Evaluation of One-Time Applications of Foliar Applied Auxin Co-Applied with Surfactant for Use in Commercial Cutting Propagation

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Abstract: Use of foliar auxin applications are increasing in the nursery and greenhouse industry. However, previous research has shown that insufficient auxin is absorbed or translocated to the site of action when foliar auxin applications are used. It is theorized that adding surfactants to foliar applications of auxin may help with the absorption and translocation of auxin to the site of action. Research was conducted to determine whether adding surfactants to one-time foliar applications of indole-3-butyric acid (IBA) would be as effective as the current industry standard, the basal quick-dip. Terminal, semi-hardwood cuttings of Red Cascade™ miniature climbing rose (Rosa ‘MOORcap’), common camellia (Camellia japonica) and ‘Southern Charm’ magnolia (Magnolia grandiflora ‘Southern Charm’) were sprayed to the drip point using Hortus IBA Water Soluble Salts™ at concentrations of 0 ppm, 50 ppm, 75 ppm, or 100 ppm for rose cuttings or 0 ppm, 500 ppm, 1000 ppm, or 1500 ppm IBA for camellia or magnolia. To serve as an industry control, the basal end of cuttings was immersed for 3-s in a solution of either 250 ppm, 4000 ppm or 2500 ppm for rose, camellia, or magnolia, respectively. A foliar application of 1500 ppm after sticking was as effective as the basal quick-dip for cuttings of ‘Southern Charm’, while other spray treatments were less effective. A basal quick-dip was more effective than a foliar spray for rooting cuttings of camellia. Auxin rate had no impact on rooting of Red Cascade™ miniature rose. The goal of commercial plant propagation is to produce high-quality rooted cuttings as quickly as possible. Plant propagation places a large demand on labor within the nursery industry, with one recent report being that labor accounts for >50% of a nursery’s budget. Our results from this trial affirm the results reported by similar trials into foliar applications of auxin suggests that the benefits of foliar applications are species dependent. Further work is warranted on examining other auxin and surfactant formulations.

Keywords: semi-hardwood cuttings; Magnolia grandiflora ‘Southern Charm’; Camellia japonica; hortus IBA; Rosa ‘MOORcap’; indole-3-butyric acid

1. Introduction

Research into foliar auxin application methods over the past decade indicated that one-time applications are the standard [1,2]. When applied to cuttings post-insertion into the media, much lower concentrations (50 to 100 ppm) of rooting hormones are required compared to other conventional application methods [3]. Overhead applications of water-soluble indole-3-butyric acid (IBA) are increasing in the nursery industry. In the nursery industry, IBA is the preferred auxin for promoting adventitious rooting compared to indole-3-acetic acid (IAA) due to its stability to heat and light [1]. Bailey Nurseries Inc. in Minnesota and Oregon has been conducting repetitive on-farm trialing for the last decade [4]. Their results indicated that many of the taxa commonly propagated respond similarly to foliar-applied auxin compared to the basal quick-dip.
to a traditional basal quick-dip. At Bailey Nurseries, propagation trays and beds are treated with a single application of water-soluble IBA ranging from 250 to 2000 ppm [4]. Decker’s Nursery in Ohio uses a battery-powered backpack sprayer to treat their cuttings since it atomized the auxin solution like the mist from the cutting irrigation system and applied a very small droplet with excellent coverage over both the top and bottom of the cutting [5]. Since propagation areas vary in size, overhead applications are applied via a backpack sprayer for small houses and reel-and-hose sprayers for larger production areas. When applied overhead, Kroin (2014) recommends to “spray the solution evenly over the cuttings until drops fall onto the media”. To do this, Bailey Nurseries aims to deliver 1 L per 60 ft² (roughly 114-136 L per 557 m²). Currently, both Decker’s Nursery and Bailey Nurseries generally treat their cuttings within 24 h of being stuck, either at the end of each day or the first thing the following morning, but application occurring during the day in conjunction with frequent mist intervals has not reduced efficacy [4,5]. Cuttings are treated in the early morning or late afternoon due to lower light levels and reduced misting requirements. For both nurseries, the switch to foliar applications reduced handling and the time cuttings spend in cold storage and the preparation room, where problems associated with lengthened exposure to low temperatures, low humidity, and/or handling can occur [4]. In 2003, 99.6% of cuttings at Bailey Nurseries were quick dipped and 0.4% were treated with foliar applications. By 2007, the percentages had reversed, with 95% of all propagated material being treated with overhead applications and 5.2% of the material being hand-dipped [4]. Currently, overhead applications of water-soluble IBA are used to treat the following genera at Bailey Nurseries Minnesota operation: Acer, Berberis, Cornus, Dierovilla, Euonymus, Forsythia, Hydrangea, Juniperus, Lonicera, Philadelphus, Physocarpus, Rhus, Rosa, Spirea, Symphoricarpos, Syringa, Thuja, Viburnum, and Weigela [4]. Nursery owners have made the switch to foliar auxin applications in a desire to reduce employee exposure to chemicals, develop a more streamlined and sanitary approach to propagation, and reduce the cost of labor associated with rooting hormone applications [4]. Another benefit of switching to overhead applications from basal quick-dips is similar rooting times and subsequent shoot and root development to basal quick-dip. However, several taxa (Amelanchier, Aronia, Rosa, and Symphoricarpos) have exhibited growth differences between treatment methods [4]. For several genera of landscape significance, foliar auxin applications resulted in delays in vegetative growth and flowering by one to two weeks compared to basal quick-dip; however, over several months the differences between vegetative growth and flowering were not discernible between foliar applications and basal quick-dip [4]. In addition, multiple trials of several taxa of Prunus and Rhododendron receiving overhead auxin did not root as well as cuttings receiving a basal quick-dip, and rooting was slower for cuttings treated with overhead applications compared to basal quick-dips [4]. Although the label for water-soluble salts identifies a zero-re-entry interval and permits application to be made while workers are present in the house, waiting to treat the cuttings until workers have finished planting is a precautionary step [4,5]. Applications are supervised by a trained and licensed applicator, reducing the number of employees exposed to the chemical. Decker’s Nursery and Bailey Nurseries have seen a more streamlined propagation process after making the switch by reducing the number of employees responsible for treating cuttings, which historically was 8 to 10 people. Limiting the number of employees that treat cutting material also ensures consistency and accuracy [4]. Decker’s Nursery has seen an estimated 20% increase in daily production by removing the extra step of dipping handfuls of cuttings [5]. By switching application methods, Bailey Nurseries and Decker’s Nursery have traded relatively high labor costs and low chemical costs for the inverse. For Decker’s Nursery, the increased hormone cost has been offset by no longer having to purchase several hundred dollars’ worth of latex gloves for the propagation staff yearly [5]. For Bailey’s Nursery, hand-dipping 90,000 cutting would normally require eight people working thirty labor hours while utilizing foliar auxin applications takes an applicator roughly one hour to prepare, apply, and clean the spray equipment when finished [4]. The chemical cost to treat those 90,000 cuttings at 750 ppm was $16 using the traditional basal quick-dip and $74 using foliar auxin applications [4]. Decker’s
Nursery has further reported that it takes one applicator no more than five minutes to treat a greenhouse that is 30′ × 98′ (2940 ft²) in area [5].

In addition, switching to a foliar application has removed the risk of stem burn using alcohol-based IBA and the potential for cross-contamination has been eliminated since cuttings are no longer dipped into a stock solution [4]. Previous work conducted by Blythe et al. [6,7] looked at common ornamental plants (Aglaonema modestum, Ficus benjamina, Gardenia augusta 'Radicans', Hedera helix 'Ivalace', Abelia × grandiflora, Hydrangea paniculata, and Lagerstroemia × ‘Natchez’) to determine if they would benefit from an overhead application of IBA + NAA [6] or K-IBA [7] when compared to traditional basal quick-dip. Results indicated that Gardenia augusta 'Radicans' benefited from an overhead application of auxin at a concentration of 25 ppm IBA + 14 ppm NAA or greater or a basal quick-dip compared to untreated cuttings [6,7]. Insufficient auxin was absorbed and translocated to the site of root initiation compared to the amount of auxin received from a basal quick-dip. It was concluded that further work with auxin formulations, surfactants, and application methods is warranted to determine whether overhead application of auxin has commercial value [6,7].

Surfactants are common in agricultural production as penetration of the leaf cuticle is required for the efficacy of foliar-applied compounds [8]. The effectiveness of foliar-applied compounds depends on the ability to penetrate through the cuticle and translocate to the site of action [9]. Surfactants enhance penetration of these chemicals by increasing the wetting capacity up to the critical micelle concentration (CMC), defined as the concentration above which any added surfactant molecules appear with high probability as micellar aggregates [10,11]. Lownds conducted research (1987) to determine the effects surfactants would have on foliar penetration of NAA and NAA-induced ethylene production by cowpea [Vigna unguiculata (L.) Walp. subsp. unguiculata cv. Dixielee]. This research indicated that foliar penetration of NAA was increased when co-applied with a surfactant (Pace, Regulaid, or Tween 20). All three induced similar qualitative changes in surface tension, contact angle, and droplet: leaf interaction. All three surfactants increased the droplet: leaf ratio. However, Regulaid was the only surfactant tested that showed a correlation between NAA penetration and interface area.

Temperature and humidity are the two most important factors affecting herbicide efficacy (i.e., foliar-applied chemicals), and are also important in cutting propagation. Optimal uptake of foliar-applied chemicals occurs in warm, humid conditions [12]. Physiologically, warm temperatures change the viscosity of the cuticle wax, thus increasing the diffusion of solutes through the cuticle [12]. While diffusion across the cuticle is increased at higher temperatures, improvements in the efficacy of the chemical are not always observed [12,13]. It has been hypothesized that this is due to reduced chemical availability caused by rapid drying of droplets in warm conditions [12]. Humidity effects on cuticle composition are not physical effects like those from temperature but are related to the rate of droplet drying and cuticle hydration [12]. Sibley et al. (2018) hypothesized that surfactants added to irrigation water would decrease leaf menisc surface tension while increasing matric and total water potential. These changes would lead to a decrease in transpiration. Plants watered with solutions containing surfactants would have lower water stress than those watered with solutions not containing surfactants [14]. Adding a surfactant at any level (0, 25, 50, 75, 100, or 125 mg·L⁻¹) to irrigation water of New Guinea impatiens ‘Celebrate Salmon’ led to an increase in height, width, growth index, fresh and dry weights compared to those irrigated with solutions not containing surfactants. In addition, Tween 20 added to irrigation water at a rate of 100 mg·L⁻¹, which is approximately the CMC of Tween 20, reduced leaf transpiration. When surfactants reach their CMC, surface tensions of solutions are at their lowest level [15]. Their results were consistent with Kubik and Michalczuk [16] in their experiments looking at the effects of surfactants on the transpiration of strawberry leaves. Strawberry leaves treated with Tween-20 showed a slight decrease in transpiration lasting 60 min before increasing back to an average level. In addition, K⁺ applied to leaves with a surfactant showed a considerable increase in transpiration. This increase is due to potassium’s role regulating stomatal opening and closing. Water-soluble salts of IBA (K-IBA) should theoretically behave like other salt compounds and break down in an aqueous solution.
to the primary components, K⁺ and IBA. Additionally, adding surfactants to vase water of cut roses has been shown to increase shelf life. Ueyama and Ichimura [17] reported that treating cut roses with their leaves retained in a 500-ppm solution of 2-hydroxy-3-ionene chloride polymer (HICP) for 4 h extended life for 6 days beyond those treated with water alone. Sibley et al. (2018) concluded that addition of surfactants to irrigation water for transplanted plugs decreased the transpiration rate and stomatal conductance, but this has not been observed or reported in a cutting propagation environment.

The objective of this research was to evaluate whether the addition of surfactants to foliar auxin solutions increased plant physiological responses compared to the industry-standard basal quick-dip for semi-hardwood cuttings of Red Cascade™ miniature rose (Rosa ‘MOORcap’), common camellia (Camellia japonica) and ‘Southern Charm’ magnolia (Magnolia grandiflora ‘Southern Charm’).

2. Materials and Methods

The research was conducted at the South Mississippi Branch Experiment Station located in Poplarville, MS, USA (latitude 30°50′38.328″ N, longitude 89°32′13.704″ W).

2.1. Plant Material

‘Red Cascade’™ miniature climbing rose (Rosa ‘MOORcap’), common camellia (Camellia japonica) and ‘Southern Charm’ (Magnolia grandiflora ‘Southern Charm’) were selected as representatives of an easy-to-root, moderate-to-root, and a difficult-to-root plant species available in the nursery industry (Figure 1).

![Figure 1](image_url) Reference samples of semi-hardwood cuttings used for this study: (top-left) average rose cutting; (top-center) typical camellia cutting; (top-right) example of wounding on Camellia japonica; (bottom-left) typical magnolia cutting; (bottom-right) example of wounding on ‘Southern Charm’ southern magnolia.

2.2. Treatments

For this experiment, the effect of four foliar auxin concentrations [0, 50, 75, and 100 ppm (rose) or 0, 500, 1000, and 1500 ppm IBA (camellia and magnolia) IBA (Hortus IBA Water Soluble Salts™; Phytotronics Inc., Earth City, MO, USA)] each at two Regulaid® concentrations [0 and 0.85 ppm (KALO Inc., Overland Park, KS, USA)] on rooting of a miniature rose, common camellia, and ‘Southern Charm’ southern magnolia. Additionally, a basal quick-dip of either 250 ppm IBA (rose), 4000 ppm IBA (camellia), or 2500 ppm IBA (magnolia) was used as an industry control.

This experiment used a complete factorial (5 auxin rates × 2 surfactant concentrations) set of treatments within a completely randomized design with 15 cuttings per treatment. Basally applied auxin rates used for this study were selected based on previously reported studies on these species [18,19], as well as conversations with industry members. In contrast, the rates used for foliar auxin applications were derived from the literature provided by Hortus [2].
2.2.1. Data Collection

At study termination, data were collected as the percentage of cuttings rooted, the number of roots per cutting, average length of the three longest roots, shoot length, and root quality. Root quality was assessed on a rating scale from 1 to 5 with 1 being a callused cutting without roots and a 5 representing a cutting with 10 or more roots. Additionally, at study termination, net photosynthetic rate (A) and stomatal conductance ($g_{sw}$) values were taken at study termination between the hours of 0730 and 1130 using the LiCOR 6800 Portable Photosynthesis System (LI-COR Biosciences; Lincoln, NE, USA).

2.2.2. Rose

Two-inch (5.1 cm), two-node medial cuttings of *Rosa* ‘Red Cascade’ were harvested from greenhouse-maintained stock plants and stuck to a depth of 0.5-inch (1.3 cm) on 9 November 2020. Propagation medium was 100% pine bark placed into 3.5-inch (8.3 cm) square production pots (T.O. Plastics, Inc., Clearwater, MN, USA). Cuttings receiving foliar applications of auxin were sprayed once to runoff with a 1-gal (3.78 L) battery-operated sprayer (One World Technologies, Inc., Anderson, SC, USA). Pine bark for this experiment was sourced from Eakes’ Nursery Supply (Seminary, MS, USA) and delivered as a mix of 50% aged and 50% fresh bark passed through a 3/8” (0.95 cm) screen. After treatment, cuttings were placed under intermittent mist applied for 6 s/10 min during daylight hours and adjusted as needed for duration of the study. The average humidity was 75.6 throughout the study, while the average temperature was 65.6 °F (18.6 °C). After 42 days, the study was terminated, and the data was collected as previously mentioned.

2.2.3. Camellia

Five-inch (12.7 cm), five-node terminal cuttings of *Camellia japonica* were harvested from established landscape plants and stuck to a depth of 0.5-inch (1.3 cm) on 16 December 2020. During cutting preparation, a one-inch (2.54 cm) wound was applied to one side of the basal end of the cutting. The propagation medium was 100% pine bark placed into 3.5-inch (8.3 cm) square production pots (T.O. Plastics, Inc., Clearwater, MN, USA). Cuttings receiving foliar applications of auxin were sprayed once to runoff with a 1-gal (3.78 L) battery-operated sprayer (One World Technologies, Inc., Anderson, SC, USA). Pine bark for this experiment was sourced from Eakes’ Nursery Supply (Seminary, MS, USA) and delivered as a mix of 50% aged and 50% fresh bark passed through a 3/8” (0.95 cm) screen. After treatment, cuttings were placed under intermittent mist applied for 6 s/10 min during daylight hours and adjusted as needed for the study’s duration. Over the course of this study, the average relative humidity was 77.9%, while the average temperature was 65 °F (18.6 °C). After 60 days, the study was terminated, and data was collected as previously mentioned.

2.2.4. ‘Southern Charm’ Magnolia

Five-inch (12.7 cm), five-node terminal cuttings of *Magnolia grandiflora* ‘Southern Charm’ were harvested from established landscape plants and stuck to a depth of 0.5-inch (1.3 cm) on 13 April 2021. During cutting preparation, one-inch (2.54 cm) wounds were applied to opposite sides of the basal end of the cutting. The propagation medium was 100% pine bark placed into 4.5-inch (12 cm) square production pots (T.O. Plastics, Inc., Clearwater, MN). Cuttings receiving foliar applications of auxin were sprayed once to runoff with a 1-gal (3.78 L) battery-operated sprayer (One World Technologies, Inc., Anderson, SC) (Figure 2). Pine bark for this experiment was sourced from Eakes’ Nursery Supply (Seminary, MS) and delivered as a mix of 50% aged and 50% fresh bark passed through a 3/8” (0.95 cm) screen. After treatment, cuttings were placed under intermittent mist applied for 4 s/4 min during daylight hours and adjusted as needed for the study’s duration. Over the course of this study, the average relative humidity was 76.9%, while the average temperature was 74.3 °F (23.5 °C). After 125 days, the study was terminated, and data was collected, as mentioned above.
Figure 2. Foliar auxin treatment being applied to a tray of Magnolia grandiflora ‘Southern Charm’.

2.2.5. Statistical Analysis

This experiment used a complete factorial (5 auxin rates × 2 surfactant concentrations) set of treatments with 15 cuttings per treatment. Data were analyzed using linear and generalized linear models with the GLIMMIX procedure of SAS version 9.4 (SAS institute, Cary, NC, USA). Mean separation was performed using the Holm-Simulated Method for multiple comparisons to maintain an overall significance level of $\alpha = 0.05$.

3. Results

3.1. Rose

The rooting percentage of rose ranged from 97% to 100%, but neither surfactant nor auxin rate impacted the rooting percentage (Table 1). Neither the use of surfactant nor auxin rate had affected number of roots, the average length of the three longest roots, shoot height, root quality, or stomatal conductance (Table 1). Auxin rate influenced net photosynthesis (Table 1). Cuttings that treated with either 50 or 100 ppm IBA resulted in higher net photosynthesis values than cuttings treated with a basal quick-dip of 250 ppm IBA (Table 1).

3.2. Camellia

The rooting percentage of camellia ranged from 23% to 50%, but neither surfactant nor auxin rate impacted the rooting percentage (Table 2). Additionally, the use of surfactant nor auxin rate did not affect shoot height or stomatal conductance (Table 2). Both surfactant use and auxin rate influenced root number. Cuttings treated with 85 ppm Regulaid® had more roots than cuttings that received no surfactant (Table 2). Cuttings treated with 4000 ppm IBA as a basal quick-dip had more roots compared to cuttings treated with foliar applications, regardless of the rate. The use of 85 ppm Regulaid® resulted in greater root lengths, greater root quality ratings, and higher net photosynthesis values than cuttings not treated with surfactant (Table 2).

3.3. ‘Southern Charm’ Magnolia

The rooting percentage of ‘Southern Charm’ magnolia ranged from 33% to 73%, but neither surfactant use nor auxin rate impacted the rooting percentage (Table 3). Neither surfactant use nor auxin rate affected the average length of the three longest roots, net photosynthesis, or stomatal conductance values (Table 3). Treating cuttings with a foliar application of 1500 ppm IBA or dipping cuttings in a 2500 ppm IBA quick dip resulted in cuttings with more roots than cuttings that received a foliar auxin application of 0, 500, or 1000 ppm IBA (Table 3). Surfactant use and auxin rate were significant for shoot height and root quality ratings (Table 3). Use of 85 ppm Regulaid® resulted in greater shoot heights and root quality ratings than cuttings not receiving surfactant at treatment initiation. For shoot height, cuttings treated with a 2500 ppm basal quick-dip had a greater shoot length than cuttings treated with 0, 500 ppm, or 1000 ppm IBA. Root quality rating for cuttings receiving foliar applications of 1500 ppm IBA or 2500 ppm basal quick-dip were greater than cuttings treated with 0, 500 ppm, or 1000 ppm IBA.
Table 1. Results of surfactant co-application with foliar-applied root promoting compounds on rooting percentage, root number, average root length, root quality, and growth of medial stem cuttings of Red Cascade™ miniature climbing rose (Rosa 'MOORcap').

| Rooting (%) | Roots (No.) | Avg. Length of Three Longest Roots (cm) | Shoot Height (cm) | RootQuality Rating | Net Photosynthesis (A) (µmol m⁻² s⁻¹) | Stomatal Conductance (gsₖ) (mol m⁻² s⁻¹) |
|-------------|-------------|------------------------------------------|------------------|-------------------|----------------------------------------|-----------------------------------------|
| Significance of treatment factors | | | | | | |
| Surfactant  y | NS | NS | NS | NS | NS | NS | NS |
| Auxin Rate  x | NS | NS | NS | NS | NS | 0.0192 | NS |
| Surfactant * Auxin Rate | NS | NS | NS | NS | NS | NS | NS |

Least squares means for main effects

| Surfactant | Auxin Rate | Rooting (%) | Roots (No.) | Avg. Length of Three Longest Roots (cm) | Shoot Height (cm) | RootQuality Rating | Net Photosynthesis (A) (µmol m⁻² s⁻¹) | Stomatal Conductance (gsₖ) (mol m⁻² s⁻¹) |
|------------|------------|-------------|-------------|------------------------------------------|------------------|-------------------|----------------------------------------|-----------------------------------------|
| 0 ppm Regulaid | 97% | 1.4 a w | 12.5 a | 1.1 a | 2.7 a | 3.5 a | 0.3 a |
| 0.85 ppm Regulaid | 97% | 1.4 a | 12.8 a | 1.0 a | 2.6 a | 3.1 a | 0.2 a |
| 0 ppm foliar IBA | 97% | 1.4 A | 12.2 A | 1.0 A | 2.7 A | 3.2 AB | 0.3 a |
| 50 ppm foliar IBA | 97% | 1.4 A | 12.8 A | 0.8 A | 2.5 A | 4.5 A | 0.1 a |
| 75 ppm foliar IBA | 100% | 1.4 A | 13.0 A | 1.2 A | 2.6 A | 3.2 AB | 0.1 a |
| 100 ppm foliar IBA | 93% | 1.5 A | 12.8 A | 1.3 A | 2.7 A | 4.4 A | 0.1 a |
| 250 basal quick-dip | 100% | 1.4 A | 12.7 A | 0.9 A | 2.7 A | 1.2 B | 0.5 a |

z Root Quality (1–5, with 1 = callused cutting without roots and 5 = ≥ 10 roots); y Surfactant: 0 ppm Regulaid or 0.85 ppm Regulaid (KALO Inc., Overland Park, KS, USA); x Auxin rate: 0, 50, 75, or 100 ppm as a foliar application or 250 ppm applied as a basal quick-dip; w When the interaction term (Surfactant * Auxin Rate) in the model is not significant (p > 0.10), main effects means for levels within each treatment factor followed by the same lower-case (surfactant concentration) or upper-case letter (auxin rate) are not significantly different using the Holm-Simulated method for multiple comparisons (α = 0.05). NS = not significant.
Table 2. Results of surfactant co-application with foliar-applied root promoting compounds on rooting percentage, root number, average root length, root quality, and growth of terminal stem cuttings of a common camellia (*Camellia japonica*).

| Rooting (%) | Roots (No.) | Avg. Length of Three Longest Roots (cm) | Shoot Height (cm) | Root Quality Rating \( z \) | Net Photosynthesis (A) (\( \mu \text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \)) | Stomatal Conductance (\( g_{sw} \)) (mol \( \cdot \text{m}^{-2} \cdot \text{s}^{-1} \)) |
|-------------|-------------|----------------------------------------|-------------------|-----------------|----------------------------|-----------------------------|
| Significance of treatment factors |
| Surfactant \( y \) | NS | <0.0001 | 0.005 | NS | 0.001 | 0.022 | NS |
| Auxin Rate \( x \) | NS | <0.0001 | NS | NS | NS | NS | NS |
| Surfactant * Auxin Rate | NS | NS | NS | NS | NS | NS | NS |

| Surfactant | Auxin Rate |
|------------|------------|
| 0 ppm Regulaid | 33% | 0.4 b \( w \) | 0.6 b | 0.3 a | 1.6 b | 2.3 a | 0.02 a |
| 0.85 ppm Regulaid | 50% | 1.4 a | 2.6 a | 0.2 a | 2.2 a | 1.4 b | 0.02 a |
| 0 ppm foliar IBA | 33% | 0.7 BC | 1.1 A | 0.3 A | 1.9 A | 2.0 A | 0.02 A |
| 500 ppm foliar IBA | 26% | 0.8 B | 0.4 A | 0.4 A | 2.0 A | 1.7 A | 0.02 A |
| 1000 ppm foliar IBA | 23% | 0.5 C | 2.2 A | 0.2 A | 1.6 A | 1.7 A | 0.03 A |
| 1500 ppm foliar IBA | 23% | 0.8 BC | 1.9 A | 0.4 A | 1.8 A | 1.9 A | 0.02 A |
| 4000 basal quick-dip | 40% | 1.6 A | 2.5 A | - | 2.4 A | 1.8 A | 0.01 A |

\( z \) Root Quality (1–5, with 1 = no roots and 5 = ≥ 10 roots); \( y \) Surfactant: 0 ppm Regulaid or 0.85 ppm Regulaid (KALO Inc., Overland Park, KS, USA); \( x \) Auxin rate: 0, 500, 1000, or 1500 ppm as a foliar application or 4000 ppm applied as a basal quick-dip; \( w \) When the interaction term (Surfactant * Auxin Rate) in the model is not significant (\( p > 0.10 \)), main effects means for levels within each treatment factor followed by the same lower-case (surfactant concentration) or upper-case letter (auxin rate) are not significantly different using the Holm-Simulated method for multiple comparisons (\( \alpha = 0.05 \)). NS = not significant.
Table 3. Influence of surfactant and auxin rate on roots and shoots of ‘Southern Charm’ southern magnolia (*Magnolia grandiflora* ‘Southern Charm’).

|                  | Rooting (%) | Roots (No.) | Avg. Length of Three Longest Roots (cm) | Shoot Height (cm) | Root Quality Rating $^z$ | Net Photosynthesis (A) ($\mu$mol m$^{-2}$·s$^{-1}$) | Stomatal Conductance (g$_{sw}$) (mol m$^{-2}$·s$^{-1}$) |
|------------------|-------------|-------------|----------------------------------------|-------------------|--------------------------|---------------------------------------------------|-----------------------------------------------|
| **Significance of treatment factors** |             |             |                                        |                   |                          |                                                   |                                               |
| Surfactant       | NS          | NS          | NS                                     | NS                | NS                       | NS                                                | NS                                            |
| Auxin Rate       | NS          | <0.0001     | NS                                     | NS                | <0.0001                  | NS                                                | NS                                            |
| Surf. * Auxin Rate | NS     | NS          | NS                                     | NS                | NS                       | NS                                                | NS                                            |

Least squares means for main effects

| Surfactant | Auxin Rate | Rooting (%) | Roots (No.) | Avg. Length of Three Longest Roots (cm) | Shoot Height (cm) | Root Quality Rating $^z$ | Net Photosynthesis (A) ($\mu$mol m$^{-2}$·s$^{-1}$) | Stomatal Conductance (g$_{sw}$) (mol m$^{-2}$·s$^{-1}$) |
|------------|------------|-------------|-------------|----------------------------------------|-------------------|--------------------------|---------------------------------------------------|-----------------------------------------------|
| 0 ppm Regulaid | 33%      | 0.9 a $^w$  | 7.9 a       | 0.6 b                                  | 2.2 b             | 6.3 a                    | 0.1 a                                             |                                               |
| 0.85 ppm Regulaid | 73%     | 1.2 a       | 7.2 a       | 1.3 a                                  | 2.5 a             | 6.3 a                    | 0.1 a                                             |                                               |
| 0 ppm foliar IBA | 33%     | 0.6 B       | 6.4 A       | 0.3 B                                  | 1.8 B             | 5.0 A                    | 0.1 A                                             |                                               |
| 500 ppm foliar IBA | 33%    | 0.3 B       | 7.8 A       | 0.5 B                                  | 1.7 B             | 5.9 A                    | 0.1 A                                             |                                               |
| 1000 ppm foliar IBA | 60%   | 0.9 B       | 9.1 A       | 0.5 B                                  | 2.1 B             | 5.9 A                    | 0.1 A                                             |                                               |
| 1500 ppm foliar IBA | 53%    | 1.6 A       | 8.4 A       | 1.2 AB                                 | 2.8 A             | 7.1 A                    | 0.1 A                                             |                                               |
| 2500 ppm foliar IBA | 60%    | 1.8 A       | 5.9 A       | 2.4 A                                  | 3.3 A             | 7.5 A                    | 0.1 A                                             |                                               |

$^z$ Root Quality (1–5, with 1 = no roots and 5 = ≥ 10 roots); $^y$ Surfactant: 0 ppm Regulaid or 0.85 ppm Regulaid (KALO Inc., Overland Park, KS, USA); $^x$ Auxin rate: 0, 500, 1000, or 1500 ppm as a foliar application or 2500 ppm applied as a basal quick-dip; $^w$ When the interaction term (Surfactant * Auxin Rate) in the model is not significant ($p > 0.10$), main effects means for levels within each treatment factor followed by the same lower-case (surfactant concentration) or upper-case letter (auxin rate) are not significantly different using the Holm-Simulated method for multiple comparisons ($\alpha = 0.05$). NS = not significant.
4. Discussion

In the nursery industry, root-promoting compounds are applied to stem cuttings to stimulate adventitious rooting in a wide range of species and cultivars [20]. Through this application, producers aim to accelerate root initiation, as well as root numbers, uniformity, and quality [1,20]. Since the first research into auxins use in propagation practices [1,21,22], the basal quick-dip has been the preferred method for plant propagators due to its speed, simplicity, and uniformity of application, and the economics of treating a large number of cuttings [23–26]. Researchers have also examined other auxin application methods to determine application efficiency [1,27]. Chadwick and Kiplinger [27] reported treating IAA at a concentration of 100 ppm or three times with a foliar application of 20 ppm was not as effective as a basal quick-dip. Furthermore, spraying stem cuttings of strawberry tree (Arbutus unedo) with 300 ppm IAA spread over 48-hrs. resulted in plant injury, and no successful rooting. Foliar applications of auxin at 300 ppm were recommended for bean (Phaseolus spp.), marigold (Tagetes spp.), coleus (Solenostemon spp.), marguerite (Argyranthemum frutescens), and carnation (Dianthus caryophyllus) [28]. Sprays with IBA resulted in more roots on cuttings compared to nontreated cuttings. While the spray technique was noted as being easier to apply, less likely to injure cuttings, and the ability to repeat applications without disturbing cuttings, it was less economical than some basal quick-dip treatments [28]. Due to the reported economic disadvantage of foliar applications, the basal quick-dip was the predominant method of applying root-promoting compounds since its inception in the late 1930s. Thanks in part to increasing labor demands, research into alternative methods (i.e., foliar auxin applications) have increased in earnest in the last 15 years [1,29]. Since the renewed interest, several reports have been published on species’ dependency of foliar applied auxin [1,6,29].

One of the primary concerns with foliar auxin applications for commercial cutting production is insignificant auxin being translocated to the site of action (i.e., basal end of stem cutting) for use in stimulating adventitious root formation compared to using a basal quick-dip [1,6,29]. Results from research conducted by Chadwick and Kiplinger [27] identified that both IBA and NAA were superior in stimulating adventitious rooting compared to IAA, thanks in part to the stabilities of the former to both heat and light degradation. It wasn’t until the 1950’s that IBA was found to be present in planta and no longer labeled as ‘synthetic auxin’ [30]. IBA has since been present in numerous plant tissues and makes up a variable percentage of the endogenous auxin concentration [31,32]. Recent research has shown that IBA levels in planta remain low until adventitious rooting occurs, stimulating an increase. For example, when exogenous IBA was applied to Arabidopsis thaliana at 10 ppm, endogenous IBA levels tripled while endogenous IAA levels doubled [33,34]. This result shows that exogenously applied IBA must be converted to IAA before use in adventitious root formation [35,36]. Previous work on auxin movement within plant tissues has shown that endogenous auxin is produced in the plant tissues before conjugation and moved to storage [1,32]. When applied to the basal end of stem cuttings, exogenous IBA must move through the tissue to the conversion site before becoming available for use. In contrast, auxin applied directly to the leaves should be converted to the usable form more quickly. However, the research into the movement of IBA applied basally or directly to the foliage warrants further investigation to verify this claim [1,32,37–39].

For rose, the use of auxin did not impact tested rooting parameters. Results are similar to those reported by Blythe et al. [6,29]. Previous work reported that the rooting response of Red Cascade™ rose increased with increasing auxin concentration. Our results indicated that the rooting parameters tested in our experiment were not impacted by increasing auxin rate. Cuttings receiving 0 ppm IBA as a foliar spray rooted similarly to those cuttings receiving a 250 ppm basal quick-dip. Previous work using Red Cascade™ used terminal, single node cuttings as their propagule, whereas, in this study, medial, multi-node cuttings were used. The use of multi-node cuttings for the propagation of Rosa spp. is recommended by Dirr and Heuser [18]. Kroin [40] reports adventitious root formation using foliar auxin...
applications for Rosa spp. produced high-quality roots when using a foliar application of 50 to 100 ppm IBA, which differs from the results observed in our study.

Results with Camellia japonica suggest that basal quick-dip is the preferred method for rooting cuttings of this species since other measured parameters were similar regardless of auxin treatment. One-time foliar applications are insufficient to improve rooting responses compared to the commercial standard basal quick-dip. Our results are similar to the propagation parameters for camellia [18,19]. Previous research by Dirr and Heuser [18,19] on camellia propagation indicated that auxin rates between 3,000 and 5,000 ppm stimulate the adventitious rooting of camellia. Previous work on the rooting of Ficus religiosa has suggested that the physiological status of the mother plant is an important prerequisite in achieving homogenous rooting of cuttings [37]. For example, changes in photosynthetic properties and water content impact carbohydrate production which plays a critical role in adventitious rooting and overall plant survival [37]. The cutting material used in this study were taken from well-established landscape plants that were part of an old arboretum and estimated to exceed 30 years of age. According to Dirr and Heuser [18,19], the time of year and age of stock plant material is critical for adventitious rooting for camellia. Further, a correlation between flowering and adventitious rooting can vary between species [37,41]. Several studies have reported that adventitious roots are not readily formed during the flowering of Eucalyptus resinifera or Backhousia citriodora [38,41]. Flowering occurred during our study. While caution was used to select cutting material without a flower bud, the physiological change the stock plant undergoes when transitioning from vegetative growth to reproductive growth could have negatively affected the adventitious rooting ability of Camellia japonica. Our results vary from Dirr and Heuser [18,19] that fall and winter months, periods were flowering occurs, may not be optimal for propagation. At any given point, the correlation between multiple environmental factors affecting the stock plant and the rooting response is controlled by the single most-limiting factor [40]. Our results conclude with other studies that the propagation period is critical for the rooting process and could be a species-dependent factor, similar to the effectiveness of foliar auxin applications as observed in the study reported above [39].

For Magnolia grandiflora ‘Southern Charm’, the best rooting was observed when using a foliar spray of 1500 ppm IBA or a 2500 ppm basal quick-dip compared to foliar applications of lower concentrations. One-time foliar applications of auxin appear to be of benefit to this species. Previous work on Magnolia species’ has shown that exogenously applied IBA is necessary to induce adventitious rooting [42]. While rooting did occur without rooting hormone, treating cuttings with IBA increased the rooting capacity significantly [39]. Previous research recommends a range of 5000 ppm to 20,000 ppm IBA in t alc, but variation among species has been reported [18,24,42,43]. As previously discussed, the age and physiological status of the mother plant are important prerequisites for homogenous rooting [37]. Cutting material of ‘Southern Charm’ used in the described study was sourced from well-maintained stock plants on the campus of Mississippi State University (Starkville, MS, USA; USDA Zone 7b) and estimated to be approximately 15 years of age. One concern growers have had with foliar auxin applications is that shoot growth was stunted in several plant genera [5]. This was not observed in our trial with ‘Southern Charm’. Cuttings receiving a 1500 ppm foliar application resulted in similar shoot lengths as cuttings treated with a 2500 ppm basal quick-dip. This resulting shoot growth from the 1500 ppm treatment and the 2500 ppm treatment was partly due to a more numerous and higher quality root system than other tested IBA concentrations. Our results are similar to those Kaur [32] reported in their study with Prunus persica. Their study observed greater plant height in a 3000 ppm IBA soak. This increase in plant height was hypothesized to increase the photosynthetic rate and, subsequently, increased carbohydrate growth. How the increase in plant height truly affected the photosynthetic rate of their cuttings is unknown; However, the increase in plant height observed in our study did not correlate with a significant increase in photosynthetic rate. Further, they observed a decrease in rooting percentage as IBA concentration increased [32]. While their study reported using hardwood cuttings as
their propagule, the literature recommends semi-hardwood cuttings taken during periods of active vegetative growth treated with 2000 ppm as a basal quick-dip for the propagation of *Prunus persica* [18,19] for cuttings taken from older stock plants. Like Kaur, our study with ‘Southern Charm’ was outside the suggested propagation period for *Magnolia* spp. [18,19,41]. In the literature, semi-hardwood cuttings taken during the fall are recommended [18,19]. However, there have been verbal accounts of nursery owners having great success with spring cuttings of ‘Southern Charm’. Rooting cuttings in the spring before flowering may benefit from the higher concentrations of endogenous auxin hypothesized to be in active; thereby leading to an optimal endogenous hormone concentration to achieve rooting that is not seen when traditional fall cuttings are taken when higher exogenous auxin levels are recommended [37,38,41]. For nursery owners, switching from a fall propagation to a spring propagation schedule may result in increased labor efficiency as spring is the optimal rooting period for numerous plants of landscape performance. Additionally, extending the propagation period for ‘Southern Charm’ would reduce the time needed for root development, allowing plants to progress down the production line and sell quicker than the currently suggested propagation window [39]. From our study, it can be concluded that the application method and auxin concentration are entirely species dependent, as has been reported by other researchers [37–46].

5. Conclusions

Commercial plant propagation aims to produce high-quality rooted cuttings as quickly as possible. Plant propagation places a large demand on labor within the nursery industry, with one recent report being that labor accounts for >50% of a nursery’s budget [1]. This present study provides new experimental data comparing basal quick-dip versus foliar auxin applications on three woody shrubs common in the landscape industry. In addition, the non-ionic surfactant Regulaid® was tested as an adjuvant for foliar auxin applications. Our results suggest that sufficient auxin was absorbed from foliar applications and translocated to the site of root initiation to result in a root response comparable to a basal quick-dip for ‘Southern Charm’ magnolia but not for common camellia or ‘Red Cascade’ miniature rose. By using a foliar application of 1500 ppm IBA on a crop of ‘Southern Charm’ magnolia, growers can eliminate the use of a basal quick-dip for the propagation of this plant. The basal quick-dip is still the preferred propagation method for common camellia and Red Cascade™ miniature rose. Our results from this trial affirm the results reported by similar trials into foliar applications of auxin, suggesting that benefits of foliar applications are species dependent [6]. Further work is warranted on examining other auxin formulations in addition to different surfactant formulations. The above methods should be applied to further woody ornamental plant species of importance to increase the literature on plant material that benefits from foliar auxin applications.

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