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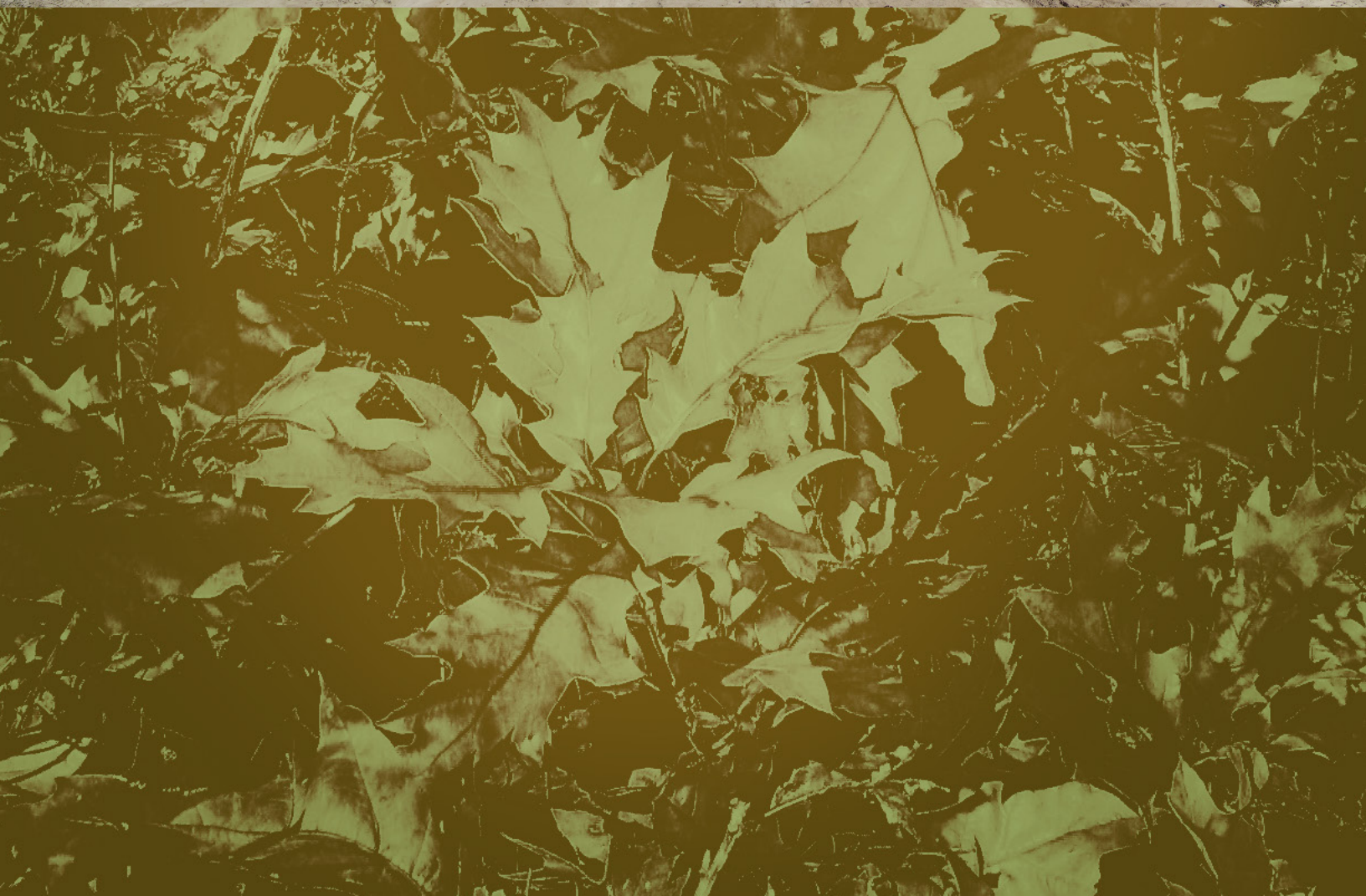
Guidelines for Securing and Planting Upland Oak Seedlings in the Southern Region

Stacy Clack, Scott E. Schlarbaum, Marcus Warwell, Barbara Crane, and Jason Rodrigue



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Cover photo: Oak seedlings being grown at a commercial tree nursery in the early part of the growing season. Courtesy photo by Scott E. Schlarbaum, The University of Tennessee. Background cover photo: Oak leaves of northern red oak (*Quercus rubra*) seedlings. USDA Forest Service photo by Stacy L. Clark.

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ABSTRACT

In this report, we provide guidelines and administrative procedures to conduct artifical regeneration activities for upland oak (*Quercus*) species. The information provided is intended to assist silviculturists and foresters in the Southern Region (Region 8) of the Forest Service, U.S. Department of Agriculture, but many of the management guidelines, specifically the sections "Collecting Your Own Acorns" and "Planting Upland Oak Seedlings" could be applied by forest managers outside of the Southern Region. The overall goal of artificial regeneration is to increase the density of advanced oak reproduction at the time of overstory removal, which is particularly important in forests where oak is difficult to regenerate due to the lack of existing seed sources or the inability to foster the development of existing regeneration into larger size classes. The Southern Region has the oldest northern red oak (*Q. rubra*) seed orchard in the country, but seed production varies from year to year. White oak (*Q. alba*) orchards are not yet in full production. Planting activities must be planned at least 1.5 years in advance to take advantage of years with abundant acorn crops, which can be difficult to time with harvesting activities. Through decades of cooperative partnerships, nursery procedures have been developed to grow and identify high-quality oak seedlings that have a better chance of competing with shade-intolerant species. Planting success will improve with competition control and herbivore protection in forests with high deer density. Site selection is important as site productivity is negatively correlated to oak's competitive ability, but planting on poor-quality sites (less than 70 site index) is usually not necessary unless oak regeneration is completely absent (e.g., conversion of pine plantations to oak forests). Artificial regeneration of upland oak species requires thoughtful planning and adaptive management that includes the use of genetically diverse, high-quality seedlings planted on appropriate sites that can be monitored and managed through the stem-exclusion stage of stand development.

KEYWORDS: Acorn collection, artificial regeneration, genetic resources, nursery production, seed orchards, seedling quality, Region 8.

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OBJECTIVE

The first law of oak silviculture is to have large, advanced oak (*Quercus*) reproduction prior to a disturbance (e.g., a regeneration harvest) (Loftis 2004). Advanced oak reproduction, however, is often not sufficient or managers lack the time and resources needed to secure it through silvicultural treatments such as prescribed burns or herbicides. This report was developed to provide specific programmatic information for silviculturists and foresters in the Southern Region (Region 8) of the Forest Service, U.S. Department of Agriculture, such as the available oak genetic resources and cost-structure payments for seedlings. We also provide silvicultural guidelines that can be adapted by any natural resource manager with an interest in planting oak seedlings as a reforestation practice. The planting guidelines were developed using the best available science, but research is relatively young and still emerging. This document will be updated as soon as the maturation of existing research and new research can be incorporated into the prescription recommendations.

Planting oak seedlings can enrich or supplement existing natural regeneration. The objectives of this guide are to:

1. Provide instructions and information on how to properly secure northern red oak (*Quercus rubra*) or white oak (*Quercus alba*) seedlings (bare root 1-0 or 2-0) through the Southern Region's genetics and silviculture programs
2. Provide synthesized information on the best practices to successfully regenerate upland oak species through planting

Figure 1—Nantahala National Forest, Beech Creek Seed Orchard, Murphy, NC. Photo courtesy of Map Data ©2021 Google.

REGIONAL GENETIC RESOURCES

Currently, the Southern Region (Region 8) relies on two upland oak seed orchards: (1) Beech Creek (Nantahala, NC) and (2) Watauga (Cherokee-North Zone, TN). The orchards were constructed to provide for the Region's reforestation needs. Beech Creek has a seed orchard of northern red oak seedlings and a grafted white oak orchard (fig. 1). These orchards are not yet in full production, largely due to their young age and their vulnerability to late season frosts. Beech Creek has a full-time orchard manager and orchard technician. The Watauga Northern Red Oak Seed Orchard is the oldest northern red oak orchard in the country (established in 1974). It is managed by the University of Tennessee's Tree Improvement Program (through agreements) and remains in full production.

Some national forests may also manage their own seed production areas (SPA's).[1] The Southern Region established nearly 20 Southern Research Station oak research plantings throughout 1990 and 2000 (Kormanik and others 2005), some of which are still being maintained by the ranger districts in the Southern Region.[2] However, most of the older plantings are not being followed or maintained.

Species Available from the Region's Genetic Resources Management Program

Among upland oaks, only northern red oak and white oak seed are currently available through the Region's Genetic Resources Management program for enrichment plantings. These species have intermittent acorn crops, which are characteristic of oak species, and will not produce reliable acorn crops every year. The acorns are used to produce high quality bare-root seedlings (1-0 or 2-0) from a commercial tree nursery (currently, the Georgia Forestry Commission State nursery in Byromville, GA) that uses advanced nursery protocols for growing seedlings (Kormanik and others 1994). The cost of seedlings for enrichment plantings obtained through the Region's Genetic Resources Management program is paid for by the Region. The Region will not cover costs related to operational plantings, whereby a site is being converted solely to oak, such as occurs during afforestation type operations.

Securing Trees Outside the Region's Genetic Resources Management Program

If you want a species other than white oak or northern red oak, or a type of seedling other than bare root, you will need to secure it from a State or commercial nursery, and the cost burden will be on the district/forest. The process is not as simple as ordering and planting seedlings. The following criteria need to be met to secure species/seedlings outside of the Region's Genetic Resources Management program:

1. The seed source should be locally adapted and genetically diverse. Many nurseries buy seed from unknown sources and the seed seller may have collected the seed from one or two heavy-producing mother trees (i.e., low

[1] A SPA is a superior stand established naturally or artificially that receives the periodic removal of undesirable trees (rogueing) and cultured for early and abundant seed production. In comparison to seed orchards, they are usually less intensively managed and tested (Rudolf 1962).

[2] Information, maps, and data reside with the relevant district silviculturists and with the regional geneticist.

genetic diversity). The best option is to collect your own seed to ensure genetic diversity (see "Collecting Your Own Acorns" section).

2. Seedling quality needs to be sufficient, but this varies greatly among nurseries. Quality will also vary by the species and stock type (see "Seedling Quality" section). For example, most white oaks are smaller than northern red oaks in the nursery (fig. 2).
    a. To assess seedling quality, visit the nursery and select a representative spot in the seedbed where the seedlings that you wish to purchase are growing. Visually evaluate all seedlings (at least 100) within the representative spot (e.g., a 10-foot section of bed) to determine the number of seedlings of sufficient quality for planting out of the total number of seedlings in the sample (see "Seedling Quality" section). Determine how many seedlings you need to purchase based on this assessment. For example, if 50 of the 100 trees are of sufficient quality, you will need to purchase twice the number of trees from the nursery to meet your planting needs. Contact the regional geneticist for questions or concerns on seedling quality.
3. Costs, seedling quality, ease of planting, and success rate will vary by stock type. Bare root is typically less expensive, easier to plant, but more variable in quality. Containers (particularly larger containers) will be more expensive and more difficult to transport and plant but less variable in quality.
4. Your decision to plant seedlings outside of those available through the Region's Genetic Resources Management program will need to be based on the availability of funds, size of the planting project, and the ability to secure locally adapted, high-quality seedlings.

Figure 2—Differences in seedling size between post oak (*Quercus stellata*; left) and northern red oak (*Q. rubra*; right) growing in a commercial tree nursery. Courtesy photo by Scott E. Schlarbaum, The University of Tennessee.

TIMEFRAME FOR ACORN COLLECTIONS AND PLANTINGS

Be aware that the oak orchards do not produce on a regular yearly cycle; acorn crops are intermittent and unpredictable from year to year. Acorn crops are vulnerable to unpredictable weather events (e.g., drought, too much rain, late season frost). More research is needed to inform the prediction and cultivation of acorn crop production.

Do not have a pine planting mentality. Acorn crops are less reliable, and acorns do not store as long as pine seeds. Acorns from the white oak group (section *Quercus*) cannot be stored after the year of collection because they germinate in the fall. Research has shown that acorns from the red oak group (section *Lobatae*) can be stored for up to 1 year after the year of collection (Bonner 1973) (Personal communication. 2021. Scott Schlarbaum, Professor, The University of Tennessee, Department of Forestry, Wildlife and Fisheries, 2431 Joe Johnson Drive, Knoxville TN 37996). Germination rates and seedling vigor will decline in stored red oak acorns, and storage efficacy appears to be partially dependent on the genetic family. Acorn storage times should be shortened as much as possible to prevent desiccation, reduce mold, and improve germination and seedling growth rates.

For both red and white oaks, make a plan for the planting activities 1.5 years in advance because of the timing related to acorn collections, nursery growth, and nursery lifting and planting dates (table 1).

Table 1—Schedule for acorn collection, nursery growth, nursery lifting and planting dates required for 1-0 bare-root nursery seedlings

Acorn collection	Nursery growth	Nursery lifting and planting dates
Fall 2022	Summer 2023	February/ March 2024
Fall 2023	Summer 2024	February/ March 2025
Fall 2024	Summer 2025	February/ March 2026

White oak (*Quercus alba*) acorns germinate in fall, limiting their ability to be stored. These acorns are already showing some damage to the germinating radicle due to lengthened time in storage. USDA Forest Service photo by Stacy L. Clark.

ORDERING AND SECURING SEEDLINGS

There are five steps to order and secure oak seedlings through the Region's Genetic Resources Management program. Exceptions to these steps may occur if the district is collecting their own seed or if planting tens of thousands of trees on a yearly basis. For example, Big Piney Ranger District on the Ozark-St. Francis National Forest has provided a separate contracting agreement with the Georgia Forestry Commission State nursery using Knudson-Vandenberg (KV) funds or other trust funds to fulfill past supplemental planting needs. The steps include:

1. The regional silviculturist informs the forest silviculturists in late summer of the potential acorn crop that is available from the Region 8 seed orchards.
2. The forest silviculturists communicate with their district silviculturists on seedling needs. After seedling needs are established, the forest silviculturists communicate to the regional silviculturists about how many seedlings they want for the planting 1.5 years from the time of collection (see table 1).
3. The acorns will be collected and shipped to a State nursery (currently, it is the Georgia Forestry Commission State nursery in Byromville, GA, southwest of Macon).
4. The regional geneticist or silviculturist communicates with the nursery to ensure quality control of germination, seedling growth, and seedling quality.
    a. The nursery lifts the seedlings and labels the bags by the national forest name and the number of seedlings for each forest.
    b. Ideally, forest representative(s) will come to the nursery to help clip root systems and ensure seedling grade standards are met (see "Seedling Quality" section).
5. Each national forest is responsible for picking up their own seedlings at the nursery.
    a. The regional silviculturist or geneticist will let forest silviculturists know when seedlings are ready for pickup, typically in February.

COLLECTING YOUR OWN ACORNS

Some forests have their own SPA or areas where acorn collections would be relatively easy. The regional orchards may not produce well in certain years, but the forests may have decent acorn production. You can collect your own acorns from any species, but first communicate with the regional geneticist about the process of collecting acorns, growing seedlings, and paying for the seedlings. The following instructions are for the collection of your own acorns:

1. Inform the regional geneticist that you will collect your own acorns and discuss the capacity of the region to pay for growing the seedlings at the nursery.
2. Ensure you are prepared for collection. You will need collection bags/containers (see step 11), buckets or tubs for floating/sinking acorns, areas to dry acorns, and coolers to store the acorns until sowing. A scale to weigh acorns (precision of 0.1 pounds is best) is optional, but it will provide the best precision in calculating the number of collected acorns.

3. Collect only enough acorns to plant later as seedlings. Account for a 30-percent loss due to poor germination[3] and an additional 40- to 60-percent loss due to seedling grading (i.e., discarding the smallest seedlings). See step number 11 to estimate acorn quantity. It may seem wasteful to collect more than three times the number of acorns than seedlings you will plant, but it saves money over the long run. Planting poor-quality seedlings will result in failure (Clark and others 2015, Kormanik and others 1997) (fig. 3). Use the following formula to determine the number of sound acorns to collect:

   number of sound acorns = (number of desired seedlings ÷ percent germination rate) ÷ percent of acceptable seedlings during grading

   For example, you will need to collect 12,500 sound acorns if you want 3,500 northern red oak seedlings to plant, with a germination rate of 70 percent and a cull rate of 60 percent (or 40 percent of your seedlings will be acceptable to plant):

   12,500 sound acorns = (3,500 seedlings ÷ 0.70) ÷ 0.4

4. Collect acorns from trees within the same geographic province as the planting location. Generally, collecting from trees within the same seed collection zone or adjacent seed collection zones as the planting area is a good rule of thumb to follow (Pike and others 2020). Go to the Eastern Seed Zone Forum website (**http://www.easternseedzones.com/**) to find seed zone maps.

   a. Pay attention to elevation. For example, if you are planting at 4,000 feet, the collection needs to be from higher elevation trees that are approximate to this elevation.

5. Collect approximately equal amounts of acorns from multiple trees (at least 10 trees spaced at one-quarter of a mile apart from each other), and then bulk the acorns together to ensure a good genetic mix. Genetics affect seedling quality and subsequent field performance (Clark and others 2016).

6. Visit collection trees multiple times starting at the peak of the acorn drop. Early dropping acorns tend to be nonviable. Collect acorns within 2 days of dropping.

   a. For white oak acorns, collect before they start germinating on the ground.

7. Ask your nursery manager if they conduct a float/sink test on acorns prior to sowing. If they do not, then you will want to conduct your own float/sink test by placing the acorns in a bucket or tub of water. Immediately, discard floating acorns and remove sinking acorns for further processing (Gribko and Jones 1995).

   a. If you conducted the float/sink test, lay out the sinking acorns on a table or mesh screen and dry for a few hours or overnight (fig. 4). The goal is to get rid of all the water on the outside of the acorns without losing any moisture from the acorn itself. Protect the drying acorns from predators such as squirrels.

8. Discard any debris such as leaves or twigs that will interfere with the machine sower at the nursery.

Figure 3—This nursery bed contains high quality 1-0 bare-root northern red oak (*Quercus rubra*) seedlings. USDA Forest Service photo by Stacy L. Clark.

Figure 4—Acorns are laid flat on screens to facilitate drying after the float/sink test and to clean debris. Courtesy photo by Jason Maxedon, Tennessee Wildlife Resources Agency.

[3] This is an estimate based on sound acorns (i.e., acorns that have gone through the float/sink test described in step number 7). Germination will decrease approximately 20 to 40 percent for acorns that have not been float tested.

Healthy white oak (*Quercus alba*) acorns gathered for planting a new crop of oak trees. USDA Forest Service photo by Stacy L. Clark.

9. Discard any acorns with caps, visible cracks, or holes.
    a. For white oak species, discard acorns with radicals longer than 0.5 inches.
10. Bag clean acorns. Cloth or 2 mil bags are best for white oak while 4 mil bags are best for northern red oak (Bonner 1973, Rink and Williams 1984).
11. Estimate the number of acorns. Bonner (2008) provides seed-yield data that can be used to calculate acorn quantity based on weight, but these data are most likely for acorns that have not been processed using the float/sink test; therefore, Bonner's (2008) seed-yield data may overestimate the quantity of sound acorns.
    a. Northern red oak seed-yield data from the Watauga Northern Red Oak Seed Orchard indicate a yield of 62 to 77 acorns per pound after the float/sink test (Clark 2020a, Clark and Schlarbaum 2018).
    b. White oak seed-yield data from Tennessee seed orchards and wild collections indicate a yield of 150 to 160 acorns per pound after the float/sink test (Personal communication. 2021. Scott Schlarbaum, Professor, The University of Tennessee, Department of Forestry, Wildlife and Fisheries, 2431 Joe Johnson Drive, Knoxville TN 37996).
    c. Be aware that acorn mass can vary from season to season, tree to tree, day of collection within a year, and acorn sizes (Clark and Schlarbaum 2018, Kormanik and others 1998).
    d. The most accurate method to estimate acorn quantity is to count out and weigh a representative sample of 100 to 200 acorns, and then weigh the entire collection to estimate quantity.
12. Label bags with your forest/district name and estimated number of acorns.
13. Place acorns in refrigerator/cooler between 37° F and 40° F with humidity control of < 50 percent. Do not freeze them!
14. Let the regional geneticist know how many acorns you collected, and they will coordinate with you on the delivery to the nursery.

PAYMENT FOR SEEDLINGS

The regional office (RO) will typically pay for seedlings grown from acorns collected at the Southern Region's seed orchards or collected by the individual forests that are targeted for SPAs, enrichment, or supplemental plantings. An exception may occur if the district is collecting their own seed and planting tens of thousands of trees on a yearly basis.[4] The RO does not pay for operational reforestation of oaks (e.g., where the stand is being converted or regenerated entirely to oak using artificial regeneration). The RO will not pay for seedlings ordered at other nurseries that were not collected by region or forest personnel.

[4] Big Piney Ranger District on the Ozark-St. Francis National Forest provides a separate contracting agreement with the Georgia Forestry Commission State nursery using KV funds or other trust funds for their supplemental planting needs.

PLANTING UPLAND OAK SEEDLINGS

Seedling Quality

One of the easiest things to control during the artificial regeneration process is seedling quality. Seedlings should not be top-clipped prior to planting as this will degrade their quality and ability to develop strong root systems (Struve 1990). Small seedlings will not catch up to the larger seedlings in height growth (fig. 5) and are more prone to animal browse and shade from competing vegetation (Clark 2017). The grading standards for seedling quality are as follows:

1. For northern red oak (1-0), seedlings should average 2.5 to 3.5 feet in height. For white oak (1-0), seedlings should average 1.5 to 2 feet in height. Seedlings will vary in quality from year to year, but we recommend discarding approximately 40 to 60 percent of the smallest sized seedlings prior to planting to increase overall seedling size and planting success rate. Note: Increased culling for seedling size increases the risk of reducing genetic diversity. Further research is needed to characterize this relationship in oaks (Campbell and Sorensen 1984).
    a. Root system development is also important and highly correlated to stem height and root-collar diameters (Clark and others 2000). Trees that meet the minimum height requirements will generally have well developed root systems (coarsely defined as trees with more than five first-order lateral roots) (Kormanik and others 1994). However, most nursery crews or forest managers are not going to count roots, and height is the most practical characteristic for seedling grading.
2. Other species: Grading standards are not developed for most other species, but a good rule of thumb would be to discard trees < 2.5 feet in height in the red oak group and 1.5 feet in height in the white oak group. Please contact the regional silviculturist for specific seedling standards.
3. If you get seedlings from seed collected through the Region's Genetic Resources Management program, steps are taken to ensure that seedlings will be graded (selected for quality) prior to planting.

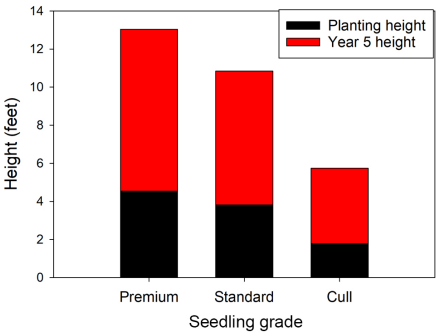

Figure 5—Five-year height growth for different seedling grades of northern red oak planted in a silvicultural clearcut.

Site Selection

Target planting locations that have easy access for planting or desirable site characteristics. Eight specific recommendations for planting locations are listed below:

1. Select sites with appropriate climatic and soil conditions.
    a. Soils should be very deep (>40 inches), well drained with a moderate pH, and a high-water holding capacity.
    b. Soils should not be compacted. Sites that are stony, particularly containing larger rocks or other fragments, will be more difficult to plant.
    c. Consider the Tree Atlas website (**https://www.fs.fed.us/nrs/atlas/tree/**) to help select sites appropriate for the species.
2. Select planting areas where natural advanced oak reproduction is absent and/or where oak reproduction is strongly desired.
    a. If you have abundant natural oak reproduction (> 500 per acre), consider silviculture methods to recruit those seedlings into a competitive size class prior to or following the overstory harvest

Figure 6—Planting high quality northern red oak seedlings in a clearcut regeneration harvest using a modified KBC bar. USDA Forest Service photo by Stacy L. Clark.

(Brose 2010, Loftis 1990, Schweitzer and others 2019). However, be aware that many of these methods are highly variable in their efficacy depending on localized site conditions (Dey 2014).

3. The best sites for planting will be on sites of moderate productivity where natural oak reproduction is insufficiently competitive, but competition can be controlled with relatively infrequent entries (Spetich and others 2002). Site index between 65 to 80 for northern red oak is ideal.
    a. Site index greater than 80 will generally require frequent and intense competition control, which is considered impractical for many managers. Other valuable species can often be grown on these highly productive sites more easily and cheaply than using methods to naturally or artificially regenerate oak species.
        - Though not adequately tested, leaving a higher residual basal area and opening the canopy in stages (e.g., a shelterwood establishment cut followed by a shelterwood removal cut and competition control) may improve the effectiveness of planting on more productive sites.
    b. Site index less than 65 typically results in sufficient natural oak regeneration, particularly for white oak if a seed source is present, because oaks are more competitive on lower quality sites compared to other species.
        - An exception could occur where oak reproduction is absent, such as pine plantations being converted to hardwood stands.
4. The selected sites should have received an initial harvest of no more than 60 percent of residual stocking, which translates to no more than 30 to 50 percent canopy cover or approximately 60 to 75 square feet per acre of basal area.
    a. Underplanting in a commercial shelterwood establishment cut or removal cut is a viable silvicultural treatment for planting, particularly for sites of higher productivity, but be aware that future entries may damage planted seedlings (Dey and others 2012).
    b. A commercial clearcut can be used (fig. 6), but it will probably require the most post-planting maintenance compared to variable retention, shelterwood harvests, or thinnings, particularly for higher quality sites.
5. Consider selecting areas that have relative ease of access (e.g., short distances to roads, gentle topography) for planting, and pre- and post-planting competition control using herbicides or mechanical methods.
6. Select planting areas that represent smaller blocks scattered throughout the stand in locations with better access or more conducive site conditions for planting (e.g., less rocky soil, gentle slopes, close to roads).
7. Select stands where deer herd density is relatively low or can be reasonably controlled with fencing or other measures. Shorter seedlings will have an increased probability for deer browse (Oswalt and others 2006).
8. Select stands where prescribed fire will not be used for at least 5 to 15 years. Seedlings will need time to either establish thick bark capable of resisting low-intensity prescribed fires (estimated to be at least 15 to 20 years after planting) or have a well-developed root system to sprout prolifically following topkill from a prescribed burn (estimated to be at least 5 years after planting) (Clark 2020b).

Site Preparation

Site preparation will improve the level of planting success, particularly for planting in forested settings.

1. Slash should be kept to a minimum to ease planting operations either through whole-tree skidding or bucking of residual slash prior to planting.
2. Prescribed burns prior to planting can also help control competition, slash, and provide a nutrient boost to planted seedlings. Ideally, prescribed burns should be timed just prior to bud-break in early spring to have the best effect on competition control.
3. Currently, herbicides are recommended to control stump sprout competition from undesirables. The following recommendations from Jeff Kochenderfer (USDA Forest Service, Region 9) are for cut-stump treatment:
    a. Use a 50-percent solution of glyphosate or a 6-percent solution of imazapyr and a surfactant in a water carrier.
    b. Treat stumps within 4 days after cutting. Treatment is best applied from June 1 to November 1 to avoid heavy sap periods (January–April).
    c. Treat the outer 2 inches of tree stumps using a backpack sprayer. Some herbicide transmissions may also occur through intraspecific root grafts of the same species.
    d. The cut-stump treatment is very cost effective when used in conjunction with mechanized feller-buncher harvesting operations.
    e. Other herbicide methods that can be used to fit your specific needs include pre-harvest hack-and-squirt and post-harvest streamline spray to sprouts.

Planting Methods

The simplest mistake can ruin a planting. Pay attention to the following considerations during your planting job:

1. It is beneficial to shorten the time between lifting from the nursery and planting in the field. Improper or lengthened storage time following lifting will decrease seedling survival and growth rates (Insley 1980). If seedlings must be stored from the time of lifting to the planting period, store them in a refrigerated cooler or a cool, dry space. It is important to ensure that the seedling bags are not overpacked and tightly wrapped to avoid desiccation.
2. The wrong planting tool can ruin the best planned planting job. A planting shovel, a modified KBC® bar (modified to be approximately 2 inches longer on each side of the blade), or an auger with a 6-inch bit is recommended to plant the larger seedlings (fig. 7). A standard dibble bar will not work. Seedlings are best planted using a bar with a wide, deep blade. If hiring a planting crew, it is important to have enough people to shadow the planters to ensure the seedlings are not trimmed further and planted correctly.
3. Seedlings should be planted to ensure the root collar is flush with the ground. Planting too deep will deprive the seedling roots of oxygen, and planting too shallow will reduce root development, causing stem dieback.
4. **Supervise the planting crew.** Make sure that the large seedlings are distributed appropriately across the site. Planters will plant the large seedlings first to lighten their loads. Do not let the planting crew trim the roots.

Figure 7—A modified KBC® bar (left) and a machine auger with a 6-inch bit (right) used to plant large high quality northern red oak and white oak seedlings. Courtesy photo by Scott E. Schlarbaum, The University of Tennessee.

Young northern red oak (*Quercus rubra*). USDA Forest Service photo by Stacy L. Clark.

5. Trees should stay in bags, preferably in a shaded location, until the planter takes them. The bottom of the bags should be facing the wind, to ensure the roots will not dry out. Remember, the fatal mistakes of planting are for the roots to dry out prior to planting and to leave air pockets in the planting hole.
6. Ideally, roots should be trimmed so that lateral roots are pruned 6 inches from the main taproot. Pruning facilitates planting and encourages growth from the severed end of the taproot (Kormanik and others 1995).

Spacing

Spacing can be modified to meet landowner objectives, but we recommend planting at a lower density (12 x 12 foot minimum spacing equals 302 trees per acre) than is standard for pine due to the higher planting costs associated with planting larger seedlings. Also, hardwood plantings are generally conducted to enrich a site, not convert to a single species plantation.

Deer Browse Protection

The best approach to mitigate deer browse is to plant taller trees that will more quickly escape browse pressure. Seedlings taller than approximately 3.5 to 4 feet have the best chance for escaping browse damage, but seedlings of this size will only occur in a few species like northern red oak. Browsing to the lateral limbs is acceptable, but repetitive browsing to the terminal bud will eventually kill the tree. Trees can be sprayed with a deer repellent at regular intervals (once every 2 months). Tree shelters (minimum 4 feet tall) and fences (minimum 6 feet tall) can also be erected, but these can be costly and difficult to establish, particularly in forested situations. Shelters will need periodic maintenance and can be removed once the terminal bud of the tree is approximately 3 to 4 feet above the shelter.

Post-Planting Maintenance

For most plantings, competition control will be needed after planting, even those using the highest quality seedlings. Unfortunately, the timing and number of re-entries and their effectiveness has had limited study with oak plantings, particularly in more productive forests of the Southern Appalachians. The use of high-quality seedlings was not generally accepted until the early 2000s, and resources for such costly studies have been sparse. The few research plantings of this type that exist are still relatively young. As they yield results, this document will be updated. There is a tradeoff between cost efficiency of post-planting maintenance and planting success rates that is not well understood. Current recommendations are:

1. Competition control using a targeted herbicide application 5 to 8 years after planting. Treat stems that are within a 45-degree cone of interference with the crown of the target seedling. Only release seedlings that will benefit from a release (seedlings < 5 feet tall or not within 50 to 60 percent of the height of competing stems will probably not benefit). A basal bark spray can be used by applying a 25-percent solution of triclopyr ester mixed with an oil carrier to the lower 6 inches of the stem you wish to kill. A basal spray works best on thin-barked species < 6 inches diameter at breast height because it is not readily translocated to attached root sprouts. Apply the herbicide solution completely around the stem until it begins to run off. A hack-and-squirt application of triclopyr ester or imazapyr can also be applied to larger stems to better suit the specific site conditions.

2. After the trees have achieved crown closure at year 12 to 25, a crop tree release can be implemented (Miller and others 2007). This involves killing undesirable trees (using a chainsaw or herbicide injection) surrounding the desirable tree. For this method to be effective, the desirable tree crown must already be in an upper crown position.

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Mature white oak (*Quercus alba*) crown. USDA Forest Service photo by Stacy L. Clark.

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In this report, we provide guidelines and administrative procedures to conduct artifical regeneration activities for upland oak (*Quercus*) species. The information provided is intended to assist silviculturists in the Southern Region (Region 8) of the Forest Service, U.S. Department of Agriculture, but many of the management guidelines, specifically the sections "Collecting Your Own Acorns" and "Planting Upland Oak Seedlings" could be applied by forest managers outside of the Southern Region. The overall goal of artificial regeneration is to increase the density of advanced oak reproduction at the time of overstory removal, which is particularly important in forests where oak is difficult to regenerate due to the lack of existing seed sources or the inability to foster the development of existing regeneration into larger size classes. The Southern Region has the oldest northern red oak (*Q. rubra*) seed orchard in the country, but seed production varies from year to year. White oak (*Q. alba*) orchards are not yet in full production. Planting activities must be planned at least 1.5 years in advance to take advantage of years with abundant acorn crops, which can be difficult to time with harvesting activities. Through decades of cooperative partnerships, nursery procedures have been developed to grow and identify high-quality oak seedlings that have a better chance of competing with shade-intolerant species. Planting success will improve with competition control and herbivore protection in forests with high deer density. Site selection is important as site productivity is negatively correlated to oak's competitive ability, but planting on poor-quality sites (less than 70 site index) is usually not necessary unless oak regeneration is completely absent (e.g., conversion of pine plantations to oak forests). Artificial regeneration of upland oak species requires thoughtful planning and adaptive management that includes the use of genetically diverse, high-quality seedlings planted on appropriate sites that can be monitored and managed through the stem-exclusion stage of stand development.

KEYWORDS: Acorn collection, artificial regeneration, genetic resources, nursery production, seed orchards, seedling quality, Region 8.