THE EFFECTS OF PROPAGATION CONTAINER DEPTH,
DIAMETER, AND MEDIA ON THE GROWTH OF
FOUR WOODY ORNAMENTALS

By

CHARLES CHRISTOPHER THREADGILL

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Thesis Approved:

Carl Whitcomb
Thesis Adviser

Ray Campbell

Ronald W. McNew

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

The production of ornamental plants by cuttings is currently the most widely used method in the nursery industry. In many cases, cuttings are stuck closely spaced in ground beds or in flats. Advocates of this system note the advantage of more cuttings per square foot and the ability to reuse the propagation medium as the two main advantages. Others argue that the spread of root pathogens, shading, and inability to transplant the rooted cutting without damaging the roots are severe demerits of this system.

The use of a small container to propagate a single cutting, thus eliminating the problem of ground beds, is rapidly increasing.

While the interest in propagation in small containers increased, manufacturers had little if any research to define the boundaries of such containers. Consequently, the manufacturers filled the needs of the nurseryman with a vast array of propagation pot sizes, shapes, and colors.

About the same time the use of small containers in propagation began, the University of California was advocating the use of soilless mixes (2).

Prior to this, many nurserymen were using combinations of fine sandy loams, horse manure, leaf mold, sawdust, peanut hulls, flu ash, pumice, wood shavings, and others, but these materials were becoming scarce and non-uniform in performance. Baker (2) indicated in 1957, that the California Nursery Industry annually used an estimated 350,000 cubic yards of soil, or the top foot of soil from 217 acres. It became clear that a reliable, uniform product to substitute for this consumption of top soil was needed.

Vermiculite, perlite, and peat moss mixes have been used extensively as components of a lightweight media. These are highly uniform substances that reduce shipping weight and increase ease of handling.

The omission of soil from the growth medium has reduced many management problems and improved plant growth, but it has also emphasized the need to understand the physical and chemical nature of the components.

Media for rooting cuttings are generally characterized by the following (22):

A. The media must hold the cutting in position firmly without excessive compaction;

B. It must provide for proper oxygen-water relationships;

C. It should be free of pathogens;

D. Be of reasonable cost; and

E. Be lightweight for ease of handling (p. 18).

The use of lightweight components in asexual propagation has many advantages over the use of soils and is well documented (21) (29).

On the other hand, little research has been done to suggest an optimum size container for the propagation of woody ornamentals.

The research reported in this thesis was designed to study the effects of container depth, diameter, and propagation media on the propagation of cuttings of four woody ornamental species. A better understanding of the water holding relationships as affected by depth and medium was pursued.

The principle objective was to determine the optimum combination of container dimensions and medium for propagation by cuttings.

CHAPTER II

LITERATURE CITED

No one knows exactly when man started propagating plants from cuttings, but the phenomena nurserymen call rooting has made rapid advancement the last half-century.

In 1934, indole-acetic acid (IAA), the first natural growth regulator in plants, was identified and immediately used in an effort to promote root initials on cuttings (29). Van de Lek (30) and Went (31) coined the term "rhizocaline" for root promoting substances in 1925. Hess (17) identified additional root promoting substances reponsible for the initiation and growth of roots, which he designated as cofactors 1, 2, 3, and 4. These cofactors have never been identified conclusively, therefore, are not used commercially at the present time.

In 1936, a mist chamber was designed by Spencer to aid in the rooting of cocoa (9), and mist propagation was born. Although this first documented attempt was a failure, by the end of the decade several other researchers were evaluating mist systems with success. Gardner (12) propagated 194 species and cultivars of shrubs, trees, perennials, and evergreens. Of the 194, only 13 failed to root.

Initially, mist was applied continuously over the cuttings. However, studies by Hess and Snyder (28) in 1955 and Sharpe (25) in 1956 showed no statistical difference between intermittent mist and continuous misting.

Media Components

Peat has been a standard component of propagation and growth media for many years. Many materials have been used and vary from field soil to mixtures of organic and synthetic substances such as sawdust, wood shavings, ground hardwood and softwood bark, sands of various types and particle sizes, soil, rice hulls, vermiculite, calcined clay, styrofoam, perlite, treated wood fibers, and rockwool.

According to Hartmann and Kester (16) a propagation medium should meet the following requirements.

A. The medium must be sufficiently firm and dense to maintain the cutting in a properly oriented position.

B. It must minimize moisture loss from the submerged portion of the cutting.

C. It must be sufficiently porous so that excessive water drains away, permitting adequate aeration.

D. It must be free from pests and disease organisms (p. 37).

Although these factors cannot be overlooked, Reisch (24) included additional considerations.

A. Inexpensive

B. Readily available and reproducible

C. Uniform and long lasting

D. Free from disease, insects, nematodes, and toxic substances

E. Easily managed

F. Well drained, with desirable air-water relations

G. Uniform temperature

H. Fairly constant in volume wet or dry (p. 78).

Matkin (22) noted the importance of the free porosity or air space in the medium. He suggested that the three physical properties a propagation media should have are: (A) free porosity as high as practical under the circumstances, (B) as deep as possible since the depth of the medium column affects the air supply, and (C) no layer of coarse material should be placed in the bottom of rooting containers since this shortens the column and raises the water table in the medium.

Past and present research continues to demonstrate the influence of propagation media on plant performance, however, there has been no research to indicate that the medium has any direct effect on root initiation.

To date, many researchers and commercial growers have found variable success with rooting plants in different media. This indicates that there is no one best medium for all plants and all conditions. The variable results are probably due to plant type, condition of the cutting, season, light, temperature, drainage, means of watering, type of structure, hormone treatments, and other factors.

Although the medium does not have a direct influence on root initiation, it may have a marked effect on root elongation, structure of root system, plant survival, and success in transplanting. For example, Long (21) indicated that many cuttings will root readily in a peat and sand (1:1) mixture, but roots of some will rapidly begin to rot due to an unfavorable air-water relation. He also indicated that finer roots were produced in 100% peat as opposed to sand. However, when the peat was kept at a low moisture content, the coarseness of roots approached those formed in sand. Chadwick (5) also found that roots of Taxus spp. were more fibrous and less brittle in peat than in sand. Franklin (11) indicated that roots formed in vermiculite were more fibrous than in sand, however, Bos (3) found the opposite to be true on cutting of *Philadelphus coronarius* 'Aarens'.

Cook and Dunsky (6) evaluated the use of perlite for propagation, and concluded that the presence of perlite facilitates rooting and allowed cuttings to root quicker than peat-sand treatments. Loach (20) observed this same phenomena in the rooting of *Skimmia japanica*.

Phipps (23) compared nine growth media for the production of *Pinus resinosa*, Red Pine seedlings. After 16 weeks, differences in stem length and diameter showed the peat-vermiculite (1:1) mix significantly superior to all others.

Ferguson and Monsen (10) also indicated that peat-vermiculite (1:2) gave the best results in producing *Cerco carpus montanus*, Mountain-Mahogany.

Container Drainage

The air-filled pore space following drainage is an important aspect of soilless mixes. It is through these air-filled pores that gases are exchanged with the atmosphere. This pore space (drainable pore space) is influenced by particle size and proportions used in the soilless mix. The calculation for drainable pore space is:

$$\text{D.P.S.} = \frac{\text{Volume drained from container ml}}{\text{Volume of water added to saturate container}}$$

Hanan (14) points out that restricted aeration in soilless media can be (A) the greatest limiting factor in the development of an extensive root system, (B) impair the essential process of respiration of an established root system by retarding both water and

and nutrient absorption, (C) prevent the orderly functioning of essential biological processes associated with good soil fertility, and (D) increase the probability of root disease problems.

White (33) suggested that for a specific soil mixture and container conformation there is a unique container capacity value, which designates the upper limit of available water for that soil and for that type and depth of container.

Most ornamental plants are propagated as seedlings or cuttings and many spend their entire life in containers. Spomer (27) indicates that the soil mass in these containers typically share two important characteristics in relation to water: smallness and shallowness. The effect of smallness simply corresponds to an inadequate water supply, however, the effect of shallowness is responsible for an excessive water content and is less obvious. The height of the container and texture of components within determine the height of the perched water table within the soil mass. A perched water table exists within the container because it is open to the atmosphere at its top and bottom. This dilemma occurs in all containers, therefore, for a given soilless mix, the average water content decreases as the average height increases (27).

Container Dimensions

The principles involved in container soil-water relations are well documented (15) (18) (26). This is not the case for studies of container dimensions. The author finds it amazing that factors so closely related to the soil-plant-air continuum as depth and diameter could have escaped critical analysis.

Whitcomb (32) studied the effects of pot sizes on the rooting of juniper cuttings. Average root grade (on a 1-10 scale) and percent of the cutting that graded four or better increased with container volume up to the 598 cc (36.5 cu. in.) capacity pot (3.5" x 3.5" x 3"), which had the highest root grades. Root grade and percent graded four or better were significantly lower when propagated in a 1605 cc (98 cu. in.) pot (6" round x 4.75" deep).

Davis and Whitcomb (7) examined the effects of five container depths and three container diameters using bottomless milk carton containers. Container depths of 7.62, 15.24, 22.86, 30.48, and 38.1 cm. (3, 6, 9, 12, and 15 in.) and widths of 3.81, 5.08, and 6.35 cm. (1.5, 2, and 2.5 in.) were studied. They found containers 6.35 cm. (2.5 in.) in width and 15.24 to 30.48 cm. (6 to 12 in.) deep to be the most promising for tree seedling production.

The effects of container diameter on the production of tree seedlings in square bottomless containers was studied by Gibson and Whitcomb (13). They evaluated the effects of three container diameters at a constant depth using Quercus rubra, Northern red oak, Pistacia chinensis, Chinese pistache, and Pinus thunbergiana, Japanese black pine as test species. They concluded that the oak and pistache responded to the increase in diameter with a significant increase in stem caliper, visual grade, and fresh root weight. The pines grew significantly taller and had a higher visual grade when grown in the two smaller containers.

In 1979, Whitcomb and Williams (34) evaluated the effects of three container depths, 8.89, 13.97, and 19.05 cm. (3.5, 5.5, and 7.5 in.) and three diameters, 4.45, 5.70, and 6.98 cm. (1.75, 2.25, and 2.75 in.) on the production of tree seedlings. They concluded that significant increases in height, caliper, top and root weights occurred for all species tested when container depth increased from 8.89 cm. (3.5 in.) to the 13.97 cm. (5.5 in.) depth, and that increasing the container diameter promoted more seedling growth compared to the narrower containers.

Appleton and Whitcomb (1) studied the effects of container size and transplant date on the growth of tree seedlings. Four container sizes 671 cc. (41 cu. in.), 360 cc. (22 cu. in.), 196 cc. (12 cu. in.), 147 cc. (9 cu. in.) and three transplant dates were evaluated in this study. All tree seedlings grown in the 671 cc. (41 cu. in.) container were taller, and had greater stem caliper, and greater number of branches than those grown in the smaller containers. This difference was still apparent 18 months from the seed planting date.

In a study conducted in 1979, Bowlin and Whitcomb (4) observed significant differences in visual root grade of Juniperus sabina 'Tamariscifolia', tam juniper rooted in four container volumes, 115, 172, 327, and 452 cc. (7, 10.5, 20, and 27.6 cu. in.) with the largest volume being the best treatment.

CHAPTER III

METHODS AND MATERIALS

Treatments were square bottomless containers with three container depths and three diameters in factorial combination with three propagation media. Container depths were 5.08, 6.98, and 10.16 cm. (2.0, 2.75, and 4.0 in.) in combination with widths of 4.57, 5.58, and 6.60 cm. (1.8, 2.2, and 2.6 in.). The nine depth x diameter combinations create five container volumes (Table I).

TABLE I

DEPTH, WIDTH COMBINATIONS AND VOLUME OF CONTAINERS

Diameter cm. (in.)	Depth cm. (in.) 5.08 (2.0)	6.98 (2.75)	10.16 (4.0)
4.57 (1.8)	106*(6.5)**	146 (8.0)	212 (13.0)
5.58 (2.2)	158 (9.7)	217 (13.3)	316 (19.3)
6.60 (2.6)	221(13.5)	304 (18.6)	442 (27.0)

*Volume in cm^3.

**Volume in in^3.

The three propagation media used in the study were peat moss and coarse perlite, 1:1 by volume, peat moss 100%, and peat moss and vermiculite, 1:1 by volume. The resulting 27 treatment combinations were replicated six times with four subsamples per treatment. A split plot design was used during propagation.

Flats 35.5 x 40.5 cm. (14 x 16 in.) with mesh bottoms were used to support the bottomless containers. Each flat held the nine pot dimensions and four subsamples per treatment with equal spacing so that shading among containers with different depths would not be a factor. All containers within a flat were filled with the same medium. Three flats of different media made up one replication.

The containers were made from milk carton stock to create the desired depths and diameters.

All treatments contained Osmocote 18-6-12 at 3.56 kg/m^3 (6.1bs/yd^3), and Micromax micronutrients at 0.593 kg/m^3 (1 lb/yd^3). Each medium was mixed in a rotating drum concrete mixer to insure equal distribution of nutrients.

Terminal stem cuttings of mojave pyracantha *Pyracantha* x 'mojave', burford holly *Ilex cornuta* 'Burfordi', san jose juniper, *Juniperus chinensis* 'San Jose', and dwarf yaupon holly *Ilex Vomitoria* 'Nana', were taken on December 14-20, 1981, from established landscape plants. Cuttings 10-15 cm. (4-6 in.) in length were selected on the basis of stem diameter and overall appearance, trimmed to a uniform height and stripped of the lower leaves. Yaupon and burford holly were treated with 0.8 percent (8000 ppm) IBA (talc preparation) and the mojave pyracantha and san jose juniper were treated with 0.20 and 1.6 percent (2500 and 16000 ppm) respectively.

After filling, the containers were placed in an unshaded fiber-glass greenhouse under a mist cycle of 4 seconds every 4 minutes during the daylight hours. Heat was provided by a gas fired heater and distributed with a convection tube beneath the benches. Temperature was maintained at a minimum of 36°C (65°F). After most of the cuttings were rooted they were moved to a gas heated greenhouse to harden off.

On March 22-24, 1982, 2 of the 4 subsamples of each species were terminated and root visual grade, fresh root, and shoot weight determined. The root grades were determined visually using a 1-10 scale with pre-selected examples where 1 = no roots, 4 = minimal roots, 7 = satisfactory roots, and 10 = excellent roots.

On April 14-20, 1982, the remaining two subsamples of san jose juniper and dwarf yaupon holly were potted into 3.8 L (1 gal.) poly bags, and grown on a poly covered ground bed in full sun.

Only one of the two remaining subsamples of mojave pyracantha and burford holly were transplanted. The pyracantha were potted into 7.5 L (2 gal.) ridgid plastic containers and placed on a poly covered ground bed in full sun. The burford holly were transplanted into 3.8 L (1 gal.) poly bags and were grown in a quonset structure covered with 30% shade cloth. After the transplants were established in the larger containers, the burford holly and mojave pyracantha were pruned once to stimulate branching.

A soilless medium consisting of ground pine bark, peat moss, and coarse sand, 3:1:1 by volume, was used for all species. Incorporated into this medium was Osmocote 17-7-12, Osmocote 18-6-12, dolomitic limestone and Micromax micronutrients at 5.93, 2.37, 2.37, and .89 kg/m^3 respectively (10, 4, 4, and 1.5 lb/yd^3).

Water was applied by overhead sprinklers as needed at approximately 2.5 cm (1 in.) of water per application. Ronstar 2 G at

3.62 kg/ha. (8 lbs AIA) was applied April 25 and August 21, 1982, to control weeds.

A randomized complete block design with six replications was used during the growing season for each species. Final evaluations of fresh root and shoot weight, and branch counts were made at termination of the experiment during November 2-22, 1982.

Physical Characteristics and Water Holding Relationships of Container Media

Container depth and the porosity of the mix affect drainage from a container. A second experiment was designed to evaluate the effects of three container depths and three media on drainage characteristics. Three container depths [(5.08, 6.98, and 10.16 cm.), (2.0, 2.75, and 4.0 in.)] and three container media (1:1 peat-perlite, 100% peat, and 1:1 peat-vermiculite) were set up in factorial combination with six replications and four subsamples. The intermediate container diameter 5.58 cm. (2.2 in.) was used in all treatments. A split plot design was used, with depth stripped within the main unit treatment, media. All containers were hand made from milk cartons as before.

The individual milk cartons were lined with a thin film of plastic and filled with the appropriate medium. Water was added to the containers until the medium was saturated. The volume of H_2O added to reach saturation was recorded for each individual container. After 48 hrs. under saturated conditions the plastic linings were punctured and the free water collected for one hour.

Total pore space, air filled pore space at container capacity, percent drainable pore space, and water held at container capacity were determined by the following equations.

Total Pore Space$_{cc}$ (TPS) = Amount of water required to fill container to point of saturation

Air Filled Pore Space at Container Capacity$_{cc}$ = TPS - Volume of water drained from saturated container

$$\text{Percent Drainable Pore Space} = \frac{\text{H2O drained from saturated containers}}{\text{Volume of water added to saturate container}}$$

Water Held at Container Capacity = TPS - Air filled pore space at container capacity

Volume Comparisons

At the onset of the first study the levels of depth and diameter were selected such that similar volumes with different depth-diameter combinations could be compared. Table II illustrates the five general volumes classes developed in the study.

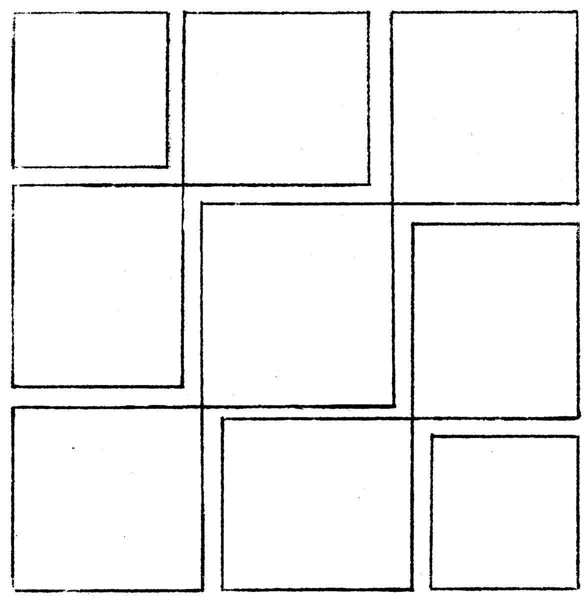
If plants were responding to volume exclusively, then regardless of the depth-diameter combination, those pots with the approximate volumes should have similar plant responses.

All the data generated throughout the duration of the experiment was analyzed a second time using volume trend analysis. In this case, the plant responses associated with the nine depth-diameter combinations were grouped into five volume classes (Table II).

TABLE II

FIVE VOLUME CLASSES WITHIN THE NINE DEPTH-DIAMETER TREATMENTS

Diameter cm. (in.)	Depth cm. (in.) 5.08 (2.0)	6.98 (2.75)	10.16 (4.0)
4.57 (1.8)			
5.58 (2.2)			
6.60 (2.6)			



CHAPTER IV

RESULTS AND DISCUSSION

Propagation Phase

Fourteen weeks after the cuttings were stuck, an evaluation of visual root grade, root weight, and shoot weight showed that plant response was most affected by rooting media.

Burford holly and mojave pyracantha root weight, shoot weight, and visual root grades were significantly greater in the peat and perlite and peat and vermiculite when compared to 100% peat (Tables III and V). No significant differences between peat and perlite and 100% peat were detected with the san jose juniper. However, peat and vermiculite was significantly lower than either peat and perlite or straight peat for all plant responses recorded (Table IV). Yaupon holly visual root grades were significantly greater in the peat and perlite than the straight peat rooting medium (Table VI).

Johnson and Hamilton (19) found that after 12 weeks _Juniperus conferta_ and _Ligustrum spp_. cuttings had significantly heavier roots when propagated in a peat and sand (1:1 ratio) medium when compared to 100% peat. They concluded that this effect was due to the nutrient holding capacity of peat.

Root weight of yaupon holly increased with increasing depth of the propagation container (Table VI). Visual root grade and shoot weights of the 6.98 cm. (2.75 in.) depth were significantly higher

TABLE III

RESPONSE OF BURFORD HOLLY TO VARIOUS CONTAINER DIMENSIONS AND MEDIA DURING PROPAGATION

Container Media	Root Weight (g)	Shoot Weight (g)	Visual Root Grade[y] (g)
P+P	1.33a[z]	2.91a	5.37a
P	0.79b	2.25b	3.65b
P+V	1.46a	3.28a	5.63a
Container Depth cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Visual Root Grade[y] (g)**
5.08 (2.0)	1.06a	3.15a	4.61ab
6.98 (2.75)	1.39b	3.10a	5.56b
10.16 (4.0)	1.13ab	2.19b	4.49a
Container Diameter cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Visual Root Grade[y] (g)**
4.57 (1.8)	0.87a	2.27a	3.98a
5.58 (2.2)	1.29b	3.06b	5.22b
6.60 (2.6)	1.42b	3.11b	5.48b

[y]Based on a scale 1 = poor; 10 = excellent.

[z]Means followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE IV

RESPONSE OF SAN JOSE JUNIPER TO VARIOUS CONTAINER DIMENSIONS AND MEDIA DURING PROPAGATION

Container Media	Root Weight (g)	Shoot Weight (g)	Visual Root Grade[y] (g)
P+P	1.29a[z]	5.84a	5.14a
P	1.23a	5.91a	5.03a
P+V	1.05b	5.33b	4.39b
Container Depth cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Visual Root Grade[y] (g)**
5.08 (2.0)	1.12a	5.98a	4.81a
6.98 (2.75)	1.26b	5.82a	5.31b
10.16 (4.0)	1.19ab	5.29b	4.50a
Container Diameter cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Visual Root Grade[y] (g)**
4.57 (1.8)	1.15a	5.50a	4.55a
5.58 (2.2)	1.17a	5.71a	4.90ab
6.60 (2.6)	1.25a	5.88a	5.12b

[y]Based on a scale 1 = poor; 10 = excellent.

[z]Means followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE V

RESPONSE OF MOJAVE PYRACANTHA TO VARIOUS CONTAINER DIMENSIONS AND MEDIA DURING PROPAGATION

Container Media	Root Weight (g)	Shoot Weight (g)	Visual Root Grade[y] (g)
P+P	0.73a[z]	1.70a	3.86a
P	0.37b	0.95b	2.55b
P+V	0.75a	1.47a	3.75a
Container Depth cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Visual Root Grade[y] (g)**
5.08 (2.0)	0.58a	1.26a	3.27a
6.98 (2.75)	0.58a	1.35a	3.31a
10.16 (4.0)	0.68a	1.46a	3.58a
Container Diameter cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Visual Root Grade[y] (g)**
4.57 (1.8)	0.59a	1.35a	3.34a
5.58 (2.2)	0.51a	1.23a	3.08a
6.60 (2.6)	0.74b	1.49a	3.75a

[y]Based on a scale 1 = poor; 10 = excellent.

[z]Means followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE VI

RESPONSE OF DWARF YAUPON HOLLY TO VARIOUS CONTAINER DIMENSIONS AND MEDIA DURING PROPAGATION

Container Media	Root Weight (g)	Shoot Weight (g)	Visual Root Grade[y] (g)
P+P	0.36a[z]	0.82a	6.22a
P	0.32a	0.81a	5.20b
P+V	0.35a	0.76a	5.75ab
Container Depth cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Visual Root Grade[y] (g)**
5.08 (2.0)	0.25a	0.75a	4.75a
6.98 (2.75)	0.36b	0.84b	6.23b
10.16 (4.0)	0.42c	0.80ab	6.29b
Container Diameter cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Visual Root Grade[y] (g)**
4.57 (1.8)	0.31a	0.75a	5.24a
5.58 (2.2)	0.33a	0.77a	5.76ab
6.60 (2.6)	0.39b	0.87b	6.17b

[y]Based on a scale 1 = poor; 10 = excellent.

[z]Means followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

than the 5.08 cm. (2.0 in.) depth. However, there was no differences between the 6.98 cm. (2.75 in.) and 10.16 cm. (4.0 in.) depths, and the added benefits of a deeper pot were questionable at this stage of the experiment. Gibson and Whitcomb (13) observed this, in regards to container depth, in the production of Japanese Black Pine in square bottomless containers.

As container depth increased from 5.08 cm. (2 in.) to 6.98 cm. (2.75 in.) there was a significant increase in root weight of burford holly (Table III) and san jose juniper (Table IV). However, as the container depth increased to 10.16 cm. (4 in.) root weight, shoot weight, and visual root grade were less than when container depth was 6.98 cm. (2.75 in.). Container depth had no effect on rooting, growth, or appearance of pyracantha (Table V).

Significant increases in root weight, shoot weight, and visual root grade for burford holly were observed with an increase from 4.57 cm. (1.8 in.) to the 5.58 cm. (2.2 in.) diameter container (Table III). With yaupon holly, however, a significant difference occurred between 4.57 cm. (1.8 in.) and 6.60 cm. (2.6 in.) diameter.

At this point in the study the best treatment, in general, appeared to be a combination of the intermediate depth, 6.98 cm. (2.75 in.) and the largest diameter, 6.60 cm. (2.6 in.) with peat and perlite as the propagation medium. The most perplexing of these results was the plant response to container depth. With every increase in container depth, regardless of mix, percent drainable pore space increases as well as the air filled pore space at container capacity (Tables XIII and XV). The saturated conditions synonomous with shallower containers diminishes as depth increases. An increase in root grade and root weight was expected as increased depth made more "favorable" $O_2 - H_2O$ conditions. Analysis of the propagation phase showed that what we assumed was more favorable became less favorable with a continuing increase in depth. This suggests that a critical moisture-oxygen balance may be more important than simply more oxygen as has previously been assumed. Perhaps the basal end of the cutting was "too wet" in the shallowest of containers and "too dry" in the deepest containers.

Production Performance

After transplanting into larger containers and a full growing season, a second and final evaluation of plant response showed a totally different picture of plant response to treatments imposed during propagation.

Significant differences in media used during propagation were still evident, however, the 100% peat treatment that was generally poorest after the first evaluation, had now significantly increased branch count, root weight, and shoot weights of all four species (Tables VII, VIII, IX and X).

Diver and Whitcomb (8) observed a similar response when evaluating slow release nutrition and media in the propagation of tam juniper. In their study, however, the 100% peat resulted in significantly heavier roots and higher root grades after propagation, as well as after one growing season.

San jose juniper shoot weight, and yaupon holly root weight, shoot weight, and branch count were significantly greater as a result of the 6.98 cm. (2.75 in.) deep propagation container compared to the 5.08 cm. (2.0 in.) depth (Tables VIII and X).

Depth of propagation container had no effect on burford holly (Table VII) or mojave pyracantha (Table IX).

No statistical differences between the 6.98 cm. (2.75 in.) and 10.16 cm. (4.0 in.) depths were observed for any parameter of the species after one growing season.

Of the four species evaluated in this study, san jose juniper was the only plant responding to increased propagation container diameter. Shoot weight, root weight, and branch count means were all significantly greater at the 6.60 cm. (2.6 in.) diameter compared to the 4.57 cm. (1.8 in.) diameter (Table VIII).

A significant mix x depth interaction for yaupon holly shoot weights and branch counts was indicated by the analysis of data collected at the termination of the experiment (Tables XI and XII).

The failure of the differences between depth means to respond similarly for the three media is evidence of interaction. For shoot weights and branch counts of yaupon holly, the 100% peat in propagation allowed the plants to produce more top growth during the growing season. Again, this response is due to factors during propagation, with the combination of peat and the 10.6 cm (4 in.) depth of propagation container being the best treatment for this species.

Container Drainage Study

Hanan (14) and White (33) point out that aeration of the medium can be the greatest limiting factor in the development of an extensive root system in containers.

An analysis of drainable pore space (Table XV) and air filled pore space at container capacity (Table XVII) indicates that the 100% peat

TABLE VII

RESPONSE OF BURFORD HOLLY TO VARIOUS CONTAINER DIMENSIONS AND MEDIA AFTER ONE GROWING SEASON

Container Depth cm. (in.)	Root Weight (g)	Shoot Weight (g)
5.08 (2.0)	44.75a[z]	43.16a
6.98 (2.75)	47.12a	43.80a
10.16 (4.0)	47.81a	44.27a
Container Diameter cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**
4.57 (1.8)	44.01a	42.91a
5.58 (2.2)	47.12a	41.77a
6.60 (2.6)	48.55a	46.55a
Container Media	**Root Weight (g)**	**Shoot Weight (g)**
P+P	42.94a	40.80a
P	50.81b	47.59b
P+V	45.94a	42.85a

[z]Means followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE VIII

RESPONSE OF SAN JOSE JUNIPER TO VARIOUS CONTAINER DIMENSIONS AND MEDIA AFTER ONE GROWING SEASON

Container Depth cm. (in.)	Root Weight (g)	Shoot Weight (g)	Branch Count
5.08 (2.0)	53.25a[z]	130.94a	4.48a
6.98 (2.75)	55.63a	144.47b	4.86a
10.16 (4.0)	56.35a	139.99b	4.47a
Container Diameter cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Branch Count**
4.57 (1.8)	52.58a	126.12a	4.18a
5.98 (2.2)	55.61ab	140.43b	4.65ab
6.60 (2.6)	57.04b	148.85b	4.97b
Container Media	**Root Weight (g)**	**Shoot Weight (g)**	**Branch Count**
P+P	53.57a	137.35b	4.50a
P	60.75b	156.98c	5.17b
P+V	51.11a	121.07a	4.12a

[z]Means followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE IX

RESPONSE OF MOJAVE PYRACANTHA TO VARIOUS CONTAINER DIMENSIONS AND MEDIA AFTER ONE GROWING SEASON

Container Depth cm. (in.)	Root Weight (g)	Shoot Weight (g)
5.08 (2.0)	152.26a[z]	249.74a
6.98 (2.75)	147.03a	255.41a
10.16 (4.0)	155.49a	267.30a
Container Diameter cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**
4.57 (1.8)	155.6a	258.47a
5.58 (2.2)	149.62a	264.30a
6.60 (2.6)	149.80a	249.68a
Container Media	**Root Weight (g)**	**Shoot Weight (g)**
P+P	151.09a	258.05ab
P	149.36a	270.46a
P+V	154.33a	243.94b

[z]Means followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE X

RESPONSE OF DWARF YAUPON HOLLY TO VARIOUS CONTAINER DIMENSIONS AND MEDIA AFTER ONE GROWING SEASON

Container Depth cm. (in.)	Root Weight (g)	Shoot Weight (g)	Branch Count
5.08 (2.0)	31.70a[z]	21.27a	52.97a
6.98 (2.75)	40.29b	28.09b	72.92b
10.16 (4.0)	43.96b	31.78b	79.29b
Container Diameter cm. (in.)	**Root Weight (g)**	**Shoot Weight (g)**	**Branch Count**
4.57 (1.8)	38.50a	26.27a	67.45a
5.58 (2.2)	39.91a	28.94a	71.45b
6.60 (2.6)	37.53a	25.93a	66.28a
Container Media	**Root Weight (g)**	**Shoot Weight (g)**	**Branch Count**
P+P	35.43a	23.84a	62.32a
P	46.17b	34.50b	83.54b
P+V	34.35a	22.80a	59.32a

[z]Means followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

contains the largest volume of air of the three media evaluated in the study. If Hanan (14) and White (33) are correct in their assessment of aeration, then perhaps the benefits of peat, which are apparent in plant growth at the end of the study, could be the result of aeration. This is further supported by the pattern of yaupon holly shoot weight means in the depth x media interaction, and a similar pattern found in the drainable pore space means in the second experiment (Tables XV, XIX, and XX).

Trend Analysis of Volume Comparisons

In general, plant response was linear to increased container volume during propagation (Tables XI through XIV). This response to container volume is not surprising, because as volume is increased, depth, diameter, or both are also increased.

There were nine depth-diameter combinations fitted into five volume classes. As Table II illustrates, treatment 1 (depth 1, diameter 1) and treatment 9 (depth 3, diameter 3) stand alone as sole representatives of their corresponding volume classes. The remaining seven depth-diameter combinations fall into one of the three remaining volume classes.

If the plants were responding to container volume alone, then the means of any depth-diameter combination within a certain volume class should be similar and not significant, using trend analysis. In general, lack of fit was significant, suggesting depth and diameter was more influential to plant response than volume (Tables XVII through XX).

TABLE XI

DEPTH x MEDIA INTERACTION ON SHOOT WEIGHTS[y] OF YAUPON HOLLY AT TERMINATION

	Depth cm. (in.)		
Media	5.08 (2.0)	6.98 (2.75)	10.16 (4.0)
P+P	17.6	26.7	27.2
P	26.5	33.6	43.4
P+V	19.7	23.8	24.8

[y]Shoot weights in grams.

TABLE XII

DEPTH x MEDIA INTERACTION ON BRANCH COUNT OF YAUPON HOLLY AT TERMINATION

	Depth cm. (in.)		
Media	5.08 (2.0)	6.98 (2.75)	10.16 (4.0)
P+P	46.3	70.8	69.8
P	62.0	86.8	101.9
P+V	50.6	61.2	66.1

TABLE XIII

PERCENT DRAINABLE PORE SPACE (AIR SPACE) IN THREE CONTAINER DEPTHS WITH THREE MEDIA

	Depth cm. (in.)		
Media	5.08 (2.0)	6.98 (2.75)	10.16 (4.0)
P+P	21.3	20.7	20.5
P	23.5	22.9	24.1
P+V	16.0	18.3	18.9

TABLE XIV

TOTAL PORE SPACE (cc) IN THREE CONTAINER DEPTHS WITH THREE MEDIA

	Depth cm. (in.)		
Media	5.08 (2.0)	6.98 (2.75)	10.16 (4.0)
P+P	116	157	215
P	118	163	220
P+V	121	163	226

TABLE XV

AIR FILLED PORE SPACE AT CONTAINER CAPACITY (cc) IN THREE CONTAINER DEPTHS WITH THREE MEDIA

	Depth cm. (in.)		
Media	5.08 (2.0)	6.98 (2.75)	10.16 (4.0)
P+P	25	33	44
P	28	37	54
P+V	19	30	43

TABLE XVI

WATER FILLED PORE SPACE AT CONTAINER CAPACITY (cc) IN THREE CONTAINER DEPTHS WITH THREE MEDIA

	Depth cm. (in.)		
Media	5.08 (2.0)	6.98 (2.75)	10.16 (4.0)
P+P	91	124	171
P	90	125	167
P+V	102	134	183

TABLE XVII

RESPONSE OF BURFORD HOLLY TO CONTAINER DESIGN DURING PROPAGATION USING VOLUME TREND ANALYSIS AND LACK OF FIT

	Volume					
	106 (6.48)	152 (9.29)	217 (13.26)	310 (18.97)	442 cc (27.04 cu. in.)	Trend Analysis
Propagation Phase:						
Root Grade	3.55	4.18	3.39	2.61	2.5	.013 linear*
Lack of Fit[z]	--	N.S.	N.S.	N.S.	--	
Root Weight (g)	0.835	1.114	1.140	1.445	1.428	.014 linear
L.O.F.	--	N.S.	.047	N.S.	--	
Shoot Weight (g)	2.746	2.967	2.740	2.917	2.626	N.S.**
L.O.F.	--	N.S.	.0001	.0395	--	
Production Phase:						
Root Weight (g)	43.66	45.59	44.74	49.16	51.55	.028 linear
L.O.F.	--	N.S.	N.S.	N.S.	--	
Shoot Weight (g)	43.22	41.87	44.02	42.49	49.72	N.S.
L.O.F.	--	N.S.	N.S.	N.S.	--	

[z]When Lack of Fit (L.O.F.) analysis is significant (i.e., OSL < .05) propagation container volume is not a primary factor influencing plant response. When L.O.F. is not significant (N.S.), propagation container volume may be a factor influencing plant response.

*When the Trend Analysis (.013 in this case) and the trend (linear) are specified, all remaining trends are non-significant (i.e., quadratic, cubic, and quartic).

**N.S. indicates that none of the trends were significant.

TABLE XVIII

RESPONSE OF SAN JOSE JUNIPER TO CONTAINER DESIGN DURING PROPAGATION USING VOLUME TREND ANALYSIS AND LACK OF FIT

	Volume					
	106 (6.48)	152 (9.29)	217 (13.26)	310 (18.97)	442 cc (27.04 cu. in.)	Trend Analysis
<u>Propagation Phase</u>:						
Root Grade	4.53	4.76	4.73	4.72	4.94	N.S.**
Lack of Fit[z]	--	N.S.	N.S.	.0008	--	
Root Weight (g)	1.12	1.17	1.18	1.18	1.35	N.S.
L.O.F.	--	N.S.	N.S.	.052	--	
Shoot Weight (g)	5.89	5.80	5.69	5.50	5.72	N.S.
L.O.F.	--	N.S.	.0232	.0069	--	
<u>Production Phase</u>:						
Branch Count	4.19	4.22	4.72	5.05	4.52	N.S.
L.O.F.	--	N.S.	.0375	N.S.	--	
Root Weight (g)	52.58	52.11	55.18	57.32	58.72	.0115 linear*
L.O.F.	--	N.S.	N.S.	N.S.	--	
Shoot Weight (g)	122.83	131.19	136.18	150.75	150.94	.0001 linear
L.O.F.	--	N.S.	.0541	.0282	--	

[z]When Lack of Fit (L.O.F.) analysis is significant (i.e., OSL < .05) propagation container volume is not a primary factor influencing plant response. When L.O.F. is not significant (N.S.), propagation container volume may be a factor influencing plant response.

*When the Trend Analysis (.0115 in this case) and the trend (linear) are specified, all remaining trends are non-significant (i.e., quadratic, cubic, and quartic).

**N.S. indicates that none of the trends were significant.

TABLE XIX

RESPONSE OF PYRACANTHA TO CONTAINER DESIGN DURING PROPAGATION USING VOLUME TREND ANALYSIS AND LACK OF FIT

	Volume					
	106 (6.48)	152 (9.29)	217 (13.26)	310 (18.97)	442 cc (27.04 cu. in.)	Trend Analysis
Propagation Phase:						
Root Grade	2.94	2.96	2.90	3.08	3.47	N.S.**
Lack of Fit[z]	--	N.S.	N.S.	N.S.	--	
Root Weight (g)	0.486	0.610	0.586	0.628	0.854	.054 linear*
L.O.F.	--	N.S.	N.S.	N.S.	--	
Shoot Weight (g)	1.19	1.32	1.33	1.41	1.61	N.S.
L.O.F.	--	N.S.	N.S.	N.S.	--	
Production Phase:						
Root Weight (g)	157.94	151.64	151.55	145.22	161.44	N.S.
L.O.F.	--	N.S.	N.S.	N.S.	--	
Shoot Weight (g)	273.0	250.37	250.81	255.85	282.44	.0084 Quad.
L.O.F.	--	N.S.	.0194	N.S.	--	

[z]When Lack of Fit (L.O.F.) analysis is significant (i.e., OSL < .05) propagation container volume is not a primary factor influencing plant response. When L.O.F. is not significant (N.S.), propagation container volume may be a factor influencing plant response.

*When the Trend Analysis (.054 in this case) and the trend (linear) are specified, all remaining trends are non-significant (i.e., quadratic, cubic, and quartic).

**N.S. indicates that none of the trends were significant.

TABLE XX

RESPONSE OF YAUPON HOLLY TO CONTAINER DESIGN DURING PROPAGATION USING VOLUME TREND ANALYSIS AND LACK OF FIT

	Volume					
	106 (6.48)	152 (9.29)	217 (13.26)	310 (18.97)	442 cc (27.04 cu. in.)	Trend Analysis
<u>Propagation Phase</u>:						
Root Grade	4.25	5.40	5.15	5.71	5.42	.0419 linear*
Lack of Fit[z]	--	N.S.	N.S.	N.S.	--	
Root Weight (g)	.231	.317	.304	.424	.505	.0001 linear
L.O.F.	--	N.S.	N.S.	N.S.	--	
Shoot Weight (g)	.728	.787	.765	.869	.880	.0312 linear
L.O.F.	--	N.S.	N.S.	N.S.	--	
<u>Production Phase</u>:						
Branch Count	54.97	65.44	65.62	74.68	83.47	.0001 linear
L.O.F.	--	.0233	.0001	N.S.	--	
Root Weight (g)	32.27	35.86	38.91	42.09	42.97	.0010 linear
L.O.F.	--	N.S.	.0002	N.S.	--	
Shoot Weight (g)	21.94	24.66	26.99	29.36	32.50	.0002 linear
L.O.F.	--	N.S.	.0003	.0286	--	

[z]When Lack of Fit (L.O.F.) analysis is significant (i.e., OSL < .05) propagation container volume is not a primary factor influencing plant response. When L.O.F. is not significant (N.S.), propagation container volume may be a factor influencing plant response.

*When the Trend Analysis (.0419 in this case) and the trend (linear) are specified, all remaining trends are non-significant (i.e., quadratic, cubic, and quartic).

Conclusions

The production of woody ornamentals in square bottomless containers appears to be affected by container dimension. The intermediate depth 6.98 cm. (2.75 in.) and intermediate diameter 5.58 cm. (2.2 in.) appears to be the superior combination for this system.

The use of peat as the sole component in propagation media (with recommended rates of Osmocote and Micromix blended throughout) is superior to the peat and perlite and peat and vermiculite blends.

This system of production continues to perform admirably. With continued research, further refinements could allow for even better performance in the future.

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VITA

Charles Christopher Threadgill

Candidate for the Degree of

Master of Science

Thesis: THE EFFECTS OF PROPAGATION CONTAINER DEPTH, DIAMETER, AND MEDIA ON THE GROWTH OF FOUR WOODY ORNAMENTALS

Major Field: Horticulture

Biographical:

Personal Data: Born in Memphis, Tennessee, March 20, 1958, the son of Mr. and Mrs. F. W. Threadgill.

Education: Graduated from West Des Moines Dowling High School, Des Moines, Iowa, in May, 1976; received Bachelor of Science degree in Agronomy (Turf Management) from Oklahoma State University, Stillwater, Oklahoma, in 1980; completed requirements for the Master of Science degree at Oklahoma State University, Stillwater, Oklahoma in December, 1983.

Professional Experience: Graduate Research Assistant, Oklahoma State University, Department of Horticulture, 1982-1983; Designer and Manager of an intercrop nursery, 1982-1983; Assistant to the Superintendent at Twin Hills Gold and Country Club, Oklahoma City, Oklahoma, 1981; Maintained Oklahoma State University Turf Grass Research Plots, and participated in roadside establishment studies under Dr. Wayne W. Huffine, 1978-1980.