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Production Method Affects Growth and Post-transplant Establishment of 'East Palatka' Holly

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Abstract. **Growth and physiological responses before and after transplanting to a simulated landscape were studied for 'East Palatka' holly *(Ilex ×attenuata* Ashe 'East Palatka') grown in plastic containers (PC), in the ground in fabric containers (FC), or in the ground conventionally. At the end of a 15-month production period, trees grown in PC had more shoot dry weight and leaf area than trees grown in FC, and they had thinner trunks than field-grown trees. Root balls on harvested field-grown trees contained 55% and those grown in FC 65% of total-tree root surface area. Trees transplanted from FC had the lowest predawn leaf xylem potential and required more frequent post-transplant irrigation than trees grown in PC or in the ground. Carbon assimilation rate and stomata1 conductance in the first week after transplanting were highest for trees planted from PC. Dry weight of regenerated roots was similar for all production methods 4 months after transplanting from the nursery, but trees grown in PC had SO% more regenerated root length, and the roots extended further into the back-fill soil.**

Landscape contractors are commonly presented with the option of purchasing landscape-sized trees produced 1) in the ground, 2) in aboveground containers, and most recently, 3) in FC in the ground. To date there are no scientific investigations comparing pre- and post-transplant response of trees grown by these production methods. Studies have been limited to comparisons among field production methods (Fuller and Meadows, 1987, 1988; Ingram et al., 1987; Magley and Struve, 1983).

With FC there may be more roots, and the roots may be smaller in diameter than those inside a traditional field-grown root ball (C.E. Whitcomb, personal communication). The response of trees to the fabric container appears to be species specific. There are reports of increased root weight inside the harvested fabric root ball (Fuller and Meadows, 1987; Ingram et al., 1987). Root balls of some species appear to be unaffected by the fabric (Ingram et al., 1987). There is one report of reduced root dry weight in the fabric-container root ball (Chong et al., 1987). The one consistent tree response appears to be an increase in root density within the fabric-container root ball (Fuller and Meadows, 1988; Harris and Gilman, 1991).

There is little evidence demonstrating that increased root density or dry weight within the root ball of FC will reduce stress following transplanting or enhanced post-transplant growth. In the only study conducted to test transplantability, increased dry weight in fabric-grown root balls, compared to field-grown trees, corresponded to an increase in regenerated roots 60 days later only in one of five species tested (Fuller and Meadows, 1988). Root regeneration for one species was lower on trees grown in FC than in the field.

Distribution of biomass within the harvested root ball (Struve et al., 1989), root surface area (Sutton, 1980), and percentage of roots harvested (Watson and Sydnor, 1987) may be important factors in successful transplanting of trees. Less than 10% of total root length is located within the root ball of trees grown in a field nursery (Gilman, 1988). The shoot : root ratio at transplanting and age of the tree may be primary factors in severity of transplant shock and recovery to pretransplant growth rates (Watson, 1985). Older and larger-diameter roots on trees contribute a disproportionate amount of weight relative to root surface area compared to smaller-diameter roots (Mengel and Kirkby, 1987). Therefore, root surface area may be a better indicator of the absorptive capability of roots than weight (Barley, 1970), but these data have not been routinely collected on shade trees.

Numerous studies compared post-transplant response of field-grown trees moved with soil root balls to those moved bare root. Post-transplant shoot growth was greater on pin oak *(Quercus palustris* Muenchh.) moved with soil root balls than with similar-sized trees moved bare-root (Magley and Struve, 1983). After 5 years, there was no difference in post-transplant growth between pecan *[Carya illinoinensis* (Wangenh.) K. Koch] trees transplanted from containers and those moved bare-root (Laiche et al., 1983). Post-transplant growth of field-grown trees has only rarely been compared with that of container-grown trees. In one of the few reports in the literature, transplanted field-grown 'Sea Green' juniper *(Juniperus chinensis* L. 'Sea Green') had slightly greater root spread and more regenerated root dry weight than transplanted container-grown plants (Blessing and Dana, 1987).

Disruption of the internal water balance on transplanted trees caused by a reduction in the size of the root system often causes transplant death (Kozlowski and Davies, 1975). Xylem pressure potential is correlated with post-transplant root regeneration (Larson, 1984) and photosynthetic rate (Reich et al., 1989); and, root regeneration is needed for transplant survival. Root regeneration may be reduced on transplanted trees subjected to water deficit (Becker et al., 1987; Witherspoon and Lumis, 1986).

A tree growing in a plastic container loses water by evapotranspiration and drainage only, but once planted in soil, it loses water by evapotranspiration, drainage, and capillary movement (Costello and Paul, 1975; Nelms and Spomer, 1983). For this reason, a

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Abbreviations: CER, carbon exchange rate; FC, fabric containers; FG, field grown; PC, plastic containers; Ψ_{leaf}, leaf water potential.

container-grown tree may need more irrigation after it is planted in the ground than when it was in the container (Spomer, 1980), and may be subjected to water stress after transplanting even though the shoot : root ratio has not been altered. The objective of this study was to compare the effects of production in PC, in the ground with FC, and in the ground conventionally on distribution of tree biomass, and to relate this to post-transplant physiology of trees of ‘East Palatka’ holly subjected to varying irrigation schedules.

Materials and Methods

Fifty-four ‘East Palatka’ holly in 16-cm-wide × 16-cm-deep (3-liter) round black PC were selected for uniformity, the container removed, and the trees planted on 1.8-m centers on 28 July and 10 and 11 Aug. 1988. Eighteen of the 54 trees were planted in 25-cm wide × 25-cm deep (lo-liter) black PC (model 030, Lerio, Mobile, Ala.) in a medium of 3 pine bark : 2 domestic peat : 1 sand (by volume) supplemented with 3.5 $kg \cdot m^{-3}$ dolomite, 0.90 $kg \cdot m^{-3}$ Perk (Vigoro Industries, Fairview Heights, Ill.), and 0.60 $kg \cdot m^{-3}$ superphosphate (20% P_2O_5). They were replanted into 34-cm wide × 30-cm deep (25-liter) PC (model 7g, Lindco Industries, Ft. Lauderdale, Fla.) on 5 Apr. 1989, and the containers were placed inside slightly larger empty black PC to buffer medium temperature (Ingram et al., 1988). The remaining 36 trees were planted in the ground in an Arrendondo fine sand (loamy, siliceous, hypothermic Grossarenic Paleudults) amended with limestone to a pH of 6.4. Half of these were planted in 25-cm wide × 25-cm deep FC (Root Control, Oklahoma City, Okla.), and the other half were planted directly in the ground (FG). There was one tree per production method in each of 18 blocks arranged in a randomized complete-block design. Trunk diameter 2.5 cm above the soil line and tree height were measured at planting.

Trees in PC were irrigated daily with 30 mm of water by individual microemitters except for 15 Dec. 1988 through 1 Feb. 1989, when irrigation was supplied on alternating days. FC and FG trees were supplied with overhead irrigation to insure a minimum of 35 mm per week of water during the growing season. Trees grown in containers also received the overhead irrigation. All trees received Osmocote 18N-2.6P-9.9K (Grace-Sierra, Milpitas, Calif.) immediately after planting at 50 g per tree evenly distributed over a 12.5-cm radius from the trunk. Trees were refertilized 5 Apr. 1989, at 110 g per tree evenly distributed over a 17-cm radius. Weeds were controlled with Rout (oxyfluorfen + oryzalin) applied at 1 kg/100 m^2 every 6 months. Final height and trunk diameter measurements were recorded on 27 Oct. 1989. The largest and smallest tree in each production method was discarded, since one field-grown tree was about twice the size of the rest of the trees, and two were much smaller than the others. If these trees were included in the study, their root balls would have been a different size than on the remaining trees in the study. There is evidence that tree size and rootball size affects growth and physiology of transplanted trees (Gilman, unpublished data).

In late Oct. 1989, four trees were selected at random from each production method (for a total of 12 trees) and cut apart to determine total biomass distribution. Roots within the root ball on FG and FC trees were separated from those outside of the root ball. Dimensions of the harvested root ball were the confines of the PC and FC, or 41-cm wide × 33-cm deep for FG trees (Amer. Assn. Nurserymen, 1990). Roots located outside the root ball were sampled by excavating a wedge defined by a 90” angle from the tree trunk (25% of total soil explored by the roots) on the east and west side of each tree. The wedge was extended as far from the trunk and as deep as needed to capture all tree roots growing outside the root ball in this wedge. Totals from the east and west sides were added and multiplied by two to estimate total roots outside the root ball.

Root length (Delta T area meter, Decagon Devices, Pullman, Wash.), root dry weight, and surface area were measured for roots in the 0 to 1 mm, >1 to 2 mm, >2 to 5 mm, >5 to 10 mm, and >10 mm root-diameter classes. Root surface area was calculated from root length, assuming roots were cylinders and using the median diameter in each root-diameter class (0.5 mm, 1.5 mm, 3.5 mm, and 7.5 mm). Root length was highly correlated with dry weight (r > 0.98) for ail root-diameter classes.

Leaf count and area of one side of the leaf (Delta T area meter) were recorded, and leaves, stems, and berries were dried separately for 8 days at 70C to a constant weight.

On 28 to 30 Oct. 1989, the remaining 12 trees from each production system (a total of 36 trees) were moved within an enclosed truck 16 km to the transplanting site. Trees grown in PC

Table 1. Influence of production method on growth of ‘East Palatka’ holly.[z]

Prod. method	Stem dry wt (g)	Berry dry wt (g)	Leaves/ tree (no.)	Tree[y] ht increase (m)	Trunk[y] diam increase (mm)	Final[y] crown width (m)	Leaf dry wt (g)	Total-top dry wt (g)	Area/ leaf (cm^2)	Total leaf area (m^2)	Total leaf area: root surface area (RSA) (0–10 mm) WIRB[w] ratio	Total-top: total-root dry wt WIRB[w] ratio	Total leaf area: root[x] surface area (RSA) (0–10 mm) ratio	Total-top: total-root[x] dry wt ratio
PC	325 a[v]	249 a	2898 a	0.50 a	16.1 b	1.12 ab	278 a	852 a	6.1 a	1.77 a	1.03 b	4.86 a	1.03 a	4.86 a
FC	233 a	202 a	1983 a	0.54 a	17.3 ab	1.07 b	164 b	599 b	5.3 b	1.07 b	1.73 ab	5.18 a	1.16 a	4.29 ab
FG	307 a	207 a	2546 a	0.67 a	18.8 a	1.23 a	227 ab	741 ab	6.1 a	1.56 ab	2.06 a	4.11 a	1.10 a	3.10 b

[z]Mean of four trees per treatment unless stated otherwise.
[y]Mean of 16 trees per treatment.
[x]Entire root system.
[w]Within the root ball.
[v]Mean separation within columns by Duncan’s multiple range test, P < 0.05.
PC, plastic container; FC, fabric container; FG, field grown.

and FC were carefully removed from the containers. Burlap and lacing used to hold the 41-cm wide × 33-cm deep root balls together on FG trees were not removed after transplanting. Trees were transplanted into 57-cm wide × 43-cm deep bottomless, black, round PC (I.E.M. Plastics, Reidsville, N.C.) placed on the ground 1.25 m apart in a randomized complete block with two replicates per production system per block (six blocks, six trees per block). The outside of each plastic container was painted with white latex paint. Arrendondo fine sand (pH 6.2) was gently backfilled into the bottomless plastic container to the top of the root ball. All trees were staked and enclosed in an open-sided, unheated quonset-style rain shelter covered with clear polyethylene 0.15 mm thick. Trees were irrigated with 75 mm of water at transplanting, then daily with 40 mm of water for 7 days.

Trunk diameter 5 cm above the soil line was measured at transplanting. Dry weight was recorded for leaves that abscised from trees after transplanting. Carbon exchange rate (CER), stomatal conductance (g), and internal : external CO_2 concentration ratio were measured on six trees per treatment 7 days before transplanting (TR – 7), TR + 1, + 3, and + 6 days, and periodically throughout the study from 1200 to 1400 HR, using a portable photosynthesis system containing a LI-COR 6200 computer and LI-COR 6250 gas analyzer (LI-COR, Lincoln, Neb.). The same six trees per treatment were selected on each measurement date, and data were recorded on the most recently matured leaf, which was typically three to five leaves from the shoot apex. Leaf area was 4.2 cm^2 in the 0.25-liter chamber, and data were recorded as the mean of three consecutive observations of at least a 5 µl CO_2 drawdown on each leaf. When drawdown time exceeded 60 sec, CER rate over time (45 sec) was recorded. Measurement days were scheduled when clear skies were expected to keep light saturation >600 $\mu mol \cdot m^{-2} \cdot sec^{-1}$.

Predawn leaf water potential (Ψ_{leaf}) was measured TR – 5 and TR +2, +4, and +6 days. Measurements of Ψ_{leaf} were made on the most recently matured leaves with a pressure chamber (Soil Moisture Equipment Co., Santa Barbara, Calif.) (Scholander et al., 1965).

Half the trees were subjected to five drying cycles, each ending with irrigation. The first drying cycle was initiated at TR +7 by withholding water from one tree per production system per block (a total of 18 trees) until predawn Ψ_{leaf} of trees in any production method averaged (six trees) –1.3 MPa. That afternoon, all 18 drought-stressed trees in all three production methods received 75 mm of water. The remaining 18 trees (nonstressed) were irrigated daily in late afternoon with 25 mm of water until termination of the study at TR + 113 days. Following the first two drying cycles, drought-stressed trees were irrigated only when predawn Ψ_{leaf} in any production method averaged –2.0 MPa. Diurnal Ψ_{leaf} was measured on two trees in each production method in the stressed and nonstressed treatments (a total of 12 trees) 2 days before, and 1 or 2 days following, irrigation of drought-stressed trees in drying cycles 1 and 2.

After irrigating at the end of the fifth drying cycle, no drought stressed trees were irrigated until the six trees in any production system had a mean predawn Ψ_{leaf} of –1.5 MPa. Then, only trees transplanted from that production were irrigated daily with 35 mm of water, and trees in the remaining two production systems were allowed to attain a similarreading before receiving daily irrigation. The study was terminated 16 days later, on TR +113 days.

The bottomless plastic container was cut away from each tree and backfill soil only (not soil or medium inside the root ball) and was completely washed from the regenerated root 113 days after transplanting. Roots growing along the inside wall of the container were straightened, and the distance between the edge of the original root ball and the root tip farthest from the edge of the root ball was measured in the north, west, south, and east directions. The average of these four values was recorded as root extension. Trunk diameter, root dry weight, and volume of water displaced by all regenerated roots was determined for all 36 trees. Average root diameter on 15 randomly selected regenerated root sections (10 to 15 cm long) were recorded for all trees. Differences among production methods were significant at $P < 0.05$, unless noted otherwise.

Results

Growth during the tree production period. During the 15-month production period, there were no significant differences among production methods for dry weight of stems or berries, leaf count, or tree height increase (Table 1). Increase in trunk diameter of FG trees (1.9 cm) was greater than on PC trees (1.6 cm) but similar to that of FC trees (1.7 cm). Crowns on FG trees were wider than on FC trees but similar to those of PC trees (1.12 cm). PC trees had more leaf and total-top dry weight than FC trees. PC and FG trees produced 13% and 12% larger leaves, respectively, than FC trees, and FC trees had less leaf area than PC trees. FG trees had a higher ratio of leaf area : root surface area within the root ball than PC trees, but there were no differences in the ratio total-top dry weight : root weight within the root ball among production methods. Total leaf area : root surface area (entire root system) ratios were similar

Table 2. Root surface area at transplanting for 'East Palatka' holly grown in plastic containers (PC), fabric containers (FC), and in the field (FG).[z]

Prod. method	Within root ball root-diam class: 0–1 mm	>1–2 mm	>2–5 mm	>5–10 mm	Total (0–10 mm)	Outside root ball root-diam class: 0–1 mm	>1–2 mm	>2–5 mm	>5–10 mm	Total (0–10 mm)	Percentage of total-tree RSA[y] (0–10 mm within root ball)
	Root surface area (cm^2, 1000s)[x]										
PC	14.8 a[w]	0.85 a	1.15 a	0.57 a	17.3 a	---	---	---	---	---	100[v]
FC	4.68 b	0.30 b	0.59 b	0.55 a	6.12 b	2.97 a	0.20 a	0.096 b	0.002 a	3.27 a	65.3 a
FG	5.53 b	0.49 b	0.97 a	0.76 a	7.76 b	5.40 a	0.45 a	0.50 a	0.099 a	6.44 a	54.6 a

[z]Means of four trees.
[y]RSA = root surface area.
[x]Root surface area calculated from root length using median diameters in each RDC.
[w]Mean separation within columns by LSD, $P < 0.05$.
[v]All roots were inside container.

among production systems (mean = 1.09), but FG trees had lower total-top dry weight : root dry weight (entire root system) ratios than PC trees.

Within the root ball, root surface area was largest on PC trees (Table 2). There was no difference between FC and FG trees, except that the surface area of 2 to 5 mm diameter roots was larger on FG trees. Outside the root ball, root surface area was larger on FG trees only for roots in the 2 to 5 mm root-diameter class. Length of the entire root system (roots 0 to 10 mm root diameter class) of PC trees (97 1 m) was similar to that of FG trees (732 m) but greater than that of FC trees (506 m).

Response to post-transplant water stress. There were no differences among production methods in predawn Ψ_{leaf} 5 days before transplanting or in CER or stomata1 conductance 7 days before transplanting (Figs. 1A–C). Trees grown in FC receiving daily irrigation after transplanting had the lowest predawn Ψ_{leaf}, 2 and 4 days after transplanting. However, there was no significant difference in predawn Ψ_{leaf} among production methods 6 days after transplanting (Fig. 1A) or thereafter for 113 days after transplanting (data not shown). One, 3, and 5 days after transplanting, CER

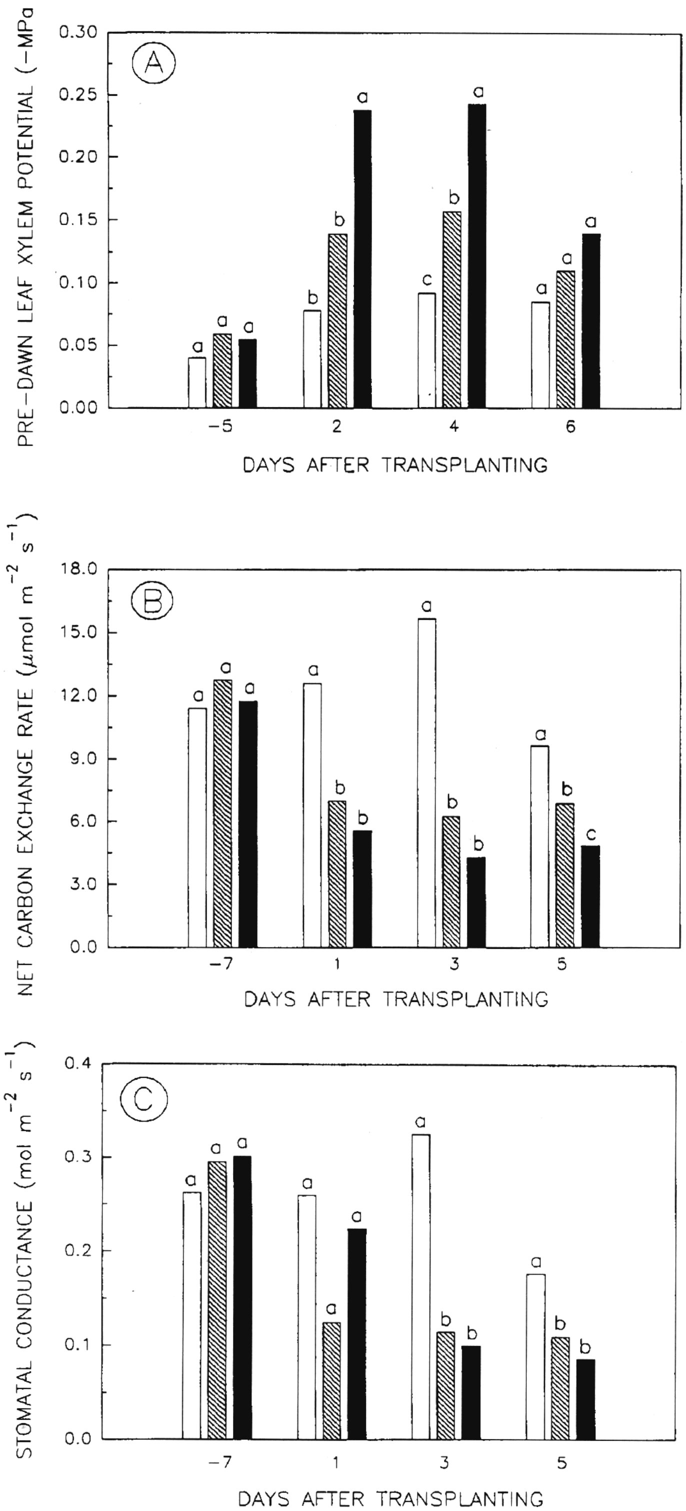

Fig. 1. **(A)** Predawn leaf xylem potential 5 days before and 2, 4, and 6 days after transplanting; **(B)** net carbon exchange rate; and **(C)** stomatal conductance of plastic container-grown (❑), field-grown (▧) and fabric container-grown (■) *Ilex ×attenuata* 'East Palatka' trees 7 days before, and 1, 3, and 5 days after transplanting. All trees received daily irrigation for 7 days following transplanting. Letters on top of bars indicate separation of means (*P* < 0.05, n = 12) among production methods by Duncan's multiple range test.

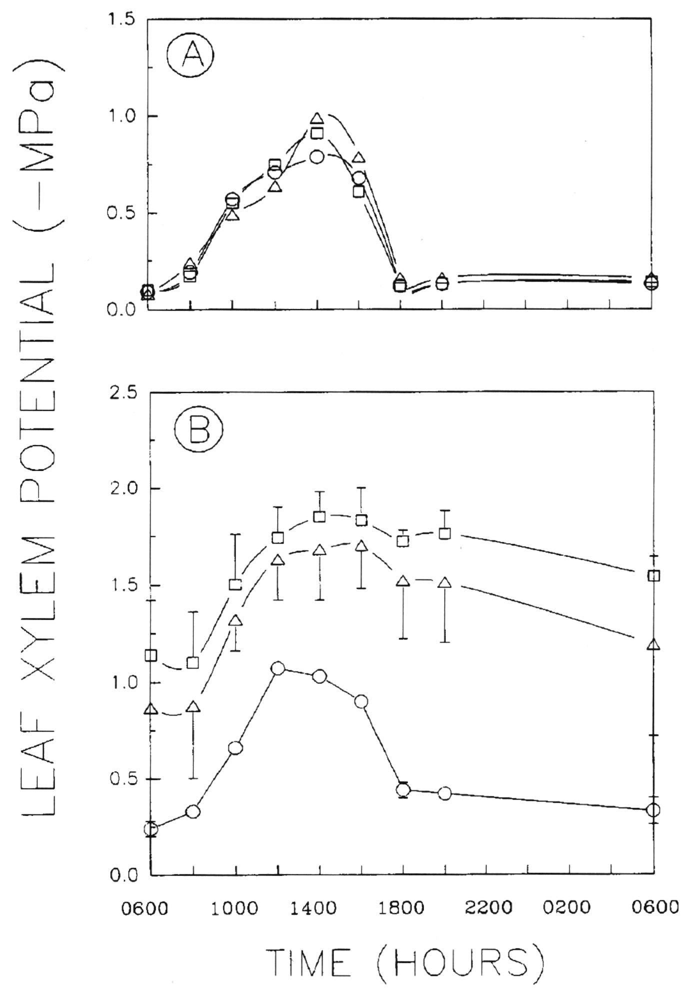

Fig. 2. **(A)** Diurnal xylem potential of well-watered (daily) and **(B)** drought-stressed plastic container-grown (❍), field-grown (Δ) and fabric container-grown (❑) *Ilex ×attenuata* 'East Palatka' transplants 10 days after withholding irrigation in the first drying cycle (16 days aftertransplanting). Eachpoint is the mean of two trees.

was highest for PC trees. FC-grown trees had a lower CER than FG trees on TR +5 days. Stomatal conductance on field and FC trees was significantly lower 3 and 5 days after transplanting than on container-grown trees (Fig. 1C). The mean ratio of internal to external CO, was 6.8 and was not affected by transplanting for any treatment (data not shown).

During the 16th day after transplanting (TR +16 days), diurnal Ψ_{leaf} pattern was similar among production methods in transplants receiving daily irrigation (Fig. 2A). Diurnal Ψ_{leaf} followed a similar pattern during TR +30 days (data not shown). However, after 10 days without irrigation in the first drying cycle (TR +16 days), PC trees were less stressed than FG and FC trees (Fig. 2B).

Trees grown in FC subjected to drought stress aftertransplanting had the lowest CER 1 day before irrigation and after 12 and 14 days without irrigation in the fourth drying cycle (60, 73, and 75 days after transplanting, respectively) (Fig. 3). In contrast, there was no difference in CER among production methods for trees receiving daily irrigation, and well-watered trees had higher CER than drought-stressed trees (data not shown).

Predawn Ψ_{leaf} for FC drought-stressed trees was lower during all dry down cycles than for PC and FG trees (for example, Fig. 4). Drought-stressed FC, FG, and PC trees took 11, 17, and 18 days without irrigation in the fifth drying cycle (89, 95, and 96 days after transplanting, respectively) to reach a similar predawn Ψ_{leaf} (–1.5 MPa). The diurnal Ψ_{leaf} pattern for FC trees after 11 days without irrigation was similar to that for FG and PC trees after 17 and 18 days without irrigation, respectively (data not shown). There were no differences among production methods or between drought-stressed treatments in predawn Ψ_{leaf} 7 days or in CER 15 days after resuming daily watering of all drought-stressed trees 96 days after transplanting.

There were no differences among production methods in root dry weight or volume of regenerated roots (Table 3) or in trunk diameter increase (data not shown) after transplanting. However, drought stressed trees receiving only periodic irrigation had a far lower regenerated root dry weight and volume than trees that were irrigated daily. Roots on PC trees irrigated daily extended further from the root ball than those from FG trees, whereas roots on PC trees subjected to periodic irrigation extended further than FG and FC trees. Dry weight of leaves that abscised from trees after transplanting was higher for FC than for PC or FG trees.

Discussion

Production method had a -direct effect on tree growth and distribution of biomass. Despite differences in total leaf area and total root surface area, the ratios total leaf area : total root surface area were similar (mean = 1.09) among production methods. This indicates that the shoot : root (surface area) ratio was not affected by tree production method. However, container-grown trees had the highest total top : total root dry weight ratios, because most of the root system of PC trees consisted of fine roots that had more surface area per gram of dry weight than the larger roots that predominated in the root system on FC and FG trees. The reason for this difference is not clear.

Because the trees in this study were only in the ground 15 months before transplanting, a much higher percentage (55%) of the total root system of FG trees was harvested than has been reported in other studies (5% to 8%) (Gilman, 1988). Trees in the previous study were originally planted bare-root and were allowed to grow twice as long before harvest as the trees in this study. Planting container-grown trees in the current study instead of bare-root trees may also have resulted in root balls with higher root densities. This difference warrants further study because it could have implications for the field-grown plants of the nursery industry.

Despite receiving irrigation each day in late afternoon, PC trees had slightly lower (not significant) predawn Ψ_{leaf} readings the following morning in the first 6 days after transplanting than before (Fig. 1A), probably as a result of water draining from the medium into the landscape soil (Costello and Paul, 1975; Nelms and Spomer, 1983). However, this slight change in predawn Ψ_{leaf} had no effect on CER (Fig. 1B) or stomatal conductance (Fig. 1C) and is probably not biologically significant.

Container-grown trees were better able to meet the transpirational needs of the plant immediately after transplanting, since no roots were lost at transplanting, and some of the many fine roots in the container root ball were along the outside of the root ball.

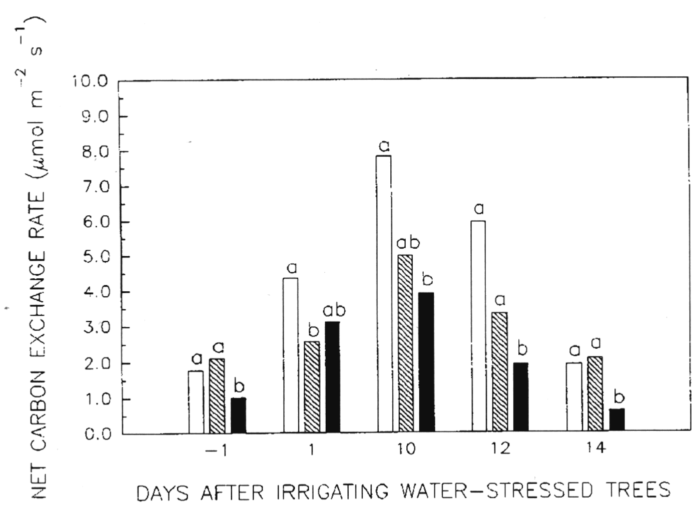

Fig. 3. Net C exchange rates (1200 to 1400 HR) for drought stressed, plastic container-grown (❑). field-grown (▧), and fabric container-grown (■) *Ilex ×attenuata* 'East Palatka' transplants 1 day before, and 1, 10, 12, and 14 days after beginning the fourth drying cycle. Letters on top of bars indicate separation of means ($P < 0.05$, n = 6) among production methods by Duncan's multiple range test.

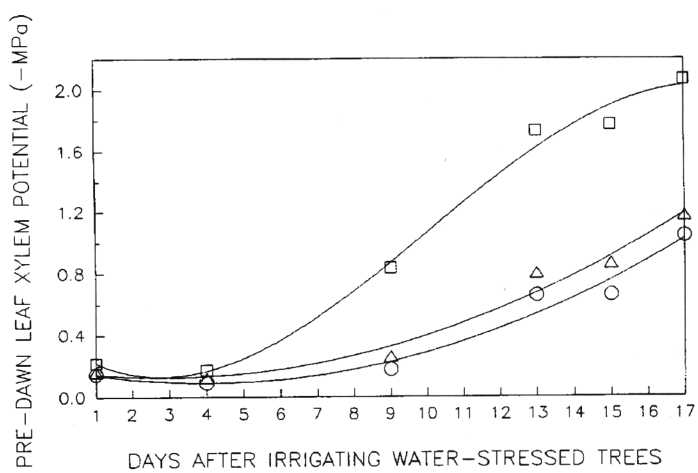

Fig. 4. Predawn xylem potential of plastic container-grown (❍), field-grown (Δ), and fabric container-grown (❑) *Ilex ×attenuata* 'East Palatka' transplants during the fourth drying cycle. Regression equations are: for plastic container-grown y =0.183–0.0448x + 0.0055x^2 (R^2= 0.962), for field-grown, y = 0.1714–0.0306x + 0.0053x^2 (R^2= 0.976), for fabric container-grown, y = 0.3599 – 0.1754x + 0.0367x^2 - 0.0012x^3 (R^2= 0.992). Predawn leaf xylem potential for well watered transplants was greater than -0.1 MPa during the same time period.

Table 3. Root dry weight, volume and extension of regenerated roots, and leaf abscission of transplanted 'East Palatka' holly.[z]

Production method	Frequency of irrigation	Root dry wt (g)	Root volume (ml)	Average maximum root extension (cm)	Leaf abscission dry wt (g)
PC	Daily	24.1	283	25.8	9.6
	Periodic	6.8	105	14.7	13.0
FC	Daily	31.1	351	24.1	22.2
	Periodic	7.0	112	11.4	33.5
FG	Daily	29.1	287	22.2	12.7
	Periodic	10.1	147	11.6	20.4
Significance					
Production method		NS	NS	*	*
Irrigation treatment		**	**	**	NS

[z]Means of six trees.
[NS],*,**Significant at $P < 0.05$, 0.01 or nonsignificant at $P > 0.05$, respectively. No interactions were significant.

Immediately after planting, the roots on the outside of the container root ball were in intimate contact with the backfill soil. This contact probably allowed the tree to continue to absorb water, even as the container medium rapidly dried. Nelms and Spomer (1983) showed that 85% of the available water in container medium can be depleted from the root ball within several hours of planting. For this reason, container-grown trees may benefit from having a large portion of their roots along the outside of the container root ball, so they can immediately grow into the landscape backfill soil.

Six days were required for the predawn Ψ_{leaf} of FG and FC to adjust to the loss of 45% and 35% of the total root system, respectively. Because FC and FG trees had similar leaf area : root surface area ratios when transplanted, they might be expected to exhibit similar post-transplant stress when watered daily, and they did (data not shown), except for 2 and 4 days after transplanting (Fig. 1A). However, FC trees consistently reached severe stress levels several days before any other production method when irrigation was withheld (Fig. 4). For example, FC trees reached a predawn Ψ_{leaf}, of -1.5 MPa in 65% of the time that it took FG trees (drying cycle 5). And when water was withheld for 10 days after transplanting in drying cycle 1, FG and PC trees were only 85% and 35% as stressed as FC trees (Fig. 2).

The greater water stress on FC trees may be due to 1) the root balls of FC trees had a similar root surface area as root balls of FG trees in only one-half the soil volume. Since root density was greater, the FC root ball may have dried quicker, causing lower predawn XP, and 2) the root ball was loosened when the fabric container was removed (also noted by Fuller and Meadows, 1988). This procedure may have damaged some of the fine roots or disturbed the intimate contact of roots with soil, thereby hindering uptake of water by the roots. Perhaps, trees from FC would be less stressed if they were harvested with a larger root ball than now is done.

FC trees were more water stressed, had a lower CER, and lost more leaves than FG or PC trees, but there were no differences among production methods in post-transplant trunk diameter increase (data not shown) or dry weight of regenerated roots. Roots extending from the root balls of PC trees had a smaller diameter than those originating from the severed roots of FG and FC trees. Calculations, using mean diameters (0.55, 0.65, and 0.65 mm for PC, FG, and FC, respectively) and volume displacement (Table 3), indicate that even though there were no differences among production methods in dry weight or volume of regenerated roots, PC trees had >50% greater root length (163 m) in the backfill soil than FG (98 m) or FC (104 m) trees. This extra length may have helped maintain a better water balance in PC trees when water was withheld following transplanting. Root growth into the backfill soil may have been enhanced in PC trees because stomata1 conductance and CER remained higher following transplanting than in FC and FG trees (Figs. 1 and 3). CER also recovered quickest for PC trees following irrigation after a dry down cycle (Fig. 3), perhaps allowing for greater assimilation of C and translocation of carbohydrates to the root system for new root growth. Carbon assimilated in current leaves can influence the extent of root regeneration (van den Dreissche, 1987), and more root regeneration probably contributed to the increased stomatal conductance and CER in trees planted from PC.

PC trees were less stressed at transplanting because of an unaltered root system. The reduced root systems of FG and FC trees were not able to replace water lost by transpiration as well as PC trees when irrigation was withheld. The consistantly higher leaf water potentials and CER following transplanting of PC trees and far larger root surface area within the root ball at transplanting probably allowed for more rapid root growth into the backfill soil, resulting in greater maximum root extension and length.

All production methods produced satisfactory transplants of 'East Palatka' holly. However, fabric container-grown trees had lower leaf water potentials and CER initially, and would require more frequent irrigation during establishment. Quality of post-transplant management is therefore an important factor when choosing trees from nurseries. If trees can be irrigated frequently after transplanting, production method has no apparent effect on tree water status (except for the 4-day period immediately following transplanting trees from the field or from FC, when they have a lower leaf water potential than trees planted from PC), but if irrigation will be limited, trees transplanted from FC or from the field may be more stressed than those planted from PC.

These results may not apply to larger than we used trees or to other tree species. Results may also be different if field-grown trees are root pruned before transplanting (Gilman and Kane, 1990). In addition, drought-stressed trees in the current study were irrigated daily for only 1 week before withholding of irrigation. There is evidence that if this daily irrigation period is extended to 2 or 3 months, root regeneration on trees transplanted from the field or from FC is greater than on trees transplanted from PC (Gilman and Harris, 1991). This could have an impact on post-transplanting water relations.

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