DIURNAL WATER STRESS DURING LANDSCAPE ESTABLISHMENT OF SLASH PINE DIFFERS AMONG THREE PRODUCTION METHODS

by R. C. Beeson, Jr. and E. F. Gilman

Abstract. Three year-old slash pine seedlings (*Pinus elliottii*) were transplanted from 3.8 liter (1 gal) plastic containers directly into the soil, in the soil within fabric containers, or into 57 liter (15 gal) plastic containers. After 2 yr in the nursery, trees grown by all three production methods were dug and re-transplanted to a new site. Eight weeks prior to transplanting, half the soil-grown trees were root pruned. Water potential was measured on needle fascicles on a diurnal basis at least monthly after transplanting. Based on comparisons of diurnal water potential curves with nontransplanted control trees, trees which were transplanted from field soil or from fabric containers were established after 27 weeks. Trees planted from plastic containers required 35 weeks to become established.

Additional index words: *Pinus elliottii*, urban forestry, container, field, fabric container.

Watson (26) suggested that transplanted trees become established when annual shoot elongation returns to pre-transplant rates. Kramer and Kozlowski (14) suggested that reduced shoot growth during this establishment period was due to a greater emphasis on root regeneration. Shoot growth would resume when a natural root:shoot ratio was re-established. In the central United States, the resumption of pre-transplant growth rates is predicted to require a year or more per inch of trunk diameter (26). In Florida and other states with mild winters, tree roots can grow continuously (7) compared to seasonal root growth found in more northern areas (17). Year-round root growth, along with much longer growing seasons, suggests that trees may establish quicker in warm climates.

During the establishment period, maintaining an adequate tree water status is crucial for survival (15). Moderate or severe water stress greatly limits photosynthetic rates (9) and phloem transport (21, 16), severely restricting the availability of current photosynthates to the roots. In small trees, current photosynthates have been shown to be the principal source of carbon for root regeneration (10). In several tree species, pre-transplant shoot pruning reduced root regeneration nearly 50% whereas similar pruning of the roots had no significant effect (2). Therefore, in plants subjected to water stress, several factors combine to severely limit root growth (23,5). Maximum root regeneration occurs when the root ball and surrounding soil are maintained near field capacity (25,24).

The unfavorable balance of reduced water-absorbing root mass to transpiring shoot mass induces various degrees of water stress in plants during the establishment period (15). Recovery from this chronic water stress is directly proportional to the rate of root regeneration (19). Shoot elongation in apples increased proportionally with the increase in root mass after transplanting (1). Photosynthesis, transpiration and stomatal conductance, all controlled by water stress, increased to pre-root pruning rates in conjunction with long-root regeneration of green ash (4). Thus, monitoring water relations of transplanted trees during the establishment period should help determine when the root system is regenerated and therefore when the tree is established.

In parts of Florida and in other areas of the country, the reservoir of potable water has become depleted, prompting restrictions on its use for

Florida Agricultural Experiment Station Journal Series No. R-02475. This project was partially funded through grants from the International Society of Aboriculture and Horticultural Research Institute.

irrigation. Transplanted trees in deep, well-drained sandy soils require near daily irrigation after transplanting to maintain field capacity and therefore maximum rates of root regeneration. Determining the rate at which trees become established in the landscape would permit us to estimate supplemental irrigation needs following transplanting. The objectives of this experiment were to 1) determine the rate at which landscape-size slash pine became established when provided with adequate irrigation, and 2) determine the influence of tree production method on establishment rate.

Material and Methods

In November 1987, 30 three year-old slash pines (*Pinus elliottii*) were planted from 3.8 liter (1 gal) plastic containers into 36 cm (14 in) fabric containers (Root Control, Stillwater, OK) placed in a field nursery and backfilled with native soil (Astatula, excessively drained fine sand). Thirty additional pines were planted directly into the same soil without a fabric container (field-grown). An additional 16 trees were planted into 57 liter (15 gal) plastic containers using a 55:36:9 (pine bark:peat:sand) container mix. Trees were grown for 2 yr with irrigation and fertilizer practices consistent with commercial nurseries.

In late November 1989, half the field-grown (15 trees) and half the fabric-grown pines (15 trees) were root pruned using a sharpened hand spade. Roots were pruned within the top 30 cm (12 in) of soil in a 25% circumference on both the east and west side of the root ball so that 50% of the total root ball circumference was pruned. Fabric-grown trees were root pruned just inside the fabric bag while field-grown trees were root pruned approximately 20 cm (8 in) from the center of the trunk.

In late January 1990, 11 of the 15 trees of each production method and root pruning treatment were transplanted into an Astatula fine sand within a kilometer (half mile) of the production site. Field-grown trees were transplanted with a three-shovel, 76 cm (30 in) diameter tree spade, adjusted to dig a root ball conforming to AAN (3) root ball diameter standards. Trees grown in fabric containers were dug with shovels and the fabric carefully removed at transplanting. Some soil was lost from the fabric-grown root ball during this process. Plastic container-grown trees were removed from the container and placed directly into the planting hole without disturbing the root ball. Backfill soil was washed into place at transplanting for all three methods. Trees were arranged on 2 m (6 feet) centers in a randomized complete block design.

Trees were irrigated daily after transplanting during the morning hours with 35 liters (9 gal) of water supplied through spray stakes (Aquaturret; Stuppy, Inc., N. Kansas City, MO). After 14 wk, irrigation frequency was reduced to every other day and the volume increased to 58 liters (15 gal), except after a rain of at least 1.25 cm (half inch). Control trees (which were not root pruned and not transplanted) were irrigated every other day throughout the experiment with 58 liters per tree except after moderate rainfall.

In March 1990 and during the late spring of 1991, regenerated roots on transplanted trees were harvested from 2 (1990) or 3 (1991) trees of each production method. Roots within a one-eighth pie section on the north and south sides (for a total of one-quarter of the entire root system) of each harvested tree were excavated and removed to the original root ball and separated into diameter classes of 0-1, >1-2, and >2-5 mm. Dry weight of roots in each diameter class was measured once a consistent oven dry weight was obtained. During excavation, the distance was measured from the trunk to the furthest root tip. Trunk diameter was measured 15 cm (6 in)above the soil at transplanting, again in March and August 1990, and January and July 1991.

Fascicle water potential was measured diurnally (measurements started before dawn and were made approximately every 2 hr until sunset) on 3 trees of each treatment on a weekly basis the first 12 wk after transplanting, then biweekly for 3 additional months, and finally monthly for the remainder of the experiment. Water potential was measured before dawn (pre-dawn) on the control trees each time it was measured on the transplanted trees, but diurnal measurements of fascicle water potential on the controls occurred only monthly. Water potential was measured on individual needle fascicles (13) with a pressure chamber (Model 3001, Soilmoisture Corp., Santa Barbara, CA) using compressed nitrogen increased at a rate of 2.5 kPa/sec. Resin covering the xylem was removed with 95% ethanol when required. Water potential was measured on one needle fascicle per tree taken from a sunny location at each 2-hr measuring period. Accumulative water stress was calculated for each diurnal curve by calculating the area above the curve to 0 MPa and then taking the absolute value (6). This permitted us to quantify the water status of each tree on a daily basis and make comparisons among treatments. Lower accumulative water stress values indicate lower water stress.

Analysis of variance among treatments was calculated for the factors of predawn and dusk fascicle water potential values and for accumulative water stress. Analysis of variance for each factor was calculated separately for each date as a randomized design of six treatments with each tree serving as a replicate. Where appropriate, means were separated using Protected LSD's (22).

Results

At transplanting, root-pruned field-grown trees had a larger trunk diameter than fabric-grown trees and all soil-grown trees were larger than trees grown in plastic containers (Fig. 1). One year after transplanting (Jan 1991), root-pruned field-grown trees were still larger in diameter than all other trees, but there were no differences in diameter between trees transplanted from fabric containers or from plastic containers. Eighteen months after transplanting (July 1991), differences in diameter among treatments were no longer significant. The rate of increase in trunk diameter was similar for both root pruned and unpruned trees within each production method for the growing seasons of Feb 1990 to Aug 1990, and Jan 1991 to July 1991. Rates of diameter increase ranged from 0.13 to 0.2 cm/month for soil-grown trees, and were significantly less than the 0.24 cm/month average for trees planted from plastic containers.

There were no significant differences calculated among treatments for root extension into the soil following transplanting or root dry weight at either root harvest. Though the trees had been transplanted only 10 weeks, maximum root elongation for all trees ranged from 37 cm (14 in) to 62 (24 in) cm away from the original root ball. By the spring of 1991, root extension from the original ball for all treatments ranged from 140 cm (55 in) to 194 cm (76 in). Though not statistically significant, 10 weeks after transplanting (March 1990) root-pruned field-grown trees had regenerated about three times the total root dry weight (43 g) of trees planted from fabric containers (15 g). Fabric-grown trees had regenerated twice the root dry weight of field-grown unpruned trees (8.6 g) or trees planted from plastic containers (7.6 g). By the spring of 1991, the dissimilarity in regenerated root mass among treatments was no longer evident.

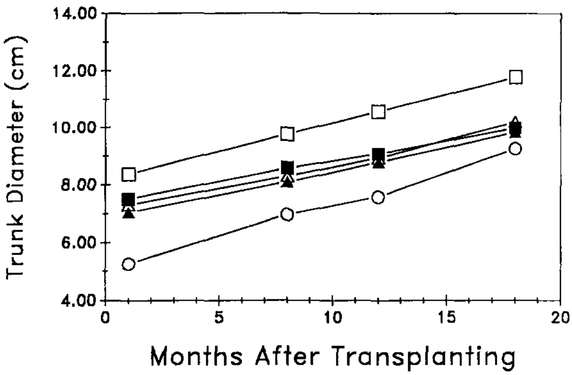

Figure 1. Mean trunk diameters at 15 cm above the soil for the five transplanted treatments measured after transplanting. Treatments consisted of field-grown trees root pruned (□) or not (■), in-ground fabric container-grown trees root pruned (Δ) or not (▲) and plastic container-grown trees (O). Each point is the mean of 10 trees.

For the first 6 weeks after transplanting, predawn fascicle water potential of all transplanted trees was significantly lower (more negative) than the control trees (Fig. 2). For the remainder of the study, differences in predawn fascicle water potential among treatments were not significant. During this early period, pre-transplant root pruning reduced the daily accumulated water stress slightly compared to non-root pruned trees, but this reduction was not significant. By 9 weeks after transplanting, there were no differences in the diurnal water relations between transplanted trees and control trees (Fig. 3). Predawn and dusk fascicle water potential, and S_Y were similar among treatments. This remained true for all soil-grown trees through the spring of 1991. However, when the frequency of irrigation was reduced to every other day 14 weeks after transplanting, pines planted from plastic containers were more stressed (significantly higher accumulative water stress) than control trees when measured on the days between irrigations (Fig. 4). Trees were irrigated on the day of measurement for 17 weeks after transplanting. Significant differences in S_Y between control and plastic container grown pines were found through 31 weeks after transplanting (Fig. 4), excluding weeks 17 and 27.

Discussion

Three criteria were used for determining tree establishment based on the diurnal water potential curves. Trees were considered established when differences in 1) accumulative water stress, 2) predawn fascicle water potential and 3) dusk fascicle water potential between nontransplanted control and transplanted trees were concurrently no longer significant. Though predawn and dusk

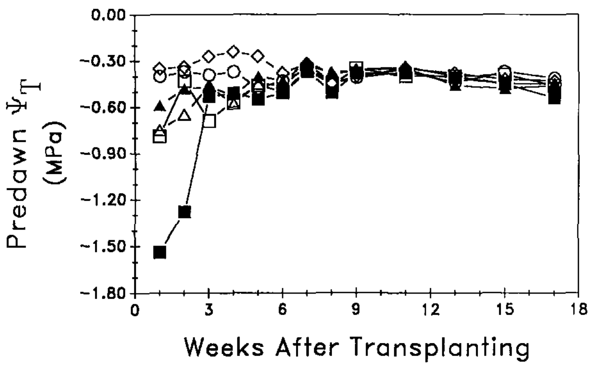

Figure 2. Predawn water potential measurements of the transplanted and control trees during the first 19 weeks after transplanting. Treatments consisted of field-grown trees root pruned (□) or not (■), in-ground fabric container-grown trees root pruned (Δ) or not (▲), plastic container-grown trees (O) and undisturbed control trees (◇). Each point is the

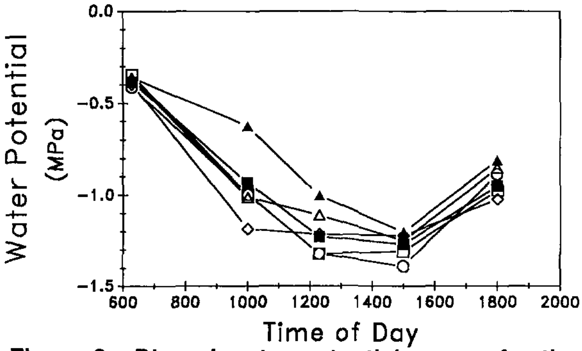

Figure 3. Diurnal water potential curves for the transplanted and control trees measured 9 weeks after transplanting. Treatments consisted of field-grown trees root pruned (□) or not (■), in-ground fabric container-grown trees root pruned (Δ) or not (▲), plastic container-grown trees (O) and undisturbed control trees (◇). Each point is the mean of 3 trees.

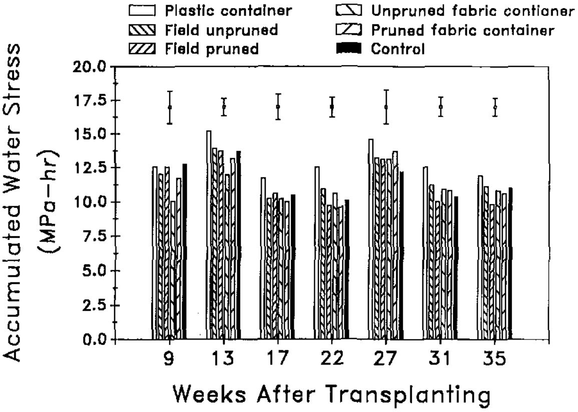

Figure 4. Accumulative water stress (S_Y) calculated at selected weeks after transplanting. The vertical line above each week represents the LSD (P=0.05) for each week. Each bar is the mean of 3 trees.

fascicle water potential may be similar between transplanted and nontransplanted trees, differences of duration of minimum fascicle water potential greatly influence the accumulative water stress calculated. Thus, accumulative water stress values are more sensitive indicators of diurnal water status than minimum fascicle water potential. High S_Y values indicate significant water stress for extended periods of time and suggest reduced photosynthesis and growth compared to plants with lower accumulative water stress values (6).

Root pruning prior to digging slightly reduced the amount of water stress measured during the first few weeks after transplanting compared to unpruned trees. Root pruning stimulates development of fibrous small-diameter roots prior to transplanting (11). Generation of small-diameter roots has been directly linked to reductions in water stress (19). The reductions in predawn fascicle water potential of the unpruned trees observed after 6 weeks were probably due to the regeneration of fine roots into the landscape soil.

Despite the slight reduction in water stress of root-pruned trees following transplanting, root-pruned trees appear to have established at the same rate as trees which were not root-pruned before transplanting. Gilman and Kane (12) also found that root pruning southern magnolia prior to transplanting had no lasting effect on growth after transplanting. Field production method also had little effect on establishment rate. The diurnal water relations of the fabric container-produced pines were similar to the spade-dug pines after the first few weeks.

Differences in the three criteria upon which establishment was judged were not significant between nontransplanted control and transplanted soil-grown trees beyond 9 weeks after transplanting. However, control trees were irrigated every other day, in contrast to daily irrigation through 14 weeks after transplanting for the transplanted trees. The most valid comparison between transplanted and nontransplanted control trees would be made on days when trees were not irrigated. Due to weather constraints, it was not always possible to make the measurements on days between irrigations. By restricting the criterion for establishment to those dates when measurements were made on days without irrigation, all soil-grown trees were established by 27 weeks after transplanting. This equates to about 2.5 months per inch trunk diameter (at 15 cm [6 in] above the soil) if irrigated as in this study. Establishment would probably take much longer if trees were subjected to greater water stress, as is the case with trees transplanted to most landscapes. Using the same criterion, trees planted from plastic containers were not established until 35 weeks after transplanting, about 4.5 months per 2.5 cm trunk diameter. Blessing and Dana (8) also reported more rapid and greater quantities of roots regenerated from transplanted field-grown juniper compared to those planted from plastic containers. Though trees planted from plastic containers had an intact root system, root exploration into soil was slower than from trees transplanted from the field and from fabric containers. Root exploration was apparently very crucial for establishing a favorable water balance. The lack of root exploration into the native soil would result in smaller soil volumes from which to extract water. This probably limited the amount of water available to the container-grown tree and explains the greater degree of water stress measured when irrigation frequency was reduced from daily to every other day. Lower fascicle water potential (more water stress) also may have resulted from bulk transfer of water from the container ball to the surrounding soil due to differences in soil texture (18, 20). Observations during the study confirmed that container root balls were often dry whereas the soil immediately adjacent to the ball was moist, even several hours following an irrigation.

Tree establishment has been defined as the point when shoot growth resumes pre-transplant rates (26). Shoot growth in the beginning of the second growing season after transplanting (1991) was visually equivalent to the year prior to transplanting for trees grown in the field and in fabric containers. For plastic container-grown trees, shoot growth was as great or greater the second season than the year prior to transplanting. Such growth confirms that the trees were well established by one year following transplanting. Further evidence for establishment by this time comes from the equivalent diurnal curves among all transplanted and nontransplanted control trees in late Jan 1991 (about 12 months after transplanting) after tree irrigation had been temporary halted during a rainless period of 9 days (data not shown).

Based on our research, slash pines transplanted from field soil or from fabric containers established much quicker than trees planted from plastic containers when supplied with adequate irrigation. The rate of establishment for field-grown trees was the same as that for fabric-grown trees. With a good irrigation regime, slash pines of 7.5

cm (3 in) trunk diameter were established within a year after transplanting and then resumed pre-transplant shoot growth. They would probably thrive on rainfall alone, without further irrigation. Plastic container-grown pines took longer to become established after planting, but once established their growth rate was as great or greater than that of soil-grown trees.

The establishment rates reported here are much quicker than the year-per-inch-caliper suggested by Watson (26) and Gilman (11). We propose these differences may be accounted for by differences in the length of the period for root growth between the midwest and central Florida, between deciduous (Watson and Gilman) and evergreen species, and the intense irrigation trees in the current study received. Further study should evaluate the economics of quick establishment with intense irrigation following planting vs. the prolonged establishment period under less ideal irrigation. Perhaps the increased costs of intense irrigation may be offset by less mortality and healthier trees.

Literature Cited

1. Abod, S. A. and A. D. Webster. 1989. Root and shoot growth of newly-transplanted apple trees as affected by rootstock cultivar, defoliation and time after transplanting. J. Hort. Sci. 64:655-666.
2. Abod, S. A. and A. D. Webster. 1990. Shoot and root pruning effects on the growth and water relations of young *Malus*, *Tilia* and *Betula* transplants. J. Hort. Sci. 65:451-459.
3. American Association of Nurserymen. 1990. American standard for nursery stock.
4. Arnold, M. A. and D. K. Struve. 1989. Green ash establishment following transplant. J. Amer. Soc. Hort. Sci. 114:591-595.
5. Becker, C. A., G. D. Morz and L. G. Fuller. 1987. The effects of moisture stress on red pine (*Pinus resinosa*) seedling growth and establishment. Can. J. For. Res. 17:813-820.
6. Beeson, Jr., R. C. 1992. Restricting overhead irrigation to dawn limits growth in container-grown woody ornamentals through small increases in diurnal water stress. HortScience. (in press, October).
7. Bevington, K. B. and W. S. Castle. 1985. Annual root growth pattern of young citrus trees in relation to shoot growth, soil temperature, and soil water content. J. Amer. Soc. Hort. Sci. 110:840-845.
8. Blessing, S. C. and M. N. Dana. 1987. Post-transplant root system expansion in *Juniperus chinensis* L. as influenced by production system, mechanical root disruption and soil type. J. Environ. Hort. 5:155-158.
9. Chaves, M. M. 1991. Effects of water deficits on carbon assimilation. J. Exp. Bot. 42:1-16.
10. Driessche, R. Van Den. 1987. Importance of current photosynthate to new root growth in planted conifer seedlings. Can. J. For. Res. 17:776-782.
11. Gilman, E. F. 1990. Tree root growth and development. II. Response to culture, management and planting. J. Environ. Hort. 8:220-227.
12. Gilman, E. F. and M. E. Kane. 1990. Growth and transplantability of *Magnolia grandiflora* following root pruning at several growth stages. HortScience 25: 74-77.
13. Johnson, N. E. and D. G. Nielsen. 1969. Pressure chamber measurements of water stress in individual pine fascicles. For. Sci. 15:452-453.
14. Kramer, P. J. and T. T. Kozlowski. 1979. Physiology of woody plants. Academic Press, NY. p. 881.
15. Kozlowski, T. T. and W. J. Davies. 1975. Control of water balance in transplanted trees. J. Arboric. 1:1-10.
16. Kuhns, M. R. and D. H. Gjerstad. 1988. Photosynthate allocation in loblolly pine (*Pinus taeda*) seedlings as affected by moisture stress. Can. J. For. Res. 18:285-291.
17. Lyr, H. and G. Hoffman. 1967. Growth rates and growth periodicity of tree roots. Intern. Rev. For. Res. 2:181-236.
18. Matheny, N. P., R. W. Harris and J. L. Paul. 1979. Irrigation requirements of transplanted container-grown plants. Proc. Intl. Plant Prop. Soc. 29:82-90.
19. Nambira, E. K. S., G. D. Bowen and R. Sands. 1979. Root regeneration and plant water status of *Pinus radiata* D. Don seedlings transplanted to different soil temperatures. J. Exp. Bot. 30:1119-1131.
20. Nelms, L. R. and L. A. Spomer. 1983. Water retention of container soils transplanted into ground beds. HortScience. 18:863-866.
21. Roberts, B. R. 1964. Effects of water stress on the translocation of photosynthetically assimilated carbon-14 in yellow-poplar. in The Formation of Wood in Forest Trees. Ed. M. H. Zimmerman. Academic Press, NY. pp. 273-288.
22. Snedecor, G.W. and W.G. Cochran. 1980. Statistical Methods, Seventh Ed. Iowa State University Press. Ames, IA. p. 507.
23. Teskey, R. O. and T. M. Hinckley. 1981. Influence of temperature and water potential on root growth of white oak. Physiol. Plant. 52:363-369.
24. Timmer, V. R. and G. Armstrong. 1989. Growth and nutrition of containerized *Pinus resinosa* seedlings at varying moisture regimes. New For. 3:171-180.
25. Witherspoon, W. R. and G. P. Lumis. 1986. Root regeneration of *Tilia cordata* cultivars after transplanting in response to root exposure and soil moisture levels. J. Arboric. 12:165-168.
26. Watson, G. W. 1985. Tree size affects root regeneration and top growth after transplanting. J. Arboric. 11:37-40.

Assist. Prof.
Central Florida Research and Education Center - Sanford, IFAS
2700 E. Celery Ave.
Sanford, FL 32771
and
Assoc. Prof.
Department of Environmental Horticulture
IFAS, Univ. of Florida
Gainesville, FL 32611, respectively

Résumé. Des semis de pin d'Elliot (*Pinus elliottii*) étaient transplantés depuis des contenants de 3.8 L vers soit, directement dans le sol, en contenants enterrés dans le sol, en contenants de plastique de 57 L. Après deux ans, les arbres étaient déterrés et retransplantés sur un nouveau site en pépinière. Huit semaine précédent la seconde transplantation, la moitié des arbres qui étaient en pleine terre furent l'objet d'un cernage des racines. Le potentiel en eau était mesuré sur les faisceaux d'aiguilles sur une base diurne au moins mensuellement après la transplantation. En étant basé sur des courbes de potentiel en eau d'arbres-contrôle non transplantés, les arbres qui étaient transplantés de la pleine terre ou des conteneurs enterrés se rétablissaient après 27 semaines. Les arbres plantés de conteneurs en plastique exigeaient une période de 35 semaines pour s'établir.

Zusammenfassung. Kiefern-Sämlinge (*Pinus elliottii*) wurden aus 3,8 l Kunststoffbehälter direkt in die Erde, in Stoffbehälter mit Erde oder in 57 l Kunststoffbehälter umgepflanzt. Nach 2 Jahren wurden die Bäume ausgegraben und an einer neuen Stelle innerhalb der Baumschule umgepflanzt. Acht Wochen nach der zweiten Umpflanzung wurde die Hälfte der Bäume, die in Erde gewachsen waren, an den Wurzeln zurückgeschnitten. Nach der Umpflanzung wurde das Wasserpotential von einem Nadelbündel (jeweils eine Tagesdosis) mindestens einmal monatlich gemessen. Im Vergleich zu Wasserpotentialkurven von nicht umgepflanzten Kontrollbäumen benötigten Bäume, die aus Felderde oder aus Stoffbehältern umgepflanzt worden waren, 27 Wochen um wieder das normale Potential zu erreichen. Bäume, die aus Plastikbehältern kamen, benötigten hingegen 35 Wochen.