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I am submitting herewith a dissertation written by Dewayne LeBron Ingram entitled "Root Development and Establishment of Woody Ornamentals Grown in Containers." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

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ROOT DEVELOPMENT AND ESTABLISHMENT OF WOODY ORNAMENTALS GROWN IN CONTAINERS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Dewayne LeBron Ingram

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TO MY WIFE, PAT

who has been continually patient, supportive and encouraging.

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ABSTRACT

This study consisted of a series of experiments designed to establish the responses of plants grown in three container media to three container designs and various backfill compositions. One experiment was conducted to establish the effect of the media particle size on root development and distribution. There was a greater number of Ilex crenata 'Green Luster' roots in the inside and middle concentric areas of the bottom two-thirds of the peat-perlite medium than the other two media in a container of conventional design. There was a greater number of Ilex roots in the outside area of the pine bark-sand media than in the outside area of the other two media. Also in this container of conventional design the number of Juniperus horizontalis 'Plumosa' roots in the bottom depth zone of the pine bark-sand medium was greater than in this zone of the other two media. Vertical dividers in the bottom of the container increased the number of Ilex roots in the outside area of the peat-perlite medium. In the container with vertical dividers the Ilex roots were more evenly distributed through the areas of the depth zones of the soil-peat-sand medium.

Ilex crenata 'Green Luster' plants were grown in four media consisting of different particle sizes of sand. It was found that there was less of the total root system in the low two-thirds of the container media of the smaller sand particles than in the container media with large sand particles.

When Ilex crenata 'Green Luster' had been grown in the peat-perlite medium, the addition of peat-perlite to the backfill soil

increased the initial root growth through the backfill. After Ilex crenata 'Rotundifolia' and Juniperus horizontalis 'Blue Rug' had been transplanted into the landscape for 15 months there was no effect of container media, backfill composition, or container size on the dry weight of roots that had grown from the original container media.

The daily maximum temperatures were equal at the three locations in the three media at a high moisture content. When the media were dry, the maximum temperature at the top location was greater then at the other locations. The rate of temperature change from the daily minimum to the maximum was greater in the dry media than in the wet media at all locations.

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CHAPTER I

INTRODUCTION

The production of woody ornamental plants in containers has greatly increased in recent years. There are many advantages to this type of production, such as, lower labor requirements, more efficient utilization of production space, lower freight costs, easier marketing practices, improved plant quality achieved through appropriate treatment of individual plant species, and producing a salable plant in a shorter time (77, 97).

There are, however, some problems associated with the production of plants in containers. One of these problems concerns root development and root distribution in a containerized growing medium. Observations show the roots of container grown plants are often concentrated near the outside surface of the soil mass, while the inside of this container medium can be void of roots (43, 87). Therefore a portion of this already limited soil volume is not being utilized by plant roots.

The establishment of container grown plants into the landscape has become a great concern to nurserymen and homeowners alike (36, 55). Observations show that frequently roots do not readily move from the original container medium into the surrounding field soil when transplanted into the landscape (31). The plant is largely dependent upon the original container medium for moisture and nutrition until the roots extend into the field soil (19).

A series of experiments was designed to establish the effects of container media and container design on the root development and root distribution of woody ornamental plants grown in containers. The physical characteristics of these media and the temperature fluctuations at various locations in the container media were established in relation to the distribution and development of the roots. Plants were then transplanted into larger containers in order to establish the effects of the three media and container designs, and three backfill compositions on the initial root development and top growth. Plants were also transplanted into the landscape in order to establish the effects of three container media and two backfill compositions on the root development and top growth after 5 and 15 months.

CHAPTER II

REVIEW OF LITERATURE

Media

Container media are selected for their maintenance of adequate water and air relations, and to provide adequate nutrient ions in order to produce the most salable plant most economically (42). The media must be light weight for economical transport of the plants, but the media must be heavy enough to provide anchorage and physical support (27, 42).

Many materials have been used as components of media for container plants (4, 42, 71, 86). These amendments and their relative proportions must be selected in respect to the requirements of specific plant species and cultural practices desired (93). There is an infinite number of container media compositions that could be employed to produce high quality plants. The cultural practices required for optimum plant performance in these varied media are often very specific (72). The grower should select the media that require the least precise management practices (27). Many researchers have reported plant responses to fertility management in regard to different media (18, 20, 74, 115).

Almost any natural field soil in a container will become too wet and the plant will suffer from poor aeration, while a coarse medium may not hold enough moisture for optimum plant growth (90, 92, 94). Poole (74) reported that the infiltration rate and available water

increases in a field soil if amended with peat or wood shavings.

The potential of container media to support plant growth can be predicted by their physical and chemical properties (18, 42, 52, 73, 80, 100, 102, 107). Conover (18) reported that satisfactory media should have 10 to 20 percent air space after drainage and 35 to 50 percent water-holding capacity by volume. DeRoo (20), Furuta (27) and Paul and Lee (66) presented similar information. According to White (107), Joiner and Conover (42) and Conover (18) the single most important chemical characteristic for a medium is the cation exchange capacity.

The optimum bulk density is a compromise between a low bulk density for a light weight unit for shipping and a higher bulk density to make the unit more stable during production and marketing (10, 80, 100). The bulk density of container media composed of field soil is lowered by the addition of organic matter (53). Joiner and Conover (42) concluded that the most satisfactory level of organic matter in these media is 40 to 50 percent. White (107) stated that as bulk density increases, the porosity and percolation rates decrease. As the organic matter in the media is broken down through time into smaller particles, the bulk density increases (54).

Total porosity is important because of its influence on media aeration (27). Total porosity is the volume proportion of space not filled with solid particles when the medium is air dry (106). While porosity is strongly correlated to percolation rate (52), the nature of porosity of the media depends on the particle size and the state of aggregation, which affects the pore size distribution. Milbocker and

Elstrodt (60) concluded that a medium consisting of particles of 1/30-1/16 inch was best for proper aeration and water-holding capacity for plant growth when compared to media consisting of mixtures of four particle size fractions. Large pores contribute much to media aeration (7, 30). When small particles are added to a medium of larger particles, the pore space is reduced (71).

The size and distribution of pore spaces determine whether pores will be filled with air after irrigation and whether readily available water will be retained for the plant (7, 20, 44). DeRoo (20) defines readily available water as the water held between container capacity and 50 cm of tension. Pokorny (71) refers to this water as the water-holding capacity of the medium. Baver et al. (7) stated that a tension of 40 cm gave the best agreement between percolation rates and porosity. Richards (78) concluded that 30 cm of tension was a good index to evaluate the moisture relations of a medium. In an experiment using container media comprised of a field soil plus various amendments, he found that very little water was held between 30 cm and 50 cm of tension.

Moisture holding capacity of soil in containers is quite different from soil in the field (90, 92, 94, 112). This is primarily due to the relatively small volume of the container (11, 39, 42, 96, 106). White and Mastarlerz (106) introduced the concept of "container capacity" to try to distinguish between the water-holding capacity of a field soil and a container medium. The actual distribution of water in container media is determined by the porosity of the media and the container depth (65, 91). Hendrickson and Veihmeyer (39) stressed the importance of the interaction of the media and container size in relation to water

distribution. When container media drain, a perched water table develops at the bottom of the container. This means the lower portion of the container is saturated after irrigation and drainage (91). The water-holding characteristics of the container media, determined by soil porosity, influence the height of saturation above the bottom of the container (27, 65, 91, 106).

Aeration of the soil medium is often the limiting factor for root growth and functioning according to many researchers (31, 33, 48, 49, 52, 101). The effectiveness of gas exchange depends largely on media texture and structure (31, 32). Aeration is usually limiting if media contain less than 10 to 12 percent noncapillary pore space (31). Aeration is also known to affect the form of root systems (31, 48, 49, 101). Grable (30) found air porosities greater than 20 percent and sometimes greater than 30 percent were needed for optimum establishment and growth of tomatoes in containers. Self and Pounders (87) reported that an air volume of 20 to 35 percent is desirable for container media. The reduction of root respiration is the first step in limiting growth by insufficient aeration. Lack of oxygen also hinders or stops uptake of most nutrients (82, 99) or permits uptake of ions such as Na or Cl which are normally excluded by some species (30).

It is a well documented fact that poor aeration increases the probability of root disease (12, 30, 35, 48, 63, 82). Grable (30) suggested that the water content of container media, which is directly related to porosity, may be more critical than aeration. Russell (82) stated that aeration is a factor in the occurrence and severity of some plant diseases. The lack of oxygen and/or excess of carbon

dioxide increases the growth and longevity of certain pathogens (35, 82).

High soil temperature has become recognized as a critical factor in the growing of plants in containers (17, 85). The temperature in container media may reach 44 to 49°C when the air temperature is 33 to 35°C (24, 25, 28, 114). This soil temperature is higher than the optimum for most plants (79, 116), although the optimum soil temperatures differ with each plant species (88). Soil temperature was found to affect the root growth, shoot growth, and nutrient content of the plants studied by Barr and Pellett (6). Fretz (24, 25) concluded that there was no significant difference in the maximum temperature recorded 2.5 cm from the sidewall and 6.4 cm deep in five different media in "one-gallon" containers. Haun and Fulmer (37) reported that a perlite mulch on the surface of container media resulted in lower maximum temperatures in the media and reduced irrigation requirements.

Containers

Clay pots were initially used to grow nursery plants, but container production accounted for only a small percentage of the nursery production before World War II. Following World War II the number 10 metal can used by food processors became available to nurserymen. This was an inexpensive container, readily available and adequate in size for the production of plants.

Many different types and sizes of containers are now being used in the nursery industry. The most common containers are made of polyethylene and range from a relatively heavy, rigid grade to a thin, lightweight shell. Containers are basically selected from an economic

viewpoint with emphasis on durability and initial cost. Although containers used in the production of plants vary in size, shape, and construction (1, 23, 41, 47, 49, 62), they all possess certain characteristics. They all isolate and support the soil mass, have an open top to expose the plant shoot, have a drainage hole or holes at the bottom, and are relatively shallow and small (91). Some plant species require containers of different configuration for optimum growth (15).

Pertuit (68) found more dry weight of roots in a double-wall plastic container with air space between the walls as compared to a single-wall container. In this experiment a polyethylene mulch on the container media surface increased the dry weight of roots regardless of the type of container. McGuire (55) reported that C. Belgiorno, a New York nurseryman, placed vertical dividers in the lower one-third of containers. It was stated that this subdivision of the root mass would increase transplanting survival by providing more contact of the root mass with the field soil.

Dickey and Poole (21, 22) studied the effect of container size on plant growth. As container size increased, the growth index of Ligustrum japonicum and Podocarpus macrophylla also increased. There was no difference in size of Rhododendron indicum 'Formosa' grown in "one-quart" and "one-gallon" containers, but plants grown in "two-gallon" containers were significantly larger. Furuta (28) reported an increase in the size of Ilex crenata 'Rotundifolia' at the end of one growing season by increasing the size of the container from "one-gallon" to "two-gallon."

Waters et al. (102) reported that the water-holding capacity per volume increased as container size decreased. This would indicate that small containers do not drain as freely as large containers. As container size decreases, the management of the fertility level becomes more critical because there is less volume of media to buffer against excess soluble salts (104).

Whitcomb (103) investigated the effect of media and the number of holes in the container sidewall on the number of growing terminals of Carissa grandiflora 'Boxwood Beauty.' He found no effect of the three media or the 0, 30, and 60 holes in the sidewalls of containers on the number of growing terminals.

Rackley and Whitcomb (75) found that three or five plants of Ligustrum japonicum, with moderate to high fertility levels, could be grown in a single container in order to achieve a salable product in less time. With three or five plants in each container, the number of terminals per container increased, but the number of bud breaks per plant slightly decreased.

Fretz (24, 25) reported that the maximum daily temperature in container media was significantly lower in containers painted white, silver, or yellow as compared to dark colored containers. Cochis (17) reported that there was no difference in the growth in "one-gallon" metal or plastic containers that were painted red, white, green or black.

Scarratt (83) reported that roots will not grow into air space below bottomless containers. There was more lateral branching of the roots than found in containers with a bottom. Hiatt and Tinus (40)

reported that containers with vertical grooves or ridges, no horizontal corners, and/or no bottom improved the configuration of Pinus roots and reduced root spiraling in the container.

Jones and Haskins (43) compared the root distribution of tomato plants grown in porous clay containers and nonporous glass containers. The root systems in the porous containers were mainly located at the interface between the soil mass and the container sidewall. The authors attributed this to the fact that there was lateral movement of water in the porous container. It was also stated that the distribution of nutrients was affected by media moisture movement which was associated with root distribution. An analysis of total soluble salts in four concentric regions of the container showed that the concentration decreased from the center of the soil mass outward in the clay container.

Roots

It has been established that roots will not extend into areas where there is a shortage of oxygen (45). Low oxygen supply in the growing medium increased the amino acid levels in cotton roots and decreased amino acids in the leaves (34).

Harris et al. (36) reported that circling of roots in a container could lead to girdling as the roots increase in diameter. Girdling of primary roots could interfere with water and nutrient transport. Wilson (113) reported that horizontal roots of red maple tend to return to the original direction of growth after having been deflected by a barrier.

Rigidity of the soil system and the size of the pores in the soil system influence the growth of plant roots (3). A soil system

composed of small glass beads can limit root growth due to mechanical resistance (109). Excess water and insufficient aeration are also characteristics of dense container media (42, 53, 90, 92, 94, 107).

In containers, root proliferation per unit volume of soil is often very great in comparison to field soils. Nutrient movement and uptake will increase because of rapid flow of water and a high concentration of roots in container media (30). Gile and Carrero (29) found that if only a portion of the roots of a particular plant was supplied with a specific ion, then those roots would absorb more of that ion per gram of root than if all the roots were supplied with that ion. The plant, however, would only be able to absorb a maximum number of ions if the entire root system was supplied with the ion. Wiersum (111) concluded that the volume of soil contributing to the nutrition of plants in the field is much smaller than the total volume occupied by the roots. Kranus (50) stated that the increased growth rate of plants in containers was related to more "intensive root functioning."

Jones and Haskins (43) suggested that the distribution of the roots in container media is related to the distribution of nutrients, which is affected by soil moisture movement. Kramer (48) reported that the amount of water and nutrients absorbed by a plant is determined by the volume of soil with which the roots are in contact. The effectiveness of a root system depends upon the efficiency of individual roots, which depends upon heredity and the environment in which they develop. Among the factors that affect the growth and absorbing surface of roots are mechanical resistance to root extension,

water supply, aeration, and chemical composition of the soil solution. Sutton (99) reported that the density of conifer roots in several soil horizons varied with the level of fertility. Cation exchange capacity (C.E.C.) of roots is an important property for nutrient uptake by the plant. Root C.E.C. of young plants is higher than that of older ones, and the highest C.E.C. is found at the growing point of the roots (61). McLean et al. (56) found a high correlation between nitrogen content in roots and the C.E.C. of these roots. Weirsum and Bakema (110) showed that the root C.E.C. is raised in media where it must compete for cations, while it is somewhat lower in a medium where primarily anions are available. Mouat (64) found highly significant differences in root C.E.C. among genotypes while variation within individual clones was low. Smith and Wallace (89) stated that the differences in root C.E.C. affect the balance of calcium and potassium absorbed by plants.

Difficulties in the evaluation of root systems have been reported by many researchers. Earlier observations of roots were done by excavation of the roots and root-washing. Racz et al. (76) used an injection method to study the root system of wheat. He injected the isotope ^{32}P into the stem of wheat and allowed it to equilibrate throughout the root system. Radiographs were then used to study the root systems.

Melhuish and Land (58, 59) outlined a method of root analysis where the top of the plant was removed and a dye was forced into the root system by pressure. The soil mass was stabilized with a plastic resin and then thin sections of the plastic impregnated soil mass were prepared for microscopic examination. The root voids, the spaces where

the roots were before they were air dried, were counted and measured microscopically.

Carley and Watson (14) compared a gravimetric method and the titration method described by Wilde and Voight (108) for estimating root surface area and found that the gravimetric method was quick and easy, but the titration method was more accurate.

A rapid rate of temperature fluctuation can increase the damage to plants caused by extreme temperatures (69). The above ground portion of the plant can become more acclimated to tolerate extreme temperatures than the roots (16). The length of time roots are exposed to an extreme temperature is also a determining factor in the degree of injury obtained. Barney (5) reported that a sudden increase in soil temperature from 20°C to 35°C caused a marked increase in root growth during the first hour, then a decrease followed by a second slight increase, and after 30 hours at 35°C root growth completely ceased. Decreasing rates of growth with increases of temperature above 30°C have been largely attributed to growth being an enzymatically controlled process (95).

Transplanting and Establishment

Harris et al. (36) concluded that a defective root system is frequently the primary reason for failure in the establishment of container grown plants in the landscape. Sutton (99) also reported that the form and size of the root system at the time of transplanting was a major factor involved in the establishment of conifers.

Plants differ in the ability to become established in the landscape after being grown in metal containers (77). Some plant roots

retain the shape of the container long after they have been transplanted into field soil (31, 55). This configuration of roots can also lead to root girdling as the plants mature (8). Some researchers have indicated that it would be beneficial to slice vertically through a container soil-root mass before transplanting (8, 36, 98). Fulmer and Jones (26) suggest that roots of container grown Ilex cornuta burfordi nana should be "disarranged in some manner" prior to planting. Their findings were based on visual ratings of root development 23 months after being transplanted in a Norfolk sand loam. Dickey and Poole (21, 22) reported that slicing vertically through the root-soil mass of container grown Ligustrum japonicum, Polocarpus macrophylla, and Rhododendron indicum 'Sweet Formosa' did not affect the height or spread of these plants one year after being transplanted.

Pirone (70) recommended that when digging a hole for a plant, the subsoil from the hole should be discarded and replaced with topsoil. Leonard et al. (51) reported an increase in the growth of young orange trees resulting from the use of soft rock phosphate as a soil amendment when transplanting. Koo (46) found that when soft rock phosphate, vermicultie, or three grades of Attapulgite clay were used as soil amendments for transplanting, young orange trees showed a significantly greater trunk diameter and canopy size than the untreated trees during the first two years. The difference in tree growth was related to difference in soil moisture provided by the soil amendment.

Pellet (67) evaluated the effect of several organic soil amendments on the height of Lonicera korolkowi zabeli after being transplanted bare root at a landscape site. He found that there was no

increase in plant height due to the soil amendments. Schulte and Whitcomb (84) reported that soil amendments did not affect the establishment of Acer saccharinum transplanted as bare root stock. The results were based on the measurement of the total linear growth of newly developed stems 4 months after being transplanted.

Roggon and Whitcomb (81) transplanted Pistacia chinensis seedlings with soil amendments of 10, 20 or 40 percent of either peat, pine bark or vermiculite. After eleven weeks the plants in the unamended soil were "equal to or taller" than plants with any of the soil amendments. There were no differences in plant height and stem diameter between the peat or vermicultie amendments or the control after 14 months. The plant height and stem diameter were smaller when the larger amounts of pine bark were used than when the smaller percentage of pine bark was added to the hole. Byrnes (13) evaluated the effects of soil amendments on the soil conditions and the establishment and growth of container grown Pittosporum tobira. He found that soil amendments of colloidal phosphate, vermiculite, peat, and pine bark increased the water-holding capacity, but only the peat and vermicultie increased the amount of water available to the plant. "Vermicultie and colloidal phosphate amendments produced better plants than peat and pine bark" in both irrigated and non-irrigated experiments. Plants that were transplanted in soils with no soil amendments grew better than those amended with vermiculite or colloidal phosphate in an irrigated experiment. In a non-irrigated experiment, the Pittosporum plants grew better in the soil amended with colloidal phosphate.

In the judgement of Costello and Paul (19), the most important

cause of losses of transplanted container grown plants in unfavorable water relations. Data they presented suggest that as the soil surrounding a transplanted container grown plant drains, moisture is pulled from the original container medium. Therefore, in a relatively dry, well drained soil, the transplanted container grown plant will require greater frequency of irrigation than if the plant had remained in the container. Hendrickson and Veihmeyer (38) concluded that water moves, but slowly, from soil at field capacity to adjacent dry soil. In the absence of roots extending through this line of marked moisture differences, the dry soil receives moisture at an extremely slow rate. McGuire (55) recommended that a transplanted container grown plant should be "watered thoroughly and frequently" until the roots grow into the surrounding soil.

CHAPTER III

PHYSICAL CHARACTERISTICS OF THE CONTAINER MEDIA

Three container media were studied in this project. One medium consisted of equal volumes of horticultural grade perlite and sphagnum peat. The second medium contained equal volumes of a clay loam soil, sphagnum peat, and a medium grade of builder's sand. The third medium consisted of three parts of pine bark and one part of a medium grade builder's sand. The pine bark was purchased from Hiwassee Land Company and 61 percent of the dry weight of the particles were greater than one millimeter in size. The particle size distribution is presented in Table 3.1.

The components of each medium were combined and passed through a soil mixer. Five containers were filled with each medium and no plants were transplanted into them. These media were exposed to the elements of the environment and watered daily for six months.

Undisturbed samples of the media were taken from the containers with no plants after six months. Aluminum cylinders, 5.24 cm in diameter and 5.16 cm in depth, were used to obtain the undisturbed samples. The media were watered thoroughly before the samples were taken, therefore, the media were near container capacity when sampled. These media varied greatly in their bulk density and percent shrinkage after drying. For this reason the water-holding characteristics determined for these media were expressed in terms of volume at container capacity (9, 28, 107).

Table 3.1. Particle analysis, expressed in percentage of dry weight, of pine bark used in the pine bark-sand medium.

NBS* Sieve No.	Screen opening (mm)	Percentage of Dry Weight
	5.00	20.8
10	2.00	23.1
18	1.00	17.2
30	0.59	11.5
40	0.42	5.8
Pan		21.5

*National Bureau of Standards

In the laboratory a 2.5 cm deep ring made of the same 5.3 cm diameter aluminum cylinder was attached to the top of the sampling cylinder containing the medium by a 2.5 cm section of bicycle innertube. The bottom of the cylinder was covered with muslin cloth held in place by a rubber band. The samples were then placed in a vacuum jar containing water just above the top surface of the medium in the sampling cylinder and subjected to a vacuum equal to 200 mm of Hg for 24 hours. The saturated samples were removed from the vacuum jar, wiped with a sponge to remove excess water in the cloth and weighed. The net weight of the saturated medium was recorded. Subsequently, the samples were placed on a tension table (78) and brought to equilibrium with a 40 cm column of water for 24 hours. The weights of the samples were then recorded. The samples were then transferred to a drying oven and dried to constant weight at 100°C.

Total porosity, aeration porosity (percent by volume), water held at 40 cm of tension (percent by volume), and bulk density were calculated as follows:

$$\text{Aeration porosity} = \frac{(\text{saturated wt.} - \text{wt. at 40 cm } H_2O)}{\text{volume of cylinder}}$$

$$\text{Percent water at 40 cm } H_2O = \frac{(\text{wt. at 40 cm } H_2O - \text{oven dry wt.})}{\text{volume of cylinder}}$$

$$\text{Total porosity} = \frac{(\text{saturated wt.} - \text{oven dry wt.})}{\text{volume of cylinder}}$$

$$\text{Bulk density} = \frac{\text{oven dry wt.}}{\text{volume of cylinder}}$$

The results of these calculations for the three media are presented in Table 3.2.

The percent of water held at one-third bars tension was determined for each medium by the porous plate method (78). The percent of water at 2, 5, 9, and 15 bars was determined by the pressure membrane method (78). The results of these procedures are presented in Table 3.3.

Table 3.2. Physical characteristics of three container media determined on a tension table.

Media		Bulk Density (g/cc)	Total Porosity (% volume)	H_2O at 40 cm Tension (% volume)
Components	Ratio			
Peat-Perlite	1:1	0.134	70.4	31.5
Soil-Peat-Sand	1:1:1	0.908	65.0	33.5
Pine Bark-Sand	3:1	0.480	74.2	34.8

Table 3.3. Water held by three container media at various tensions expressed as a percentage of the volume at container capacity.

Media	Moisture Tension (bars)	Percentage of H_2O By Volume
Peat-Perlite	1/3	24.83
	2	21.37
	5	21.29
	9	19.85
	15	19.65
Soil-Peat-Sand	1/3	18.03
	2	11.93
	5	10.02
	9	8.35
	15	7.74
Pine Bark-Sand	1/3	26.17
	2	20.64
	5	19.56
	9	16.08
	15	14.62

CHAPTER IV

TEMPERATURE FLUCTUATIONS AS AFFECTED BY CONTAINER MEDIA AND MOISTURE CONTENT

I. Materials and Methods

Juniperus horizontalis 'Plumosa' was grown in polyethylene containers 17 cm deep, 13.5 cm diameter at the base, and 15 cm diameter at the bottom of the sidewall. The plants were grown for 14 months in three growing media. The media were: (1) one part peat and one part perlite, (2) one part soil, one part peat, and one part sand, and (3) three parts pine bark and one part sand, as described in Chapter III.

The plants were placed in a growth chamber with 12 hours of light and 12 hours of darkness. The temperature was maintained at 32°C during the light hours and 20°C during the dark hours. Light was provided by a combination of incandescent and fluorescent bulbs positioned 30 cm above the top of the containers. The light intensity was approximately 28 x 10^3 lux.

Two moisture levels were maintained. One half of the samples was kept dry and one half was saturated with water at 20°C at the beginning of the dark period. The 24 hour recording of the temperatures started 6 hours after the media were watered, and no more water was added during the recording of the temperatures.

A YSI twelve channel scanning tele-thermometer and YSI model 80A recorder were employed to record temperature fluctuations. The

temperature at each location was recorded for a 5 minute period each hour. The temperature fluctuations were recorded at three locations in each container. The three locations in the container were: 2 cm from the side and 2 cm from the bottom (bottom), 2 cm from the side and 2 cm from the upper soil surface (top), and 7 cm from the side and at equal distance from the top and bottom of the soil mass (middle). The ambient air temperature in the growth chamber was also recorded.

The experiment was designed with a split-plot arrangement of treatments with four replications. The temperature fluctuations were recorded in three containers at a time. The fluctuations were only recorded the second day of the temperature readings. At the end of the second day the three containers that had been tested were removed and the probes were placed in three other containers that had been allowed to acclimate to the growth chamber conditions. Three new containers were then placed in the chamber to adjust for two days to the chamber conditions. These procedures were repeated until all 24 samples had been tested.

The temperature fluctuations were recorded, and variables were defined to aid in the interpretation of the results. These variables included the average maximum and minimum daily temperatures, and the rates of temperature change from the daily minimum to the maximum and from the daily maximum to the minimum.

II. Results and Discussion

The average maximum daily temperature recorded at the three locations in the container media with two moisture levels are presented

in Table 4.1. The maximum temperature was the same at all locations of each wet medium. The maximum temperature was higher at the top location in the dry media than in the wet media. In the dry peat-perlite medium the maximum temperature was higher at the top location than at the middle and bottom locations. The maximum temperature was higher at the top location than at the bottom location of the dry soil-peat-sand medium, but the maximum temperature at the middle location was not different from that at the top or bottom location. In the dry pine bark-sand medium the maximum temperature at the middle location was higher than at the bottom.

The thermal diffusivity of a soil denotes the temperature change as heat flows from adjacent layers. Thermal diffusivity increases with increasing moisture content, but reaches a maximum before soil saturation (7). Based on this statement, the thermal diffusivity was greater in all media if the moisture content was high than if the media were dry.

There was no effect of the container media on the rate of temperature change. The rate of temperature change from the daily minimum to the maximum was greater in the dry media (4°C/hr.) than in the wet media (3°C/hr.) at all locations. It was also determined that the rate of this temperature change was greater at the top location (4.5°C/hr.) than the middle (3.0°C/hr.) and bottom (2.9°C/hr.) location regardless of the media moisture content.

The effects of media moisture content on the average minimum daily temperature and the rate of temperature change from the daily maximum to the minimum are presented in Table 4.2. The average minimum

Table 4.1. Average maximum daily temperatures recorded at three locations in three container media with two moisture contents.

Media	Moisture Contents	Location	Maximum Temperature (°C)
Peat-Perlite	Dry	Top	35.8 a[z]
Peat-Perlite	Dry	Middle	33.8 cde
Peat-Perlite	Dry	Bottom	33.8 cde
Peat-Perlite	Wet	Top	33.8 cde
Peat-Perlite	Wet	Middle	33.8 cde
Peat-Perlite	Wet	Bottom	33.5 cdef
Soil-Peat-Sand	Dry	Top	35.0 ab
Soil-Peat-Sand	Dry	Middle	34.3 bc
Soil-Peat-Sand	Dry	Bottom	33.3 cdef
Soil-Peat-Sand	Wet	Top	33.0 def
Soil-Peat-Sand	Wet	Middle	32.5 f
Soil-Peat-Sand	Wet	Bottom	32.8 ef
Pine Bark-Sand	Dry	Top	35.5 a
Pine Bark-Sand	Dry	Middle	33.8 cde
Pine Bark-Sand	Dry	Bottom	32.5 f
Pine Bark-Sand	Wet	Top	33.0 def
Pine Bark-Sand	Wet	Middle	34.0 cd
Pine Bark-Sand	Wet	Bottom	34.0 cd

[z]Mean separation by Duncan's multiple range test, 5 percent level.

Table 4.2. Average minimum daily temperatures, and the rate of temperature change from the daily maximum to the minimum, at three locations in container media as affected by moisture content.

Moisture Content	Location	Minimum Temperature (°C)	Rate of Temperature change (°C/hr.)
Dry	Top	20.0 a[z]	5.6 a
Dry	Middle	19.8 a	3.5 cd
Dry	Bottom	20.0 a	4.0 bc
Wet	Top	19.3 b	4.2 b
Wet	Middle	19.9 a	3.1 de
Wet	Bottom	20.0 a	2.9 de

[z]Means within a column separated by Duncan's multiple range test, 5 percent level.

temperature at the top location of the wet media was statistically lower than the temperatures at middle and bottom locations of the wet media or at the three locations of the dry media. This difference in the average minimum temperature, however, was less than 1°C.

The rate of change from the maximum to the minimum was higher at the top location than the other two locations regardless of media moisture content (Table 4.2). However, the rate of this temperature change was higher at the top location of the dry media than the top location of the wet media. There was no difference in the rate of this temperature change between the middle and bottom locations in the wet or the dry media, although the rate of change was higher at the bottom of the dry media than at the bottom of the wet media.

CHAPTER V

ROOT DEVELOPMENT AND DISTRIBUTION AS AFFECTED BY CONTAINER MEDIA, CONTAINER DESIGN AND PARTICLE SIZE

I. Experiment A

Materials and Methods

Rooted cuttings of Ilex crenata 'Green Luster' and Juniperus horizontalis 'Plumosa' were selected for uniformity and transplanted into "one-gallon" containers which were 15 cm deep with a 13.5 cm diameter at the bottom and 17 cm diameter at the top. The plants were transplanted into three different container media and three different container designs. The three media were previously characterized in Chapter III.

The containers were constructed of semi-rigid polyethylene and were of equal size. Three container designs were used. One container was of "conventional" design with four drain holes at the bottom of the sidewall. The second container was of a "swiss cheese" design with 12 holes, 2 cm in diameter, equally spaced in the sidewall in addition to the four drain holes at the bottom of the sidewall. The lower 7.5 cm portion of the third container was divided into four equal quadrants by closely fitted vertical plastic dividers. The dividers were sealed into the container by floral adhesive clay.

The experiment was designed to conform to a randomized complete block design with four replications of the nine treatments for each of the two plant species. There were six samples per experimental unit.

The following amounts of nutrients were incorporated into each cubic meter of the soil media:

2373 g Osmocote (18-9-9)
2373 g superphosphate (0-20-0)
2966 g gypsum - in the pine bark medium only
2966 g agricultural ground limestone
593 g magnesium sulfate
148 g fritted trace elements

Gypsum was incorporated in all the media containing pine bark, while calcium carbonate was added to the soil-peat-sand and peat-perlite media. This was done to prevent an anticipated rapid rise in pH in the bark medium (2).

The plants were potted on August 1, 1974 and placed under 50 percent shade for two weeks. Then they were moved to an open cold frame in order to prevent direct solar incidence on the sidewalls of the container (24, 28, 85, 114). The containers were heeled in sawdust from November 25, 1974 to April 23, 1975 in order to insure protection of the roots from low temperatures.

After the plants were potted, all treatments received the same fertilization. Slow release fertilizer (Osmocote 14-14-14) was applied as a topdress on March 26 and July 25 at the recommended rate of one "scant teaspoon" (approximately 2.5 g) per container. The plants were watered according to the requirements of each medium. Weed competition was kept to a minimum by hand weeding.

The root development and distribution were evaluated on September 15, 1975. One sample per experimental unit was chosen at random for this analysis. The above ground portions of the plants were excised, oven dried, and the dry weights recorded. The roots located in nine divisions of the container media were also observed. Two horizontal

cuts divided the soil mass into three slices of equal thickness designated in Figure 5.1 as the bottom (B), second (S), and top (T) depth zones. The root mass on the lower surface of the bottom slice was removed to expose root cross sections. Three concentric areas of equal surface area on the lower surface of each slice were designated as the outside (O), middle (M), and inside (I) areas (Figure 5.1).

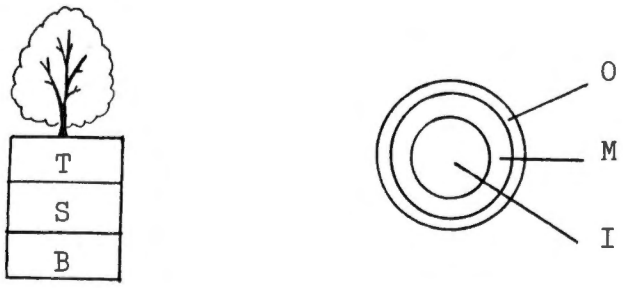


Figure 5.1. Divisions of the container media in Experiment A.

Therefore, there were three concentric areas on each of the three depth zones to give a total of nine divisions per sample that were evaluated. The number of root ends exposed on the lower surface of each of the nine divisions were counted and recorded. A root end in this case could have been a root cross section or a meristemic root tip. In most cases the root ends exposed were a result of the cut through the soil mass.

Results and Discussion

There was no effect of the container media or the container design on the dry weight of the top portion of the plant. The number

of Ilex crenata 'Green Luster' roots in the three depth zones and in the three concentric areas as affected by three container media in a container of conventional design is presented in Table 5.1. There was a larger number of roots in the second and bottom depth zones and the middle and inside areas of the peat-perlite medium than the soil-peat-sand and pine bark-sand media. There was no effect of the container media on the number of roots in the outside area of the top depth zone.

The number of Ilex roots found in the three concentric areas of the peat-perlite medium as affected by container design is presented in Table 5.2. There was no effect of container design on the number of roots in the three depth zones of the peat-perlite medium. The number of roots in the outside area through the three depth zones of the peat-perlite medium was less in the container with the vertical dividers than in the other two container designs. The container design had no effect on the number of roots found in the middle and inside areas of all depth zones of the peat-perlite medium.

The effect of container design on the number of Ilex roots in the three areas of the three depth zones of the soil-peat-sand medium is presented in Table 5.3. There was a greater number of roots in the top outside division of the soil-peat-sand medium in the containers of conventional design than in the other two container designs. There was a greater number of roots in the bottom outside division of the soil-peat-sand medium if the container had holes in the sidewall than if the container was of conventional design. The number of roots in this zone was greater in the container with holes in the sidewall than in the container with vertical dividers. There was a larger number of roots in

Table 5.1. Effects of three container media on the average number of Ilex crenata 'Green Luster' roots in three depth zones and in three concentric areas in a conventional "one-gallon" container.

Zone		Container Media		
Depth	Area	Peat-Perlite	Soil-Peat-Sand	Pine Bark-Sand
Top		186.2 a[z]	196.4 a	175.5 a
Second		209.0 a	180.7 b	175.3 b
Bottom		290.9 a	212.2 c	269.2 b
	Outside	299.7 a	308.2 a	320.9 a
	Middle	213.4 a	159.8 b	159.2 b
	Inside	173.0 a	121.2 b	139.8 b

[z]Mean separation within a row by Duncan's multiple range test, 5 percent level.

Table 5.2. Effects of three container designs on the average number of Ilex crenata 'Green Luster' roots in three concentric areas of a peat-perlite container medium.

Area Zone	Container Design		
	Conventional	Sidewall Holes	Vertical Dividers
Outside	299.7 al[z]	320.2 al	253.7 bl
Middle	213.4 am	198.1 am	201.1 am
Inside	173.0 an	176.9 an	176.2 an

[z]Mean separation within a row (ab) and within a column (lmn) by Duncan's multiple range test, 5 percent level.

Table 5.3. Effects of three container designs on the average number of Ilex crenata 'Green Luster' roots in three areas of three depth zones in a soil-peat-sand medium.

Zone		Container Design		
Depth	Area	Conventional	Sidewall Holes	Vertical Dividers
Top	Outside	285.2 am[z]	207.2 bn	232.0 blm
Top	Middle	174.8 an	169.0 ano	192.0 am
Top	Inside	129.2 ano	122.0 aop	141.2 am
Second	Outside	293.8 an	276.8 abm	236.5 blm
Second	Middle	134.8 ano	157.2 anop	155.5 am
Second	Inside	113.5 ao	106.2 aop	144.8 am
Bottom	Outside	345.8 bl	407.0 al	274.2 cl
Bottom	Middle	170.0 ano	190.5 an	192.2 am
Bottom	Inside	120.8 bno	119.2 bop	201.2 am

[z]Mean separation within a row (abc) and within a column (lmnop) by Duncan's multiple range test, 5 percent level.

the bottom inside division of the containers with vertical dividers than in the same division of the containers of the other two designs.

There was a greater number of Ilex roots in the outside area of all three depth zones of the pine bark-sand medium if the container was of conventional design than if the container was of either of the other designs (Table 5.4). There was a greater number of roots in all the areas of the top depth zone of the pine bark-sand medium in the conventional container than in the containers of the other two designs. However, the vertical dividers in the bottom of the container resulted in a larger number of roots in the middle area of the bottom depth zone when compared to the same division in containers of the other two designs. When there were holes in the sidewall of the container there was a smaller number of roots in the inside area of the bottom depth zone of the pine bark-sand medium than there was in the same division in containers of the other two designs.

The container media and container design had no effect on the number of Juniperus horizontalis 'Plumosa' roots in the concentric areas of the media. Across all container media and container designs the average number of roots in the outside area (137.6) was greater than in the middle area (80.9) and a greater number of roots was in the middle area than in the inside area (70.7). Through comparison of the effects of the three container designs on the number of roots in the various divisions of each container medium, it was concluded that the design of the container had no effect on the number of roots in the divisions of the peat-perlite and pine bark-sand media. In the soil-peat-sand medium the design of the container had no effect on the

Table 5.4. Effects of three container designs on the average number of Ilex crenata 'Green Luster' roots in three areas of three depth zones in a pine bark-sand medium.

Zone		Container Design		
Depth	Area	Conventional	Sidewall Holes	Vertical Dividers
Top	Outside	243.2 an[z]	176.2 bmn	196.2 bn
Top	Middle	147.5 ap	82.8 bp	92.0 bo
Top	Inside	135.8 ap	65.5 bp	86.0 bo
Second	Outside	306.5 am	197.5 cm	249.8 bm
Second	Middle	120.5 apq	105.0 aop	112.5 ao
Second	Inside	99.0 aq	63.8 ap	100.5 ao
Bottom	Outside	413.0 al	375.2 bl	357.0 bl
Bottom	Middle	209.8 bo	171.0 bmn	248.5 am
Bottom	Inside	184.8 ao	139.2 bno	219.5 amn

[z]Mean separation within a row (abc) and within a column (lmnopq) by Duncan's multiple range test, 5 percent level.

number of roots in the areas of the depth zones of the medium, but the average number of roots in a division was greater in containers of conventional design (98.0) and containers with vertical dividers in the bottom (103.5) than in containers with holes in the sidewall (75.3).

Through the comparison of the effects of the three container media on the number of Juniperus roots in the divisions in each container design, it was concluded that there was no effect of the container media on the number of roots in the concentric areas in each of the three container designs. The effects of the container media on the average number of Juniperus roots in the three depth zones in the container of conventional design is presented in Table 5.5. There was a greater number of roots in the bottom depth zone of the pine bark-sand medium than in the bottom depth zone of the soil-peat-sand medium. There also was a greater number of roots in the bottom depth zone of the soil-peat-sand medium than in the peat-perlite medium. In the container with holes in the sidewall, there was a lower number of roots in the second and bottom depth zones of the soil-peat-sand medium than in the pine bark-sand medium (Table 5.6). However, there was an equal number of roots in each depth zone of the pine bark-sand medium in this type of container. In the container with vertical dividers in the bottom, the number of roots in the top depth zone of the peat-perlite medium was greater than in the top depth zone of the soil-peat-sand and pine bark-sand media (Table 5.7). The number of Juniperus roots in the second depth zone of the pine bark-sand medium was lower than in this depth zone of the other two media.

Table 5.5. Effects of three container media on the average number of Juniperus horizontalis 'Plumosa' roots in three depth zones in a conventional "one-gallon" container.

Depth Zone	Container Media		
	Peat-Perlite	Soil-Peat-Sand	Pine Bark-Sand
Top	122.6 al[z]	111.8 al	105.3 al
Second	81.5 am	95.5 am	86.8 am
Bottom	67.1 cm	86.8 bm	112.5 al

[z]Mean separation within a row (abc) and within a column (lm) by Duncan's multiple range test, 5 percent level.

Table 5.6. Effects of three container media on the average number of Juniperus horizontalis 'Plumosa' roots in three depth zones in a container with holes in the sidewall.

Depth Zone	Container Media		
	Peat-Perlite	Soil-Peat-Sand	Pine Bark-Sand
Top	103.4 al[z]	93.0 al	114.4 al
Second	75.3 abm	68.1 bm	94.3 al
Bottom	82.6 ablm	64.8 bm	101.2 al

[z]Mean separation within rows (ab) and within columns (lm) by Duncan's multiple range test, 5 percent level.

Table 5.7. Effects of three container media on the average number of Juniperus horizontalis 'Plumosa' roots in three depth zones in a container with vertical dividers in the bottom.

Depth Zone	Container Media		
	Peat-Perlite	Soil-Peat-Sand	Pine Bark-Sand
Top	130.7 al[z]	114.3 bl	102.7 bl
Second	102.4 am	96.7 am	77.9 bm
Bottom	101.3 am	99.7 am	111.2 al

[z]Mean separation within rows (ab) and within columns (lm) by Duncan's multiple range test, 5 percent level.

II. Experiment B

Materials and Methods

The purpose of this experiment was to evaluate the effects of container media particle size on the root distribution and relative root surface area of *Ilex crenata* 'Rotundifolia.'

Rooted cuttings, taken from the same mother plant, were transplanted into "one-quart" containers which were 13 cm deep, 12 cm in diameter at the top, and 11.5 cm at the bottom. The effects of four growing media, each composed of a different size of sand particles, were evaluated. These four sand fractions were separated from the same river sand source. The four sand particle sizes were:

1. Fine gravel; 4.0 mm - 2.0 mm diameter; held between No. 5 and No. 10 mesh sieves.
2. Very coarse sand; 2.0 mm - 1.0 mm diameter; held between No. 10 and No. 18 mesh sieves.
3. Coarse sand; 1.0 mm - 0.5 mm diameter; held between No. 18 and No. 35 mesh sieves.
4. Medium to very fine sand; less than 0.5 mm diameter; passed through No. 35 mesh sieves.

The experiment was a completely randomized design with five replications.

The plants were potted January 9, 1976 and were grown in a greenhouse for two months to allow for adequate root growth. The different water-holding capacities of the four media required each medium be watered individually. An indicator plant was grown in the four media to aid in determining proper irrigation frequencies. Bean seedlings were used as indicator plants, because they wilted from water stress before the *Ilex* showed wilting symptoms. Each medium

was watered when its indicator plant began to wilt.

After the two month growing period the distribution and relative surface area of the roots were determined. The volume of sand, with intact roots, in each container was divided into six equal volumes. Two horizontal cuts were made through the sand-root complex to yield three equal volumes designated in Figure 5.2 as the bottom (B), second (S), and top (T) depth zones. Each slice was divided into two equal volumes and designated as the outside (O) and inside (I) concentric areas as in Figure 5.2. The roots were separated from the sand in each of the six divisions. Dry weights of the roots were recorded

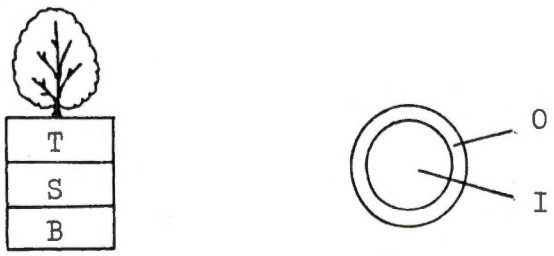


Figure 5.2. Divisions of the container media in Experiment B.

and the relative surface areas were determined by the titration method as described by Wilde and Voigt (108). The dried roots were dipped into a solution of 3 N HCl for 15 seconds and allowed to drain for 5 minutes. Then the roots were washed in 250 ml of distilled water. The thin coat of 3 N HCl on the root surface made a dilute acid in the 250 ml of distilled water. From this dilute acid solution, 100 ml were taken and titrated with 0.3 N NaOH until the solution was again neutral. A phenolphthalein indicator was used to determine the point of complete

neutralization. The ml of NaOH required for neutralization was used to compare the relative surface area of the roots from each of the six zones of the four media. The relative surface area per unit of dry weight of roots were also computed.

Results and Discussion

The particle size of the sand media had no effect on the total dry weight of container grown Ilex crenata 'Rotundifolia' roots. However, there were differences in the distribution of roots and the relative surface area per dry weight of roots in the six divisions of these media. Roots with a high ratio of surface area to dry weight had a relatively smaller diameter than roots with a low ratio.

There was a difference in the dry weight of roots in the two areas of the three depth zones across all media (Table 5.8). In the top depth zone there was a greater dry weight of roots in the inside area than the outside area, however, a greater dry weight of roots was found in the outside area than the inside area of the second and bottom depth zones. It would be expected for the inside area of the top depth zone to contain a larger dry weight of roots, since this is where the primary roots originated.

An equal dry weight of roots was harvested from the three depth zones of the medium consisting of sand particles of 4.0 to 2.0 mm in size (Table 5.9). In Table 5.10 the data for this medium show a smaller ratio of relative surface area to dry weight of roots in the inside area than in the outside area of the top depth zone. This indicates that the roots in the inside area of this depth zone were larger in diameter than the roots in the outside area.

Table 5.8. Mean dry weight of Ilex crenata 'Rotundifolia' roots removed from the six divisions of container media of different sizes of sand.

Zone		Dry Weight (g)
Depth	Area	
Top	Outside	1.36 bc[z]
Top	Inside	3.51 a
Second	Outside	1.81 b
Second	Inside	0.66 de
Bottom	Outside	1.00 cd
Bottom	Inside	0.24 e

[z]Mean separation by Duncan's multiple range test, 5 percent level.

Table 5.9. Effect of container media composed of different particle sizes of sand on the average dry weight of Ilex crenata 'Rotundifolia' roots in the three depth zones of the container.

Media Sand Size (mm)	Depth Zone	Dry Weight (g)
4.0-2.0	Top	1.54 cd[z]
4.0-2.0	Second	1.37 cde
4.0-2.0	Bottom	1.32 cde
2.0-1.0	Top	2.72 a
2.0-1.0	Second	1.86 bc
2.0-1.0	Bottom	.58 ef
1.0-0.5	Top	2.47 ab
1.0-0.5	Second	1.01 cdef
1.0-0.5	Bottom	.46 ef
< 0.5	Top	3.02 a
< 0.5	Second	.70 def
< 0.5	Bottom	.14 f

[z]Mean separation by Duncan's multiple range test, 5 percent level.

Table 5.10. Relative surface area of roots in the two area zones of the three depth zones in two container media of different sizes of sand particles.

Sand Size	Depth Zone	Area Zone	Relative Surface Area/ Dry Weight (ml/g)
4.0-2.0	Top	Outside	15.64 a[z]
4.0-2.0	Top	Inside	5.12 b
4.0-2.0	Second	Outside	9.42 ab
4.0-2.0	Second	Inside	15.03 a
4.0-2.0	Bottom	Outside	11.65 ab
4.0-2.0	Bottom	Inside	14.43 a
< 0.5	Top	Outside	15.40 a[z]
< 0.5	Top	Inside	8.23 b
< 0.5	Second	Outside	16.33 a
< 0.5	Second	Inside	19.32 a
< 0.5	Bottom	Outside	17.29 a
< 0.5	Bottom	Inside	0.00 c

[z]Mean separation for each sand size by Duncan's multiple range test, 5 percent level.

In the container medium of sand particles of 2.0 to 1.0 mm there was a greater dry weight of roots in the top depth zone than the second depth zone and more in the second depth zone than in the bottom depth zone (Table 5.9). There was no difference in the ratio of relative surface area to dry weight of roots in the six divisions of this container medium indicating that the roots had equivalent diameters throughout this medium. The dry weight of roots in the top depth zone of the container medium of sand particles of 1.0 to 0.5 mm in size was greater than that in the second and bottom depth zones (Table 5.9). There was no difference in the ratio of relative surface area to dry weight of roots in the two areas of all three depth zones of this medium. There was a higher ratio of relative surface area to dry weight of roots in the top depth zone (20.0 ml/g) than in the bottom depth zone (10.7 ml/g), however, the ratio in the second depth zone (14.9 ml/g) was not different from the ratio in either top or bottom depth zones.

It can be noted in Table 5.9 that a larger proportion of the roots were in the top depth zone of the media of the smaller sand particle than the media composed of the larger sand particles. In the medium with sand particles less than 0.5 mm there was more dry weight of roots in the top depth zone than the second and bottom depth zones (Table 5.9). The data presented in Table 5.10 indicate that the roots in the inside area of the top depth zone of this medium were larger in diameter than the roots in the outside area. It has been reported that the height of water saturation above the bottom of the container after irrigation is higher in media of smaller particles than in media of larger particles. This may explain why there was a smaller proportion of

the total root system in the lower two-thirds of the container media composed of smaller particles of sand than in the media composed of larger sand particles.

CHAPTER VI

EFFECTS OF CONTAINER MEDIA, CONTAINER DESIGN, AND BACKFILL COMPOSITION ON ROOT DEVELOPMENT

I. Methods and Materials

Ilex crenata 'Green Luster' and Juniperus horizontalis 'Plumosa' rooted cuttings were transplanted on August 4, 1974 in three media and three container designs as previously described in Chapter V. The cultural practices employed during the growth of these plants were also presented in Chapter V. The experimental design was a randomized complete block design with four replications.

These plants were transplanted on August 7, 1975 from the original containers into "three-gallon" containers which were 10 cm larger in diameter and 5 cm deeper than the original container. Three backfills were used. A backfill is a medium that is placed around the original container medium when tranpslanted into a larger container or a planting hole in the landscape. One backfill consisted of medium to fine silica sand, the second backfill was nonpasteurized clay loam soil, and the third backfill (an amended soil backfill) was a mixture of one part clay loam and one part of the container medium in which the plant was grown. For example, if a plant was grown in the peat-perlite medium, the amended backfill would be comprised of equal volumes of peat-perlite and clay loam. The plants were watered according to the water-holding characteristics of each medium. Data presented in Table 3.2, p. 21 show that the media differed little in the

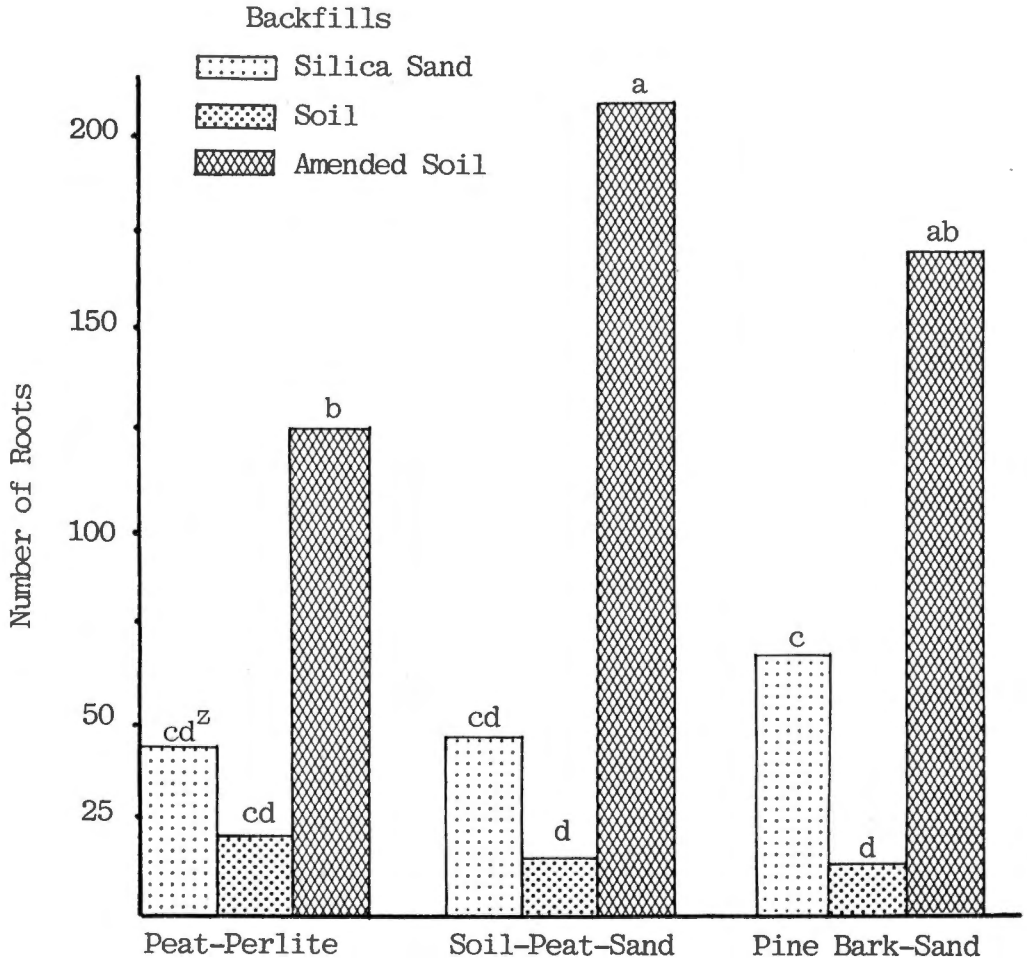
amount of water held at tensions less than 40 cm.

Root movement was established after a growing period of 6 weeks. The number of roots that had reached the sidewall of the larger container was recorded. This was the number of roots that had grown 5 cm or more in length through the backfill. The backfill was then gently washed from the roots to expose the roots that had extended from the original container media. These exposed roots were removed and their oven dry weights were recorded.

II. Results and Discussion

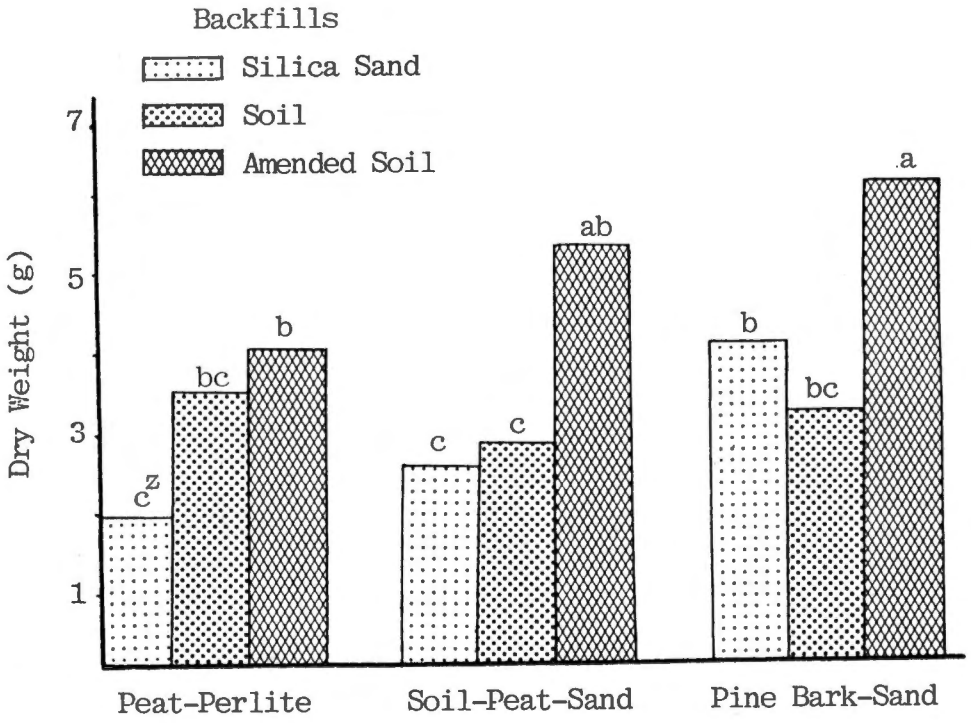
The effect of the backfill composition on the number of Ilex crenata 'Green Luster' roots that extended through the backfill was dependent upon the container medium in which the plant was grown. A greater number of roots had grown from all container media through the amended backfill, composed of loam soil and the container medium, than through the other two backfills (Figure 6.1). A larger number of roots had grown through the amended backfill from the soil-peat-sand medium than the peat-perlite medium. The container media had no effect on the number of roots that had grown into the clay loam backfill. A greater number of roots extended through the silica sand backfill than through the clay loam backfill when the roots were growing from the pine bark-sand medium.

There was also a significant interaction between the effects of the container media and the backfill composition on the dry weight of Ilex roots that had extended into the backfill (Figure 6.2). There was a significantly greater dry weight of roots extending from the pine bark-



[z]Mean separation by Duncan's multiple range test, 5 percent level.

Figure 6.1. Effects of three media and three backfill compositions on the number of Ilex crenata 'Green Luster' roots growing through the backfill.



[z]Mean separation by Duncan's multiple range test, 5 percent level.

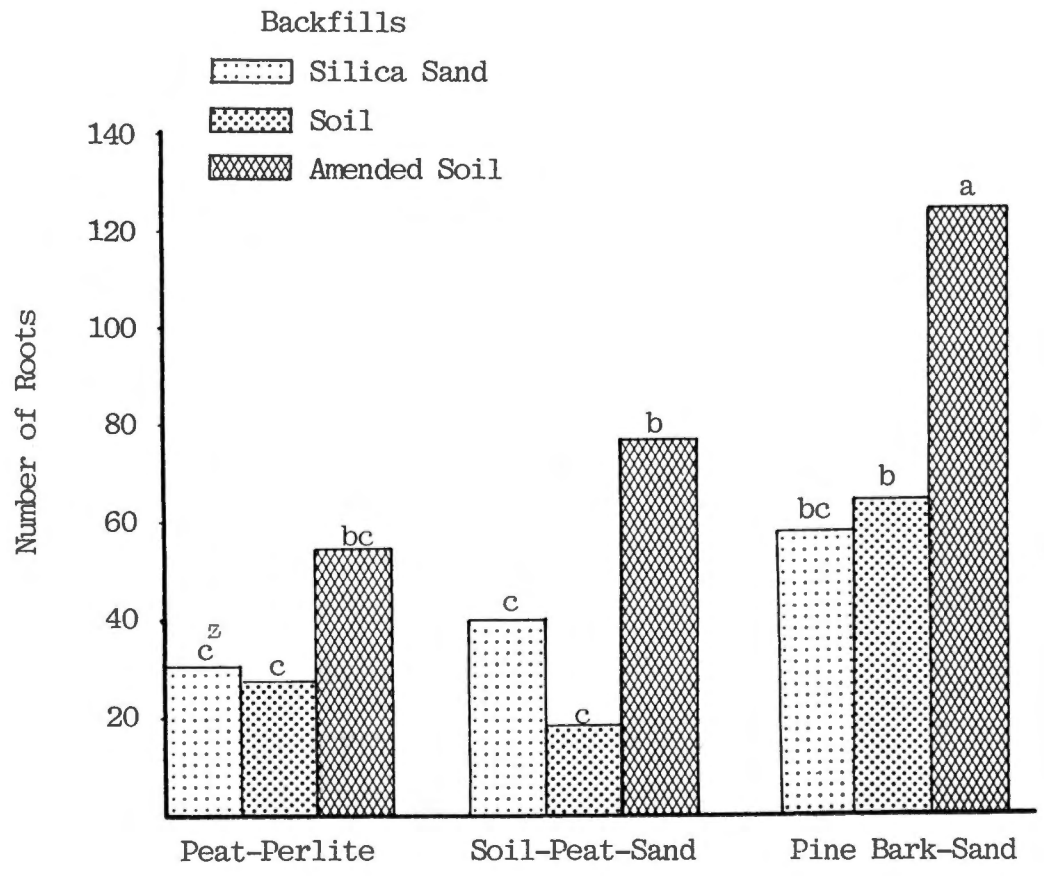
Figure 6.2. Effects of three media and three backfill compositions on the dry weight of Ilex crenata 'Green Luster' roots in the backfill.

sand and soil-peat-sand media into the amended backfill than the other two backfills. There was a greater dry weight of roots that had grown from the peat-perlite medium into the amended soil backfill than into the silica sand backfill, but the dry weight of roots in the soil backfill was not different from the roots in either of the other two backfills. The container medium had no effect on the dry weight of roots that had grown into the unamended clay loam backfill.

The number of Juniperus horizontalis 'Plumosa' roots that had extended through the various backfills was affected by the container media in which they were grown (Figure 6.3). There were more Juniperus roots extending through the amended backfill from the pine bark-sand medium than any other treatment combination. A greater number of roots extended through the amended backfill as compared to the other two backfills when the container medium was soil-peat-sand or pine bark-sand. The backfills had no effect on the number of roots extending through the backfill from the peat-perlite medium.

The backfills in this study had no effect on the dry weight of Juniperus roots in the backfill. There was, however, a greater dry weight of roots that grew from the pine bark-sand medium (3.41 g) than from the soil-peat-sand (2.23 g) or peat-perlite medium (1.92 g).

The design of the "one-gallon" container had no effect on the root development of either the Ilex or Juniperus plants that were transplanted into the three gallon containers.



[z]Mean separation by Duncan's multiple range test, 5 percent level.

Figure 6.3. Effects of three media and three backfill compositions on the number of Juniperus horizontalis 'Plumosa' roots that had grown through the backfill.

CHAPTER VII

EFFECTS OF CONTAINER MEDIA AND BACKFILL COMPOSITION ON THE ESTABLISHMENT OF CONTAINER GROWN PLANTS IN THE LANDSCAPE

I. Experiment C

Materials and Methods

Ilex crenata 'Green Luster' was grown in "one-gallon" containers with three container media. The media were peat-perlite, soil-peat-sand and pine bark-sand as described in Chapter III. The cultural practices were adjusted to fit the characteristics of each medium, and at the end of an 18 month growing period there were no significant effects of media on the dry weight or size of the above-ground portion of the plant.

These plants were transplanted in the field April 20, 1976. Before being transplanted the plants were pruned to an uniform size and were fertilized with liquid fertilizer (20-20-20) at a concentration of 200 ppm.

The site of the experiment was selected because of minimal variation in the soil characteristics. A randomized complete block design was employed to account for the effect of any soil variations at this location. The treatments were replicated five times.

The experiment was located on the second terrace near the Tennessee River in Knoxville, Tennessee. This area was gently sloping to flat and the soils are generally well drained. This Etowah soil (fine-loamy, siliceous, thermic Typic Paleudults) was brownish in color

with a yellowish red subsoil. The surface horizon was approximately 10 inches deep and classified as a loam, although the clay content was 26 percent, just below that of a clay loam. The B horizon was a heavier clay loam with 40 percent clay content.

The holes for the plants were dug with a tractor powered soil auger. The holes were 30 cm in diameter and 25 cm deep. The inside walls of the holes were scraped with a shovel in an attempt to disturb the glazed soil surface made by the soil auger. Backfills of two different compositions were used. One backfill consisted of the original field soil from the hole. The other was an amended backfill consisting of equal volumes of the field soil and the type of medium in which the plant was grown. For example, if a plant was grown in a peat-perlite medium, the amended backfill contained equal volumes of peat-perlite and the field soil.

The plants were watered every week unless there was adequate rainfall. The weeds near the plants were pulled by hand, and the weeds in the general area were controlled with glyphosate. The experiment was terminated and the plants were evaluated on September 7 and 8, 1976.

The plants were dug by hand and the root systems were evaluated. The number of roots that grew from the original container media through the backfill and into the undisturbed field soil was recorded. The number of roots that had grown through the backfill but did not enter the undisturbed field, and the dry weight of roots in the backfill were also determined.

Mercury manometers were used in this study in an attempt to

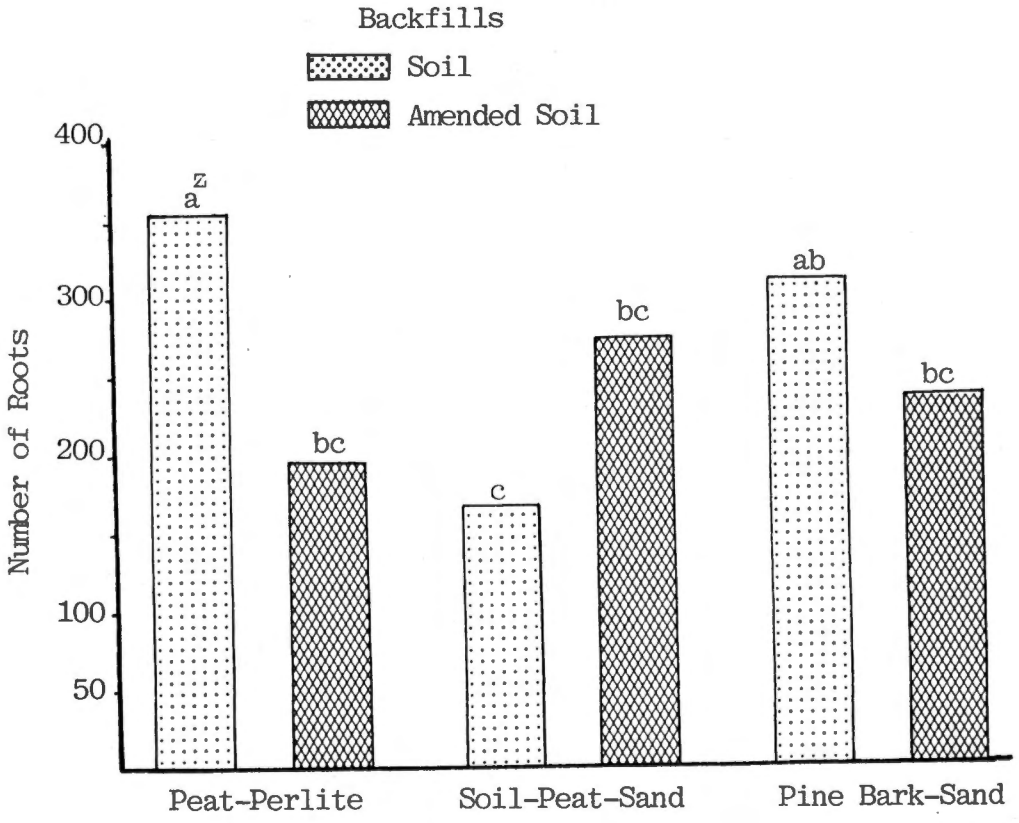
monitor the changes in moisture tension in each medium after they were transplanted and watered. The porous cup of a manometer was placed in the center of each transplanted container medium and the moisture tensions were recorded for one week. The manometers were then put in the media that were in containers. The weight of water lost between each manometer reading was then recorded in an attempt to correlate the manometer readings to moisture loss.

Results and Discussion

There was 100 percent survival of all treatment combinations. During the evaluation of the root systems it was determined that roots had not moved into the undisturbed field soil. The roots that reached the undisturbed soil curved and grew along the interface between the backfill and the undisturbed field soil.

There was a significant interaction of the effects of media and backfill compositions on the number of roots that moved through the backfill (Figure 7.1). There was a greater number of roots that had extended through the amended backfill than through the unamended backfill from the peat-perlite medium. The backfill composition had no effect on the number of roots that moved through the backfill from the soil-peat-sand and pine bark-sand media. There was a significantly larger number of roots that extended through the amended backfill from the peat-perlite and pine bark-sand media than from the soil-peat-sand medium.

It was determined that a greater dry weight of roots had grown into the backfills from the soil-peat-sand medium than from the pine



[z]Mean separation by Duncan's multiple range test, 5 percent level.

Figure 7.1. Effects of container media and backfill composition on the number of Ilex crenata 'Green Luster' roots extending through the backfill but not into the undisturbed field soil.

bark-sand medium (Table 7.1). The dry weight of roots in the backfill from the peat-perlite medium was not different from the dry weight of roots extending from the soil-peat-sand or pine bark-sand media. The backfill composition did not affect the dry weight of roots found in the backfill.

The manometer readings and associated water loss were extremely variable. The author feels this was not an accurate method of monitoring moisture tension in container media, therefore the data will not be presented.

II. Experiment D

Materials and Methods

Ilex crenata 'Rotundifolia' and *Juniperus horizontalis* 'Blue Rug' were grown for two years in "one and two-gallon" containers with three container media. The three media were peat-perlite, soil-peat-sand and pine bark-sand as characterized in Chapter III.

These plants were transplanted in the field April 21, 1976. The plants were pruned to an uniform size and fertilized twice in a 10 day period with liquid fertilizer (20-20-20) at 200 ppm before being transplanted. The site of the experiment was as described for Experiment C. A randomized complete block design with four replications was used in this study.

The holes were dug with a soil auger. The holes for the plants in the "one-gallon" containers were 30 cm in diameter and 25 cm in depth. The inside walls of the holes were scraped with a shovel as described in Experiment C. The holes for the plants in the "two-gallon" containers

Table 7.1. Dry weight of Ilex crenata 'Green Luster' roots that extended into the backfill from three container media.

Media	Roots-Dry Wt. (g)
Soil-Peat-Sand	12.63 a[z]
Peat-Perlite	11.98 ab
Pine Bark-Sand	9.20 b

[z]Mean separation by Duncan's multiple range test, 5 percent level.

were dug 30 cm in diameter and 30 cm deep with the soil auger, then the diameter was increased to 35 cm with a shovel.

The same two backfill compositions were used as described for Experiment C. One backfill consisted of the original soil from the hole. An amended backfill contained equal volumes of the field soil and the medium in which the plant was grown. The plants were watered every week the first summer unless there was adequate rainfall. The plants were not watered after the first summer. The weeds were controlled as previously outlined for Experiment C.

September 6, 1976 and July 17, 1977 the above-ground portion of these plants was evaluated. The records included the percent survival, plant height (mean of the two tallest points from the ground of the Ilex sp. only), plant width (mean of two greatest widths), the number of shoot terminals, and the average length of the five longest new shoots. A growth index equal to the sum of the average height and the average width divided by two was calculated for the Ilex sp.

The plants were dug by hand July 18 and 19, 1977 and the root systems were evaluated. The soil and backfill was washed from the roots that had grown from the original container media and these roots were removed. The roots were then dried in an oven at 70°C. The dry weights of the roots that had grown from the original container media were recorded.

It was the intention of the author to observe the number or dry weight of the roots that had moved into the undisturbed field soil. This however was not feasible because it was often impossible to locate the interface between the backfill and the undisturbed field soil.

Results and Discussion

The container media, container size and backfill composition had no effect on the width, number of shoot terminals or the length of the new shoots of Juniperus horizontalis 'Blue Rug' 5 or 15 months after being transplanted. Also there was no difference in the dry weight of Juniperus roots that had grown from the original container media 15 months after being transplanted.

Five months after being transplanted the Ilex crenata 'Rotundifolia' plants that had been grown in "one-gallon" containers were taller if the backfill had been amended. The average height of the plants with the amended backfill and the backfill of original soil were 33.7 cm and 31.2 cm respectively The backfill composition and container media had no effect on plant height or the length of the new shoots of the plants grown in "two-gallon" containers.

After this five month period the average length of the five longest new shoots of the Ilex plants grown in "one-gallon" containers was greater if the container medium had been soil-peat-sand rather than peat-perlite or pine bark-sand. The average length of the five longest shoots was 13.9 cm for the soil-peat-sand medium, 10.6 cm for the peat-perlite medium and 10.3 cm for the pine bark-sand medium. There was no effect of the media on the shoot length of Ilex plants grown in "two-gallon" containers.

The width, number of shoot terminals, and the growth index of the Ilex plants grown in "two-gallon" containers were greater five months after being transplanted than of plants grown in "one-gallon" containers (Table 7.2). The average length of the five longest shoots

Table 7.2. Effect of container size on the width, growth index, and number of shoot terminals of Ilex crenata 'Rotundifolia' 5 months after being transplanted.

Container Size	Width (cm)	Number of Terminals	Growth Index
One Gallon	42.2 b[z]	113.6 b	37.3 b
Two Gallon	46.6 a	129.8 a	40.1 a

[z]Mean separation within a column by Duncan's multiple range test, 5 percent level.

of the Ilex grown in the peat-perlite medium was greater at this time if the plants were grown in the "two-gallon" rather than in "one-gallon" containers (Table 7.3). The container size had no effect on the average shoot length of the Ilex plants grown in the soil-peat-sand and pine bark-sand container media. After being transplanted for 15 months, the growth index and the width of the Ilex plants were greater if the plants had been grown in "two-gallon" containers than in "one-gallon" containers (Table 7.4). The size of the container in which the plants were grown had no effect on the plant height, width or the dry weight of roots that had extended from the original container media into the backfill 15 months after being transplanted.

Table 7.3. Effect of container media and container size on the average length of the five longest shoots of Ilex crenata 'Rotundifolia' 5 months after being transplanted.

Container Media	Container Size	Mean Shoot Length (cm)
Peat-Perlite	One Gallon	10.6 b[z]
Peat-Perlite	Two Gallon	15.7 a
Soil-Peat-Sand	One Gallon	13.9 ab
Soil-Peat-Sand	Two Gallon	13.8 ab
Pine Bark-Sand	One Gallon	10.4 b
Pine Bark-Sand	Two Gallon	12.2 b

[z]Mean separation by Duncan's multiple range test, 5 percent level.

Table 7.4. Effect of container size on the width and growth index of *Ilex crenata* 'Rotundifolia' 15 months after being transplanted.

Container Size	Width (cm)	Growth Index
One Gallon	44.3 b[z]	39.5 b
Two Gallon	51.4 a	43.0 a

[z]Mean separation within a column by Duncan's multiple range test, 5 percent level.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

A larger number of woody ornamental plants are being grown in containers today than ever before. There are many advantages to this type of nursery production, but there are also some problems associated with the growing of plants in containers. One of these problems is concerned with the fact that the roots of container grown plants are often concentrated near the outside surface of the soil mass (43, 87). It has also been reported that roots may not readily move from the original container media into the undisturbed field soil when transplanted into the landscape (31). Many researchers have reported the effects of media on the top growth of various plants grown in containers (11, 18, 20, 31, 65, 66, 103), but the effects of the media on the root development and root distribution have not been reported.

Three container media were used in this study. The responses of plants grown in these different media to three container designs, and also the responses to various backfill compositions when transplanted into larger containers or into the landscape were established. Temperature fluctuations at three locations in the container media as affected by moisture content were also determined. One experiment was conducted to establish the effect of media particle size on root development and root distribution.

The three container media used in this study were peat-perlite, soil-peat-sand, and pine bark-sand. In a "one-gallon" container of

conventional design the number of Ilex crenata 'Green Luster' roots in the inside and middle concentric areas of the bottom two-thirds of the peat-perlite medium was greater than in the same divisions of the other two media. In a container with vertical dividers in the bottom, there were a greater number of Ilex roots in the outside area of the peat-perlite medium than in the containers of the other two designs. There was a greater number of Juniperus horizontalis 'Plumosa' roots in the top depth zone of the peat-perlite medium than in the other two media in the container with vertical dividers.

The number of Ilex crenata 'Green Luster' roots were more evenly distributed through the areas of each depth zone of the soil-peat-sand medium in the container with vertical dividers than in the containers of the other two designs. In the container of conventional design the number of Ilex roots in the outside area of all depth zones of the pine bark-sand medium was greater than in the same division of the other two media. Also in the container of conventional design the number of Juniperus roots in the bottom depth zone of the pine bark-sand medium was greater than in the same zone of the other two media.

In association with the distribution of roots in container media, an experiment was conducted to establish the effects of media particle size on the distribution of roots. Plants were grown in four media consisting of different particle sizes of sand. It was found that there was less of the total root system of Ilex crenata 'Rotundifolia' in the bottom two-thirds of the container media of smaller sand particles than in a container media with larger sand particles.

When Ilex crenata 'Green Luster' plants were transplanted from

"one-gallon" to "three-gallon" containers the addition of an amendment to the backfill soil increased the number of roots that had grown through the backfill in 6 weeks from all container media. The addition of the amendment to the backfill also increased the dry weight of roots in the backfill when the original container medium was soil-peat-sand or pine bark-sand. The addition of an amendment to the backfill increased the number of Juniperus horizontalis 'Plumosa' roots that had grown through the backfill from the soil-peat-sand and the pine bark-sand media, but not from the peat-perlite medium.

When Ilex crenata 'Green Luster' plants were grown in the peat-perlite medium and transplanted into the landscape, the addition of peat-perlite to the backfill soil increased the initial root movement through the backfill. The backfill composition had no effect on the initial movement of the Ilex roots from the soil-peat-sand or pine bark-sand media. After Ilex crenata 'Rotundifolia' and Juniperus horizontalis 'Blue Rug' had been transplanted into the landscape for 15 months, neither the container media, backfill composition or container size had an effect on the dry weight of roots that had grown from the container media.

Five months after being transplanted into the landscape the Ilex crenata 'Rotundifolia' plants that had been grown in "one-gallon" containers were taller if the backfill had been amended. The average shoot length of the Ilex plants that had been grown in the peat-perlite medium was greater after being transplanted 5 months if the container had been a "two-gallon" rather than a "one-gallon" size. There was no difference due to the media or backfill composition after 15 months.

An experiment was conducted in a growth chamber to establish the effects of moisture content on the temperature fluctuations at three locations in three container media. The three container media were composed of quite different materials as indicated by the bulk densities. However, the media differed little in their total porosity and water-holding capacity. For this reason the temperature recordings in the media at a high moisture content were equal. When the media were dry, their composition affected the mean maximum temperature at the various locations in the container media. The mean maximum temperature at the top location of the dry peat-perlite medium was 2°C higher than at the middle and bottom locations. In the soil-peat-sand medium the mean maximum temperature at the top location was higher than at the bottom location. The mean maximum temperature at the top location in the dry pine bark-sand medium was greater than at the middle location, which was greater than at the bottom location. There was a 3°C difference in the mean maximum temperature at the top and bottom locations in this dry medium.

This study has shown that the container media in which plants are grown can influence the response of these plants to specific growing conditions. Additional research is needed in order to establish the influence of various container media on the response of ornamental plants to diverse growing conditions.

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