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INFLUENCE OF IRRIGATION METHOD AND CONTAINER TYPE ON Northern Red Oak SEEDLING GROWTH AND MEDIA ELECTRICAL CONDUCTIVITY

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ABSTRACT

Container production of hardwood seedlings has not been extensively practiced. Efficient nursery production of hardwood seedlings in containers can be limited by formation of a broad foliar canopy, which limits irrigation uniformity. This study was established to investigate suitability of subirrigation, a method of irrigating seedlings from the container base that relies on rise of water through capillary action, for production of broad-leaved hardwood seedlings. Northern red oak (*Quercus rubra* L. [Fagaceae]) seeds were sown into 4 container types, and seedlings were grown in a controlled greenhouse environment under either traditional overhead irrigation or subirrigation. Media electrical conductivity (EC) was measured at container depths of 1, 5, and 10 cm (0.4, 2, and 4 in) after 57 d. Subirrigated seedlings had significantly higher EC at each depth compared with overhead irrigated seedlings, with a trend of decreasing EC with increasing measurement depth. A significant container type x irrigation method interaction suggested potential for toxic EC levels in some subirrigated containers, which can be alleviated by periodic leaching using clear water to dissipate salts from the top 1 cm (0.4 in). At the end of the growing period, seedling height and root-collar diameter were not influenced by irrigation method or container type, indicating that subirrigation is suitable for hardwood seedling production.

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KEY WORDS

container propagation, ebb-and-flow, hardwood seedlings, flood irrigation, seedling quality, subirrigation

NOMENCLATURE

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While container production of hardwood seedlings for forestry uses has not been extensively practiced in the US, demand has increased recently for container hardwood seedlings, and thus an increase in production is likely. In the Central Hardwood Forest Region of the US, interest in using container seedlings for nontraditional afforestation situations, such as riparian restoration (Grossman and others 2003) and reclamation of former surface coal mines (Davis and Jacobs 2004), is steadily growing. Irrigation presents a greater challenge for container propagation of hardwood seedlings as compared with conifers because hardwood species are often characterized by a broader foliar canopy that limits the quantity and uniformity of water reaching the growing media. This leads to decreased uniformity in seedling growth and generally lower water-use efficiency. Subirrigation, an irrigation method whereby water is delivered from beneath containers, shows promise as a means of improving efficiency of irrigation of hardwood seedlings (Coggeshall and Van Sambeek 2002; Dumroese and others 2006), thereby improving seedling quality and stock uniformity.

Subirrigation works based on the principle of capillarity (Coggeshall and Van Sambeek 2002), in which the surface of a liquid is elevated or depressed depending on the relative attraction of the molecules of the liquid for one another and for those of the solid. Thus, water is able to rise up through the growing media within a container. The distance that water will rise depends on several factors, including container configuration and the chemical and physical properties of the media. As macropore space decreases, water will move higher in the container.

The few studies investigating the effects of subirrigation on forest tree species and agronomic crops have identified potential advantages associated with reduced incidence of disease, improved crop growth, and improved water-use efficiency. Because foliage remains dry, the risk of foliar diseases, such as *Botrytis cinerea* in *Pinus* spp. L. (Pinaceae) and *Picea* spp. L. (Pinaceae) (Lick 1996) and *Puccinia horiana* in *Chrysanthemum* spp. (Asteraceae) (Oh and Kim 1998), are decreased.

Seedling morphology of subirrigated *Pinus* spp. and *Picea* spp. had a higher coefficient of uniformity when compared with overhead traveling boom irrigation because the edge effect was reduced (Lick 1996). Subirrigated *Canna* x *generalis* cultivars had greater shoot growth and took less time to flower than plants that were overhead irrigated (Yeh and others 2004). Subirrigated lettuce (*Lactuca sativa* [Asteraceae]) and tomato (*Lycopersicon esculentum* [Solanaceae]) seedlings grew significantly taller than their overhead irrigated controls, and subirrigated tomato plants also had greater leaf area (Ahmed and others 2000). As well, at least in the case of *Chrysanthemum* spp., subirrigation was more effective at maintaining an appropriate leaf temperature and wetness, resulting in minimal reductions in photosynthesis and growth (Oh and Kim 1998).

Increased water-use efficiency is another major potential benefit associated with subirrigation (Coggeshall and Van Sambeek 2003; Dumroese and others 2006). Subirrigation of lettuce and tomato crops resulted in an 86% decrease in water use compared with overhead irrigation (Ahmed and others 2000). Use of a capillary mat system (a form of subirrigation) in production of 5 different plant species resulted in water use at only 36% of the amount used in overhead irrigation (Goodwin and others 2003). Using subirrigation, Lick (1996) reported a 55% reduction in the amount of nutrient solution required for production of *Pinus* spp. and *Picea* spp. as well as a decrease in fertigation frequency; the result was a 70% total reduction in water and fertilizer use. Decreasing overall water use, and re-using water within the closed-circuit loop characteristic of subirrigation, effectively controls leachate, preventing potential contamination of local water sources. Subirrigation can be inexpensive to establish (Coggeshall and Van Sambeek 2003), and subsequent production costs associated with water and fertilizer delivery may be lower than those with overhead irrigation (Lick 1996; Oh and Kim 1998).

Some potential problems have been identified associated with water quality, disease incidence, and water availability during certain growth phases of the crop. A clean water source is needed to minimize salt accumulation (Landis and Wilkinson 2004), which could be a limiting factor if high levels of fertilizer are required. The added buildup of salts through the capillary nature of water flow with subirrigation could be of concern for plant production. In the production of *Canna* x *generalis* cultivars using subirrigation, growth was reduced when growing media electrical conductivity exceeded 1.25 dS/m (Yeh and others 2004).

Other problems that may emerge include proliferation of waterborne pathogens such as *Pythium* spp. and *Phytopthera* spp. (Landis and Wilkinson 2004), which could be exacerbated as a dense foliar canopy, coupled with elevated summer temperatures, create high humidity conditions favored by many pathogens. Moreover, specific disease problems may be associated with specific media types used in subirrigation.

The potential loss of misting as a cooling alternative could be detrimental to plant growth during high-heat days in the summer. Depending on the container configuration, media type, and silvics of the species involved, early growth may require supplemental irrigation until roots are adequately developed. Lack of air-pruning of roots associated with use of subirrigation is another consideration; this may be ameliorated with use of copper coatings in containers though it is unknown how copper leaching might influence water quality.

Our study objectives were to: 1) identify the potential suitability of subirrigation for production of container hardwood seedlings; 2) assess the importance of container type to seedling growth; and 3) identify the effect of irrigation method and container type on media salt concentration at different container depths. Identification of interactions between container type and irrigation method would prove useful to development of future studies and application of this method operationally.

MATERIALS AND METHODS

The experiment was established as a 4 container type x 2 irrigation method factorial design with 3 replications. Each replication consisted of 2 benches (1 each of subirrigation and overhead irrigation) with container treatments (1 of each container type) randomly distributed within each bench. Northern red oak (*Quercus rubra* L. [Fagaceae]) was chosen as the trial species based on its common use in plantation establishment in Indiana (Jacobs and others 2004) and the broad canopy developed by seedlings in the nursery at a relatively young age. Acorns were collected locally in autumn 2004 and stored over the winter at –2 °C (28 °F) until 1 d prior to sowing, at which point they were soaked in water for 24 h and then sown directly into each of the containers on 17 May 2005. We used containers manufactured by Beaver Plastics (Styroblock™ and Copperblock™ 60 cavities per container; Edmonton, Alberta, Canada) and Jiffy Products (New Brunswick) Ltd (Jiffy Pellets 36 pellets per tray; Shippegan, New Brunswick, Canada). See Table 1 for descriptions. Because Jiffy containers consist of 100% *Sphagnum* peat moss, we used 100% *Sphagnum* spp. peat moss in the Beaver Plastics containers.

Sown containers were placed in the Department of Horticulture and Landscape Architecture Plant Growth Facility at Purdue University, West Lafayette, Indiana (40° 25'N, 86° 55'W). Seedlings were grown with mean day and night temperatures of 24 °C (75 °F) and 20 °C (68 °F), respectively, under ambient light conditions and with either overhead irrigation or subirrigation. Seedlings were irrigated when container weight decreased to 75% of saturated weight. Overhead irrigation was accomplished by hand-watering containers to container capacity. Seedlings were subirrigated using plastic benches (Midwest GroMaster Inc, St Charles, Illinois), reservoir tanks, submersible pumps, and timers. Under each bench was a 285-l (75-gal) plastic reservoir tank filled with water and a submersible pump connected to an electronic timer. At designated intervals, water was pumped up into the plastic benches with duration just long enough to fill the bench (approximately 4 cm [1.5 in] deep). Once the bench was full, the pump cycled off and the irrigation water drained back through the pump into the reservoir. When necessary, the cycle was repeated until containers were brought to capacity. To ensure that seedlings were not nutrient deficient, they were fertilized to container capacity with 200 ppm N, 29 ppm P_2O_5, 167 ppm K_2O, 67 ppm Ca, 30 ppm Mg, and micronutrients supplied with a commercial fertilizer formulation (15N:5P_2O_5:15K_2O; Miracle Gro® Excel® Cal-Mag, The Scotts Company, Marysville, Ohio)

TABLE 1

Specifications for containers used.

Manufacturer	Container type	Top diameter (cm)	Depth (cm)	Volume (cm³)	Cavities (m²)
Beaver Plastics	Superblock™ 512A	5.1	12	220	284
	Copperblock™ 512A	5.1	12	220	284
Manufacturer	**Pellet type**	**Pellet diameter (cm)**	**Depth (cm)**	**Volume (cm³)**	**Pellets (m²)**
Jiffy Products	Jiffy (50100)	5.5	10	250	224
	Jiffy-Super (50150)	5.5	15	350	224

TABLE 2

Height and root-collar diameter (mean ± SE) of northern red oak seedlings under different irrigation regimes and in different container types. For each parameter, letters indicate significant differences at α = 0.05 using Tukey's HSD (n = 75 per treatment).

		Shoot height (cm)		Root-collar diameter (mm)	
Manufacturer	Container model	Subirrigation	Overhead irrigation	Subirrigation	Overhead irrigation
Beaver Plastics	Superblock™ 512A	14.6±1.0A	13.9±0.7A	3.10±0.17ab	3.29±0.10ab
	Copperblock™ 512A	14.8±1.1A	14.7±0.6A	2.78±0.14b	3.45±0.11a
Jiffy Products	Jiffy (50100)	14.9±1.1A	17.8±1.0A	3.33±0.13ab	3.23±0.16ab
	Jiffy-Super (50150)	15.5±1.0A	14.6±0.9A	3.38±0.22ab	2.93±0.20ab

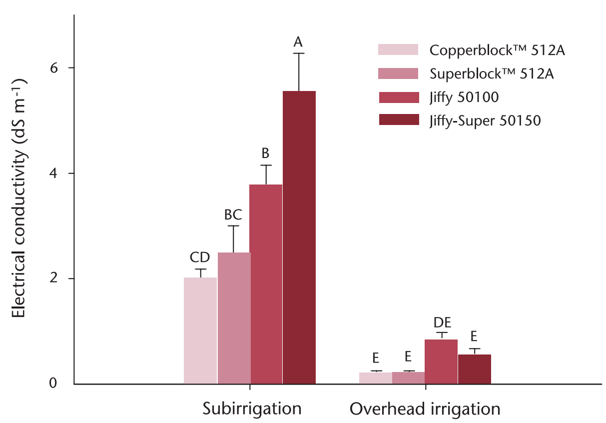

Figure 1. Effects of container type x irrigation method interaction on EC level in top 1 cm of container media profile. Letters indicate differences significant at α = 0.05 using Tukey's HSD (n = 45 per treatment).

on days 10, 20, 30, 40, and 50 after sowing. Overhead irrigated seedlings were fertilized by hand-watering; subirrigated seedlings were flooded with the same water-soluble fertilizer but benches were drained of excess fertilizer solution to avoid contamination of water in the reservoir tanks. To minimize error due to edge effect, buffers were established using northern red oak.

We assessed seedling height, root-collar diameter (RCD), and growing media electrical conductivity (EC) at 57 d (13 July 2005) after sowing. Shoot heights were measured from the root-collar to the base of the terminal bud, while RCDs were measured using calipers at the root collar on 25 seedlings per treatment for each replication. Approximately 1 h after irrigation, we sampled EC at 3 depths within each container (1, 5, and 10 cm [0.4, 2, 4 in]) for 15 containers in each treatment replication using the Field Scout Soil EC Probe and Meter (Spectrum Technologies, Plainfield, Illinois). On 14 July 2005, seedlings in the subirrigated treatments were watered to saturation using overhead irrigation; EC was then remeasured to assess potential EC changes with leaching. Irrigation water was collected directly from the spigot and from the holding tank at the end of the experiment and EC was measured.

SAS® software (SAS Institute, Cary, North Carolina) was used for all data analysis. Data were analyzed using analysis of variance (ANOVA) for a split-plot design (SAS subroutine PROC MIXED) to identify significant differences ($P < 0.05$) among treatments for seedling morphological attributes and media EC values. When significant differences were detected in the ANOVA, Tukey's HSD test was used to separate treatments at $\alpha = 0.05$. SAS subroutine PROC TTEST was used to compare initial with final EC. For response parameters, the experimental unit was the mean value of each group of seedlings from a treatment replication and the sampling unit was each individual seedling.

RESULTS

Height was not influenced by container type ($P = 0.2258$) or irrigation method ($P = 0.7888$), and no significant interaction between the 2 factors ($P = 0.2377$) was detected (Table 2). Neither container type ($P = 0.7926$) nor irrigation method ($P = 0.1728$) had a significant influence on RCD, but these 2 factors significantly interacted ($P = 0.0018$). Seedlings grown in Copperblock™ containers had significantly larger RCD with overhead irrigation than with subirrigation (Table 2).

At a depth of 1 cm (0.4 in) in the container media profile, the container type x irrigation method interaction was significant ($P < 0.0001$; Figure 1). Investigation of main effects found that EC was significantly higher ($P < 0.0001$) in subirrigated containers (3.31 ± 0.26 dS/m [mean ± standard error]) compared with overhead irrigated containers (0.39 ± 0.03 dS/m). EC was also significantly higher ($P < 0.0001$) for seedlings grown in Jiffy (2.58 ± 0.30 dS/m) and Jiffy-Super (2.91 ± 0.46 dS/m) pellets compared with Superblock™ (1.17 ± 0.24 dS/m) and Copperblock™ (0.93 ± 0.11 dS/m) containers.

At a depth of 5 cm (2 in) in the container media profile the container type x irrigation method interaction was significant ($P = 0.0002$) (Figure 2). Regarding main effects, similar trends to those exhibited at 1 cm persisted with EC being significantly higher ($P < 0.0001$) in subirrigated containers (1.32 ± 0.10 dS/m) compared with overhead irrigated containers (0.55 ± 0.05 dS/m). Container type also significantly ($P < 0.0001$) influenced media EC with Jiffy-Super pellets (1.84 ± 0.18 dS/m) having higher EC than all other containers and Jiffy pellets (1.43 ± 0.11 dS/m) having higher EC than Superblock™ (0.45 ± 0.03 dS/m) and Copperblock™ (0.44 ± 0.04 dS/m) containers.

The container type x irrigation method interaction was also significant ($P = 0.0008$; Figure 3) when EC was measured at a container media depth of 10 cm (4 in). As a main effect, irrigation method was still significant ($P < 0.0001$), with subirrigated seedlings (0.99 ± 0.03 dS/m) continuing to maintain higher EC than overhead irrigated seedlings (0.73 ± 0.04 dS/m). Container type also significantly ($P < 0.0001$) influenced EC, with Jiffy pellets (1.13 ± 0.05 dS/m) and Jiffy-Super pellets (1.09 ± 0.10

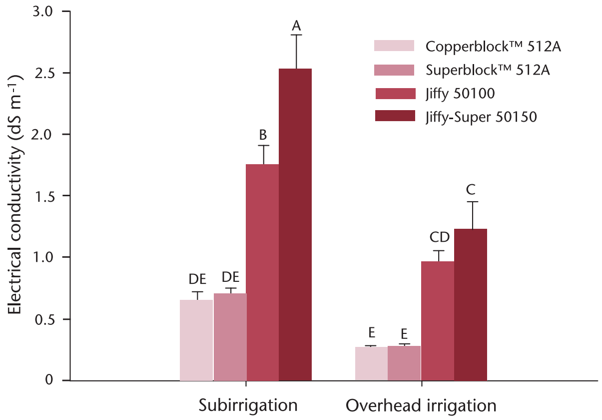

Figure 2. Effects of container type x irrigation method interaction on EC level in top 5 cm of container media profile. Letters indicate differences significant at $\alpha = 0.05$ using Tukey's HSD (n = 45 per treatment).

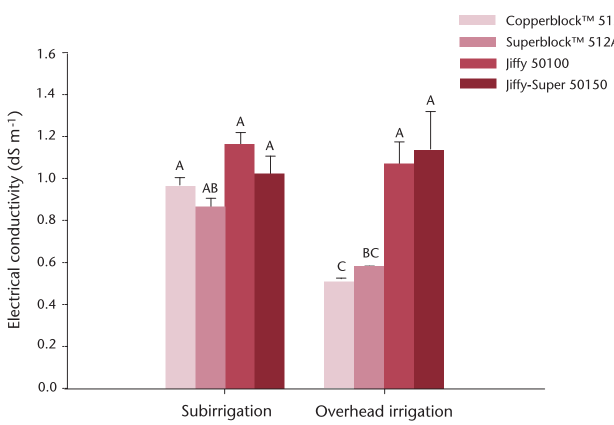

Figure 3. Effects of container type x irrigation method interaction on EC level in top 10 cm of container media profile. Letters indicate differences significant at $\alpha = 0.05$ using Tukey's HSD (n = 45 per treatment).

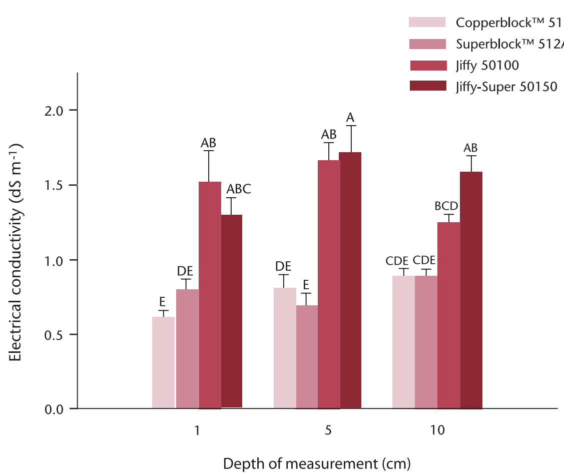

Figure 4. Effects of container type x irrigation method interaction on EC level at 3 different media depths following complete saturation by means of overhead irrigation. Letters indicate differences significant at $\alpha = 0.05$ using Tukey's HSD (n = 45 per treatment).

dS/m) having higher EC than Superblock™ (0.71 ± 0.03 dS/m) and Copperblock™ (0.69 ± 0.03 dS/m) containers.

After leaching subirrigated seedlings with clear water, container type was significant ($P < 0.0001$) for EC across all depths with Jiffy pellets (1.48 ± 0.08 dS/m) and Jiffy-Super pellets (1.53 ± 0.08 dS/m) having higher EC than Superblock™ (0.80 ± 0.04 dS/m) and Copperblock™ (0.77 ± 0.04 dS/m) containers. Although measurement depth did not significantly influence EC ($P = 0.1035$), the container type x measurement depth interaction was significant ($P = 0.0077$; Figure 4). The water used to fill the subirrigation holding tanks had an initial EC of 0.77 ± 0.01 dS/m, significantly lower ($P = 0.0029$) than the EC measured 0.94 ± 0.02 dS/m prior to leaching on 14 July.

DISCUSSION

Seedling morphology was generally similar between subirrigation and overhead irrigation, concurring with results for other tree species (Lick 1996; Dumroese and others 2006; Landis and others 2006). The notable exception was the interaction between container type and irrigation method, whereby Copperblock™ containers had smaller RCD when subirrigated than when overhead irrigated (Table 2). Because the other 3 container types did not have a copper-based method of lateral root pruning, this indicates a potential root pruning x irrigation method interaction. Given that root contact with copper causes root-tip mortality, there is potential that subirrigation resulted in infiltration of copper into the seedling root zone and thus decreased live root area. Given the lack of effect of copper treatment on overhead irrigated seedlings, however, and existing literature (for example, Wenny and others 1988), it is possible that this is a spurious effect and, while statistically significant, is not representative of biological significance. Should that be the case, based on morphological assessment, subirrigation is neither limiting nor beneficial compared with overhead irrigation in production of northern red oak seedlings.

We detected differences in growing media EC among irrigation systems, container type, depths within the growing media, and initial and final water in the subirrigation holding tanks. For subirrigated seedlings, EC was highest at the surface of the growing media. Similar results were reported for *Gerbera jamesonii* var. *shogun* (Asteraceae) (Zheng and others 2005). Moreover, Goodwin and others (2003) and Dumroese and others (2006) found higher EC in the surface layers of subirrigated containers compared with overhead irrigation. These results are similar to those found in our study, in which little variation occurred in EC at each of the 3 measured depths for overhead irrigated seedlings, while a downward trend of EC with depth was detected in subirrigated seedlings.

Jiffy and Jiffy-Super pellets tended to have higher EC levels than Superblock™ and Copperblock™ containers (see Figures

1–4). This could be related to the soft-wall versus hard-wall structure of the container types, whereby the soft-wall pellets had greater retention of salts at the perimeter due to the fibrous border, resulting in less movement of salts throughout the growing media compared with the hard-wall containers. Further explanation of this phenomenon could be associated with the exposed sides of the pellets acting to draw moisture out, thereby causing salt accumulation at these points and resulting in overall higher salt retention than in Superblock™ and Copperblock™ containers. The high salt concentrations observed in the Jiffy and Jiffy-Super pellets at the 1 cm depth may be of concern as an EC of 4.0 dS/m reflects the upper threshold for seedling propagation of many plant species; some forest tree species are sensitive at much lower levels (Landis 1988; Jacobs and Timmer 2005). Potential for toxicity associated with high EC levels can be mitigated by adjusting the amount of fertilizer applied (for example, Zheng and others 2005), using controlled release fertilizer rather than soluble fertilizer (Klock-Moore and Broschat 2001), and using a single, overhead irrigation with clear water as demonstrated in this study to reduce salt levels in the upper portions of the containers. Moreover, the higher EC levels maintained throughout the subirrigated containers suggest potential to decrease fertilizer quantities needed for crop production.

We detected a significant, albeit small, accumulation of salts within the subirrigation holding tanks. This is most likely because subirrigation involved a closed-circuit irrigation cycle whereby ions nonessential for plant growth may have accumulated (Carmassi and others 2005). If these values had risen to a level at which plant growth may have been limited, the problem could be simply ameliorated through periodic replenishment of holding tank water.

CONCLUSIONS AND FUTURE DIRECTIONS

We observed that northern red oak seedlings can be grown in containers using subirrigation, with little morphological difference from overhead irrigated seedlings, despite high EC levels in the upper portion of subirrigated containers. High EC levels in subirrigated containers can be lowered with a single, clear-water overhead irrigation. Future research is needed to help optimize subirrigation systems for use across a spectrum of broadleaf forest tree species. Identification of suitable media types with an appropriate range of chemical and physical properties is required as, for example, Caron and others (2005) found that growing media with 60% *Sphagnum* spp. peat moss by volume provided better capillary rise than that with only 30% *Sphagnum* spp. peat moss. A better understanding of the influence of container configuration on seedling development is also necessary. Growing regimes, in particular fertilization protocols, will need to be adjusted for subirrigation systems.

With potential environmental and economic benefits, such as reduced risk of disease, decreased production costs, controlled leachate, improved crop uniformity, and increased water-use efficiency, this system represents a promising new technology for nursery production of broad-leaved forest tree species.

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