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A TWO-PLANE INTERNALLY IRRIGATED ROOT OBSERVATION SYSTEM FOR FOREST NURSERY STOCK

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The capacity of forest nursery stock to produce new roots when field planted has long been recognized a factor in subsequent survival and growth. The potential for this new root growth usually has been measured in a controlled environment such as a greenhouse or growth chamber. Traditionally, root growth measurements have been made of seedlings transplanted to pots; new root lengths that have developed over a 4- to 8-week period then are measured (Webb 1977, Stone and Schubert 1959, Farmer 1975). However, this approach does not permit the simultaneous evaluation of root and shoot growth, and thus time-dependent root-shoot interactions. Our research on oak (*Quercus* spp.) nursery stock indicates that timing as well as amount of root growth relative to initial shoot growth after field planting may be a factor governing future growth and survival (Johnson 1979). Time-dependent root-shoot relations may be particularly important in hardwoods exhibiting periodic shoot elongation (Borchert 1975).

Root observation chambers offer a solution to the problem of simultaneously observing root and shoot development. Although many root observation techniques have been developed, most rely on the positive geotropic response of roots which forces them to grow along a sloping transparent surface (Murdoch *et al.* 1974, Lonkerd and Ritchie 1979). For studying forest nursery stock, slopes of root observation chambers have generally been 30° or less from vertical, with the entire seedling tilted to this angle (Larson 1962).

We designed a root observation chamber specifically for forest nursery stock that also uses a sloping transparent surface. However, our system has two other important features. First, the detachable planter (upper) section of our system maintains the transplanted seedling in a normal vertical plane; only the newly regenerated roots grow against the slanted (60° from vertical) plexiglass root observation plane. The 60° angle assures that most new roots will be observable through the plexiglass. Second, the root observation (lower) section is internally irrigated throughout its length to facilitate uniform moisture distribution. Details of the design, construction, and use of this root observation system are described below.

SYSTEM DESCRIPTION

Materials and Construction

The root observation system consists of two components: (1) an upper vertical section (planter) that accommodates a seedling with a root system up to 23 cm long and the potting medium, and (2) a lower root observation section sloped 60° from vertical that contains the rooting medium and irrigation tubing (fig. 1).

Both components can be constructed of 3 mm (0.10 in.) transparent plexiglass mounted on strips of 19 by 19 mm (¾ by ¾ in.) pine. However, thinner and less expensive clear styrene sheeting 2 mm (0.08 in.) thick can be substituted for all or part of the plexiglass components. We used the more expensive plexiglass only for the root observation window, i.e., the bottom of the lower section. However, to simplify

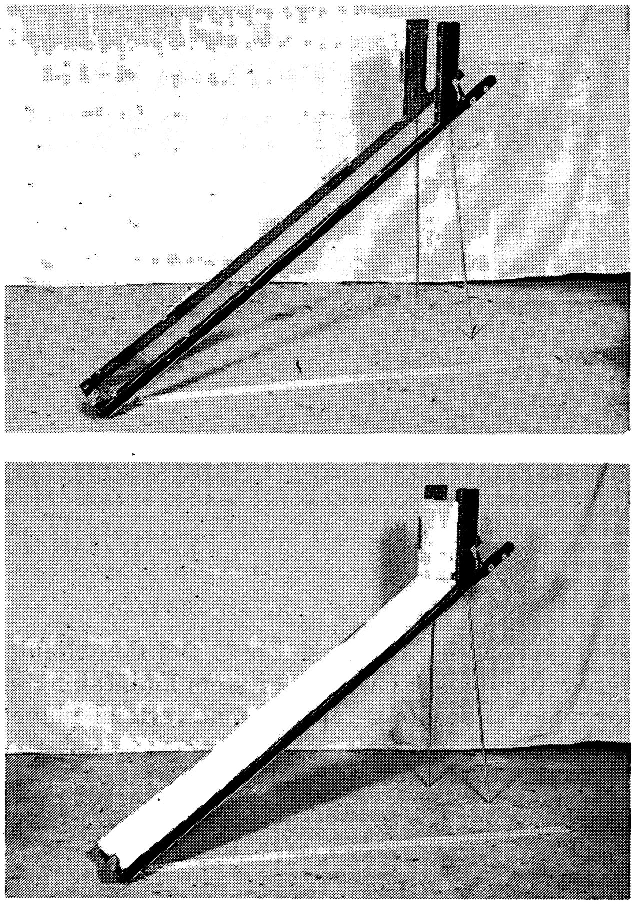

Figure 1.—*Root observation chamber constructed of plexiglass and wood (a); with styrofoam insulation shields in place (b).*

further description, both materials will be referred to as plexiglass. Most of the plexiglass pieces can be cut on a table saw with a fine-toothed blade. Round-head #6 screws 1.9 cm (¾ in.) long fitted with washers 1.2 cm (½ in.) in diameter were used throughout.

The planter section is constructed of four pieces of plexiglass mounted on four strips of pine. The front plate is 13.8 cm (5½ in.) wide by 23.5 cm (9¼ in.) high. The back plate is the same width, but 21.8 cm (8⅝ in.) high. The two side plates are 5.0 cm (2 in.) wide by 23.5 cm (9¼ in.) high at the front and 21.8 cm (8⅝ in.) high at the rear. The bottom edge of each side plate is cut at an angle of 30°.

Each side plate is mounted on the inside of the two pine strips with screws. The front and rear edge of each side plate is framed with the pine strips which are cut at a 30° angle on their bottom ends so they parallel the edges of the side plates. The front and back plates are then attached to form a box with interior measurements of 5.0 cm (2 in.) by 9.7 cm (3⅞ in.) and a maximum depth of 23 cm (9⅛ in.). The interior volume of the planter is approximately 1067 cc (65 in.^{3}) (fig. 2).

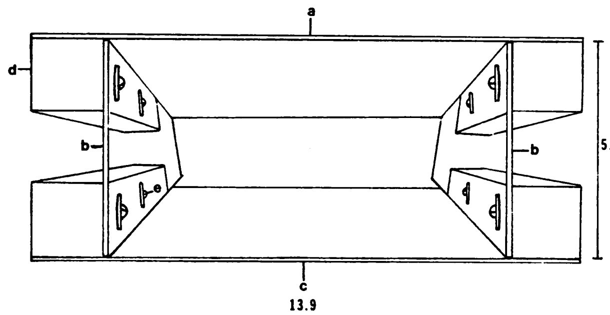

Figure 2.—*Top perspective of planter section—a. plexiglass back plate; b. plexiglass front plate; c. plexiglass side plate (2); d. 19 by 19 mm (¾ by ¾ in.) pine strip; e. 19 mm (¾ in.) #6 screws fitted with 16 mm (½ in.) diameter washers (dimensions are in cm).*

The root observation section is constructed of two plexiglass plates which also are mounted on pine strips. The top plate is 101.6 cm (40 in.) long and 13.8 cm (5½ in.) wide. The bottom plate (root observation window) is 121.9 cm (48 in.) long and 13.8 cm (5½ in.) wide. These two plates are mounted with screws on two parallel side stops 121.9 cm (48 in.) long and a 10 cm (4 in.) long stop across the bottom. Screws are spaced 15 cm (6 in.) apart when using the heavier plexiglass and about half this distance when the styrene is used.

The bottom pine strip has eight 3 mm (⅛ in.) holes drilled through it for water drainage and a 1.6 cm (⅝ in.) hole at the center of its length to accommodate the irrigation tubing (fig. 3). Twelve additional 3 mm (⅛ in.) water drain holes were drilled in the bottom plate within 2 cm of its lower end. The interior volume of the root observation section from the upper edge of the top plate to the bottom of the chamber is approximately 1932 cc (118 in.^{3}). The viewing surface for observing root growth is 10 cm (4 in.) by approximately 1 m (40 in.).

Prior to assembling the root observation chambers, the wood components can be treated with a wood preservative such as copper napthanate; pentachlorophenol should not be used because it is extremely phytotoxic.

The two components are fastened together by a pair of 8.9 cm (3½ in.) flat metal corner braces and six screws (fig. 4). A sheet of styrofoam 1.9 cm (¾ in.) thick was placed over the top plate of the root observation section to provide insulation from direct

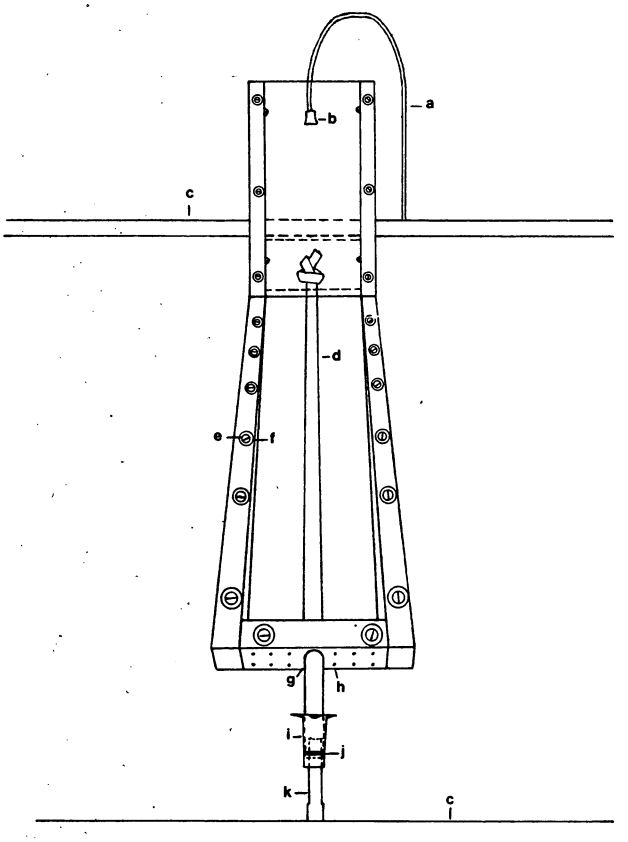

Figure 3.—*End perspective of the complete root observation chamber showing irrigation system—a. 1.5 mm (0.05 in.) inside diameter Chapin Leader Tubing; b. drop-in weight; c. 1.9 cm (3/4 in.) PVC main water line; d. 1.5 cm (0.60 in.) Viaflo tubing; e. 19 mm (3/4 in.) #6 screw; f. 13 mm (1/2 in.) diameter washer; g. 16 mm (5/8 in.) hole in bottom pine stop for Viaflo tubing; h. 3 mm (1/8 in.) drain hole; i. Viaflo cone connector; j. o-ring; and k. feeder tubing.*

sunlight. Styrofoam was held in place by 6.4 cm (2½ in.) long sections of 2.5 cm (1 in.) wide galvanized drywall corner bead. A shorter piece of styrofoam was similarly held in place on the planter wall with south exposure (fig. 1b). Over the insulation, extra heavy duty aluminum foil was wrapped around both upper and lower components to keep the growth chamber dark and to reflect solar radiation. The foil over the root observation window was removed for periodic measurements.

To irrigate the root observation section, we used DuPont Viaflo[1] irrigation tubing.[2] This tubing is made from a ribbon-like porous plastic that inflates under pressure and allows the slow passage of water through micron-size pores in the tubing wall. Flow rate for the 1.5 cm (0.60 in.) diameter tubing is about 2 liters per minute (3 gpm) per 300 m (1,000 ft.) of tubing. The tubing requires line pressures of 21 to 34 kPa (3 to 5 psi). This low pressure requirement ordinarily will necessitate the installation of a pressure regulator and gauge on the main irrigation line.

Connecting the irrigation tubing to a main line can be done with connectors designed for the Viaflo system which include a connector cone, o-ring, and feeder tube (fig. 3i, j, k). If the main water line is constructed of PVC, the feeder tube can be inserted directly into it by cutting a hole 9 mm (3/8 in.) in diameter in the PVC; the insertion hole should be drilled with a tapered bit available for this purpose. To minimize the amount of feeder tubing needed, we installed a 1.9 cm (3/4 in.) PVC main water line about 10 cm (4 in.) from the lower end of the root observation section (fig. 3); this main line could then be used to service a series of chambers.

After connection to the main line, the irrigation tubing is inserted through the tubing hole in the pine strip of the bottom of the root observation section (fig. 3g) and extended up to and under the base of the back plate of the planter section. Because the tubing is ribbon-like when not inflated, it can be slipped between the bottom of the planter's back plate and the inside of the root observation window. About 15 cm (6 in.) of tubing should extend beyond (above) the back plate wall of the planter section; a half-hitch knot was used to stop water flow out this free end of the tubing.

The planter section was irrigated with 1.5 mm (0.06 in.) inside diameter Chapin Leader Tubes[1] with "drop-in" weights. The leader tubes were connected to a 1.9 cm (3/4 in.) PVC main line that rested on the pine strips of the observation section (fig. 3). This irrigation line was used periodically to apply a complete nutrient solution via a nutrient proportioner and an automatic timer system; it was independent of the Viaflo system which was connected to a separate timer system.

Materials cost (1980) per growth chamber, with 2 mm (0.08 in.) styrene substituted for plexiglass for all but the root observation window, was approximately $12; this includes all materials except the irrigation system components. Construction time per growth chamber unit was approximately one man-hour.

[1]*Mention of trade names does not constitute endorsement of the product by the U.S. Department of Agriculture, Forest Service.*

[2]*This product is no longer available but similar products are available from other manufacturers.*

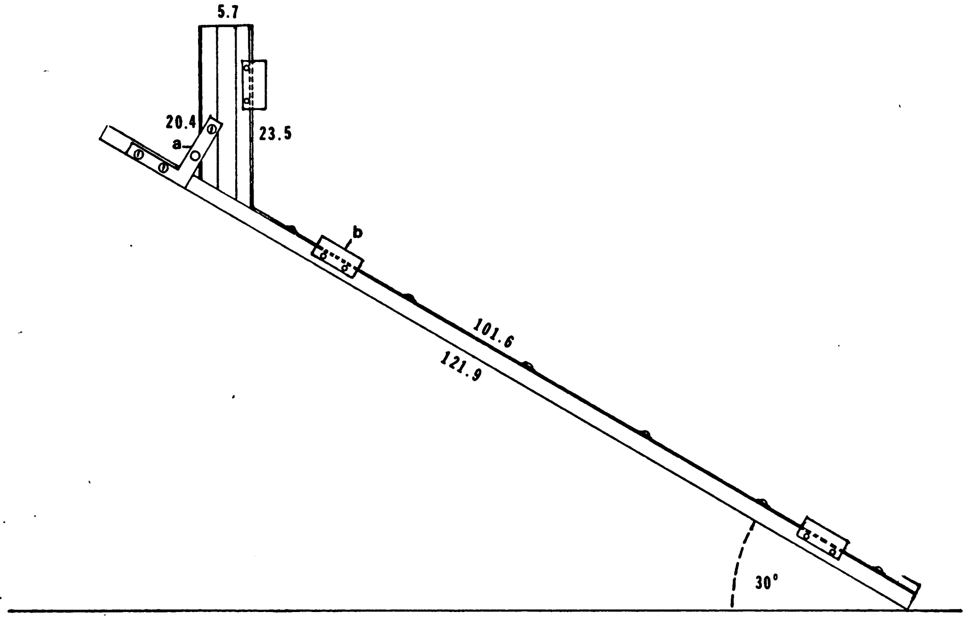

Figure 4.—*Side view of root observation chamber—a. 8.9 cm (3½ in.) flat metal corner brace; b. 2.5 cm (1 in.) wide drywall corner bead to hold styrofoam insulation in place (dimensions are in cm).*

Using the System

Almost any kind of potting medium can be used with the system, including soil. In our root growth studies, we found the commercially available mixtures of fine vermiculite and peat worked well. The root observation chamber can be filled through the planter section if the rooting medium is fine and dry; otherwise it may be better to fill the chamber with the planter section removed. When filling, the chamber can be lightly tapped on the floor to eliminate voids; while doing this, care should be taken to keep the Viaflo tubing centered. With wet potting materials or those that don't flow easily, filling may best be accomplished by laying the root observation section flat, removing the top plate, and evenly spreading the medium by hand.

To monitor temperatures inside the root observation section, we inserted thermistor probes through 6 mm (¼ in.) holes drilled through the sides of the pine stop. Soil moisture similarly could be monitored psychrometrically.

Bare-root seedlings must be root pruned to no more than 23 cm (9 in.) in length before they can be transplanted to the planter section. If longer roots are needed or desired, the planter section easily can be redesigned to accommodate them. In our work with oaks, we press all first-order lateral roots up to and parallel with the tap root with one hand, and then clip both the tap root and laterals at a point 20 cm below the root collar. Thus, the root pruning point for all major roots will be at the same depth when transplanted. In oaks and other tap-rooted species, practically all of the new root regeneration will originate at or near the point of root pruning. With containerized seedlings that have "air-pruned" roots (Tinus and McDonald 1979), no root pruning will be necessary; most new root regeneration after transplanting will occur at the tip of the root plug.[3]

When the seedling is transplanted to the root observation chamber, it should be positioned in the planter section so the lower tips of all pruned roots or the root plug just touch the inside of the root observation window. The point at which these roots meet the root observation window can then be marked on the bottom of the window with a strip of masking tape or a waterproof, fine-point, felt-tip marking pen. New roots then can be measured from this initial reference

[3]*An exception to this will occur when container stock is grown in containers with walls treated with a growth inhibitor. In tap-rooted species, this will create a tap root bearing very short first-order laterals that produce a "bottle-brush" root morphology (Burdett 1978).*

line. Roots can be measured until they reach the bottom of the root observation section. In our oak studies this has usually permitted an 8- to 10-week study period and allowed us to follow root growth through 2 or 3 flushes.

We devised a line intersection method for estimating total root lengths observable through the root observation window. To facilitate this, we used a strip of clear acetate 10 cm wide by 100 cm long. A series of parallel lines were drawn across the width of the strip at 1 cm intervals. These lines were made with a waterproof, fine-point, felt-tip marker and numbered consecutively from 1 to 100 (for measuring roots up to 1 m below reference line).

When root measurements were being made, the acetate strip was overlaid on the root observation window, and the top edge (zero line) aligned with the masking tape reference line. Starting at line number one on the acetate strip, the number of observable roots intersecting each line was recorded on 80 column computer code sheets. From these data entries, an estimate of total root length was calculated by summing the number of roots at each intersection. One-half cm was added to each root at its last (lowermost) intersection, based on the assumption that, on the average, roots will extend half the distance between the last intersection at which they were observed and the next line. This correction was not actually made during data recording, but was made in the data summary computer program. In this program, a "last" root intersection was identified whenever there was a decrease in the number of root intersections between consecutive lines from the reference line to the 100 cm line. This correction also was applied to the last (lowermost) observed intersection in a series. Computationally, total root length (TRL) was thus estimated as:

$$TRL = \Sigma[n_1 + 0.5(n_1-n_2) + n_2 + 0.5(n_2-n_3) + n_3 + 0.5(n_3-n_4) + \ldots$$
$$n_{99} + 0.5(n_{99}-n_{100}) + n_{100} + 0.5(n_{100})];$$

where TRL = estimated total root length (cm); n_1, n_2, n_3 .... n_{100} = number or roots (n) intersecting cm lines 1, 2, 3, ... 100; n_1-n_2, n_2-n_3, etc., are set equal to zero when their values are negative.

This method provides a relatively quick and precise way to estimate total root length *in situ*. However, the method assumes that roots are growing in a straight line at right angles to the intersection lines. These assumptions are fairly well met when the rooting medium consists of fine and low density materials like peat and fine vermiculite. When coarse or higher density materials are used, roots may kink and turn as they encounter resistance in the rooting medium. Under these conditions, the line-intercept technique described by Newman (1966) may be more appropriate because it does not assume that individual roots form a straight line or grow in any particular direction.

LITERATURE CITED

Borchert, Rolf. 1975. Endogenous shoot growth rhythms and indeterminate shoot growth in oak. Physiologia Plantarum 35(2):152-157.

Burdett, A. N. 1978. Control of root morphogenesis for improved mechanical stability in container-grown lodgepole pine. Canadian Journal of Forest Research 8(4):483-486.

Farmer, R. E., Jr. 1975. Dormancy and root regeneration of northern red oak. Canadian Journal of Forest Research 5(2):176-185.

Johnson, Paul S. 1979. Growth potential and field performance of planted oaks. p. 113-119. *In* Regenerating oaks in upland hardwood forests. J. S. Wright Forestry Conference Proceedings. H. A. Holt and B. C. Fischer, eds. Purdue University, Lafayette, Indiana.

Larson, M. M. 1962. Construction and use of glass-faced boxes to study root development of tree seedlings. U.S. Department of Agriculture Forest Service, Research Note RM-73, 4 p. U.S. Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Lonkerd, W. E., and J. T. Ritchie. 1979. Split root observation system for root dynamics studies. Agronomy Journal 71(3):519-522.

Murdoch, C. L., R. A. Criley, and S. K. Fukuda. 1974. An inexpensive method for the study of root growth in containers of solid media. Hortscience 9(3):221.

Newman, E. I. 1966. A method of estimating the total length of root in a sample. Journal of Applied Ecology 3(1):139-145.

Stone, Edward C., and Gilbert H. Schubert. 1959. Root regeneration by ponderosa pine seedlings lifted at different times of the year. Forest Science 5(4):322-332.

Tinus, Richard W., and Stephen E. McDonald. 1979. How to grow seedlings in containers in greenhouses. U.S. Department of Agriculture Forest Service, General Technical Report RM-60, 256 p. U.S. Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Webb, D. Paul. 1977. Root regeneration and bud dormancy of sugar maple, silver maple, and white ash seedlings: effects of chilling. Forest Science 23(4):474-483.

Johnson, Paul S., Charles W. Putnam, and William G. Mares.

1981. A two-plane internally irrigated root observation system for forest nursery stock. U.S. Department of Agriculture Forest Service, Research Paper NC-197, 6 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

A root observation chamber designed for forest nursery stock is described. The chamber consists of a lower root observation section and a detachable upper "planter" section, both constructed of plexiglass and wood; the lower section is internally irrigated by a porous irrigation tube and the upper section by a "leader tube."

KEY WORDS: Root chamber, root growth, root regeneration, rhizotron.

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