EFFECT OF PROPAGATION CONTAINER DESIGN ON ROOT CONFIGURATION AND SUBSEQUENT GROWTH OF PLANTS GROWN FROM SEED

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PREFACE

This study is concerned with the development of an optimal root system through the use of modifications to the propagation container. The primary objective is to determine if specific modifications increase the number of lateral roots developed in plants grown from seed.

Some special problems encountered during the study included rodent damage to one tree species which limited the data for that part of the study.

I wish to convey special thanks to my major adviser, Dr. Carl E. Whitcomb, Oklahoma State University, Nursery Research Station for his patience, guidance, understanding and friendship beyond the call of duty throughout my master's work. Appreciation is also extended to Dr. P. L. Claypool, Department of Statistics, Oklahoma State University, for his time spent in discussing analysis of data and conclusions. Also thanks is extended to the other committee member, Dr. David W. Buchanan for his encouragement and sense of humor during the final stages of this writing.

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Finally, in dedication to my daughter, Amy, for her encouragement, assistance and resistance throughout my academic endeavors. We've both grown from the experience. To my son, Shawn, who made his appearance during my graduate work and was too small to understand why "Mommy" had to leave him with the beautiful lady from Venezuela.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page
XII.	Stem Height of Tree Seedlings Grown With Five Container Designs	22
XIII.	Stem Caliper of Tree Seedlings Grown With Five Container Designs	23
XIV.	Root Weight of Tree Seedlings Grown With Five Container Designs	24
XV.	Bottom Root Count of Tree Seedlings Grown With Five Container Designs	25
XVI.	Side Root Counts of Tree Seedlings Grown With Five Container Designs	26

CHAPTER I

INTRODUCTION

Tree seedlings are conventionally grown in ground beds for one to two growing seasons before transplanted into the field or containers. This method does not produce the desired plant growth, survival and quality after transplanting due to crowding and stress. Minimal applications of fertilizer and irrigation water during the propagation phase of the tree seedlings further reduce plant quality.

Container grown nursery stock is becoming a more widely accepted method for producing tree seedlings. Container production of tree seedlings has produced larger plant material in a shorter time compared to ground beds. Research in nutrition, watering methods, growth media, light, container volume and container design have all improved plant response. The need for the container system is documented by Whitcomb (19). Although improvements have been made in producing high quality nursery stock, container production has introduced problems in root system quality and subsequent anchorage and survival after transplanting.

Conventional methods of producing nursery tree seedlings by direct seeding into ground beds, did not provide for modification of the root system other than undercutting, wrenching and lateral root pruning. When done correctly, these procedures gave reasonable rates of survival and an acceptable root system in most cases (10). This method produced the quantity of tree seedlings needed, however, the quality of the seedling root system and subsequent survival remained substandard. In the nursery industry when trees were dug and offered for sale at a much larger size, the root quality, survival, and plant performance following transplanting was marginal.

During transplanting the roots of bareroot seedlings are often forced into a kinked position causing root wrapping and eventually grafting of the roots. These roots distortions reduce root growth and plant stability throughout the life of the plant (6, 16). Stone and Norbert (14) indicated that if root kinking and spiraling in container grown seedlings is not corrected prior to transplanting, many of the transplants produce malformed root systems, resulting in structural failure near the crown-root juncture or a root system incapable of providing satisfactory stability after transplanting.

During the last ten years emphasis has been directed toward the container and its effect on roots of tree seedlings. This has produced a variety of container shapes, sizes and configurations. Each container has advantages and disadvantages associated with size, shape, storage, ability to be handled and ease of seedling removal at time of transplanting. A major disadvantage is the distorted seedling root system. Seedling root systems conform to the shape and size of the container and is limited by volume of growth medium and available nutrients. Much of the time the seedling roots spiral in the liner container causing a distortion that remains throughout the life of the plant. Harris et. al. (7) indicated in the container nursery industry root distortions often begin when the seedling is moved from seed flat to liner container and subsequently to a larger container. Their study indicated that when root pruning and care in transplanting was done at both stages of transplanting the percentage of plants having seriously-kinked roots were significantly reduced, and the number of plants having acceptable root systems more than doubled. Roots which were longer than the depth of the container in which they were transplanted led to a kinked-root which produced root circling in a high percentage of the plants studied. This indicated that root pruning is beneficial in reducing root distortions when transplanted to a larger container and ultimately to the final landscape site.

Davis and Whitcomb (2,3) determined root development was best for the species tested in square bottomless containers 6.3 cm (2.5 inches) square with a depth of 15.2 to 20.9 cm (6 to 9 inches). Air-root-pruning suppressed tap root development, stimulating secondary lateral root development. The lateral roots grew to the sides or corners and downward and were again air-pruned at the bottom producing a more fibrous root system. Increased access to moisture and nutrients stimulated greater top growth.

Hathaway and Whitcomb (8) studied the effects of a 3.8 liter (one gallon) square bottomless container and a 3.8 liter (one gallon) round plastic container with a bottom, for one growing season. Root systems which developed in the square bottomless container were extremely fibrous as opposed to a spiralled less fibrous root system that developed in the round containers with bottoms. Increased root branching was correlated with a substantial increase in stem caliper and top growth. This was probably due to the gain in root surface area absorbing more nutrients and water.

Gibson and Whitcomb (5) using larger bottomless containers indicated that container size as well as shape has a dramatic effect on seedling root development and growth. Northern Red Oak, Querous rubra and Chinese pistache, Pistache chinesis responded well to the increase in container size. As the primary taproot is air-pruned, the laterals that develop are also air-pruned. This process is repeated until the container is filled with roots. With the increase in root branching relative to volume of growth medium, more nutrients are absorbed resulting in an increase in growth. Tree survival after transplanting proved best when a moderate sized, 1.9 liter, (one-half gallon) milk carton was used and the seedling was transplanted prior to restriction of growth due to the limited volume of growth medium, approximately six months for most species.

Work by Hiatt and Tinus (9) with modified propagation containers indicated that root system quality could be improved by adding vertical grooves in the sidewall of the container. After two years, trees grown in containers with vertical grooves had less root coiling and better recovery after transplanting than those grown in smooth walled containers.

The need for improved survival and subsequent tree growth following transplanting continues to be of great importance biologically and economically (1). If root growth and quality could be improved by modifying the design of containers for tree seedlings, it would assist both the nursery industry and the forest industry as well.

Persson (12) indicated modifications to a container for prevention of root spiralling must meet the following criteria: (a) four vertical ribs within the container, (b) a large bottom hole for air-root-pruning, (c) uniform taper to or rounded bottom and (d) an adequate volume of growth medium. As Persson was developing the criteria for container modification, Kinghorn (11) proposed container design should (a) retain the vertical orientation of the taproot, and although it may be terminated by cutting, drying or chemical inhibition, its viability should be retained so that it can resume downward growth when the tree is transplanted, (b) prevent spiralling of the first order lateral roots, and (c) separate the first order lateral roots to prevent premature grafting or roots disrupt normal translocation of photosynthate downward.

Dickinson and Whitcomb (4) studied containers modified with vertical ribs glued to the container wall. The ribs stopped root spiralling and stimulated secondary root branching. The increase in absorptive root surface area resulted in larger stem diameter and top growth. However, when ribs were tall enough to be effective, the containers could not be stacked and were therefore impractical. In addition, the roots of two of the test species produced sufficient pressure to bend the ribs and continued to spiral in the container.

Work by Whitcomb et. al. (21) with modified propagation containers indicated that root system quality can be improved in the propagation container. Vertical air-root-pruning was accomplished by removing slits in the corners of small containers. As the root grows downward and outward, it contacts the openings and roots are air-pruned, stimulating secondary branching and producing a more fibrous root system.

Whitcomb (18) further modified of the container sidewall to incorporate air-root-pruning. Vertical offset openings were cut in the sides of conventional polyethylene containers. The off set of the container sidewall in conjunction with air-root-pruning stopped spiralling of roots and stimulated secondary root branching. An increase in root branching resulted in increased plant growth. Additionally, this container design overcame the stacking problem encountered in the study by Dickinson and Whitcomb (4).

Whitcomb and Williams (22) used a variation of the internal rib container design to stimulate root branching. Four reverse-beveled bidirectional stairstep obstructions were affixed to the inside of the container wall. A root grows outward and contacts the side of the container and forced to circle. As the root tips become entrapped in the acute reverse angle of the obstruction, root growth was stopped because the spiral dominance of the root tip was reduced or eliminated, and secondary branching occurred. The number of root tips increased both on the sides and bottom of the root ball. This provided greater root and stem branching, an increase in stem diameter and more rapid establishment after transplanting.

Threadgill and Whitcomb (15) demonstrated that root weight and fibrous development increased as the propagation container diameter increased up to an optimal diameter of 6.3 cm (2.5 inches) square and a depth of 7.6 cm (3 inches).

Reiger and Whitcomb (13) conducted studies using 14 to 24 inch fabric containers for tree root control in the field with excellent results. Roots penetrated the fabric wall, but due to the size of the opening and strength of the fabric root diameter was restricted. This restriction stimulated root branching without root wrapping or distortion. In addition, accumulation of carbohydrates at the root-fabric interface provided very rapid root establishment following transplanting (20). However, considerable increase in root diameter must occur before the root restriction occurs therefore the short term growth of seedlings in the fabric container may not be practical.

The study compares the most promising container designs for tree seedling propagation and attempts to determine how each design influences top and root development at early stages of tree seedling growth and rate of root development after transplanting.

Experiment One was designed with five containers and tree fertilizer levels to determine if anticipated increased root branching and fertilizer rates interact to stimulate plant growth.

Experiment Two was based on the partial analysis of the data from experiment One. Five container designs were used with the best fertilizer level from Experiment one.

CHAPTER II

METHODS AND MATERIALS

Two new container designs were constructed and three containers were selected from the wide variety of commercially available containers to study the effects of container design on root configuration and subsequent growth after transplanting.

The five containers all had open bottoms for air-root-pruning. Their construction and dimensions were:

(a) Two strips of spun bonded and needle punched polypropylene fabric used in manufacture of Field-Grow containers were sewn together to form a circular container approximately 3.8 cm. (3.0 inches) in diameter by 10.1 cm (4 inches) high with an approximate volume of 64.5 cubic centimeters (25.4 cubic inches).

(b) Polyvinylchloride (PUC) pipe 6.3 cm (2.5 inches) in diameter was cut into 10.1 cm (4 inches) lengths. Each length was fitted with four small reverse beveled bidirectional inserts cut from the same 6.3 cm (2.5 inch) PUC pipe. The volume was approximately 50.8 cubic centimeters (20 cubic inches).

(c) Same as (b) without inserts with an approximate volume of 60.2 cubic centimeters (20.3 cubic inches).

(d) Polyethylene-coated milk carton stock was used to construct containers 6.3 cm (2.5 inches) square by 10.1 cm (4 inches) tall. These containers had a volume of approximately 63.5 cubic centimeters (25 inches).

(e) A commercially available polyethylene plastic container developed for tree seedlings, 5.7 cm (2.5 inches) square by 12.7 cm (5 inches) tall with small internal vertical ridges and having an approximate volume of 57.7 cubic centimeters (22.0 cubic inches).

Experiment One

Three fertilizer levels were used with each of the five container designs. Containers were randomly positioned in open mesh bottom trays lined with one layer of newspaper for ease of filling and handling and air-root-pruning. Containers were filled with a peat-perlite propagation medium (1:1 by volume) amended with 18N-2.6P-10K (18-6-12) Osmocote 1.8 kg, 3.8 kg, and 5.4 kg per cubic meter (3,6 and 9 lb per cubic yard) and 0.59 kg per cubic meter (1 lb per cubic yard) of Micromax Micronutrients to determine if fertility interacts with root branching to stimulate tree seedling growth.

The study was conducted as a randomized block design with three by five factorial arrangement of treatments. Each treatment was replicated six times with two subunits per replication.

Plant materials were selected to provide a range of root characteristics from very course, shumard oak and bald cypress, to very fibrous, lace bark elm and Formosan sweetgum with Japanese black pine and cluster pine falling in the intermediate range. On June 10, 1983 bald cypress, Taxodium distichum; lacebark elm, Ulmus parvifolia; sawtooth oak, Quercus acutissima; Japanese black pine, Pinus thunbergiana; cluster pine, Pinus pinaster; and sweetgum, Liquidambar formosana; were direct seeded into the containers.

Seedlings were germinated and grown in an unheated quonset style greenhouse covered with 30% shade and single layer of polyethylene sheeting.

Sides of the structure were open to allow for air flow for stem flexing and air-root-pruning. Watering was by overhead sprinklers as needed.

On September 1, both subunits were evaluated for stem height and caliper when roots had emerged from the bottom of the containers and air-root-pruned. One subunit was selected at random and sacrificed for top and root weights. A visual root grade on a scale of one to ten was determined using preselected standards. The remaining subunit was transplanted into a 3.8 liter (one gallon) container using a bark-peat-sand (3:1:1 by volume) amended with 8.3 kg (14 lbs) of 17N-2.6P-9K (17-7-12) Osmocate, 0.89 kg (1.5 lbs) Micromax Micronutrients and 3.8 kg (6 lbs) dolomite per cubic meter (cubic yard). Transplants were placed on an open container bed in full sun to determine if root configuration enhanced subsequent growth after transplanting. Overhead irrigation was used to supply irrigation water as needed.

Three weeks after transplanting, top and root weights, root counts and visual root grades were determined. Data was not collected for the cluster pine due to severe loss of seedlings following transplant. Data for lacebark elm was limited to root weight for evaluations taken after transplanting as rabbits destroyed the tops after placement on the container bed.

Analysis of the data prompted an immediate follow-up study since the fertilizer levels had a much greater effect than container design.

Experiment Two

Follow-up study was carried out with the same five containers, however only the high fertilizer rate (5.4 kg per cubic meter (9 lbs per cubic yard) of 18N-2.6P-9K (18-6-12) Osmocote) was used. Three subunits rather than two were used to further reduce the influence of seedling variation on the data.

Species selected provided root systems that range from very coarse: English oak, Quercus robur, Chinese pistache, Pistacia chinensis, and redbue, Cercis canadensis, to very fine: sweetgum, Liquidambar formosana, with loblolly pine, Pinus taeda being intermediate.

Prior to planting, the redbud seed was scarified in concentrated sulfuric acid to reduce the thick seed coat for faster germination. All seed were direct-seeded into the containers on December 26, 1983.

Due to seasonal conditions the containers were placed in a heated greenhouse maintained at 18^{o}C (65^{o}F), for germination and subsequent growth. Watering was by hand, as needed.

On January 10th, snowgum, Eucalyptus nephpohilia, an intermediate rooted species, was used to replace the sweetgum which did not germinate.

Trays holding the redbud and loblolly pine were moved, April 23, from the gas-heated greenhouse to the unheated tree seedling structure when temperatures had warmed sufficiently to prevent frost damage. The Chinese Pistache and English Oak were discarded due to poor seed germination.

By April 5th, the snowgum roots had been repeatedly air-pruned at the bottom of the containers. All three were transplanted to 3.8 liter (one gallon) containers using a growth medium of bark-peat-sant (3:1:1 by volume) amended with 8.3 kg (14 lbs) 17N-2.6P-9K (17-7-12) Osmocate, 0.89 kg (1.5) lbs) Micromax Micronutrients and 3.8 kg (6 lbs) of dolomite per cubic meter (cubic yard). The newly transplanted seedlings remained in the greenhouse. After 16 days roots had grown to the container wall. The root ball was removed intact and root tips that had grown to the container wall were counted, and then returned to their containers for further growth.

During the first week of June, 1984 the redbud and loblolly pine were transplanted to 3.8 liter (one gallon) containers using the same growth medium and fertilizer regime. These containers were placed on an open container bed in full sun with overhead sprinklers.

On June 27, 1984 and July 10, 1984 evaluation of stem height and caliper, top and root weight and side and bottom root counts were taken for redbud and loblolly pine, respectively.

Each species was analysed as a separate experiment in both experiment one and experiment two. Significant differences were determined using analysis of variance and a protected LSD test.

CHAPTER III

RESULTS

Experiment One

There was no significant interaction between container design and fertilizer, therefore only main effects are reported.

Ten weeks after seeding, stem height of all five species averaged over both subunits, increased with increasing fertilizer level, however, the 5.4 kg rate was not significantly better than the 3.6 kg rate.

TABLE I

MAIN EFFECTS OF THREE FERTILIZER LEVELS ON STEM HEIGHT[z] OF TREE SEEDLINGS AFTER 10 WEEKS

Fertilizer Rate kg/m3 (lbs/yd3)	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
1.8 (3)	34.3^{y}_{a}	8.5_{a}	22.1_{a}	37.2_{a}	23.9_{a}
3.6 (6)	41.3_{ab}	9.7_{ab}	32.3_{b}	43.7_{ab}	29.9_{ab}
5.4 (9)	47.2_{b}	11.9_{b}	33.4_{b}	49.9_{b}	33.4_{b}

z Centimeters

y Values followed by the same letter are not significantly different as the 0.05 level using a protected LSD test.

Stem caliper was greater at the 5.4 kg rate for bald cypress whereas Japanese black pine, sawtooth oak and Formosan sweetgum were about the same for both the 3.6 and 54. kg rate. Stem caliper of lacebark elm increased with increasing fertilizer but the differences were not significant (Table II).

TABLE II

MAIN EFFECT OF THREE FERTILIZER LEVELS ON STEM CALIPER[z] OF TREE SEEDLINGS AFTER 10 WEEKS

Fertilizer Rate kg/m3 (lbs/yd3)	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
1.8 (3)	3.9^{y}_{a}	2.1_a	1.9_a	3.0_a	2.5_a
3.6 (6)	4.3_a	2.7_b	2.2_a	3.7_b	3.3_b
5.4 (9)	5.3_b	2.9_b	2.5_a	3.8_b	3.7_b

z Millimeters
y Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

Top weights means suggested an increase with increasing fertilizer in all cases, however, differences were not significant for bald cypress and lacebark elm but the 3.6 and 5.4 kg rate were heavier than the 1.8 kg rate for the Japanese black pine, Formosan sweetgum and sawthooth oak (Table III).

TABLE III

MAIN EFFECT OF THREE FERTILIZER LEVELS ON TOP WEIGHT[z] OF TREE SEEDLINGS AFTER 10 WEEKS

Fertilizer Rate kg/m3 (lbs/yd3)	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
1.8 (3)	3.9^{y}_{a}	3.5_{a}	4.2_{a}	7.8_{a}	5.2_{a}
3.6 (6)	4.9_{a}	5.2_{ab}	5.5_{a}	10.0_{ab}	7.7_{ab}
5.4 (9)	7.4_{a}	5.7_{b}	7.9_{a}	13.6_{b}	11.9_{b}

z Grams

y Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

Root weight and root visual grade, after 10 weeks, suggested a general increase with increased fertilizer, however only the root weights of Formosan sweetgum and sawtooth oak were significantly greater at the 3.6 and 5.4 kg rate compared to the low level of fertilizer (Tables IV and V).

TABLE IV

MAIN EFFECT OF THREE FERTILIZER LEVELS ON ROOT WEIGHT[z] OF TREE SEEDLINGS AFTER 10 WEEKS

Fertilizer Rate kg/m3 (lbs/yd3)	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
1.8 (3)	3.2^{y}_{a}	5.5_{a}	3.0_{a}	3.9_{a}	2.9_{a}
3.6 (6)	3.8_{a}	5.8_{a}	3.7_{a}	5.4_{ab}	4.9_{ab}
5.4 (9)	4.2_{a}	7.1_{a}	4.4_{a}	7.1_{b}	5.6_{b}

z Grams
y Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE V

MAIN EFFECT OF THREE FERTILIZER LEVELS ON VISUAL ROOT GRADE[z] AFTER 10 WEEKS

Fertilizer Rate kg/m3 (lbs/yd3)	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
1.8 (3)	6.4^{y}_{a}	6.5_{a}	5.7_{a}	5.1_{a}	4.6_{a}
3.6 (6)	6.9_{a}	7.1_{a}	6.1_{a}	6.7_{a}	6.5_{a}
5.4 (9)	7.5_{a}	7.1_{a}	6.5_{a}	7.0_{a}	6.7_{a}

z 1 - poorest 10 = best
y Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

Plant response to container design was variable among the five test species and within a species relative to various growth parameters mesured. Generally, the milk carton and reverse beveled bidirectional insert container were superior to the fiber container, round PVC container and the plastic tree seedling container.

Top weight of bald cypress, Japanese black pine and lacebark elm grown in the five containers were not significantly different (Table VI). Sawtooth oak was similar in top weight when grown in any of the containers except the fiber container while the Formosan sweetgum was greatest in the milk carton and round PVC container and smallest in the fiber container (Table VI).

TABLE VI

TOP WEIGHT OF TREE SEEDLINGS GROWN WITH FIVE CONTAINER DESIGNS AT THE HIGH FERTILIZER LEVEL

Container	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
Fiber container	7.7 a [z]	5.8 a	9.8 a	10.0 a [y]	8.5 a
Milk Carton	6.6 a	7.0 a	5.5 a	15.0 b	15.7 cd
Plastic tree seedling cont.	5.1 a	7.5 a	6.0 a	15.9 b	12.0 bc
Reverse beveled bidirectional insert cont.	9.5 a	8.2 a	11.1 a	15.5 b	10.9 ab
Round PVC	8.5 a	5.0 a	7.1 a	14.2 b	17.0 d

z Values are means of 12 observations.

y Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

Stem calipers were not significantly different for any of the five test species when grown in the five containers and compared at the high fertilizer level. (Table VII). Stem height was similar for bald cypress with all containers except the plastic tree seedling container (Table VIII), however, there were no significant differences for the other four species.

TABLE VII

STEM CALIPER OF TREE SEEDLINGS GROWN WITH FIVE CONTAINER DESIGNS AT THE HIGH FERTILIZER LEVEL

Container	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
Fiber container	5.5^{z}_{a}	2.9_a	2.8_a	3.3_a	3.2_a
Milk Carton	5.1_a	3.0_a	2.4_a	4.2_a	4.0_a
Plastic tree seedling cont.	4.3_a	3.0_a	2.2_a	4.2_a	4.0_a
Reverse beveled bidirectional insert cont.	5.8_a	3.3_a	2.8_a	3.8_a	3.6_a
Round PVC	5.5_a	2.6_a	2.6_a	3.9_a	4.2_a

z Values are means of 12 observations.
Y Values followed by the same letter are not significantly different at the o.05 level using a protected LSD test.

TABLE VIII

STEM HEIGHT OF TREE SEEDLINGS GROWN IN FIVE CONTAINER DESIGNS AT THE HIGH FERTILIZER LEVEL

Container	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
Fiber container	52.0_{b}^{zy}	12.3_{a}	39.0_{a}	44.8_{a}	31.1_{a}
Milk Carton	43.8_{b}	12.2_{a}	31.2_{a}	46.7_{a}	34.3_{a}
Plastic tree seedling cont.	34.6_{a}	13.3_{a}	30.5_{a}	52.2_{a}	30.4_{a}
Reverse beveled bidirectional insert cont.	52.2_{b}	12.4_{a}	37.7_{a}	54.5_{a}	34.3_{a}
Round PVC	48.6_{b}	9.4_{a}	33.8_{a}	51.6_{a}	37.3_{a}

z Values are means of 12 observations.
y Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

Root weights and visual root grades of lacebark elm, sawtooth oak and Formosan sweetgum were not significantly different among the five container designs (Tables IX and X). On the other hand, root weights and root visual grade of Japanese black pine were greatest in the container with the reverse beveled bidirectional inserts and least in the fiber container (Tables IX and X). Root weight of the bald cypress was not significant in response to container design, although there was a large variation in mean weights (Table IX). Bald cypress root weights were similar in the fiber container, round PVC, reverse beveled bidirectional insert container and lowest in the plastic tree seedling container (Table X).

TABLE IX

ROOT WEIGHT OF TREE SEEDLINGS GROWN WITH FIVE CONTAINER DESIGNS AT THE HIGH FERTILIZER LEVEL

Container	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
Fiber container	5.5^{z}_{a}	1.6^{y}_{a}	4.6_{a}	4.5_{a}	3.3_{a}
Milk Carton	4.2_{a}	3.3_{bc}	2.9_{a}	5.6_{a}	7.3_{a}
Plastic tree seedling cont.	1.6_{a}	4.3_{cd}	4.5_{a}	7.1_{a}	6.1_{a}
Reverse beveled bidirectional insert cont.	5.0_{a}	4.8_{d}	7.0_{a}	7.2_{a}	5.2_{a}
Round PVC	4.7_{a}	2.5_{ab}	3.3_{a}	6.2_{a}	6.2_{a}

z Values are means of 12 observations.

y Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE X

VISUAL ROOT GRADE ^{z} OF TREE SEEDLINGS GROWN IN FIVE CONTAINER DESIGNS AT THE HIGH FERTILIZER LEVEL

Container	bald cypress	Japanese black pine	lacebark elm	sawtooth oak	Formosan sweetgum
Fiber container	9.0_c^{yx}	4.4_a	7.8_a	6.1_a	4.3_a
Milk Carton	7.5_b	7.3_{bc}	5.4_a	6.3_a	7.0_a
Plastic tree seedling cont.	4.0_a	8.6_{cd}	6.8_a	8.0_a	6.5_a
Reverse beveled bidirectional insert cont.	8.5_c	9.5_c	8.8_a	7.8_a	6.0_a
Round PVC	8.5_c	6.0_{ab}	6.1_a	7.0_a	7.4_a

z 1 = poorest 10 = best
y Values are means of 12 observations.
x Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

Experiment Two

Three weeks after transplanting into larger containers, there were no significant differences in top weights of redbud and eucalyptus in response to containers design (Table XI). Top weight of loblolly pine, was greatest in any of the containers except the fiber container (Table XI).

TABLE XI

TOP WEIGHT OF TREE SEEDLINGS GROWN WITH FIVE CONTAINER DESIGNS

Container	redbud	loblolly pine	eucalyptus
Fiber container	8.2^{z}_{a}	23.8^{y}_{a}	90.0_{a}
Milk Carton	12.3_{a}	32.2_{b}	88.8_{a}
Plastic tree seedling cont.	8.8_{a}	33.5_{b}	90.3_{a}
Reverse beveled bidirectional insert cont.	13.2_{a}	34.2_{b}	82.5_{a}
Round PVC	11.0_{a}	32.3_{b}	90.3_{a}

z Values are means of 12 observations.
y Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

Stem height and caliper of redbud were not significantly influenced by the container designs although seedlings grown in the reverse beveled bidirectional container were generally largest (Table XII and XIII). Stem height and caliper were greatest for loblolly pine in all container designs except the fiber container (Tables XII and XIII).

Root weights for redbud and eucalyptus were not significantly influenced by container design (Table XIV). Loblolly pine root weights were greatest in all containers except the fabric (Table XIV).

After transplanting, counts of roots growing from the bottom of the container growth medium were not different among the container designs for redbud and loblolly pines, however, eucalyptus had most new roots with the PVC containers with or without the reverse beveled bidirectional insert and least with the fiber container (Table XV). Those roots counts for eucalyptus represent the total root count 16 days after transplanting.

After thirty-five days the number of roots growing from the side of the mass of container growth medium was not significant for redbud and eucalyptus, loblolly pine, root growth was significantly less with the fiber container and all other treatments were equal (Table XVI).

TABLE XII

STEM HEIGHT OF TREE SEEDLINGS GROWN WITH FIVE CONTAINER DESIGNS

Container	redbud	loblolly pine	eucalyptus
Fiber container	3.7^{z}_{a}	6.0^{x}_{a}	-[y]
Milk Carton	4.2_{a}	7.2_{b}	-
Plastic tree seedling cont.	3.3_{a}	7.3_{b}	-
Reverse beveled bidirectional insert cont.	4.5_{a}	7.2_{b}	-
Round PVC	3.7_{a}	7.2_{b}	-

z Values are means of 18 observations.
y Stem height was not taken due to the low branching habit.
x Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE XIII

STEM CALIPER OF TREE SEEDLINGS GROWN WITH FIVE CONTAINER DESIGNS

Container	redbud	loblolly pine	eucalyptus
Fiber container	3.7[z] a	6.0[x] a	-[y]
Milk Carton	4.2 a	7.2 b	-
Plastic tree seedling cont.	3.3 a	7.3 b	-
Reverse beveled bidirectional insert cont.	4.5 a	7.2 b	-
Round PVC	3.7 a	7.2 b	-

z Values are means of 18 observations.
y Stem height was not taken due to the low branching habit.
x Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE XIV

ROOT WEIGHT OF TREE SEEDLINGS GROWN WITH
FIVE CONTAINER DESIGNS

Container	redbud	loblolly pine	eucalyptus
Fiber container	13.2^{z}_{a}	19.0^{y}_{a}	16.8_{a}
Milk Carton	14.7_{a}	25.5_{b}	16.8_{a}
Plastic tree seedling cont.	13.0_{a}	26.5_{b}	18.8_{a}
Reverse beveled bidirectional insert cont.	17.3_{a}	24.5_{b}	20.0_{a}
Round PVC	14.8_{a}	24.8_{b}	17.8_{a}

z Values are means of 18 observations.
x Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE XV

BOTTOM ROOT COUNTS[z] OF TREE SEEDLINGS GROWN WITH FIVE CONTAINER DESIGNS

Container	redbud	loblolly pine	eucalyptus
Fiber container	17.2_{a}^{x}	41.0_{a}	$15.7_{a}^{y,w}$
Milk Carton	22.8_{a}	44.8_{a}	76.3_{b}
Plastic tree seedling cont.	14.2_{a}	62.7_{a}	68.5_{b}
Reverse beveled bidirectional insert cont.	20.7_{a}	51.8_{a}	81.5_{bc}
Round PVC	16.8_{a}	49.7_{a}	95.6_{c}

z Small numbers of roots were the desired effect.

y Values represent root counts for total root ball 16 days after transplanting for eucalyptus only.

x Values are means of 18 observations.

w Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

TABLE XVI

SIDE ROOT COUNTS OF TREE SEEDLINGS GROWN WITH FIVE CONTAINER DESIGNS

Container	redbud	loblolly pine	eucalyptus
Fiber container	78.7^{z}_{a}	60.5^{x}_{a}	176.8^{y}_{a}
Milk Carton	76.7_{a}	92.3_{b}	176.8_{a}
Plastic tree seedling cont.	57.0_{a}	77.5_{b}	197.7_{a}
Reverse beveled bidirectional insert cont.	93.8_{a}	83.3_{b}	133.8_{a}
Round PVC	82.2_{a}	88.5_{b}	168.2_{a}

z Values are means of 18 observations.

y Values represent side root counts 35 days after transplanting.

x Values followed by the same letter are not significantly different at the 0.05 level using a protected LSD test.

CHAPTER IV

DISCUSSION

The general response of the five species to increased fertilizer incorporated into the growth medium is consistent with previous research by Gibson and Whitcomb (5) and Whitcomb (17, 19). The lack of growth response to the various containers, was unexpected. The fabric containers were difficult to remove, resulting in considerable root loss which probably accounts for the poor plant response in most instances. Container with the reverse beveled bidirectional insert generally performed well, but no better than the milk carton or plastic tree seedling container. This was a surprise since Whitcomb and Williams (22) reported a substantial increase in top weight, stem caliper and branching of several shrub species. This difference may be due to the short period of time the roots were exposed to this container modification (three months) whereas Whitcomb and Williams (22) grew plants for six months.

The general lack of growth response to these five different container designs suggests that further container modification may not provide sufficient plant response to justify the expense. Another major factor that must be kept in mind is the vast seedling variation present with all species used in the study. In some cases, three fold differences were not significantly different due to variation among plants. Considering the tremendous difficulty encountered in construction of the reverse beveled bidirectional insert container, the seedling variation and reexamining the study, it probably would have been better to use one or two species with many more replications or subunits.

CHAPTER V

SUMMARY AND CONCLUSIONS

The objective of this research was to determine the effect of five container designs on root response and subsequent plant growth after transplanting.

Although, significant differences were generally not observed at the 0.05 level for most of the plant growth responses, inspection of the means for the observations in both experiment one and two suggest some response.

The poor response of species seeded in the fiber container was probably due to substantial loss of roots at the transplant date when the container was removed from the root ball. This does not appear to be a problem with larger plant material grown in the field as reported by Reiger and Whitcomb (13).

There are indications from previous studies that some species may be specific for a particular container and the length of time plant material should be held in the propagation container before transplanting, is of importance.

Further studies need to be conducted to determine if there is an "ideal" container suitable for all plant material used for tree production for nurseries and reforestation projects but using less variable genetic material and many replications.

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