Auxin Application to Stem Cuttings of Selected Woody Landscape Plants by Incorporation Into a Stabilized Organic Rooting Substrate[1]

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Abstract

Stem cuttings of *Buxus sinica* var. *insularis* 'Wintergreen', *Elaeagnus* x *ebbingei*, *Ficus benjamina*, *Gardenia augusta* 'Radicans', *Ilex glabra* 'Nigra', *Ilex vomitoria* 'Nana', *Juniperus conferta* 'Blue Pacific', *Ternstroemia gymnanthera*, and *Trachelospermum asiaticum* were inserted into a stabilized organic rooting substrate (plugs comprised of peat and a polymer binder) that had been soaked in water, aqueous solutions of K-IBA (15 to 75 ppm), or K-IBA + K-NAA (15 ppm + 7.5 ppm to 60 ppm + 30 ppm). Rooting and initial shoot growth responses were compared with cuttings receiving a basal quick-dip in K-IBA (1000 ppm) or K-IBA + K-NAA (1000 ppm + 500 ppm). Rooting percentage, number of roots per rooted cutting, and total root length per rooted cutting for cuttings rooted in auxin-treated plugs were similar to or greater than cuttings receiving a basal quick-dip; lesser results were obtained in a few cases with K-IBA + K-NAA. Percent of rooted cuttings with new shoots and shoot length per rooted cutting for cuttings rooted in plugs treated with K-IBA were mostly similar to cuttings receiving a basal quick-dip in K-IBA, while cuttings rooted in plugs treated with K-IBA + K-NAA exhibited similar or lesser results compared to cuttings receiving a basal quick-dip in K-IBA + K-NAA.

Index words: vegetative propagation, root-promoting chemicals, rooting substrate, plug production, plant growth regulators, adventitious rooting.

Growth regulators used in this study: K-IBA, potassium salt of indole-3-butyric acid; K-NAA, potassium salt of 1-naphthaleneacetic acid.

Species used in this study: 'Wintergreen' boxwood [*Buxus sinica* (Rehd. & Wils.) M. Cheng var. *insularis* (Nakai) M. Cheng 'Wintergreen']; Ebbinge's silverberry (*Elaeagnus* x *ebbingei* Boom ex Door.); weeping fig (*Ficus benjamina* L.); dwarf gardenia [*Gardenia augusta* (L.) Merrill 'Radicans']; 'Nigra' inkberry [*Ilex glabra* (L.) A. Gray 'Nigra']; dwarf yaupon holly (*Ilex vomitoria* Ait. 'Nana'); 'Blue Pacific' shore juniper (*Juniperus conferta* Parl. 'Blue Pacific'); Japanese ternstroemia [*Ternstroemia gymnanthera* (Wight & Arn.) Sprague]; Asian star jasmine [*Trachelospermum asiaticum* (Siebold & Zucc.) Nakai].

Significance to the Nursery Industry

Auxins as root-promoting chemicals are typically applied to stem cuttings as a basal quick-dip. Alternative methods of application, such as application of auxin via the rooting substrate, could have potential for improving employee safety through use of lower chemical concentrations and reduction of production costs with improved labor processes and automation. Stem cuttings treated with a conventional basal quick-dip receive a brief, or acute, exposure to an auxin solution, while cuttings treated with auxin via a stabilized organic substrate receive an extended, or chronic, exposure to the auxin solution. Results from our research demonstrate that woody stem cuttings can be rooted successfully in an auxin-treated, stabilized organic substrate (plugs comprised of peat and a polymer binder).

Depending upon the species, auxin formulation, and auxin concentration (and likely other factors such as stage of growth of the stock plant, rooting environment, composition of the substrate, etc.), an extended period of exposure can result in rooting and initial shoot growth that is less than, similar to, or better than results with a conventional basal quick-dip. Application of auxin to stem cuttings via the substrate can also allow use of a lower auxin concentration than that typically utilized for a basal quick-dip and reduce employee exposure to the chemicals. Cuttings treated with auxin in this manner receive an extended period of exposure to the auxin solution without the need for the repeated handling required with the extended basal soak technique (the latter generally requiring that the cuttings be bundled prior to placement in a shallow layer of auxin solution). Results suggest that auxin application via the substrate has potential to improve rooting response with a variety of plant species in comparison to a basal quick-dip, while being compatible with automated production systems.

Introduction

The ability of auxins to promote rooting of stem cuttings of ornamental plants has been known since the 1930s (3). In commercial propagation, auxin is typically applied to stem cuttings as a basal quick-dip using liquid or talc formulations or an extended basal soak using liquid formulations (5). Less common methods of applying auxin to stem cuttings include application via a foliar spray, insertion of auxin-treated objects into the cutting base, and total immersion of whole cuttings in an auxin solution (1, 2).

Current Worker Protection Standards in the United States mandate that employees receive safety training prior to using agricultural chemicals, including plant growth regulators such as auxins (often labeled as 'rooting hormones'), and wear personal protective safety equipment (11, 12). With

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concurrent emphasis on improving employee safety and reducing production costs through improved labor processes and automation, propagators could benefit from alternative methods of auxin application that permit use of lower concentrations and use of automated equipment. Incorporation of auxins directly into the rooting substrate could be one means of accomplishing these goals.

The literature contains no mention of auxin application to conventional stem cuttings by way of the rooting substrate; however, auxin-containing substrates for rooting are utilized in other methods of propagation. Microcuttings produced in tissue culture are often rooted in a Stage III substrate containing auxin (7). Auxin can also be incorporated into the rooting substrate used for air layering (13). Various retail products used as a post-transplant soil drench contain low concentrations of auxin. While basally applied auxin is capable of encouraging adventitious rooting, at elevated levels it can also inhibit subsequent budbreak (4, 10).

Stabilized organic substrates in the form of plugs have been used in commercial horticulture for cutting propagation, as well as seedling production and micropropagation (8, 9, 14, 15). Whereas conventional plugs are formed of loose component materials and rely upon a developed root system to prevent the plug from crumbling upon removal from plug trays, plugs manufactured using a stabilized organic substrate maintain their shape both in and out of a container as well as with or without the presence of a root system.

Therefore, the objective of the following research was to determine whether auxin applied as K-IBA or K-IBA + K-NAA via a stabilized organic substrate could be at least as effective as a basal quick-dip application for rooting cuttings of selected woody landscape plants. A preliminary study (data not presented) indicated that a low concentration of auxin (<100 ppm) applied via a stabilized organic substrate has potential for satisfactory cutting response in comparison to a conventional basal quick-dip.

Materials and Methods

Q Plug™ rooting plugs, stabilized organic substrate units containing peat and a polymer binder, were utilized as rooting substrate units, along with their corresponding plug trays as containers (International Horticultural Technologies, Hollister, CA). All plugs were dried for 24 hr at 46C (115F) and then soaked by submergence for 24 hr in deionized water or in auxin solutions. Auxin solutions were prepared by dissolving K-IBA or K-IBA + K-NAA (Sigma Chem. Co., St. Louis, MO) in deionized water to provide K-IBA at 15, 30, 45, 60, or 75 ppm, and K-IBA + K-NAA at 15 + 7.5, 30 + 15, 45 + 22.5, or 60 + 30 ppm.

Square plugs (8 cm^3 vol) and 288-cell polypropylene trays [trays: 52 cm × 26.7 cm (20.5 in × 10.5 in); cells: 1.9 cm (0.75 in) top diameter × 2.5 cm (1.0 in) depth] were used for cuttings of *Buxus sinica* var. *insularis* 'Wintergreen', with 180 plugs placed into the tray using eight of the 12 lengthwise rows of cells, leaving every third row of cells empty. Round plugs (19 cm^3 vol) and 200-cell polystyrene trays [trays: 34.3 cm × 67.3 cm (13.5 in × 26.5 in); cells: 2.6 cm (1.1 in) top diameter × 5.7 cm (2.25 in) depth] were used for cuttings of *Elaeagnus* x *ebbingei*, with 180 plugs placed into the tray leaving the first and last widthwise rows of cells empty. Hexagonal plugs (16.5 cm^3 vol.) and 144-cell polypropylene trays [tray: 52 cm × 26.7 cm (20.5 in × 10.5 in); cells: 2.5 cm (1.0 in) top diameter × 3.8 cm (1.5 in) depth] were used for cuttings of *Ficus benjamina*, *Juniperus conferta* 'Blue Pacific', and *Ternstroemia gymnanthera*, with 90 plugs placed into five of the eight cells per widthwise row of each tray (two trays per species) using a pattern of four alternating cells per row plus an additional fifth cell in a varying cell location in each row. Star-shaped plugs (4.5 cm^3 vol) and 406-cell polystyrene trays [trays: 54 cm × 25.4 cm (21.25 in × 10.0 in); cells: 1.3 cm (0.5 in) top diameter × 3.2 cm (1.25 in) depth] were used for cuttings of *Gardenia augusta* 'Radicans', *Ilex glabra* 'Nigra', *Ilex vomitoria* 'Nana', and *Trachelospermum asiaticum*, with 180 plugs placed into alternating cells throughout the tray (one tray per species), leaving the first and the last two widthwise rows of cells empty. Treatments were assigned to tray cells using a completely randomized design.

Cutting propagation material was collected from greenhouse container-grown stock plants (*Ficus benjamina*), outdoor container-grown stock plants (*Buxus sinica* var. *insularis* 'Wintergreen'), or landscape stock plants (all other species) on the campus of Auburn University, Auburn, AL (32°36'N, 85°29'W, USDA Hardiness Zone 8a). Semi-hardwood stem cuttings of *Buxus sinica* var. *insularis* 'Wintergreen' were prepared as 5 cm (2 in) long, three-node subterminal cuttings with leaves removed from the basal node, inserted into plugs on February 20, 2003, and evaluated after 87 days. Semi-hardwood stem cuttings of *Elaeagnus* x *ebbingei* were prepared as 5 cm (2 in) long, four-node subterminal cuttings with a leaf removed from the basal node, inserted into plugs on February 20, 2003, and evaluated after 88 days. Semi-hardwood stem cuttings of *Ficus benjamina* were prepared with three mature leaves and a leaf removed from the basal node, inserted into plugs on December 8, 2002, and evaluated for rooting after 71 days (with no shoot growth having developed at this time). Plugs of rooted cuttings of *Ficus benjamina* were planted using Fafard 3B mix (a blend of peat, perlite, vermiculite, and pine bark; Conrad Fafard, Inc., Agawam, MA) into individual pots of X-3SQSP sheets of square pots [181 cm^3 (11 in^3) soil vol per pot] set into L1020NCR polystyrene trays (Landmark Plastics, Akron, OH) and grown for an additional 91 days for evaluation of initial shoot growth. Semi-hardwood stem cuttings of *Gardenia augusta* 'Radicans' were prepared as 2.5 cm (1 in) long, two-node subterminal cuttings with leaves removed from the basal node, inserted into plugs on January 8, 2003, and evaluated for rooting after 105 days (with no shoot growth having developed at this time). Plugs of rooted cuttings of *Gardenia augusta* 'Radicans' were planted in the same manner as *Ficus benjamina* and grown for an additional 52 days for evaluation of initial shoot growth. Semi-hardwood stem cuttings of *Ilex glabra* 'Nigra' were prepared as 3.8 cm (1.5 in) long terminal cuttings with leaves removed from the basal 1.3 cm (0.5 in), inserted into plugs on January 18, 2003, and evaluated after 118 days. Hardwood stem cuttings of *Ilex vomitoria* 'Nana' were prepared as 10 cm (4 in) long subterminal cuttings with leaves removed from the basal 1.3 cm (0.5 in), inserted into plugs on January 18, 2002, and evaluated after 119 days. Hardwood stem cuttings of *Juniperus conferta* 'Blue Pacific' were prepared as 10 cm (4 in) subterminal cuttings with branchlets removed from the basal 1.3 cm (0.5 in), inserted into plugs on December 9, 2002, and evaluated after 84 days. Semi-hardwood stem cuttings of *Ternstroemia gymnanthera* were prepared as 5 cm (2 in) long terminal cuttings with leaves removed from the basal 2.5 cm (1 in), inserted into plugs on February 21, 2003, and evaluated after 105 days. Semi-hardwood stem cuttings of *Trachelospermum asiaticum* were prepared as 7 cm (2.75 in) long, two-node subterminal cuttings, inserted into plugs on January 18, 2003, and evaluated after 53 days. All cuttings were inserted into plugs to a depth of 5 mm.

Cuttings in one treatment received no auxin treatment, while cuttings in a second and third treatment received a 1 sec basal quick-dip in 1000 ppm K-IBA or 1000 ppm K-IBA + 500 ppm KNAA (dissolved in deionized water), respectively; cuttings in these three treatments were inserted to a depth of 0.6 cm (0.25 in) into plugs that had been soaked in water. Cuttings in the remaining nine treatments were inserted to the same depth into plugs that had been soaked in auxin solutions. Cuttings of all species were inserted in separate trays with 15 cuttings per treatment and placed under a greenhouse mist system providing overhead mist for 6 seconds every 20 minutes during daylight hours. After potting, rooted cuttings of *Ficus benjamina* and *Gardenia augusta* 'Radicans' were grown under the same mist system. Maximum photosynthetically active radiation measured in the greenhouse on the cutting bench with a LI-6200 portable photosynthesis system (LI-COR, Inc., Lincoln, NE) was 600 □mol/m^2/sec and daily maximum/minimum temperatures in the greenhouse were 27 ± 6C (80 ± 10F)/18 ± 3C (65 ± 5F).

Rooting percentage and percentage of rooted cuttings with shoot growth were evaluated with logistic regression and compared with the corresponding basal quick-dip treatment (percentages for treatment 1 were compared with both basal quick-dip treatments) using single degree-of-freedom orthogonal contrasts. A cutting was classified as rooted if it produced at least one root visible on the outer surface of the plug upon removal from the cell tray. Roots emerging from the cutting base were used for root counts and root length measurements. Least squares means were calculated for number of roots, total root length, and total shoot length per rooted cutting. Regression analysis was used to determine trends in responses (number of roots, total root length, and total shoot length per rooted cutting) to auxin levels in the treated plugs, and Dunnett's Test was used to compare treatment means for these three variables with the corresponding basal quick-dip treatment (means for treatment 1 were compared with both basal quick-dip treatments). A significance level of $\alpha = 0.10$ was selected in advance based upon preliminary trials which showed clusters of *p*-values at or below 0.10 when using the same sample size. Statistical analyses were conducted using the SAS® System, Release 8.2 (SAS Institute, Inc., Cary, NC).

Results and Discussion

Treatment of stem cuttings with auxin may be used not only to increase the percentage of cuttings that initiate roots, but also to hasten root initiation and increase the uniformity of rooting (5). Effectiveness of exogenous applications of auxin in promoting rooting on stem cuttings is dependant on adequate absorption by plant tissue. Absorption of auxin solutions at the base of stem cuttings can be influenced by auxin concentration and treatment duration, with increasing concentration and duration providing greater uptake (6). However, supraoptimal levels of auxin may inhibit budbreak or shoot development (2, 4, 10).

In the current study, acceptable rooting percentages were obtained using several auxin treatments or with no auxin treatment with all species/cultivars tested. Cutting propagation material of optimal quality was utilized for preparation of all cuttings. Material of varying quality, sometimes the only type of material available in large-scale production, could produce different (sometimes lesser) results. In the latter case, commercial propagators often utilize auxin treatments to ensure relatively consistent rooting responses throughout the cutting crop, even on a generally easy-to-root species or cultivar.

Buxus sinica var. *insularis* 'Wintergreen'. All treatments resulted in 100% rooting (Table 1). Number of roots per rooted cutting in untreated and auxin-treated plugs was similar to cuttings receiving a basal quick-dip. Total root length was greater for cuttings rooted in plugs treated with 60 ppm K-IBA than cuttings receiving a basal quick-dip in 1000 ppm K-IBA. Percent of rooted cuttings with shoots and total shoot length was similar for cuttings in untreated and auxin-treated plugs compared to cuttings receiving a basal quick-dip, indicating no inhibitory effect on initial shoot growth by supplying auxin via the substrate. The data suggests that enhancement of root number, root length, and shoot development with auxin-treated cuttings over untreated cuttings could be indicated if a larger sample size had been used in the trial.

Elaeagnus x *ebbingei*. Cuttings in plugs treated with 45 ppm K-IBA and 60 ppm K-IBA produced greater rooting percentages than cuttings receiving a basal quick-dip in 1000 ppm K-IBA (Table 1). Cuttings rooted in plugs treated with concentrations of K-IBA ≥ 30 ppm or K-IBA + K-NAA ≥ 45 ppm + 22.5 ppm produced more roots than cuttings treated with the corresponding basal quick-dip treatments, while total root length was greater for cuttings rooted in plugs treated with K-IBA at concentrations of 45 ppm and 60 ppm or K-IBA + K-NAA ≥ 30 ppm + 15 ppm than cuttings treated with the corresponding basal quick-dip treatments. Cuttings showed an increasing response in number of roots and total root length with increasing concentration of K-IBA + K-NAA. Overall results indicate that the inclusion of K-NAA in the treated plugs was beneficial to root development.

Percent of rooted cuttings with new shoots for cuttings in untreated and K-IBA-treated plugs was similar to cuttings receiving a basal quick-dip in K-IBA, and similar or greater for cuttings in untreated and K-IBA + K-NAA-treated plugs compared to cuttings receiving a basal quick-dip in K-IBA + K-NAA. Cuttings rooted in plugs treated with K-IBA showed a decreasing linear response in total shoot length with increasing auxin concentration. However, indication of some suppression of shoot growth in auxin-treated plugs did not appear to be due to the effect of auxin alone, as the response was not exhibited with the K-IBA + K-NAA-treated plugs; other factors, such as size of the root system and its promoting effect on shoot growth, could have influenced the rate of initial shoot development as well.

Ficus benjamina. Auxin was not necessary to induce rooting; however, cuttings in most of the K-IBA treatments and all of the K-IBA + K-NAA treatments produced more roots per cutting than did their corresponding basal quick-dip treatments (Table 1). Total root length was greater on cuttings rooted in plugs treated with K-IBA at 30 ppm and 75 ppm or K-IBA + K-NAA at concentrations ≥ 30 ppm + 15 ppm. All rooted cuttings produced new shoot growth. Total shoot length was less on cuttings rooted in plugs treated with K-IBA +

Table 1. **Rooting and initial shoot growth response of stem cuttings of selected woody landscape plants to K-IBA or K-IBA + K-NAA applied via a treated plug or a basal quick-dip.**

Auxin treatment (ppm)[z]	Rooting (%)[y]	Mean no. roots/rooted cutting[x]	Mean total root length/rooted cutting (mm)[x]	Rooted cuttings with new shoots (%)	Mean total shoot length/rooted cutting (mm)[x]
***Buxus sinica* var. *insularis* 'Wintergreen'**					
Untreated	100.0%	8.7	227	60.0%	5.3
15 K-IBA treated plug	100.0%	10.1	315	93.3%	7.5
30 K-IBA treated plug	100.0%	10.7	324	80.0%	8.0
45 K-IBA treated plug	100.0%	10.3	312	73.3%	9.0
60 K-IBA treated plug	100.0%	9.9	361A[w]	66.7%	4.4
75 K-IBA treated plug	100.0%	9.8	342	73.3%	6.3
Response[v]	NS	NS	L**	NS	NS
1000 K-IBA basal quick-dip	100.0%	8.9	276	73.3%	5.1
15 K-IBA + 7.5 K-NAA treated plug	100.0%	9.9	321	73.3%	9.5
30 K-IBA + 15 K-NAA treated plug	100.0%	9.4	341	80.0%	7.3
45 K-IBA + 22.5 K-NAA treated plug	100.0%	8.3	317	66.7%	5.7
60 K-IBA + 30 K-NAA treated plug	100.0%	9.4	272	80.0%	7.1
Response[v]	NS	NS	Q**	NS	NS
1000 K-IBA + 500 K-NAA basal quick-dip	100.0%	10.5	300	66.7%	6.5
Elaeagnus* x *ebbingei					
Untreated	66.7%	2.5	132	100.0%B[u]	40.4 B
15 K-IBA treated plug	66.7%	2.5	131	100.0%	30.3
30 K-IBA treated plug	60.0%	3.6A	176	100.0%	38.7
45 K-IBA treated plug	86.7%A	3.8A	210A	100.0%	26.5
60 K-IBA treated plug	86.7%A	3.7A	205A	100.0%	19.0a
75 K-IBA treated plug	73.3%	3.2A	156	90.9%	13.2a
Response[v]	NS	L*Q*	Q*	NS	L***
1000 K-IBA basal quick-dip	60.0%	2.0	107	88.9%	32.4
15 K-IBA + 7.5 K-NAA treated plug	40.0%	2.7	146	83.3%	17.8
30 K-IBA + 15 K-NAA treated plug	80.0%	4.3	225 B	83.3%	16.6
45 K-IBA + 22.5 K-NAA treated plug	60.0%	6.8 B	333 B	100.0% B	26.3
60 K-IBA + 30 K-NAA treated plug	73.3%	6.9 B	354 B	100.0% B	20.7
Response[v]	NS	L***	L***	NS	L*Q**
1000 K-IBA + 500 K-NAA basal quick-dip	53.3%	2.5	126	75.0%	21.6
Ficus benjamina					
Untreated	100.0%	5.3	225	100.0%	142.7
15 K-IBA treated plug	100.0%	6.6	285	100.0%	157.3
30 K-IBA treated plug	100.0%	9.8A	391A	100.0%	137.5
45 K-IBA treated plug	100.0%	8.9A	326	100.0%	168.5
60 K-IBA treated plug	100.0%	7.1	278	100.0%	143.3
75 K-IBA treated plug	100.0%	9.9A	376A	100.0%	106.3
Response[v]	NS	L***Q*	L**	NS	NS
1000 K-IBA basal quick-dip	100.0%	6.6	254	100.0%	147.9
15 K-IBA + 7.5 K-NAA treated plug	100.0%	10.6 B	352	100.0%	110.4b
30 K-IBA + 15 K-NAA treated plug	100.0%	10.7 B	357 B	100.0%	98.1b
45 K-IBA + 22.5 K-NAA treated plug	100.0%	11.3 B	392 B	100.0%	87.6b
60 K-IBA + 30 K-NAA treated plug	100.0%	9.5 B	295 B	100.0%	158.5
Response[v]	NS	L***Q***	L*Q***	NS	Q***
1000 K-IBA + 500 K-NAA basal quick-dip	100.0%	5.8	241	100.0%	186.7

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Table 1. Rooting and initial shoot growth response of stem cuttings of selected woody landscape plants to K-IBA or K-IBA + K-NAA applied via a treated plug or a basal quick-dip. (continued)

Auxin treatment (ppm)[z]	Rooting (%)[y]	Mean no. roots/rooted cutting[x]	Mean total root length/rooted cutting (mm)[x]	Rooted cuttings with new shoots (%)	Mean total shoot length/rooted cutting (mm)[x]
			***Gardenia augusta* ‘Radicans’**		
Untreated	100.0%	5.7	166ab	100.0%	16.9
15 K-IBA treated plug	100.0%	5.7	215	93.3%	13.7
30 K-IBA treated plug	100.0%	6.8	270	100.0%	16.5
45 K-IBA treated plug	100.0%	7.2	281	100.0%	13.4
60 K-IBA treated plug	100.0%	7.3	297A	100.0%	12.9
75 K-IBA treated plug	100.0%	9.3A	391A	100.0%	17.5
Response[v]	NS	L***	L***	NS	NS
1000 K-IBA basal quick-dip	100.0%	6.4	245	100.0%	17.9
15 K-IBA + 7.5 K-NAA treated plug	100.0%	7.6	323	100.0%	12.7b
30 K-IBA + 15 K-NAA treated plug	100.0%	8.5	348 B	93.3%	10.3b
45 K-IBA + 22.5 K-NAA treated plug	100.0%	9.9 B	419 B	100.0%	11.3b
60 K-IBA + 30 K-NAA treated plug	100.0%	10.1 B	406 B	93.3%	12.0b
Response[v]	NS	L***	L***Q**	NS	L**Q**
1000 K-IBA + 500 K-NAA basal quick-dip	100.0%	7.2	273	100.0%	18.7
			***Ilex glabra* ‘Nigra’**		
Untreated	100.0%	5.4	153	80.0%	9.8
15 K-IBA treated plug	100.0%	6.5A	191A	86.7%	11.7
30 K-IBA treated plug	100.0%	5.2	157	86.7%	7.9
45 K-IBA treated plug	100.0%	6.1A	176A	93.3%	10.9
60 K-IBA treated plug	100.0%	6.0A	167A	86.7%	12.9
75 K-IBA treated plug	93.3%	6.8A	202A	100.0%	13.1
Response[v]	NS	NS	NS	L*	NS
1000 K-IBA basal quick-dip	93.3%	4.8	124	92.9%	7.9
15 K-IBA + 7.5 K-NAA treated plug	100.0%	5.1	143	86.7%	11.1
30 K-IBA + 15 K-NAA treated plug	93.3%	3.6b	109	57.1%	7.1
45 K-IBA + 22.5 K-NAA treated plug	100.0%	4.5	129	66.7%	8.0
60 K-IBA + 30 K-NAA treated plug	93.3%	3.6b	97b	64.3%	7.5
Response[v]	NS	L**	L**	NS	NS
1000 K-IBA + 500 K-NAA basal quick-dip	100.0%	5.1	137	80.0%	10.3
			***Ilex vomitoria* ‘Nana’**		
Untreated	86.7%	3.2	62	100.0%	5.5
15 K-IBA treated plug	53.3%	3.9	81	100.0%	5.3
30 K-IBA treated plug	80.0%	4.2	91	100.0%	4.7
45 K-IBA treated plug	40.0%	4.2	105	100.0%	7.3
60 K-IBA treated plug	80.0%	4.5	107	100.0%	7.3
75 K-IBA treated plug	86.7%	5.2A	132A	100.0%	7.4
Response[v]	Q*	L*	L*	NS	NS
1000 K-IBA basal quick-dip	73.3%	3.0	65	90.9%	5.6
15 K-IBA + 7.5 K-NAA treated plug	60.0%	3.1	74	66.7%b	3.2
30 K-IBA + 15 K-NAA treated plug	6.7%b	1.0	15	0.0%b	0.0b
45 K-IBA + 22.5 K-NAA treated plug	0.0%b	—	—	—	—
60 K-IBA + 30 K-NAA treated plug	0.0%b	—	—	—	—
Response[v]	L***	L*	Q**	L***	L***
1000 K-IBA + 500 K-NAA basal quick-dip	86.7%	3.0	66	92.3%	5.6

Table 1 continued on page 68

Table 1. Rooting and initial shoot growth response of stem cuttings of selected woody landscape plants to K-IBA or K-IBA + K-NAA applied via a treated plug or a basal quick-dip. (continued)

Auxin treatment (ppm)[z]	Rooting (%)[y]	Mean no. roots/rooted cutting[x]	Mean total root length/rooted cutting (mm)[x]	Rooted cuttings with new shoots (%)	Mean total shoot length/rooted cutting (mm)[x]
***Juniperus conferta* 'Blue Pacific'**					
Untreated	66.7%	7.8	280	90.0%	5.8ab
15 K-IBA treated plug	86.7%	9.0	320	100.0%	10.2
30 K-IBA treated plug	80.0%	14.5A	454A	91.7%	9.2
45 K-IBA treated plug	86.7%	15.8A	540A	92.3%	6.6a
60 K-IBA treated plug	93.3%	21.8A	652A	92.9%	8.4
75 K-IBA treated plug	93.3%	16.5A	498A	92.9%	8.3
Response[v]	NS	L***	L**	NS	NS
1000 K-IBA basal quick-dip	73.3%	5.6	171	90.9%	12.6
15 K-IBA + 7.5 K-NAA treated plug	86.7% B	12.4	434	92.3%	7.5b
30 K-IBA + 15 K-NAA treated plug	60.0%	10.9	363	100.0%	7.8b
45 K-IBA + 22.5 K-NAA treated plug	53.3%	7.3	239	37.5%b	1.9b
60 K-IBA + 30 K-NAA treated plug	13.3%b	1.5	29b	50.0%b	1.5b
Response[v]	L***Q*	L*Q*	L*Q*	NS	NS
1000 K-IBA + 500 K-NAA basal quick-dip	60.0%	9.9	318	100.0%	12.9
Ternstroemia gymnanthera					
Untreated	66.7%	3.1	99	100.0%AB	23.3
15 K-IBA treated plug	46.7%	2.9	72	85.7%	18.3
30 K-IBA treated plug	66.7%	4.0	119	80.0%	19.1
45 K-IBA treated plug	53.3%	2.4	60	75.0%	25.0
60 K-IBA treated plug	73.3%	2.5	72	63.6%	24.2
75 K-IBA treated plug	60.0%	2.3	55	66.7%	23.9
Response[v]	NS	NS	NS	L*	NS
1000 K-IBA basal quick-dip	60.0%	4.8	150	66.7%	20.8
15 K-IBA + 7.5 K-NAA treated plug	53.3%	5.5 B	188 B	75.0%	16.6
30 K-IBA + 15 K-NAA treated plug	46.7%	3.4	104	71.4%	24.6
45 K-IBA + 22.5 K-NAA treated plug	13.3%b	5.5	198	0.0%b	0.0b
60 K-IBA + 30 K-NAA treated plug	33.3%	2.4	76	20.0%b	3.4b
Response[v]	L**	NS	NS	L***	L**
1000 K-IBA + 500 K-NAA basal quick-dip	60.0%	1.9	50	66.7%	29.3
Trachelospermum asiaticum					
Untreated	100.0%	17.2A	82	100.0%	262.7
15 K-IBA treated plug	100.0%	19.7A	83	100.0%	285.5A
30 K-IBA treated plug	100.0%	15.4	80	100.0%	220.7
45 K-IBA treated plug	100.0%	16.7	87	100.0%	257.9
60 K-IBA treated plug	100.0%	17.5A	69	100.0%	240.3
75 K-IBA treated plug	100.0%	18.3A	80	100.0%	258.9
Response[v]	NS	NS	NS	NS	L*
1000 K-IBA basal quick-dip	100.0%	13.4	73	100.0%	213.1
15 K-IBA + 7.5 K-NAA treated plug	100.0%	16.7	71	100.0%	263.8
30 K-IBA + 15 K-NAA treated plug	100.0%	16.3	73	100.0%	248.0
45 K-IBA + 22.5 K-NAA treated plug	100.0%	20.9B	68	100.0%	314.0
60 K-IBA + 30 K-NAA treated plug	100.0%	23.3B	71	100.0%	343.1B
Response[v]	NS	L** Q*	NS	NS	L*
1000 K-IBA + 500 K-NAA basal quick-dip	100.0%	15.7	74	100.0%	263.3

[z]Plugs were soaked in auxin (for the nine K-IBA and K-IBA + K-NAA treatments) or water (for the 'Untreated', '1000 K-IBA basal quick-dip', and '1000 K-IBA + 500 K-NAA basal quick-dip' treatments) prior to placement in plug trays and insertion of cuttings.

[y]Fifteen cuttings per treatment per species/cultivar.

[x]Least squares means calculated using rooted cuttings only.

[w]Percentages and means for untreated cuttings or cuttings treated with K-IBA followed by 'a' or 'A' within a column, species/cultivar, and auxin formulation are significantly less or greater, respectively, than for the K-IBA basal quick-dip treatment according to single degree-of-freedom orthogonal contrasts for percentages and Dunnett's Test for all other variables ($\alpha = 0.10$).

[v]Nonsignificant (NS) or significant linear (L) or quadratic (Q) regression response by species/cultivar and auxin formulation at $P \leq 0.10$ (*), 0.01 (**), or 0.001 (***). Untreated cuttings were included in each regression analysis.

[u]Percentages and means for untreated cuttings or cuttings treated with K-IBA + K-NAA followed by 'b' or 'B' within a column, species/cultivar, and auxin formulation are significantly less or greater, respectively, than the mean for the K-IBA + K-NAA basal quick-dip treatment according to single degree-of-freedom orthogonal contrasts for percentages and Dunnett's Test for all other variables ($\alpha \leq 0.10$).

K-NAA at concentrations ≤ 45 ppm + 22.5 ppm, indicating than K-NAA could have caused some suppression of shoot growth. However, rooted cuttings in plugs treated with 60 ppm K-IBA + 30 ppm K-NAA did not exhibit any suppression; the cause of this anomaly was not evident.

Gardenia augusta 'Radicans'. Cuttings rooted at 100% in all treatments; however cuttings rooted in plugs treated with K-IBA at 75 ppm or K-IBA + K-NAA at 45 ppm + 22.5 ppm and 60 ppm + 30 ppm produced more roots than cuttings receiving a basal quick-dip in K-IBA or K-IBA + K-NAA (Table 1). Cuttings rooted in plugs treated with K-IBA at concentrations of 60 ppm and 75 ppm or K-IBA + K-NAA at concentrations ≥ 30 ppm K-IBA + 15 ppm K-NAA produced greater total root length than cuttings receiving the basal quick-dip treatments, while total root length was less on cuttings receiving no auxin treatment. In addition, cuttings rooted in auxin-treated plugs exhibited a increasing linear response in number of roots with increasing auxin concentration with both K-IBA treatments and K-IBA + K-NAA treatments. Results indicate that, while auxin is not required to stimulate rooting on this species, auxin is required to optimize the root number.

Most cuttings exhibited new shoot development. Total shoot length on cuttings rooted in untreated plugs and K-IBA treated plugs was similar to cuttings receiving the K-IBA basal quick-dip, but lower on cuttings rooted in K-IBA + K-NAA-treated plugs compared to the K-IBA + K-NAA basal quick-dip. However, suppression of initial shoot growth on cuttings rooted in the K-IBA + K-NAA-treated plugs appeared to be temporary, as a general examination of the plants after an additional month showed no readily observable differences among the treatments.

Although detailed observation of the rooted cuttings was not continued beyond the initial period of root development and shoot growth, our general observation was that cuttings with the largest root systems (greatest root number and/or total root length) grew faster than those with smaller root systems. This may be an advantage to growers seeking to minimize production time of this or other cutting-grown crops, particularly short-term production crops.

Ilex glabra 'Nigra'. Auxin was not required to initiate roots on cuttings of this species; however, most of the K-IBA treatments produced more roots and greater total root length per rooted cutting than the K-IBA basal quick-dip (Table 1). Number of roots and total root length on cuttings treated with K-IBA + K-NAA was similar or less than on cuttings receiving a basal quick-dip in K-IBA + K-NAA, suggesting that K-IBA alone is preferable to a combination of K-IBA + K-NAA for overall root development with this species. Percent of rooted cuttings with shoots and total shoot length was similar for cuttings in untreated and auxin-treated plugs compared to cuttings receiving a basal quick-dip, indicating no inhibitory effect on shoot growth when supplying auxin by way of the substrate.

Ilex vomitoria 'Nana'. Cuttings in untreated and K-IBA-treated plugs produced rooting percentages similar to cuttings receiving a basal quick-dip in K-IBA (Table 1). However, cuttings rooted in plugs treated with K-IBA + K-NAA at concentrations ≥ 30 ppm + 15 ppm exhibited little or no rooting, indicating that K-NAA is undesirable for incorporation into the rooting substrate for this species. K-IBA at 75 ppm produced the greatest number of roots and total root length per rooted cutting. New shoots developed on all cuttings rooted in untreated and K-IBA-treated plugs, while fewer rooted cuttings produced new shoot growth in the K-IBA + K-NAA-treated plugs compared to cuttings receiving a basal quick-dip. Total shoot length on rooted cuttings in the untreated and K-IBA treated plugs was similar to cuttings receiving a basal quick-dip in K-IBA, indicating no shoot suppressive activity by these auxin treatments.

Juniperus conferta 'Blue Pacific'. Rooting percentages for cuttings rooted in untreated and K-IBA-treated plugs were similar to cuttings receiving a basal quick-dip in K-IBA (Table 1); however, rooting percentages were greater for cuttings treated with K-IBA at 60 ppm and 75 ppm than for untreated cuttings (according to single degree-of-freedom orthogonal contrasts; actual $P = 0.06$ for both contrasts). Cuttings in plugs treated with K-IBA + K-NAA showed a decreasing response in rooting percentage; rooting percentages with K-IBA + K-NAA at 15 ppm + 7.5 and 60 ppm + 30 ppm were higher and lower, respectively, than with the basal quick-dip in K-IBA + K-NAA. Cuttings rooted in plugs treated with K-IBA at concentrations ≥ 30 ppm produced more roots per cutting and greater total root length than cuttings receiving a basal quick-dip in K-IBA. Number of roots on cuttings rooted in K-IBA + K-NAA-treated plugs was similar to the basal quick-dip in K-IBA + K-NAA, except at the highest concentration at which total root length was less.

Percent of rooted cuttings with new shoot growth in plugs treated with K-IBA + K-NAA at 45 ppm + 22.5 ppm and 60 ppm + 30 ppm was lower than with cuttings receiving the basal quick-dip in K-IBA + K-NAA; results with other treatments were similar to the basal quick-dip treatments. Total shoot length was less with untreated cuttings compared to either of the basal quick-dip treatments and less on rooted cuttings in K-IBA + K-NAA-treated plugs compared to the K-IBA + K-NAA basal quick-dip. Overall results indicate that K-IBA treatments were preferable to K-IBA + K-NAA treatments for rooting cuttings of this cultivar.

Ternstroemia gymnanthera. Rooting percentages with untreated cuttings and cuttings in auxin-treated plugs were similar to cuttings receiving the basal quick-dip treatments, except for cuttings in plugs treated with 45 ppm + 22.5 ppm K-IBA + K-NAA which had a lower rooting percentage (Table 1). Number of roots and total root length per rooted cutting with untreated cuttings and cuttings in auxin-treated plugs were also similar to cuttings receiving the basal quick-dip treatments, except for cuttings in plugs treated with 15 ppm + 7.5 ppm K-IBA + K-NAA which had more roots.

Percent of cuttings with new shoots was greater with cuttings receiving no auxin treatment compared to the basal quick-dip treatments, less with cuttings treated with K-IBA + K-NAA at concentrations ≥ 45 ppm + 22.5 ppm, and similar for all other treatments. Total shoot length on cuttings rooted in plugs treated with K-IBA + K-NAA at concentrations ≥ 45 ppm + 22.5 ppm was less than with cuttings receiving the K-IBA + K-NAA basal quick-dip and similar for all other treatments compared to their respective basal quick-dip treatments. Overall, results with this species indicate that satisfactory rooting and subsequent shoot growth could be obtained without auxin treatment.

Trachelospermum asiaticum. Cuttings in all treatments produced roots and new shoots (Table 1). Number of roots on untreated cuttings and cuttings rooted in auxin-treated plugs was similar or greater than cuttings receiving the basal quick-dip treatments, while total root length was similar with all treatments. Total shoot length was greater with cuttings rooted in plugs treated with K-IBA at 15 ppm and K-IBA + K-NAA at 60 ppm + 30 ppm compared to their respective basal quick-dip treatments, and similar for other treatments.

Rooting percentage, number of roots per rooted cutting, and total root length per rooted cutting for stem cuttings rooted in plugs treated with K-IBA or K-IBA + K-NAA were generally similar to, and sometimes greater than, cuttings receiving a basal quick-dip. In a few cases, lesser results were obtained with the rooting of certain species when K-NAA was included with K-IBA in the plugs treatments, and generally were noted at the higher concentrations of auxin tested.

Percent of rooted cuttings with new shoots and shoot length per rooted cutting for cuttings rooted in plugs treated with K-IBA were mostly similar to cuttings receiving a basal quick-dip, indicating the K-IBA treatments did not tend to have an inhibitory or suppressive effect on budbreak and shoot growth. Shoot growth response on cuttings rooted in plugs treated with K-IBA + K-NAA varied among species.

Rooting responses with untreated cuttings were generally similar to cuttings treated with either K-IBA or K-IBA + K-NAA as a basal quick-dip, exceptions being stem cuttings of *Gardenia augusta* 'Radicans' which produced greater total root length in response to both quick-dip treatments than when untreated and stem cuttings of *Trachelospermum asiaticum* which produced more roots when untreated compared to cuttings receiving a basal quick-dip in K-IBA alone. All species tested showed improved rooting (greater rooting percentage, number of roots, and/or total root length) in at least one of the auxin-treated plug treatments in comparison to one or both of the basal quick-dip treatments.

Results indicate that improvements in rooting of both easy- and less-easy-to-root species over a conventional basal quick-dip are possible by applying auxin to stem cuttings via a stabilized organic substrate provided an appropriate formulation and concentration of auxin is selected. Comparative results between the two methods of application could vary depending upon the type and concentration of auxin utilized for the basal quick-dip. Although more work is needed, results suggest that, along with providing equal or better rooting response with a variety of plant species, use of auxin-treated plugs for stem cuttings can permit use of lower chemical concentrations. In addition, elimination of the manual quick-dip process on cuttings benefiting from auxin treatment is a possibility. The technique is compatible with automated production systems where manual steps in the propagation process are reduced or eliminated.

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