SUCCESSFUL TREE PLANTING TECHNIQUES FOR DRASTICALLY DISTURBED LANDS: A CASE STUDY OF THE PROPAGATIONAND PLANTING OF CONTAINER-GROWN OAK AND NUT TREES IN MISSOURI[1]

by

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Abstract: Successful tree seedling establishment on drastically disturbed lands is contingent on seven major variables: 1) selection of proper native species, 2) purchase of the best quality planting stock, 3) correct handling of planting stock, 4) correct planting techniques, 5) effective control of competing vegetation, 6) proper soil conditions and preparation, 7) weather. Exotic species should not be planted to avoid past mistakes such as kudzu, Japanese honeysuckle, sericea lespedeza and chestnut blight. A major concern of reclamation specialists and ecosystem restorationists is obtaining high-quality plant materials with the correct provenance. Ecosystem restorationists, reclamation specialists, park managers and private landowners can easily and cheaply propagate native oak or other hardwood species from local parent stock using Whitcomb bottomless containers. Proper seed collection, storage and preparation techniques as well as propagation methods are critical for seedling growth and development into quality air-pruned planting stock. Air-pruned seedlings of local provenance can be outplanted in the fall after one growing season with little transplanting shock while developing extensive root systems prior to soil freezing in winter. Establishment success of container-grown seedlings greatly exceeds that of spring-planted bare-root seedlings. Fall-planted, container-grown seedlings have a decided advantage since their roots continue to grow throughout the fall and much of the winter, enabling them to better withstand summer drought and weedy competitors. Container-grown seedlings also allow a five- to six-month planting season compared to bare-root seedlings' four to six weeks. Since propagation costs are minimal, planters who grow their own save money on the planting stock. Because the quality is higher, home-grown seedlings have greater establishment success, saving labor, time and money. With better survival rates, far fewer trees need be planted as compared to bare-root seedlings.

Additional Keywords: Reclamation, Ecosystem Restoration, Reforestation

Introduction

Many hard-earned lessons learned by reclamation specialists are frequently ignored or forgotten by their successors. Successful tree planting is dependent upon a few simple techniques. Trees are effective in reclamation because mining can create deep, nontoxic mine soils that are often more productive than many adjacent forest soils. AML and SMCRA Title V mine lands can become important commercial and recreational forest resources with proper planning and management.

Trees produce large amounts of organic matter in mine soils that promote nutrient cycling, particularly that of nitrogen and phosphorus. Tree roots break up compaction by creating root channels. Large tap-rooted species such as bur *oak (Quercus macrocarpa),* swamp white oak *(Quercus bicolor),* and baldcypress *(Taxodium distichum)* are particularly effective (Ashby and Vogel, 1993). Tree root systems stabilize the reclamation site by reducing erosion and sedimentation. Certain trees species tolerate high acidity and low fertility, typical soil conditions found on many mine sites. Trees are extremely important for wildlife habitat. In Midwest farm country, mine lands may be the only "dense" timber in the landscape.

Early reclamation efforts of mine lands in the East and Midwest centered on afforestation. Early tree planting efforts in the East and Midwest were based on observation of woody invasion and natural succession of trees on abandoned mine spoils (Croxton, 1928). Clark (1954) found that tree planting success on mine lands

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depends on soil chemistry, soil texture, water-holding capacity and the effects of erosion and sedimentation. This assumes planting materials and methods are uniformly good and that compaction is not a problem.

Ashby and Vogel in their excellent reference *Tree Planting on Mined Lands in the Midwest: A Handbook (I* 993) argue that there are seven major environmental factors and physical characteristics in tree planting success: 1) climate: macro- and micro-climate, 2) soil physical factors: texture, organic matter, coarse fragments, surface roughness, compaction and drainage, 3) soil chemical factors: reaction or pH, toxic elements and soil infertility, particularly of nitrogen and phosphorus, 4) competition with herbaceous groundcovers, 5) lack of soil organisms, 6) mammals and birds, and 7) fire.

Vogel (I 987) writes that the reclamation specialist ***can control*** six factors that influence planting success: 1) quality of planting stock, 2) care of planting stock, 3) method of planting, 4) time of planting, 5) competition from herbaceous vegetation, and 6) soil compaction. Vogel also argues that following proper establishment techniques is as important as selecting the appropriate plant species.

Reclamation specialists must combine these environmental factors and physical characteristics with correct administrative and technical procedures. Hence, successful tree establishment on drastically disturbed lands such as coal mine sites, is contingent upon seven major variables: ***1. selection of proper native species, 2. purchase of the best quality planting stock, 3. correct handling of planting stock, 4. correct planting techniques, 5. effective control of competing vegetation, 6. proper soil condition and preparation, and 7. weather.***

These variables are omnipresent, regardless of unique regional conditions. It does not matter whether the reclamation specialist is planting gamble oak *(Quercus gambelii)* under 15 inches of annual precipitation in Utah or northern red oak *(Quercus rubra)* with 45 inches in Pennsylvania. The utilization of specific establishment techniques largely depends on the reclamation budget. However the reclamation specialist must be aware that the most expensive parts of tree establishment are buying the planting stock and paying the planter. Without proper establishment techniques, the very best stock, planted with the best care may be nothing more than food for soil decomposers.

The author has propagated approximately 1,500 container-grown oak and nut tree seedlings per year since 1990, outplanting on abandoned mine lands and old fields in central and western Missouri. Seedlings grown in the Whitcomb bottomless containers result in the taproot being "air-pruned." The taproot grows through the bottom of the container and is exposed to the air. The apical meristem desiccates and die which stimulates lateral root development throughout the container. Once planted, a lateral root establishes a new taproot or multiple laterals that form codominant, branched main roots (Whitcomb, 1988). First-year establishment success for container-grown seedlings is approximately twice the success of bare-root seedlings in sideby-side field trials in Missouri. White et al (I 970), planting hardwoods and McDonald (I 99 1) using pines and Douglas-fir, confirm higher establishment success rates for container grown seedlings in native soils.

Greatest mortality of container-grown seedlings in Missouri resulted largely from excessive competing vegetation and rodent damage in winter. It was not obvious than any container-grown seedlings were lost due to moisture stress. Bare-rooted seedlings were usually lost in the initial flush of growth or in mid-summer due to moisture stress. Tap-rooted hardwoods such as oak, hickory and walnut responded well to air-pruning, which resulted from using bottomless containers. In many oak plantings, the tops of seedlings die back in midsummer but later sprout back from adventitious buds located at the root collar. This is a common survival mechanism of most oak species (Olson and Boyce, 197 1, Dixon, et at, 1984, Merz and Boyce, 1956, and Liming and Johnston, 1944). Seedlings were propagated in the author's backyard, placed upon a raised, welded hog or cattle panel, with four-inch squares, and protected from squirrels by a wood frame and chicken wire. Bare-root seedlings were purchased from the Forrest Keeling Nursery in Elsberry, Missouri and from the Missouri Department of Conservation George 0. White State Forest Nursery.

Discussion

Selection of ***native species*** is important for reclamation success, particularly for ecosystem functioning. The Surface Mining Control and Reclamation Act, Section 515(b)(19) requires Title V reclamation to create "...a ***diverse,*** effective, and permanent vegetative cover of the same seasonal variety ***native*** to the area affected and capable of ***self-regeneration*** and ***plant succession*** at least equal in extent to the natural vegetation of the area..." Reclamation in this country has not often achieved this goal, largely because of the next clause, which reads: "...except that ***introduced species*** may be used in the revegetation process where desirable and necessary to achieve the postmining land use plan." (SMCRA, 1993) (italics are the author's). The use of trees for reclamation must function as a part of the natural ecosystem of the region. The reclamation specialist must work with these natural processes rather than against them. Native cover crops that promote native tree seedling establishment also tend to promote natural succession. Although Title IV (AML) is not required to adhere to Section 515, AML programs should set goals to enhance and restore diversity and ecosystem functioning of reclamation sites, rather create more low-quality pasture composed solely of alien monocultures.

Native tree species are often adapted to the environmental conditions of the reclamation site (Limstrom, 1963). Many native species in the humid East and Midwest are tolerant of acidic natural soil conditions. Therefore, these species may be effective since they tolerate acidic mine soil conditions as well. Observing natural invasion and succession of native species on acidic AML spoils may provide clues for species selection. The reclamation specialist can purchase seedlings of these species from regional nurseries specializing in or growing large selections of native species. Seeds or propagules can be collected from specimens growing on the mine site, grown by the specialist as described in the case study, and planted on the reclamation site. The reclamation specialist should avoid planting native species that are overly aggressive. Black locust *(Robinia psuedoacacia*) is native to the East and is commonly used as a nurse crop, has sometimes proven to be overly aggressive and persistent in mine lands, slowing natural succession and limiting species diversity due to its dense shade and ability to spread by root sprouts. Plass (1977) found that the exotic black alder *(Alnus glutiiiosa),* grown as a nurse crop, can be effective in enriching mine soils, but can overtop desired species of hardwoods and conifers, limiting their establishment success. Species such as black locust and black alder should have Iii-nited use in reclamation plantings, unless the reclamation specialist is prepared to remove these species once the soil is properly developed and replant with more desirable species (Seidel and Brinkman, 1962).

The disastrous ecological effects of aggressive exotic and naturalized plant species on native plant communities is well-documented. *Kudzu (Pueraria lobata)* and Japanese *honeysuckle (Lonerica.japonica)* are two examples of "conservation" species that have escaped from mine and roadside stabilization plantings and pose significant threats to adjacent native plant communities. Other exotic pests have been introduced by accident by importing infected wood products, plant materials and other commodities. Chestnut blight, Dutch elm disease and the gypsy moth are three of the best known and well-documented examples of pathogens and pests that were inadvertently introduced into North America. Reclamation specialists must avoid the desire of quick and easy plant establishment by using exotics, and focus on the long-term effects of reclamation and ecosystem functioning. Many exotic plants delay native plant invasion and natural succession of drastically disturbed lands.

Purchase of or propagation of quality planting stock is obviously important. This includes selecting materials propagated from stock adapted to local conditions and climate (Limstrom, 1963). The reclamation specialist should purchase planting stock or collect seed from trees growing within the correct climatic zone. Authorities specify that seed provenance (the place of seed origin) be a certain number of miles north or south, and east or west of the planting site. Elevation also should be considered in mountain regions. The best rule is to select stock that can tolerate the planting site's minimum low temperature and survive the region's usual drought conditions. These can be determined from meteorological data. Drought effects on drastically disturbed lands may be of much greater duration and intensity than on a region's native soils.

The stock should be healthy, showing little damage to roots or shoots, and no mold, offensive smell or dry roots. Planting stock is expensive. Poor-quality stock has little chance for survival and should be returned for replacement or credit. The reclamation specialist can propagate stock in-house. Using container grown stock greatly improves seedling establishment. Seed can be selected by the reclamation specialist from plants that are from local sources and adapted and growing under similar environmental conditions, Seed collected from plants growing on drastically disturbed lands may have a "genetic" advantage under these conditions and may prove effective in reclamation success. The container-grown case study emphasizes these points.

Typically, bare-root seedlings with larger calipers (the diameter of the seedling at its root-collar) have much greater establishment success than smaller ones. Voges (I 987) recommend that most conifers and hardwoods have a minimum caliper diameter of 0. I to 0. *15* inches (2.5 to 4mm). Thompson and Schultz (1995) suggest that nurseries should focus on root system development and grade seedlings on root system classification rather than shoot growth. Survival, height and diameter growth of red oak seedlings was significantly greater in Iowa when the seedlings had 10 or more first-order lateral roots.

Bare-root seedlings are grown in nursery beds from one to several years. They are removed (called "lifting") from the beds while dormant and sold or transplanted to a different bed for further growth. Nursery stock is sold based on the age and number of times the seedling has been transplanted. For example, seedlings grown in a bed for one season and sold are I -0 stock. Seedlings grown two years with one lift and transplanted to a bed for the second season growing are 2-1 stock. The first number refers to seedling age, while the second refers to the number of times lifted and transplanted. Lifting cuts the deep roots of tap-rooted species which stimulates lateral root growth. This is physiologically similar to the air-pruning treatment described in the container-grown seedling case study. Both stimulate lateral root development. Improper lifting can result in shock to the seedling, leading to delayed growth or even death.

Correct handling of planting stock is crucial to establishment success. The reclamation specialist should inspect the nursery prior to purchasing stock to ensure the material is handled correctly. Seedlings should be free of defects, correctly sized and graded, and properly store, packaged and shipped. Nurseries that cannot meet these high standards should be avoided. No matter how well the nursery, some material may be shipped that does not meet these quality standards. A good nursery will accept the return of defective material and replace it or credit it to a future purchase. Nurseries that refuse returns should not be used.

Once the stock is delivered, it should be protected from drying winds, freezing or hot temperatures and direct sunlight. Stock can be covered in the field by straw, tarps or reflective heat blankets. The best protection is in a cool, dry bam, garage or other structure. Stock should be planted quickly following its shipment from the nursery. Bare-root stock should be inspected for defects once the bundles are opened. Roots should be protected from drying with moist, shredded papers, peat moss or other water absorbent materials. Water-absorbent gels can be used to keep the roots moist while planting.

One issue that always arises is that of pruning. Most experienced tree planters agree that the root-to-shoot ratio should be maintained around 1: 1. Conifers should never have leaders pruned. Most hardwood species can be root-pruned to facilitate planting, only if the pruning is less than one/three the total root area. Root pruning of hardwoods may require shoot pruning to maintain the 1: I ratio. Shoots should be pruned slightly above a live lateral bud to allow it to develop into a terminal shoot.

Correct planting techniques are simple but often overlooked. Tourney and Korstian (I 93 1) write , "The chief aim in [tree] planting should be to interrupt growth to the least possible degree consistent with economy." The establishment success of container-grown seedlings illustrates this point. Seedlings should be planted with shoots near vertical, in a hole that is large enough to accept the roots easily without bending or twisting, and with the soil tamped gently around the roots without excessive compaction. Bare-root seedlings must be planted with the root collar at or slightly below the soil line. Bare-root seedlings must be planted after the last heavy spring frost date to minimize the potential of frost-heaving. Any deviation from these rules should not be tolerated.

Mechanical planting is a cheap alternative to hand planting. Both methods require similar correct handling and planting procedures for success. Mechanical planting is only as good as the efforts of the planting contractor and his or her equipment. Select a proven type of mechanical planter and an effective operator. Consult with state and federal foresters about the types of machines available and the operator's credentials in a region before issuing a contract. As with hand planting, find contractors who do good work.

Rugged terrain and rocky soils limit the use of mechanical planters. Wet soil conditions are not conducive to effective planting. Mechanical planters increase compaction on wet soils. Mechanical planting is quicker than hand planting. This can be important when there are many acres to plant and the planting window is short.

Inspect the trees following planting. Place a guarantee clause in the tree planting contract to compel the contractor to perform correctly. Require performance bonds and reference checks. Good tree planters want these contract conditions because they can compete with and outbid the marginal operators.

Effective control of competing vegetation often is overlooked prior to tree planting. Dense ground cover is desirable to prevent erosion and sedimentation on a reclamation site. However, it may increase rodent populations that can destroy tree seedlings. It also may enhance browsing by deer and rabbits. Established herbaceous ground covers typically can out-compete tree seedlings, particularly during the first growing season. Water is usually the most limiting factor in tree-seedling establishment on mine lands (Munshower, 1994, Ashby and Vogel, 1993, Limstrom, 1960, Vogel, 1980, and Clark, 1954). The extensive root systems of herbaceous plants out-compete young seedling roots for water and nutrients as the seedlings overcome transplant shock and summer droughts. Competing herbaceous plants can overtop tree seedlings, reducing photosynthesis and cause shoot dieback and sometimes complete mortality.

Researchers suggest that competition for sunlight can be the chief limiting factor for successful establishment when water is not limiting (Hoich, 193 1, Toumey, 1929, and Carvell and Tryon, 1961). The container-grown case study supports this belief. Anderson, et al (I 989) believes that vegetation must be controlled for the first four years following planting to ensure successful establishment. This time period may be excessive in the Midwest for some tree species, although growth will certainly be affected by the extra competition in the seedlings' early years.

Aggressive alleleopathic species, such as tall fescue *(Festuca arundinacea)* should not be used as a cover species in areas to be planted in trees. Less competitive and aggressive species such as redtop *(Agrostis alba), timothy (Phleum pretense)* or perennial ryegrass *(Lolium perenne)* should be planted at rates of two to four pounds of pure live seed per acre. A low-growing legume such as white clover *(Trffolium repens)* or common lespedeza *(Lespedeza striate)* can be planted at low seeding rates to add nitrogen. Adapt cover crop selections to local conditions.

Competing vegetation can be removed by "scalping." This can be done mechanically, by discing, roto-tilling, drag bucket or manually by using hoes, mattocks or shovels. Vegetation is "scalped", leaving bare soil to receive the planted seedlings. This process can be expensive and time and labor intensive but very effective. Applying herbicides in strips or spotting is less expensive than physical scalping and very effective for vegetation control, but the environmental and human health and safety issues must be considered. All chemical applications must be performed according to label directions. Never apply chemicals in standing water.

The reclamation specialist must not scalp vegetation in such a fashion as to permit erosion. Always disc or apply herbicides along the contour, leaving swales, ditches and channels undisturbed and well-vegetated.

Most hardwood seedlings need only one year of scalping to become established.
Although less aggressive annual weeds quickly invade the scalped areas, they typically pose little threat to healthy seedlings in the second season. If tall annual weeds overtop seedlings in the first season, a clipping with a sickle bar or a hydraulic arm mower set high enough to miss the seedling is effective. The mowed material can be raked or thrown at the base of the seedling to function as an organic mulch.

Tree shelters, ground cover control blankets and mulches also can be very effective, but can be extremely costly and labor intensive (Ashby, 1995, and Smith, 1993). Tree shelters are particularly effective in protecting seedlings from animal browsing and from spot herbicide applications. Kjelgren, et al (I 994) found that tree shelters with or without deep-ripping, greatly improved survival of white oak seedlings on a reclaimed dragline mine in Illinois. Birds often use the shelters for perches, sometimes breaking young shoots. Paper wasps and mud daubers build nests inside the tubes that can pose a hazard to inspectors.

Proper soil condition and soil preparation are the foundations of successful tree establishment. Certain basic edaphic or soil conditions must be present before trees can be successfully established. Mine soils tend to be low in organic matter, nitrogen and phosphorus. Water infiltration is slow and water-holding capacity is low in graded mine soils due to compaction. Compacted mine soils accentuates the effects of soil acidity on plants and decreases water availability. Some mine soils contain acid-forming or toxicity-forming materials that impede seedling establishment.

Reclamation is a soil-building process. In natural systems, drastically disturbed lands undergo a succession of living organisms that may take decades or even centuries for successful colonization to occur. The foundation of natural succession is the development of a biological system with the plant community being the most visible portion. However, before this plant community can be expressed, a soil biological system must be developed that creates environmental conditions that allow those plants to complete their life cycles. Plants are most susceptible to harsh environmental conditions and disturbance just after germination. Many plants produce abundant seeds because most seedlings will die. The environmental changes of the micro-site that result from a developing soil biological system enable many young seedlings to survive this early establishment period (Blake, 1935, and Daubenmire, 1959).

Reclamation attempts to telescope this multi-seasonal development of a diverse and complex soil biological system into a few short years. Often, on drastically disturbed lands reclamation specialists attempt to create a stable soil system in one season. Reclamation failures give testimony to our lack of understanding of natural processes. Bradshaw (1987) writes that ecosystem restoration...... is a considerable intellectual challenge requiring that we not only understand the nature of the ecosystem itself, but also the nature of the damage and how to repair it ... *land restoration is an acid test of our ecological understanding."* The goal should be to develop a sustainable soil biological system even if it takes several years. Unless topsoil is imported with its biological system intact, it will take time to develop such a system. In most instances, topsoil should not be "borrowed" because it is never returned, and this practice only increases the amount of disturbance.

Low pH can greatly affect seedling establishment. Acid-forming materials present in many mine spoils can lower spoil pH far below what is acceptable for most tree species. As the pH drops, metals such as aluminum, manganese and iron increases in solution. Aluminum is especially toxic to plant root growth. (Berg and Voges, 1973) As a general rule, do not plant trees on mine soils with a surface pH of 5.0 or less. Before planting, amend acidic mine soils with neutralizing material such as agricultural lime, or use organic matter to buffer the acidity and raise the pH. Otherwise, plant trees in less acidic microsites such as protected slopes and depressions and let natural succession finish the job in later years. Natural invasion patterns can provide clues to the location of these microsites. Field pH determination using hydrion papers is effective in verifying these microsites.

Mine soil fertility can be improved by growing nitrogen-fixing cover crops such as legumes. Plants create soil organic matter that promotes nutrient cycling and soil microbial activity. Virtually all plant-available nitrogen and phosphorus in soils are derived from the decomposition of organic matter by microbes (Brady, 1996). Organic matter increases water-holding capacity, increases cation exchange capacity, buffers soil pH, lowers bulk density and promotes the development of a diverse, soil microbial population. These factors greatly improve the success of seedling establishment. Green manure cover crops can be disced into graded mine spoils to improve soil fertility and organic matter levels. Organic matter can improve soil pH and buffer the exchangeable acidity, improving revegetation and seeding establishment success (Berg and Vogel, 1973, and Brady, 1996).

Low soil fertility can also be addressed by liming and chemical fertilization. While cheap and effective, chemical fertilizers can pose environmental hazards if improperly used and impede the development of native plants adapted to low fertility levels often associated with mine soils. The reclamation specialist must look at the long-term goals of reclamation to determine the proper course of action.

Water is the most limiting factor in tree or shrub establishment (Gjerstad et al, 1984. Munshower, 1994, Ashby and Vogel, 1993, Limstrum, 1960, Vogel, 1980, and Clark, 1954). Excessive compaction of clay-dominated mine soils caused by heavy earth-moving equipment decreases mine soil water-holding capacity. Tree seedling roots have difficulty penetrating compacted mine soils. The effects of drought are accentuated in compacted mine soils, and often result in transplanted seedlings dying because their root systems are not extensive or deep. Compaction also impedes the infiltration of water into the mine soil. In wet periods, this can result in water-logged or anaerobic conditions that can kill seedlings or severely damage their root systems (Clark, 1954, Munshower, 1994, and Ashby, 1993). Czapowskyj (1970) found that grading sandy or rocky, coarse-textured mine spoils improves tree seedlings' performance in Pennsylvania by reducing the slopes and thereby increasing water infiltration into the spoil. This result may be limited to extremely coarse textured spoils and cannot be considered typical of most spoil conditions in the Midwest. Grading clay-rich mine soils can result in compaction and ponding of water.

Deep ripping by ripper bars, subsoilers, V-shank rippers or rome plows pulled by bulldozers is often effective in breaking up compaction, increasing water infiltration and increasing penetration of tree roots. Ripping down 24 to 48 inches greatly improves seedling establishment rates. A second pass, angled on a 60 degree bias rather than perpendicular to the first, seems to be most effective in breaking up compacted spoil. In 1995, ripping costs ranged from \$ 1 00 to \$200 per acre, to a depth of 24 to 36 inches on 20-foot centers. Tree planting costs can total \$200 to \$300 per acre. Ripping increased first season bare-root survival rates from 30%-

40% to 60%-80% for an investment of $100-$200 per acre, resulting in a total treeplanting cost ranging from $300-$500 per acre. Ripping may be the critical factor in stand survival in a drought year. Ripping increases surface roughness which promotes water retention in microhollows. Ripping slows near surface wind velocities, reduces erosion and slows evapotranspiration (Ashby and Vogel, 1993). Torbert and Burger (1 996) found that minimal grading and surface roughness such as that left by ripping greatly improved tree growth and minimized erosion by increasing infiltration. Ripping also removes competing vegetation from the planting rows. Anecdotal evidence suggests that ripping may increase rodent predation of seedlings by providing habitat and easier access to roots (Ashby, 1992). While this may be locally devastating, heavy rodent predation may only be cyclical, tied to vole and other rodent population cycles. These factors tend to promote tree establishment. Additional plantings required to replace dead stock may almost double the cost of tree planting to $400 to $600 per acre. Does it not make sense to spend a few more dollars up front to ensure higher establishment rates and minimize replacement costs by ripping and scalping?

Weather can be the most crucial factor in tree-planting success. As mentioned earlier, water is usually the most limiting factor in treeseedling establishment. All the best soil preparation, high-quality planting stock and proper planting methods can go for naught if it does not rain. Munshower (I 994) suggests planting trees and shrubs just prior to the period of maximum precipitation. Even so, droughts like that of 1980 and 1988, or even a pronounced spring drought during the first season, can destroy a tree planting. Like a farmer, the reclamation specialist must be an optimist, believing that the weather will be favorable and that the best laid plans and the expense will not be in vain. However, when the weather is not favorable, the reclamation specialist must accept failure, adapt to new conditions and revise plans, but never give up. In the arid West, optimal establishment years are few, and the native plant community ecology studies provide evidence that most seedlings are established in those optimal years (Munshower, 1996). Although, optimal establishment years are more frequent in the humid East and Midwest (Daubenmire, 1959), failures do occur and can play a major role in reclamation success.

Methods/Container-Grown Case Study

Qualitative observation of establishment success of container-grown seedlings since 1990 suggests a first-season survival rate of 90% for air-pruned bur oak and pecan grown in half-gallon bottomless containers. This compares to 35% survival of 2-year-old bare-root stock grown at either a local commercial nursery or the state forest nursery. These were side-by-side plot trials of seedlings planted in prepared rows of prairie soils in Conservation Reserve Program (CRP) crop fields in western Missouri. Additional test plots were established in neutral graded mine spoils and in a grassy, old field. Rows were set along the contour at 15-foot centers, disced and planted by hand. Container-grown seedlings were planted in the fall, and bare-root seedlings were planted in the spring. Success rates were slightly higher in very fine sandy loam soils mapped as Bates loam (2 to 5% slopes, fine-loamy, siliceous, thermic Typic Argiudolls), compared to silty clay soils mapped as Kenoma (2 to 5% slopes, fine, montmorillinitic, then-nic Vertic Argiudolls) (USDA, 1995). Competition became intense in mid-summer as late-season weeds such as common and giant ragweed, giant foxtail, cocklebur and beggar ticks germinated from the old-field seedbank. The rows were mowed in July to prevent shading of the seedlings.

A second test plot was established on rough-graded, neutral mine spoils, (silty clay texture with 15% shale charmers, 5 % sandstone pebbles and few sandstone cobbles) in western Missouri. Establishment success in the first season was approximately 75% for containergrown bur oak and pecan compared to 30% for bare-root seedlings. Compaction was minimal since all grading was performed by a D-3 dozer knocking the tops off the spoil ridges, pushing the fill into the valleys between ridges. Wind disseminated species, particularly broomsedge, slowly colonized the plots, competing with the seedlings. Adjacent mine lands were heavily vegetated, enabling deer to browse the plot undisturbed. Japanese honeysuckle invaded the mine spoil plots from outside by rapidly spreading vines.

A third test plot was established in central Missouri on loess-derived forest soils that had been cleared in the 19th century, then farmed and planted to tall fescue in recent decades. In places, much of the A horizon had been eroded and mixed by plowing into the E horizon. The soils were classified by the author as eroded Winfield silt loam (fine-silty mixed, mesic, Typic Haptudalfs) (USDA, 1994). Fescue sod was removed with a heavy hoe around each seedling to reduce competition at the time of establishment. Spraying could be as effective, but must be done while the seedlings are dormant. First-year survival rates for container-grown bur and northern red oak were 90% compared to 35% for bare-root. Mortality was high during the first winter due to a large population of voles (*Microtus* spp.). The author suspects the rodent predation is due to the greater nutritional content of container-grown seedlings compared to natural seedlings in the grass pasture. Cattle were removed from the pasture prior to planting, and the vole population exploded afterward.

Moisture was excessive at all sites during the period of fall 1992 to summer 1995. There was a pronounced water deficit in the summer of 1990 and in 1995, resulting in correspondingly lower establishment rates. Prolonged soil saturation resulted in anaerobic conditions in upland soils due to excessive rain throughout the summer of 1993. Many seedlings were observed to have suffered extensive root rot, killing the seedlings outright or indirectly by winter kill. Success rates were high in the well-drained Bates loam during the wet period.

Appendix I outlines successful oak seedling propagation techniques.

Conclusion

The container-grown seedling methodology outlined in the case study has proven successful in small-scale establishment of deep taprooted hardwoods that are extremely difficult or impossible to transplant. Species without prominent taproots such as birch, ash and maple receive no advantage from air-pruning as compared to traditional containers. All species of oaks, walnuts and hickories, including pecan, responded well to air-pruning via bottomless containers. Baldcypress, hackberry, tulip-poplar, Kentucky coffeetree, persimmon and basswood are effectively grown and outplanted using the air-pruned method (Lovelace, 1996). Many later-successional species planted to enrich the mine land ecosystem, are prevented or are limited in their natural ability to invade drastically disturbed lands due to the distance from the site to a seed source (Ashby et al, 1990). Out-planted container-grown seedlings are more readily established with an intact root system as compared to bare-root. Growth and development of the air-pruned root system are rapid, enabling the seedlings to more readily survive harsh competition for water and nutrients in the first growing system than bare-root seedlings. Fall planting accentuates this difference. Container-grown seedlings continue to send out roots until the soil approaches freezing temperatures, which in Missouri are from late December to February. Some of the lateral roots enlarge and grow downward, developing into a multi-stemmed taproot system. Container-grown seedlings have a much greater planting window than bare-root in the East and Midwest, since their roots are continually growing which reduces or eliminates transplanting shock (Tinus and Owston, 1984). Bare-root seedlings can only be planted while dormant in the spring, allowing little time to establish an effective root system that can compete against annual weeds and survive during summer drought.

Ashby (1980) found that natural succession processes on drastically disturbed lands mimic classic old-field succession. Often desirable oak and nut seed trees are not near mine lands in the Midwest, therefore cannot colonize mine lands. With the bottomless container method, hard-to-find oak and nut seedlings can be propagated from seed collected from local parent stock that are adapted to the unique growing conditions of the planting area. High-quality, container-grown, air-pruned, seedlings can be used to enhance the biological diversity and wildlife habitat of drastically disturbed lands. Planting long-lived oaks and hickories passes a legacy from one generation to another that outlasts many day-to-day labors.

Successful tree-seedling establishment largely depends on the seven variables listed in the introduction of this paper. Water remains the chief limiting factor in seedling establishment. Compaction is the chief culprit in limiting tree root development, in water infiltration and water-holding capacity of mine soils. Soil chemistry plays a major role in establishment success since many weathering byproducts of mine spoils are salts that absorb water and disperse clay particles, which further limits plant available water. Acid-forming materials directly affect root growth. Low pH solubilizes metals in soils, especially aluminum which is extremely toxic to plant roots. Low organic matter in mine soils results in low nutrient levels, particularly nitrogen and phosphorus, poor nutrient cycling and low soil microbial populations.

These conditions can be overcome by adequate analysis of soil conditions and soil preparation. Soil preparation includes liming, ripping, scalping, fertilizing or the use of green manure crops. Purchase good planting stock of locally adapted native species, especially if the mine soils are acidic. The stock must be correctly handled and planted. Once all this is done, establishment is largely up to nature. If weather conditions are favorable, the stand should be successfully established in the critical first season. However, the reclamation specialist must be patient and be able to withstand the pressure of supervisors, regulators, landowners and the general public, who may not understand that tree-planting success takes time. Finally, get out of the office and observe what works and adapt to local conditions.

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Oak Propagation Techniques

Fall/Winter

1. Collect acorns that have proper color and no weevil holes, cracks or other surface blemishes. Do not collect green seeds. Acorns with caps still affixed should be discarded. Larger acorns tend to produce larger seedlings. Whether this difference is a short-term or long-term effect is not clear. However, it is obvious that a larger transplanted seedling has greater survival rates. (Downs and McQuilkin, 1944, McComb, 1934 and Korstian, 1929).
2. Acorns should be floated in water. Those that float should be discarded since they tend to be dead or damaged. Acorns that sink should be collected and allowed to dry to the touch on newspapers in a cool, dark location. Most acoms desiccate quickly, resulting in a serious reduction in viability. Sound acoms typically have a germination rate of 75 to 90 percent. For successful germination, white oak *(Leucobalanus)* group acorns must have a moisture content above 30 to 50 percent, with a minimum of 20 to 30 percent for the red oak *(Erythobalanus)* group (USDA, 1948). Bur oak acoms should have their caps removed for the float test.
3. Collect dried acoms into one-gallon sealable plastic bags, preferably freezer-type bags.
4. Place acom-filled bags in a refrigerator set at 34 degrees F to overwinter. Periodically, check and remove acoms damaged by weevil larvae and mold.
5. Hickory nuts, pecans, walnuts and hazelnuts require moist stratification for proper germination. They should be stored in a moist mixture of half sand and half ground peat. Storage containers with air-tight lids should be used. Place storage containers in a cool, unheated location to overwinter. Floating cannot be used to remove dead or damaged nuts. Check periodically to maintain moisture level. Do not saturate the mixture because the nuts can rot.

Spring

1. In mid-March, check *Leucobalanus* (white oak group) acoms for the emergence of the radicle (first root) from the acom tip.
2. Plant acoms in Whitcomb bottomless containers (also called milk cartons) that are resting off the ground after the threat of a hard freeze (around 25 degrees F) is over. Flats with welded wire bottoms can be built to hold the containers. Acorns should be carefully planted once the radicle has emerged. The radicle should be planted with the growing tip pointed downward. Radicies planted upward cause the roots to spiral or bind. Planting can continue until the middle of June, although growth may be less than in earlier stock. *Erythobalanus* (red oak group) acoms germinate more slowly than *Leucobalanus.* Do not wait for radicle emergence to plant.
3. The potting mix that has yielded the best growth and development for the author is two parts topsoil (silt loam, very fine sandy loam or silty clay loam is preferred), two parts ground peat (commercial quality with no sticks or stems) and one part composted manure (available at nurseries and discount stores in 40-pound plastic bags). Soil compaction or dense, tight potting mix can delay radicle emergence or even damage the radicle itself. Therefore, it is imperative to have a loose potting

mixture. (Korstian, 1927, and Connell, 196 1). White (I 970) found that using soil alone in the potting mix greatly reduces seedling growth. Using topsoil from oak-hickory regions inoculates the seedling roots with mycorrhizal fungi. Although there is always a risk of introducing pathogens or pests from the topsoil, the benefits of mycoffhizal inoculation outweigh the risk (Dixon et al, 1984). The peat reduces total weight and improves the soil mix structure. Organic matter in the potting mix greatly improves seedling root development and improves waterholding capacity. This is particularly important for oak, hickory, pecan and walnut seedlings (Lovelace, 1996). Manure in the mix provides slow-release nutrients.

4. Cover the plastic container bottoms with one layer of newspaper to initially contain the soil mix. The bottomless nature of the containers allows the taproot to grow downward until it penetrates beyond the container. At this point, the exposed root meristem dies, hence the term "air-pruned." This prevents the root spiraling and girdling common in container-grown oaks and hickories. The air-pruned taproot stimulates the growth of lateral roots, which fill the container by the end of summer. Species with strong taproot tendencies reestablish this growth pattern once outplanted (Lovelace, 1992).
5. Periodically inspect stratified hickory, pecan and walnut seeds. Nuts that have opened or have emerging radicles should be planted immediately.
6. Protect planted containers left outdoors from squirrels. They will wipe out an entire planting within hours once they smell the nuts. Downs and McQuilkin (I 944) found rodents, particularly deer mice, *Peromyscus maniculatus,* to be more damaging to dropped acorns in the forest than squirrels or chipmunks. Whether that is true in the backyard remains to be seen.
7. Do not plant defective, weevily, discolored or excessively moldy acorns. By June 1, do not plant hickory nuts, pecans or walnuts that have not split open for radicle emergence. Throw these to the squirrels since it is unlikely they will germinate.
8. Planted containers should have a 1/8- to 1/4-inch-thick surface layer of shredded bark or coarse sawdust. This provides a protective mulch that reduces evaporative losses and inhibits puddling and compaction of the soil surface. The mulch layer can save the seedlings from desiccation on a windy August day. This also mimics the natural revegetation process by simulating forest floor litter. Korstian (1927), Barrett (193 I), McComb (1934) and Corvell (961) allemphasizethe importance of a protective organic layer for effective seed germination and seeding establishment. This remains true for outside grown, container-grown seedlings.

Summer

1. Keep the soil mix moist but not saturated during the entire growing season. Too much water causes the seeds and roots to rot. Once the secondary leaves emerge, transpiration becomes rapid and water in the plastic containers can be quickly depleted. Weeds should be pulled from the container soil.
2. In July and August, check the seedlings every day for moisture stress. Water as needed.
3. Insects usually are not a problem, but mold and mildew can cause leaf problems during a wet spring. Insect pests can be crushed by hand. Spraying should be done only as a last resort.
4. Transplant early, well-developed seedlings by late July into one-gallon, two gallon or five-gallon plastic pots for further flushes of growth. Only air-pruned seedlings should be transplanted into the plastic pots to prevent root spiraling and binding. Potted seedlings must be outplanted in the first fall season to prevent root spiraling and binding.
5. White oak, chinkapin oak and post oak seedlings tend to be small and slowly established in the first season. Initially, plant acoms in six-inch grow tubes and transplant to half-gallon milk carton containers by August. These seedlings will be too small to plant in the coming fall and should be stored overwinter for another growing season before planting.
6. Inspect all seedlings to ensure air-pruning has occurred. If not, prune the taproot with hand shears.
7. Seedlings grow best in full sun from the east in the morning, with light shade from midday to evening. Try to find a hedge row or large tree, and locate seedlings on its east side. Allow the canopy to shade the seedlings by midday. Deep shade is not desirable.

Fall

1. Outplant healthy, vigorous seedlings as soon as daytime temperatures begin to drop into the low 80s and the fall showers begin.
2. Scalp overly competitive grasses by hoeing or spraying around the planted seedling. Make a twoto three-foot-diameter clearing around each seedling. Plastic tree tubes can greatly increase survival and growth of transplants, but cost must be considered.
3. Discard seedlings that are too weak, spindly or short. It is too much work to plant container-grown stock that will not survive.

4. Store small, slowly established white, chinkapin and post oaks for the winter in a cool, dark, moist place such as a root cellar or earth-contact basement. They should have undergone a good freeze to slow or stop shoot biologic activity prior to storage. Roots continue to grow in winter until the soil temperature approaches freezing.
5. Seedlings can be planted successfully until early December if properly mulched and located in a protected location. Frost-heaving can be a concern for unmutched seedlings or plantings located in exposed areas susceptible to frost-heaving. Good fall establishment enables the seedling to send out deep roots in preparation for summer drought and competition for moisture and nutrients. The result is that container-grown seedlings give the planter five to six months to plant stock as compared to the one-month bare-root seedling planting window.
6. Store extra seedlings overwinter for a spring planting. These can be planted from mid-February to the end of April.
7. **Select the correct native species, and adapt to local conditions.**