Nursery Production Method Influences Growth of Hickories[1]

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Abstract

Hickories (*Carya* Nutt.) include multiple stately, native trees that offer ornamental features and site adaptability. Immense interest exists in effectively producing these trees, however, due to their lag-phase shoot growth and strong development of a taproot with minimal fibrous-root branching, these trees exhibit resistance to standard growing techniques and are purportedly difficult to transplant successfully. New commercial products such as modified nursery containers are touted as better alternatives to traditional production techniques. If these new products are effective, they provide new opportunities for developing hickory crops for nursery production. We questioned whether traditional field-grown production, above-ground containers, or above-ground bags could be used to effectively grow bare-root whips of hickories and northern pecan. When differences between treatments occurred, growth was generally greatest with plants grown in above-ground bags, followed by above-ground container-grown plants, and lowest with field-grown plants. Species differences were detected, indicating not all species of *Carya* should be treated identically in the nursery. Additional factors such as unusual nutritional deficiencies of container-grown stock were encountered, suggesting some *Carya* species may exhibit unique requirements in the nursery.

Species used in this study: bitternut hickory [*Carya cordiformis* (Wangenh.) K. Koch]; pecan [*C. illinoinensis* (Wangenh.) K. Koch]; kingnut hickory [*C. laciniosa* (F. Michx.) Loudon]; and shagbark hickory [*C. ovata* (Mill.) K. Koch].

Index words: *Carya*, containers, fabric bag, field-grown, shoot extension.

Significance to the Horticulture Industry

Hickories have long been desired for use in ornamental horticulture yet are seldom produced in the nursery trade. Claims of slow shoot development and poor transplant success are the most common purported reasons why these plants are not more broadly cultivated. However, little evidence has been published to support these claims. We evaluated vegetative growth responses of four different *Carya* species at different production intervals when field-grown, above-ground container-grown, or cultivated in above-ground bags. The results indicated that not all hickory species grow at the same rate and no single production method was better than the others for each of the species studied. However, we suggest growers strongly consider adopting bitternut hickory [*Carya cordiformis* (Wangenh.) K. Koch] and kingnut hickory [*C. laciniosa* (F. Michx.) Loudon] into production for what appear to be accelerated rates of growth relative to their congeners. In addition, the above-ground bag production system was generally better suited to maximizing vegetative growth of these two species. Prior to adopting these crops, growers should consider the apparent supplemental nickel requirements of some hickories when cultivated in containers. Further research is needed to generate uniform production protocols; however, the results of this study serve as a baseline for growers interested in adopting hickories into cultivation or supporting existing crops.

Introduction

While sought after for their ornamental appeal and environmental tolerances, hickories are rarely encountered in the nursery trade. Hickories have potential to be more widely grown nursery crops, yet their production is currently limited. Among the reasons explaining why hickories are not produced on a large scale are limited asexual propagation protocols, slow shoot development, and claims of resistance to successful transplanting due to their coarse root morphology and strong taproots (Miller and Graves 2019). It is common in the nursery trade to blame resistance to successful establishment on root morphology (Burkhart 2006). Typically, species thought of as resistant to successful transplanting exhibit coarse roots, taproots, and minimal development of fibrous lateral roots (Gilman 1990a, Jacobs et al. 2009). Aside from *Carya* (Dirr 2009), many taxa are categorized as difficult to transplant as a function of their coarse roots, with species belonging to the genera *Nyssa* L. and *Pinus* L. serving as examples commonly encountered in managed landscapes (Gilman 1990a, Stephens and Sutton 2015). In the green industry it is typical to pursue container production for species classified as difficult to transplant rather than field production methods where stock is harvested balled and burlapped (B&B) or as bare root (BR) material (Davidson et al. 2000). The goal of this strategy is to minimize root disturbance and maximize the number of roots on the tree at the time of planting (Gilman 1990b).

Due to their reputation for resistance to successful transplanting, cultivation of hickories in containers may be

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an appropriate strategy for production in the nursery. However, little to no information exists regarding their performance in container production. Dirr (2009) describes obtaining stock of *Carya ovata* (Mill.) K. Koch (shagbark hickory) and observing a 60% mortality rate among the seedlings, postulating this experience is also indicative of expected results for other species in the genus. Dirr and Warren (2019), describing their efforts to trial 30.5 cm (12 in) tall seedlings of shagbark hickory in containers, explain the plants did not grow a discernable amount within the first three years, suggesting container production may not be feasible in the nursery. In modern cultivation of pecan [*C. illinoinensis* (Wangenh.) K. Koch], a major nut crop species, commercial production in the nursery is largely composed of container-grown stock or field-grown plants intended to be harvested bareroot (McEachern 2020); however, transplant success remains a challenge relative to other woody plant species. Each method of production entails advantages and disadvantages for the grower and end-consumer. For example, in comparison to field-grown plants, container-grown nursery stock is easier and cheaper to transport, transplant success is typically increased, and growers have more control over crop inputs (Davidson et al. 2000). On the contrary, container-grown nursery stock is more likely to develop deformed root architecture as a function of the confined rooting area of a nursery pot and growers may need to provide greater chemical inputs into container production than with plants in a field setting (Davidson et al. 2000). With these potential advantages and/or disadvantages, there is a need to trial hickories in container production to determine the value of the method and its role in the integration of hickories into commercial horticulture.

In addition to the comparisons between production methods, there are also factors to consider within each production category. Due to the desirable advantages of container production, new strategies and technologies have been introduced into commercial horticulture in recent years to combat the negative consequences of root deflection (Arnold 1996, Miller and Bassuk 2018). Among these are a variety of strategies for mechanically removing root deformation (Cregg and Ellison 2018, Gilman and Wiese 2012, Rouse and Cregg 2021, Weicherding et al. 2007) or an assortment of technologies involving containers of different sizes, forms, and compositions purportedly capable of reducing, circumventing, or eliminating root deformation (Amoroso et al. 2010, Miller and Bassuk 2018, McGrath et al. 2021). These alternative container types generally aim to direct, sequester, or desiccate roots with the goal of modifying their architecture by encouraging branching while also reducing deformation due to deflection.

With so little empirical evidence available concerning the production of hickories in containers and an inundation of claims made regarding the advantages of alternative container technologies, we questioned how four species of *Carya* would perform when cultivated in standard field production, as above-ground container-grown stock, or grown in above-ground bag production [RootTrapper® II (#10 equiv.) bags (Rootmaker Products Co., Huntsville, AL)]. Our objectives were to assess the effects of production method on plant growth and characterize species differences by evaluating the development of bare root stock of *C. cordiformis* (bitternut hickory), *C. illinoinensis* (pecan) *C. laciniosa* (kingnut hickory), and *C. ovata* (shagbark hickory) after two and four years of production.

Materials and Methods

In 2017, bare-root liners (seedlings grown in an in-ground seedbed prior to lifting and shaking soil from roots, intended to be planted out as nursery stock), ranging in height from 30.48 - 86.36 cm (12 – 34 in), of *C. illinoinensis* and *C. laciniosa* were purchased from the Iowa State Forestry Nursery (Ames, IA) and the George O. White State Forest Nursery (Licking, MO), respectively, whereas whips of *C. cordiformis* and *C. ovata* [30.48-60.96 cm (12 – 24 in)] were obtained from Forrest Keeling Nursery (Elsberry, MO). Bare-root stock was shipped in spring of 2018, kept hydrated, and stored in a cooler maintained at 4 C (39.2 F) until planting. Stock of seed origin were selected due to their availability as whips and because they offer a broader genetic base from which to draw species-level conclusions.

Plants were graded and randomly assigned to treatments (field-grown, above-ground container-grown, or above-ground bag). Fourteen single-plant replicates ($n=14$) of *C. illinoinensis*, *C. laciniosa*, and *C. ovata* as well as twelve ($n=12$) *C. cordiformis* were assigned to the field. Twelve single-plant replicates per species were each assigned to the above-ground container-grown and above-ground bag treatments ($n=12$). Prior to implementing treatments, plants were marked with an acrylic paint spot at 2.5 cm (1 in) above the root collar for subsequent growth measurements. In June of 2018, a field with Hudson-clay-loam soil (pH 5.65; 2.59% organic matter) located at the Bluegrass Lane Turf and Landscape Research Center, in Ithaca, NY (lat. 42.48° N, long. 76.47° W, elevation 335 m) was prepared by surface tilling to a depth of 15.24 cm (6 in). In mid-June plants were either planted in a randomized design in rows with 3.0 m (9.8 ft) spacing on center (field), or potted into standard #10 plastic containers (above-ground container-grown), or into the #10 equivalent size [38.1 cm (15 in) height, 35.56 cm (14 in) diameter] RootTrapper® II containers (above-ground bag) using LM-6 (≈3:1 peat:perlite) potting substrate (Lambert Peat Moss, Inc., Riviere-Ouelle, Quebec, Canada). The RootTrapper® II containers consisted of a synthetic bi-layer fabric construction with a wooly needle felt interior and a white polypropylene coating which covered all exterior walls except for an exposed strip of felt located around the base of the container for increased drainage. After planting, trees in the field were irrigated for four hours with a circulating overhead sprinkler every other day for three weeks, after which supplemental irrigation ceased. After potting, container treatments were irrigated to container capacity, moved to an outdoor nursery also located at the Bluegrass Lane Turf and Landscape Research Center, placed randomly, and attached to drip irrigation where they were watered twice daily [≈1L (33.8 fl oz)] throughout

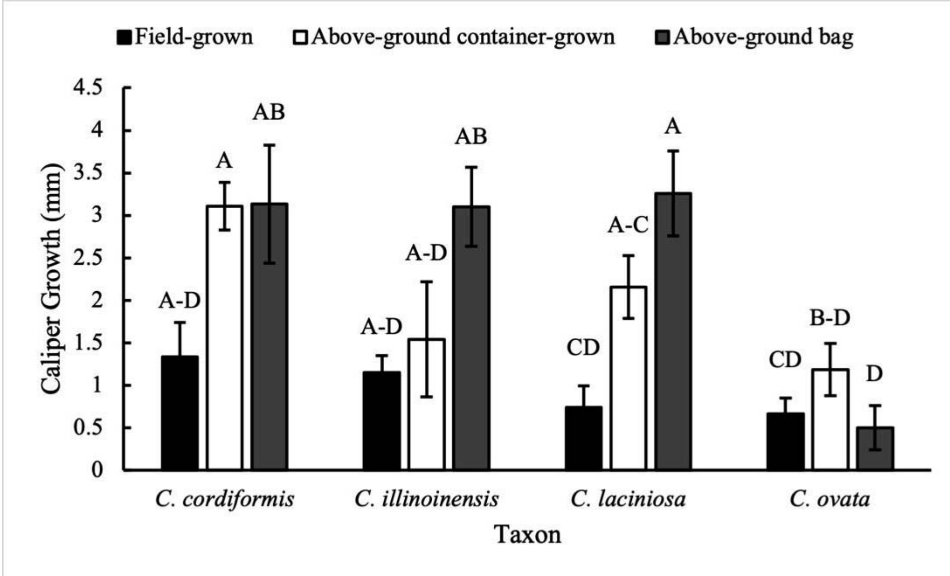

Fig. 1. Caliper growth measured 2.5 cm (1 in) above the soil line of four species of *Carya* (*C. cordiformis*, *C. illinoinensis*, *C. lacniniosa*, and *C. ovata*) grown using different production methods (field-grown, above-ground container-grown, or above-ground bag) at the conclusion of the second year of cultivation. Means across species and treatments with the same letter are not different according to Tukey's honestly significant difference test ($P \leq 0.05$). Error bars indicate the standard error of the mean.

each growing season. All plants were top dressed with 133 g (0.29 lb.) of Osmocote Plus 15-9-12 (ICL Specialty Fertilizers, Dublin, OH) slow release fertilizer [15% N (derived from ammonia and nitrate), 9% P_2O_5, 12% K_2O, 1.3% Mg, 5.9% S, 0.02% B, 0.05% Cu, 0.46% Fe, 0.06% Mn, 0.02% Mo, and 0.05% Zn] at the time of planting or potting as well as each subsequent spring. Plants of either above-ground treatment were overwintered in an unheated polyhouse.

Plant growth was monitored at the conclusion of the second growing season (2019) or in late June after growth expanded and hardened off mid-way through the fourth growing season (2021; year four). Data for *C. illinoinensis* is only reported for year two, because of a reduced number of healthy plants in containers available for assessment at the end of the study. During data collection, caliper growth was measured at the acrylic paint spot [2.5 cm (1 in) above the root collar] using a digital micrometer and determined based off the difference from the previous growing season. Shoot extension was measured as the distance between the proximal-most and distal-most point of the shoot extension that occurred in that year.

Shortly after growth initiated in year three (2020), leaf and shoot expansion slowed or ceased on the plants in the above-ground production systems which had previously exhibited the most vigorous growth. Foliage began displaying necrotic margins, curling of the lamina, and finally stem dieback. *Carya illinoinensis* and *C. cordiformis* displayed the most severe symptoms and were most uniformly afflicted, whereas symptoms manifested sporadically with *C. laciniosa* and *C. ovata*. None of the plants of any species growing in the field exhibited these symptoms at any time. Symptoms appeared consistent with mouse ear disorder, a function of nickel deficiency (Wood et al., 2004a), and all plants in each treatment were supplied a foliar spray of Nickel Plus® (Nipan LLC., Valdosta, GA) at a rate of 9.46 ml Nickel Plus® per 3.79 L H_2O (0.32 fl oz per gal). Shortly after application, symptoms ceased, and normal expansion resumed for most plants. However, some plants did not immediately exhibit a resumption of normal growth due to their episodic nature. Because symptoms appeared to be resolved after treatment with Nickel Plus®, a subsequent treatment was implemented two weeks after bud break on all plants in 2021. A separate formal assessment utilizing *C. cordiformis* confirmed these symptoms were the result of mouse ear disorder (Miller and Bassuk 2022).

Data were subject to a two-way ANOVA. To meet the assumptions of the model, all responses but shoot extension for year two (log transformed) were square root transformed. Post-hoc analysis was performed using Tukey's Honestly Significant Difference Test ($P \leq 0.05$). All data were analyzed using JMP Pro 15 software (JMP Version 15; SAS Institute Inc., Cary, NC).

Results and Discussion

An interaction between taxon and treatment was observed for caliper growth ($P = 0.0029$) and shoot extension ($P = 0.0226$) in year two. An interaction was not detected for shoot extension (year four); however, it was affected by the main effect of treatment ($P = 0.0314$). Caliper growth (year four) was unaffected by an interaction or main effect.

Caliper growth. In year two, caliper growth of field-grown plants was not different across species. No differences were observed across above-ground container-grown or above-ground bag-grown *C. cordiformis*, *C. illinoinensis*, and *C. laciniosa* (Fig. 1). Cultivated in above-ground containers, *C. cordiformis* exhibited a 162.7% increase over *C. ovata* (Fig. 1). Grown in above-ground

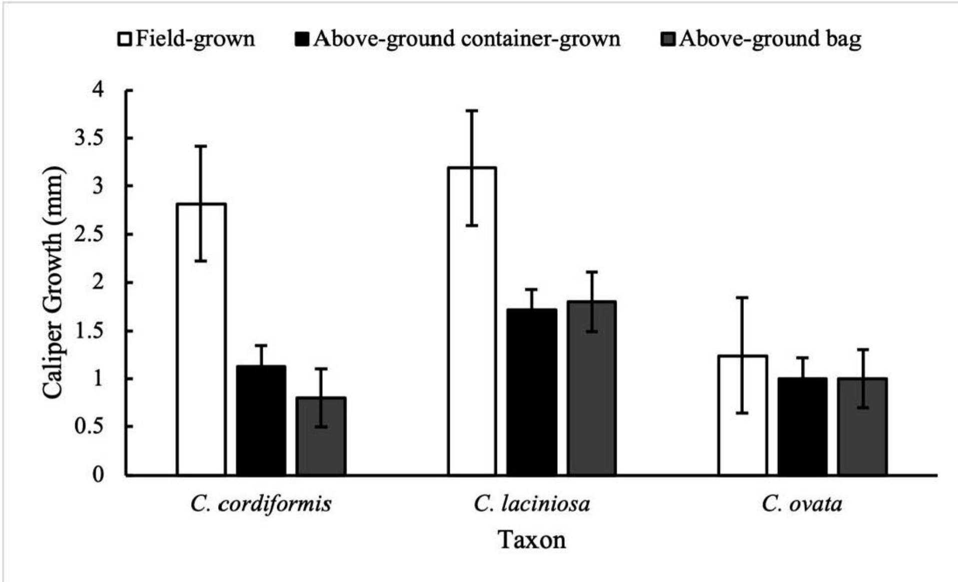

Fig. 2. **Caliper growth measured at 2.5 cm (1 in) above the soil line of three species of *Carya* (*C. cordiformis*, *C. lacniniosa*, and *C. ovata*) grown using different production methods (field-grown, above-ground container-grown, or above-ground bag) measured midway through the fourth growing season. No statistical differences were detected. Error bars indicate the standard error of the mean.**

bags, a 526%, 518%, and 560% increase over *C. ovata* was observed for *C. cordiformis*, *C. illinoinensis*, and *C. laciniosa*, respectively (Fig. 1). Within species, no differences were observed across treatments except for a 357.1% increase for *C. laciniosa* in above-ground bags over field-grown plants.

In year four, no differences in caliper were observed across species or treatments. However, a numerical trend towards increases in the field-grown plants manifested in *C. cordiformis* and *C. laciniosa*, possibly a consequence of the initial occurrence of nickel deficiency with plants cultivated in the above-ground systems in year three (Fig. 2).

Shoot extension. Within species in year two, no differences were observed for shoot extension across treatments for *C. illinoinensis* and *C. ovata* (Fig. 3). Above-ground container-grown and above-ground bag treatments resulted in similar shoot extension within *C. cordiformis* and within *C. laciniosa* (Fig. 3). Compared to plants grown in the field, both above-ground treatments resulted in increased shoot extension for *C. cordiformis* while only above-ground bag-grown plants exhibited an increase for *C. laciniosa* (Fig. 3). Within treatments, species differences occurred. For example, among above-ground bag-grown plants *C. cordiformis* exhibited a

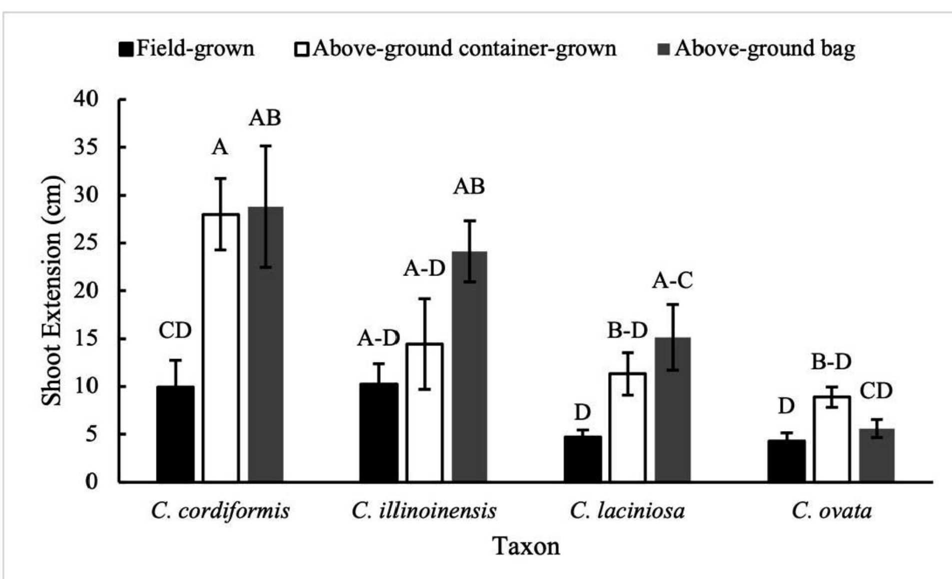

Fig. 3. **Shoot extension (cm) of four species of *Carya* (*C. cordiformis*, *C. illinoinensis*, *C. lacniniosa*, and *C. ovata*) grown using different production methods (field-grown, above-ground container-grown, or above-ground bag) at the conclusion of the second year of cultivation. Means across species and treatments with the same letter are not different according to Tukey's honestly significant difference test ($P \leq 0.05$). Error bars indicate the standard error of the mean.**

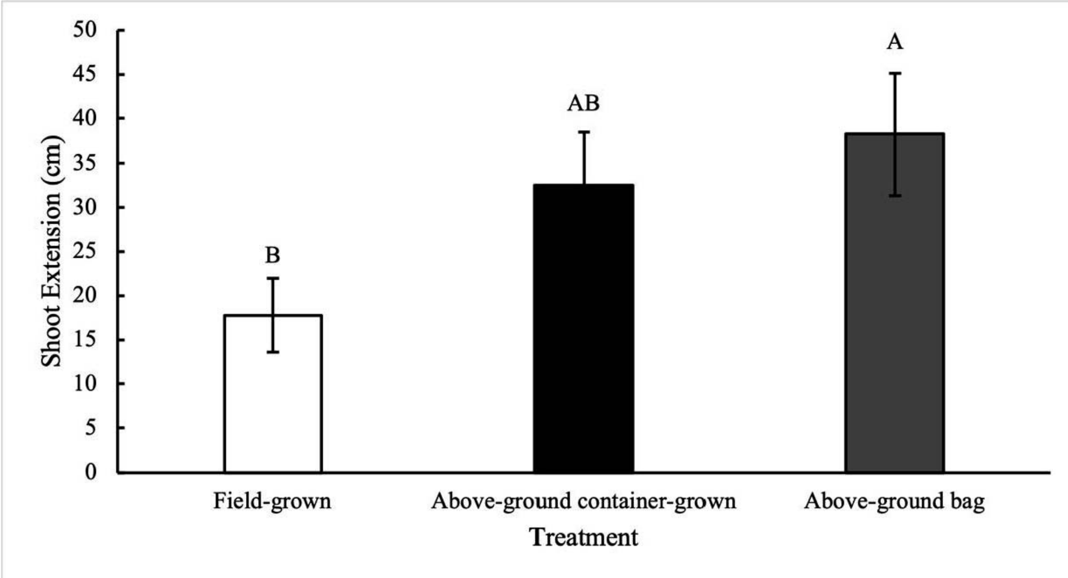

Fig. 4. **Shoot extension (cm) of all three species of *Carya* (*C. cordiformis*, *C. lacniniosa*, and *C. ovata*) measured midway through the fourth growing season in response to treatment by cultivation in the field (field-grown), in a standard (#10) plastic container (above-ground container-grown), or in a RootTrapper® II container (above-ground bag). Data were pooled across taxa to demonstrate the main effect of treatment. Means with the same letter are not different according to Tukey's honestly significant difference test ($P \leq 0.05$). Error bars indicate the standard error of the mean.**

414.3% increase over *C. ovata* (Fig. 3). However, no differences were detected between species for plants cultivated in the field in year two (Fig. 3). In year four, no species differences were detected (Fig. 4). Shoot extension between the above-ground treatments were not different, and no discernable variance was detected between above-ground container-grown plants and field-grown plants (Fig. 4). However, there was a 64.4% increase in shoot extension for plants grown in above-ground bags over field-grown plants (Fig. 4).

Based on the results of this study, no single production method evoked superior growth responses from all species of hickories. The variability of growth within each species was high. While this was useful in obtaining better data for making species-level conclusions, it indicates that one limiting component of producing hickories is their non-uniform response to cultivation. Throughout the study, individual plants were noted for their vigorous growth. These observations may support the case for making clonal selections, not only for desired characteristics in the landscape, but for amenability to cultivation.

Mixed results were obtained by comparing growth responses of above-ground container-grown plants to those which were field-grown. Yet in multiple cases, plants grown using above-ground bags exhibited better growth than those in the field. One reason that potentially explains this difference is the control over resource inputs between the two production categories. Container-grown stock require supplemental water and fertilization whereas it is not common practice to irrigate and provide additional nutrition for field stock, aside from the time of establishment. This component elucidates a clear advantage that container stock has over field-grown material; however, it does not entirely explain the differences observed in our study. If that were the case, we would expect the above-ground container-grown plants, which received the same amount of water as those in above-ground bags, to have been more competitive than the field-grown stock. This trend suggests some other difference between the above-ground and field-grown treatments resulted in variations in growth between these production systems.

The major differences between the two above-ground production types are their composition (plastic versus fabric) and their color. The exterior of the RootTrapper® II bags is white whereas the standard plastic pots were black. Assuming the color of the containers affected the root zone temperature, this may have been a factor that affected growth. Graves et al., (1991) demonstrated that *Ailanthus altissima* (Mill.) Swingle. grown with a root zone temperature of 34 C (93.2 F) displayed decreased vegetative growth responses compared to plants grown with a root zone of 24 C (75.2 F). While root temperature may have varied between the containers, there were no discernable growth differences between above-ground container-grown plants and plants grown with above-ground bags, indicating that root temperature was likely not a deciding factor. One factor that should be explored further in future research is the effect of rootzone aeration between these systems. The substrates in the above-ground treatments within this experiment rarely dried down between waterings, however, the clear difference in their material compositions could lead to differences in root health and subsequently plant performance. Likewise, soil texture within field-growing settings could play a role in plant performance.

Amoroso et al. (2010) trialed nursery pots of different shapes on *Tilia cordata* (Mill.) and *Ulmus minor* (Mill.) and found reductions in root deformation in *T. cordata* with a container shape employing open, air-pruning sides compared to a standard, smooth-walled pot. However, their results also indicated that the air-pruning pot yielded reductions in biomass of *U. minor* (Amoroso et al. 2010). Our study did not assess root morphological variation between treatments, rather responses in vegetative growth. We did not find evidence to indicate one above-ground container type was superior to another in this regard.

One key difference observed between field-grown stock and plants grown above-ground was the occurrence of symptoms akin to mouse ear disorder only on the hickories grown above-ground. Whereas nickel was available for plant uptake in the field soil, adequate levels of available nickel were lacking in the container media. The issue did not affect growth in year two, however, we suspect the disorder played a role in the change in responses observed in year four. The susceptibility of pecan to mouse ear disorder when cultivated in certain field settings and in containers has been previously documented (Wood et al. 2004b, 2004c) while the susceptibility of bitternut hickory was more recently discovered (Miller and Bassuk 2022). However, this phenomenon has not been explored in other *Carya* species. The occurrence of this disorder in our study, mainly with pecan and bitternut hickory, supports the need for future research to explore the unique nutritional demands of *Carya* species in production.

Further research is needed to refine and propose protocols for the effective production of hickories. However, claims of difficulty posed in literature and throughout the industry may be uninformed generalizations based on the most familiar taxa, *C. illinoinensis* and *C. ovata*. Our data support the claim that *C. ovata* is a slower growing taxon and that its congeners display unique growth patterns, some of which may be more amenable to production and use in the landscape. Therefore, we recommend nursery growers consider adopting *C. cordiformis* and *C. laciniosa* into production. If producers can choose between field production or growing hickories in above-ground bags, our data indicate the latter method maximizes growth of the two recommended taxa.

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