EFFECT OF ACORN SIZE ON THE SEEDLING GROWTH OF SHUMARD OAK, *QUERCUS SHUMARDII*, BUCKL.

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Chapter I

Introduction

Native range

Shumard oak, belonging to the beech family Fagaceae, is a native of the rich bottomlands in the eastern half of Oklahoma (Little, 1991). There are two varieties of Shumard oak: *Quercus shumardii* Buckl. var. *shumardii*, the typical variety found in the southeastern United States and *Q. shumardii* var. *texana* (Buckl.) Ashe, also known as the Texas oak, found in central Texas and Oklahoma (Figure 1). It is also known as spotted oak, Schneck oak, Shumard red oak, southern red oak, and swamp red oak. It was named after Benjamin Franklin Shumard (1820 - '69), the state geologist of Texas. It is a lowland tree growing scattered with other hardwoods on moist, well-drained soils associated with large and small streams where it exhibits moderately fast growth (Edwards, 1990).

Climate

The growing season in the natural range of Shumard oak usually extends from 210 - 250 days (Edwards, 1990). The average annual temperature is 16 - 21 °C (60 - 70 °F) with an average annual precipitation of 1140 - 1400 mm (45 -

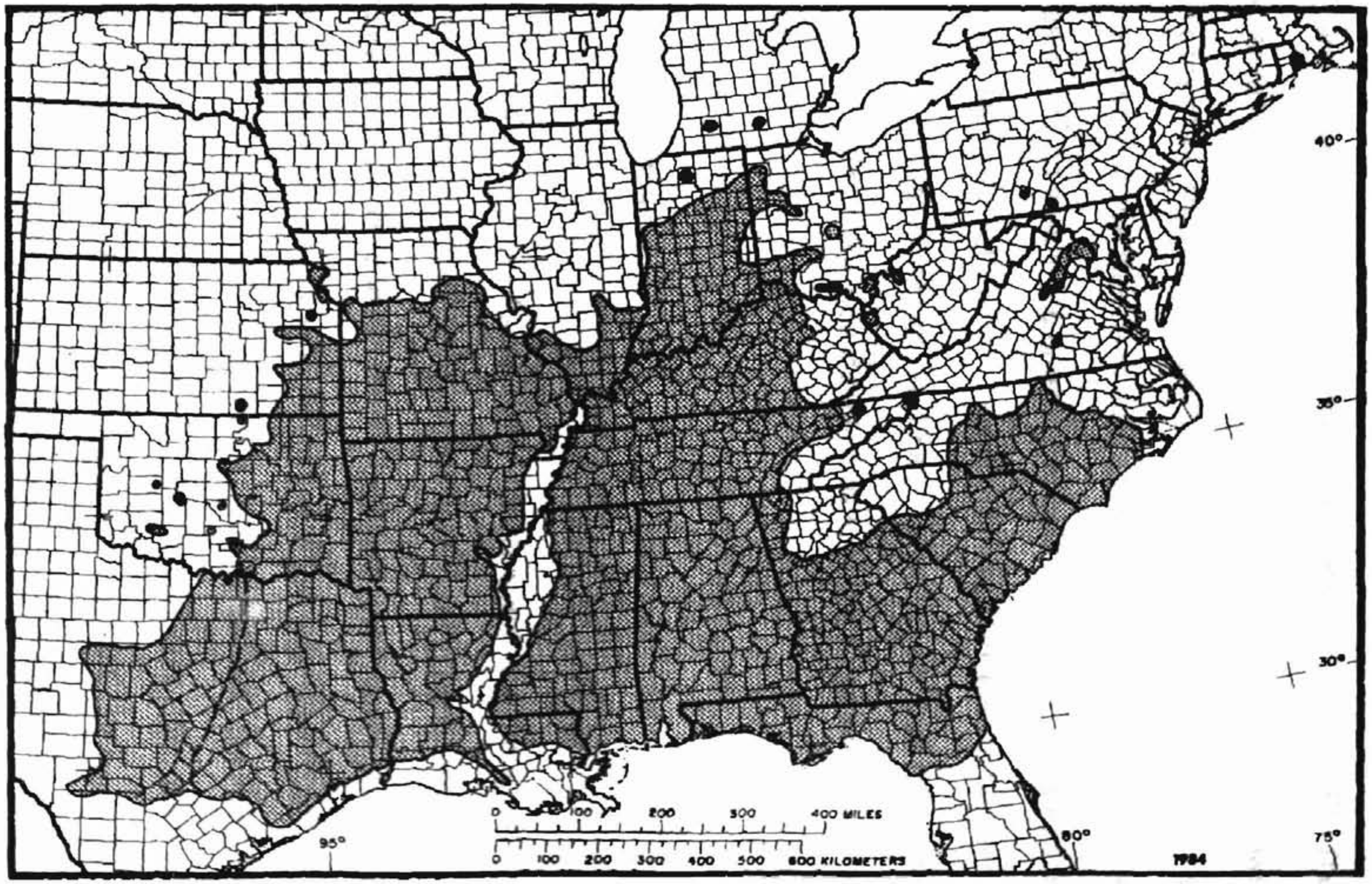


Figure 1. Distribution of Shumard oak in the southeastern United States. The broken line separates eastward the typical variety and westward the variety, Texas oak (Edwards, 1990).

55 inch) in its whole range. In Texas and Oklahoma the average annual rainfall is only about 640 mm (25 inch). The annual maximum temperature is 38 °C (100 °F) and the annual minimum temperature is about - 9 °C (15 °F). The majority of the rainfall occurs from April through September. Shumard oak grows best in the rich sites of the southern forests that have moist, well-drained loamy soils found on terraces, colluvial sites, and adjacent bluffs associated with large and small streams and on soils in the orders of Alfisols, Inceptisols, and Vertisols. It is found in the hammocks of the Coastal Plains and appears to be tolerant of sites with high pH up to 7.5 (Edwards, 1990). However, the ideal pH range for the growth of Shumard oak was identified as 4.4 - 6.2 (Williston and LaFayette, 1978).

Species composition

Shumard oak is intolerant of shade, flooding, and drought (Edwards, 1990). At maturity it retards the growth of competing understory vegetation, apparently by an allelopathic effect. It is one of the prominent oaks in the oak-hickory region but it is not a dominant tree in this extensive region. So it is not a true climax tree in most of the oak-hickory communities. Shumard oak is included in the forest cover type Swamp Chestnut Oak-Cherrybark Oak. The main associates are willow oak (*Q. phellos*), water oak (*Q. falcata*), post oak (*Q. stellata*), American elm (*Ulmus americana*), winged elm (*U. alata*), water hickory (*Carya aquatica*), southern magnolia (*Magnolia grandiflora*), yellow poplar

(*Liriodendron tulipifera*), beech (*Fagus grandifolia*), and occasionally loblolly pine (*Pinus taeda*) and spruce (*Picea glabra*).

Flowering and fruiting

The oaks of the United States belong to a group called "temperate recalcitrants": they are "temperate" because they grow primarily in the temperate zone and they are "recalcitrants" because their seeds (acorns) do not tolerate desiccation below a critical moisture content, approximately 25 - 35 % (Bonner, 1992). Flowering of Shumard oak occurs during March and April and the flowers are unisexual and monoecious (Edwards, 1990). The fruit is an egg-shaped acorn, 1.5 - 3 cm (5/8 - 1¼ inch) long, enclosed in a saucer-shaped cup with pubescent scales (Harlow et al. 1996). Acorns ripen and fall to the ground during September and October of their second year. Shumard oak is a consistent acorn producer and bumper crops are produced every 2 - 4 years. The minimum seed-bearing age is 25 years and the optimum production occurs at about 50 years. The cleaned seeds range from 172 - 282 / kg (78 - 128 / lb) with an average of 220 / kg (100 / lb). The germination of acorn is hypogeal and in nursery beds it will be complete within 3 - 5 weeks. Shumard oak does not propagate readily on moist sites or by cuttings.

Growth conditions

Shumard oak on favorable bottomland sites grows well and reaches a height of 30.5 m (100 ft) or more, with a trunk diameter of 0.9 - 1.2 m (3 - 4 ft) (Edwards, 1990). The volume reported for all sites (pines and hardwoods) was 7.3 m^3 / ha (259 ft^3 / ac). Heavy pole stands contain more than 430 stems / ha (175 stems / acre), with a trunk diameter of 13 - 28 cm (5 - 11 inch) at breast height.

Pests and diseases

Acorn-infesting insects are the most studied group of pests affecting oak regeneration (Oak et al., 1991). No insect was found specifically associated with Shumard oak (Edwards, 1990). As in many other oaks, acorn is attacked by weevils belonging to the genus *Curculio*. Embryos in infested acorns that escape damage may germinate but seedlings grow slower than those from the uninfested acorns. Hot water treatment is the best method for controlling weevil larvae in infested acorns. The key elements are temperature of water and duration of treatment (Oak et al., 1991). Crocker and Morgan (1983) prescribed hot water treatment for 30 - 45 minutes at 43 °C (6 °F) followed by quenching in cold water for live oak (*Q. virginiana*) acorns without causing loss of viability. The most widespread nursery diseases are caused by fungi belonging to the genera *Phytophthora* and *Cylindrocladium* affecting the roots of seedlings (Oak et al., 1991). Affeltranger and Burns (1983) reported that several species of *Cylindrocladium* cause root rot in the seedlings of Shumard oak. Sanitation, soil management, and soil drenching using benomyl (Benlate) have been suggested for controlling *Cylindrocladium*.

Uses

The acorns of Shumard oak serve as an important food for many species of birds and mammals (Edwards, 1990). Commercially, the wood is marketed with other red oak lumber, and is used for flooring, furniture, interior trim, and cabinetry. Additionally, the tree is planted for ornamental and landscape purposes.

Nursery production

As per 1994 statistics, about 1.8 billion tree seedlings were produced by all the forest and conservation tree nurseries in the United States, out of which about 450 million seedlings (24.5 %) were produced by the state nurseries alone (Okholm and Abriel, 1994). The Forest Regeneration Center located at Washington, in McClain County, OK, is the only one of its kind in the state producing seedlings of different conifers as well as broad-leaf species for conservation planting. Shumard oak is among the important species raised for distribution among private landowners of Oklahoma. After one year's growth, the seedlings are ready to harvest from the nursery beds. They are then sorted to remove the culls, and the saleable seedlings are packed into bundles of 50 each, and stored at a temperature of 1 - 2 °C (33 - 36 °F) and a relative humidity of about 100 %, until dispersal to the target landowners.

Problem

The acorns collected each year vary much in size as do the seedlings raised from them. The variability in seed size and their influence on seedling growth was a subject of great interest among researchers in the past. Much research has been done to determine the effect of seed size on seedling growth, but most studies were concerned with pine species such as, ponderosa pine (*Pinus ponderosa*), loblolly pine (*P. taeda*), slash pine (*P. elliotti*), Douglas-fir (*Psedotsuga menziesii*), white spruce (*Picea glauca*) or different broad-leaf species, including oaks. This suggested the importance of the influence of the size of the propagule which developed into seedlings. One of the pitfalls of the studies was that the seeds were separated into only two or three broad groups such as, small, medium, and large based on size, or light, medium, and heavy based on weight. The results of those studies were variable. Shumard oak was also included in a few experiments. But there was no in-depth study conducted with Shumard oak to guide nursery managers in sizing acorns before sowing. Therefore, this study was conducted to determine the effect of acorn size on the first year growth of the seedlings of Shumard oak by separating the acorns into different size classes prior to sowing.

Purpose

If acorn size is closely related to seedling size, this would have important application in the nursery practice. The acorns could be sized using screens modified to suit the requirements of the nursery and the size of the acorns of Shumard oak. After sizing and eliminating the extreme sizes, sowing the uniform size acorns would result in uniform size seedlings. This would reduce the variability among the seedlings in the nursery and in turn, would reduce the cull percent. After lifting the seedlings from the nursery the culls are discarded and the remaining seedlings are packed into bundles of 50 each before storage and distribution. All the seedlings with stem diameters less than 4.5 mm (3/16 inch) at about 2 cm (0.79 inch) above the root collar are considered as cull. Currently, 5 - 10 % of the seedlings are removed as culls. Without any culls, all the seedlings produced in the nursery could be saleable. Additionally, a mechanized precision planter could be used by nursery managers to lower the cost and time involved in planting operations.

Objectives

The objectives of the experiment were based on the null hypotheses that there was no difference among the sizes of acorns of Shumard oak collected by the state nursery, and the variability among seedlings was not directly related to acorn size. Therefore, the objectives of this study were:

(1) to determine the relationship between acorn size and seedling growth of Shumard oak,

(2) to determine if acorn size affects the seasonal pattern of growth of the seedlings, and

(3) to determine if sizing of acorns increases uniformity among seedlings in the nursery.

Limitations of the study

Pilferage of acorns by birds and wildlife during winter was a major concern for the fall planted acorns. This was one reason for the reduced germination in the nursery. As physical protection is not feasible in a large nursery practice, species with large seeds such as, bur oak and pecan were usually planted on the eastern side of the nursery, preferably not directly adjacent to the wind breaks which provided cover for wildlife. Heavy rainfall during the stratification period might wash out the topsoil and uncover some of the acorns, which would reduce the germination percent. Another setback of the experiment was that the summer was very hot and dry, causing some difficulty in excavating the complete length of tap root of the seedlings from the dry soil. As most of the first-order lateral roots were restricted to the upper 20 or 25 cm (7.9 - 9.9 inch) length of tap root, this was not a major problem.

Chapter II

Review of Literature

Historical

The effect of seed size and sizing has been of much interest among researchers in the past. One of the earliest studies related to sizing of acorns dates back to the experiment conducted by Nesterov in 1914 at the Moscow Agricultural College (Eytingen, 1915). He used only three grades of acorns based on weight such as, very small, medium, and large. He found that the weight of acorns had a considerable effect upon the growth of the young oaks. McComb (1934) studied the relation between the weights of acorns and seedling variables in chestnut oak (*Q. prinus*), and found that there was a close relation between them. The seed size affected the survival of the plant in stressful environments. The larger seeds enhanced the flexibility in the shoot/root allometry, speed of germination and overall growth. Righter (1945) in a study with pines concluded that under uniform nursery conditions, the selection of large seeds would result in the production of a population of uniformly large seedlings making the range of variation relatively small. Since then, many studies have been conducted with sizing, but most of them were restricted to only three grades such as, small, medium, and large based on size, or light, medium, and heavy based on weight.

Sizing the conifers

Burgar (1964) using the seeds of white spruce, *Picea glauca* found significant differences in the height and weight of the seedlings, but no significant differences were found in the total germination and survival rate during the first year. In an attempt to reduce the variability among seedlings by sizing the seeds of ponderosa pine, (*P. ponderosa*) Edgren and Bigelow (1972) showed that density was more uniform by sowing large or medium size seeds than by sowing small or unsized seeds. Since small seeds caused greatest variability in sowing density and produced smaller seedlings, researchers recommended elimination of small seeds from sowing or they have to be sown separately to get greater seedling density. Ghosh et al. (1976) concluded that the seedlings from small seeds of three *Pinus* species were significantly higher in germination percent as compared to the seedlings from large seeds which had higher total biomass. The medium seeds had higher mean daily germination, peak value of germination, height growth, and root/shoot ratio compared to the other two grades.

Dunlap and Barnett (1983) found that larger seeds of loblolly pine, *Pinus taeda* germinated more quickly and produced larger germinants after 28 days of growth. Therefore, uniformity in growth of the seedlings was related to the germination pattern, influenced by seed size and seed weight. In a study with slash pine, *Pinus elliotti,* Belcher et al. (1984) graded seeds into ten groups based on diameter and density. The seeds were graded into large, medium, and small, then each of the groups were further graded into heavy, medium and light, with an additional group called jumbo. They found that the large seeds produced large seedlings, and that by separating the seeds into size classes, a more uniform seedbed density might be obtained. The uniformity in the density was derived through more uniform germination of the sized seeds. The large seeds produced larger seedlings than did the small seeds, as observed by Bonner (1987) in a study with *Liquidambar styraciflua*, *Pinus elliotti*, and *P. echinata*. The large seeds of *L. styraciflua* exhibited highest germination percent. The seed size had no significant effect with *P. echinata,* while *P. elliotti* gave varying results.

Sizing the broad-leaf species

Seiwa and Kikuzawa (1991) in an experiment with 31 deciduous broad-leaf tree species showed that seed size positively affected the initial seedling height and leaf longevity, and negatively affected the duration of leaf emergence and leaf turnover rate. They concluded that the importance of seed size in determining seedling establishment success depended on the relationship between seasonal change in environmental light conditions and the characteristics of seedling phenology, which were related to seed size. As a consequence, large seeds produced more vigorous and competitively superior seedlings. The root biomass was significantly different for the three seed sizes: there was greater biomass in the seedlings from large seeds followed by medium and small ones. Jurado and Westoby (1992) observed that heavier-seeded species were able to emerge from greater depths in the soil than the lighterseeded ones, in a study conducted with 32 different species in a drought prone area in Australia. Agboola (1996) in an experiment with three tropical tree species, concluded that total dry weight of the seedlings from large seeds was 2 - 3 times greater than that from small seeds. In a study with *Pongamia pinnata*, Manonmani et al. (1996) found that irrespective of the seed source, large seeds proved superior in germination percent and vigor, and that a positive correlation existed between seed size and seedling quality attributes. In a recent study involving three grades (small, medium, and large) based on the length of the seeds of *Cryptocarya alba*, Chacon et al. (1998) found that large seeds increased the germination, seedling growth, and survival.

Sizing the oaks

Tripathi and Khan (1990) found a higher survival rate and dry matter production in the seedlings of two species of *Quercus* with larger seeds. The rapid and higher germination was attributable to the larger food reserves in the acorns. An increased proportion of protein, lipid, and carbohydrate provided readily available energy that stimulated germination. Long and Jones (1992) determined the biomass partitioning in the seedlings of ten *Quercus* species native to the southeastern United States. They found that, oaks native to bottomland environments partitioned a significantly greater amount of biomass to the shoot per unit of root mass than did oaks native to upland environments. All species used an average of 70 % of the initial acorn mass during the first growing season. This would seem to confer an advantage to the large-seeded oaks over the small-seeded ones in that, they obtained a greater amount of energy from the acorn during the first year of growth. The results suggested that biomass partitioning in oak seedlings was an evolutionary response allowing oaks to compete efficiently for limiting resources on a site. In a later study with fourteen oak species, Long and Jones (1996) concluded that seed size was generally unrelated to seedling growth within the species. However, when the species were compared, those with larger mean seed size produced larger seedlings. Although seed size influenced seedling growth, no clear relationship between seed size and soil moisture habitat was found. The seed size affected survival of the seedlings in stressful environments. The larger seeds enhanced the flexibility in shoot/root allometry, speed of germination, and overall growth. After studying the effects of seed size, cotyledon reserves, and herbivory on seedling survival and growth of two oak species, Bonfil (1998) found a positive relation between acorn mass and growth and survival of the seedlings. The larger seedlings were better in enduring the loss of cotyledons and aerial biomass, and were able to confront stressful environments in early stages. Therefore, a direct relation between propagule size and seedling growth was observed in most of the studies related to sizing.

Chapter III

Materials and Methods

Acorn collection

The acorns of Shumard oak were mature by late September or early October. They were collected by the state nursery from the campuses of the University of Oklahoma, Norman, and Oklahoma State University, Stillwater. Every year the state nursery collects Shumard oak acorns of about 544 kg (1200 lb) by fresh weight. The trees for acorn collection were previously identified as superior and consistent seed producers. After collecting acorns from the ground they were stored in burlap bags and taken to the state nursery. Then they were soaked in water for about 15 hr to raise the moisture content, and to remove the floating acorns and other debris. All the acorns and debris floating on the surface of the water were discarded. Then the defect-free acorns were stored in cold temperature at 1 - 2 °C (33 - 36 °F) until sizing and sowing.

Acorn sizing

The acorns for the experiment were supplied by the state nursery from the 1997 crop. Twenty-seven kg (60 lb) of acorns were brought to the Regeneration Laboratory of the Department of Forestry, Oklahoma State University, Stillwater, for sizing. The acorns were initially separated into four broad groups using three different sieves having mesh sizes of 16 mm (5/8 inch), 19 mm (3/4 inch), and 22.4 mm (7/8 inch). Then they were sized into 10, 1 mm (0.04 inch) diameter classes ranging from 13 - 13.9 to 22 - 22.9 mm (0.51 - 0.55 to 0.87 - 0.90 inch) using a caliper (Table 1). All defective acorns (about 17 %), were discarded to ensure maximum germination. The average weight of the defect-free acorns (83 %) belonging to each diameter class was also calculated. The smallest size (13 - 13.9 mm) weighed 2.08 g (0.005 lb), while the largest size (22 - 22.9 mm) weighed 7.12 g (0.02 lb, Figure 2). Majority of acorns (91 %) belonged to 16 - 16.9 to 20 - 20.9 mm (0.63 - 0.67 to 0.79 - 0.82 inch) diameter classes. After sizing they were kept in separate polythene bags, labeled, and stored at a temperature of 1 - 4 °C (33 - 40 °F) until sowing. As there was not enough acorns for the experiment belonging to the diameter classes 13 - 13.9, 14 - 14.9, and 22 - 22.9 mm (0.51 - 0.55, 0.55 - 0.59, and 0.87 - 0.90 inch), these sizes were not used. Therefore, eight treatments such as, 15 - 15.9, 16 - 16.9, 17 - 17.9, 18 - 18.9, 19 - 19.9, 20 - 20.9, and 21 - 21.9 mm (0.59 - 0.63, 0.63 - 0.67, 0.67 - 0.70, 0.71 - 0.74, 0.75 - 0.78, 0.79 - 0.82, and 0.83 - 0.86 inch) diameter, and an unsized control were used for the experiment.

Bed preparation

The experiment was conducted under the standard nursery cultural procedures. The site preparation for making the beds was initiated during the summer of 1997 when the soil was very hot and dry, using a subsoiler (ripper), followed by disking, harrowing, and land planing. Then raised beds of

Table 1. Diameter class, number of acorns, percent of defect-free acorns to the total, and average weight, after sizing 27.2 kg (60 lb) acorns of Shumard oak.

No.	Diameter class (mm)	Defect-free acorns (No.)	Defective acorns (No.)	Total acorns (No.)	Percent of defect-free total	Fresh weight (g)
1.	13 - 13.9 *	5	--	5	0.10	2.08
2.	14 - 14.9 *	22	8	30	0.43	2.42
3.	15 - 15.9	188	34	222	3.71	2.93
4.	16 - 16.9	805	130	935	15.87	3.50
5.	17 - 17.9	1286	216	1502	25.35	4.13
6.	18 - 18.9	1183	222	1405	23.32	4.68
7.	19 - 19.9	825	205	1030	16.26	5.25
8.	20 - 20.9	524	144	668	10.33	5.78
9.	21 - 21.9	181	44	225	3.57	6.30
10.	22 - 22.9 *	54	9	63	1.06	7.12
11.	Control	--	--	--	--	4.50
	Total	5073	1012	6085	100.00	--

(* - Acorn sizes not used in the experiment.)

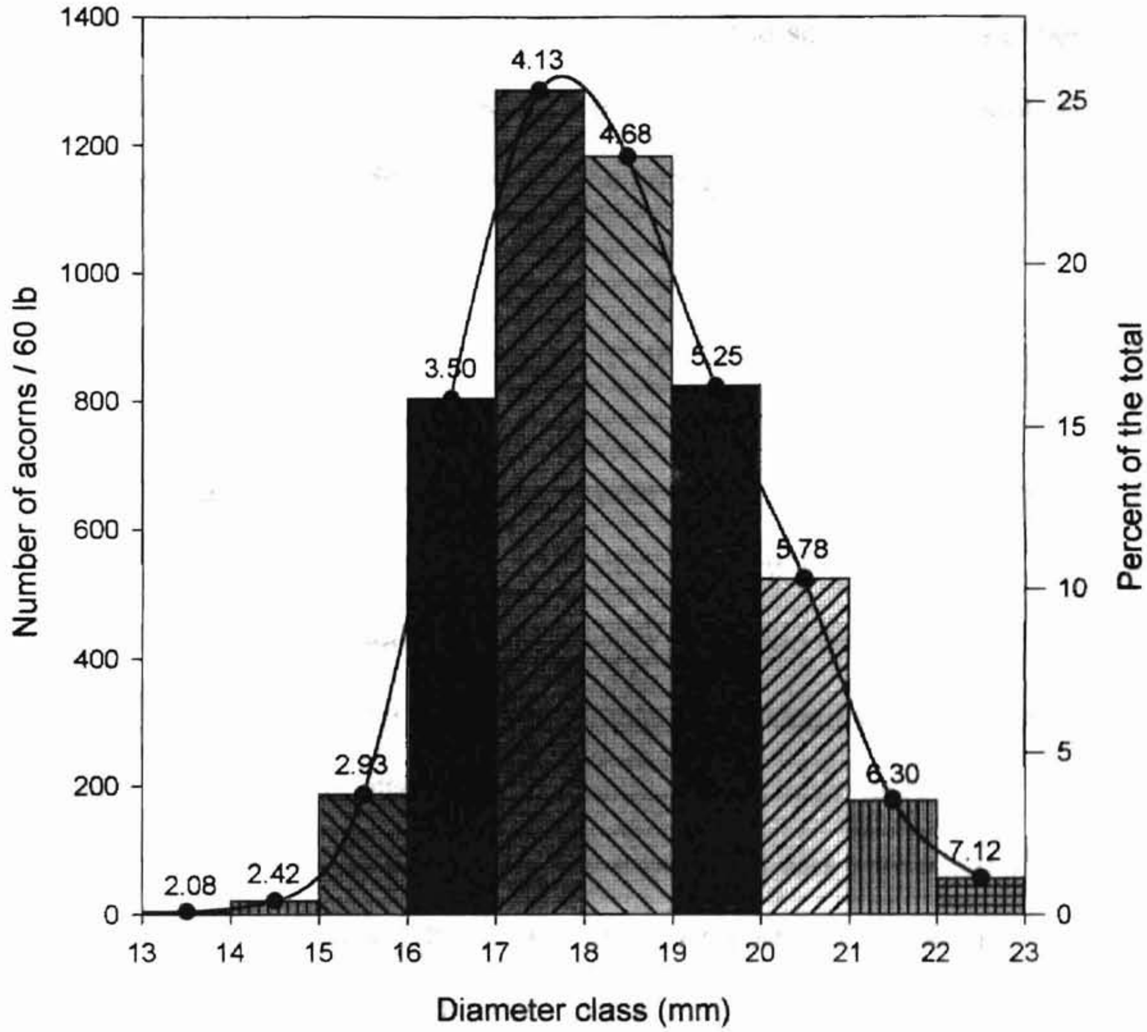
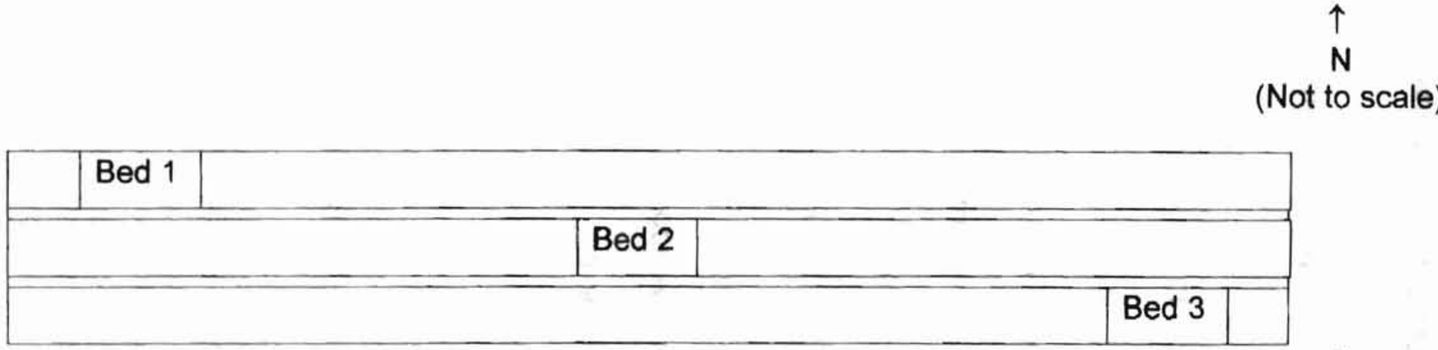


Figure 2. Number of sized Shumard oak acorns in diameter class and their percent of the total, with average fresh weight (g) on top.

approximately 183 x 1.4 m (600 x 4½ ft) size were prepared using a Fobro Kulti-roto-tiller along the east-west direction. Four furrows having a depth of 5.08 - 10.16 cm (2 - 4 inch) and spaced 25.4 cm (10 inch) apart were made along the length of the beds using a shop-made furrow maker. Phosphorus fertilizer at the rate of 45.4 kg / ha (100 lb / ac) was added to the soil at the time of bed preparation. The three replicates of the experiment were located about 46 m (150 ft) apart on three different beds in the nursery used for Shumard oak planting.

Layout and planting

The experiment contained eight treatments with five acorns each (Figure 3). Two treatments were accommodated in each one foot length of the furrow. Thus 40 acorns were sown in each one foot length of the bed which formed one plot at harvest. Eleven plots were numbered serially for making the harvests at random. In order to reduce edge effect, an unsized acorn was sown as border in each furrow in between two harvest plots. The experiment was conducted in a randomized complete block design arranged as a split-plot (Appendix). The main plot was harvest and the subplot was seed size. Each seedling served as the subsampling unit. The acorns were sown on November 18, 1997 when the soil was adequately moist. They were pressed into the furrow and covered with soil. The beds were leveled with a shop-made roller. Sawdust was spread on the beds to a thickness of about 1.25 cm (½ inch) with a light covering of paper-based hydromulch on top. Immediately after planting the beds were irrigated.



A

1	2	3	4	5	6	7	8	9	10	11
18 16	21 c	21 20	20 18	19 21	19 17	21 c	21 19	17 20	c 18	17 15
21 15	19 20	17 18	16 17	16 20	16 15	16 19	15 20	18 21	19 21	18 16
17 c	18 15	15 c	21 c	15 17	c 21	18 17	16 c	19 c	15 20	21 19
19 20	16 17	19 16	15 19	18 c	18 20	20 15	17 18	16 15	16 17	20 c
2	11	7	9	8	5	3	10	4	1	6

B

18 18 18 18 18	16 16 16 16 16
21 21 21 21 21	15 15 15 15 15
17 17 17 17 17	c c c c c
19 19 19 19 19	20 20 20 20 20

C

Figure 3. Plotplan for Shumard oak sowing. A - Three replicates; B - Bed 1 showing plot numbers (above) and random harvests (below); and C - Plot 1 (Harvest 2) with eight treatments and five acorns each (15 = 15 -15.9, 16 = 16 - 16.9, 17 = 17 - 17.9, 18 = 18 - 18.9, 19 = 19 - 19.9, 20 = 20 - 20.9, 21 = 21 - 21.9 mm, & c = Control).

Thereafter frequent watering was done until germination and during seedling emergence. A flag was inserted into the soil on the northwest corner of each plot to identify the plot at the time of harvest.

Germination and cultural operations

The acorns of Shumard oak exhibit dormancy which can be broken by stratification (Dey and Buchanan, 1995). As the acorns were sown during the fall they were stratified in the field during the winter and germination started by late April. The germination was complete within 3 - 5 weeks. During germination the acorns were frequently watered. Once germination was complete, watering was done at least two times a week. As the summer was very hot, watering schedule extended up to six days a week. No supplemental fertilization was done during the growth period. As there was no serious pest problem associated with the crop, fungicide and herbicide applications were not warranted. An attempt was made during the summer to wrench the roots using a Fibro Root Wrencher, but it could not be done due to the unusually dry soil profile.

Harvests and data collection

Eleven harvests were made every 2 - 4 weeks starting from April 24, 1998, and the seedlings were brought to the laboratory for taking measurements. The last harvest was made on January 25, 1999. While excavating maximum care was given to verify the acorn size by digging around the acorns remaining attached to the seedlings. The acorns were collected along with the seedlings and put inside labeled polythene bags. The plants serving as border were left in the bed to reduce edge effect on the remaining seedlings in the unharvested plots. The seedling dimensions on fresh samples were collected including stem length, number of leaves, number of branches, stem diameter at about 2 cm (0.78 inch) from the root collar, and length of tap root. The number of first-order lateral roots having a diameter of 1 mm (0.04 inch) or more were counted along the tap root up to a length of 30 cm (11.8 inch) for harvests 8 to 11. Then the plant parts were dried at 70 °C (158 °F) for 48 - 72 hr and measurements on the oven dried materials such as, stem weight, leaf weight, pericarp weight, kernel weight, tap root weight, and laterals weight, were also recorded. At the time of the last harvest an additional random sample of 10 plants each were harvested from three regular nursery beds. Soil samples were collected from each nursery bed to measure the soil pH. The pH was recorded as 6.1, within the range suggested for Shumard oak (Williston and LaFayette, 1978). Data on atmospheric temperature were collected from the Oklahoma Mesonet (Figure 4).

Data analysis

Analysis of variance procedures (General Linear Models) were performed on all data using SAS Statistical Software (SAS, 1989) at $p \leq 0.05$, and the means separations were carried out using LSD on significant effects. The experimental layout was a randomized complete block design with three blocks. The plot of five acorns was the experimental unit and each seedling served as the sampling unit. Harvests were analyzed separately.

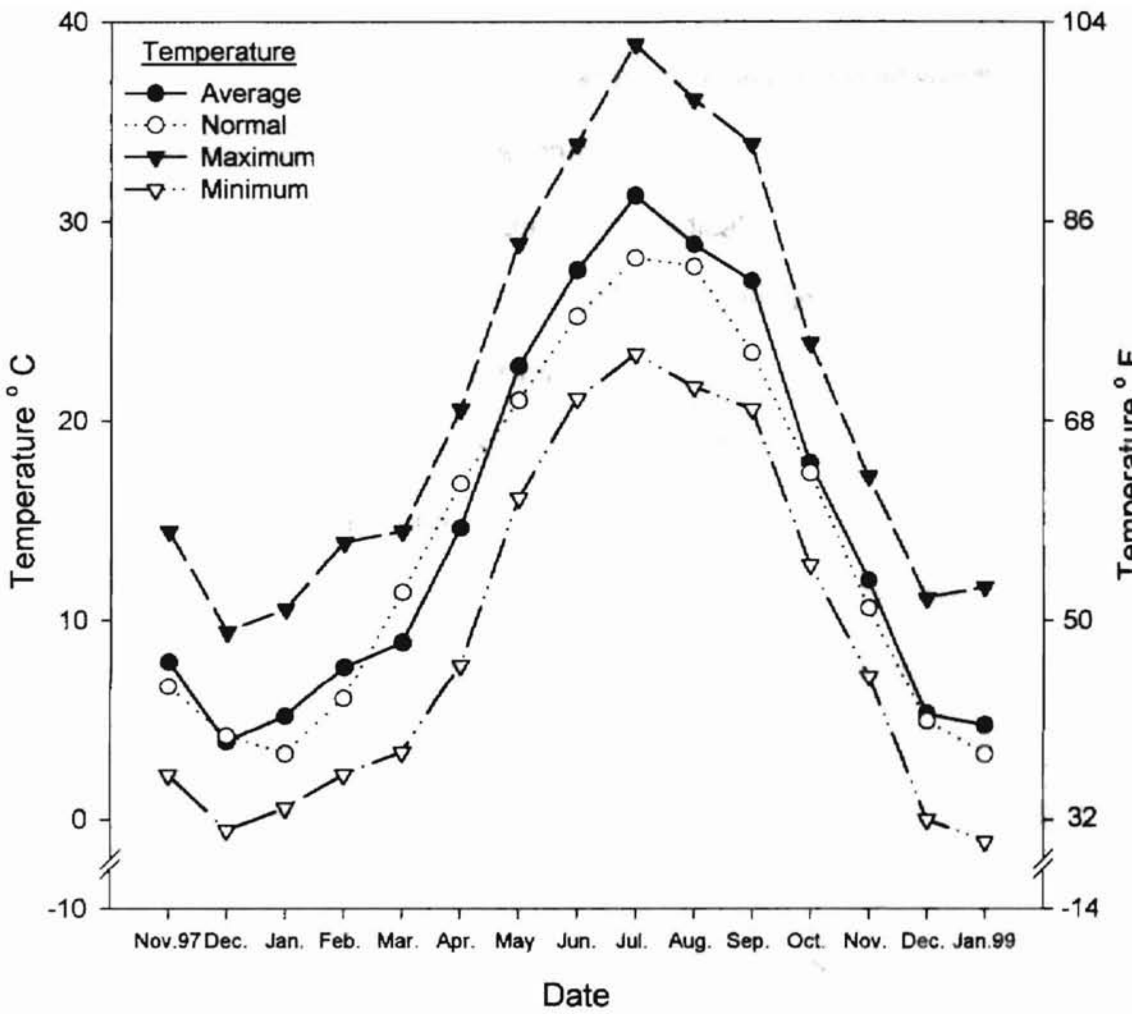


Figure 4. Average, average normal (30 yr average), maximum, and minimum temperatures at the Mesonet station at Washington, OK, from the date of sowing acorns until the last harvest of seedlings.

Chapter IV

Results and Discussion

Introduction

There was a significant effect of acorn size on almost all seedling variables, except the number of branches, branches per cm of stem length, length of tap root, and survival percent. This indicated a direct relation between the size of acorns and the first year growth of the seedlings in the nursery (Tables 2, and 3). The seedlings from acorns of 15 - 15.9 mm diameter were smaller and contained less biomass. The seedlings from acorns of 21 - 21.9 mm diameter were taller and contained more biomass. The seedlings from acorns of 16 - 16.9, 17 - 17.9, 18 - 18.9, 19 - 19.9, and 20 - 20.9 mm diameter were intermediate in height as well as biomass production. The acorns used as control produced seedlings with variable dimensions, in most cases they had mean values equivalent to those of the seedlings from acorns of 16 - 16.9, 17 - 17.9 or 18 - 18.9 mm diameter. In the early summer, seedlings did not show much difference in growth dimensions among acorn sizes, but by late August they started to grow faster, and this continued until November (Figures 5, 6, and 7). This showed that about half of the growth occurred after August. As the first frost after sowing arrived late (Figure 4), this provided extended growth conditions to the seedlings. The acorn kernel supplied nutrients to the growing seedlings until July (Figure 8). By January, all the nutrients inside the kernel were exhausted and the kernel decreased in weight. Even though acorns

Table 2. Mean stem length, stem dry weight, stem volume, number of leaves, and leaf dry weight, for one-year old Shumard oak seedlings grown in the nursery and measured in January. Means followed by different letters are different at $p \leq 0.05$.

No.	Diameter class (mm)	Stem length (cm)	Stem dry weight (g)	Stem volume (cm^3)	Number * of leaves	Leaf dry * weight (g)
1.	15 - 15.9	44.87 c	5.99 c	5.77 d	26.80 d	3.38 d
2.	16 - 16.9	52.78 bc	5.12 c	8.38 cd	33.87 cd	4.51 cd
3.	17 - 17.9	59.55 b	6.88 c	12.37 bc	46.40 bc	5.58 c
4.	18 - 18.9	54.56 bc	6.57 c	10.92 c	43.53 c	5.66 c
5.	19 - 19.9	60.01 b	7.98 bc	13.21 bc	57.87 b	8.17 b
6.	20 - 20.9	65.48 ab	9.93 b	17.41 ab	72.67 a	11.42 a
7.	21 - 21.9	78.42 a	12.85 a	22.27 a	60.00 ab	9.21 b
8.	Control	53.87 bc	6.85 c	10.90 c	35.07 cd	4.90 cd

(* - Due to leaf fall in January, mean values correspond to the harvest made in November.)

Table 3. Mean root dry weight, number of lateral roots, root collar diameter, shoot-root ratio, and dry weight of acorn kernel, for one-year old Shumard oak seedlings grown in the nursery and measured in January. Means followed by different letters are different at $p \leq 0.05$.

No.	Diameter class (mm)	Root dry weight (g)	Lateral roots (No.)	Root collar diameter (mm)	Shoot-root ratio	Kernel* dry weight (g)
1.	15 - 15.9	6.52 e	5.34 c	6.47 e	1.58 b	0.69 c
2.	16 - 16.9	8.51 de	6.39 bc	7.23 de	1.85 b	1.02 bc
3.	17 - 17.9	10.17 cd	8.40 b	8.01 bcd	1.95 b	0.79 bc
4.	18 - 18.9	10.82 cd	8.26 b	7.92 bcd	1.78 b	1.17 abc
5.	19 - 19.9	12.15 bc	8.35 b	8.48 bc	2.07 b	1.31 ab
6.	20 - 20.9	14.46 ab	8.28 b	8.89 ab	2.07 b	1.11 bc
7.	21 - 21.9	16.44 a	12.16 a	9.89 a	2.63 a	1.65 a
8.	Control	9.95 cde	8.93 b	7.75 cd	1.84 b	0.71 c

(* - As the kernels were completely exhausted in January, mean values correspond to the harvest made in November.)

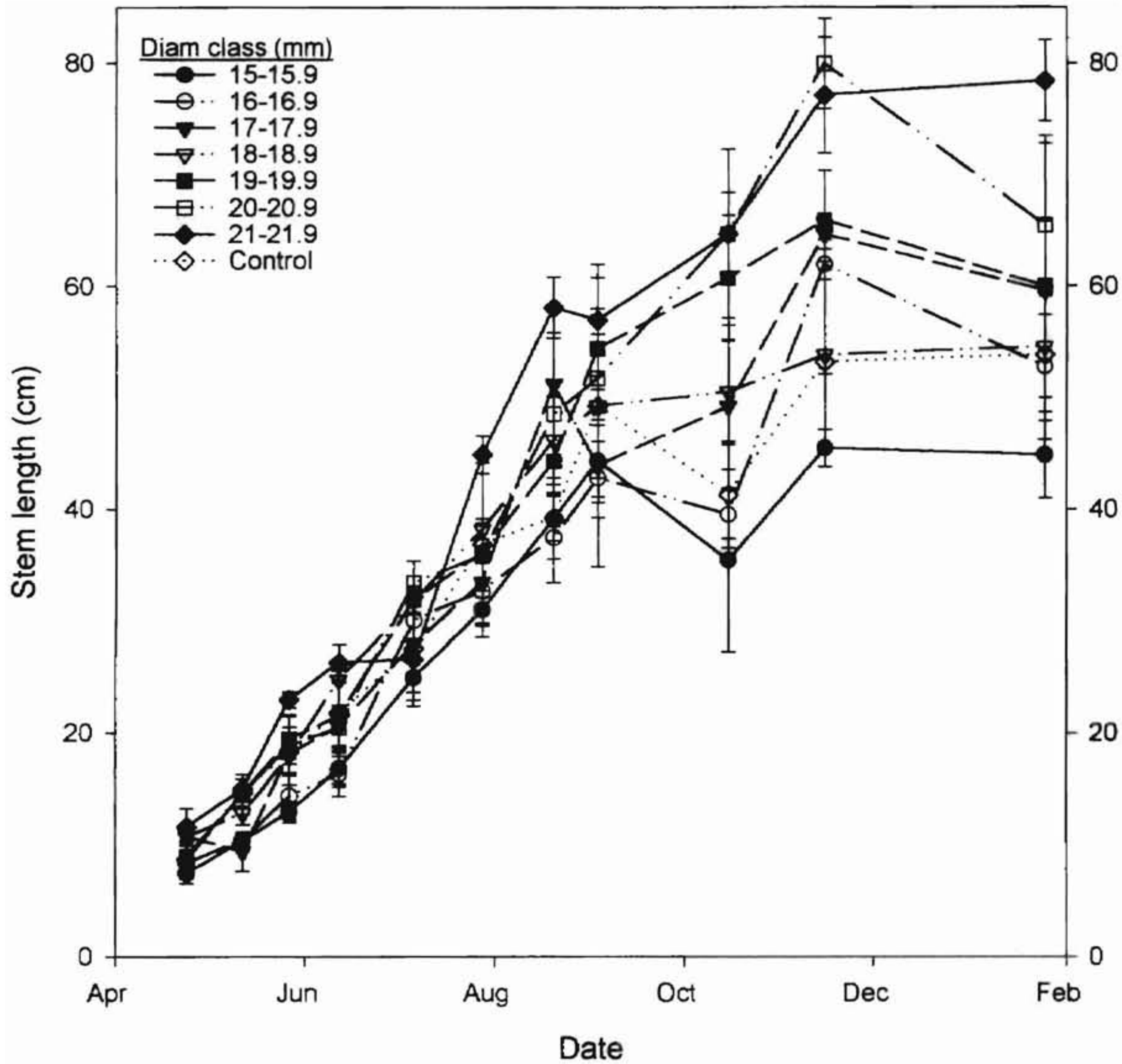


Figure 5. Effect of acorn size on length of stem.

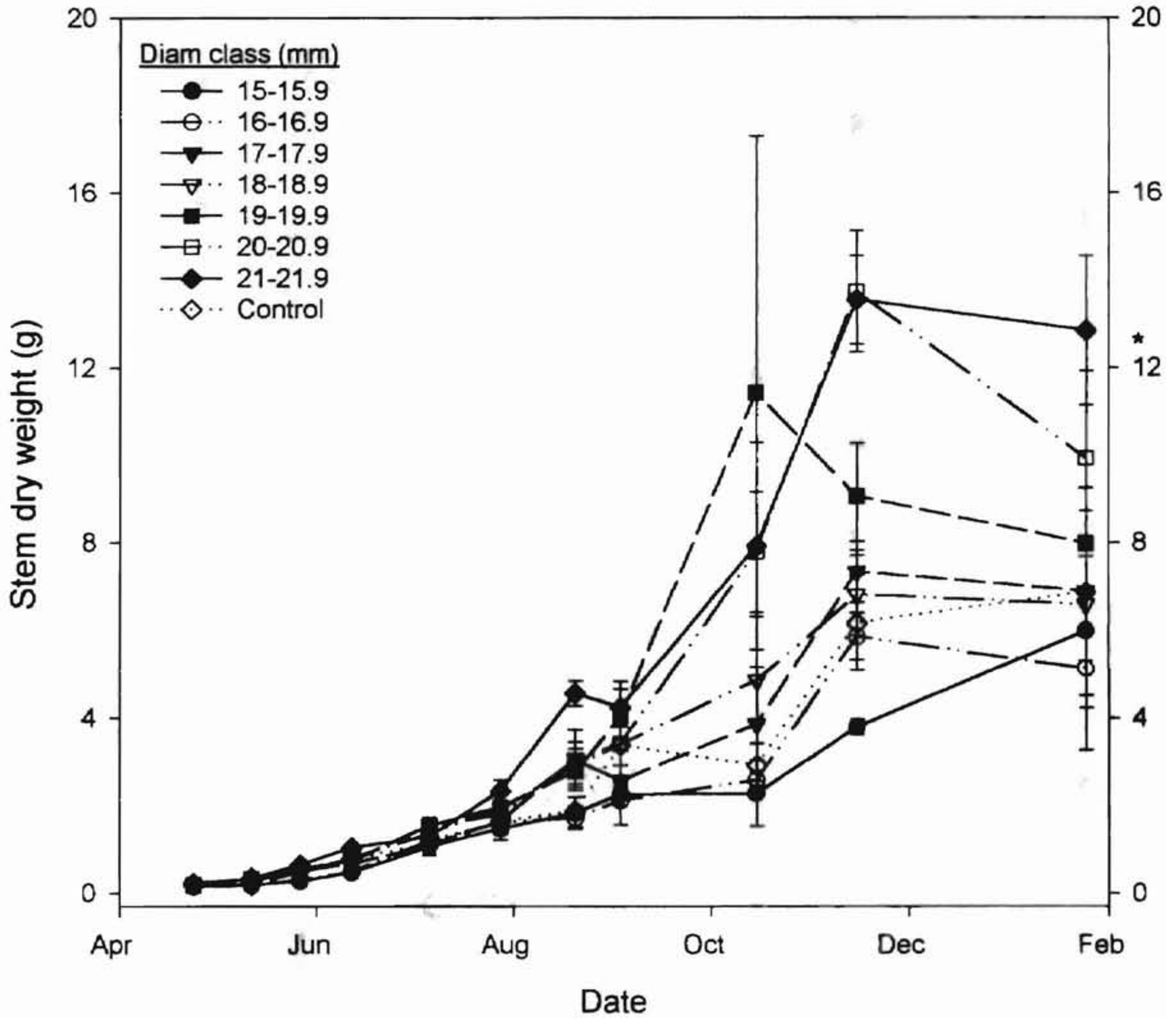


Figure 6. Effect of acorn size on dry weight of stem.
(* - Additional samples lifted from the regular nursery beds produced greater dry weight.)

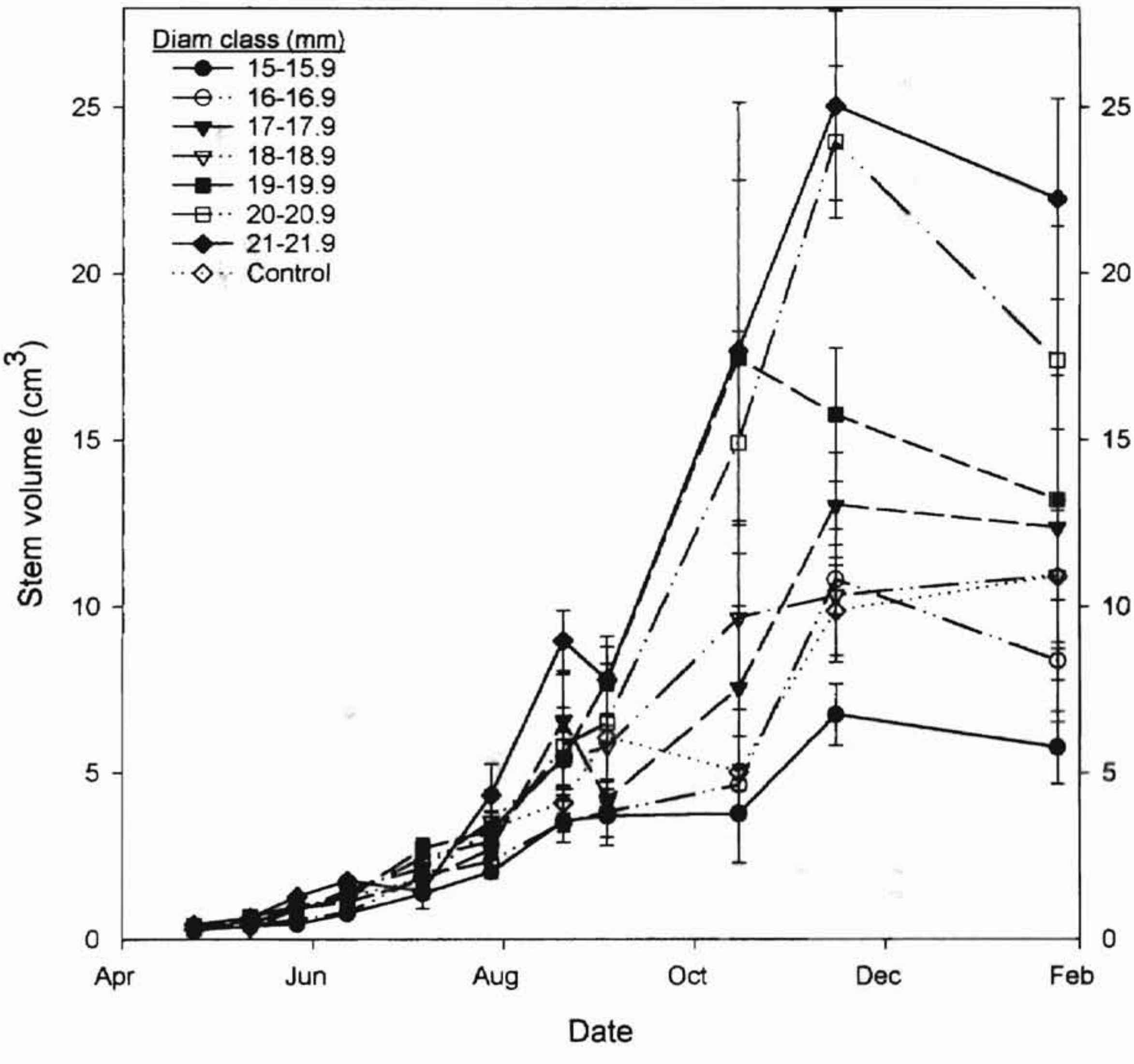


Figure 7. Effect of acorn size on volume of stem.

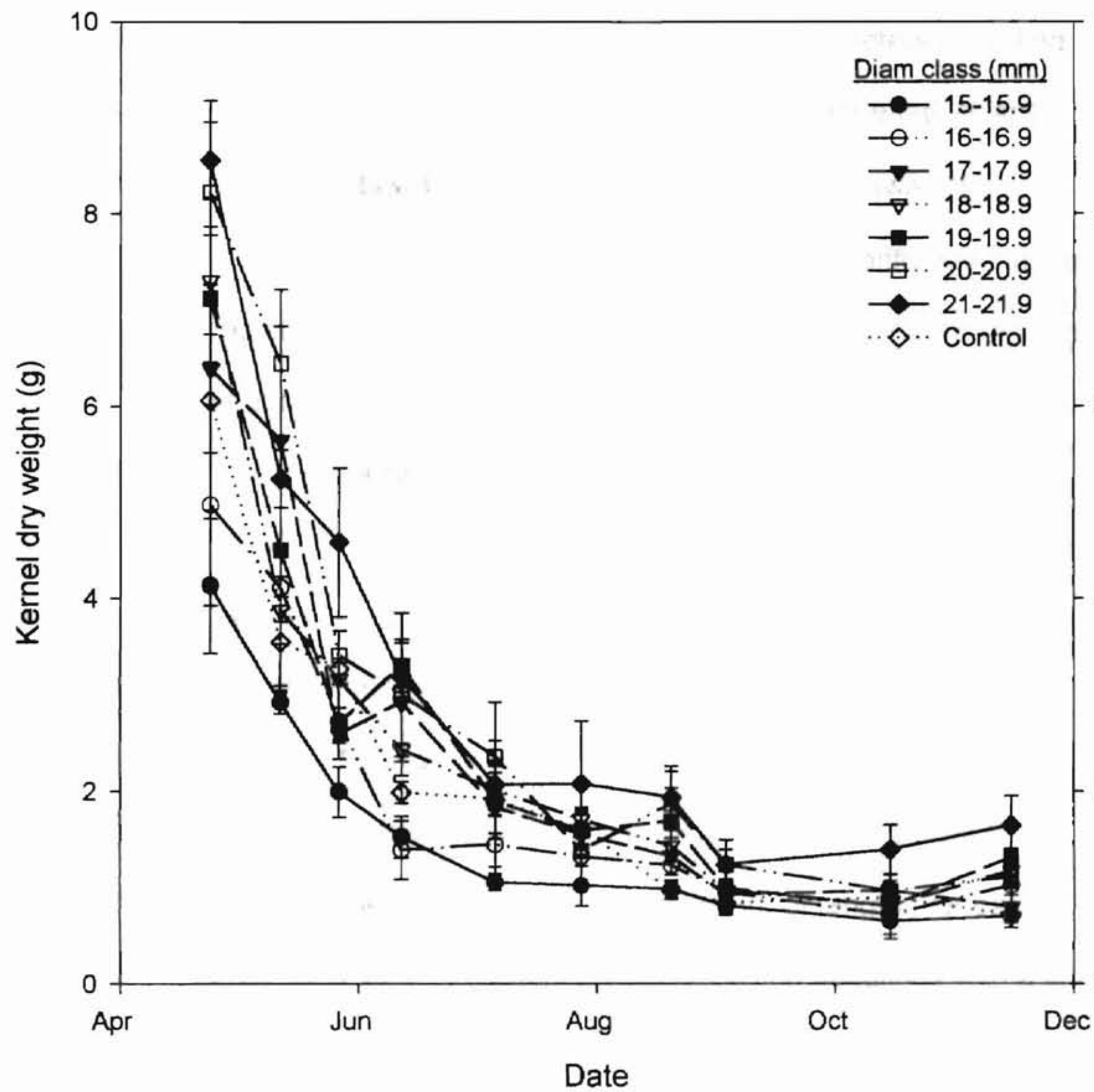


Figure 8. Dry weight of acorn kernel.

produced seedlings with variable growth dimensions, they followed the same seasonal pattern of growth.

Effect of acorn size on the shoot

Stem length, one of the most important decisive parameters in sorting between the saleable and cull seedlings, showed a significant effect of acorn size ($p < 0.008$). Similar results were reported by Seiwa and Kikuzawa (1991), Bonfil (1998), and Chacon et al. (1998). Even though there was no difference in stem length early in the season, faster growth and difference in height were noticed from late August until November (Figure 5). There was no extension of stem length after late November and the seedlings had an average height ranging from 45 to 80 cm (17.7 - 31.5 inch, Table 2). About half of the stem elongation occurred from late August to November. The seedlings from acorns of 15 - 15.9 mm diameter were the smallest with a height of 44.87 cm (17.7 inch), while seedlings from acorns of 21 - 21.9 mm diameter were the largest with a height of 78.42 cm (30.9 inch). All other sizes including the control ranged from 50 to 65 cm (19.7 to 25.6 inch) in height. The recommended shoot lengths for bare rootstock of the red oaks vary. Stroempl (1985) classified seedlings with a shoot length of 55 - 75 cm (21.7 - 29.5 inch) as large, and those with 30 - 45 cm (11.8 - 17.7 inch) as small. Therefore, the ideal seedlings belonged to those from acorns of 16 - 16.9 to 20 - 20.9 mm diameter.

Significant differences in the dry weight ($p < 0.0012$) and volume ($p < 0.0002$) of stem were noticed from late August until November, due to the increase in stem diameter (Figures 6 and 7, respectively). Long and Jones (1992) observed that oaks native to bottomland environments partitioned a significantly greater amount of biomass to shoots per unit of root mass than did oaks native to uplands. The seedlings had an average dry weight of 5 - 10 g (0.01 - 0.02 lb). The seedlings from acorns of 21 - 21.9 mm diameter contained a significantly greater dry weight of 12.85 g (0.03 lb). The additional samples lifted from the regular nursery beds adjacent to the experimental plots accounted for a greater dry weight of 12.5 g (0.03 lb) compared to the control which had a dry weight of about 7 g (0.02 lb, Figure 6). No difference was noticed in the dry weight of seedlings from acorns of 15 - 15.9, 16 - 16.9, 17 - 17.9, 18 - 18.9 mm diameter and control (Table 2). The volume of stem varied from 5.77 - 22.27 cm^3 (0.35 - 1.36 $inch^3$), produced by acorns of 15 - 15.9 and 21 - 21.9 mm diameter, respectively (Figure 7). On an average, the seedlings from the other acorn sizes produced a stem volume within a range of 8 - 17 cm^3 (0.49 - 1.04 $inch^3$). No difference in the seasonal growth pattern was noticed in stem length, dry weight and volume of stem. The warmer temperature provided extended growth conditions to the seedlings.

Even though the number and dry weight of leaves were of less importance in the nursery practice, significant differences due to acorn size was noticed among the seedlings ($p < 0.0001$ and $p < 0.0001$, respectively, Table 2). The number of leaves ranged from 27 to 73, in seedlings from acorns of 15 - 15.9 and 20 - 20.9 mm diameter, respectively (Table 2). A significant increase in the number of leaves was noticed from July to September, regardless of acorn size (Figure 9). A similar trend was observed in the dry weight of leaves, with a minimum of 3.38 g (0.007 lb) and a maximum of 11.42 g (0.03 lb) contained by seedlings from acorns of 15 - 15.9 and 20 - 20.9 mm diameter, respectively (Figure 10). In general, the dry weight of leaves varied from 5 to 9 g (0.01 to 0.02 lb). The seedlings from acorns of 20 - 20.9 mm diameter contained more leaves and a greater leaf dry weight than did the seedlings from acorns of 21 - 21.9 mm diameter. As most of the leaves were dead and fallen, the data on number and dry weight of leaves on the last harvest were not available. Chacon et al. (1998) found a similar positive relationship in the seedlings of *Cryptocarya alba*. The seedlings from large and medium seeds partitioned significantly greater amount of biomass to the leaves than did seedlings from small seeds.

There was no significant difference in the number of branches produced by seedlings from different acorn sizes (Figure 11). The number of branches was within a range of 1.34 - 2.81, produced by seedlings from acorns of 16 - 16.9 and 21 - 21.9 mm diameter, respectively. Similarly, the number of branches per cm of stem length was about 0.04, showing no significant difference among acorn sizes.

Effect of acorn size on the roots

There was no significant difference in the length of tap root, except in the October harvest (Figure 12). This was contrary to the results of Chacon et al.

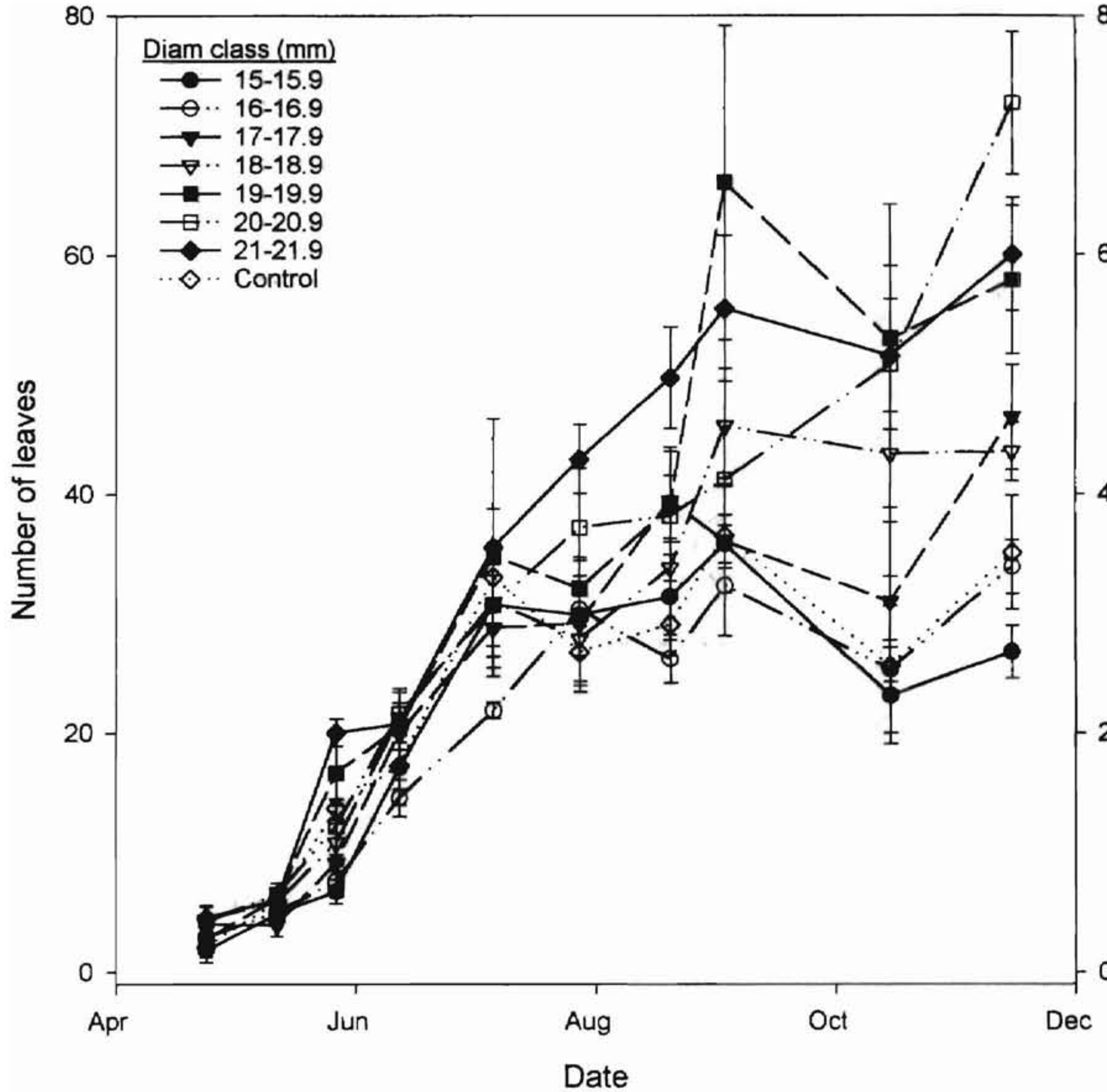


Figure 9. Effect of acorn size on number of leaves.

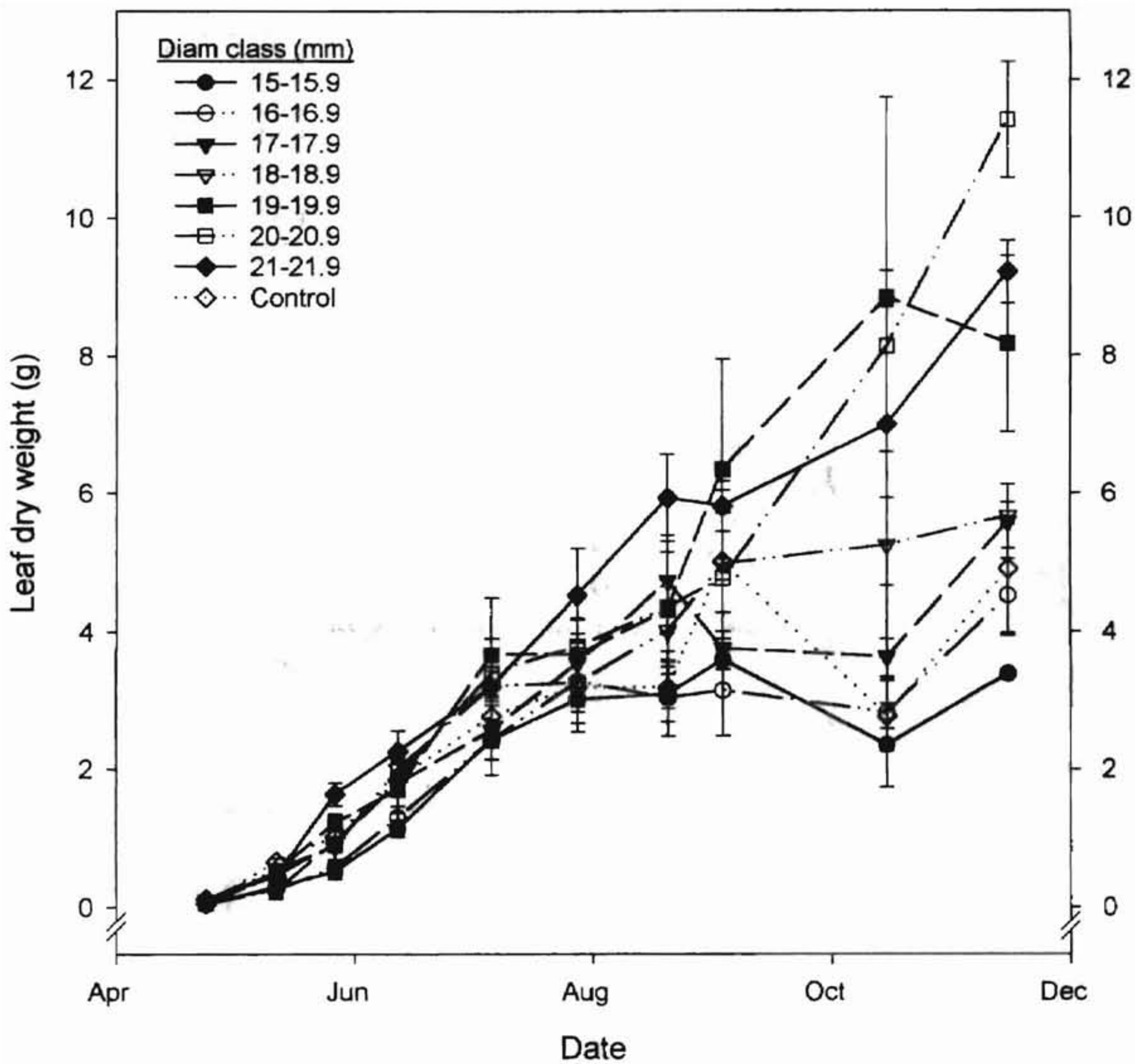


Figure 10. Effect of acorn size on dry weight of leaves.

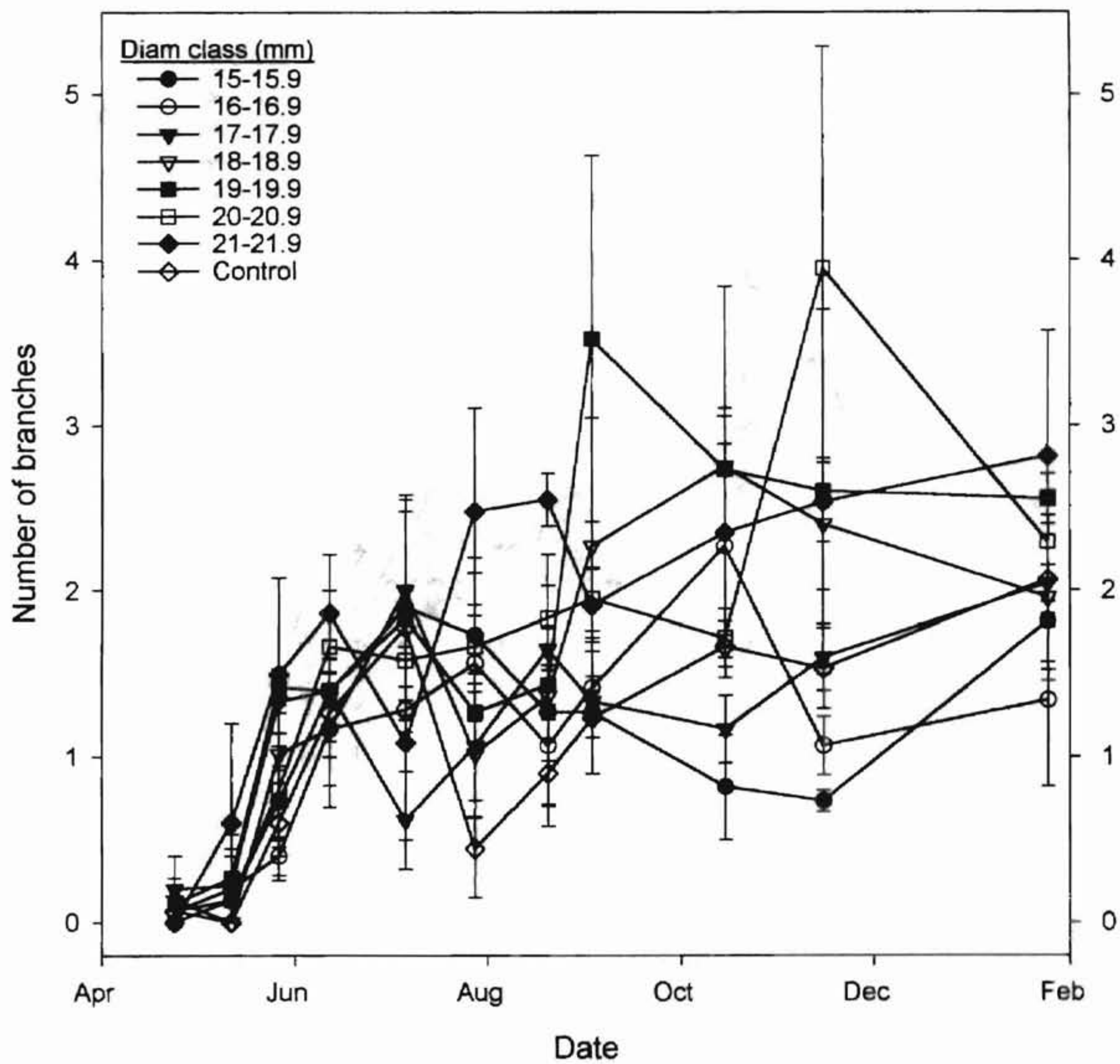


Figure 11. Effect of acorn size on number of branches.

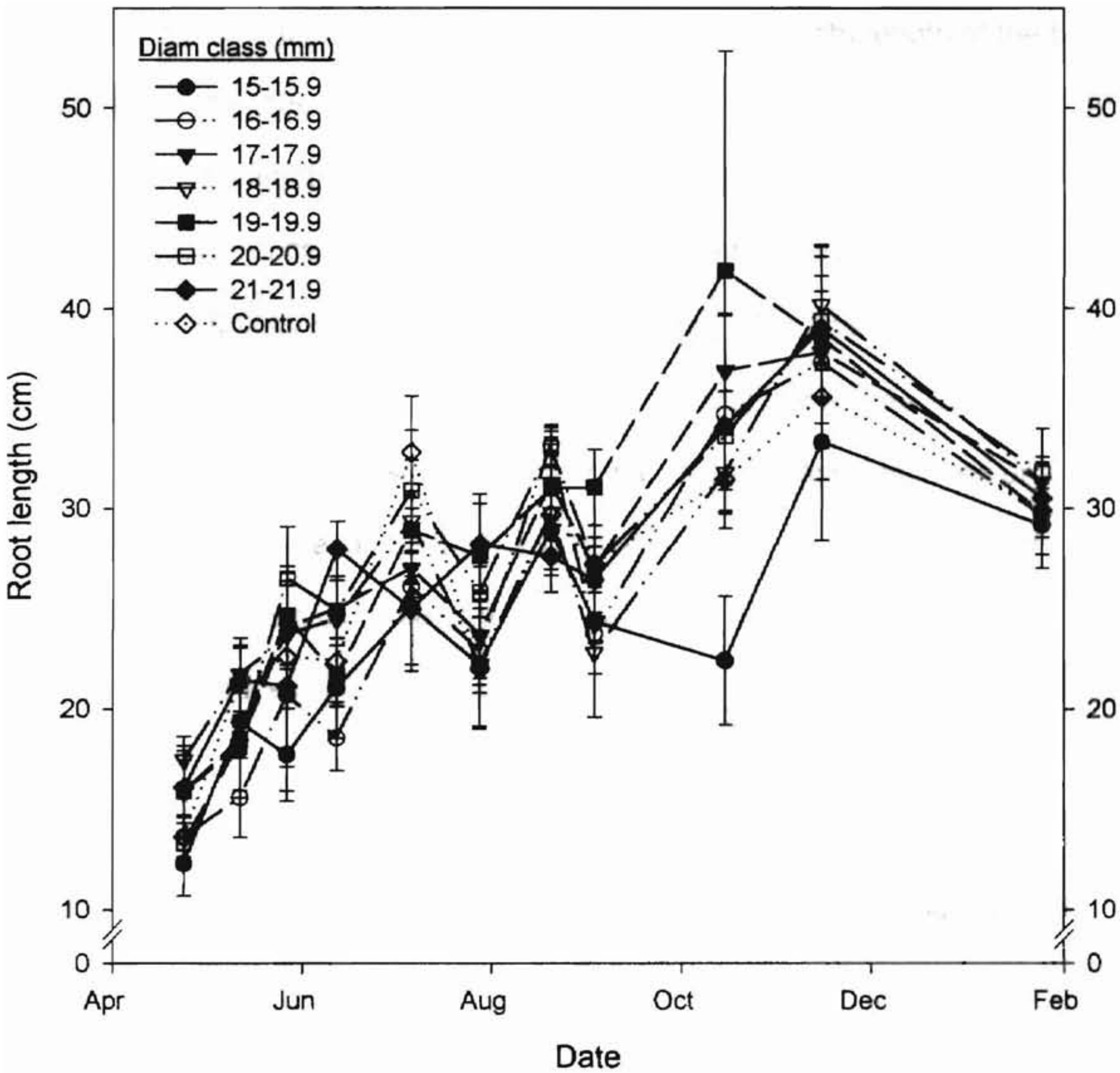


Figure 12. Effect of acorn size on length of tap root.

(1998). They found that the amount of the reserves in the cotyledons was positively related to the length of tap root. The reason for the absence of significance in other harvests might be due to the lack of complete length of the tap root while lifting. The very dry soil profile affected the excavation of the complete length of tap root. On an average, 30 cm (11.8 inch) length of the tap root was lifted. As most of the root biomass was contributed by the upper 20 - 25 cm (7.9 - 9.9 inch) length of tap root where most of the permanent first-order lateral roots were concentrated, the dry weight of roots showed significant differences ($p < 0.0007$) after late September (Figure 13). This is similar to the results of Chacon et al. (1998). Compared to the shoot, roots grew faster later in the growing season. As a result, increase in the root biomass continued until early December. The seedlings from acorns of 21 - 21.9 mm diameter produced maximum root biomass of 16.44 g (0.04 lb), while minimum biomass of 6.52 g (0.01 lb) was produced by seedlings from acorns of 15 - 15.9 mm diameter (Table 3).

Significant differences among seedlings were noticed in the production of the number of first-order lateral roots having a diameter of 1 mm (0.04 inch) or more (Figure 14). Lateral roots greater than 1 mm (0.04 inch) diameter were more likely to persist through all the nursery and out-planting activities, and hence they could be considered permanent (Thompson and Schultz, 1989). Most of them were restricted to the upper 20 - 25 cm (7.9 - 9.9 inch) length of tap root which contributed to the bulk of root biomass. The seedlings from

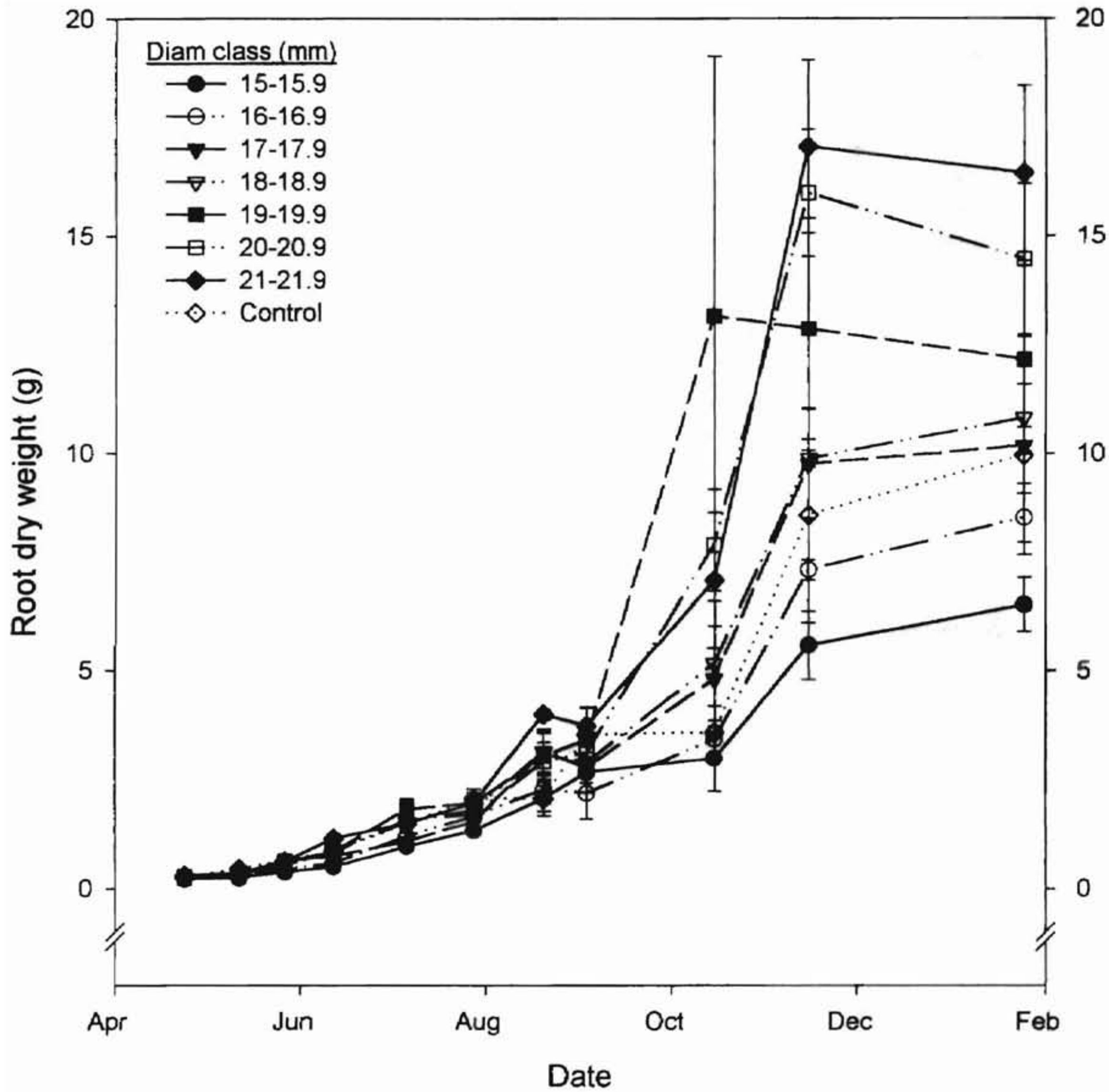


Figure 13. Effect of acorn size on dry weight of roots.

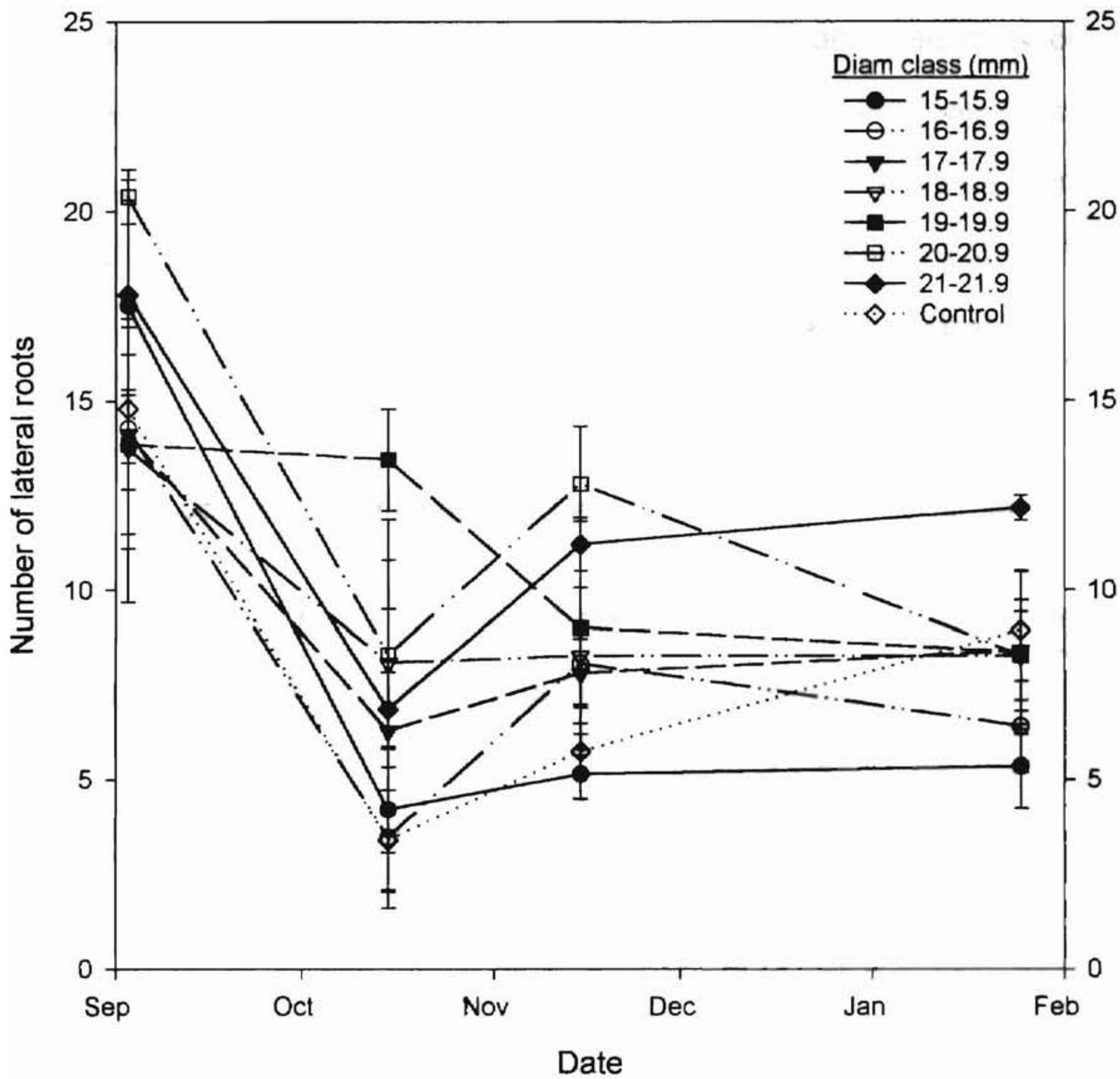


Figure 14. Effect of acorn size on number of first-order lateral roots.

acorns of 21 - 21.9 mm diameter produced the greatest number of first-order lateral roots (12), while the minimum (5) was produced by seedlings from acorns of 15 - 15.9 mm diameter. On an average, seedlings produced permanent lateral roots ranging from 6 to 8. Dey and Buchanan (1995) recommended that bare rootstock of the red oak should have at least five or six permanent first-order lateral roots for acceptable survival and growth performance. The number of lateral roots per cm length of tap root was 0.3, produced by seedlings from acorns of 16 - 16.9 to 20 - 20.9 mm diameter (Figure 15). Even though the seedlings from acorns of 15 - 15.9 and 21 - 21.9 mm diameter showed differences in the number of lateral roots per cm (0.2 and 0.4, respectively), they were not statistically significant.

Effect on the root collar diameter, shoot/root ratio, and survival percent

The stem diameter near the root collar seemed to be a useful grading standard for oaks and this was represented variously by different researchers. Stroempl (1985) classified seedlings having a root collar diameter of 7.4 - 8.5 mm (0.29 - 0.33 inch) as large stock and seedlings with less than 4.5 mm (0.18 inch) diameter as culls. The lowest and highest root collar diameters recorded were 6 and 10 mm (0.23 - 0.39 inch), produced by seedlings from acorns of 15 - 15.9 and 21 - 21.9 mm diameter, respectively (Table 3). In general, root collar diameter was within a range of 7 to 9 mm (0.28 - 0.35 inch), contained by seedlings from the other acorn sizes (Table 3). Even though the mean root collar diameter of the smallest size was not below the cull standard, some of the seedlings recorded even less than 4.5 mm (0.18 inch). Except in September, significant differences in the root collar diameter

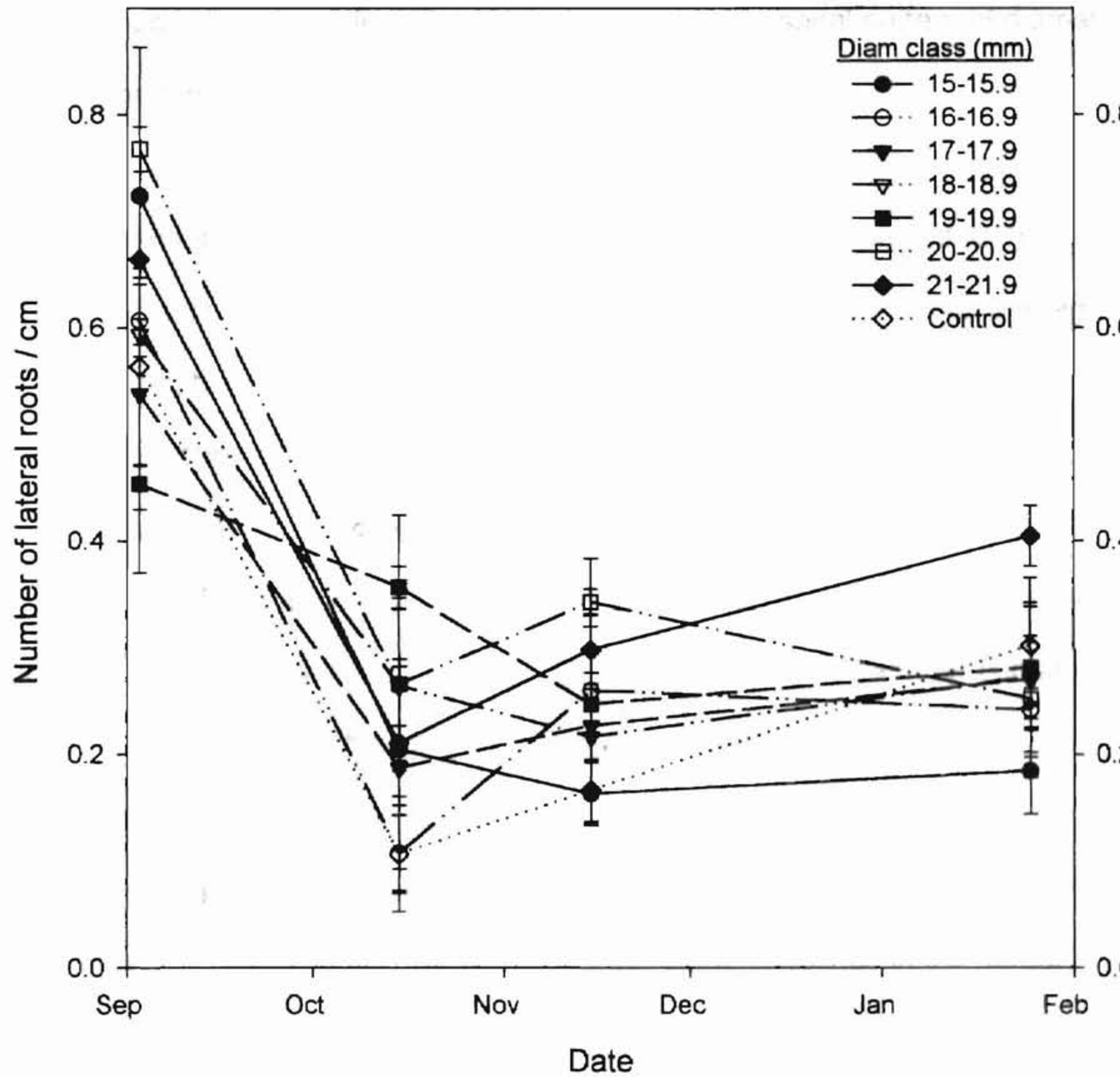


Figure 15. Effect of acorn size on number of lateral roots / cm of tap root.

were noticed from the harvests made from August to January, due to faster growth rate by late summer (Figure 16). The late arrival of winter provided extended growth conditions. The diameter expansion of the seedlings contributed to the significant difference in the biomass production of both shoot and root portions. No difference was noticed in the seasonal pattern of diameter expansion among the seedlings from different acorn sizes.

A shoot/root ratio of 2:1 or 3:1 based on length was expected for the saleable Shumard oak seedlings while lifting from the nursery, with an average tap root length of about 20 - 25 cm (7.9 - 9.9 inch). As the soil was very dry, most of the lower end of the tap root could not be harvested. The maximum (2.63) and minimum (1.58) shoot/root ratios were obtained from the seedlings from acorns of 21 - 21.9 and 15 - 15.9 mm diameter, respectively (Table 3). In general, seedlings from acorns of 16 - 16.9 to 20 - 20.9 mm diameter contained a shoot/root ratio close to two, based on length. Long and Jones (1996) recommended that the development of smaller shoot/root ratio was not necessarily a predictor of how a species or genotype would perform when the soil resources were scarce. The shoot growth of the seedlings in the nursery was faster from August to November, and the late arrival of the first frost after sowing provided extended growth conditions. A shoot/root ratio of 3:1 was possible when the seedlings were root-wrenched in the summer. The unusually hot and dry summer made the soil very hard which inhibited root wrenching. Significant differences in the shoot/root ratio were noticed in the harvests made

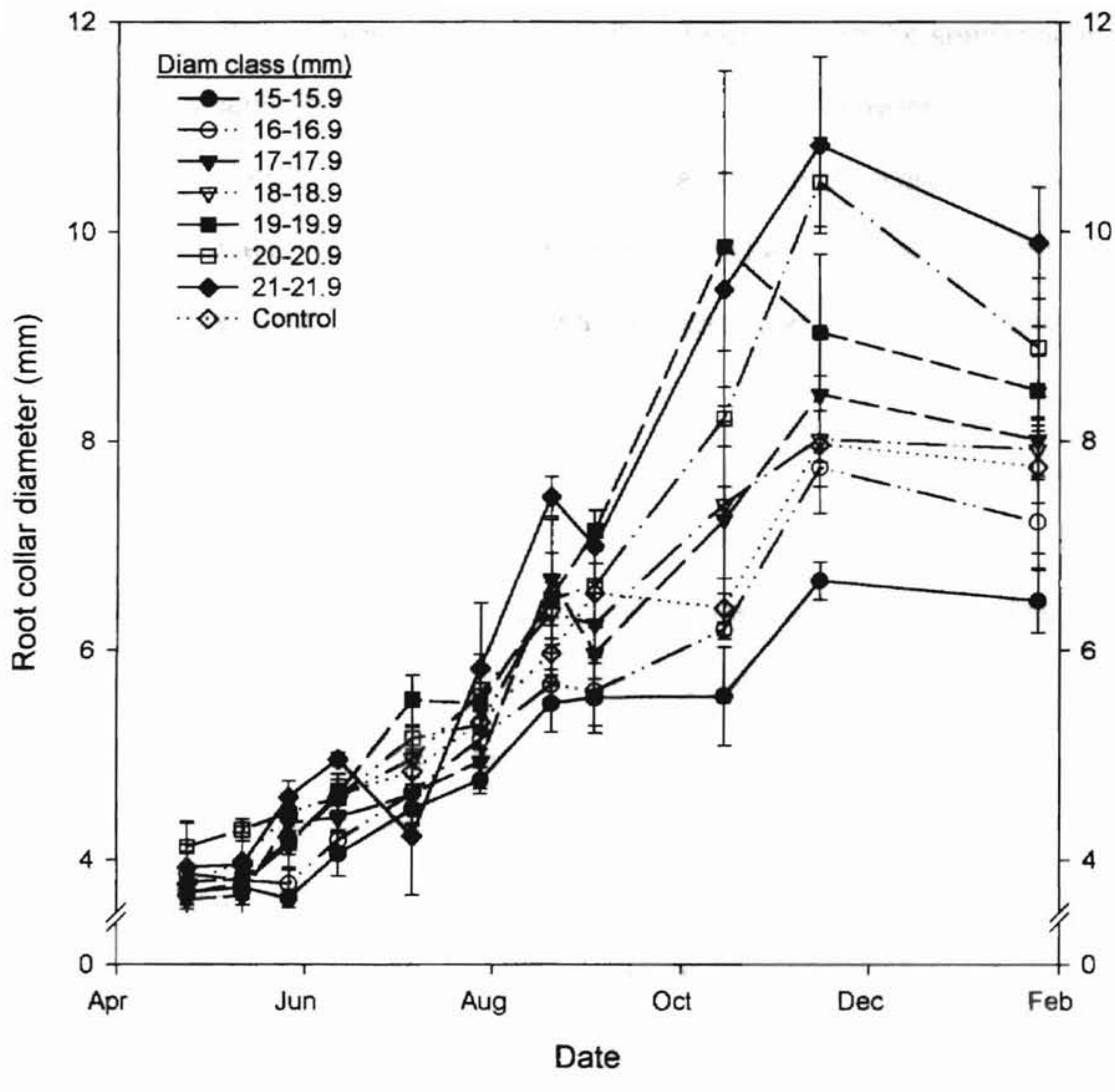


Figure 16. Effect of acorn size on root collar diameter.

from August to January, except September (Figure 17). The seedlings from acorns of 21 - 21.9 mm diameter were significantly different from seedlings from the other acorn sizes ($p < 0.0359$).

The percent survival was not significantly different among the seedlings in the eight treatments, but there was a significant difference between two replicates. The bed on the west side of the nursery showed the greatest survival with a mean value of 95 %, while the minimum (80 %) was noticed from the bed on the east side. In general, 90 % survival was noticed with all the acorn sizes.

Dry weight of the acorn kernel

Significant differences were noticed in the dry weight of the kernel of acorns lifted along with seedlings ($p < 0.0209$). As the kernel was totally exhausted by January, the data were related to the harvest made in November. Long and Jones (1992) reported that all ten species studied consumed about 70 % of the initial acorn mass during the first year of growth, and the initial acorn mass was significantly correlated with final seedling size. This would seem to confer an advantage to the large-seeded oaks over the small-seeded ones in that they obtain a greater amount of energy from the acorns during the first year of growth. The dry weight of the kernel after harvest ranged from 0.69 to 1.65 g (0.002 to 0.004 lb), for acorns of 15 - 15.9 and 21 - 21.9 mm diameter, respectively (Table 3). The acorns showed a gradual decline in the kernel biomass until July (Figure

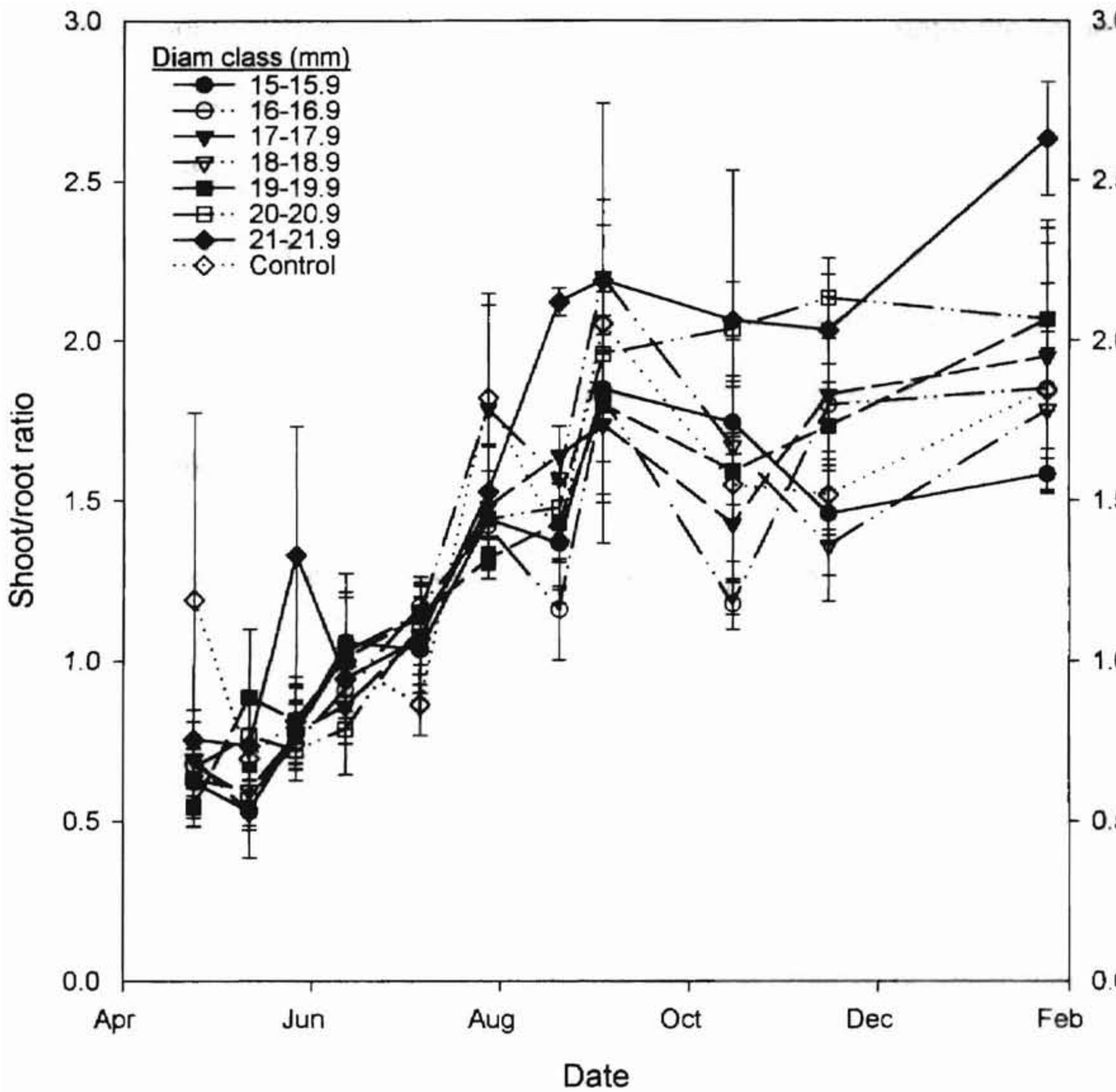


Figure 17. Effect of acorn size on shoot/root ratio.

8). The difference in the initial size of the seedlings helped them to compete for space and nutrients available in the nursery beds, which later differentiated into seedlings with variable dimensions. Tripathi and Khan (1990) reported that an increased proportion of protein, lipid, and carbohydrate provided the readily available energy that stimulated germination. Therefore, the greater the kernel biomass, the larger the seedling dimensions during the first year of growth of the seedlings in the nursery. Other factors such as, seed bed density and severe competition among seedlings also contributed to the difference in biomass production. The seedlings which were initially smaller failed to compete successfully with seedlings arising from larger acorns, and resulted with smaller seedling dimensions.

Effect of acorn size on the seasonal pattern of growth

Even though acorns produced seedlings with variable growth dimensions, they followed the same pattern of growth. Seiwa and Kikuzawa (1991) reported that the importance of seed size in determining seedling establishment success depended on the relationship between the seasonal change of the environmental light conditions and the characteristics of the seedling phenology, which were related to seed size. Since germination in late spring no significant difference in growth was noticed until August. When the seedlings exhibited differences in growth dimensions by late August they followed the same pattern until the cessation of growth in the fall. The seedlings from acorns of smaller sizes grew comparatively slower than did the seedlings from acorns of larger sizes. This showed no difference in the seasonal pattern of growth of the seedlings. This has a significant importance in the nursery practice in that, nursery managers are interested to know how the sized acorns respond to seasonal changes. All the seedlings from sized acorns would be more uniform in growth in the nursery which result in less variability.

Chapter V

Conclusions and Recommendations

Introduction

The statistical analyses showed a significant effect of acorn size on all seedling variables ($p < 0.05$). A direct relation between acorn size and the first year of growth of seedlings in the nursery was observed. This suggested to reject the null hypothesis. The relation between acorn size and seedling growth has a significant importance in the nursery practice as seedlings were grown in the nursery beds for only one year before being used for conservation planting. Seedlings from acorns of 15 - 15.9 mm diameter were smaller and contained less biomass, while seedlings from acorns of 21 - 21.9 mm diameter were larger with more biomass. This was true with most of the seedling variables. The acorns belonging to these two diameter classes accounted for less than 10 % in a total of 27.2 kg (60 lb) used in the experiment, while the majority of acorns (90 %) came from 16 - 16.9 to 20 - 20.9 mm diameter classes (Figure 18). Most of the seedling variables of these diameter classes exhibited less variability among the seedlings. Moreover, there was no difference in the seasonal pattern of growth among the seedlings. Therefore, the following suggestions are given with respect to the practical implication of sizing, growth of seedlings in the nursery, and uniformity among the crop.

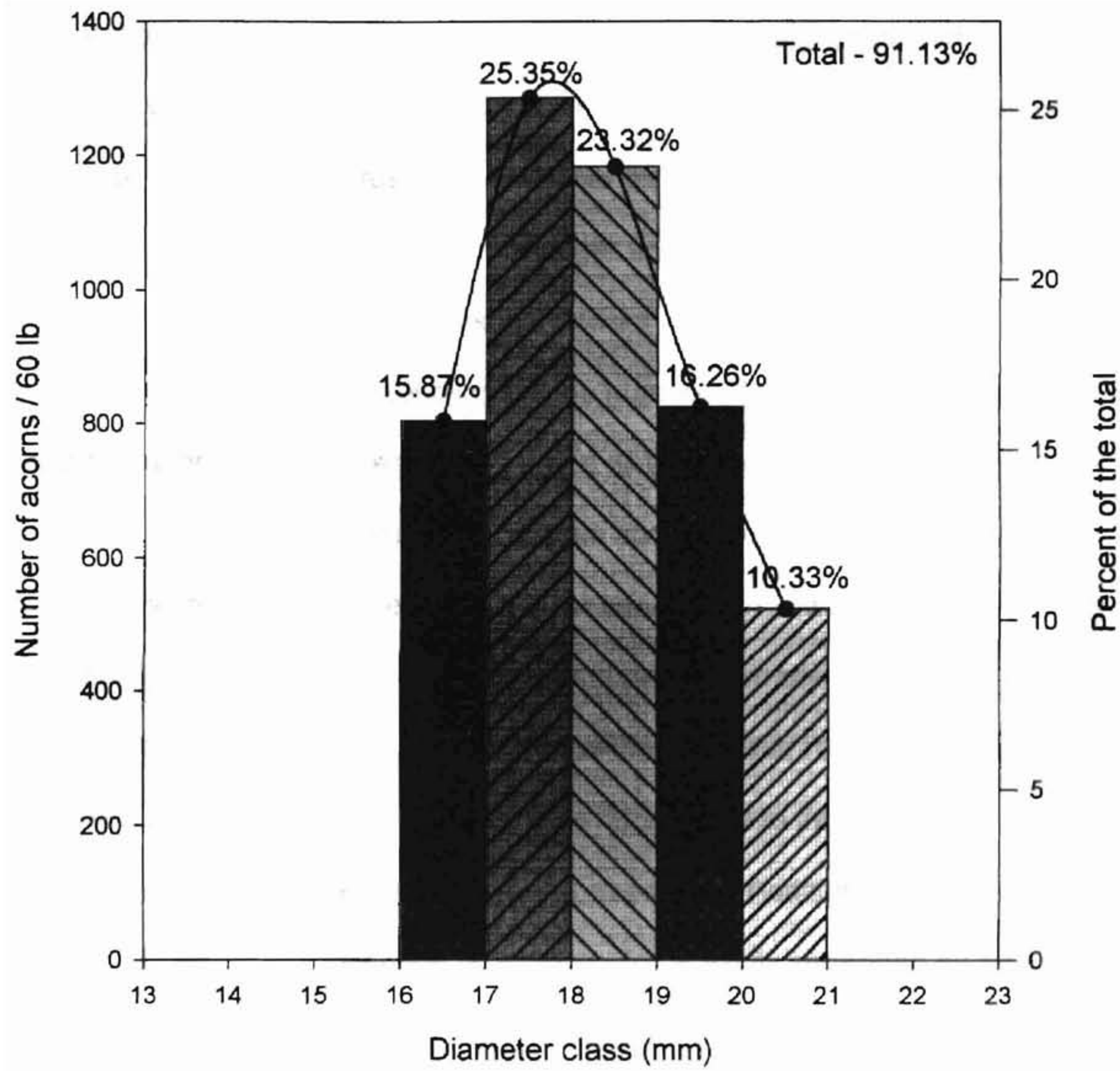


Figure 18. Number of sized Shumard oak acorns in diameter class with less variability in size and their percent of the total.

1. Acorn sizing

The acorns could be sized before sowing using screens modified to suit the diameter of acorns ranging from 16 - 16.9 to 20 - 20.9 mm, as they formed the bulk of the collection. The acorns of 15 - 15.9 mm diameter produced smaller seedlings with less biomass and they were comparatively inefficient in competing with larger seedlings and resulted with lower biomass. The seedlings from acorns of 21 - 21.9 mm diameter were larger and contained more biomass. As there was no difference in the seasonal pattern of growth of the seedlings, sizing will not affect the growth of seedlings in the nursery. The split and highly damaged acorns could be easily separated while using screens for sizing. This will result in increased germination. Edgren and Bigelow (1972) recommended that since small seeds caused the greatest variability in sowing density and also produced small seedlings, they must be eliminated from sowing or they must be sown separately. Bonner (1987) also prescribed a similar recommendation that small seeds must be sown separately from larger ones to increase uniformity, as the variability resulted mainly from smaller seedlings. Additionally, the large acorns of 22 - 22.9 mm diameter or more could be easily separated by sizing. They could be used for producing very large seedlings for landscape planting, even though this is not a current objective of the state nursery. Sluder (1991) reported that grading seeds and seedlings into size classes was advantageous to the nursery and forest managers if it produced uniformity in the sowing density, germination rate, size of the planting stock, and survival in the field.

2. Precision sowing by machines

The sized acorns could be sown by machines which involve less human labor. This results in more output within the limited time due to the fluctuating atmospheric and edaphic conditions during the fall. Additionally, precision planting by machines provide better control in planting depth. Acorns of uniform size could be placed at proper depth assuring uniformity in time and percent of germination. By proper sowing, the acorns could be protected from pilferage by squirrels, rodents, and birds to some extent. This also helps in preventing the acorns being washed out during heavy rains.

3. Uniformity among seedlings

By planting sized acorns uniformity among seedlings could be increased. This results in less cull seedlings. The current cull percent of 5 - 10 could be reduced greatly. Uniformity in density is derived through a more uniform germination of sized acorns and uniform growth of seedlings (Belcher et al., 1984). Moreover, uniform seedlings could respond uniformly to cultural treatments offered to the seedlings in the nursery. Above all, while the seedlings are lifted from the nursery they need less handling before storage to remove the culls. This results in great savings in labor, time and money. Grading the seeds was relatively easy and inexpensive while grading the seedlings was expensive and time consuming (Sluder, 1991).

4. Other advantages

Jurado and Westoby (1992) suggested that species with heavier seeds were able to emerge from greater depths in the soil than did species with lighter seeds. The seed size might affect survival of the plant in stressful environments and larger seeds might enhance the flexibility in shoot/root allometry, speed of germination and overall growth (Long and Jones, 1996). Bonfil (1998) found that seedlings from larger acorns were better in enduring the loss of cotyledons and aerial biomass, and were better equipped to confront stress in the juvenile stage. Therefore, seedlings from uniformly large seed sizes may be better for planting on sites with adverse conditions.

The seedlings from larger seeds were superior in growth enhancement within a species in a high carbon dioxide environment. This has an important implication while considering plants with intra-specific variation in the models designed to predict forest response to elevated carbon dioxide in the atmosphere (Miao, 1995). As there is an increasing level of carbon dioxide in the atmosphere, by planting seedlings from uniformly large acorns may be beneficial to effectively utilize the changing conditions of the environment.

Kormanick et al. (1995) found that large seedlings were able to overcome transplant shock and they established before they were overtopped by competing vegetation. Large pre-harvest advanced oak regeneration was needed for maintaining a significant oak component in future stands. It was practical to produce large seedlings that mimic sizes recommended for natural advance oak regeneration. Hence, uniformly large seedlings can be produced in the nursery by sizing acorns before sowing and they may be better in enduring the transplant shock. This will result in increased field survival of the transplanted stock.

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APPENDIX

PROTOCOL DESCRIPTION FORM

Experiment number: 1 Date: July, 1999

Experimentation objectives

1. To determine the relationship between acorn size and seedling growth of Shumard oak,
2. To determine if acorn size affects the seasonal pattern of growth of seedlings, and
3. To determine if sizing of acorns increases uniformity among seedlings in the nursery.

Population of interest

- Shumard oak acorns

Experimental unit & Subsampling unit (if any)

- Main unit (whole plot) - Harvest
- Sub unit (sub plot) - Flat/treatment/acorn size
- Subsampling unit - Seedling

Response variables:

Decision variables

- Stem length, No.of leaves, No.of branches, Root collar diameter, Tap root length, and No.of lateral roots] Fresh samples
- Dry weight of stem, Dry weight of leaves, Dry weight of pericarp, Dry weight of kernel, Dry weight of tap root, and Dry weight of lateral roots] Dried samples

Ancillary variables

- Sieves, Caliper, and Ruler for sizing and taking measurements
- Implements for lifting seedlings
- Hot air oven for drying plant materials
- Weather data from Oklahoma mesonet

Treatment structure

- Two-way treatment structure (a x b factorial)

Levels of each treatment (Experimentation groups)

- Harvest - 11 levels, and Size - 8 levels

Design structure

- Split-plot in a RCBD, with subsampling (Block = Bed/replicate)

Randomization and replication

- SAS, SAS Institute Inc., Cary, NC - 27513
- 8 Sizes x 5 Seedlings x 3 Replicates x 11 Harvests = 1320 Subsamples

2

VITA

Premkumar Thondikkattil

Candidate for the Degree of

Master of Science

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Major Field: Forest Resources

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