Potential for Phytotoxicity Using Alcohol-containing Solutions of Auxin in Cutting Propagation

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Abstract. **In response to commercial propagators' concerns regarding potential phytotoxicity of alcohol used in root-promoting solutions of auxin for cutting propagation, three studies were conducted using stem cuttings of seven herbaceous and woody plant taxa. In study 1, cuttings received a basal quick dip in solutions prepared with indole-3-butyric acid (IBA; as water-soluble salts) at three rates (0, 1000, or 2000 ppm) in combination with isopropyl alcohol at three rates (0%, 25%, or 50%). In study 2, cuttings received a basal quick dip in solutions prepared with IBA + 1-naphthalene acetic acid from a liquid concentrate at three rates (0 + 0, 500 + 250, or 1000 + 500 ppm) in combination with isopropyl alcohol at three rates [minimum required to maintain the auxins in solution (0%, 7.5%, or 15%, respectively), 25%, or 50%]. In study 3, cuttings were treated with a 5-second, total immersion in solutions prepared with IBA (as water-soluble salts) at three rates (0, 100, or 200 ppm) in combination with isopropyl alcohol at three rates (0%, 25%, or 50%). Stem cuttings of African wormwood (*Artemisia afra*), Mammoth™ 'Yellow Quill' chrysanthemum (*Chrysanthemum ×hybridum*), 'Mary Helen' geranium (*Pelargonium ×hortorum*), 'Coral' impatiens (*Impatiens ×hybrida*), 'New Gold' lantana (*Lantana camara*), weeping fig (*Ficus benjamina*), and star jasmine (*Trachelospermum jasminoides*) were used in all three studies. Cuttings of any one taxon were collected in separate batches for each study at an appropriate time of year for that taxon. All cuttings were rooted under intermittent mist in a greenhouse. Rooted and unrooted cuttings were assessed for phytotoxicity as observable stem necrosis ("stem burn") and leaf necrosis ("leaf burn"). In study 1, the nine treatments did not cause any stem or leaf necrosis on cuttings of the seven taxa. In study 2, the nine treatments did not cause any stem or leaf necrosis on cuttings of any of the seven taxa, except for limited stem necrosis on some cuttings of 'New Gold' lantana. In study 3, the nine treatments did not cause any stem or leaf necrosis on cuttings of Mammoth™ 'Yellow Quill' chrysanthemum, 'Coral' impatiens, or weeping fig but caused stem and leaf necrosis on cuttings of African wormwood, 'Mary Helen' geranium, and 'New Gold' lantana. No stem or leaf necrosis was observed on cuttings of star jasmine; however, solutions containing 50% alcohol (regardless of IBA rate) increased the percentage of dead cuttings of this taxon compared with solutions containing 0% or 25% alcohol. Overall, use of alcohol-containing solutions of auxin applied with a basal quick dip resulted in no or little phytotoxicity on stem cuttings, whereas cutting response to total immersion in alcohol-containing solutions of IBA varied by taxon from no to severe phototoxicity.**

Plant propagation, the process of multiplying selected plant species by sexual and asexual methods, is a fundamental activity in nursery plant production (Hartmann et al. 2011). Asexual propagation allows growers to produce new plants from production stock, maintain genetic characteristics of clonal plant selections, and meet consumer demand. Asexual propagation by stem cuttings involves promoting initiation of adventitious roots on leafy (and sometimes leafless) stem pieces during the growing season (herbaceous, softwood, and semihardwood cuttings) or dormant season (hardwood cuttings) (Hartmann et al. 2011).

Auxins are one of several naturally occurring phytohormones in plants and are involved with many plant responses; however, their most important role in plant propagation is to promote adventitious rooting of cuttings (Crawford 2005). Formulations of indole-3-butyric acid (IBA) alone and IBA + 1-naphthalene acetic acid (NAA) are used in commercial nursery production to initiate rooting, increase rooting percentage, and enhance quality and number of roots. These auxin-containing products (commonly referred to in the nursery industry as "rooting hormones") are available in liquid concentrate, powder (talc), and water-soluble salt forms (Blythe et al. 2007). In the United States, only products registered with the Environmental Protection Agency may be sold and used for commercial nursery propagation (Boyer et al. 2013).

There are several methods of auxin application used in stem cutting propagation. The basal quick-dip method is used most often due to its ease of application directly to the site of rooting (Crawford 2005). Application of auxin to cutting foliage using total immersion into a solution of auxin (before insertion into a rooting substrate) or using a foliar spray (after insertion into a rooting substrate) is effective for some crops (Drahn 2007; Kohler et al. 2022; Strasko 1992; Van Bragt et al. 1976). Effectiveness of exogenous applications of auxins depends on adequate translocation from the application site to the site of adventitious root formation. Translocation of applied auxins has been reported to occur acropetally in xylem with the transpiration stream and then laterally into surrounding tissues (Blythe et al. 2007).

Isopropyl alcohol and ethyl alcohol can be used as solvents or carriers for auxin formulations when using the basal quick-dip method. Some propagators add alcohol to prevent precipitation of auxin solutions in refrigerated storage and to avoid possible contamination of solutions during use with the basal quick-dip method (Skimina C, personal communication).

There have been reports in nursery industry publications that use of alcohol in auxin solutions can cause phototoxicity exhibited as necrosis of stem or leaf tissue ("stem burn" or "leaf burn") on stem cuttings (Berry 1994; Cerveny and Gibson 2005; Kroin 2011, 2015). In a survey of Southeastern US nurseries conducted by McCracken (1987), 23 of 38 nurseries reported phytotoxicity symptoms thought to be due to alcohol in the IBA solutions being used for stem cutting propagation of 30 taxa of primarily woody crops. McCracken (1987) examined solutions of reagent grade IBA (0, 1000, 3000, or 5000 ppm) prepared

with the solvents ethanol, isopropyl alcohol, polyethylene glycol 400, or propylene glycol (each at 50% by volume) applied as a 5-s basal quick dip on cuttings of five taxa [leaf cuttings of 'Royal Ace' tomato (*Solanum lycopersicum*) and stem cuttings of 'Aurora' geranium (*Pelargonium ×hortorum*), 'Crimson Pygmy' barberry (*Berberis thunbergii*), 'Schilling's Dwarf' yaupon holly (*Ilex vomitoria*), and variegated privet (*Ligustrum* sp.)] and did not observe any phytotoxicity on any of the five taxa with any treatment combination. To date, there have been no similar studies published using commercial auxin-containing products that are registered by the US Environmental Protection Agency.

In response to commercial propagators' inquiries, this study was conducted to examine the potential of alcohol-containing solutions of auxin prepared using commercial auxin formulations to cause visible phytotoxicity when applied to stem cuttings of seven herbaceous and woody ornamental taxa using the basal quick-dip method or the total immersion method.

Materials and methods

Three studies were conducted between Jul 2015 and Jun 2016 at the South Mississippi Branch Experiment Station in Poplarville, MS, USA. Seven herbaceous and woody ornamental plant taxa were used for the seven experiments in each of the three studies: African wormwood (*Artemisia afra*), Mammoth™ 'Yellow Quill' chrysanthemum (*Chrysanthemum ×hybridum)* (Anderson et al. 2012), 'Mary Helen' geranium (*Pelargonium ×hortorum*), 'Coral' impatiens (*Impatiens ×hybrida*), 'New Gold' lantana (*Lantana camara*), weeping fig (*Ficus benjamina*), and star jasmine (*Trachelospermum jasminoides*). Cuttings of any one taxon were collected at an appropriate time of year for that taxon in three separate batches for each of the three studies. Cuttings of each of the seven taxa were used for the seven experiments within each of the three studies. Cutting source, cutting type, cutting length, depth of insertion into the rooting substrate, propagation month, rooting duration, and average daily minimum/maximum greenhouse temperatures during the rooting of each taxon are listed in Table 1. All cuttings were freshly prepared to a uniform size appropriate for each taxon, and leaves were removed from the bottom node of each cutting. All flowers and flower buds were removed from cuttings of 'Coral' impatiens.

Study 1 treatments. Cuttings received a 1-s basal dip to a depth of 1 cm in a solution at ambient temperature containing IBA (Hortus IBA water-soluble salts; Phytotronics Inc., Earth City, MO, USA) at 0, 1000, or 2000 ppm IBA prepared with isopropyl alcohol to final rates of 0%, 25%, or 50% (by volume), for a total of nine treatment combinations, with 0% alcohol plus 0 ppm IBA being a water-only treatment.

Study 2 treatments. Cuttings received a 1-s basal dip to a depth of 1 cm in a solution at ambient temperature containing IBA + NAA (Dip 'N' Grow; Dip 'N' Grow, Inc., Clackamas, OR, USA) containing 0 ppm IBA + 0 ppm NAA, 500 ppm IBA + 250 ppm NAA, or 1000 ppm IBA + 500 ppm NAA, each prepared using three rates of isopropyl alcohol (by volume): the minimum required to keep the auxin in solution (0%, 7.5%, or 15%, respectively), 25%, or 50%, for a total of nine treatment combinations with 0% alcohol plus 0 ppm IBA + 0 ppm NAA being a water-only treatment. The alcohol content of the Dip 'N' Grow concentrate (68% at that time) was taken into account when calculating the volume of isopropyl alcohol to be added to obtain the final alcohol content in each treatment solution. The minimum rates of isopropyl alcohol required to keep auxin in solution were determined in a preliminary evaluation in which glass beakers containing 250 ml of solution (Dip 'N' Grow diluted with deionized water and isopropyl alcohol) were prepared with seven rates of alcohol ranging from 0% to 15% (with 2.5% increments) for each rate of IBA + NAA (excluding treatments with no auxin), sealed with parafilm, placed on a laboratory bench at 70 °F, and visually evaluated over 24 h for precipitation of auxin crystals (which will be unavailable for uptake by cuttings). The solutions with the lowest rate of alcohol and absence of precipitated auxin crystals were identified to indicate the minimum percentage of alcohol required for each rate of IBA + NAA.

Study 3 treatments. Cuttings were individually and totally immersed for 5 s in a solution containing IBA (Hortus IBA water-soluble salts) at 0, 100, or 200 ppm IBA at ambient temperature prepared with isopropyl alcohol to final rates of 0%, 25%, or 50% (by volume), for a total of nine treatment combinations, with 0% alcohol plus 0 ppm IBA being a water-only treatment. After immersion, cuttings were shaken to remove excess solution and held in an air-conditioned room until the foliage had dried.

Post-treatment handling. Following specific treatments with auxin solutions in each experiment, all cuttings were inserted to a uniform depth into a peatmoss and pine bark-based potting mix (Fafard 3B; Conrad Fafard, Agawam, MA, USA) in individual cells of 50-cell propagation trays (PROP-50-RD; T.O. Plastics, Inc., Clearwater, MN, USA) set in carrying trays (FG1020A; J&M Plastics Inc., Royse City, TX, USA). Treated cuttings were assigned to cells using a completely randomized design with 33 cuttings per treatment and placed

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Table 1. Herbaceous and woody ornamental crops providing stem cuttings in each of three studies examining potential phytotoxicity of alcohol used in root-promoting solutions of auxin, with specifications on cutting preparation, propagation timing and environment, and rooting duration under intermittent mist[i] and ambient light in a climate-controlled greenhouse in Poplarville, MS.

Crop (taxon)	Cutting source	Cutting type	Cutting length (cm)	Depth of insertion[ii] (cm)	Propagation mo.	Rooting duration (d)	Avg daily min/max greenhouse temp (°F)
African wormwood	Field-grown stock[iii]	Herbaceous, subterminal	5	1.0	May	30	67 ± 4/84 ± 5
Mammoth™ 'Yellow Quill' chrysanthemum	Purchased[iv]	Herbaceous, terminal	5	1.0	Jan	30	62 ± 3/68 ± 4
'Mary Helen' geranium	Field-grown stock[iii]	Herbaceous, terminal	12.5	1.0	Oct	55	63 ± 3/72 ± 4
'Coral' impatiens	Container-grown stock[iii]	Herbaceous, terminal	5	1.0	Jul	55	72 ± 4/88 ± 5
'New Gold' lantana	Landscape planting[iii]	Softwood, subterminal	7.5	1.0	Jul, Aug	55	71 ± 4/88 ± 5
Weeping fig	Container-grown stock[iii]	Semihardwood, terminal	5	1.0	Jul, Aug	55	71 ± 4/88 ± 5
Star jasmine	Landscape planting[iii]	Semihardwood, subterminal	5	1.0	Jul, Aug	55	71 ± 4/88 ± 5

[i] Intermittent mist was provided for 10 s every 10 min during daylight hours.
[ii] Depth of insertion of the cutting into the rooting substrate that maintained the cuttings in an upright position. In study 1 and study 2, the 1-cm basal dip into treatment solutions matched the depth of insertion into the rooting substrate. Use of a 1-cm (or 0.5-in) dip is common in nursery practice for cuttings like those used in this study.
[iii] Cuttings collected from plants at the South Mississippi Branch Experiment Station in Poplarville, MS, USA.
[iv] Cuttings obtained from Ball Horticultural Company, West Chicago, IL, USA.

under intermittent mist (10 s every 10 min during daylight hours) on a bench in a climate-controlled greenhouse under ambient light. Maximum photosynthetically active radiation at the bench level in the greenhouse was 310 $\mu mol \cdot m^{-2} \cdot s^{-1}$ during the winter and 522.5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ during the summer. Temperatures were monitored with a HOBO Pro RH/Temp data logger (Onset Computer Corp., Bourne, MA, USA) placed with the cuttings.

Data collection. Upon harvest, dead and live cuttings were separated and counted to assess mortality. All live cuttings were rooted at harvest (i.e., there were no live cuttings that remained unrooted upon harvest). Rooting substrate was removed from roots by washing with water, and individual cuttings were visually assessed for stem necrosis (basal stem necrosis in studies 1 and 2; general stem necrosis in study 3) and leaf necrosis by recording presence of tissue necrosis (yes/no) and extent (percentage of tissue affected) and mortality. When mortality occurred within a treatment, only live cuttings were assessed for stem and leaf necrosis. Root systems were dried individually in a horizontal air flow oven (model 1680; VWR International/Sheldon Manufacturing, Inc., Cornelius, OR, USA) for a minimum of 48 h at 50 °C to constant weight, and the root dry weight (RDW) was recorded.

Statistical analysis. The data were analyzed using linear models (for continuous response data) and generalized linear models (binary response data) using the GLIMMIX procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC, USA), with auxin rate and alcohol rate as qualitative treatment factors. If the interaction term was not significant ($P > 0.20$), the main effects were evaluated; otherwise, simple effects were evaluated. Comparisons of least squares means among three rates of alcohol and three rates of IBA + NAA (main effects) or comparisons among three levels of one treatment factor at each level of the other treatment factor (simple effects) were made using the Shaffer-simulated adjustment for multiple comparisons ($\alpha = 0.10$). A significance level of 0.20 for evaluating the interaction term and a significance level of 0.10 for evaluating mean comparisons were selected to reduce the chance of type II errors.

Results

Study 1. Means and results of statistical analyses for all taxa in study 1 are presented in Table 2. The 1-s duration of the basal dip used in both study 1 and study 2 is commonly used in commercial nursery propagation, being selected instead of a longer duration based on the finding by Gouws et al. (1990) that most auxin is absorbed within the first second of treatment through the basal cut surface of a cutting.

Few or no cuttings of African wormwood died during the experiment, with neither alcohol nor IBA rates showing any significant effect on mortality. Live cuttings at harvest showed no basal stem necrosis or leaf necrosis, regardless of alcohol rate or IBA rate. Examination of simple effects showed that RDW was greater using 1000 or 2000 ppm IBA compared with 0 ppm IBA in solutions containing 0% alcohol, similar among IBA rates in solutions containing 25% alcohol, and higher using 0 or 1000 ppm IBA compared with 2000 ppm IBA in solutions containing 50% alcohol.

Few or no cuttings of Mammoth™ 'Yellow Quill' chrysanthemum died when dipped in solutions containing 0% or 25% alcohol at any IBA rate, but 15.2% of cuttings died when dipped in solutions containing 50% alcohol with either 0 ppm IBA or 2000 ppm IBA. Live cuttings at harvest showed no basal stem necrosis or leaf necrosis, regardless of alcohol rate or IBA rate. Examination of simple effects showed that RDW was consistently less using solutions with 2000 ppm IBA compared with 0 ppm IBA among all alcohol rates.

Some cuttings of 'Mary Helen' geranium died in all treatments except one. Examination of main effects showed that alcohol rates had no significant effect on mortality, whereas IBA rate showed an effect, but with no consistent trend. Live cuttings showed no basal stem necrosis or leaf necrosis at harvest, regardless of alcohol rate or IBA rate. Examination of simple effects did not show a definite increasing or decreasing trend in RDW with increasing IBA rate using solutions with 0% or 25% alcohol, but RDW was significantly greater using 1000 ppm or 2000 ppm IBA compared with 0 ppm IBA in solutions with 50% alcohol.

Only one cutting of 'Coral' impatiens died during the experiment. Cuttings showed no basal stem necrosis or leaf necrosis at harvest, regardless of alcohol rate or IBA rate. Examination of simple effects showed no significant differences in RDW among IBA rates in solutions with either 0% or 25% alcohol, but RDW was greater using no IBA among solutions with 50% alcohol. Live cuttings at harvest showed no basal stem necrosis or leaf necrosis, regardless of alcohol or IBA rate.

No cuttings of 'New Gold' lantana dipped in the water-only solution died during the experiment, whereas cuttings dipped in other solutions showed low to moderate mortality (9.1% to 30.3%). Examination of simple effects showed a possible increase in mortality with increasing IBA rate, but such an increase was not consistent within the three alcohol rates. Live cuttings at harvest showed no basal stem necrosis or leaf necrosis, regardless of alcohol or IBA rate. Examination of main effects showed RDW to be similar among both alcohol and IBA rates.

Among cuttings of weeping fig, there was some indication of greater mortality with increasing alcohol rate, but no consistent trend was apparent, especially considering that cuttings receiving a basal quick dip in the water-only solution showed the second-highest mortality (21.2%). The age of the stock plants may have contributed somewhat to the rooting results (Husen 2012). Low to moderate rooting percentages of stem cuttings of weeping fig without the use of an auxin treatment have been reported by Ilem et al. (2023), with micropropagation often preferred for clonal selections (Kristiansen 1992). All surviving cuttings rooted and showed no basal stem necrosis or leaf necrosis upon harvest, regardless of alcohol rate or IBA rate. Examination of simple effects showed RDW to be similar among IBA rates in solutions with 0% alcohol but higher using 2000 ppm IBA in solutions with either 25% or 50% alcohol.

Rooted cuttings of star jasmine showed little or no mortality and no basal stem necrosis or leaf necrosis upon harvest, regardless of alcohol rate or IBA rate. Examination of simple effects showed RDW to be similar among IBA rates in solutions with 0% alcohol but higher using 1000 ppm IBA in solutions containing either 25% or 50% alcohol.

Study 2. The means and results of statistical analyses for all taxa in study 2 are presented in Table 3. Some (0% to 12.5%) cuttings of African wormwood died within treatments, but this appeared to be unrelated to alcohol rate or auxin rate. Rooted cuttings that had been dipped in solutions containing the minimum rate or 25% rate of alcohol showed no basal stem necrosis or leaf necrosis upon harvest, regardless of auxin rate, whereas cuttings treated with solutions containing 50% alcohol showed only slight basal stem necrosis. Examination of simple effects showed RDW to be greatest using 500 ppm IBA + 250 ppm NAA with the minimum rate of alcohol, and using 500 ppm IBA + 250 ppm NAA or 1000 ppm IBA + 500 ppm NAA with 50% alcohol, whereas RDW was least using 1000 ppm IBA + 500 ppm NAA with the minimum rate of alcohol and using 0 ppm IBA + 0 ppm NAA with 50% alcohol.

No cuttings of Mammoth™ 'Yellow Quill' chrysanthemum died using seven of the nine treatments. Only two cuttings died using the water-only treatment and two using the treatment with 25% alcohol and no auxin, so apparently mortality was not due to treatment factors. No live cuttings in any treatment showed any basal stem necrosis or leaf necrosis upon harvest. Examination of simple effects showed some differences in RDW among auxin rates using solutions containing the minimum rate and 25% rate of alcohol, but there was no consistent trend.

Cuttings of 'Mary Helen' geranium that died during the experiment ranged widely among treatments, with no dead cuttings using a dip in water only or a dip in 500 ppm IBA + 250 ppm NAA and 50% alcohol. Maximum mortality rates were 21.2% using 500 ppm IBA + 250 ppm NAA and the minimum rate of alcohol, 42.4% using 1000 ppm IBA + 500 ppm NAA and 25% alcohol, and 18.2% using 1000 ppm IBA + 500 ppm NAA and 50% alcohol. None of the live cuttings at harvest showed any basal stem necrosis or leaf necrosis. Examination of simple effects showed no consistent trend in RDW with increasing rate of auxin within any rate of alcohol.

Cuttings of 'Coral' impatiens were all alive at the end of the experiment when dipped in water only with no

Table 2. Percentage of dead cuttings, percentage of live cuttings showing basal stem necrosis and percentage of affected stem tissue, percentage of live cuttings showing leaf necrosis and percentage of affected leaf tissue, and root dry weight of rooted stem cuttings upon harvest[i] of seven herbaceous and woody crops treated with a basal quick dip in solutions prepared with three rates of isopropyl alcohol (by volume) in combination with three rates of indole-3-butyric acid (IBA; Hortus IBA water-soluble salts; Hortus USA Corp., New York, NY, USA) and rooted under intermittent mist in a greenhouse (study 1) (n = 33).

Treatment	Dead cuttings (%)	Live cuttings with stem necrosis (%)	Stem tissue with necrosis (%)	Live cuttings with leaf necrosis (%)	Leaf tissue with necrosis (%)	Root dry wt (g)
African wormwood						
Significance (*P*)						
Alcohol	0.9997	–	–	–	–	0.0004
IBA	0.9309	–	–	–	–	0.5488
Alcohol × IBA	0.9927	–	–	–	–	0.0081
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.124 b
0% alcohol ×1000 ppm IBA	0.0	0.0	0.0	0.0	0.0	0.143 a
0% alcohol × 2000 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.150 a
25% alcohol × 0 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.128 A
25% alcohol × 1000 ppm IBA	3.0	0.0	0.0	0.0	0.0	0.116 A
25% alcohol × 2000 ppm IBA	3.0	0.0	0.0	0.0	0.0	0.119 A
50% alcohol × 0 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.148 a′
50% alcohol × 1000 ppm IBA	0.0	0.0	0.0	0.0	0.0	0.157 a′
50% alcohol × 2000 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.128 b′
Main effects means[iii]						
0% alcohol	3.2 a	–	–	–	–	–
25% alcohol	3.2 a	–	–	–	–	–
50% alcohol	3.2 a	–	–	–	–	–
0 ppm IBA	6.1 A	–	–	–	–	–
1000 ppm IBA	1.0 A	–	–	–	–	–
2000 ppm IBA	5.1 A	–	–	–	–	–
Mammoth™ 'Yellow Quill' chrysanthemum						
Significance (*P*)						
Alcohol	<0.0001	–	–	–	–	<0.0001
IBA	0.1859	–	–	–	–	<0.0001
Alcohol × IBA	0.0119	–	–	–	–	<0.0001
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	0.0 a	0.0	0.0	0.0	0.0	0.196 a
0% alcohol × 1000 ppm IBA	3.0 a	0.0	0.0	0.0	0.0	0.182 a
0% alcohol × 2000 ppm IBA	0.0 a	0.0	0.0	0.0	0.0	0.163 b
25% alcohol × 0 ppm IBA	0.0 A	0.0	0.0	0.0	0.0	0.238 A
25% alcohol × 1000 ppm IBA	0.0 A	0.0	0.0	0.0	0.0	0.154 B
25% alcohol × 2000 ppm IBA	0.0 A	0.0	0.0	0.0	0.0	0.169 B
50% alcohol × 0 ppm IBA	15.2 a′	0.0	0.0	0.0	0.0	0.117 a′
50% alcohol × 1000 ppm IBA	0.0 b′	0.0	0.0	0.0	0.0	0.135 a′
50% alcohol × 2000 ppm IBA	15.2 a′	0.0	0.0	0.0	0.0	0.090 b′
'Mary Helen' geranium						
Significance (*P*)						
Alcohol	0.8837	–	–	–	–	0.9573
IBA	0.0087	–	–	–	–	0.0002
Alcohol × IBA	0.6060	–	–	–	–	0.0003
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	9.1	0.0	0.0	0.0	0.0	0.171 a
0% alcohol × 1000 ppm IBA	0.0	0.0	0.0	0.0	0.0	0.143 b
0% alcohol × 2000 ppm IBA	21.2	0.0	0.0	0.0	0.0	0.186 a
25% alcohol × 0 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.177 A
25% alcohol × 1000 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.130 B
25% alcohol × 2000 ppm IBA	15.2	0.0	0.0	0.0	0.0	0.185 A
50% alcohol × 0 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.126 b′

(Continued on next page)

Table 2. (*Continued*)

Treatment	Dead cuttings (%)	Live cuttings with stem necrosis (%)	Stem tissue with necrosis (%)	Live cuttings with leaf necrosis (%)	Leaf tissue with necrosis (%)	Root dry wt (g)
50% alcohol × 1000 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.177 a′
50% alcohol × 2000 ppm IBA	12.1	0.0	0.0	0.0	0.0	0.192 a′
Main effects means[iii]						
0% alcohol	10.1 a	–	–	–	–	–
25% alcohol	9.1 a	–	–	–	–	–
50% alcohol	8.1 a	–	–	–	–	–
0 ppm IBA	7.1 AB	–	–	–	–	–
1000 ppm IBA	4.0 B	–	–	–	–	–
2000 ppm IBA	16.2 A	–	–	–	–	–
'Coral' impatiens						
Significance (*P*)						
Alcohol	0.3692	–	–	–	–	0.5939
IBA	0.3692	–	–	–	–	0.4632
Alcohol × IBA	0.4079	–	–	–	–	0.0344
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	0.0	0.0	0.0	0.0	0.0	1.569 a
0% alcohol × 1000 ppm IBA	0.0	0.0	0.0	0.0	0.0	1.611 a
0% alcohol × 2000 ppm IBA	0.0	0.0	0.0	0.0	0.0	1.767 a
25% alcohol × 0 ppm IBA	0.0	0.0	0.0	0.0	0.0	1.726 A
25% alcohol × 1000 ppm IBA	3.0	0.0	0.0	0.0	0.0	1.639 A
25% alcohol × 2000 ppm IBA	0.0	0.0	0.0	0.0	0.0	1.843 A
50% alcohol × 0 ppm IBA	0.0	0.0	0.0	0.0	0.0	2.006 a′
50% alcohol × 1000 ppm IBA	0.0	0.0	0.0	0.0	0.0	1.688 b′
50% alcohol × 2000 ppm IBA	0.0	0.0	0.0	0.0	0.0	1.508 b′
Main effects means[iii]						
0% alcohol	0.0 a	–	–	–	–	–
25% alcohol	1.0 a	–	–	–	–	–
50% alcohol	0.0 a	–	–	–	–	–
0 ppm IBA	0.0 A	–	–	–	–	–
1000 ppm IBA	1.0 A	–	–	–	–	–
2000 ppm IBA	0.0 A	–	–	–	–	–
'New Gold' lantana						
Significance (*P*)						
Alcohol	0.0691	–	–	–	–	0.1288
IBA	0.2787	–	–	–	–	0.2807
Alcohol × IBA	0.0211	–	–	–	–	0.2007
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	0.0 b	0.0	0.0	0.0	0.0	0.075
0% alcohol × 1000 ppm IBA	12.1 ab	0.0	0.0	0.0	0.0	0.076
0% alcohol × 2000 ppm IBA	15.2 a	0.0	0.0	0.0	0.0	0.078
25% alcohol × 0 ppm IBA	9.1 B	0.0	0.0	0.0	0.0	0.073
25% alcohol × 1000 ppm IBA	15.2 B	0.0	0.0	0.0	0.0	0.079
25% alcohol × 2000 ppm IBA	30.3 A	0.0	0.0	0.0	0.0	0.087
50% alcohol × 0 ppm IBA	24.2 a′	0.0	0.0	0.0	0.0	0.081
50% alcohol × 1000 ppm IBA	27.3 a′	0.0	0.0	0.0	0.0	0.096
50% alcohol × 2000 ppm IBA	9.1 b′	0.0	0.0	0.0	0.0	0.079
Main effects means[iii]						
0% alcohol	–	–	–	–	–	0.076 a
25% alcohol	–	–	–	–	–	0.079 a
50% alcohol	–	–	–	–	–	0.085 a
0 ppm IBA	–	–	–	–	–	0.076 A
1000 ppm IBA	–	–	–	–	–	0.083 A
2000 ppm IBA	–	–	–	–	–	0.081 A

(Continued on next page)

Table 2. (*Continued*)

Treatment	Dead cuttings (%)	Live cuttings with stem necrosis (%)	Stem tissue with necrosis (%)	Live cuttings with leaf necrosis (%)	Leaf tissue with necrosis (%)	Root dry wt (g)
Weeping fig						
Significance (*P*)						
Alcohol	0.0062	–	–	–	–	0.1630
IBA	0.0446	–	–	–	–	0.0358
Alcohol × IBA	0.1252	–	–	–	–	0.1667
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	21.2 a	0.0	0.0	0.0	0.0	0.077 a
0% alcohol × 1000 ppm IBA	9.1 a	0.0	0.0	0.0	0.0	0.096 a
0% alcohol × 2000 ppm IBA	9.1 a	0.0	0.0	0.0	0.0	0.079 a
25% alcohol × 0 ppm IBA	9.1 A	0.0	0.0	0.0	0.0	0.072 B
25% alcohol × 1000 ppm IBA	15.2 A	0.0	0.0	0.0	0.0	0.071 B
25% alcohol × 2000 ppm IBA	9.1 A	0.0	0.0	0.0	0.0	0.102 A
50% alcohol × 0 ppm IBA	42.4 a′	0.0	0.0	0.0	0.0	0.081 b′
50% alcohol × 1000 ppm IBA	15.2 b′	0.0	0.0	0.0	0.0	0.093 b′
50% alcohol × 2000 ppm IBA	21.2 b′	0.0	0.0	0.0	0.0	0.123 a′
Star jasmine						
Significance (*P*)						
Alcohol	0.9999	–	–	–	–	<0.0001
IBA	1.0000	–	–	–	–	<0.0001
Alcohol × IBA	1.0000	–	–	–	–	0.0005
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	0.0	0.0	0.0	0.0	0.0	0.164 a
0% alcohol × 1000 ppm IBA	3.0	0.0	0.0	0.0	0.0	0.166 a
0% alcohol × 2000 ppm IBA	0.0	0.0	0.0	0.0	0.0	0.154 a
25% alcohol × 0 ppm IBA	3.0	0.0	0.0	0.0	0.0	0.208 B
25% alcohol × 1000 ppm IBA	0.0	0.0	0.0	0.0	0.0	0.256 A
25% alcohol × 2000 ppm IBA	3.0	0.0	0.0	0.0	0.0	0.183 B
50% alcohol × 0 ppm IBA	0.0	0.0	0.0	0.0	0.0	0.194 c′
50% alcohol × 1000 ppm IBA	0.0	0.0	0.0	0.0	0.0	0.352 a′
50% alcohol × 2000 ppm IBA	0.0	0.0	0.0	0.0	0.0	0.284 b′
Main effects means[iii]						
0% alcohol	1.0 a	–	–	–	–	–
25% alcohol	2.0 a	–	–	–	–	–
50% alcohol	1.0 a	–	–	–	–	–
0 ppm IBA	1.0 A	–	–	–	–	–
1000 ppm IBA	1.0 A	–	–	–	–	–
2000 ppm IBA	1.0 A	–	–	–	–	–

[i] Rooting duration from treatment until harvest: 30 d for African wormwood and Mammoth™ 'Yellow Quill' chrysanthemum; 55 d for all other taxa. Upon harvest, all live cuttings were rooted.

[ii] When the interaction term in the model is significant ($P \leq 0.20$), simple effects means (treatment means for all rates of IBA grouped within each rate of alcohol) followed by the same lowercase letter, uppercase letter, or lowercase letter primed (to distinguish the three sets of letter groupings) are not significantly different using the Shaffer-simulated adjustment for multiple comparisons ($\alpha = 0.10$); otherwise, the treatment means are presented without letter groupings for informational purposes.

[iii] When the interaction term in the model is not significant ($P > 0.20$), main effects means for rates within each treatment factor followed by the same lowercase letter or uppercase letter (to distinguish the two sets of letter groupings) are not significantly different using the Shaffer-simulated method for multiple comparisons ($\alpha = 0.10$).

auxin, whereas dead cuttings in other treatments ranged from 6.1% to 18.2%, with an apparent trend in greater mortality with increasing rate of alcohol. None of the live cuttings at harvest showed any basal stem necrosis or leaf necrosis. Examination of main effects showed the greatest RDW of live cuttings at harvest using solutions with 50% alcohol and solutions containing auxin.

Although some (21.2% to 33.3%) cuttings of 'New Gold' lantana died among treatments during the experiment, these losses were not attributable to alcohol rate or auxin rate. Cuttings were obtained from landscape plants in midsummer, which can result in lower rooting percentages than cuttings obtained from nursery container-grown plants. Hartmann et al. (2011) and Cristofori et al. (2010) describe the importance of cutting condition, collection time, and age of cuttings to optimize propagation results. None of the live cuttings at harvest showed any basal stem necrosis or leaf necrosis. RDW showed a tendency to increase using the minimum rate and the 50% rate of alcohol but not using the 25% rate of alcohol.

Some cuttings of weeping fig died among treatments during the experiment. Examination of simple effects showed greater mortality using the highest auxin rate among treatments with the minimum rate of alcohol

Table 3. Percentage of dead cuttings, percentage of live cuttings showing basal stem necrosis and percentage of affected stem tissue, percentage of live cuttings showing leaf necrosis and percentage of affected leaf tissue, and root dry weight of rooted stem cuttings upon harvest[i] of seven herbaceous and woody crops treated with a basal quick dip in solutions prepared with three rates of indole-3-butyric acid plus 1-naphthaleneacetic acid (IBA + NAA; Dip 'N' Grow; Dip 'N' Grow Inc., Clackamas, OR, USA) and rooted under intermittent mist in a greenhouse (study 2) (n = 33).

Treatment	Dead cuttings (%)	Live cuttings with stem necrosis (%)	Stem tissue with necrosis (%)	Live cuttings with leaf necrosis (%)	Leaf tissue with necrosis (%)	Root dry wt (g)
African wormwood						
Significance (*P*)						
Alcohol	0.7330	0.0011	0.0011	–	–	0.7521
IBA + NAA	0.9769	0.8474	0.8474	–	–	0.0030
Alcohol × IBA + NAA	0.9782	0.9546	0.9546	–	–	0.0043
Treatment means grouped by alcohol rate[ii]						
Minimum alcohol[iv] × 0 ppm IBA + 0 ppm NAA	12.5	0.0	0.0	0.0	0.0	0.161 ab
Minimum alcohol[iv] × 500 ppm IBA + 250 ppm NAA	9.1	0.0	0.0	0.0	0.0	0.179 a
Minimum alcohol[iv] × 1000 ppm IBA + 500 ppm NAA	9.1	0.0	0.0	0.0	0.0	0.151 b
25% alcohol × 0 ppm IBA + 0 ppm NAA	6.1	0.0	0.0	0.0	0.0	0.161 A
25% alcohol × 500 ppm IBA + 250 ppm NAA	6.1	0.0	0.0	0.0	0.0	0.165 A
25% alcohol × 1000 ppm IBA + 500 ppm NAA	9.1	0.0	0.0	0.0	0.0	0.161 A
50% alcohol × 0 ppm IBA + 0 ppm NAA	6.1	6.5	0.6	0.0	0.0	0.137 b′
50% alcohol × 500 ppm IBA + 250 ppm NAA	6.1	9.7	1.0	0.0	0.0	0.183 a′
50% alcohol × 1000 ppm IBA + 500 ppm NAA	0.0	6.1	0.6	0.0	0.0	0.181 a′
Main effects means[iii]						
Minimum alcohol[iv]	10.2 a	0.0 b	0.0 b	–	–	–
25% alcohol	7.0 a	0.0 b	0.0 b	–	–	–
50% alcohol	4.0 a	7.4 a	0.7 a	–	–	–
0 ppm IBA + 0 ppm NAA	7.7 A	2.1 A	0.2 A	–	–	–
500 ppm IBA + 250 ppm NAA	6.6 A	3.2 A	0.3 A	–	–	–
1000 ppm IBA + 500 ppm NAA	5.7 A	2.0 A	0.2 A	–	–	–
Mammoth™ 'Yellow Quill' chrysanthemum						
Significance (*P*)						
Alcohol	0.3462	–	–	–	–	0.4367
IBA + NAA	0.0151	–	–	–	–	0.6767
Alcohol × IBA + NAA	0.3743	–	–	–	–	0.0090
Treatment means grouped by alcohol rate[ii]						
Minimum alcohol[iv] × 0 ppm IBA + 0 ppm NAA	6.1	0.0	0.0	0.0	0.0	0.179 a
Minimum alcohol[iv] × 500 ppm IBA + 250 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.146 b
Minimum alcohol[iv] × 1000 ppm IBA + 500 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.160 ab
25% alcohol × 0 ppm IBA + 0 ppm NAA	6.1	0.0	0.0	0.0	0.0	0.141 B
25% alcohol × 500 ppm IBA + 250 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.155 AB
25% alcohol × 1000 ppm IBA + 500 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.170 A
50% alcohol × 0 ppm IBA + 0 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.147 a′
50% alcohol × 500 ppm IBA + 250 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.162 a′
50% alcohol × 1000 ppm IBA + 500 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.150 a′
Main effects means[iii]						
Minimum alcohol[iv]	2.0 a	–	–	–	–	–
25% alcohol	2.0 a	–	–	–	–	–
50% alcohol	0.0 a	–	–	–	–	–
0 ppm IBA + 0 ppm NAA	4.0 A	–	–	–	–	–
500 ppm IBA + 250 ppm NAA	0.0 B	–	–	–	–	–
1000 ppm IBA + 500 ppm NAA	0.0 B	–	–	–	–	–
'Mary Helen' geranium						
Significance (*P*)						
Alcohol	0.9996	–	–	–	–	<0.0001
IBA + NAA	0.9994	–	–	–	–	0.0064
Alcohol × IBA + NAA	0.0112	–	–	–	–	0.0019

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Table 3. (*Continued*)

Treatment	Dead cuttings (%)	Live cuttings with stem necrosis (%)	Stem tissue with necrosis (%)	Live cuttings with leaf necrosis (%)	Leaf tissue with necrosis (%)	Root dry wt (g)
Treatment means grouped by alcohol rate[ii]						
Minimum alcohol[iv] × 0 ppm IBA + 0 ppm NAA	0.0 b	0.0	0.0	0.0	0.0	0.150 b
Minimum alcohol[iv] × 500 ppm IBA + 250 ppm NAA	21.2 a	0.0	0.0	0.0	0.0	0.203 a
Minimum alcohol[iv] × 1000 ppm IBA + 500 ppm NAA	6.1 b	0.0	0.0	0.0	0.0	0.177 b
25% alcohol × 0 ppm IBA + 0 ppm NAA	3.0 B	0.0	0.0	0.0	0.0	0.202 A
25% alcohol × 500 ppm IBA + 250 ppm NAA	6.1 B	0.0	0.0	0.0	0.0	0.174 B
25% alcohol × 1000 ppm IBA + 500 ppm NAA	42.4 A	0.0	0.0	0.0	0.0	0.212 A
50% alcohol × 0 ppm IBA + 0 ppm NAA	9.1 a′b′	0.0	0.0	0.0	0.0	0.205 b′
50% alcohol × 500 ppm IBA + 250 ppm NAA	0.0 b′	0.0	0.0	0.0	0.0	0.265 a′
50% alcohol × 1000 ppm IBA + 500 ppm NAA	18.2 a′	0.0	0.0	0.0	0.0	0.247 a′
'Coral' impatiens						
Significance (*P*)						
Alcohol	0.9868	–	–	–	–	<0.0001
IBA + NAA	0.8390	–	–	–	–	0.0057
Alcohol × IBA + NAA	0.7823	–	–	–	–	0.2016
Treatment means grouped by alcohol rate[ii]						
Minimum alcohol[iv] × 0 ppm IBA + 0 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.191
Minimum alcohol[iv] × 500 ppm IBA + 250 ppm NAA	9.1	0.0	0.0	0.0	0.0	0.224
Minimum alcohol[iv] × 1000 ppm IBA + 500 ppm NAA	6.1	0.0	0.0	0.0	0.0	0.226
25% alcohol × 0 ppm IBA + 0 ppm NAA	12.1	0.0	0.0	0.0	0.0	0.208
25% alcohol × 500 ppm IBA + 250 ppm NAA	9.1	0.0	0.0	0.0	0.0	0.220
25% alcohol × 1000 ppm IBA + 500 ppm NAA	15.2	0.0	0.0	0.0	0.0	0.220
50% alcohol × 0 ppm IBA + 0 ppm NAA	18.2	0.0	0.0	0.0	0.0	0.244
50% alcohol × 500 ppm IBA + 250 ppm NAA	6.1	0.0	0.0	0.0	0.0	0.272
50% alcohol × 1000 ppm IBA + 500 ppm NAA	12.1	0.0	0.0	0.0	0.0	0.243
Main effects means[iii]						
Minimum alcohol[iv]	5.1 a	–	–	–	–	0.214 b
25% alcohol	12.1 a	–	–	–	–	0.216 b
50% alcohol	12.1 a	–	–	–	–	0.253 a
0 ppm IBA + 0 ppm NAA	10.1 A	–	–	–	–	0.214 B
500 ppm IBA + 250 ppm NAA	8.1 A	–	–	–	–	0.239 A
1000 ppm IBA + 500 ppm NAA	11.1 A	–	–	–	–	0.230 A
'New Gold' lantana						
Significance (*P*)						
Alcohol	0.5067	–	–	–	–	0.0008
IBA + NAA	0.9267	–	–	–	–	0.0525
Alcohol × IBA + NAA	0.6813	–	–	–	–	0.0082
Treatment means grouped by alcohol rate[ii]						
Minimum alcohol[iv] × 0 ppm IBA + 0 ppm NAA	24.2	0.0	0.0	0.0	0.0	0.078 b
Minimum alcohol[iv] × 500 ppm IBA + 250 ppm NAA	24.2	0.0	0.0	0.0	0.0	0.092 ab
Minimum alcohol[iv] × 1000 ppm IBA + 500 ppm NAA	33.3	0.0	0.0	0.0	0.0	0.095 a
25% alcohol × 0 ppm IBA + 0 ppm NAA	33.3	0.0	0.0	0.0	0.0	0.112 A
25% alcohol × 500 ppm IBA + 250 ppm NAA	30.3	0.0	0.0	0.0	0.0	0.125 A
25% alcohol × 1000 ppm IBA + 500 ppm NAA	24.2	0.0	0.0	0.0	0.0	0.091 B
50% alcohol × 0 ppm IBA + 0 ppm NAA	18.2	0.0	0.0	0.0	0.0	0.086 b′
50% alcohol × 500 ppm IBA + 250 ppm NAA	27.3	0.0	0.0	0.0	0.0	0.098 a′b′
50% alcohol × 1000 ppm IBA + 500 ppm NAA	21.2	0.0	0.0	0.0	0.0	0.103 a′
Main effects means[iii]						
Minimum alcohol[iv]	27.3 a	–	–	–	–	–
25% alcohol	29.3 a	–	–	–	–	–
50% alcohol	22.2 a	–	–	–	–	–
0 ppm IBA + 0 ppm NAA	25.1 A	–	–	–	–	–
500 ppm IBA + 250 ppm NAA	27.2 A	–	–	–	–	–
1000 ppm IBA + 500 ppm NAA	26.2 A	–	–	–	–	–

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Table 3. (*Continued*)

Treatment	Dead cuttings (%)	Live cuttings with stem necrosis (%)	Stem tissue with necrosis (%)	Live cuttings with leaf necrosis (%)	Leaf tissue with necrosis (%)	Root dry wt (g)
Weeping fig						
Significance (*P*)						
Alcohol	0.5778	–	–	–	–	<0.0001
IBA + NAA	0.0569	–	–	–	–	0.0002
Alcohol × IBA + NAA	0.0271	–	–	–	–	<0.0001
Treatment means grouped by alcohol rate[ii]						
Minimum alcohol[iv] × 0 ppm IBA + 0 ppm NAA	9.1 b	0.0	0.0	0.0	0.0	0.148 a
Minimum alcohol[iv] × 500 ppm IBA + 250 ppm NAA	9.1 b	0.0	0.0	0.0	0.0	0.155 a
Minimum alcohol[iv] × 1000 ppm IBA + 500 ppm NAA	27.3 a	0.0	0.0	0.0	0.0	0.158 a
25% alcohol × 0 ppm IBA + 0 ppm NAA	6.1 A	0.0	0.0	0.0	0.0	0.187 B
25% alcohol × 500 ppm IBA + 250 ppm NAA	15.2 A	0.0	0.0	0.0	0.0	0.160 B
25% alcohol × 1000 ppm IBA + 500 ppm NAA	18.2 A	0.0	0.0	0.0	0.0	0.224 A
50% alcohol × 0 ppm IBA + 0 ppm NAA	36.4 a′	0.0	0.0	0.0	0.0	0.227 a′
50% alcohol × 500 ppm IBA + 250 ppm NAA	6.1 b′	0.0	0.0	0.0	0.0	0.150 b′
50% alcohol × 1000 ppm IBA + 500 ppm NAA	21.2 a′	0.0	0.0	0.0	0.0	0.109 c′
Star jasmine						
Significance (*P*)						
Alcohol	0.4503	–	–	–	–	0.9472
IBA + NAA	0.0041	–	–	–	–	0.9095
Alcohol × IBA + NAA	0.5260	–	–	–	–	0.2053
Treatment means grouped by alcohol rate[ii]						
Minimum alcohol[iv] × 0 ppm IBA + 0 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.146
Minimum alcohol[iv] × 500 ppm IBA + 250 ppm NAA	3.0	0.0	0.0	0.0	0.0	0.159
Minimum alcohol[iv] × 1000 ppm IBA + 500 ppm NAA	12.1	0.0	0.0	0.0	0.0	0.148
25% alcohol × 0 ppm IBA + 0 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.159
25% alcohol × 500 ppm IBA + 250 ppm NAA	3.0	0.0	0.0	0.0	0.0	0.138
25% alcohol × 1000 ppm IBA + 500 ppm NAA	3.0	0.0	0.0	0.0	0.0	0.164
50% alcohol × 0 ppm IBA + 0 ppm NAA	0.0	0.0	0.0	0.0	0.0	0.158
50% alcohol × 500 ppm IBA + 250 ppm NAA	3.0	0.0	0.0	0.0	0.0	0.157
50% alcohol × 1000 ppm IBA + 500 ppm NAA	12.1	0.0	0.0	0.0	0.0	0.139
Main effects means[iii]						
Minimum alcohol[iv]	5.1 a	–	–	–	–	0.151 a
25% alcohol	2.0 a	–	–	–	–	0.154 a
50% alcohol	5.1 a	–	–	–	–	0.152 a
0 ppm IBA + 0 ppm NAA	0.0 B	–	–	–	–	0.154 A
500 ppm IBA + 250 ppm NAA	3.0 B	–	–	–	–	0.152 A
1000 ppm IBA + 500 ppm NAA	9.1 A	–	–	–	–	0.151 A

[i] Rooting duration from treatment until harvest: 30 d for African wormwood and Mammoth™ 'Yellow Quill' chrysanthemum; 55 d for all other taxa. Upon harvest, all live cuttings were rooted.

[ii] When the interaction term in the model is significant ($P \leq 0.20$), simple effects means (treatment means for all rates of IBA + NAA grouped within each rate of alcohol) followed by the same lowercase letter, uppercase letter, or lowercase letter primed (to distinguish the three sets of letter groupings) are not significantly different using the Shaffer-simulated adjustment for multiple comparisons ($\alpha = 0.10$); otherwise, the treatment means are presented without letter groupings for informational purposes.

[iii] When the interaction term in the model is not significant ($P > 0.20$), main effects means for rates within each treatment factor followed by the same lowercase letter or uppercase letter (to distinguish the two sets of letter groupings) are not significantly different using the Shaffer-simulated method for multiple comparisons ($\alpha = 0.10$).

[iv] Minimum alcohol: The minimum rate of alcohol required to keep the auxins in solution after dilution of the liquid Dip 'N' Grow® concentrate: 0% alcohol for 0 ppm IBA + 0 ppm NAA, 7.5% alcohol for 500 ppm IBA + 250 ppm NAA, and 15% alcohol for 1000 ppm IBA + 500 ppm NAA.

and using no auxin among treatments with the 50% rate of alcohol, but no significant differences among auxin rates among treatments with the 25% rate of alcohol. None of the live cuttings at harvest showed any basal stem necrosis or leaf necrosis. Examination of simple effects showed RDW was similar among auxin rates using the minimum rate of alcohol, greater with the highest auxin rate using 25% alcohol, and highest with no auxin using 50% alcohol.

No or very few cuttings of star jasmine died among treatments during the experiment. Examining main effects, similar mortality rates were seen among rates of alcohol and a slightly greater rate using the highest rate of auxin. None of the live cuttings at harvest showed any basal stem necrosis or leaf necrosis. Examination of simple effects showed no significant differences in RDW among rates of alcohol or IBA.

Study 3. The means and results of statistical analyses for all taxa in study 3 are presented in Table 4. The rates of IBA used in study 3 with a 5-s immersion were lower than rates used

Table 4. Percentage of dead cuttings, percentage of live cuttings showing basal stem necrosis and percentage of affected stem tissue, percentage of live cuttings showing leaf necrosis and percentage of affected leaf tissue, and root dry weight of rooted stem cuttings upon harvest[i] of seven herbaceous and woody crops treated with a 5-s, total immersion in solutions prepared with three rates of isopropyl alcohol (by volume) in combination with three rates of indole-3-butyric acid (IBA; Hortus IBA water-soluble salts; Hortus USA Corp., New York, NY, USA) and rooted under intermittent mist in a greenhouse (study 3) (n = 33).

Treatment	Dead cuttings (%)	Live cuttings with stem necrosis (%)	Stem tissue with necrosis (%)	Live cuttings with leaf necrosis (%)	Leaf tissue with necrosis (%)	Root dry wt (g)
African wormwood						
Significance (*P*)						
Alcohol	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
IBA	0.9997	0.5041	0.0714	0.0041	0.0907	0.0009
Alcohol × IBA	0.5078	0.5041	0.0714	0.0041	0.0907	0.8226
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	12.1	0.0	0.0 a	0.0 a	0.0 a	0.106
0% alcohol × 100 ppm IBA	9.1	0.0	0.0 a	0.0 a	0.0 a	0.106
0% alcohol × 200 ppm IBA	3.0	0.0	0.0 a	0.0 a	0.0 a	0.134
25% alcohol × 0 ppm IBA	45.5	72.2	15.8 B	44.4 A	8.3 A	0.063
25% alcohol × 100 ppm IBA	27.3	58.3	15.8 B	16.7 B	3.3 B	0.057
25% alcohol × 200 ppm IBA	54.6	66.7	27.3 A	53.3 A	9.3 A	0.098
50% alcohol × 0 ppm IBA	97.0	100.0	80.0 –	100.0 –	10.0 –	0.050
50% alcohol × 100 ppm IBA	100.0	–	–	–	–	–
50% alcohol × 200 ppm IBA	100.0	–	–	–	–	–
Main effects means[iii]						
0% alcohol	7.8 c	0.0 b	–	–	–	0.115 a
25% alcohol	42.2 b	65.3 a	–	–	–	0.072 b
50% alcohol	99.0 a	97.3 a	–	–	–	0.053 b
0 ppm IBA	68.6 A	56.9 A	–	–	–	0.071 B
100 ppm IBA	55.0 A	51.1 A	–	–	–	0.068 B
200 ppm IBA	70.5 A	54.7 A	–	–	–	0.101 A
Mammoth™ 'Yellow Quill' chrysanthemum						
Significance (*P*)						
Alcohol	0.2292	–	–	–	–	0.5097
IBA	0.8095	–	–	–	–	0.1468
Alcohol × IBA	0.0790	–	–	–	–	0.2347
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	0.0 b	0.0	0.0	0.0	0.0	0.179
0% alcohol × 100 ppm IBA	6.1 a	0.0	0.0	0.0	0.0	0.172
0% alcohol × 200 ppm IBA	0.0 b	0.0	0.0	0.0	0.0	0.179
25% alcohol × 0 ppm IBA	3.0 AB	0.0	0.0	0.0	0.0	0.185
25% alcohol × 100 ppm IBA	0.0 B	0.0	0.0	0.0	0.0	0.184
25% alcohol × 200 ppm IBA	6.1 A	0.0	0.0	0.0	0.0	0.184
50% alcohol × 0 ppm IBA	0.0 a′	0.0	0.0	0.0	0.0	0.168
50% alcohol × 100 ppm IBA	0.0 a′	0.0	0.0	0.0	0.0	0.160
50% alcohol × 200 ppm IBA	0.0 a′	0.0	0.0	0.0	0.0	0.199
Main effects means[iii]						
0% alcohol	–	–	–	–	–	0.177 a
25% alcohol	–	–	–	–	–	0.185 a
50% alcohol	–	–	–	–	–	0.176 a
0 ppm IBA	–	–	–	–	–	0.177 A
100 ppm IBA	–	–	–	–	–	0.172 A
200 ppm IBA	–	–	–	–	–	0.188 A
'Mary Helen' geranium						
Significance (*P*)						
Alcohol	<0.0001	–	–	<0.0001	<0.0001	<0.0001
IBA	0.1328	–	–	0.0023	0.0088	0.0001
Alcohol × IBA	0.0017	–	–	0.0023	0.0088	0.0040

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Table 4. (*Continued*)

Treatment	Dead cuttings (%)	Live cuttings with stem necrosis (%)	Stem tissue with necrosis (%)	Live cuttings with leaf necrosis (%)	Leaf tissue with necrosis (%)	Root dry wt (g)
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	6.1 a	0.0	0.0	0.0 a	0.0 a	0.162 b
0% alcohol × 100 ppm IBA	6.1 a	0.0	0.0	0.0 a	0.0 a	0.166 b
0% alcohol × 200 ppm IBA	12.1 a	0.0	0.0	0.0 a	0.0 a	0.192 a
25% alcohol × 0 ppm IBA	87.9 A	0.0	0.0	100.0 A	32.5 A	0.038 B
25% alcohol × 100 ppm IBA	90.9 A	0.0	0.0	66.7 B	20.0 B	0.170 A
25% alcohol × 200 ppm IBA	63.6 B	0.0	0.0	91.7 A	20.0 B	0.132 A
50% alcohol × 0 ppm IBA	100.0 a	–	–	–	–	–
50% alcohol × 100 ppm IBA	100.0 a	–	–	–	–	–
50% alcohol × 200 ppm IBA	100.0 a	–	–	–	–	–
'Coral' impatiens						
Significance (*P*)						
Alcohol	0.2396	–	–	–	–	0.0351
IBA	0.8147	–	–	–	–	0.9359
Alcohol × IBA	0.0873	–	–	–	–	0.8013
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	0.0 b	0.0	0.0	0.0	0.0	1.462
0% alcohol × 100 ppm IBA	0.0 b	0.0	0.0	0.0	0.0	1.518
0% alcohol × 200 ppm IBA	6.1 a	0.0	0.0	0.0	0.0	1.547
25% alcohol × 0 ppm IBA	0.0 A	0.0	0.0	0.0	0.0	1.520
25% alcohol × 100 ppm IBA	0.0 A	0.0	0.0	0.0	0.0	1.574
25% alcohol × 200 ppm IBA	0.0 A	0.0	0.0	0.0	0.0	1.574
50% alcohol × 0 ppm IBA	6.1 a′	0.0	0.0	0.0	0.0	1.837
50% alcohol × 100 ppm IBA	3.0 a′b′	0.0	0.0	0.0	0.0	1.653
50% alcohol × 200 ppm IBA	0.0 b′	0.0	0.0	0.0	0.0	1.721
Main effects means[iii]						
0% alcohol	–	–	–	–	–	1.509 b
25% alcohol	–	–	–	–	–	1.556 b
50% alcohol	–	–	–	–	–	1.737 a
0 ppm IBA	–	–	–	–	–	1.606 A
100 ppm IBA	–	–	–	–	–	1.582 A
200 ppm IBA	–	–	–	–	–	1.614 A
'New Gold' lantana						
Significance (*P*)						
Alcohol	0.0165	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
IBA	0.0595	0.2965	0.1654	0.2922	0.3169	0.0004
Alcohol × IBA	0.1384	0.1443	0.7296	0.2994	0.7242	0.0423
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	3.0 a	0.0a	0.0	0.0	0.0	0.146 b
0% alcohol × 100 ppm IBA	3.0 a	0.0a	0.0	0.0	0.0	0.198 a
0% alcohol × 200 ppm IBA	3.0 a	0.0a	0.0	0.0	0.0	0.171 ab
25% alcohol × 0 ppm IBA	0.0 A	69.7a	10.3	36.4	11.2	0.120 A
25% alcohol × 100 ppm IBA	6.1 A	45.5b	11.5	54.8	14.2	0.129 A
25% alcohol × 200 ppm IBA	0.0 A	42.4b	6.4	42.4	13.3	0.143 A
50% alcohol × 0 ppm IBA	15.2 a′	51.6a′	14.0	71.4	22.1	0.076 b′
50% alcohol × 100 ppm IBA	15.2 a′	50.0a′	13.3	75.0	29.3	0.103 b′
50% alcohol × 200 ppm IBA	0.0 b′	57.6a′	7.6	87.9	30.3	0.142 a′
Main effects means[iii]						
0% alcohol	–	–	0.0 b	0.0 c	0.0 c	–
25% alcohol	–	–	9.4 a	44.4 b	12.9 b	–
50% alcohol	–	–	11.6 a	78.5 a	27.4 a	–
0 ppm IBA	–	–	8.1 A	36.0 A	11.2 A	–
100 ppm IBA	–	–	8.3 A	43.5 A	14.5 A	–
200 ppm IBA	–	–	4.6 A	43.5 A	14.6 A	–

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Table 4. (*Continued*)

Treatment	Dead cuttings (%)	Live cuttings with stem necrosis (%)	Stem tissue with necrosis (%)	Live cuttings with leaf necrosis (%)	Leaf tissue with necrosis (%)	Root dry wt (g)
Weeping fig						
Significance (*P*)						
Alcohol	0.6247	–	–	–	–	0.2456
IBA	0.1267	–	–	–	–	0.0047
Alcohol × IBA	0.9077	–	–	–	–	<0.0001
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.150 a
0% alcohol × 100 ppm IBA	21.2	0.0	0.0	0.0	0.0	0.122 b
0% alcohol × 200 ppm IBA	12.1	0.0	0.0	0.0	0.0	0.167 a
25% alcohol × 0 ppm IBA	12.1	0.0	0.0	0.0	0.0	0.129 B
25% alcohol × 100 ppm IBA	18.2	0.0	0.0	0.0	0.0	0.157 A
25% alcohol × 200 ppm IBA	12.1	0.0	0.0	0.0	0.0	0.165 A
50% alcohol × 0 ppm IBA	12.1	0.0	0.0	0.0	0.0	0.132 b′
50% alcohol × 100 ppm IBA	21.2	0.0	0.0	0.0	0.0	0.198 a′
50% alcohol × 200 ppm IBA	18.2	0.0	0.0	0.0	0.0	0.149 b′
Main effects means[iii]						
0% alcohol	11.8 a	–	–	–	–	–
25% alcohol	13.9 a	–	–	–	–	–
50% alcohol	16.8 a	–	–	–	–	–
0 ppm IBA	9.7 A	–	–	–	–	–
100 ppm IBA	20.2 A	–	–	–	–	–
200 ppm IBA	13.9 A	–	–	–	–	–
Star jasmine						
Significance (*P*)						
Alcohol	0.0007	–	–	–	–	<0.0001
IBA	0.3565	–	–	–	–	<0.0001
Alcohol × IBA	0.5981	–	–	–	–	0.0125
Treatment means grouped by alcohol rate[ii]						
0% alcohol × 0 ppm IBA	9.1	0.0	0.0	0.0	0.0	0.222 b
0% alcohol × 100 ppm IBA	12.1	0.0	0.0	0.0	0.0	0.238 b
0% alcohol × 200 ppm IBA	12.1	0.0	0.0	0.0	0.0	0.371 a
25% alcohol × 0 ppm IBA	21.2	0.0	0.0	0.0	0.0	0.194 B
25% alcohol × 100 ppm IBA	6.1	0.0	0.0	0.0	0.0	0.196 B
25% alcohol × 200 ppm IBA	9.1	0.0	0.0	0.0	0.0	0.345 A
50% alcohol × 0 ppm IBA	39.4	0.0	0.0	0.0	0.0	0.192 a′
50% alcohol × 100 ppm IBA	27.3	0.0	0.0	0.0	0.0	0.171 a′
50% alcohol × 200 ppm IBA	24.2	0.0	0.0	0.0	0.0	0.197 a′
Main effects means[iii]						
0% alcohol	10.8 b	–	–	–	–	–
25% alcohol	11.8 b	–	–	–	–	–
50% alcohol	30.0 a	–	–	–	–	–
0 ppm IBA	21.7 A	–	–	–	–	–
100 ppm IBA	13.7 A	–	–	–	–	–
200 ppm IBA	13.7 A	–	–	–	–	–

[i] Rooting duration from treatment until harvest: 30 d for African wormwood and Mammoth™ 'Yellow Quill' chrysanthemum; 55 d for all other taxa. Upon harvest, all live cuttings were rooted.

[ii] When the interaction term in the model is significant ($P \leq 0.20$), simple effects means (treatment means for all rates of IBA grouped within each rate of alcohol) followed by the same lowercase letter, uppercase letter, or lowercase letter primed (to distinguish the three sets of letter groupings) are not significantly different using the Shaffer-simulated adjustment for multiple comparisons ($\alpha = 0.10$); otherwise, the treatment means are presented without letter groupings for informational purposes.

[iii] When the interaction term in the model is not significant ($P > 0.20$), main effects means for rates within each treatment factor followed by the same lowercase letter or uppercase letter (to distinguish the two sets of letter groupings) are not significantly different using the Shaffer-simulated method for multiple comparisons ($\alpha = 0.10$).

in study 1 with a 1-s basal quick-dip based on results of past studies with foliar application of auxin tested on relatively easy-to-root taxa in comparison with a basal quick dip (Blythe 2003).

Cuttings of African wormwood were adversely affected by immersion in solutions containing alcohol, regardless of IBA rate. Only a few cuttings died during the experiment following immersion in solutions containing no alcohol, 27.3% to 45.5% of cuttings died following immersion in solutions containing 25% alcohol, and 97.0% to 100% of cuttings died

following immersion in solutions containing 50% alcohol. Among live cuttings at harvest, cuttings immersed in solutions containing no alcohol showed no basal stem necrosis or leaf necrosis, whereas cuttings immersed in solutions containing alcohol often showed basal stem necrosis, along with leaf necrosis. Examining main effects, RDW among live cuttings at harvest was greater for cuttings immersed in solutions without alcohol and greatest for cuttings immersed in solutions with the highest rate of IBA.

Cuttings of Mammoth™ 'Yellow Quill' chrysanthemum exhibited no apparent adverse effects following immersion in the nine treatment solutions, regardless of alcohol or IBA rate. Examining main effects, RDW of rooted cuttings was similar among alcohol rates and IBA rates.

Cuttings of 'Mary Helen' geranium were adversely affected by immersion in solutions containing alcohol, regardless of IBA rate. Examining simple effects, very few cuttings died after immersion in solutions containing no alcohol, a majority of cuttings (63.6% to 90.9%) died after immersion in solutions containing 25% alcohol, and all cuttings died after immersion in solutions containing 50% alcohol. Live cuttings at harvest that had been immersed in solutions containing no alcohol exhibited no basal stem necrosis or leaf necrosis. Cuttings that had been immersed in solutions containing 25% alcohol exhibited no basal stem necrosis, but most cuttings (66.7% to 100.0%) did exhibit leaf necrosis on 20.0% to 32.5% of the leaf area. Examining simple effects, RDW of cuttings immersed in solutions containing no alcohol was greatest using 200 ppm IBA, whereas RDW of cuttings immersed in solutions containing 25% alcohol was greatest using 100 and 200 ppm IBA.

No or very few cuttings of 'Coral' impatiens died among treatments during the experiment, with examination of main effects showing no consistent trend with increasing rate of IBA among the three rates of alcohol. Live cuttings at harvest showed no basal stem necrosis or leaf necrosis, regardless of alcohol rate or IBA rate. An additional response revealed upon harvest of impatiens cuttings was stem epinasty, with 25% of cuttings that had been immersed in the solution containing 50% alcohol and 100 ppm IBA and 100% of cuttings that had been immersed in the solution containing 50% alcohol and 200 ppm IBA exhibiting temporary stem epinasty. Stems of these cuttings grew horizontally for a limited time before curving upward and resuming normal, vertical growth, whereas no impatiens cuttings in other treatment exhibited this response (results not shown).

Cuttings of 'New Gold' lantana were adversely affected by immersion in solutions containing alcohol, with IBA rate showing no definitive effect. The mortality rate was 3.0% for cuttings immersed in all solutions containing no alcohol, 0.0% to 6.1% for cuttings immersed in solutions containing 25% alcohol, and 0.0% to 15.2% for cuttings immersed in solutions containing 50% alcohol. Among live cuttings at harvest, cuttings immersed in solutions containing no alcohol exhibited no basal stem necrosis, whereas cuttings immersed in solutions containing 25% or 50% alcohol exhibited basal stem necrosis. Similarly, cuttings immersed in solutions containing no alcohol exhibited no leaf necrosis but did exhibit leaf necrosis with all solutions containing alcohol. Examining main effects, the percentage of cuttings and the leaf tissue area exhibiting leaf necrosis increased with increasing alcohol rate. RDW showed a generally decreasing trend with increasing alcohol rate.

Cuttings of weeping fig showed no significant difference in percentage of dead cuttings among alcohol or IBA rates, based on examination of main effects. None of the live cuttings at harvest showed any basal stem necrosis or leaf necrosis. Based on examination of simple effects, there were differences in RDW among IBA rates, but there was no consistent trend in these differences within each alcohol rate.

Cuttings of star jasmine at harvest showed dead cuttings (10.8% to 30.0%) within all treatments. Examination of main effects showed that more cuttings died using with the highest rate of alcohol but no significant differences among rates of IBA. None of the live cuttings at harvest showed any basal stem necrosis or leaf necrosis. Examination of simple effects for RDW showed larger root systems using the highest IBA rate in solutions containing 0% or 25% alcohol, but no differences among IBA rates in solutions containing 50% alcohol.

Discussion

Use of alcohol-containing solutions of auxin applied with a basal quick dip in studies 1 and 2 resulted in little or no adverse effect on stem cuttings of the seven taxa, particularly using only 25% alcohol. These results are consistent with those of McCracken (1987) using solutions of alcohol and technical grade IBA for rooting cuttings of woody crops. The lower rates of auxin in studies 1 and 2 provided good rooting results for the seven taxa used in this study, but auxin was clearly unnecessary for cuttings of impatiens.

Based on our results, it is recommended that propagators use no more than 25% alcohol in solutions with auxin rates similar to those used in this study for basal quick-dip application. Alcohol does not need to be used in solutions with water-soluble IBA, unless the propagator prefers some alcohol for storage of prepared auxin solution and/or a special need to avoid possible cross-contamination of pathogens via water-only solutions. Dilution of alcohol-based rooting concentrates requires the addition of alcohol to ensure that the auxin remains in solution (especially with higher rates of auxin), with a final solution containing at least 50% alcohol being common in commercial propagation (Boyer et al. 2013; Hartmann et al. 2011). The 25% rate of alcohol was satisfactory for the auxin rates used in this study. Propagators wanting to test the minimum rate of alcohol needed to prevent auxin from precipitating out of solution (observable as crystals in the test sample) should take into account the percentage of alcohol in their alcohol-based rooting concentrate (available in the product's safety data sheet) and in their source of alcohol (e.g., 70% to 99.9% for isopropyl alcohol) when preparing test sample dilutions for selected rates of auxin.

Cutting response to a total immersion in IBA solutions (study 3) varied by taxon. Cuttings of African wormwood, 'Mary Helen' geranium, 'New Gold' lantana, and star jasmine were adversely affected by solutions containing alcohol, whereas cuttings of Mammoth™ 'Yellow Quill' chrysanthemum and weeping fig were unaffected. It is likely that alcohol is enhancing the uptake of auxin into

plant tissues to levels that are toxic to some taxa. Hartmann et al. (2011) indicate that IBA may be toxic to softwood cuttings of certain species. They also note that auxins used in excessive concentrations can cause leaf yellowing and abscission, stem necrosis, and eventual death of cuttings in general.

Cuttings of impatiens temporarily exhibited stem epinasty when treated with solutions containing 50% alcohol, indicating enhanced uptake of IBA using a higher rate of alcohol. Stem epinasty was previously reported by Snow (1945) using plants of Himalayan balsam [(*Impatiens glandulifera* (syn. *I. roylei*)] treated with auxin.

In commercial practice, application of auxin to the entire cutting is most often done using a foliar spray application rather than total immersion. However, use of total immersion was selected in study 3 to ensure uniform application of the solutions to the cutting stems and foliage among all taxa and to maximize any potential effects of the IBA solutions on the cuttings, whereas uniformity using a foliar spray can vary with spray pressure and speed of application. Previous research using the total immersion method has involved use of water-soluble formulations of auxin, with no reports of phytotoxicity (Strasko 1992; Van Bragt et al. 1976). Therefore, to avoid phototoxicity with cuttings across multiple taxa using the total immersion method or foliar spray method, it is recommended that fresh solutions of water-soluble auxin without alcohol be used. Otherwise, alcohol-containing solutions of auxin must be tested for potential phytotoxicity on each taxon before large-scale cutting propagation.

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