Effect of Incorporating Controlled-release Fertilizer on Adventitious Rooting and Growth of *Artemisia*, *Gaura*, and *Nepeta*[1]

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Abstract

Controlled-release fertilizer was incorporated into the rooting substrate to determine its effect on adventitious rooting and subsequent growth of three herbaceous perennials: *Artemisia ludoviciana* 'Valerie Finnis,' *Gaura lindheimeri* 'Whirling Butterflies,' and *Nepeta* x *faassenii* 'Six Hills Giant.' Nutrient treatments consisted of a control, and four treatments each of Nutricote® 13–13–13 Type 180 and 18–6–8 Type 180 at 3, 6, 9, and 12 g/liter (5, 10, 15, and 20 lbs/cu yd) incorporated into the rooting substrate. These treatments equate to N rates of 0, 0.38, 0.77, 1.16, 1.54, 0.53, 1.07, 1.6, and 2.13 g/liter (N at 0, 0.65, 1.3, 1.95, 2.6, 0.9, 1.8, 2.7, and 3.6 lbs/cu yd), respectively. Incorporating controlled-release fertilizer into the rooting substrate at levels equal to or greater than 0.77 g/liter (1.3 lbs/cu yd) increased shoot dry weights, but had no effect on adventitious rooting and little influence on root number or root dry weight. This in turn influenced shoot:root ratios and potentially plant quality. There was no difference between the two formulations.

Index words: vegetative propagation, herbaceous perennials, Nutricote®, controlled-release fertilizer.

Species used in this study: white sage (*Artemisia ludoviciana* Nutt.'Valerie Finnis'), white gaura (*Gaura lindheimeri* Engelm. & Gray 'Whirling Butterflies'), and catmint (*Nepeta* x *faassenii* Bergmans ex Stearn. 'Six Hills Giant').

Significance to the Nursery Industry

Incorporating controlled-release fertilizer (CRF) into the rooting substrate had no impact on adventitious rooting percentage and little influence on root number or root dry weight. It did improve visual appearances of plants as well as shoot dry weights. However, the greater response for shoot growth relative to root growth suggests that N promotes shoot growth more than root growth, which can potentially influence the quality of the liner. In addition, leaching of nutrients might occur because of the absence or limited size of the root system. This in turn is wasteful and may result in runoff contamination. Fertilizing cuttings immediately after roots are formed will provide nutrients early in the growth of the cuttings, but the timing and rate of N fertilization must be optimized to reduce mortality and achieve plants approaching ideal shoot:root ratios. Good nutrition programs continued in the liner stage and production phase should result in stronger, healthier plants in less time. Hastening growth and reducing the number of days in the nursery can greatly increase profitability.

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Introduction

White sage (*Artemisia ludoviciana* Nutt.'Valerie Finnis'), white gaura (*Gaura lindheimeri* Engelm. & Gray 'Whirling Butterflies'), and catmint (*Nepeta* x *faassenii* Bergmans ex Stearn. 'Six Hills Giant') are three herbaceous perennials that are increasing in popularity. As with any taxon, propagating and producing marketable, high quality plants of these three taxa in the least amount of time is a goal for all nursery operators. Producing high quality nursery stock begins with quality liners possessing deep-green leaf color, a developed root system, and a potential to grow rapidly following transplanting (17). Although accelerating growth may not result in higher quality, reducing production time potentially reduces costs and increases profits.

Fertility has a major impact on quality and production time. In most production systems, fertilizers are normally applied sometime after rooting or transplanting. During adventitious rooting of cuttings, optimal nutrition can be an important factor in improving propagation success. Reports are contradictory as to whether fertilizer improves rooting percentages during propagation (2, 4, 7, 18, 20, 21, 22, 23), but it is generally accepted that once roots emerge, fertilizers can be beneficial (5). However, a balance between shoot and root growth is required. Optimum quantity, formulation, and time of application are unclear and depend on method of propagation as well as taxon.

Nutrients have been supplied to cuttings through intermittent mist, subirrigation, surface application as water soluble or granular fertilizers, and incorporation into the rooting substrate, with varying effects on adventitious rooting, plant growth, and plant quality. Use of intermittent mist is a common practice for producing rooted cuttings. However, nutrient deficiencies have resulted from cuttings propagated under mist due to leaching of mineral nutrients caused by mist and/or growth of cuttings during propagation without adequate nutrition (5). Applying nutrients through an intermittent mist system helps replenish nutrients lost by leaching, but this method may encourage growth of algae on substrate surfaces, stimulate weed growth in aisles, and waste fertilizer. Subirrigation is suitable for rooting many woody species (23), but herbaceous and softwood cuttings tend to desiccate without high humidity surrounding the leaves. Surface application may require repeated applications along with the associated labor costs (15, 19, 20). An alternative is CRFs incorporated into the substrate (14, 18, 20, 21). This practice would render optimal nutrients available as adventitious roots emerge.

Therefore, the objectives of this study were to: (1) compare adventitious rooting and subsequent growth of rooted liners of three herbaceous taxa in response to two formulations of CRF incorporated into the propagation substrate, and (2) determine optimal levels of incorporated CRF to accelerate plant growth.

Materials and Methods

Tip cuttings of *Artemisia ludoviciana*, *Gaura lindheimeri* 'Whirling Butterflies', and *Nepeta* x *faassenii* 'Six Hills Giant' were collected from landscape plantings on July 1, placed on ice, and transported to the Plant Science Greenhouses at Michigan State University, East Lansing. Cuttings were dipped in the insecticide Merit 75 WP {Imidacloprid, 1-[(6-Chloro-3-pyridinyl)methyl]-N-nitro-2-imidazolidinimine, Bayer Corp., Kansas City, MO} and recut to 7.6 cm (3 in) for *Artemisia* and 5 cm (2 in) for *Gaura* and *Nepeta*. Basal leaves were removed on all cuttings prior to dipping in a solution of IBA at 1000 mg/liter (1000 ppm). Cuttings were placed in 36-cell flats containing a commercial soilless substrate (BioComp BC-5S, BioComp, Inc., Edenton, NC). Individual cells had length, width, and depth measurements of 5.7 cm (2.3 in).

The experimental design was a split-plot with taxon as the main plot factor and nutrient treatment as the sub-plot factor. Nutrient treatments consisted of a control, and four treatments each of Nutricote® 13–13–13 Type 180 and 18–6–8 Type 180 at 3, 6, 9, and 12 g/liter (5, 10, 15, and 20 lbs/cu yd) incorporated into the substrate. These treatments equate to N rates of 0, 0.38, 0.77, 1.16, 1.54, 0.53, 1.07, 1.6, and 2.13 g/liter (N at 0, 0.65, 1.3, 1.95, 2.6, 0.9, 1.8, 2.7, and 3.6 lbs/cu yd), respectively. Nutricote® is a polyolefin-coated CRF whose release of nutrients is controlled by the amount of a chemical release agent in the resin coating (Agrivert, Inc., Webster, TX). The study consisted of 4 blocks, 3 taxa, 9 nutrient treatments, and 4 cuttings per replication within each block/nutrient, taxon treatment. Taxa were randomized within blocks. There were 144 cuttings per taxon for a total of 432 cuttings.

Flats were placed under intermittent mist in a glass greenhouse under natural photoperiod and irradiance and provided with bottom heat. Irradiance levels were maintained below 1500 fc by pulling shade cloth when necessary. Air and substrate temperatures were maintained at 23 ± 2.5C (73 ± 4F) and 26 ± 1C (79 ± 2F), respectively. Irradiance was measured at canopy level with quantum sensors (model LI-189; LI-COR, Lincoln, NE). Mist frequency was controlled by irradiance level with continuous adjustment of frequency as a function of relative humidity. Vapor pressure deficit (VPD) was set not to exceed 0.7 kPa. Temperatures, irradiance levels, and VPD on each bench were monitored with 36-gauge (0.127-mm-diameter) type E thermocouples connected to CR10 dataloggers (Campbell Scientific, Logan, UT) that collected data every 10 sec and recorded hourly averages.

After 21 days, misting was discontinued, and flats were moved to another bench and grown at 23 ± 2.5C (73 ± 4F) for an additional 14 days under natural light and photoperiod. Plants were top watered as needed. At day 35, plants were evaluated with a visual rating (ranging from 0 to 5, with a higher number representing higher quality), and rooting percentages were recorded. Roots of the resulting plantlets were washed free of substrate, the number of primary roots were counted, and separated from shoots. Roots and shoots were dried for 72 hr at 60C (140F) and weighed. Root weight ratios were calculated and are defined as root dry weight divided by total plant dry weight.

Data were subjected to analysis of covariance to determine if there were differences between the 13–13–13 and 18–6–8 formulations. Treatment effects for rooting percentage (survival), visual assessment, shoot dry weight, number of primary roots, root dry weights, and root weight ratios were compared by analysis of variance (PROC GLM, SAS Institute, Cary, NC). None of the non-rooted cuttings survived, whereas those that rooted remained alive for the duration of the experiment. Treatment effects on rooting (survival) were also compared by analysis of variance following an arcsin-square root transformation, but the transformations did not improve the normality of the distribution or the ho-

Table 1. **Overall ANOVA showing significant sources of variation resulting from nine rates of controlled-release fertilizer incorporated into propagation media at 0, 0.38, 0.53, 0.77, 1.07, 1.16, 1.54, 1.60, and 2.13 g/liter of N for three herbaceous perennials (*Artemisia ludoviciana* 'Valerie Finnis', *Gaura lindheimeri* 'Whirling Butterflies', and *Nepeta* x *faassenii* 'Six Hills Giant').**

Source	df	Rooting (%)	Root number	Root dry wt.	Visual rating	Shoot dry wt.	Root wt. Ratio
Taxon	2	0.0299	NS	0.0001	0.0012[z]	0.0001	0.0001
Fert[y]	8	NS	0.0047	0.0120	0.0001	0.0001	0.0001
Spec * Fert	16	NS	NS	NS	0.0001	0.0001	0.0001

[z]*P*-value, Significance at $P \leq 0.05$.

[y]Fertilizer treatment.

[NS]Nonsignificant.

mogeneity of the variances. Therefore, actual data were used to determine statistical differences, and means reported in tables and figures are non-transformed values. Significant differences among taxa were separated by Tukey's Studentized Range test (HSD). Means for all levels of nitrogen were compared to the control by Dunnett's test (16). Regression equations were fit to increasing levels of N.

Results and Discussion

Analysis of covariance indicated that there were no differences in response between the two formulations of Nutricote® (13–13–13 and 18–6–8), thus data were analyzed on amount of N incorporated into the substrate.

Adventitious rooting over fertility treatment was significantly different among taxa (Table 1) with rooting percentages ranging from 93% for *Nepeta* to 81% for *Gaura*. This result might be expected because of the genetic variation among taxa in regards to rooting (8). Similarly, differences were evident among taxa for visual ratings, shoot and root dry weights, and root weight ratios (Table 1). The number of roots per cutting did not differ among taxa. Regardless, the thrust of this study was to observe the different responses attributed to the quantity of N incorporated into the substrate.

Effect of N on rooting percentage. The level of N incorporated into the substrate had no effect on rooting of individual taxa (Table 2) or when each individual rate of N was compared to the control (Table 3). This agrees with results of Johnson and Hamilton (7), where percent rooting for cuttings of *Ligustrum japonicum* and *Juniperus conferta* were not influenced when the propagation substrate was topdressed with Osmocote® 18–6–12 or 14–14–14. However, unfertilized cuttings of *Eucalyptus grandis* (4) resulted in higher rooting than those that were fertilized.

In contrast, numerous studies have reported that fertilization does improve rooting. Adventitious rooting of *Syringa vulgaris* 'Charles Joly' and 'Michael Buchner' increased from 15% to 42% and from 7% to 19%, respectively, when subirrigated with a solution of complete fertilizer that contained N at 5.4 mM as opposed to subirrigation with tap water (2). Similarly, cuttings of *Acer rubrum* 'Franksred' subirrigated with a solution containing N at 3.6 or 7.2 $mol \cdot m^{-3}$ exhibited greater than 90% rooting after two weeks, whereas only 8% of unfertilized cuttings had rooted (23). In addition, CRF in the rooting substrate increased rooting of *Eucalyptus globulus* (21). Furthermore, rooting percentage of softwood cuttings of *Ligustrum obtusifolium*, *Buxus sempervirens*, *Lonicera morrowii*, *Pachysandra terminalis*, and *Philadelphus coronarius* was greater under nutrient mist (22).

Several explanations may help explain the contradictory results. First, rooting response to N may depend on taxon. Ward and Whitcomb (18) reported rooting response of cuttings to CRF varied from species to species with some plants exhibiting significantly greater rooting with fertilizer and some plants showing no difference with or without fertilizer. In some species, fertilizer may be absorbed to nourish the whole cutting or may have local effects on the callus at the base, from which roots normally emerged (21). Wott and Tukey, Jr. (22) also suggested that softwood cuttings were more responsive to nutrient mist than mature or hardwood cuttings. This is logical as softwood cuttings usually root in less time so roots can take up nutrients and influence subsequent growth. With this reasoning, one would expect rooting of herbaceous cuttings to be influenced by nutrients, but this was not the case in our study.

Table 2. **Effect of controlled-release fertilizer incorporated into propagation media at 0, 0.38, 0.53, 0.77, 1.07, 1.16, 1.54, 1.60, and 2.13 g/liter of N on plant attributes of three herbaceous perennials (*Artemisia ludoviciana* 'Valerie Finnis', *Gaura lindheimeri* 'Whirling Butterflies', and *Nepeta* x *faassenii* 'Six Hills Giant'). Data averaged over N treatments.**

Source	df	Rooting (%)	Root number	Root dry wt.	Visual rating	Shoot dry wt.	Root wt. Ratio
Artemisia[z]	8	NS	NS	NS	NS	0.0077[w]	NS
Gaura[y]	8	NS	0.0021	0.0001	0.0001	0.0001	0.0029
Nepeta[x]	8	NS	NS	NS	0.0001	0.0001	0.0001

[z]*Artemisia ludoviciana* 'Valerie Finnis'.

[y]*Gaura lindheimeri* 'Whirling Butterflies'.

[x]*Nepeta* x *faassenii* 'Six Hills Giant'.

[w]*P*-value, Significance at $P \leq 0.05$.

[NS]Nonsignificant.

Table 3. **Plant attributes resulting from controlled-release fertilizer incorporated into propagation substrate at 0.38, 0.53, 0.77, 1.07, 1.16, 1.54, 1.60, and 2.13 g/liter of N compared to a control of 0 g/liter via Dunnett's test. Data averaged over three herbaceous perennials (*Artemisia ludoviciana* 'Valerie Finnis', *Gaura lindheimeri* 'Whirling Butterflies', and *Nepeta* x *faassenii* 'Six Hills Giant').**

Comparison N (g/liter)	Rooting (%)	Root number	Root dry wt.	Visual rating	Shoot dry wt.	Root wt. ratio
2.13 – 0	NS[z]	NS	**	**	**	**
1.60 – 0	NS	**	NS	**	**	**
1.54 – 0	NS	**	**	**	**	**
1.16 – 0	NS	**	NS	**	**	**
1.07 – 0	NS	NS	NS	**	**	**
0.77 – 0	NS	NS	NS	**	**	NS
0.53 – 0	NS	NS	NS	**	NS	NS
0.38 – 0	NS	NS	NS	NS	NS	NS

[z]NS, **: nonsignificant and significant comparisons by Dunnett's Test, $P \leq 0.05$.

Although adventitious rooting and mineral nutrition are intimately related, the subject is complex because root formation on stem cuttings is a multi-stage process. Blazich (5) divides the adventitious rooting process into two general stages consisting of root initiation and root growth and development. When considering the influence of various mineral nutrients on adventitious rooting one must consider the role of a particular nutrient in each stage of the process.

Fertility treatments causing increased percent rooting could be interpreted as reflecting greater root initiation. On the other hand, caution should be exercised in the use of such data because root initiation takes place on the cellular level, so these data are really indirect measures of root initiation. Unless anatomical or similar studies are conducted, one does not necessarily have a true measure of root initiation (5). Regardless, it is generally accepted that once roots emerge, fertilizers can be beneficial as the developing roots can absorb nutrients (5).

Root number and root dry weight. The effect of fertilization on number of primary roots per cutting and total root dry weight was significant only for *Gaura* (Table 2). Both characteristics increased linearly with increasing N level (Figs. 1A and 1B), however the R^2 values are low and only account for a small portion of the variation. In previous work the number of roots per cutting was significantly greater in leafy cuttings of *Rosa* 'Dalas' given weekly fertilizer applications compared to those receiving no fertilization (13). Also, root mass was greater in cuttings of *Acer rubrum* 'Franksred' (23) and *Juniperus conferta* (7) receiving higher levels of N. The effect of nutrients on root number and root dry weight can depend greatly on the timing of fertilizer application. Cuttings of *Ilex crenata* 'Helleri' initially fertilized soon after roots were visible were larger than cuttings for which fertilization was either delayed or withheld (6). In these cuttings, N accumulated in cuttings immediately after roots were first visible but not before (6).

Wott and Tukey, Jr. (22), found root quality of softwood cuttings of several woody species was better under nutrient mist than conventional mist. In contrast, they observed that hardwood cuttings of *Euonymous fortunei* (Turcz.) Hand.-Mazz. 'Vegetus' produced root systems that were larger, heavier, and more fibrous without the addition of fertilizer. These results suggest that softwood cuttings were more responsive to nutrient mist than mature or hardwood cuttings. This is probably because softwood cuttings usually root in less time so roots can take up nutrients and influence subsequent growth. In some cases, fertilizer may inhibit root development if an initial release of nutrients burns the newly formed roots (7).

Visual rating and shoot dry weight. Visual ratings and shoot dry weights tend to be correlated because the top portion of the plant is what is normally seen. In our study both were

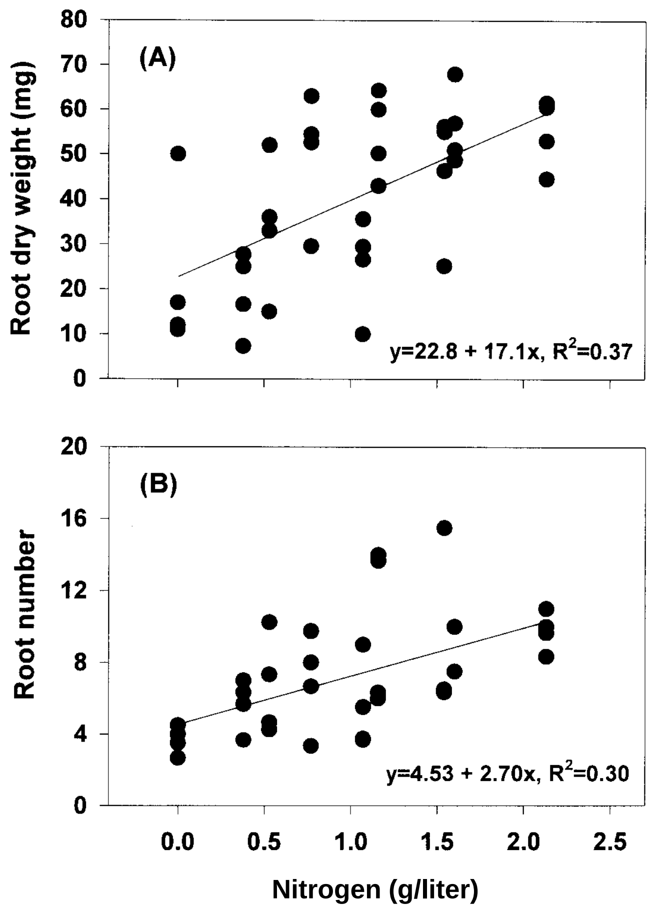

Fig. 1. **Effect of controlled-release fertilizer incorporated into propagation media at 0, 0.38, 0.53, 0.77, 1.07, 1.16, 1.54, 1.60, and 2.13 g/liter of N on (A) root dry weight of *Gaura lindheimeri* 'Whirling Butterflies' and (B) number of primary roots per cutting of *Gaura lindheimeri* 'Whirling Butterflies'. Each symbol is a mean of four observations.**

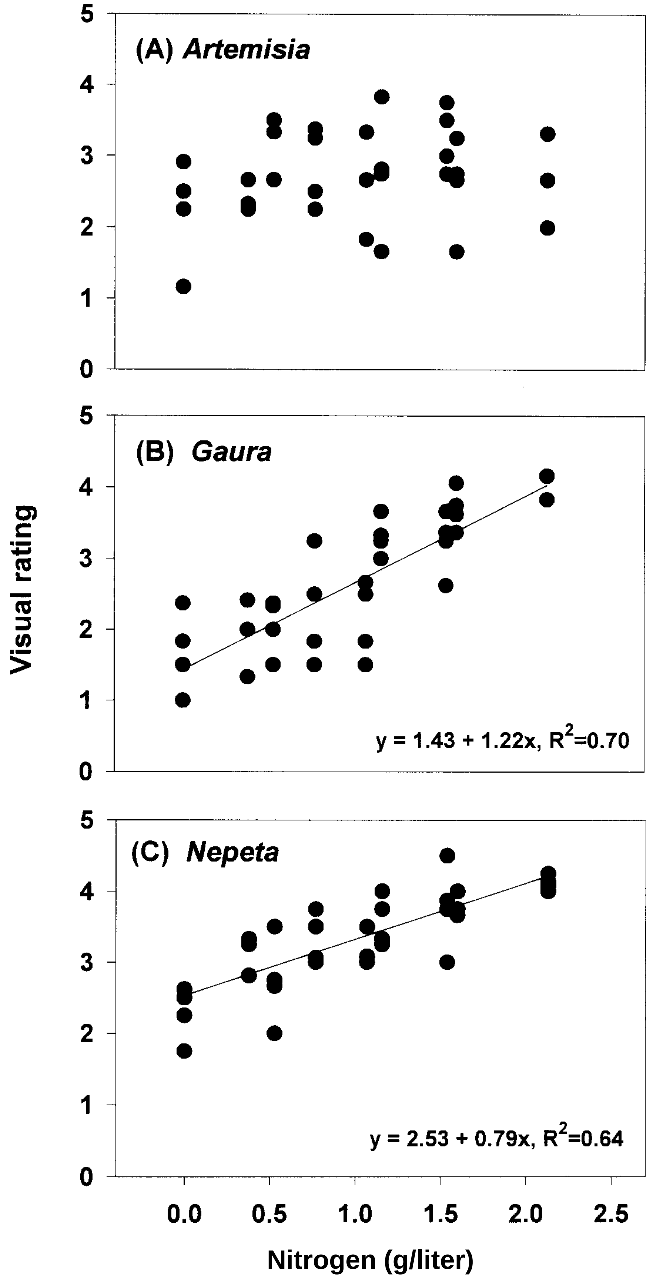

Fig. 2. **Effect of controlled-release fertilizer incorporated into propagation media at 0, 0.38, 0.53, 0.77, 1.07, 1.16, 1.54, 1.60, and 2.13 g/liter of N on visual rating of (A) *Artemisia ludoviciana* 'Valerie Finnis', (B) *Gaura lindheimeri* 'Whirling Butterflies', and (C) *Nepeta* x *faassenii* 'Six Hills Giant'. Each symbol is a mean of four observations.**

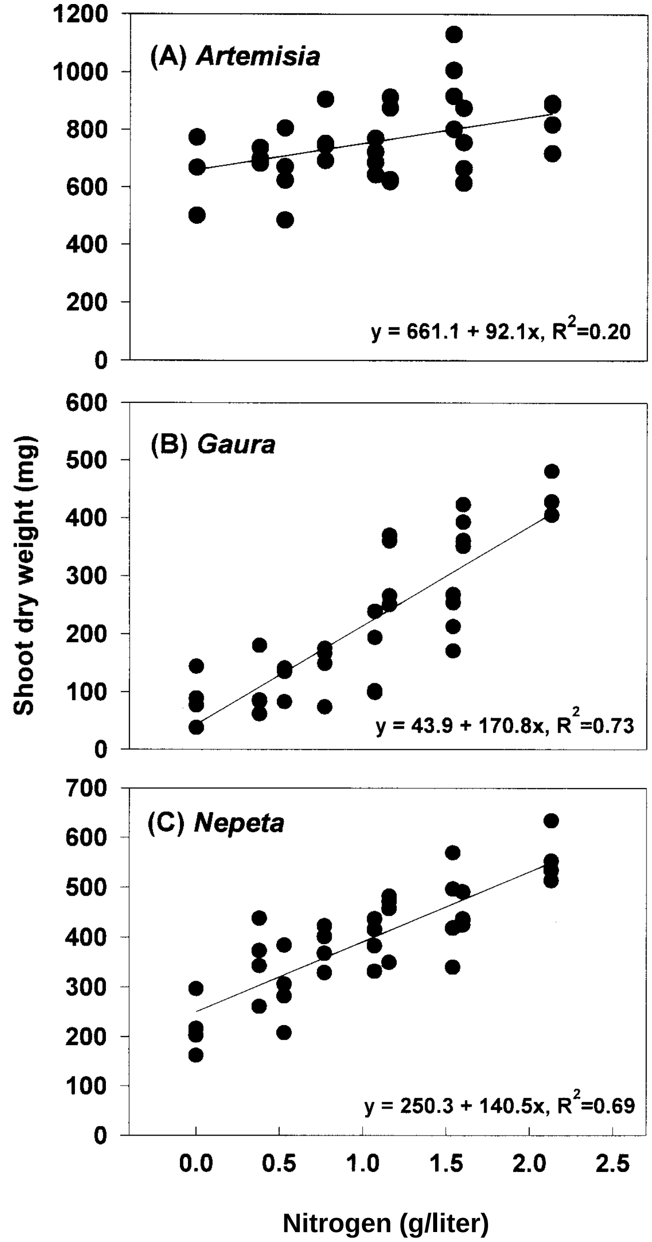

Fig. 3. **Effect of controlled-release fertilizer incorporated into propagation media at 0, 0.38, 0.53, 0.77, 1.07, 1.16, 1.54, 1.60, and 2.13 g/liter of N on shoot dry weight of (A) *Artemisia ludoviciana* 'Valerie Finnis', (B) *Gaura lindheimeri* 'Whirling Butterflies', and (C) *Nepeta* x *faassenii* 'Six Hills Giant'. Each symbol is a mean of four observations.**

influenced by taxon, N, and a taxon × N interaction (Table 1). Visual ratings increased linearly for both *Gaura* and *Nepeta* with increasing levels of N incorporated into the propagation substrate (Fig. 2). However, there was no observable trend for *Artemisia*. Based on regression equations, shoot dry weights increased linearly for all taxa with increasing N levels (Fig. 3). The slope of the curves for *Gaura* and *Nepeta* were steeper than that for *Artemisia*.

Our results for *Gaura* and *Nepeta* agree with the work of Ward and Whitcomb (19), who found that high visual ratings and maximum plant growth were obtained with *Ilex crenata* 'Hetzi' when N was incorporated into the rooting substrate. Likewise, improved shoot development was evident in cuttings of *Ligustrum japonicum and Juniperus conferta* ten weeks after the propagation substrate was top-dressed with Osmocote® 18–6–12 or 14–14–14 (7). Greater shoot growth has also been associated with a greater chlorophyll content in the leaves as was the case with cuttings of *Acer rubrum* 'Franksred' receiving higher levels of N (23).

Shoot:root ratio, root weight ratio, and quality of marketable plant. Nitrogen is the major nutrient that influences shoot growth. However, root growth does not respond in the same way. Generally, a high N level that maximizes shoot growth will produce relatively small root systems (17). This was evident in our study; N exhibited a greater influence on above-ground characteristics such as visual rating and shoot dry weight than below-ground measurements such as root number or root dry weight. Shoot dry weights were significantly different from the control for all N treatments except 0.38 and 0.53 g/liter, whereas, root number and root dry weight generally differed only at the higher levels of N application (Table 3). This phenomenon has been shown in numerous studies (1, 3, 9, 11, 14, 15).

Even though a plant possessing a high shoot:root ratio may look healthy and marketable to the consumer, it is not necessarily a plant of high quality. For example, N had significant effects on biomass allocation to stem, needles, and roots for *Pinus taeda* (10). Low N resulted in smaller seedling size, but relatively more biomass was allocated to roots than under the high N condition. They also found that plants that allocated a greater proportion of their biomass to roots as seedling size increased had a tendency to be taller as they matured. A high relative rate of root growth compared to shoot growth in the seedling stage has been correlated with greater overall growth (10, 12). One would expect a similar response for rooted cuttings.

Every species has some intermediate N level at which the combination of shoot and root growth is optimized, although that level is not necessarily optimal for either individual growth response (17). To prevent this imbalance it is necessary to apply less N than the plants can potentially use. Otherwise, plants with small root systems will not grow as well after they are transplanted. Although production time is not directly related to quality plugs or cuttings, it is important from a business perspective.

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