stuck) and after shaking the roots free of rooting substrate, and the number of primary roots per rooted cutting were recorded.

General procedures: Growth and overwinter survival. At the end of the propagation phase, all roots of rooted cuttings were cut to a maximum length of 5 cm (2.0 in) which typically removed more than half their length. The cuttings were then transplanted into Metromix 360 substrate (O.M. Scotts, Marysville, OH), left under intermittent mist for three days and moved to the stock plant glasshouse where they were watered and fertilized according to the stock plant regime. The rooted cuttings were transplanted to flats as used for propagation at 24 per flat, giving a mean root volume per transplant of about 460 cm^3 (28 in^3), or in trays of individual cells (IPL® Rigi-Pots™ IP 200, 5.0 × 12 cm, dia by depth [2 × 4.7 in], of approximate individual root volume 120 cm^3 [7 in^3]). The flats of cuttings were transferred to a minimum heat (7C [45F]) polyhouse for overwintering. On March 28, 2003, the length of the longest shoot per cutting and overwinter survival, as a percentage of the original number transplanted, were recorded.

General procedures: Data analysis. Where numbers were insufficient for analysis of variance, comparisons were made by χ^2 using Yates' correction for continuity (8). In this case, the data were consolidated from at least two replications of cuttings per treatment which had been arranged in a randomized block design, except for the overall comparisons between Trials 1 and 2 (which were adjacent and contemporaneous). Confidence limits are based on samples of at least n = 8 and are cited at the 95% confidence level. Analysis was performed using the statistical package INSTAT supplied by the University of Reading, U.K.

Trials 1 and 2: Stock plant decapitation and cutting leaf number: Propagation. Thirty two stock plants were divided into two equal groups on April 9, 2002, when shoot length was 54.7 ± 4.8 cm, (21 ± 1.9 in), shoot mid-point diameter was 3.5 ± 0.3 mm (0.14 ± 0.01 in) and there were 4.5 ± 0.8 shoots per plant, all arising from the base. There was no lateral growth on the shoots nor were there any shoots from the base of the stock plant which gave the stock plants a cane-like appearance. Half of the stock plants were decapitated by removing the shoot apices and immature leaves (those leaves less than one-half full-size); the other stock plants were not decapitated.

Twenty-one days later, when the propagation trials were established, mean shoot length of the intact plants had increased by 22% to 66.6 ± 6.9 cm (26.2 ± 2.7 in), while in these and the decapitated plants, shoot mid-point diameter had increased by 14.5% and 15.1% respectively. At this time the axillary buds of the most distal node were visibly swollen in one third of decapitated shoots, and one third of these were beginning to flush. There was no axillary shoot growth from any other node, or any growth from the base, in either stock plant form.

Cuttings were harvested from the four most distal nodes per shoot, beginning in the intact plants with the node closest to the apex whose leaves were at least 75% fully expanded (node 1). This meant that node 1 cuttings from the intact plants were thinner (2.5 ± 0.3 mm vs 2.7 ± 0.4 mm [0.10 ± 0.014 in vs 0.11 ± 0.15 in]) and softer than node 1 cuttings from the decapitated plants. There was less difference in stem thickness and stiffness among more proximal nodes.

In Trial 1, cuttings were left with two leaves, while in Trial 2 one of the two opposite leaves per cutting was removed without damaging the axillary bud. In each trial there were 4 × 2 treatment combinations, node position (nodes 1 to 4) × stock plant form (intact or decapitated), arranged in a split-plot design with two blocks and 16 cuttings per sub plot. Main and sub plots were 'node position' and 'stockplant form', respectively. There were 256 cuttings per trial, 512 cuttings in total, and cuttings were randomized across trials.

At the end of the propagation phase, the length of the longest root per cutting was measured in 12 cuttings from each of four groups (n = 48), from the intact and the decapitated stock plant treatments in the two trials. Comparisons among these four groups were made using simple randomized design ANOVAs of root length. The incidence of axillary shoot flushing was recorded in all cuttings.

Trials 1 and 2: Stock plant decapitation and cutting leaf number: Growth and overwinter survival. From each of the four treatment combinations (one-leaf or two-leaf cuttings, stock plants decapitated or left intact), 96 rooted cuttings were selected at the end of the propagation phase and divided into two closely comparable groups. One group was transplanted into flats, the other into cells. In total there were 384 transplants, 192 in eight flats and 192 in eight cell trays. The percentage of flushing shoots was recorded 30 days after transplanting, and overwinter survival was recorded as described.

Trial 3: The form of the cutting with growing axillary shoots, and fertilizer: Propagation. The harvest of cuttings for Trials 1 and 2 reduced the shoot length of the stock plants by about one third. The remaining proximal regions of the shoots were further reduced if necessary to leave about four well-foliated nodes. Twenty four days later, May 24, cuttings were harvested from node 1 (the most distal remaining node) and the contiguous node 2, when shoots had grown from all axils of these cuttings and were up to 5.0 cm (2.0 in) long (mean length = 2.6 cm [1.02 in]). One-leaf, one-node cuttings were then prepared and one of the two axillary shoots per cutting (in either the leafy or the now leafless axil) were excised at the base.

In each of four flats there were two main plots of 30 cuttings (nodes 1 and 2), and within each of these there were two sub plots of 15 cuttings each (shoot in leafy or leafless axil; 240 cuttings in total). The treatment combinations were assigned to the four flats as follows: (a) stock plants originally decapitated, rooting substrate fertilized with CRF; (b) stock plants originally decapitated, rooting substrate not fertilized with CRF; (c) stock plants originally intact, rooting substrate fertilized with CRF; or (d), stock plants originally intact, rooting substrate not fertilized with CRF. There were three planned comparisons: (i) cutting form (axillary shoot in leafy axil vs. leafless axil); (ii) pre-harvest node position (node 1 vs. node 2); and (iii), a comparison among the combinations of stock plant type and CRF addition described above. The three comparisons were made by ANOVAs of plot means. The first two were randomized complete block designs with eight blocks (main plots) in the first and four blocks (flats) in the second. The third comparison was analysed by ANOVA as a completely randomized design with four treatments (flats) of four plots each. For each comparison, three variables were analysed: initial shoot length, final shoot length and the number of roots per rooted cutting.

At the end of the propagation phase, the following individual-cutting observations were made on the surviving fertilized cuttings from originally intact stock plants: final shoot length, cutting stem thickness and length, the length of any visible die-back extending from the base of the cutting, and root number in two 180° sectors (the leafy and leafless sectors) of the stem. The latter was expressed as the percentage of roots in the sector of the stem containing the axillary shoot. Relationships between these variables were investigated by linear regression.

Trial 3: The form of the cutting with growing axillary shoots, and fertilizer: Growth and overwinter survival. From all treatments, 12 and 36 cuttings were selected which had been propagated in unfertilized and fertilized trays, respectively. These were divided into closely comparable groups; half were transplanted into flats (6 + 18 = 24), half into cell trays. Axillary shoot length was recorded at transplanting and 30 days after transplanting, and overwinter survival was recorded as described previously. Comparisons of length of the longest shoot per transplant after overwintering were made by simple randomised design ANOVAs.

Trial 4: Root constriction and fertilizer: Propagation. Cuttings were harvested from intact greenhouse-grown stock plants on June 28, reduced to one leaf (without damaging the axillary bud) and stuck in four containers. Two were flats, pre-fertilized with CRF or not, and two were trays of small plugs, pre-fertilized or not. Not all plugs in the trays were stuck with cuttings, to give a similar stocking in the two container types. There were 56 cuttings per container in four plots of 14 cuttings each (224 cuttings total). Blocks consisted of contiguous plots, one from each container, giving a 2 × 2 factorial layout (tray type × CRF) with four blocks. The number of cuttings with at least one flushing axillary shoot was recorded 28 days after the trial was established.

Results and Discussion

Trials 1 and 2: Stock plant decapitation and cutting leaf number: Propagation. All cuttings survived during propagation and all rooted. In both trials, the number of roots per rooted cutting increased with node position from node 1 (the most distal) through node 4 (Table 1). The increased number of roots per rooted cuttings was associated with increasing thickness and stiffness in the stem of the cutting. Also, in both trials, cuttings from stock plants whose shoots had been decapitated 21 days prior to cutting harvest had consistently more roots per rooted cutting than those from intact stock plants (26.3 vs 17.4, averaged over node number, in both Trials, Table 1). Cuttings from decapitated stock plants had firmer stems and their leaves were deeper green than those from intact stock plants. When averaged over nodes and stock plant forms, removing one leaf from the single node cuttings before cuttings were stuck reduced the number of roots per rooted cutting from 25.4 (for two-leaf cuttings, Trial 1) to 18.4 (for one-leaf cuttings, Trial 2; Table 1).

At the end of the propagation phase, axillary buds on all cuttings (two buds per cutting) were swollen and some had flushed. Prior decapitation of stock plants, or reducing the cuttings' leaves from two to one at sticking, nearly doubled the percentage of cuttings flushing by the end of the propa-

Table 1. The percent of single node cuttings with one or more axillary shoots flushed at the end of the propagation period, and the number of roots per rooted cutting in two trials of *Viburnum dentatum* 'Chicago Luster', Trials 1 and 2.

			Roots per rooted cuttings		
			Stock plant form		
Trial[z]	Node[y]	Cuttings flushing (%)	Intact[x]	Decapitated	Mean
1	1	14.1[w]	12.3	16.2	14.2
	2	1.6	18.2	28.0	23.1
	3	7.8	23.3	37.5	30.2
	4	17.2	28.2	39.4	33.8
	Mean	10.2	20.5	30.3	25.4
2	1	17.2	9.2	10.9	10.0
	2	7.8	11.4	14.9	13.1
	3	20.3	15.5	28.3	21.9
	4	43.7	21.5	35.5	28.5
	Mean	22.3	14.4	22.4	18.4

[z]At sticking, cuttings were either left with two leaves (Trial 1) or reduced to one leaf (Trial 2).

[y]Node 1 was the most distal node of four contiguous nodes on individual shoots.

[x]Cuttings were harvested from intact or previously decapitated stock plants. Decapitated stock plants had the shoot apices and immature leaves (leaves less than on-half full size) removed 21 days prior to cutting harvest.

[w]Each value is the mean of 64 cuttings.

gation period (Table 2). In addition, over half of the flushed shoots in one-leaf cuttings had started to elongate (up to 3 cm [1.1 in]) compared to no increase in the two-leaf cuttings

Of the 57 one-leaf cuttings that flushed, 8, 8 and 41 flushed from both axils, the leafy axil and the opposing leafless axil, respectively. Thus, the rate of shoot flushing in the leafy axils was significantly lower, 28% (16 of 57 cuttings), than in the leaf-less axils, 86% (49 of 57 cuttings, $P < 0.001$).

The mean length of the longest root per cutting was significantly greater in cuttings from intact than from decapitated stock plants (16.5 and 13.9 cm [6.50 and 5.47 in]; $P = 0.035$), but there was no difference in root length between one- and two-leaf cuttings (14.7 cm [5.79 in] and 15.7 cm [6.18 in]; $P = 0.379$), despite the larger difference in the number of roots per rooted cutting.

Trials 1 and 2: Stock plant decapitation and cutting leaf number: Propagation. Growth and overwinter survival. All cuttings had some shoot growth following overwintering (mean length of the longest shoot per cutting was 10.9 cm [4.29 in]). Although cuttings from decapitated vs intact stock plants, and one-leaf vs two-leaf cuttings, had high percentages of cuttings flushing at the end of the propagation phase but, subsequent shoot growth, and overwintering survival percentage, were less (Table 2).

At transplanting, the percentage of cuttings flushing was similar whether the cuttings were transplanted into flats (47.9% [n = 192] or cells (51.0% [n = 192], $P = 0.584$). After overwintering, axillary shoots were over twice the length as those on cuttings transplanted to flats than to cells: 15.1 cm [5.94 in] vs 6.6 cm [2.60 in], respectively (Table 3). Overwinter survival, averaged over both trials, was 19% greater in flats than in cells (49.5 vs 30.3%, respectively, Table 3).

Table 2. Percentage of single node rooted cuttings of *Viburnum dentatum* 'Chicago Luster' where one or more one axillary buds flushed by the end of the propagation period or 30 days later, and their overwinter survival as affected by stock plant form or the number of leaves per cutting, Trials 1 and 2.

Stock plant form or number of leaves per cutting	End of propagation (%)	Thirty days post-propagation (%)	Overwinter survival (%)
Intact[z]	12.1[x]	69.8	57.3
Decapitated	20.3	29.2	22.4
χ^2 1 df	5.8	61.8	47.3
P-value	0.016	0.0001	0.0001
One-leaf[y]	22.3	45.3	32.8
Two-leaf	10.2	53.6	46.9
χ^2 1 df	12.9	2.3	7.3
P-value	0.000	0.129	0.007

[z]Cuttings were harvested from intact or previously decapitated stock plants. Decapitated stock plants had the shoot apices and immature leaves (leaves less than on-half full size) removed 21 days prior to cutting harvest.

[y]At sticking, single node cuttings were either left with two leaves or reduced to one leaf.

[x]Each value is the mean of 256 cuttings (for the end of propagation period) or 192 cuttings (for 30 days after propagation and for overwintering survival).

However, the greater overwintering survival among plants grown in flats was not solely attributable to the longer shoots. Among those plants with shoot length less than 12 cm (4.7 in), those grown and overwintered in flats had 87.9% (n = 33) overwintering survival, while those grown and overwintered in cells had 48.9% (n = 94) overwintering survival.

Overwintering survival for cuttings transplanted into flats (Tables 2 and 3) suggests that overwintering survival is in-

Table 3. Overwinter survival and mean length of the longest shoot per cutting after overwintering, in cuttings harvested from intact or decapitated stock plants, and transplanted at the end of the propagation phase into flats or cells, Trials 1 and 2.

Stock plant form[z]	Number of leaves per cutting[y]	Trans-planted to	Longest shoot at transplanting (cm)	Overwintering survival (%)
Intact	1	Flat	10.2[x]	47.9
	2		16.7	95.8
Decapitated	1	Flat	13.6	20.8
	2		20.0	33.3
		Mean	15.1	49.5
Intact	1	Cell	6.5	33.3
	2		6.1	52.1
Decapitated	1	Cell	9.0	29.2
	2		4.8	6.3
		Mean	6.6	30.3

[z]Cuttings were harvested from intact or previously decapitated stock plants. Decapitated stock plants had the shoot apices and immature leaves (leaves less than on-half full size) removed 21 days prior to cutting harvest.

[y]At sticking, single node cuttings were either left with two leaves or reduced to one leaf.

[x]Each value is the mean of 48 cuttings.

Table 4. Initial and final axillary shoot length and the number of roots per rooted cuttings in single node cuttings of *Viburnum dentatum* 'Chicago Luster' as affected by shoot position on the cutting or node number, Trial 3.

Shoot position or node number[z]	Shoot length (cm) initial	Shoot length (cm) final	Number of roots per rooted cutting
Leafy axil	2.7[y]	5.5	29.2
Leafless axil	2.4	5.7	32.7
P-value	0.096	0.320	0.054
Node 1	2.6	5.2	34.1
Node 2	2.6	6.0	27.8
P-value	0.823	0.020	0.004

[z]Cuttings were stuck with one actively growing axillary shoot retained in either the leafy axil or in the opposing leafless axil. Node number on the stock plant was either the most distal node (node 1) or the adjacent subdistal node (node 2).

[y]Each value is the mean of 120 cuttings.

creased with increasing shoot length and decreased by increasing number of roots per cutting: OWS = (SL_{PO} – R/Rc), where OWS is overwintering survival, SL_{PO} is shoot length after overwintering and R/Rc is roots per rooted cutting. The relationship is speculative and may not hold for cuttings transplanted into cells, in which root growth is constrained.

Trial 3: The form of the cutting with growing axillary shoots, and fertilizer: Propagation. Whether the axillary shoot grew from the leafless or the leafy axil of one-leaf cuttings, there were no significant differences in initial shoot length, final shoot length or the number of roots per rooted cutting (Table 4). Node 2 cuttings had greater shoot growth during the propagation phase but fewer roots per rooted cutting than node 1 cuttings (Table 4).

When averaged over stock plant forms, incorporating CRF in the rooting substrate did not significantly increase shoot length at the end of the propagation period (6.2 vs 5.0 cm [2.44 vs 1.97 in, $P = 0.251$] for CRF vs no CRF respectively), or affect the number of roots per rooted cutting (31.5 vs 30.5, $P = 0.344$, Table 5). However, the visual effects of the CRF were striking; the new leaves on fertilized cuttings were larger and darker green than those propagated without CRF.

Axillary shoots were initially longer in cuttings from originally decapitated stock plants (3.2 cm vs 2.0 cm [1.26 vs 0.79 in], $P = 0.001$) and this difference was maintained to the end of the propagation phase (4.4 vs 6.8, averaged over stock plant forms, P = 0.0.50; Table 5). Stock plant decapitation did not affect the number of roots per rooted cutting (33.2 vs 28.7 for decapitated vs not decapitated stock plants, respectively, $P = 0.151$). The persistence of the difference in shoot length was unexpected since the stock plants were originally decapitated 45 days before the cuttings were harvested, and cuttings for Trials 1 and 2 had been harvested in the interim.

Overall, percent survival was higher in unfertilized cuttings (99%, n = 120) than in fertilized cuttings (87% , n = 120; $P < 0.001$). Among fertilized cuttings, survival was lower in cuttings from originally intact stock plants (78%, n = 60) than in those from originally decapitated stock plants (95%, n = 60; $P = 0.016$), while percent survival was similar whether the axillary shoot was in the leafy axil (83%, n = 60) or leafless axil of the cutting (90%, n = 60; $P = 0.439$). Most of the fertilized cuttings classified as 'dead' had died back from the base, killing the stem below the level of the rooting substrate.

For the incorporated controlled release fertilizer in to the propagation substrate and intact stock plant treatment combination, 43 cuttings were available for individual-basis observations. In the 23 cuttings whose axillary shoots grew from the leafless axil, 68% (n = 864) of the roots arose from the 180° stem sector below the shoot. In the 20 cuttings whose axillary shoots grew from the leafy axil, 74% (n = 593) of the roots arose from the sector of the stem below the shoot. Thus, the presence of the leaf subtending the shoot increased the percentage of roots in that stem sector from 68 to 74% ($P = 0.019$).

The correlation matrices (6 × 6 variables) for the cuttings whose shoots were in the leafy axil showed that the numbers of roots per rooted cutting (range 12–62 roots) was unrelated to axillary shoot length (0.5 to 9.0 mm [0.02 to 0.35 in]), cutting length (6 to 15 mm [0.24 to 0.59 in]), cutting thickness (3.0–6.3 mm [0.12 to 0.26 in]), length of die-back from the base (0 to 32 mm [0 to 1.26 in]) or percentage of roots in the sector of the stem opposing the axillary shoot (3–53%). Die-back from the base of the cutting tended to increase with axillary shoot length ($r^2 = 0.30$; $P = 0.013$) and was more extensive in the sector with fewer roots, so that the extent of die-back was also positively correlated with the asymmetry of root emergence ($r^2 = 0.57$; $P < 0.001$).

Trial 3: The form of the cutting with growing axillary shoots, and fertilizer: Growth and overwinter survival. At the end of the propagation phase, shoot length in cuttings stuck in fertilized substrate was longer than those stuck in unfertilized substrate, 6.2 cm vs 5.0 cm (2.44 vs 1.97 in, $P = 0.02$) when shoot length was averaged over stock plant forms, Table 5. Thirty days after transplanting, all axillary shoots were healthy and shoot extension growth had resumed in 90%

Table 5. Shoot length at the end of the propagation phase and number of roots per rooted cutting in cuttings from stock plants either decapitated 21 days prior to cutting collection or left intact. Cuttings were stuck in substrate with controlled-release fertilizer incorporated or not, Trial 3.

Stock plant type[z]	Fertilizer incorporation during propagation (kg/m^3)[y]	Shoot length (cm)	Number of roots per rooted cutting
Intact	3	4.9[x]	30.4
	0	3.9	27.1
	Mean	4.4	28.7
Decapitated	3	7.5	30.5
	0	6.1	35.8
	Mean	6.8	33.2

[z]Cuttings were harvested from intact or previously decapitated stock plants. Decapitated stock plants had the shoot apices and immature leaves (leaves less than on-half full size) removed 21 days prior to cutting harvest.

[y]Cuttings were stuck in substrate fertilized or not by incorporating 3 kg per m 15N–3.8P–7.4K Osmocote Plus controlled release fertilizer.

[x]Each value is the mean of 30 cuttings.

of plants (n = 48). At this time, shoot length was 11.2 ± 1.4 cm (4.41 ± 0.55 in) vs 7.7 ± 1.4 cm (3.03 ± 0.55 in) in cuttings originally stuck in rooting substrate fertilized with CRF or not fertilized, respectively. Thus, incorporating CRF in the propagation substrate resulted either in more rapid recovery from transplanting shock, more rapid growth after transplanting, or both.

All 48 transplants survived the winter whether they had been fertilized with CRF during the propagation phase or not, or whether they were transplanted to flats or cells. At the end of the winter, transplants in flats had longer axillary shoots than those in cells (22.5 vs 15.8, [8.8 vs 6.2 in], $P = 0.033$), and those fertilized with CRF during the propagation phase had longer shoots, 16.5 to 22.9 cm (6.5 to 9.0 in [$P = 0.0001$] for CRF incorporated vs no CRF, respectievely).

Trial 4: *Root constriction and fertilizer: Propagation*. Twenty eight days after this trial was established, the type of container (flat or cell tray) did not affect the percentage of cuttings flushing (53 vs 59% for flats and cells respectively, $P = 0.401$), but those cuttings with CRF incorporated into the propagation substrate had a significantly greater percentage of cuttings flushing than those propagated without CRF (48 vs 32%, $P = 0.004$). There was no interaction between container type and the presence or absence of CRF in the propagation substrate ($P = 0.501$).

We found 'Chicago Luster' viburnum is easily propagated from stem cuttings taken from potted greenhouse-grown stock plants. There was little mortality in the propagation phase and all surviving cuttings rooted. Stock plant and cutting manipulation affected rooting and overwintering survival. For instance, the removal of one leaf from two-leaf cuttings at sticking and the pre-harvest decapitation of stock plant shoots, increased the percentage of axillary shoots flushing at the end of the propagation phase, but subsequent shoot growth and overwinter survival were reduced (Trials 1 and 2; Table 2). The former treatment reduced, while the latter increased, the roots per rooted cutting, compared to the respective controls (Table 1). The lower shoot growth after propagation in one-leaf cuttings relative to two-leaf cuttings may be attributed to sub-optimal leaf area. Less shoot growth 30 days after propagation in cuttings from decapitated stock plants may be attributed to root competition with shoot growth for photosynthate; cuttings from decapitated stock plants had more roots per rooted cutting than cuttings from intact stock plants.

However, root-shoot competition was not evident in Trial 3, whose cuttings had one actively-growing axillary shoot (mean length 2.6 cm [1.02 in]) at sticking. The shoots grew another 3 cm (1.18 in) during the propagation phase (Trial 3, Table 5), yet the number of roots per rooted cuttings was higher than in Trials 1 and 2 (31 vs 22 roots per rooted cutting). The form of the cutting in Trial 3, which was clearly favorable, was obtained by prior decapitation of the stock plant as in Trials 1 and 2, but the shoots were further developed because the decapitation took place later in the season and the interval between decapitation and harvest was longer.

A multiple regression model: $OWS = (SL_{PO} - R/Rc)$, where OWS is overwintering survival, SL_{PO} is shoot length after overwintering and R/Rc is roots per rooted cutting, speculatively describes overwintering success in the context of Trials 1 and 2. The model predicts that overwintering survival increases with increasing shoot length but decreases with increasing numbers of roots per rooted cutting, and would help to explain the weak relationship between shoot length and overwintering success (12).

Shoot flushing on cuttings during or after the propagation phase (as in Trials 1 and 2) depends on radial growth in the main stem of the cutting for the development of normal vascular connections and subsequent shoot extension. Such radial growth in the propagation phase is largely confined to residual pre-harvest growth, which diminishes with time from severance at least while cuttings are unrooted. In contrast, the vascular connections of the larger shoots on Trial 3 cuttings would have been established prior to sticking, facilitating further shoot growth during and after propagation.

In Trial 2, axillary shoots flushed mainly from the leafless axil, as reported for *Acer palmatum* cuttings (7). Pinching out one of the two axillary buds or shoots at sticking is also expected to invigorate growth in the remaining shoot, as in *Eucalyptus grandis* (11). Thus, in taxa like 'Chicago Luster' viburnum and *A. palmatum* (10), leaf and shoot removal would tend to have a reinforcing effect on shoot growth if one leaf and the opposing bud/shoot were retained (as in Trial 3). Preparing this form of cutting takes longer, but the cost of preparation would likely be offset by a higher sticking density, by the more rapid growth of the single axillary shoot, and by avoiding the need to remove a competing shoot in a later formative pruning. The 'one leaf and opposite shoot' cutting type would particularly facilitate central leader development in single-node cuttings and in opposite-budded taxa.

Cuttings are often transplanted from flats to individual containers after rooting, and this procedure generally disturbs the roots and may check shoot growth. Rooted cuttings from Trials 1, 2 and 3 were transplanted in a deliberately harsh procedure in which the rooting substrate was shaken free from the roots and the roots were pruned before transplanting. Nevertheless, all rooted cuttings survived, and shoots on cuttings from Trial 3 (with active shoot growth at sticking) resumed growth quickly, growing a further 3 to 5 cm (1.2 to 2.0 in) within 30 days of transplanting. These plants had 100% overwintering survival (vs 40% for plants from Trials 1 and 2), even though they were propagated later in the season. Thus, shoot growth after rooting is more important to overwinter survival than root damage following propagation or propagating later in the season.

Incorporating CRF in the rooting substrate during the propagation phase had little effect on the number of roots per rooted cutting or on shoot growth during propagation (Trial 3, Table 5). However, the new leaves on fertilized cuttings were larger and darker green, suggesting that some fertilizer had been taken up through the base of the cutting before roots emerged. Rooted cuttings from fertilized and unfertilized propagation substrate were transplanted into the same (fertilized) substrate at the end of the propagation phase. The carry-over effect of the CRF during the propagation phase was surprisingly marked; after overwintering, shoots on CRF cuttings were about 10 cm (3.9 in) longer than those on non-CRF cuttings, although only about 1 cm (0.39 in) of this difference was apparent by the end of the propagation phase (Table 5). Incorporating CRF in the propagation substrate also increased the percentage of cuttings flushing at the end of the propagation phase in Trial 4.

Cuttings that died when propagated in substrate with incorporated CRF died back from the base, and the amount of die-back increased with increasing axillary shoot length (Trial

3). Basal stem dieback is consistent with elevated fertilizer levels in the rooting substrate, and the axillary shoot may increase the predisposition to injury by causing an increase in mineral uptake through the base of the cutting prior to rooting. In the context of this study, incorporation of CRF into the propagation substrate should be less than the 3 kg/m^3 used.

Root constriction has not been explored as a method of promoting the flushing or initial growth of shoots because it inhibits shoot growth in the longer term (2), and easily causes root malformation. Root constriction during the propagation phase did not promote shoot flushing by Day 28 in Trial 4, and transplanting to individual cells rather than flats reduced subsequent shoot extension growth in Trials 1 and 2.

Our study differed from others (such as those reviewed in 7) because we manipulated stock plants and cuttings before sticking to affect overwintering success, where other studies tired to affect overwintering success after root initiation. Cuttings with actively growing axillary shoots at sticking, obtained by prior decapitation of the stock plant, had rapid subsequent shoot growth and overwintered with 100% success (compared to 40% success for cuttings without actively growing axillary shoots at sticking). The removal of one leaf and the opposing axillary bud or shoot per node from these cuttings at stickting also promoted subsequent axillary shoot growth. A potential negative consequence of this form of cutting is an asymmetrical root system since most roots arose in the stem sector below the shoot. However, this is unlikely to be a serious concern in *Viburmum dentatum* 'Chicago Luster' because of the high number of roots regenerated per rooted cutting.

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