NUTRITION AND IRRIGATION REGIME AFFECT SIZE AND EARLY GROWTH OF WHITE OAK SEEDLINGS

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ABSTRACT.—Modifications of our nursery protocol for oaks during 1997 and 1998 by instituting dormant season irrigation resulted in high white oak seedling quality. The improved growth was associated with the consistent presence of succulent fibrous roots on the upper 10 to 15 cm of taproots. Many of these fibrous roots on 1-1 stock were as sturdy as many of the permanent first-order lateral roots. White oak seedlings from the 1998 nursery crop grown under the modified irrigation schedule have developed well in the field. At age 4 many are 4.0 m tall with up to 50 mm stem diameters.

White oak, (*Quercus alba* L., WO), one of the most valuable and versatile oak species throughout its range, is capable of regenerating by either seeds or sprouts (Rogers 1990). The species has a reputation of being a slow grower, and it persists and thrives on low quality sites where few faster growing competitors exist. On high quality mesic sites, its slow growth is often detrimental because it cannot compete with the many faster growing or shade tolerant species. In this situation, artificial regeneration has been attempted to supplement poor naturally regenerated WO seedlings. However, it has met with little success (Rogers 1990).

In the early 1980s, the major impediment to artificial regeneration of WO was the absence of quality seedlings. Some agencies suggested that because artificial regeneration results were so poor, further attempts should be discouraged until nursery and outplanting technology were improved (Boyette 1980, Hill 1986). In 1984, research was initiated at the USDA Forest Service Institute of Tree Root Biology (ITRB) in Athens, Georgia, to develop a nursery protocol for growing oak seedlings that would enable the formulation of a biologically based grading system.

Initially, WO and northern red oak, (*Quercus rubra* L., NRO) were the species receiving the most attention for developing nursery production standards. In 1984, few forest tree nurseries were growing hardwoods in the southern United States because the primary emphasis then was on pine seedling production. However, the oak decline problem was of great concern to groups such as furniture manufacturers and wildlife organizations who were aware of declining oak populations on high quality mesic sites. A potential solution to reverse oak decline led to enrichment plantings in recently harvested or in under-stocked oak decline stands. Unfortunately, this was not vigorously pursued because of WO's reputation for slow growth in the nursery. Average heights (HGT) of shippable seedlings were less than 25 cm tall with root collar diameter (RCD) of 4 mm or less (Wichman and Coggeshall 1983).

This paper does not report the results of a single study, but rather summarizes a gradually evolving procedure for producing seedlings with consistent morphology conducive for artificial regeneration of WO. Until we lifted and evaluated the 1996 nursery crop, WO root system morphology was considered to be different from other oaks tested. White oak had consistently produced fewer first-order-lateral roots (FOLR) and fibrous feeder roots along the first 10 to 15 cm of the taproot.

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In all our previous nursery trials, WO seedlings never approached the stem sizes attained by NRO seedlings. The initial nursery trials with WO at the ITRB experimental nursery used the nursery seedling sizes obtained from the Georgia Forestry Commission's Nursery Program as "standards." The seedlings produced in our initial trials did not represent a significant improvement in quality from those produced in the Georgia Forestry Commission or reported by others (Wichman and Coggeshall 1983, Rogers 1990).

NURSERY TRIALS BEFORE 1990

In 1986, after several modifications in seasonal N application rates, a significant improvement in WO seedling sizes was finally realized (Kormanik and others 1989). Afterwards, we did little research on WO for several years due to poor acorn availability. Rather, we concentrated on developing nursery protocols for NRO for which acorns were readily available from the USDA Forest Service Watauga Seed Orchard located in eastern Tennessee. After developing a reliable protocol for NRO nursery production in the early 1990s, we resumed research on improving WO seedling morphology (Kormanik and others 1994).

The initial nursery research prior to 1990s was done with acorns collected from grafted mother trees established at the USDA Forest Service Beech Creek Seed Orchard in western North Carolina, using the same nursery fertility protocol that was developed for NRO (Kormanik and others 1995, 1998). Acorn germination from these grafted mother trees ranged between 10 to 60 percent despite extra care that was used for collection and storage.

Although poor germination resulted in abundant nursery bed spacing, these WO acorns produced seedlings of unsatisfactory quality. We continued to test the Beech Creek Seed Orchard WO almost exclusively since they represented years of orchard development by the USDA Forest Service Southern Region genetics program and contained mother trees from throughout the southern Appalachian Mountain range.

Data from almost all these grafted selections were poor and difficult to interpret. For example, it was common to have a significant percentage (10 to 20 percent) of the acorns germinate but never develop an epicotyl. In these cases, the radicle would develop normally until the stored food in the cotyledons was exhausted and then it would begin to deteriorate. The cause of this abnormality is unknown. Absence of epicotyl development is not common, but we could find no evidence of insect damage, epicotyl breakage, or fungal damage to account for failure of epicotyls in our trials.

Equally disturbing was the percentage of the developing seedlings that had multiple tops and other maladies that were considered unacceptable for outplanting stock. Eventually, WO acorns from wild collections were included in our tests along with those from the Beech Creek grafted orchard. Poor germination and other abnormalities so common to the WO seedlings from grafted stock acorns were seldom observed with seedlings obtained from wild acorn collections.

NURSERY TRIALS 1990 TO 1996

Early tests using acorns from non-grafted parents germinated well and produced seedlings that developed sizes comparable to those reported earlier (Kormanik and others 1989). However, we continued to find that less than 40 percent of the WO seedlings were of acceptable quality for outplanting. These seedlings characteristically had few FOLR and fine feeder roots along the top 10 to 15 cm of the taproot.

Our root evaluation system, which relied heavily on numbers of permanent FOLR that developed along the top 30 cm of the taproot, yielded a distribution of 30, 30, and 40 percent for good, intermediate, and cull seedlings, respectively. Variations in seedling root morphological development and its relationship to seedling size proved perplexing. Larger seedlings were obviously associated with better FOLR root development, but the absence of FOLR was not always associated with undesirable stem development.

In 1996, a greenhouse test was conducted to study early taproot development following fall sowing in an attempt to mimic early seasonal growth in outdoor nursery beds. Usually, there is a long period between rainfalls during the post-fall acorn sowing period and epicotyl emergence in early spring. Irrigation prior to epicotyl emergence was not considered important in outdoor nursery beds and is still seldom practiced in southern nurseries.

Irrigation of the acorns germinating in the greenhouse was routine and was always considered essential for their development. This research showed that the taproots from the greenhouse had abundant feeder root development before epicotyl emergence and subsequent development of more permanent FOLR. This early dormant season development of the WO radicle is well known, but past research showed that comparable feeder root development was not always occurring in our nursery beds. Early presence of such feeder root development in late winter or spring in our outdoor trials had not been of concern, and no attempt had been made to follow their development.

CURRENT NURSERY PROCEDURES

The baseline fertility level developed by the USDA Forest Service's ITRB in conjunction with the Georgia Forestry Commission is used to produce oak seedlings and 35 other hardwood species. All fields in the nursery are tested annually for nutrient status and the soils are adjusted to correct any significant departures from the baseline protocol. The soil nutrient concentrations at the Flint Nursery are adjusted to maintain extractable levels of Ca, K, P, Mg, Cu, Zn, and B at 500, 130, 100, 50, 0.3 to 3, 3 to 8 and 0.4 to 1.2 parts per million, respectively.

For oaks and most other hardwood species, 1,345 kg ha^{-1} of NH_4NO_3 is applied to the developing seedlings throughout the growing season. Small initial applications are gradually increased as the seedlings develop and utilize the short-lived nitrogen applications. Thus, the first two applications are generally at rates equivalent to 17 kg ha^{-1} and the third at 56 kg ha^{-1}. The next six applications are at 168 kg ha^{-1} and the final two at 112 kg ha^{-1}. Nitrogen applications begin in mid-May and continue at 10-day intervals until mid-September. Nitrogen top dressing is reduced or even discontinued in early fall to stop height growth when seedlings are more than 1 m tall. Irrigation is applied as needed to prevent water stress or to reduce heat stress during the growing season.

By 1998, it became apparent that our basic fertility protocol was just as effective with WO as it has been with NRO at our experimental nursery and at the Georgia Forestry Commission's Flint River Nursery as long as irrigation was applied periodically during the dormant season to prevent desiccation of the acorns and developing radicles. Dormant season irrigation of nursery beds, coupled with the ITRB basic fertility baseline protocol, has resulted in over 50 percent of WO seedlings now either meeting or exceeding minimum standards originally set up for the faster growing NRO seedlings. Those standards for FOLR number, HGT, and RCD are: 6, 70 cm, and 8 mm, respectively.

RESULTS

Improvement in WO seedling quality has been steady since the realization of the importance that dormant season irrigation has on WO root morphology. The 1986 data in figure 1 represented what we thought were acceptable distributions and sizes for WO seedlings under the nursery management protocol at that time (Kormanik and others 1989). The seedlings from the 1986 data still essentially represent WO seedling production standards in the southern United States for 1-0 stock. The data from the 1998 and 2000 indicate the potential improvement easily attained by using the modified ITRB nursery protocol.

Nursery Trials

In 2001, a portion of the 2000 experimental nursery crop was replanted into the beds after being evaluated for size and FOLR number.

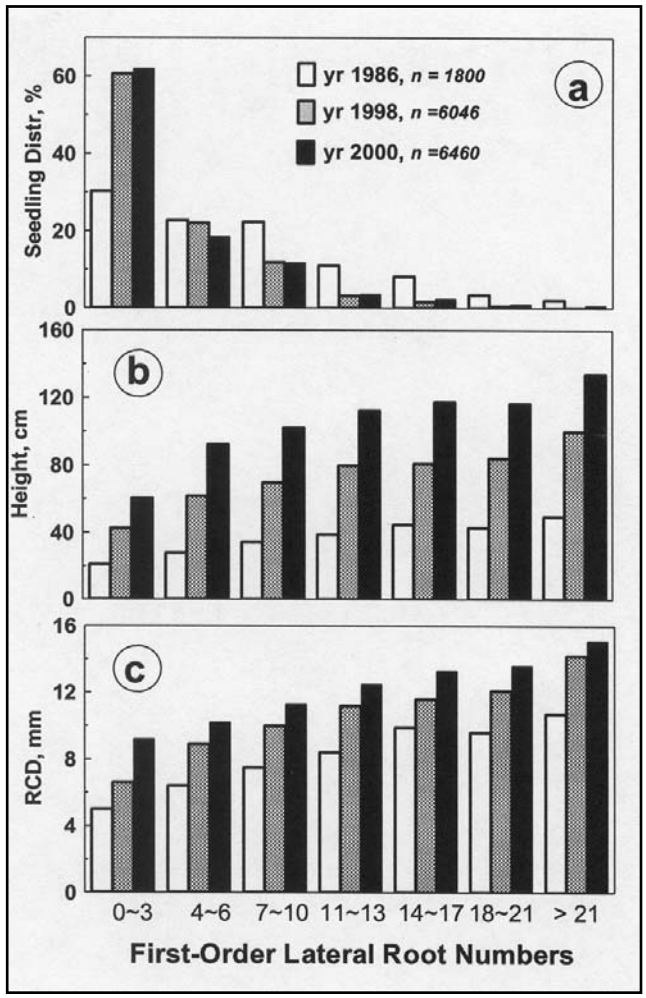

Figure 1.—*Mean values for (a) seedling distribution by first-order lateral root (FOLR) groups, (b) height, and (c) root collar diameter (RCD) for 1-0 white oak seedlings during three different years of production with an Institute of Tree Root Biology nursery protocol.*

Until the 1-1 stock was lifted from the nursery beds and re-evaluated in 2002, the FOLR group (0-3) was generally considered to be culls because of their substandard sizes (figs. 1b and 1c). Many of the seedlings in the 4-6 FOLR category were also placed in the cull grouping because they were below minimum shippable standards for both HGT and RCD. Past experiences showed that few of these individuals in the 0-3 or 4-6 FOLR groupings proved vigorous when transplanted into fertile nursery beds for further development as 1-1 stock. Indeed, most seedlings that were not competitive as 1-0 stock failed to meet standards the second year, even in fertile, irrigated nursery transplant beds (fig. 2).

In 2000, based upon observations of root development following dormant season irrigation, an additional criterion was added to our seedling evaluation procedure for WO: the presence of succulent fibrous roots along a seedling's taproot. This condition was rarely encountered before dormant season irrigation was initiated. Thus, its potential importance was overlooked. Previously, seedlings with zero FOLR were always classified as "cull", and were seldom deemed to be of shippable quality.

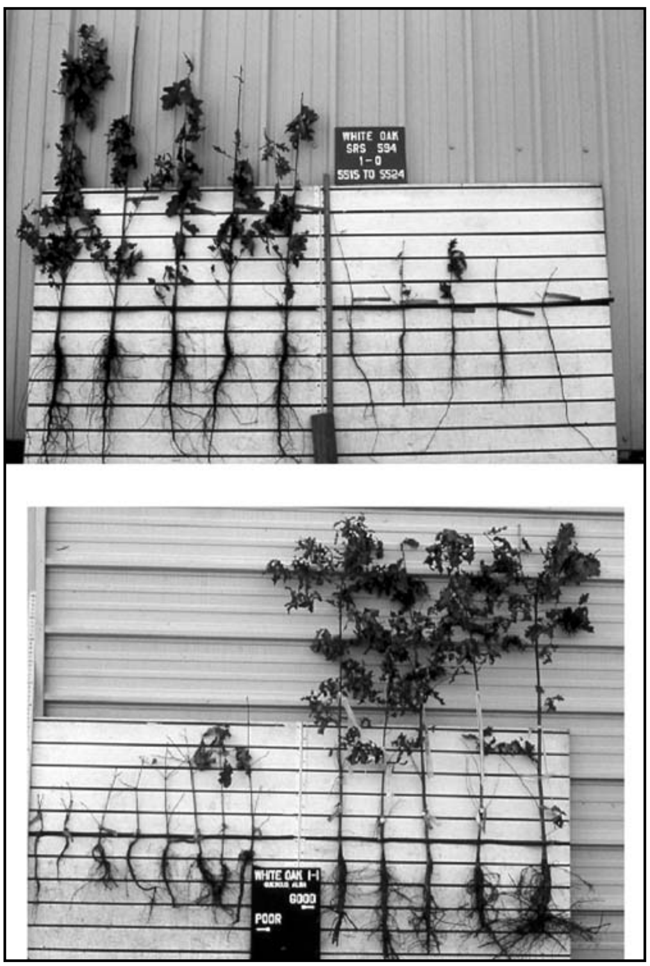

Figure 2.—*The seedlings in the best and poorest 25 to 30 percent of any half-sib progeny groups are significantly different in sizes and competitive ability. (a) White oak seedling as 1-0 stock, (b) white oak transplanted into nursery beds and lifted as 1-1 stock.*

In the year 2000 crop, this zero FOLR group represented 30 percent of the 1-0 seedling crop (figs. 2 and 3a). In addition, many seedlings in the l-3 FOLR group were also down graded to cull because of their small sizes, resulting in an additional 33 percent to the cull group (fig. 3). This 63 percent total was comparable to the cull percentage that had remained stable with our nursery protocol since the l986 crop (Kormanik and others 1989). The 35 to 40 percent of WO seedlings in the ≥ 4 category was also a rather consistent percentage and characteristically represented shippable seedlings (fig. 3a).

When the graded seedlings were lifted as 1-1 stock, the value of the succulent fibrous root systems became readily apparent (figs. 3b, 3c, and 3d). Those 1-0 individuals with 3 or fewer FOLR and no succulent fibrous roots (21 and 14 percent) generally developed the fewest new FOLR and had the poorest stem development (figs. 3c and 3d). Compared with 1-0 seedlings with an abundance of succulent, fibrous roots, 1-0 stock with fewer than four FOLR and without abundant fibrous roots grew fewer new FOLR and much less in HGT and RCD during the additional year in nursery beds. In all cases, those seedlings with FOLR of ≥ 4 and with or without fibrous roots yielded the best development as 1-1 stock (figs. 2, 3c, and 3d).

The importance of dormant season irrigation to the morphological development of WO seedling roots and subsequent seedling vigor must be stressed. Dormant season irrigation is a new development and is not yet commonly practiced in forest tree nurseries in the southern United States where soils do not freeze during the winter period. Thus, we now consider for inclusion in "cull" only those seedlings without either adequate FOLR or succulent fibrous roots.

For the past 3 years, dormant season irrigation has essentially reduced our culling rate from about 65 percent to 30 percent in our research trials and in the commercial production of the Georgia Forestry Commission nursery. The best 35 to 40 percent of the seedlings have consistently performed well after outplanting in the field. Those from the lowest 30 percent have not performed adequately even when transplanted into fertile nursery beds.

White Oak Field Performance

The Georgia Forestry Commission began developing new WO seedling seed orchards, based primarily on seedlings with the most robust root system. Of course, these also were the tallest seedlings with the largest RCD. In 1994, using FOLR number as the strongest grading criterion, a second-generation seed orchard was established adjacent to their Flint River Nursery. By ages 5 to 6, many of these trees were producing acorns in sufficient numbers that allowed progeny testing to begin in the nursery. In year 2000, a third generation WO seed orchard was developed from a 6-year-old second-generation seed orchard (Georgia Forestry Commission 2000).

In 1998, the first outplanting of WO seedlings was undertaken using seedlings that had benefit of dormant season irrigation. This potential seed orchard established in a small clearcut in North Georgia includes 30 different progeny groups with a total of 1,250 seedlings. Without supplemental irrigation or fertilization, most family progenies have 95 percent survival and many trees were 3.5 to 4.3 m tall with DBH of ≥ 50 mm at age 4. The only exceptions are those seedlings from grafted mother trees. Their survival is poor, with 100 percent mortality in some plots. This performance is even more impressive in the light of record-setting droughts endured by these seedlings since their establishment.

CONCLUSIONS

In the southern states where it is best to sow oak during late fall, irrigation is essential for preventing acorn desiccation prior to radicle emergence and for providing conditions for

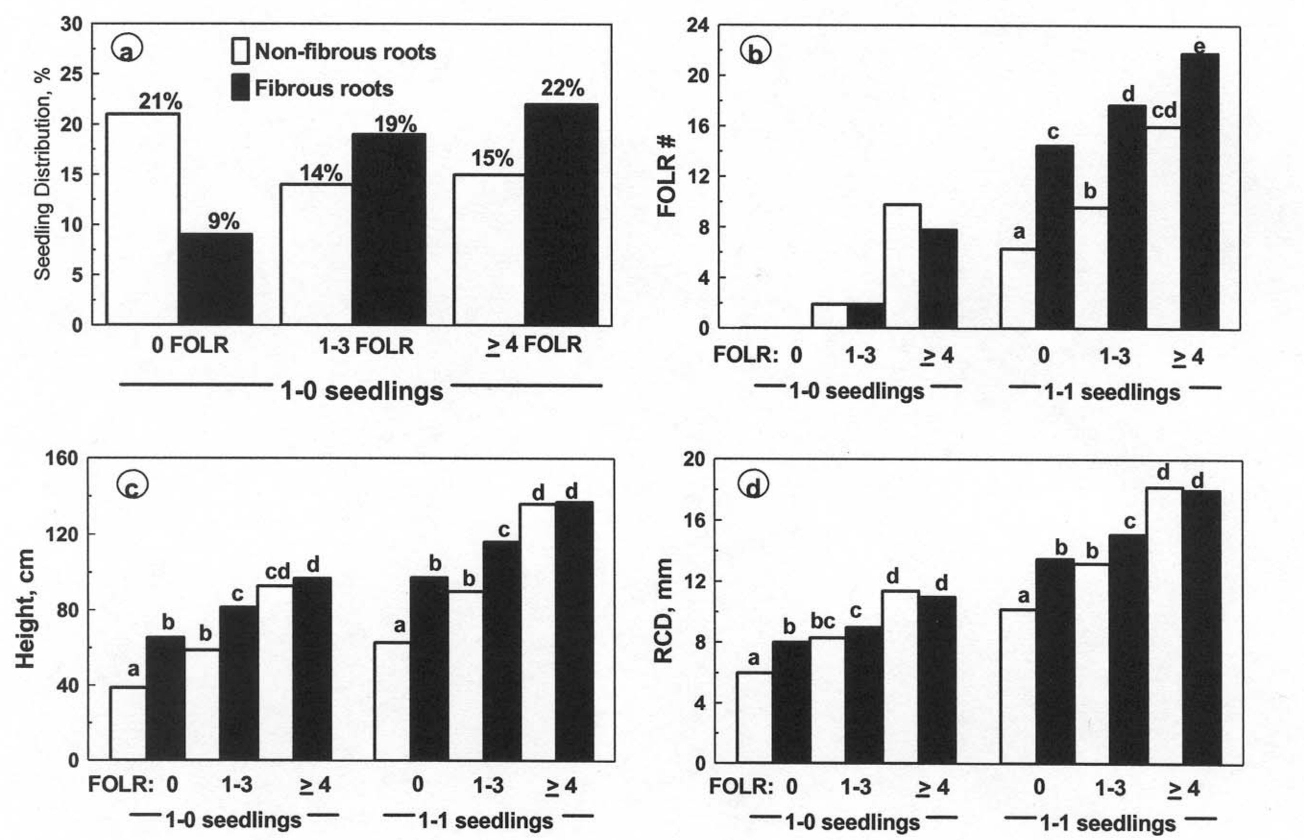

Figure 3.—*Mean values for (a) seedling distribution by specific first-order lateral root (FOLR) groups and presence of fibrous roots, (b) FOLR number, (c) height, and (d) root collar diameter (RCD) for 1-0 white oak seedlings grown in 2000 and then transplanted into similar nursery beds and grown for another year. Data presented here are from seedlings which were systematically selected as every tenth seedling in nursery beds during 2000. Means with same letters within an age class are not significantly different based on Tukey's test at the P = 0.05 level.*

optimum taproot development prior to epicotyl emergence. The nursery fertility protocol developed by the USDA Forest Services ITRB has consistently produced large competitive NRO, but until dormant season irrigation was initiated, WO seedlings had much smaller size.

Dormant season irrigation has increased shippable seedlings from 40 to 70 percent for some families' progeny. The small seedlings representing 30 percent cull group have seldom been competitive, either in nursery transplant beds or under field conditions. However, those from the best 40 percent have normally made satisfactory growth in the field. Those from the middle 30 percent may need more maintenance to remain competitive than normally available.

LITERATURE CITED

Boyette, W.G. 1980. Performance of ten species of 1-2 oak transplants in North Carolina after six and seven growing seasons. For. Note 45. Raleigh, NC: North Carolina Forest Service. 4 p.

Georgia Forestry Commission. 2000. Unpublished file data. Dry Branch, GA: Georgia Forestry Commission.

Hill, J.A. 1986. Survival of Pennsylvania State Nursery seedlings 1971-1981. In: Proceedings, Northeastern area nurserymen's conference; 1986 July 14-17; State College, PA. Northeastern State, Federal and Provincial Nursery Association: 1-4.

Kormanik, P.P.; Ruehe, J.L.; Muse, H.D. 1989. Frequency distribution of lateral roots of 1-0 bare-root white oak seedlings. Res. Note SE-353. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 5 p.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994. Toward a single nursery protocol for oak seedlings. In: Proceedings, 22d Southern forest tree improvement conference; 1993 June 14-17; Atlanta, GA: 89-98.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L.; Zarnoch, S.J. 1995. Oak regeneration - why big is better. In: Lands, T.D.; Cregg, B., tech. coords. Proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. PNW-365. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 117-123.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L.; Zarnoch, S.J.; Schlarbaum, S. 1998. Heritability of first-order-lateral roots in five *Quercus* species: effect on 1-0 seedling quality evaluation. In: Steiner, K.C., ed. Proceedings, Diversity and adaptation in oak species; 1997 October 12-17; University Park, PA: The Pennsylvannia State University: 194-200.

Rogers, R. 1990. *Quercus alba*. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North American, Volume 2, Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 605-613.

Wichman, J.R.; Coggeshall, M.V. 1983. The effects of seedbed density and fertilization on 1-0 white oak nursery stock. Tree Planters' Notes. 34: 13-15.