Root growth potential, water relations and carbohydrate status of ash alternative species following pre-plant storage

Dana S. Ellison^a, Robert Schutzki^a, Pascal Nzokou^b, Bert Cregg^{a,b,*}

^aMichigan State University, Department of Horticulture, 1066 Bogue St., East Lansing, MI 48823 USA

^bMichigan State University, Department of Forestry, 408 Wilson Rd., East Lansing, MI 48824 USA

*Corresponding author: Tel: + 517 353 0335. Email address: cregg@msu.edu

1 Root growth potential, water relations and carbohydrate status of ash alternative
2 species following pre-plant storage.

3 *Additional index words.* water potential; sweating; heeled-in; *Celtis occidentalis*,
4 *Taxodium distichum*; *Quercus bicolor*, *Quercus rubra*; *Quercus ellipsoidalis*; *Fraxinus*
5 *americana*

6
7
8
9
10
11
12
13 *Abstract.* The catastrophic loss of ash (*Fraxinus spp.*) trees in the midwestern United
14 States due to emerald ash borer has emphasized the need for greater diversity in urban
15 and community forests. However, the availability of some important *Fraxinus* alternative
16 species may be limited due to difficulties in nursery production. We conducted two trials
17 to examine growth and physiological responses of bare-root tree liners to pre-plant
18 storage and handling. In both trials, bare-root liners were given one of four treatments
19 for three weeks prior to planting: 1) control, 2) cold storage (4°C), 3) sweating (warm,
20 moist storage), or 4) heeled-in (outdoor storage). Subjecting trees to a warm, moist
21 environment before planting (sweating) increased shoot dieback of *Celtic occidentalis*
22 trees. Root growth potential was very low for *Quercus spp.* trees and varied by
23 treatment for *Celtis occidentalis* trees. *Taxodium distichum* trees had a relatively high

24 root growth potential in all treatments. Stem water potential measured immediately
25 before and after pre-plant treatments indicated that *Quercus spp.* trees and *T. distichum*
26 trees were able to rehydrate during sweating while water stress in *C. occidentalis* trees
27 remained high (stem water potential <-2.0 MPa). The results suggest that poor
28 transplanting success reported for *Quercus spp.* trees may be related to low root growth
29 potential, whereas poor establishment of *Celtis occidentalis* trees is related to a
30 combination of factors including desiccation, poor root regeneration and poor
31 carbohydrate status. None of the pre-plant treatments reduced shoot dieback compared
32 to control trees that were not stored prior to planting.

Introduction

Outbreaks of exotic invasive pests such as emerald ash borer (EAB; *Agrilus planipennis* Fairmaire) and Dutch elm disease (*Ophiostoma ulmi* (Buisman) Nannf.) have highlighted the need for improved species diversity in urban and community forests. Emerald ash borer has devastated *Fraxinus spp.* tree populations, killing tens of millions of trees throughout the midwestern and eastern United States (Herms and McCullough, 2014). As communities develop tree planting programs to replace tree cover lost to EAB, university extension services and others have proposed alternative shade tree species for nursery growers, landscapers and homeowners to reference (Cregg and Schutzki, 2004; Iles, 2012; Jull, n.d.).

Shade tree nurseries typically start their production cycle with bare-root liners; ranging from 1.3-2 m tall whips to 4 cm caliper lightly branched trees. The majority of liners are grown at specialty nurseries in the Pacific Northwest of the United States and then shipped throughout the country on refrigerated trucks in early spring (Englert et al., 1993). Once trees are delivered, nurseries may plant them immediately, either in the field or in containers, or may store them prior to planting. Stored trees may be kept in large coolers or heeled-in into mulch or container substrate until planting. While many shade tree species and cultivars in the nursery trade are routinely and successfully produced from bare-root liners, certain species experience significant mortality or shoot dieback after bare-root storage and handling. Among commonly recommended *Fraxinus* alternatives, oaks (*Quercus spp.*), hackberry (*Celtis occidentalis* L.), and

baldcypress (*Taxodium distichum* (L.) Rich. var. *distichum*), are often mentioned by growers as being problematic.

Both research and practical experience suggest several factors may lead to poor transplant stress in bare-root liners. For example, bare-root trees may become desiccated during storage and handling. Some species, such as Norway maple (*Acer platanoides* L.) are desiccation-tolerant and can withstand low water status conditions, while others are desiccation-intolerant and do not succeed under low water status conditions (Murakami et al., 1990). Reestablishment of root systems after transplanting is also an important factor for tree survival (Struve 1990, 2009). Handling or mishandling of bare-root trees frequently affects root growth potential (RGP) when trees are lifted and stored (Simpson and Ritchie, 1996). Carbohydrate status including total non-structural carbohydrates and total starch reserves in roots and shoots have also been implicated in survival bare-root trees after planting (Kobe, 1997; Dey et al., 2008).

Cold storage is the most common means to reduce stress to tree liners between receipt at the nursery and planting. However, some nurseries 'heel-in' trees as a means of storage, especially if coolers are not available. Heeling-in consists of placing the bare-root trees in a trenched section of substrate or mulch, covering, and watering them in. This may reduce transplant shock and increase root regeneration (Starbuck et al., 2005). 'Sweating' (placing trees in a warm, moist environment) is often recommended for recalcitrant trees. The objective of sweating is to rehydrate the stem and root system by increasing the humidity and temperature surrounding the plants (Halcomb and

Fulcher, 2004). However, little systematic research has been conducted on this practice to quantify its efficacy or determine its physiological impact on tree liners.

In this project, we examined the effects of pre-plant handling on transplant stress of ash alternative species in a typical nursery production system. The overall goal of this project was to improve the availability and success of important *Fraxinus* alternative species in production nurseries to facilitate a more diverse urban landscape. The specific objectives of the present study were to: 1) determine the effect of pre-plant handling on initial survival and growth of common *Fraxinus* alternatives and 2) determine the physiological responses to pre-plant conditions.

Materials and Methods

The project was conducted as two studies; one conducted in 2010 and one conducted in 2011. We describe experimental procedures for the 2010 study and then highlight changes for 2011 trial.

2010 Season

Plant material and treatments

On April 12, 2010 we received 192 bare-root liners (1.5 m tall whips or lightly branched liners) via refrigerated truck from a commercial liner nursery (J. Frank Schmidt & Son Co., Boring, Oregon USA). The shipment included 48 trees from each of four species; hackberry (*Celtis occidentalis* L.), swamp white oak (*Quercus bicolor* Willd.), red oak (*Quercus rubra* L.), and baldcypress (*Taxodium distichum* (L.) L.C. Rich). Each tree was immediately tagged and assigned at random to one of four pre-plant storage

treatments: 1) control, 2) heeling-in, 3) cold storage, or 4) sweating. All treatments, except control, were maintained for three weeks (April 12 to May 5). Trees in the control treatment were not stored and were planted immediately after they were off-loaded from the truck. The 'heeled-in' treatment was designed to simulate a common nursery practice of storing trees outdoors prior to planting. The trees were positioned upright outdoors at a research nursery at the Michigan State University Horticulture Teaching and Research Center (HTRC) Holt, MI. Tree roots were covered with a container substrate mix of pine bark-peat moss (80:20; v:v). Trees were watered daily, for approximately 30 minutes, with an overhead sprinkler. Mean air temperature during the heeling-in storage was 11.7°C (range -2.0° – 26.4°C). Trees in 'cold storage' were placed in a 4°C walk-in cooler at the HTRC. Trees were positioned upright in large wooden crates with their roots covered with straw and watered as needed to prevent root desiccation, approximately four times/week. The 'sweating' treatment was designed to replicate a common nursery practice used to stimulate growth on recalcitrant trees (Halcomb and Fulcher, 2004). Trees were placed on the floor of a hoop greenhouse with double-walled poly (4 mil) at the MSU Forestry Tree Research Center (TRC). Trees were alternated with layers of wet burlap and then covered with a large sheet of white plastic. Burlap was checked daily and watered as needed to prevent desiccation, approximately four times/week. The greenhouse temperature was set to 20°C. Mean temperature under the plastic during the sweating period was 24.2°C (range 19.7° – 36.5°C).

Evaluations

Water potential was determined on shoots of each tree immediately upon arrival at the HTRC and after exposure to the various pre-plant treatments (Ritchie and Hinckley, 1975). Water potential was measured on shoots collected from side branches using a portable pressure chamber (Model 600, PMS Instruments, Corvallis, Oregon USA). After treatments were applied for three weeks, a subset of trees from each treatment was assigned at random to one of two evaluations: container planting or root growth potential test.

Root Growth Potential (RGP) test

Root growth potential was evaluated by planting trees in a gravel culture system for three weeks and quantifying new root growth. Control trees were placed in the gravel culture system immediately upon receipt; trees in the three pre-plant treatments were placed in the gravel culture system after three weeks of treatment. Trees were planted in 95-liter containers filled with washed pea-gravel in a hoop greenhouse with clear double-walled poly (4 mil) at the TRC. Four trees, one from each treatment x species combination, were planted in each container with eight replications. Root systems were kept constantly moist using a micro-sprinkler system, which consisted of three pressure compensated spray stakes per container (12 liter per hour, Netafim USA, Fresno CA), which uniformly wetted the entire container surface. Microsprinklers were controlled by an automatic timer and irrigation was set to run for 8 seconds every 16 minutes. After three weeks trees were removed from the gravel and new root growth was assessed by counting the number of new white roots and measuring root lengths of a

random sample of ten new roots. Total new root length was estimated as number of new roots x average new root length.

Container planting

We planted an additional four trees per species x treatment combination, including control trees, in 57-liter containers filled with a mixture of pine bark and peat moss (80:20, v:v). Trees were watered to run-off by hand two to three times/week and grown outdoors on a container pad at the HTRC until 1 October.

Growth

Height and stem diameter were measured at planting and the end of the growing season (container-grown trees). Stem diameter was measured with digital calipers 8 cm above the graft union on the *C. occidentalis*, *Q. bicolor*, and *Q. rubra* and 15 cm above the root collar on the *T. distichum*. Some trees exhibited stem dieback. Stem dieback was measured as the distance from the top-most portion of the terminal leader to the point where current season growth initiated.

2011 Season

Plant material and treatments

On April 11, 2011, we received 240 bare-root liners (1.5-1.8 m whips/lightly branched liners) via refrigerated truck from J. Frank Schmidt & Son Co. Nursery. The shipment included 48 trees from each of five species: *C. occidentalis*, *Q. rubra*, *T. distichum*, white ash (*Fraxinus americana* L.), and northern pin oak (*Quercus ellipsoidalis* E.J. Hill).

Quercus ellipsoidalis trees were substituted for *Q. bicolor* trees due to availability from the cooperating production nursery. White ash (*F. americana*) trees, which typically transplant easily, were included for comparative purposes. Each tree was immediately tagged and assigned at random to one of four treatments: 1) control, 2) heeling-in, 3) cold storage, or 4) sweating. The same pre-planting treatments were executed on the trees as in the 2010 season. The cold-storage was modified by laying the bare-root trees horizontally on the floor of a walk-in cooler at the HTRC. The roots were covered with straw and a plastic covering and kept moist for the treatment period.

Pre- and post-lifting sampling

In order to assess the condition of trees prior to shipment, we measured shoot water potential and collected root and shoot samples for carbohydrate analysis on trees from each species before and after lifting at the liner production nursery in Oregon. Pre-lifting samples were taken on February 3, 2011 while the trees were still in the nursery fields. Post-lifting samples were collected from trees in the outdoor storage area of the nursery on March 31, 2011. Shoot and root samples were collected on both dates for carbohydrate analyses. Shoot samples consisted of segments of terminal and lateral shoots approximately 10 cm long. Root samples consisted of 5-10 grams (fresh weight) of fine roots (<4 mm dia.). Samples were placed in plastic bags and shipped overnight in a cooler with dry ice to the lab at Michigan State University.

RGP, shoot growth, water potential

Root growth potential, shoot growth and water potential were assessed as in the 2010 study. Shoot water potential was not assessed on the *F. americana* trees since the liners were unbranched and did not have side shoots suitable for sampling.

Carbohydrate and starch analysis

Total non-structural carbohydrate content was determined on samples collected before and after lifting at the liner nursery. Carbohydrate content was determined colorimetrically using the phenol-sulfuric acid method (DuBois et al., 1956). D-glucose was used for the standard curve. Tree shoot and root samples from the carbohydrate analysis were used to find percent starch content (Bergmeyer and Bernt, 1974; Ebell, 1969; Keller and Loescher, 1989). By this method, starch, following hydrolysis with amyloglucosidase, was analyzed enzymatically with glucose oxidase.

Statistical analyses

For both years, effects of treatment, species, and interaction of species and treatment on each response variable were evaluated by analysis of variance. Data were analyzed as a completely randomized design using the model $y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \epsilon_{ijk}$; where y_{ijk} =response variable; α_i =species effect; β_j =treatment effect; and ϵ =experimental error. Where significant ($P < 0.05$) species or treatment effects were indicated, means were separated by Tukey's studentized range test (HSD).

Results

2010 Season

214 *Pre-plant water status*

215 Initial water potential (Ψ_w) of shoots of all trees was relatively low upon arrival from the
216 liner nursery, ranging from -1.5 MPa for the *T. distichum* trees to -3.7 MPa for the *C.*
217 *occidentalis* trees (Fig. 1a). Pre-plant treatments did not consistently improve water
218 status. For *Quercus rubra* and *T. distichum*, trees that were cold-stored had the lowest
219 overall Ψ_w . Heeling-in improved water status of *C. occidentalis* and *Q. rubra* trees
220 compared to the untreated controls. For all four species, heeling-in was better than cold
221 storage for improving water potential. Trees of the two *Quercus spp.* showed water
222 status recovery following the sweating treatments compared to the control trees (Fig.
223 1a).

225 *Root growth potential*

226 Root growth potential (RGP) varied by species but was not affected by pre-plant
227 treatments. *Taxodium distichum* trees produced the highest number of new roots while
228 both *Quercus spp.* showed consistently low RGP, generating less than 30 new roots per
229 tree during the three week RGP test (Fig. 1b). *Celtis occidentalis* trees that were
230 heeled-in prior to the RGP test produced an average of 180 new roots. Species and
231 treatment effects on total new root length were similar to trends on root number (data
232 not shown).

234 *Shoot growth/stem dieback*

235 In general, pre-plant treatments had little effect on stem growth or dieback after planting
236 although there were a few exceptions to this trend. In the container-planted trial,
237 sweating increased stem dieback for *C. occidentalis* trees (Fig. 1c).

239
240
241
242
243
244

Fig. 1. Mean water potential (a), mean root growth potential (b), and mean growth/die-back of bare-root tree liners of four species subjected to four pre-plant treatments; Control (not stored), Heel (heeled-in outdoors for three weeks), Store (cold stored at 4 deg. C. for three weeks) or Sweat (Stored in warm, moist conditions for three weeks) prior to planting in 2010. Data are means $\pm$ S.E. Means within a species not followed by the same letter are significantly different at $p < 0.05$ level. Mean separation by Tukey's studentized range (HSD) test.

2011 Season

Pre-plant water status

Stem Ψ_w of all trees decreased ($P < 0.05$) from the time they were lifted at the liner nursery in Oregon (post-lift) until they arrived on the truck in East Lansing, MI (Control) (Fig. 2). This indicates significant water loss occurred from the trees during storage and shipping. Species varied in their ability to re-hydrate during the pre-plant treatments. *Quercus rubra* trees showed significant Ψ_w recovery after heeling-in and sweating. In contrast, sweating reduced Ψ_w of *C. occidentalis* trees (Fig. 2).

Fig. 2 Mean water potential of bare-root tree liners of four species prior to lifting (Pre-Lift), after lifting (Post-Lift), and subjected to four pre-plant treatments; Control (not stored), Heel (heeled-in outdoors for three weeks), Store (cold stored at 4 deg. C. for three weeks) or Sweat (Stored in warm, moist conditions for three weeks) prior to planting in 2011. Data are means $\pm$ S.E. Means within a species not followed by the same letter are significantly different at $p < 0.05$ level. Mean separation by Tukey's studentized range (HSD) test. Water potential of *Fraxinus americana* liners was not determined due to logistical limitations.

261

262 *Root growth potential*

263 Root growth potential (RGP) varied among species but not treatments within species
264 (Fig. 3a). *Fraxinus americana* and *T. distichum* trees showed significantly greater new
265 root growth in response to all treatments compared to trees of the other species. Trees
266 of both of the *Quercus spp.* had consistently low root regeneration across all pre-plant
267 treatments (Fig. 3a).

268 *Shoot growth/stem dieback*

269 Tree growth responses to pre-plant treatments varied by species. None of the pre-plant
270 treatments improved stem growth relative to the control for any species (Fig. 3b). *Celtis*
271 *occidentalis* trees showed dieback in all treatments. Sweating trees before planting
272 reduced growth of *F. americana* trees.

273

274 *Carbohydrate analysis*

275 Total nonstructural carbohydrates (TNC) of root and shoot tissue varied with species
276 and time of sample collection (Fig. 4). Nonstructural carbohydrate concentration of root
277 tissue of *Q. ellipsoidalis*, *Q. rubra* and *T. distichum* trees increased from the initial
278 sample and the post-harvest sample. *Celtis occidentalis* and *F. americana* trees, in
279 contrast, decreased or had no change in TNC (Fig. 4a). Total nonstructural
280 carbohydrates of shoots did not vary between samples collected pre- and post-lifting,
281 except for shoots of *Fraxinus americana* trees, which decreased in TNC between the
282 two dates (Fig. 4b). *Celtis occidentalis* trees had lowest shoot TNC among all the trees
283 sampled.

Fig. 3. Mean root growth potential (a), and mean growth/die-back of bare-root tree liners of five species subjected to four pre-plant treatments; Control (not stored), Heel (heeled-in outdoors for three weeks), Store (cold stored at 4 deg. C. for three weeks) or Sweat (Stored in warm, moist conditions for three weeks) prior to planting in 2011. Data are means $\pm$ S.E. Means within a species not followed by the same letter are significantly different at $p < 0.05$ level. Mean separation by Tukey's studentized range (HSD) test.

Starch analysis

Starch concentration of roots did not differ between pre- and post-lifting sampling date, except for *T. distichum* trees, which increased in starch concentration between sample dates (Fig. 4c). Among all species examined, *C. occidentalis* had the lowest amount of starch present in roots (Fig. 4c). Starch concentrations were much lower in shoots than in roots (Fig. 4d) and were higher in shoots of *F. americana* trees than the other species. There was no consistent pattern of variation in shoot starch concentration between sample dates (Fig. 4d).

Discussion

Poor survival or extensive stem dieback is a frequent problem when transplanting many species of bare-root shade tree liners, including several trees species that are promoted as replacements for *Fraxinus spp.* trees lost to emerald ash borer in the United States. Carbohydrate status, desiccation, and ability to re-establish new roots have all been implicated as causes of poor transplanting success in deciduous trees (Lundberg et al., 1990; McKay, 1996; Scianna et al., 2005; Struve, 1990, 2009). The responses of shade tree liners to storage in this study were often species-specific and suggest that different factors may play a role in poor transplant success, depending on the species. Similarly, RGP and transplant success of Washington hawthorn trees were more sensitive to pre-plant desiccation than Norway maple (Bates and Niemiera, 1994; Bates et al. 1994). This suggests that nurseries should consider tailoring strategies for dealing with recalcitrant trees based on species. Below we consider the responses of each of the species or genera studied and the key limitations for each.

Fig. 4 Mean total non-structural carbohydrate content of roots (a), mean total non-structural carbohydrate content of shoots (b) mean starch concentration of roots (c), and mean starch content of shoots (d) of bare-root tree liners of five species before lifting at the nursery (Pre-lift) and after lifting (Post-lift) in 2011.

318
319 *Quercus spp.*

320 Survival of *Quercus spp.* seedlings following transplanting has been related to root
321 growth potential (Villar-Salvador et al., 2004) or carbohydrate status (Farmer, 1978). In
322 the current study *Quercus spp.* liners consistently had relatively low RGP and root TNC.
323 In contrast, *Quercus spp.* tree liners maintained a relatively high capacity for
324 rehydration; as demonstrated by the effectiveness of the heeling-in and sweating
325 treatments in the 2010 and 2011 experiments. Sweating also improved plant water
326 status of *Q. bicolor* liners in 2010. Rehydration before planting may be especially
327 important for *Quercus spp.* since their root growth potential is sensitive to storage-
328 induced dehydration (Genere et al. 2004).

329 *Taxodium distichum*

330 Shoot desiccation appeared to be the main limiting factor for *T. distichum*. *Taxodium*
331 *distichum* liners maintained very high root growth potential in 2010 and 2011
332 experiments, regardless of pre-plant storage condition. They also had comparatively
333 high TNC and starch concentrations. However, *T. distichum* liners dehydrated
334 dramatically between the liner nursery and the research nursery and did not rehydrate
335 during sweating or heeling-in. This suggests that while roots systems of *T. distichum* are
336 resilient to pre-plant storage the shoots of *T. distichum* trees are sensitive to
337 dehydration and need to be carefully protected following lifting.

338 *Fraxinus americana*

339 *Fraxinus spp.* were widely popular as urban trees in the United States because of their
340 broad site tolerance. In addition they are amenable to nursery culture and relatively
341 easy to grow from bare-root liners. In this study *F. americana* did not exhibit any

dieback or other transplant issues, which was consistent with their high RGP and high TNC and starch levels.

Celtis occidentalis

Celtis occidentalis liners appear to represent a ‘worst case’ scenario in response to lifting and storage; exhibiting comparatively little ability to rehydrate, low carbohydrate reserves and generally low RGP. Although several technical bulletins (Halcomb and Fulcher, 2004; USDA 2002) and nursery guides suggest sweating bare-root *C. occidentalis* liners before planting, we did not observe any benefit to sweating in either of the trials in this project. Growers may ultimately have more success with alternative production strategies, such as container-grown liners than with bare-root liners.

Conclusion

The importance of tree diversity on the resilience of urban forests is widely recognized (Santamour, 1990; Morgenroth et al., 2016). In order to ensure diverse and healthy urban forests for the future, shade tree nurseries must be able to produce a wide array of tree species, including many that are often difficult to produce from standard bare-root liners. Our results indicate that the causes of poor transplant success are complex and key limiting factors differ among species. For example, *Quercus spp.* liners may be successfully rehydrated via sweating or heeling-in, whereas *C. occidentalis* liners suffer from multiple limitations and therefore more difficult to address. Growers need to recognize that some species may require different storage and handling strategies and in some cases alternative production strategies (e.g. container liners) may be required.

365 Acknowledgements

366 We thank Randy Klevickas, Bill Chase, Arianna Wilcox, and Brent Crain for their
367 valuable assistance. This project was funded by Michigan's plant agriculture initiative at
368 Michigan State University, Project GREEN; the USDA National Institute of Food and
369 Agriculture Hatch project MICL001978; and the J. Frank Schmidt Family Charitable
370 Foundation. We gratefully acknowledge in-kind contributions from Nursery Supplies,
371 Inc., Renewed Earth, and J. Frank Schmidt and Sons Co.

372

373 **Literature cited**

- 374 Bates, R.M., and Niemiera, A.X. (1994). Mist Irrigation reduces post-transplant
375 desiccation of bare-root trees. *J. Environ. Hort.* 12(1), 1-3.
- 376 Bates, R.M., Niemiera, A.X., and Seiler, J.R. (1994). Cold storage method affects root
377 and shoot water potential of bare-root Hawthorn and Maple trees. *J. Environ. Hort.*
378 12(4), 219-222.
- 379 Bergmeyer, H. U., and Bernt, E. (1974). Determination with glucose oxidase and
380 peroxidase. *Methods of Enzymatic Analysis*, 2(3), 1205–1212.
- 381 Cregg, B., and Schutzki, R. (2004). *Recommended alternatives to ash trees for*
382 *Michigan's lower peninsula. MSU Extension Bulletin* (Vol. E-2925, pp. 1–12).
- 383 Dey, D. C., Jacobs, D., McNabb, K., Miller, G., Baldwin, V., and Foster, G. (2008).
384 Artificial regeneration of major oak (*Quercus*) species in the eastern United
385 States—a review of the literature. *Forest Science*, 54(1), 77-106.
- 386 DuBois, M., Gilles, K. a., Hamilton, J. K., Rebers, P. A., and Smith, F. (1956).
387 Colorimetric Method for Determination of Sugars and Related Substances.
388 *Analytical Chemistry*, 28(3), 350–356.
- 389 Ebell, L. F. (1969). Specific total starch determinations in conifer tissues with glucose
390 oxidase. *Phytochemistry*, 8, 25–36.
- 391 Englert, J.M., Fuchigami, L.H., and Chen, T.H.H., 1993. Bare-root basics. How to
392 handle bare-root trees and shrubs after transplanting. *American Nurseryman*
393 Feb:56-59.
- 394 Englert, J. M., Warren, K., Fuchigami, L. H., and Chen, T. H. H. (1993). Antidesiccant
395 compounds improve the survival of bare-root deciduous nursery trees. *Journal of*
396 *the American Society for Horticultural Science*, 118(2), 228–235.
- 397 Farmer, R.E., Jr. (1978). Seasonal carbohydrate levels in roots of Appalachian
398 hardwood planting stock. *Tree Planters' Notes* 29:22-24.
- 399 Genere, B., Garriou, D., Omarzad, O., Grivet, J. P., and Hagege, D. (2004). Effect of a
400 strong cold storage induced desiccation on metabolic solutes, stock quality and
401 regrowth, in seedlings of two oak species. *Trees*, 18(5), 559–565.
- 402 Halcomb, M., and Fulcher, A. (2004). Sweating nursery stock to break dormancy.
403 <http://www.ca.uky.edu/HLA/Dunwell/LnrSweat.html>

404 Herms, D.A., and McCullough, D.G. (2014). Emerald ash borer invasion of North
 405 America: History, biology, ecology, impacts, and management. *Ann. Rev. of*
 406 *Entomology*. 59: 13-30.

407 Iles, J. (2012). Alternatives to ash. *American Nurseryman*, February, 6–9.

408 Jull, L. G. (n.d.). Alternatives to ash trees. *EAB News and Resources*. Retrieved March
 409 9, 2012, from <http://labs.russell.wisc.edu/eab/eab-news-and-resources/>

410 Keller, J. D., and Loescher, W. H. (1989). Nonstructural carbohydrate partitioning in
 411 perennial parts of sweet cherry. *Journal of the American Society for Horticultural*
 412 *Science*, 114(6), 969–975.

413 Kobe, R. K. (1997). Carbohydrate allocation to storage as a basis of interspecific
 414 variation in sapling survivorship and growth. *Oikos*, 80, 226–233.

415 Lundberg, J. D. D., Tabbush, P. M., Cannell, M. G. R., Sheppard, L. J., and Murray, M.
 416 B. (1990). The influence of desiccation , rough handling and cold storage on the
 417 quality and establishment of sitka spruce planting stock. *Forestry*, 63(2), 129–141.

418 McKay, H. M. (1996). A review of the effect of stresses between lifting and planting on
 419 nursery stock quality and performance. *New Forests*, 13, 363–393.

420 Morgenroth, J., Östberg, J., Konijnendijk van den Bosch, C., Nielsen, A. B., Hauer, R.,
 421 Sjöman, H., Chen, W., and Jansson, M. (2016). Urban tree diversity—Taking stock
 422 and looking ahead. *Urban Forestry & Urban Greening* 15: 1-5.

423 Murakami, P., Chen, T., and Fuchigami, L. H. (1990). Desiccation tolerance of
 424 deciduous plants during postharvest handling. *Journal of Environmental*
 425 *Horticulture*, 8(1), 22–25.

426 Ritchie, G.A and T.M. Hinckley. (1975) *The pressure chamber as an instrument for*
 427 *ecological research*. *Adv. in Ecol Res*. 9:165-254.

428 Santamour, F. S. (1990). Trees for urban planting: diversity uniformity, and common
 429 sense. *METRIA* 7, 57–65.

430 Scianna, J. D., Logar, R., and Ogle, D. (2005). Temporary storage and handling of
 431 container, bareroot, and cutting stock. *Plant Materials Technical Note, MT-*
 432 *51(2005)*, 1–6.

433 Simpson, D. G., and Ritchie, G. A. (1996). Does RGP predict field performance? A
 434 debate. *New Forests*, 13, 249–273.

- 435 Starbuck, C., Struve, D. K., and Mathers, H. (2005). Bareroot and balled-and-burlapped
436 red oak and green ash can be summer transplanted using the Missouri Gravel Bed
437 system. *Hort Technology*, 15(1), 122–127.
- 438 Struve, D. K. (1990). Root regeneration in transplanted deciduous nursery stock. *Hort*
439 *Science*, 25(3), 266–270.
- 440 Struve, D. K. (2009). Tree establishment: a review of some of the factors affecting
441 transplant survival and establishment. *Arboriculture and Urban Forestry*, 35(1), 10–
442 13.
- 443 Unites States Departmetn of Agricutlure (USDA) Natural Resroures Conservation
444 Service (2002). Plant Fact Sheet: Common hackberry (*Celtis occidentalis* L.)
445 plants.usda.gov/factsheet/pdf/fs_ceoc.pdf
- 446 Villar-Salvador, P., Planelles, R., Enriquez, E., and Rubira, J. P. (2004). Nursery
447 cultivation regimes, plant functional attributes, and field performance relationships
448 in the Mediterranean oak *Quercus ilex* L. *Forest Ecology and Management*, 196(2),
449 257-266.