Planting and Care of Fine Hardwood Seedlings

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Nursery Production of Hardwood Seedlings

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Introduction

Access to quality tree seedlings is an essential component of a successful hardwood reforestation project. Hardwood plantations may be established by sowing seed directly to a field site, but the success of direct seeding operations has been inconsistent for many species, which indicates that more research is needed before this practice can be recommended. For that reason, the vast majority of hardwood plantations in the Central Hardwood Region are established using seedlings grown in nurseries. Production of quality seedlings that are likely to survive and grow well following field planting depends on proper coordination of a sequence of steps. Failure to pay attention to necessary details of any of these steps may result in poor-quality seedlings that limit reforestation success.

Large-scale production bare-root nursery in Indiana

This paper will provide the seedling user with a general overview of steps required to produce high-quality hardwood seedlings. This publication will not serve as a guide for the nursery production manager, but should convey knowledge necessary for the hardwood seedling buyer to properly communicate with nursery personnel to ensure delivery of quality seedlings.

Types of Nursery Operations

The two main types of nursery operations are bare-root and containerized. Bare-root forest-tree seedlings are grown in fields much like any agricultural crop. The seedlings are termed bare-root because roots are exposed at field planting. The vast majority (i.e., 98 percent) of hardwood seedlings planted in the Central Hardwood Region originate from bare-root nurseries.

Containerized nurseries generally produce seedlings inside a greenhouse. Seedlings are grown in containers that may range in size from very small (two cubic inches) to very large (five gallons or more). In the Central Hardwood Region, most hardwood seedlings grown in containerized nurseries are currently produced in relatively large containers (one gallon or more). This limits their applicability to only selected reforestation practices (e.g., landscaping), because these seedlings are substantially more expensive than bare-root seedlings. For example, in 2003, the retail cost for 100 bare-root northern red oak seedlings from a state nursery in Indiana was $25.30, while the cost of 100 three-gallon seedlings from a private containerized nursery was $1065.00.

The USFS Directory of Forest and Conservation Nurseries is an excellent source for identifying both bare-root and containerized nurseries (online at http://www.rngr.net)

A containerized nursery producing oak seedlings

Because only a small proportion of hardwood seedlings are currently produced in containers in the Central Hardwood Region, only bare-root seedling nursery operations will be discussed in the remainder of this paper.

Seed collection after harvest and from standing trees

Procurement and Processing of Seed

Successful nursery seedling production depends on obtaining good seed. Many large nurseries have a seed expert who is knowledgeable in tree improvement and seed processing. The actual practices for obtaining seed in the Central Hardwood Region vary among nurseries. Many large nurseries pay local entrepreneurs for delivery of good seed, which comes from trees following a harvest, or from standing trees in easy-to-collect areas such as parks or cemeteries. It is essential that seeds originate from the same general area as the intended planting site to ensure that trees are adapted to grow well in their new environment.

Tremendous gains have been made with tree improvement programs that are designed to enhance the commercial timber quality of conifer species in the western and southeastern United States. Experts select individuals for desirable characteristics such as fast growth, tree form, and resistance to disease. Seed from these sources may then be used to regenerate new forests. While some gains have been made with important hardwood timber species, such as black walnut (Beineke 1989), hardwood tree improvement programs are in their infancy. The majority of seed used for hardwood regeneration currently comes from "unimproved" sources. These sources, however, have the benefit of high genetic diversity. This is an important consideration in the Central Hardwood Region where trees are generally planted with a conservation goal that includes many important objectives (e.g., wildlife habitat, timber production, and soil and water protection).

The USFS Woody Plant Seed Manual provides an excellent overview of seed requirements for most forest tree species (online at http://www.rngr.net)

After seed is delivered to a nursery, steps must be taken to ensure that the seed will germinate properly. First, it must be verified that the seed is actually from a particular species. Seed from each species has distinguishing characteristics (e.g., size, shape, markings) that experts may use for identification. Proper identification is important because the seedling buyer expects to receive a particular species. The percentage of "viable" seed must then be determined. There are several tests that nurseries commonly use to determine if seed is viable. This helps the nursery to know how much seed to actually sow. If the viability for a seed lot is determined to be 50 percent, the nursery must sow two times more seed than they expect to have seedlings. Hardwood species vary tremendously in the percentage of viable seed that may be obtained (e.g., yellow poplar viability may be less than 10 percent, while black walnut is typically 50 percent).

Proper species identification is also important because each species has unique requirements that must be understood to achieve successful germination, as their adaptations have evolved to survive in nature. Species have differences in the amount of time for which they must be stratified, or exposed to relatively low temperatures in cold storage, simulating overwintering. Seed from species in the white oak grouping (adapted to germinate in the fall) will germinate with little exposure to low temperatures, while seed from species in the red oak grouping (adapted to germinate in the spring) must undergo a winter cold treatment before seed will germinate. Some species require that seed be scarified, a mechanical abrasion treatment which may simulate the seed passing through the intestines of an animal. Species also differ in their ability to withstand prolonged storage without a loss of seed viability. For example, yellow poplar seed may remain viable for 10 years in storage, while seed of the oaks may remain viable for only one year.

Overcup oak seed stratified using cold storage

Sowing of Seed

After completing any treatments necessary to promote germination, seed may be sown directly into prepared nursery beds. Sowing is typically done in the fall or spring using machines that are set to apply seed at a pre-determined spacing. Sowing density is dependent on expected seed viability and desired growing density. Lower bed densities generally result in the production of larger seedlings, which reduces the number of seedlings that may be harvested in a given nursery area. Most nurseries strategize to identify a growing density that provides quality seedlings, while still maximizing production. In reality, target densities are rarely attained uniformly across a nursery, resulting in a wide range of seedling sizes. Typical target operational growing densities for different species of hardwood seedlings in the Central Hardwood Region are 4 to 12 seedlings per square foot.

Straw applied to bare-root nursery beds following sowing helps to reduce seed predation.

Because seed in nurseries may be eaten by rodents, deer, and birds following sowing, measures are sometimes taken to reduce incidence of predation prior to or shortly after germination. Straw may be used to cover seed. Other measures may include trapping, poison, hunting, and fencing.

Culturing the Seedling

To produce quality tree seedlings that are likely to survive and grow well following planting, proper culturing of young seedlings following germination is necessary. Although there is much debate among nursery managers and scientists as to the best methods for growing hardwood seedlings, most nurseries follow some general practices.

Control of Soil-Borne Diseases

There are many organisms that live and reproduce in soils that may threaten a crop of seedlings. Of particular concern are detrimental root rots (e.g., *Fusarium*, *Phytophthora*, and *Cylindrocladium spp.*), nematodes, blights, and fungi. Control of soil-borne diseases is difficult, but can be achieved primarily through crop rotation, planting of species on soils where they are best adapted, maintaining good soil drainage, use of cover crops that are antagonistic to soil pathogens, and application of pesticides. Maintaining high levels of organic matter in soils also represents a potential way to improve fungi and bacteria populations, which can combat some seedling pathogens, nematodes, and insects (Rose et al. 1995). Many nurseries utilize cover crops, such as sorghum and corn. These crops help to add organic material into the soil after the residual plant material is incorporated into the soil.

Sowing seed into bare-root nursery beds using a precision seeder

Nursery soils have traditionally been fumigated with the chemicals methyl bromide and chloropicrin, which kill many soil organisms. Soil fumigation, however, does not necessarily reduce the incidence of root rots. Spores of water molds can be found in surface irrigation water and may be reintroduced with irrigation. Fumigation is primarily useful for control of nematodes and some diseases. Because methyl bromide apparently contributes to global warming, it has been listed for elimination by 2005. Some nurseries have petitioned to extend the banning date of methyl bromide, and many nursery representatives have been searching for additional alternatives for soil disease control. Although some options have been identified, soil-borne diseases may be a greater concern for future crops.

Irrigation, Fertilization, and Weed Control

Nurseries apply water by irrigation to promote seedling growth. Access to adequate water following germination is probably the most

Fumigation of nursery beds using methyl bromide

important single factor dictating initial seedling development. This is because without sufficient water, photosynthesis is severely limited. Most bare-root nurseries use rotating sprinklers to water seedling beds. These sprinklers must be properly calibrated such that each area receives nearly equal watering. Rainfall also adds to the amount of water that seedlings receive. Many nurseries closely monitor water characteristics (e.g., pH, salinity) and adjust water as necessary to resolve potential problems.

Proper seedling growth in the nursery is also dependent upon access to adequate levels of essential nutrients. In addition to the benefits of nutrients during nursery growth, seedlings will also store nutrients in stem and roots for use after field planting. Although soil nutrient levels may be improved by incorporation of organic fertilizers, such as manure, nutrient release from these materials is generally inconsistent. Thus, inorganic fertilizers are applied to seedlings in nurseries. Fertilizers in granular or liquid form may be added to nursery beds at several application points during the growing season.

Irrigating nursery beds using rotating sprinklers

Control of unwanted vegetation further promotes vigorous growth of a crop of seedlings. Fumigation with methyl bromide will kill most weed seeds prior to germination. Many nurseries then apply a pre-emergent herbicide prior to or after sowing and may make subsequent applications with a post-emergent herbicide. Care must be taken to prevent herbicide damage to the seedling crop when applying herbicides. Nurseries may remove weeds by hand during the growing season.

Pests may threaten seedling crops by feeding on leaves or other succulent tissue; in fact, the potato leafhopper is a common pest in bare-root nurseries in the Central Hardwood Region. Insecticides must be applied periodically to limit damage that pests may cause. Intensity of application varies with pest pressure, which fluctuates seasonally and among years.

Manipulating Root Development

Although the seedling user is most familiar with the above ground portion of the seedling, root system morphology is also of critical concern in producing quality hardwood seedlings. Research has shown that seedlings with a greater number of large lateral roots tend to perform better in the field than those with less large lateral roots (Thompson and Schultz 1995; Schultz and Thompson 1996; Ward et al. 2000). A fibrous root system (quantity of very fine roots) enhances the root surface area that may be used for water and nutrient uptake after field transplant. To stimulate a fibrous root system and the production of lateral roots in the upper rooting zone, many nurseries undercut seedlings approximately 10 inches below ground line during active growth (termed "root wrenching"). This procedure, similar to the loss of roots as a result of some type of mechanical damage in nature, causes seedlings to produce new roots to compensate for those lost. Typically, more new roots are produced than the number lost (Schultz and Thompson 1996). Nurseries vary in the number and seasonal timing of root wrenching operations performed.

Root wrenching of bare-root hardwood seedlings to promote root system development

Inducing Dormancy

Seedlings must be properly conditioned to handle the stresses of winter and transplanting. Without being physiologically dormant, actively growing seedlings are at risk for damage from a late season frost. Seedlings that are not fully dormant may be severely damaged and subsequently die as a result of the shock associated with being lifted from a nursery bed, packed, placed into cold storage, transported, and planted. The primary impetus for induction of physiological dormancy is a reduction in daylight hours and exposure to colder temperatures. This occurs naturally in nurseries at the end of the growing season. Other common methods to slow seedling growth and help harden seedlings for winter are decreasing the frequency of irrigation and altering fertilization regimes. Decreasing or suspending nitrogen fertilization, and maintaining or increasing potassium and phosphorus is commonly used to help condition seedlings for dormancy.

Seedling Lifting, Packing, and Storage

After seedlings have completed nursery growth, they must be successfully lifted from nursery beds or containers, packed, and stored before being shipped or made available for customer pickup. These procedures may significantly impact seedling physiological condition and subsequent survival following planting. Seedlings may be lifted from nursery beds from the fall through early spring. Timing of lifting is typically based on weather, phenological characteristics of the species, and nursery storage capacity. To lift seedlings from nursery beds, an undercutting blade is used to sever roots and loosen soil, such that seedlings may be removed from beds with minimal injury. It is essential that lifting from nursery beds occur only when seedlings are fully dormant and able to resist the stresses associated with lifting, packing, and storing.

After being lifted, seedlings are transported to a grading area where they are sorted and packaged for storage and shipping. Because roots of bare-root seedlings are exposed following lifting, it is critical that roots remain moist, and exposure to high temperatures, direct sun, or winds that dry roots is minimized. Desiccated roots will likely become non-functional when the seedling is transplanted to the field. Seedlings should remain covered whenever possible.

Once seedlings reach the nursery grading area, trained personnel sort and remove those seedlings not meeting grading criteria. These seedlings, often termed culls, may be damaged or have an unacceptable small diameter at the root collar, height, number of large lateral roots, or combination thereof. Specific culling standards vary among nurseries, species, and even years.

Following grading, acceptable seedlings are packaged for storage. Packing materials help to physically protect seedlings during storage and shipping. Actual packing materials vary among nurseries. Boxes are often considered too expensive for large hardwood seedlings. Many bare-root nurseries use kraft-polyethylene bags, which are bundled with seedling tops exposed and roots enclosed within the bag. A moist material, such as sphagnum moss, may be added to roots to limit drying. Root coatings, often used with southern pines, are not commonly used with hardwoods in the Central Hardwood Region.

Lifting green ash seedlings from a nursery bed

Hardwood seedlings are most often stored at temperatures of 33 to 40˚F following packing and prior to shipping or customer pickup, and they are stored at a relative humidity greater than 80 percent. This helps ensure that seedlings remain moist and physiologically dormant prior to shipping for planting. Many nurseries have large coolers in which they store seedling bundles on racks. Sufficient space must be available between bundles to promote proper air circulation. This helps regulate temperature consistency and minimizes the chance for introduction of disease and mold. Seedlings continue to respire and expend stored carbohydrates while in cold stor-

Packing hardwood seedlings using kraft-polyethylene bags and moistened sphagnum moss


Large-scale seedling storage cooler

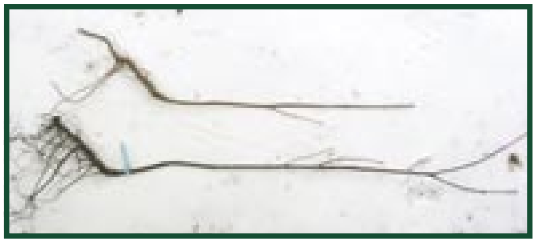

Pickup of a small order of seedlings at the nursery

age. Freezer storage is rarely used in the Central Hardwood Region, although it is an important long-term storage method for conifers in other regions to minimize respiration and prevent mold. When storing hardwood seedlings for extended periods, it is possible that freezer storage may provide a more effective means of minimizing any loss of seedling vigor (Englert et al. 1993).

Hardwood seedlings in the Central Hardwood Region are either picked up at the nursery or delivered to the seedling user. Just as seedlings must remain in cold storage prior to pickup, it is best if seedlings remain in cold storage after pickup and until planting. Large orders are generally shipped in refrigerated trailers. Small orders that are not picked up at the nursery are often shipped without refrigeration. When it is not possible to cold store seedlings during transport, seedlings should receive proper air circulation and remain free of direct sun, high temperatures, and drying winds at all times. It is best if seedlings are planted as soon as possible (within several days of pickup).

Stocktypes

The term "stocktype" refers to the designation type of a nursery seedling being offered for sale. Two main distinctions are related to whether the seedling was produced in a bare-root or containerized nursery. All bare-root nursery seedlings receive an additional designation related to age and whether or not the seedling was transplanted during growing years. In the Central Hardwood Region, most bare-root hardwood seedlings are grown for only one year in a single nursery bed before being sold for field planting. Thus, they are termed 1+0 bare-root. For some species (e.g., white oak), nurseries grow seedlings a second year to reach a desired size. If the seedling remains in the same nursery bed for both growing seasons, the stocktype designation is 2+0. Occasionally, nurseries lift a group of seedlings from a nursery bed after the first growing season and transplant them to a different nursery bed for a second year of growth. These seedlings are then termed 1+1. Transplanting may result in a larger and more fibrous root system than that found on seedlings grown in the same bed for a second year to become 2+0.


Northern red oak seedlings of different stocktypes: 1+0 bare-root (top) and 2+0 bare-root (bottom)

Seedling Quality

Although this paper is intended to provide only background information regarding nursery operations, this section will present the landowner with crucial information needed to assess the quality of seedlings used for reforestation jobs. This information is useful for dealing with nurseries, forest consultants, and tree planters. Seedling quality is certainly more important than seedling quantity, as poor quality seedlings will never reach the growth potential of good quality seedlings in the field. It is preferable to plant fewer seedlings of good quality than many poor quality seedlings.

Seedling Quality Defined

Attention to detail in all steps of nursery operations, shipping, storage, transport, and handling is required to provide the tree planter with "quality" hardwood seedlings. There is much debate as to what truly constitutes a quality seedling. Most people agree that a higher quality seedling is one that performs exceptionally well in the field when all other conditions are equal. No single attribute may be used to define seedling quality. Instead, multiple characteristics related to both morphology and physiology must be combined to determine if a seedling has the capacity to excel in the field (Rose et al. 1990; Puttonen 1996). The range of characteristics useful for defining seedling quality varies somewhat between species. This is especially true in the Central Hardwood Region where many different species, all with distinct ecological characteristics, are planted. Attributes defining seedling quality may also be dependent on the condition of the intended outplanting site and objectives of the landowner.

Morphological and Physiological Quality

In addition to the aforementioned importance of root morphology, research has also shown that other morphological characteristics of hardwood nursery seedlings, such as large root collar diameter and shoot length improve field performance (Dey and Parker 1997). With a greater initial height at planting, seedlings are better able to out-compete weeds than smaller seedlings. This is especially important on sites that are prone to excessive weed competition. Seedlings with a larger root collar diameter will have more stored carbohydrates, which provide energy immediately following planting while seedlings reestablish root-soil contact to extract resources from the site.

It may be difficult for the seedling user to visually identify the morphological quality of hardwood seedlings. Part of this stems from the fact that there are more than 50 species of hardwood seedlings planted in the Central Hardwood Region, each with unique morphological characteristics. For example, a poor quality black walnut seedling may have more large lateral roots than a good quality white oak seedling. Thus, it is helpful to understand the general morphological character of each species of interest.

Many nurseries primarily grade and characterize seedlings based on height (from root collar to terminal bud) and root collar diameter. When comparing the morphology of seedlings from a single species, taller seedlings with a larger root collar diameter are probably superior in morphological quality than those with lesser values for these characteristics. Other morphological characteristics that may reflect seedling quality and may be visually assessed include a well-lignified stem, a balanced root to shoot ratio, extensive root system fibrosity, large root volume, many large lateral roots, and large, firm buds.

Physiological characteristics, such as dormancy status, root growth potential, nutrient levels, and carbohydrate storage are probably equally significant in determining hardwood seedling quality (Farmer 1975; Englert et al. 1993). Physiological quality is much more difficult for the user to assess upon seedling delivery than morphological quality. A common physiological problem that may be identified is the incidence of a seedling “breaking bud” (i.e. growing leaves) prior to planting. This indicates that the seedling is not physiologically dormant and could die or grow poorly when exposed to the shock of storage and transplanting. Abundant mold indicates that seedlings may have been stored for too long and/or too wet, and vigor may be reduced. A fermented or sour smell when a bag of seedlings is opened may indicate that seedlings were exposed to excessive heat during shipping and may be physiologically damaged. Seedlings that appear to be very dry following delivery were likely stored at inadequate moisture contents or for too long. It is especially critical that the root systems remain moist up until planting, otherwise roots may die or become non-functional following transplanting.

Genetic Quality

The genetic quality of seedlings must also be considered prior to planting. Genetic considerations regarding tree improvement programs and maintaining genetic diversity have been discussed previously. Perhaps the most crucial element of genetic quality that the seedling user must be aware of is seed origin. Seed should be collected from the same general area as the intended outplanting site.

Over many generations, trees have adapted to the local environmental growing conditions of a given region. Thus, they will generally withstand the environmental extremes (e.g., cold, drought) that may occur infrequently in a region. By moving and planting seed away from an area where it was adapted, trees may no longer be able to tolerate the periodic climatic extremes of a new region. The new trees may grow well for 10 or more years, and then die following an unusually intense cold event. Trees originating from a different region may also grow slower over time, or be more susceptible to insect and disease problems than local sources.

There is much debate among forest geneticists as to how far seed may be transferred safely, and relatively little scientific evidence is available regarding this issue for hardwood species. Studies on black walnut have shown that moving seed north beyond 150 to 200 miles resulted in reduction in growth and survival as compared to local sources (Bey 1980). Thus, the seedling buyer must be aware of seed origin when attaining seedlings. By purchasing seedlings from local state or private nurseries, the risk of planting seedlings that are not adapted to the region is minimized. This risk increases substantially, however, when acquiring seedlings from nurseries located a considerable distance from the intended outplanting site.

Summary

Nursery production of hardwood seedlings in the Central Hardwood Region is a complex procedure because of the demand for a large number of species and the large variation in ecological characteristics among these species. The vast majority of seedlings planted in the Central Hardwood Region currently originate from bare-root nurseries. Producing quality seedlings in these nurseries is dependent upon proper coordination and execution of a sequence of steps. Seed must first be appropriately procured, processed, and sown. Seedlings must then be properly cultured during nursery growth. Following the growing season, seedlings must be effectively lifted, packed, stored, and transported. Failure to pay attention to necessary details of any of these steps may result in poor quality seedlings that limit reforestation success. Seedling quality consists of morphological, physiological, and genetic aspects. The seedling buyer should understand how to evaluate the quality of seedlings received from the nursery to help ensure that seedlings will perform well following planting.

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