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The Horhizotron™: A New Instrument for Measuring Root Growth

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SUMMARY. **Root growth following transplanting allows a plant to exploit water and nutrient resources in the soil backfill (landscape) or container substrate and thus is a critical factor for transplant survival. The Horhizotron, a horizontal root growth measurement instrument, has been developed and evaluated for use in measuring root growth under a variety of root environments. The design of the Horhizotron includes four wedge-shaped glass quadrants that extend away from a plant's root ball allowing measurement of roots as they grow out from the original root ball. The substrate in each quadrant can be modified in order to evaluate the effect of substrate or root environment on root growth. Materials used for construction were lightweight, durable, easy to assemble, and readily available from full service building supply stores. Units were suitable for use on a greenhouse bench or outdoors in contact with the ground. Horhizotrons provided a simple, nondestructive method to measure root growth over time under a wide range of rhizosphere conditions.**

Although frequently excluded from data collection and analysis in horticultural research, root growth and root system architecture are important factors influencing plant performance and survival. Of the factors affecting establishment of container-grown ornamental plants, root growth following transplanting is one of the most important (Watson and Himelick, 1997). Exploitation of the surrounding landscape soil or container substrate is critical for the plant to obtain water and mineral nutrients needed for healthy growth and development. Time to initiation of new root growth is important in predicting or describing transplant success, since initiation of new root growth shortly after transplanting has been correlated with successful transplant establishment (Woods, 1959). Understanding genetic and environmental factors as well as planting and cultural techniques that improve root growth could potentially improve landscape establishment of container-grown ornamental plants which would have a positive economic impact on the landscape industry.

Following transplanting into the landscape, the majority of plant roots initially grow horizontally into the soil, substrate, or backfill (Perry, 1982). Many techniques have been developed to measure root growth (Bohm, 1979). However, in the past most methods focused on the vertical distribution of roots through the soil. Traditional below-ground rhizotrons may allow observation of some lateral growth, however they are expensive and may be difficult to construct (Huck and Taylor, 1982). Trench-profile and core methods describe vertical distribution and root length and number but are destructive (Vepraskas and Hoyt, 1988). Sophisticated mini-rhizotrons that utilize small cameras and underground tubes are expensive and provide information only on a limited number of roots (Bohm,1979; McMichael et al., 1992).

Some container-type rhizotrons have been developed using clear plastic walls, but these do not allow measurement of horizontal root growth away from the original root ball into the surrounding soil or substrate (advancement of the root growth "front"). A unique technique that utilized a three-sided container made of glass was used to study the relationship between root and shoot growth (Frohlich and Dietze, 1970), however, a clear picture of the direction of root growth could not be determined. Other container methods involve destructive sampling of root systems either at the end of the experiment (limited information) or several times throughout an experiment (labor intensive) (Wright et al., 2004).

Other less traditional methods for measuring root growth have been examined, but have limitations. Use of dye for the purpose of staining and thus distinguishing between new and old roots requires that plants be removed from their substrate to track root growth (Arnold and Young, 1990; Wright et al., 2004). Computerized and digital image analysis techniques are frequently destructive and may only measure total length of all roots combined and may not describe root architecture and distribution in the soil (Wright et al., 2004). Connecting pot techniques have been used to apply different root-zone treatments to the same plant (Whitcomb et al., 1969), but these require multiple pots per experimental unit and do not simulate the natural distribution of roots in the soil.

Improved understanding of root growth and the factors that affect it is critical in the development of landscape strategies that improve survival of difficult-to-transplant species. There is a need to develop a technique that can easily monitor horizontal root

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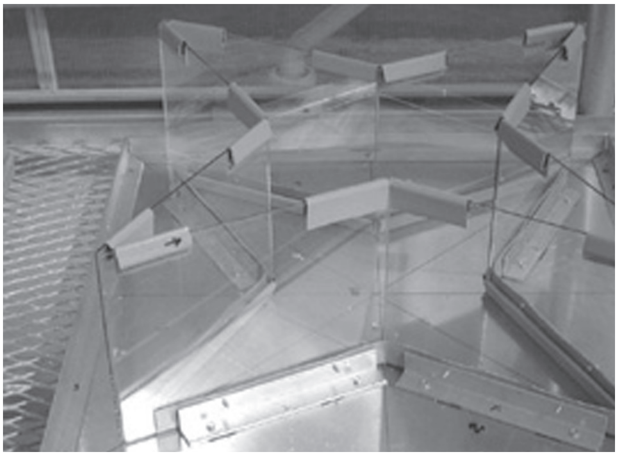

Fig. 1. Horhizotron quadrants are constructed from glass panes connected by vinyl j-channels and are attached to an aluminum base. These quadrants intersect and extend outward from the container root ball. The base is secured to a frame constructed from treated wood.

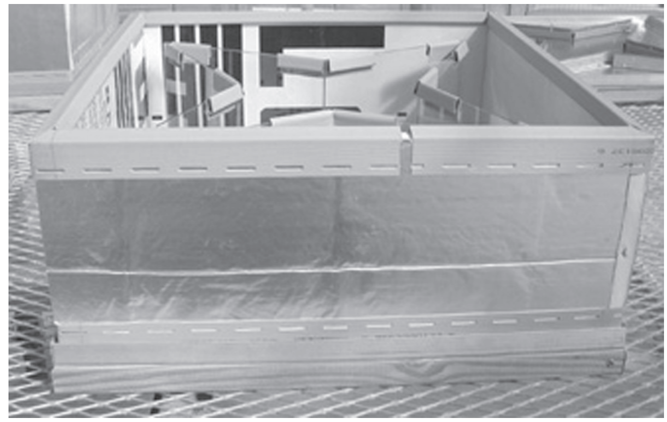

Fig. 2. Exterior walls of the Horhizotron are constructed from foam insulation board and are connected on top and bottom by vinyl j-channels.

growth under a wide range of soil, environmental, and plant conditions. The Horhizotron (horizontal root growth measurement instrument), a technology recently developed cooperatively at Auburn University and Virginia Tech, provides a simple, non-destructive method to measure root growth over time in a wide range of root environments. This paper describes construction criteria for the Horhizotron and procedures used to monitor root growth under experimental conditions.

Materials and methods

Horhizotron prototypes were built to confirm their potential for measuring root growth. The design of the Horhizotron allows a plant (removed from its container) to be fitted within eight panes of glass that extend away from the root ball to form four wedge-shaped quadrants around the original root ball. An overhead view of the instrument (Fig. 1) shows the four quadrants in the shape of a star as they extend outward. Substrate in each quadrant can be modified in various ways (chemically, physically, etc.) to study the effects of different rhizosphere conditions on root growth.

Quadrants were constructed from 1/8 inch (3.2 mm) thick glass panes [8 × 10.5 inches (20.3 × 26.67 cm)] held together on the top and bottom with vinyl j-channels (Fig. 1). The bottom j-channel was connected to 1-inch (2.5 cm) angle aluminum that was attached with self-tapping screws to a 2 ft × 2 ft × 1/8 inch (0.6 m × 0.6 m × 3.2 mm) aluminum base in a configuration forming the wedge-shaped quadrants. The aluminum base was attached to a wooden frame constructed from 2 × 2-inch (5.1 cm) treated lumber (Fig. 1). To exclude light from and provide insulation against dramatic temperature fluctuations for the root system, exterior walls were constructed from 3/4 inch (19.1 mm) thick foam insulation board (aluminum foil on outside and plastic on inside). Four foam insulation boards [24 × 10 inches (61.0 × 25.4 cm)] were assembled together in one unit by connecting with top and bottom vinyl j-channels, and the walls were held in place on the aluminum base by a rim constructed from 1-inch angle aluminum attached to the perimeter of the base (Fig. 2).

Horhizotrons for outdoor use were constructed by eliminating the wood frame and aluminum base and placing the connected glass quadrants directly on the ground (Fig. 3). The unit was stabilized on the ground by driving four 0.39-inch (1 cm) concrete reinforcing bars into the ground at the inner intersection of the glass plates. Exterior wall units for outdoor use were made as described above and placed directly on the ground around the glass quadrants (Fig. 4). Upper lids for all Horhizotrons (indoors and outdoors) were fitted inside each box and consisted of two sections of foam insulation board, each with a portion cut out to expose the substrate surface immediately around the plant stem, and allow for easy removal of the lids (Fig. 4).

Preliminary trials to study plant growth and techniques for root measurement in Horhizotrons were conducted. A ‘Green Beauty’ boxwood (*Buxus microphylla*) plant removed from a 1-gal (3.8 L) container and a ‘Olympic Wedding’ mountain laurel (*Kalmia latifolia*) plant removed from a 5-gal (18.9 L) container were each situated in the center of separate Horhizotrons with the root ball in contact with the inner points of the wedge-shaped quadrants. Each quadrant surrounding the boxwood plant was filled with a pine bark substrate amended with 6 lb/yard^3 (3.6 kg·m^3) dolomitic limestone and 1.5 lb/yard^3 (0.89 kg·m^{-3}) Micromax (Scotts-Sierra, Marysville, Ohio). Quadrants surrounding the mountain laurel were filled with unamended pine bark. Substrates in Horhizotrons of both taxa were top-dressed with 1.8 oz (50 g) of 15N–3.9P–9.8K Osmocote Plus (Scotts-Sierra), distributed evenly over the surface of the root ball and all quadrants. Boxwood and mountain laurel plants were grown at Virginia Tech and mountain laurel plants were grown at Auburn University in a greenhouse from May to Aug. 2003 at day/night temperatures of approximately 78.8/69.8 °F (26/21 °C). Additional plants of mountain laurel were placed in Horhizotrons constructed outdoors at Virginia Tech and grown over the same period of time. Quadrants in outdoor Horhizotrons were filled with pine bark, and Osmocote Plus fertilizer was applied as described above. All plants were hand watered as needed so that the original root ball as well as the quadrants remained moist.

Fig. 3. Horhizotrons were constructed for outdoor use by assembling quadrants directly on the ground and eliminating the aluminum base and wood frame.

Fig. 4. Exterior walls of Horhizotrons assembled outdoors were placed directly on the ground. The upper lid shown has portions cut out to expose the substrate surface immediately around the plant stem (same lid as for Horhizotrons used indoors).

Results and discussion

Horhizotron prototypes provided a simple yet effective method for measuring root growth. As roots grew away from the original container ball into the different quadrants, they intersected and grew along the glass panes of each quadrant. As these new roots grew, their progression along the glass panes was measured. Root growth rates were determined by measuring weekly the length of the five longest roots on each of the two sides of a quadrant. Root growth measurements from the two glass surfaces of each quadrant were averaged to obtain the experimental value for that quadrant. For statistical analysis purposes, the experimental design would be a randomized complete-block design with each Horhizotron representing one block (replication) and up to four different substrates or substrate treatments distributed randomly among the four quadrants. It is assumed that each individual plant will be affected by all substrate treatments within a Horhizotron simultaneously. Unlike traditional root growth studies, where individual plants are exposed to separate rhizosphere conditions, all plants used in an experiment employing Horhizotrons will be grown under similar conditions, decreasing the potentially confounding effect that plant stress could have on root growth. Thus, because all plants in a given experiment are in the same "health," effects of a substrate treatment on root growth may indeed be isolated.

Although the root systems of mountain laurel (extremely fine) and boxwood (coarse) are quite different, time to new root growth initiation following transplanting, rate, duration, and direction of root growth, and the total length of roots of both taxa were easily measured. Root growth of 'Olympic Wedding' mountain laurel primarily occurred parallel to the substrate surface, while 'Green Beauty' boxwood roots grew at a –45° angle with respect to the substrate surface (Fig. 5). A transparent grid placed against each glass pane was helpful for quantifying root distribution and location on that surface and allowed for comparison of root system architecture between the two taxa. The surface of each quadrant may also be photographed, with digital or computer analysis used subsequently to quantify root growth. Frequency of root growth measurements depends on the rate of root growth as influenced by taxa and in the future will also likely depend on

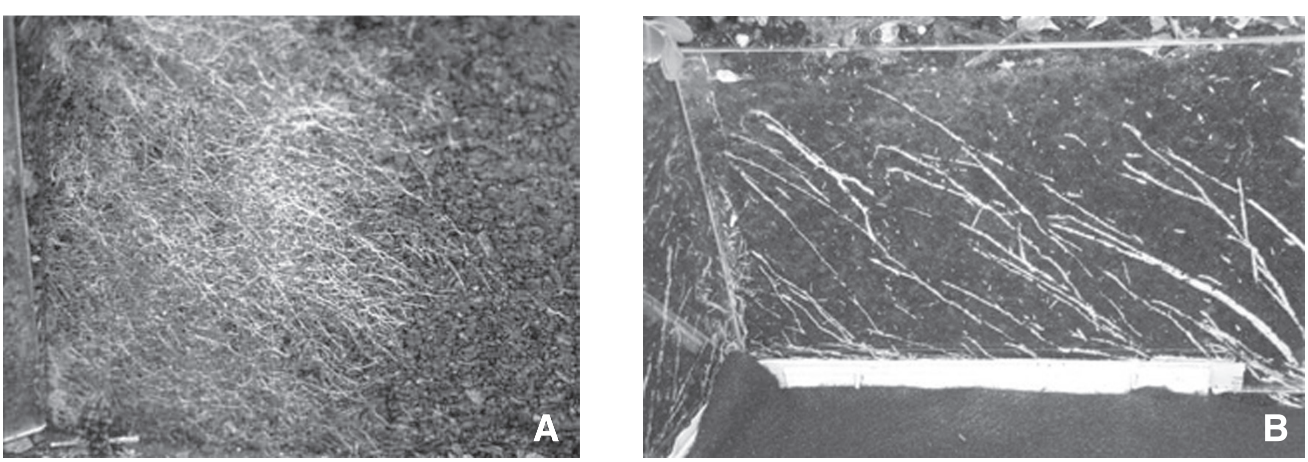

Fig. 5. Root system architectures of (A) mountain laurel (glass panes removed) and (B) boxwood are visible after 3 months in a Horhizotron.

experimental treatments. With the two taxa mentioned here, weekly measurements were adequate for greenhouse- and field-grown plants. Roots grew 4 to 6 inches (10.2 to 15.2 cm) over a 2–3 month period—a rate of about 2.5 inches per week. New root growth for all plants was measurable after four weeks. Contact between the ground and the substrate in Horhizotrons installed outdoors simulated naturalistic conditions (drainage, temperature, moisture, and earthworm and insect colonization) for root growth within each quadrant.

In recently constructed prototypes, dimensions used were suitable for plants in 1-, 3-, or 5-gal (3.8-, 11.4-, or 18.9-L) containers, however, the technique may be used for any size plants by adjusting the position and size of the quadrants to accommodate smaller or larger root balls. The length and width of each unit [2 × 2 ft (0.6 m)] was suitable for use in the greenhouse (several Horhizotrons can fit on a single greenhouse bench), making year-round experimentation possible; they may also be used outdoors to provide a description of seasonal root growth. The wood frame base allowed for easy lifting and movement of the Horhizotron on a greenhouse bench. Handles may also be attached to the sides of the wood frame for ease in carrying. Because the intersection of the quadrants with the base was not sealed, drainage of the substrate in each quadrant occurred easily, however holes may also be drilled under each quadrant to facilitate drainage. Exterior walls, which provided protection for the root system from light and temperature fluctuations, could be lifted from the Horhizotron simultaneously as a unit for easy root examination. Materials used for construction were durable (withstood daily irrigation over several months), lightweight, and easy to disassemble, clean, and reassemble for use in subsequent experiments. All materials used for construction were available at full service building supply stores, and the cost of materials was less than $50.00 per Horhizotron constructed. To provide a sturdy yet convenient design for the Horhizotron, different materials and methods of assembly will continue to be evaluated to ensure maximum utility and durability.

The Horhizotron provides a simple, non-destructive method to measure root growth under a variety of rhizosphere conditions. Observing root growth away from the original root ball and along the glass panes was similar to observing the advancement of the root "front" or the rate and direction of root growth into the surrounding backfill (landscape) or container substrate. Additionally, the ease with which the root environments were manipulated (modifying the environment of each quadrant in greenhouse or outdoor environments) suggests that this technique will have broad application for use in horticultural research. Future reports by these authors will present data of studies currently underway using Horhizotron technology.

Other possible experiments using the Horhizotron are numerous and include research on soil or substrate chemical and physical properties; seasonal root growth periodicity; effect of plant root:shoot ratio, plant nutrition, and time of transplanting on landscape establishment; effects of plant growth regulators, herbicides, allelopathy, and other chemical treatments on root growth; effect of drought and root-zone temperature in root growth; root growth comparisons between cultivars, species, and provenances; interactions between insect pests and root growth; mycorrhizal studies; and propagation techniques. Because of the importance of root growth for transplant establishment in the landscape, as well as the growth and development of all types of plants, this technology will be useful for research on horticultural crops (ornamental woody trees and shrubs, ornamental herbaceous perennials and annuals, and vegetable and fruit crops) as well as forestry, turf, and agronomic crop species.

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