TOWARD A SINGLE NURSERY PROTOCOL FOR OAK SEEDLINGS

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ABSTRACT

After a soil fertility baseline had been determined for the Georgia Forestry Commission's (GFC) Morgan Nursery, a single nursery protocol consistently produced high quality oak seedlings. The fertility baseline developed at the Institute of Tree Root Biology (ITRB) Whitehall Experimental Nursery and adjusted for three GFC nurseries has a background target level at CA, K, P, Mg, Cu, Zn, and B of 500, 80, 80, 50, 0.3-3, 3-8 and 0.4-1.2 ppm, respectively, at time of sowing. Up to 1345 kg/ha of NH_4NO_3 are applied throughout the growing season in small increments at regularly scheduled intervals. When most seedlings are entering their second growth flush regular irrigation is stopped, and water is provided only when tensionmeters register 30 to 50 centibars. The desired seedbed density is between 54 and 57/m .

This protocol permits ready identification of competitive seedlings. Individuals with the potential to develop hfgh numbers of first-order lateral roots (FOLR) are wall established in the dominant canopy in nursery beds. Based'on stem and root characteristics, approximately half of the seedlings of most species can be classified as desirable. For most species of oak, competitive ability of these seedlings after outplanting has not been determined. Specific species *attributes* based on their site required are obvious when seedlings are lifted and are discussed.

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INTRODUCTION

Over 30 species of oak are important components of southern forests and all of them may become important in different tree improvement programs there. Presently only 5 or 6 species are normally grown in southern forest tree nurseries and production is low. *However, even with those* most commonly grown, northern red oak (Quercus rubra) and white oak (Q. alba), it has been difficult to consistently produce large, high quality seedlings. With both of these species it has also been difficult to obtain adequate natural or artificial regeneration (Boyette 1980, Hill 1986).

The new national initiatives on ecosystem management, restorational ecology, biodiversity, and sustainable multiple use management will increase the demand for hardwood seedlings. This will be especially true with the heavy-seeded hardwoods like the oaks, which are important sources of wild life food as well as timber.

Some individual members of the genus Quercus grow well over a surprisingly narrow range of sites. One species may be found primarily on the most xeric upland Piedmont sites, another on the best mesic sites, and still another in bottomlands. Thus, the genus is ubiquitous over a wide range conditions, but the individual species are not.

If the nursery requirement of seedlings from different sites paralled their natural **ones,** production of oak seedlings.of many species would be very difficult and expensive. Fortunately, the results of the preliminary nursery study described here indicate that oak seedlings of many species can be grown under nearly identical nursery conditions.

At the USDA Forest Service's, Institute of Tree Root Biology (ITRB), we have been modifying and testing various nursery practices in conjunction with research on root morphology and first-order lateral root **(FOLR)** development on various hardwoods and conifers (Kormanik and Muse 1986, Ruehle and Kormanik 1986, Kormanik et al. 1989, 1990). We have placed considerable emphasis on clarifying how plant metabolism **and** soil management practices affect root and stem development (Kormanik et al. 1992, Sung et al. 1989, 1993).

While our early efforts concentrated on **sweetgum** (Liquidambar **styraciflua)** and **loblolly** pine **(Pinus** taeda), we also studied oaks at the Whitehall Experimental Nursery. We found that we could grow most.hardwoods and conifers with a single soil fertility baseline for Ca, P, **K,** Mg, Cu and **Zn** if we modified the nitrogen and ***irrigation*** practices to accommodate individual species (Kormanik, et al. 1992). In 1986, we began trying to adapt our research findings for hardwaods at the three forest tree nurseries operated by the Georgia Forestry Commission.

Typically, only 3 or 4 **species** of oak were available in any given year, and the numbers of each were usually limited. While the fertility baseline may differ somewhat among nursery locations, we found that amount and timing of nitrogen and **water** applications were the keys to production of high-quality oak seedlings. Nursery practices for a few species became nearly routine, but we wanted to be able to grow a broad range of oak species. We decided to try and test a series of species needed for restorational ecology efforts at the U.S. Forest Service's Savannah River Forest Station, Aiken, SC, from a wide range of environmental and edaphic conditions.

OBJECTIVE

'The objectives of our study were: (1) to determine if a single nursery management protocol could be used for growing many species of oak in a single nursery, (2) to determine the numbers and positions of **FOLR** on the **taproot,** and (3) to compare morphological characteristics of species with diverse site requirements.

METHODS

In October-November acorns were collected by GFC personnel from randomly chosen individuals throughout the state. The acorns from a given species were composited. Altogether acorns were collected from **15** species of oak: Quercus **alba** (white), **Q. falcata** var. falcata (southern red), **Q.** falcata var. pagodifolia (cherrybark), **Q.** lyrata (overcup), **Q.** macrocarpa **(bur), Q.** michauxii (swamp chestnut), **Q. nigra** (water), **Q.** nuttallii (nuttall), **Q.** palustris (pin), **Q.** rubra (northern red), . **Q.** shumardii (shumard), **Q.** stellata (post), **Q.** velutina (black), **Q.** virginiana (live), and **Q.** laurifolia

(Darlington). The acorns were kept in the cold storage facilities at the GFC's Morgan Nursery at Byron, GA, until they were hand-sown in December.

Based upon research at the three Commission nurseries and the Institute's experimental nursery, a single soil fertility level was chosen that has provided good seedling responses for all hardwoods tested.. The soil fertility baseline had been developed by applying or withholding fertilizers over a 3 year period. All soil analyses were obtained from the A&L Laboratories, Memphis, Tennessee.

Soil levels of Ca, K, P, Mg, Cu, Zn, and B were adjusted to 500, 80, 80, 50 0.3-3, 3-8 and 0.4-1.2 ppm, respectively. Nitrogen was applied as NH_4NO_3 at rates equivalent to 1345 kg/ha (1200 lbs/acre). The first two application was at a rate equivalent to 17 kg/ha (15 lbs/acre), the third at 56 kg/ha (50 lbs/acre). The next six applications were at 168 kg/ha (150 lbs/acre) and the final two at 112 kg/ha (100 lbs/acre). Nitrogen applications started in mid-May were continued at 10-day intervals until mid-September.

The acorns were hand-sown for a density of 54 to $57/m^2$ (5 to 7 ft^2) but the number of acorns available for each species varied'widely. We had 10 to 20 times as many of the more commonly collected species, like northern red and white oak, as we had of less common species like Darlington oak. Accordingly, we sowed the beds continuously with a single species until all its acorns were gone, left a 2 to 3 m (6 to 10 ft) space and started sowing another species. The total area used directly in this study was approximately 5% of the entire field sown to many different hardwood species as well as to other oak seedlots.

While the root systems became established, seedlings were provided regular small daily applications of water. After the first growth flush was essentially completed and seedlings were into their second flush, water was applied when the moisture tensionmeters registered 30-50 centibar at 15-20 cm depth (6 to 8 inches). A total of 24 cm (9.5 inches) of irrigation water was applied during the growing season. Irrigation was essentially discontinued by mid-October. Rainfall of 91 cm (36 inches) was well distributed from April through December and only in October were there 3 weeks of below average rainfall.

The seedlings were undercut to 25-30 cm (10 to 12 inches) and lifted in mid-February. One hundred seedlings of each species were randomly selected for measurement of root collar diameter (RCD), height, and number of FOLR greater than 1 mm in diameter. Distribution of FOLR along the taproot and mycorrhizal development on fine feeder roots also were observed.

Our intent was to observe how each species developed under the nursery protocol. We planned no species comparisons, and we made no effort to quantify genetic variation by keeping track of mother trees. Seedlots were mixed as they are in normal hardwood nursery operations.

RESULTS AND DISCUSSION

This research, earlier trials, and subsequent yearly nursery tests in 1991 and 1992 at different GFC nurseries have demonstrated that it is feasible to use a single nursery fertility baseline nursery for hardwood seedling production once the background fertility level has been established at the specific nursery. This approach works for a multitude of oak species, regardless of their environmental and edaphic requirements. This finding alone should significantly simplify and enhance oak seedling production.

Nitrogen and Irrigation Managment

Oaks (and hardwoods in general) require higher soil fertility than do many pines in the Southern United States. After the soil fertility baseline is established at a specific nursery which may take 2 or 3 growing seasons, the primary management inputs are nitrogen and water. Rather large oak seedlings are desirable and growing them requires adequate nitrogen. Oaks form mesic and hydric sites require nitrogen applications at 10- to 12-day intervals to maintain continuous elongation, and the species from xeric sites also reach their maximum size with this consistent supply of nitrogen.

Usually throughout the summer 20 to 30% of the seedlings are in the flushing phase. It takes several weeks for a given flush to mature before physiological restraints permit another flush to occur. If during this resting stage nitrogen and water are limiting, subsequent flushes may be severely restricted and the elongation of the current flush is reduced. During resting periods between flushes roots grow and expand. We have counted five distinct "growth rings" on the taproots of northern red oak seedlings that have undergone six growth flushes during a 26- to 30-week nursery growing season.

Most nursery operators irrigate when they think it is necessary or on some predetermined schedule such as a given amount of water per week. Consequently, nurseries more often are over than under-irrigated. Over watering is expensive and it can leach away K and N. In addition, most young seedlings have a poor tolerance for wet feet. In general soils with a sandy texture need water in mid-summer more frequently than do soils with more clay and silt. By irrigating from tensionmeter readings leaching losses of essential elements can be reduced and the guess work can be removed from the process. For several years, we have been observing that southern red oak leaves seem to wilt on clear, hot and humid days soon after irrigation even though tensionmeters are registering less than 20 centibars. Other oaks do not begin to show stress until several days after the tensionmeters have reached 70 centibars. Thus, seedling appearance is not a good indicator of the need to irrigate.

General Observations

The observed ranges in FOLR numbers, heights, and RCDs are shown in Table 1. The means for this data set plus percentages of seedlings with less than the mean number of FOLR for the species are shown in Table 2. Table 3 includes comparable data for comparative purposes from 3 different years when fertility trials were being run at the ITRB experimental nursery.

Table 1. Ranges in numbers of first order lateral root (FOLR) and stem characteristics for 15 species of oak grown in the Georgia Forestry Commission Nursery - 1991.

Species	Range FOLR	X Height range (cm)	X RCD range (mm)
Southern Red	0-9	26-59	4.9-8.7
Live	1-12	28-76	3.8-9.7
Darlington	0-13	14-60	3.5-11.7
White	0-21	21-80	4.4-15.8
Water	0-18	21-63	2.9-11.8
Bur	0-29	27-114	5.8-19.5
Swamp Chestnut	0-19	33-80	6.3-21.2
Cherrybark	0-17	52-112	4.1-12.6
Post	0-21	31-89	6.5-14.3
Nuttall	0-20	42-138	5.5-19.9
Pin	1-21	31-120	5.6-20.5
*Northern Red	1-23	24-143	5.0-14.6
Black	1-22	38-147	6.7-15.6
Shumard	1-27	65-165	5.7-14.1
Overcup	0-32	61-137	7.0-24.7

Table 2. Mean number of first-order lateral root (FOLR), heights and root collar diameters and percentages of seedlings with less than mean number of FOLR for 15 species of oak in 1991 nursery trial.

Species	X FOLR number	% Seedlings <X FOLR	X Height (cm)	X RCD (mm)
Southern Red	2	46	42	6.2
Live	3	57	44	5.6
Darlington	4	41	35	7.7
White	4	52	35	7.5
Water	5	53	39	6.4
Bur	5	53	54	9.9
Swamp Chestnut	6	60	48	10.5
Cherrybark	7	45	95	9.1
Post	7	53	73	10.7
Nuttall	8	38	94	13.0
Pin	9	45	66	11.8
Northern Red	9	56	71	9.0
Black	10	47	95.	11.0
Shumard	11	52	128	11.3
Overcup	13	48	99	14.7

Table 3. Ranges and means for number of first order lateral root (FOLR) and stem characteristics for three species of oak grown in the Whitehall Experimental Nursery.

Year and Species	X FOLR	% Seedlings <X FOLR	Range	X HGT (cm)	Range (cm)	X RCD (mm)	Range (mm)
1986 Cherrybark[a]	5	54	0-17	83	20-152	6.63	2.4-14.2
White[b] 1987	7	53	0-34	34	6-111	7.50	1.5-15.5
1988 Northern red[a]	8	56	0-41	74	9-144	8.62	2.2-14.5

[a] Average of 200 seedlings from each of 12 open-pollinated half-sib progeny.

[b] Average of 200 seedlings from each of 3 open-pollinated half-sib progeny.

Generally species from more xeric sites had fewer and smaller ranges in FOLR numbers than species from mesic or hydric sites. This reduced number of FOLR was associated with overall smaller RCDs and less total height (Table 2). Earlier we reported (Ruehle and Kormanik 1986, Kormanik et al. 1989) that perhaps less than half of the oaks produced in our nurseries may be competitive in the field. How to identify these potentially competitive oak seedlings must be determined, after outplanting but we have found that, the greater the number of FOLR in the nursery, the more competitive the seedling.

Although we will have *to* await the results of outplanting trials, we suspect that individuals producing fewer FOLR than the average for the species will perform poorly in the field. We think this rule of thumb will hold together even when the mean FOLR is 2 as in southern red oak or 11 as in **overcup oak.** Thus, the percentage of seedlings with less than the average FOLR number (Table 2) may be extremely important. Even with different growing conditions in different years, the percentage of seedlings with fewer than the mean number of FOLR remained reasonably consistent (Tables 2 and 3).

Species Performance

Observations with these 15 species were obtained from a single nursery. However, six of them (northern red, white, swamp chestnut, cherrybark, southern red, and water) have been followed regularly for 5 to 6 years at the other nurseries. The Morgan nursery was simply the first where the fertility baseline was attempted on a large scale and it took about 3 growing seasons to bring the various nutrients into the balance we were striving to attain.

It appears that as long as bed density remains reasonably near the specific limits f54 to 57/m^2) root relationships observed here remained relatively similar. Only when seedlings are excessively stressed or grown at higher densities wili the root morphology be significantly altered.

Our goal in these nursery trials is to learn how to grow oak seedlings to average heights of 0.75 to 1.40 m. Increasing irrigation and nitrogen applications, have not significantly increased heights of the xeric *site* oaks. However, under higher luxuriant conditions, the other oaks tended to get larger than we desire at the present time.

The only xeric species we have studied over several years has been southern red'oak. In all cases, FOLR root development has been poor and mycorrhizal development has been virtually absent. In all cases, swamp chestnut and cherrybark oak have become heavily mycorrhizal and northern red and white oak have moderate but good mycorrhizal development.

The observed attributes of individual species are listed below:

Southern red oak.--Very few FOLR were produced. This absence of FOLR production has been noted in several other seedling trials. The greatest carbon allocation in seedling roots appeared to go into **taproot** development. Mycorrhizal development was very poor even on individuals that produced several FOLR. Individuals with the highest number of FOLR were the most competitive. Study of this species will be interesting and challenging.

Live oak.--Development of **FOLR** was either good or very poor. Intermediate development was lacking. The **taproot** may be a critical storage sink. Few if any mycorrhizae were observed on any seedling. A pronounced bulbous swelling was formed about 2.5 to 4.0 m below the root collar. Cutting.it half revealed soft tissue with the consistency of a potato. Some of the smallest individuals with few, if any, FOLR had the largest swellings.

Darlington oak.--Over 80% of the seedlings had no FOLR in the 6 inches directly below the root collar. **The** few FOLR that were present were frequently 4 to 6 mm in diameter and could support the entire seedlings weight with a minimum of flexing. Mycorrhizae were essentially absent. The few we found were at the root collar and were not associated with the lateral roots. Many seedlings had multiple tops and the leaves still had not developed abscission **layer** in February.

White oak.--As in earlier trials, this species has displayed a wide range **in** rootsystem development. **The** very best 10 to 20% had a large diameter **taproot** with many FOLR. Another 20 to 30% seedlings had large diameter **taproots** with few FOLR. **The** stem characteristics of these two groups comparable, but seedlings with the greater number of FOLR had larger **RCDs.** The **remaining** seedlings had few FOLR and small diameter **taproots.** ***They were*** **consistently** non competitive in the nursery. Small isolated patches of **mycorrhizae** were present on the seedlings with many **FOLR.**

Water oak.--Individuals with few of **FOLR** were were least **competitive** in the beds. Seedlings with the large RCD were the tallest ones. Those **with** few **FOLR** **had unacceptably** small **RCDs.** Leaf morphology ranged widely. Few **mycorrhizae** **were observed** on any seedling.

Bur oak.--The relationship between seedling size and FOLR numbers was very strong. Only walnut seedlings have been observed with such large diameter taproots. The 10 to 20% with these large taproots and high FOLR numbers with FOLR diameters of ca 3 mm were really impressive seedlings. Perhaps 25% had large diameter taproots but few FOLR. The seedlings with small diameter taproots had few FOLR, small RCDs, and unacceptable form. Most seedlings had 5 flushes, but the poorest seedlings with ≤3 FOLR normally had 3 flushes. Small patches of mycorrhizae were found on only two seedlings.

Swamp Chestnut.--Assessment FOLR development was very difficult on this species. In addition to lateral roots with diameters larger than 1.0 mm there were countless others with diameters of ca 0.25 mm. Both the large and small lateral roots were so heavily mycorrhizal that the taproot was not readily visible without moving the dense mycorrhizal complex. Small seedlings with few ≥1 mm FOLR had considerably fewer mycorrhizal feeder roots. The individuals with massive root systems all had 5 to 6 growth flushes, while those with few roots had 3 to 4 flushes. Most of the seedlings with only 1 to 3 FOLR not only had inferior stem development but also had badly deformed taproots. Some taproots "corkscrewed" 1 to 3'times in complete 360 degree circles. This condition inhibited both stem and root development. Such taproot deformity has since been found on this species in all trials where it has been included.

Gherrybark.--On individual seedlings, FOLR diameters ranged widely. It was not unusual to have diameters from 1 to 7 mm on the same seedlings. Almost all the FOLR were on the first 20 cm of the taproot. Even though the nursery soil was not excessively moist, many seedlings had development water roots that appeared to emerge from prolifered lenticels. All of these water roots were unbranched and some were up to 24 cm long. Some suberized FOLR with diameters of 1.5 mm to 2.5 mm developed long water root extensions. 'The largest seedlings had the best developed FOLR and had up to 6 or 7 growth flushes. Mycorrhizae developed along the entire lengths of FOLR, but development was not nearly as dense as with swamp chestnut oak.

Post.--A high percentage of the trees had forked or multiple tops leading us to wonder whether the acorns were from a single mother tree. Multiple stems developed rather consistently at the beginning of the fourth flush. Most seedlings had 4 or 5 flushes; the very poorest had only 3. As with Darlington oak, FOLR were absent within 20 cm of the root collar. In most oak species FOLR development begins just below the root collar. Mycorrhizae were observed on only 8 seedlings, and their development was spotty and sparse.

Nuttall.--FOLR had rather large diameters of up to 9 mm and were uniformly distributed along the entire excavated taproot. Not all seedlings had water roots, but those that did had unbranched ones, that often were 15 to 20 cm long. The largest diameter and tallest seedlings had the very large diameter FOLR. The relationship between FOLR development and stem diameter and height growth was close. Most individuals had 5 to 7 flushes but even the smallest ones had at least 4 flushes. Mycorrhizal development was uniform and dense along the entire lengths of mature FOLR. Even taproots had uniform and dense mycorrhizal short roots.

Pin.--Individuals either had a robust root system with abundant FOLR and a stocky stem or few FOLR and a short stem with a small diameter. Thus, the junk was easy to pick out. Good seedlings would be extremely difficult to ship, however, because of the large diameter FOLR (up to 12 mm) and excessively long laterals. FOLR up to 90 cm long were excavated. Even if they were held near their distal end, they supported the entire seedling's weight. Mycorrhizal development was present on only a few seedlings, and it was sparse and light.

Northern **red.**--FOLR were concentrated in but not limited to the top 20 cm of **taproot.** Competitive seedlings all had **large numbers** of FOLR and had between 5 and 6 flushes. Individuals with few FOLR had 2 to 3 flushes. Mycorrhizal development was scattered but moderate where it occurred. Most FOLR diameters were in a narrow range from 1 to 4 mm. Seedlings of this species may have had the most striking differences based on FOLR numbers.

Black. --Root systems had large diameter **taproots** and many well-developed **FOLR.** The FOLR diameters varied from 1 to 7 mm and this range frequently occurred on an individual seedling. Mycorrhizal development was infrequent and sparse. The better seedlings seemed ideal for planting. The best 50% of the seedlings should be competitive.

Shumard.-- FOLR diameters ranged from about 1.5 to 3.0 mm. On individual seedlings, FOLR diameters were the most uniform of any observed on any species. All seedlings, regardless of size, had 4 to 5 growth flushes. Mycorrhizae were abundant and dense but short roots were very thin and delicate. The mycorrhizal feeder roots dropped off 'very quickly after the roots were excavated. Abundance of mycorrhizae therefore was assessed at lifting and not when FOLR were counted and growth data were collected.

Overcup.--Of these 15 species of oak, **overcup** had undoubtedly the best and most uniformly developed FOLR. **Taproots** often were 1 1/2 to 2 times larger in diameter than root collars. The FOLR were 1 to 3 mm diameter and they remained flexible even though they were 1 to 2 m long. Water roots up to 5 cm long and 3 mm in diameter were present. They were "crisp" and popped like a celery stick when broken. Mycorrhizae were abundant and dense throughout the length of the FOLR and occurred in clusters along the **taproot.** The mycorrhizae clusters were so abundant that it was difficult to remove the attached soil to examine the FOLR morphology. This was the only species in which we would not cull individuals with fewer than the mean FOLR number. The seedlings all consistently had just 5 flushes, and less than 10% would have been considered culls by the authors.

CONCLUSIONS

Our results demonstrate that a multitude of oak species can be grown in a single nursery with one management protocol. It is equally evident that more nitrogen and close monitoring of water use will be required to maintain continued stem and root development throughout the growing season.

This and subsequent work also show species-specific growth patterns among oaks, Seedlings of species, normally found on xeric sites will not be as **large** as those species found on mesic and hydric sites. Species typically found on moist bottomlands or seasonally hydric sites have better developed lateral root systems. These species also have the best mycorrhizal development. The reason for species difference in mycorrhizal development in the nursery was not readily apparent but there was a gradient in abundance with xeric < mesic <

hydric sites. The gradient has been observed in other trials but its biological significance has not been clarified.

On species that occur in moist wetlands water roots developed in the nursery beds in late fall even though the beds were not saturated. This phenomenon deserves additional study.

Competitive individuals of all species - those in dominant and codominant canopy positions - had more than the mean number of FOLR for the species in question. Based on competitiveness and root development in the nursery, it appears that about half of oak seedlings may not be competitive after outplanting.

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