FIRST-YEAR SURVIVAL OF NORTHERN RED OAK SEEDLINGS PLANTED ON FORMER SURFACE COAL MINES IN INDIANA[1]

Anthony S. Davis[2] and Douglass F. Jacobs[2]

Abstract. Surface mining of coal in Indiana is an important industry. Post-mining sites are often characterized by poor soil physical properties, low nutrient availability, and severe compaction 30 cm below the soil surface. These characteristics can result in poor seedling survival, low productivity, erosion, and therefore low land value, which may ultimately lead to conversion of the land to other uses. For reclamation to forestland to be effective, seedling establishment success must be improved. Myriad studies have assessed the influence of stocktype, mycorrhizae, and fertilization on seedling survival and performance; however, few have studied their influence on northern red oak (*Quercus rubra* L.) planted on reclaimed mined lands. The objectives of this research are to compare the effectiveness of four stocktypes and assess the contribution of controlled-release fertilizer and mycorrhizal inoculation to survival and performance of northern red oak on reclaimed mined lands. Northern red oak is known to survive on a variety of sites and has a high commercial value and was therefore selected as the trial species. The four stocktypes consisted of June-sown and January-sown containerized seedlings, and standard-density (75 seedlings/m^2) and low-density (21 seedlings/m^2) one year old bareroot seedlings. Three treatments were applied to each stocktype: mycorrhizal inoculation (MI), addition of controlled-release fertilizer (CRF), and both MI and addition of CRF. A control, with neither MI nor addition of CRF, was established for each stocktype. Seedlings were planted in April 2003 at two sites and initial height and root-collar diameter were recorded. Survival was assessed in October 2003. Survival for low-density (68%) and standard-density (69%) bareroot seedling stocktypes, and June-sown containerized seedlings that did not receive CRF (64%) was greater than that of June-sown containerized seedlings that received CRF (35%) and January-sown containerized seedlings (30%). That CRF negatively influenced seedling survival in June-sown containerized seedlings indicates that the interactions between seedling development and CRF need further investigation.

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[2] Anthony S. Davis is a Graduate Research Assistant in the Hardwood Tree Improvement and Regeneration Center, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907-2033.

Douglass F. Jacobs is Assistant Professor in the Hardwood Tree Improvement and Regeneration Center, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907-2033.

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Introduction

Coal mining in Indiana is an important industry and has been practiced since the early 1800s (Indiana Coal Council 2003). The source of coal in Indiana, the Illinois coal basin, provides a surface area of known coal reserves totaling over 16,000 km^2. Surface coal mines in Indiana range in size from less than 40 ha to greater than 4,000 ha. Extraction of coal causes great changes to the physical, chemical, and biological characteristics of the site (Singh et al. 2002). To date approximately 40% of known coal reserves in Indiana have been extracted (OSM 1998), and the continued exploitation of those reserves will depend on the demand for coal. Without anthropogenic intervention, these sites would take decades longer to revegetate (Wali 1999). Therefore, immense efforts are made to reclaim these sites. In Indiana, orders from the state-operated seedling nurseries for mined land reclamation total approximately one million seedlings annually (Conrad 1999). Survival of these seedlings after out-planting is low (Andersen et al. 1989; Chaney et al. 1995). To restore these sites to forestland efficiently, seedling establishment success must be improved. As future use of coal is expected to increase (Economist 2002; Inc 2003), there is an imminent need to identify those processes that can improve the success of reclamation projects on mined lands.

After surface mining operations have been completed, reclamation of these sites is a legislative requirement (U.S. Congress 1977; OSM 1993; Smyth and Dearden 1998). The Surface Mining Control and Reclamation Act (SMCRA) of 1977 (Public law 87-95) was enacted to address concerns regarding environmental problems associated with coal mining (U.S. Congress 1977; EPA 2000). There are many benefits associated with this type of restoration, including improvements to hydrological processes where re-vegetation leads to decreased erosion and sediment flow and increased pH in runoff (Olyphant and Harper 1995), an increase in the area of forest cover, and provision of productive timber lands (Torbert et al. 1996). Thus, the Office of Surface Mining Reclamation and Enforcement (OSMRE) advocates the reclamation of abandoned mine lands (AMLs), with funds provided through SMCRA. Reforestation of mined lands has, in some instances, proven to be more productive than on un-mined counterparts (Torbert et al. 1996; Burger et al. 1998; Rodrigue et al. 2002).

According to SMCRA, the post-mining site must be graded to blend with the surrounding landscape. While efforts must be made to limit soil compaction, this process usually creates a hardpan layer that limits seedling survival (Torbert et al. 1996). Soil physical properties are vastly different when compared to un-mined sites and can limit plant establishment. For example, soils at mined sites have higher bulk density, coarse fragments, and clay content, and have lower porosity, permeability, and holding capacity than non-mined reference sites (Bussler et al. 1984). Topsoil is usually replaced to an average depth of 30 cm, below which a hardpan layer often creates a perched water table (Bussler et at. 1984; Andersen et al. 1989). Chemical properties of reclaimed mined land soils in Indiana are suitable for plant growth and should not limit successful vegetation establishment (Bussler et al. 1984), as has been the case in other regions (Bradshaw 1983; Howard et al. 1988; Roberts et al. 1988; Bendfeldt et al. 2001; Walker 2001).

The office of Surface Mining Control and Reclamation requires the survival of 1125 seedlings/ha after a 3-yr period to constitute forestland. Successful reclamation of mined lands is dependant on several factors. In many ways, success depends on the same factors as traditional afforestation, including effective site preparation, competition control, proper species selection, and continual, thoughtful management (Fix 1993). If forest management is defined as meeting a set of objectives through on-the-ground actions to maintain a forest that provides a set of values (Erdle and Sullivan 1998), then reclamation of mined lands must follow this same process (Gardner 2001). Providing a legacy for future generations, provision of wildlife habitat, conserving the environment, and timber production are important values to Indiana landowners (Ross-Davis et al. *in press*). Therefore, since many former mine lands are privately owned, forests established on mined lands must be designed with these values in mind. Seedling stocktype, inoculation with mycorrhizae, fertilization, and use of appropriate species can contribute to the successful establishment of plantations.

<u>Stocktype</u>

Mined lands due for reclamation in Indiana have typically been reforested using Indiana Department of Natural Resources (I-DNR) nursery-grown bareroot seedlings. While the majority of plantations established on former agricultural sites are established successfully (Jacobs et al. *in press*), attaining similar establishment success on former mined lands has been less successful (Andersen et al. 1989; Chaney et al. 1995). To effectively restore these sites to uses associated with forestland (e.g., timber production) seedling establishment must be improved, which may be done through use of seedlings stocktypes that can better tolerate the stresses associated with harsh conditions, such as those found on former mined lands. Seedlings grown in containers, a cost effective system used for conifer production throughout the western United States and Canada, may be better able to minimize these stresses by reducing transplant shock. Transplant shock is the reduced growth of seedlings caused by acclimatization to new environmental conditions (Rietveld 1989).

Loss of roots during lifting is a major cause of transplant shock (Struve and Joly 1992). Given that containerized seedlings maintain their entire root system when transplanted, transplant shock can be considerably reduced through use of containerized seedlings (Miller 1999; BCMOF 2001). Containerized seedlings also maintain higher water potential during the first year following out-planting compared to bareroot seedlings (Dixon et al. 1983; Crunkilton et al. 1992), which can further reduce shock to the seedling caused by site acclimatization. Reduction of transplant shock can lead to increased survival and growth rate, as Vyse (1981) estimated that transplant shock could equate to the loss of 1 or 2 years of growth. Containerized seedlings often yield more uniform growth than do bareroot seedlings upon out-planting (van Eerden 1999; Wilson and Vitols 1999), along with a more fibrous root system (WRP 1993). Given the multitude of container shapes and sizes available, it is possible to produce a specific size and shape of seedling roots for a specific purpose such as mined land reclamation (e.g., shallow containers for shallow soils) (Bainbridge 1994).

As bareroot seedlings perform well on many high quality sites, the benefits of using container grown seedlings for reforesting harsh sites may be greater than on high quality sites (Pope 1993). Fall planted containerized northern red oak seedlings performed significantly better than bareroot seedlings on drier sites (Wilson and Vitols 1999). Containerized seedlings are also recommended as being able to outperform bareroot seedlings on sites with shallow soils (BCMOF 1999; Kiiskila 1998). In California, container stock was used to successfully revegetate mined lands where other attempts had failed (Rodgers 1994). The advantages of using containerized stock on poorer or drier sites may be caused by the physical protection of the roots, and provision of nutrients and water provided by the plug (McKay 1996). More studies are needed to clearly identify the trends associated with using containerized seedlings as studies have found both noticeable (McKay 1996; Miller 1999) and negligible (Kost and Houston 1994;

McKay 1996) increases in survival of northern red oak with containerized seedlings compared to bareroot seedlings.

Mycorrhizal inoculation

In natural conditions, tree roots form a symbiotic relationship with an assemblage of soil-inhabiting fungi called mycorrhizae. These mycorrhizae act as an extension of the tree's root system, with very fine hyphal filaments ramifying throughout the soil. Northern red oak forms associations with several species of mycorrhizae, including *Pisolithus* spp., *Scleroderma* spp., and *Rhizopogon* spp. (Beckjord and McIntosh 1983). Mycorrhizae increase water and nutrient uptake, tolerance of low pH and toxic levels of metals, and improve resistance to pathogens, all of which often lead to higher growth rates in trees (Marx 1977; Dixon et al. 1980; Sharpe and Marx 1986; Burgess et al. 1994; Egerton-Warbuton and Griffen 1995; Khasa et al. 2001). These growth rates may persist for extended periods, as seven years after out-planting inoculated English oak (*Quercus robur* L.) had significantly greater growth compared to controls (Garbaye and Churin 1997).

Inoculation of plants with mycorrhizae on former mined lands has been successful at improving yields (Miao and Marrs 2000) and increasing survivorship (Cordell 1996; Cordell et al. 2000). Loblolly pine (*Pinus taeda* L.) planted on reclaimed surface mine sites demonstrated increased nutrient uptake and absorption of water after inoculation with *Pisolithus tinctorius* (Walker et al. 1989). However, not all studies have reported improvements based on mycorrhizal inoculation. Northern red oak was successfully colonized by *Pisolithus tinctorius* in mined land reclamation but there was no effect on seedling survival (Kost and Houston 1994), and in old-field plantings inoculation of oak with mycorrhizae has not led to increased growth or survival over un-inoculated seedlings (Pope 1993; Gilman 2001). This may be due to unsuccessful or insufficient colonization of the root system.

Given the dry nature of many mined sites, and that severe drought has a negative effect on northern red oak (Demchik and Sharpe 2000), there may be an added symbiosis of using mycorrhizae on these sites as the effects of inoculation increased with a dry summer in English oak seedlings (Garbaye and Churin 1997). Black oak (*Quercus velutina*) seedlings inoculated with *Pisolithus tinctorius* had greater water potential values than un-inoculated seedlings (Dixon et al. 1983), and *Pisolithus tinctorius* inoculated white oak (*Quercus alba* L.) seedlings exhibited increased drought resistance (Dixon et al. 1980). In some cases, inoculation of sweetgum (*Liquidambar styraciflua* L.) seedlings with mycorrhizae has mitigated the effects of soil compaction (Simmons and Pope 1987, 1988), which can be a limiting factor for seedling establishment on reclaimed mined lands.

A key to successful attainment of the benefits of inoculation with mycorrhizae is persistence of mycorrhizae over time. Persistence is greater when there is limited competition from naturally occurring mycorrhizae (Di Battista et al. 2002), as is the case in the soils of mined lands. However, low pH and high Al concentrations greatly reduced mycorrhizal colonization of balsam fir (*Abies balsamea* (L.) Mill.) seedlings (Entry et al. 1987), and ectomycorrhizal colonization of northern red oak was lowest on sites with no canopy cover (Zhou and Sharik 1997), both of which could lead to problems in mine reclamation scenarios.

<u>Controlled-release fertilizer</u>

Incorporating controlled-release fertilizer (CRF) into the media of containerized seedlings offers a new technology that may improve reforestation success (Haase and Rose 1997). Addition of CRF can improve growth of seedlings in the field, especially in situations where there are limited nutrients available. Nutrient losses of CRF may be lower than those of traditional soluble fertilizers, resulting in greater availability of nutrients to plants (Dou and Alva 1998, Walker 2001). Most research into the use of fertilizers to stimulate tree growth has focused on conifer production, and results have shown increased height and diameter growth using CRF (Krasowski et al. 1999, Hinesley et al. 2001, Khasa et al. 2001, Fan and et al. 2002, Moore et al. 2002). After 18 years, fertilized hardwood seedlings planted on bottomlands in Tennessee were significantly larger than unfertilized controls (Devine et al. 2000). CRF incorporated into the medium of containerized seedlings offers the advantage of increasing the effectiveness with which nutrients are made available to the seedling (Reddell et al. 1999). However, consideration must be given to the application rate, as excessive addition of CRF can lead to seedling mortality (Fan et al. 2002).

Use of fertilization holds great potential for improving seedling performance on former mined lands. Native deciduous species had greater growth rates with application of fertilizer on mine spoils (Singh and Singh 2001). For green ash (*Fraxinus pennsylvanica* Marsh.) and silver maple (*Acer saccharinum* L.), survival was greater with addition of nitrogen and phosphorus fertilizers to mined sites in Ohio (Kost et al. 1994). With conifer seedlings used for reforestation of former mined lands, fertilization increased survival (Torbert et al. 2000) and height and diameter growth (Torbert et al. 2000; Walker 2001, 2002a, b). Addition of CRF to Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.) seedlings on a former sulfur mine in Nevada significantly increased foliar nutrient levels (Walker 2001, 2002a). Since young oak seedlings are largely dependent on their internal nutrient reserves, addition of CRF will likely benefit seedling growth.

Interactions between mycorrhizal inoculation and the addition of CRF are expected. Nutrient availability influenced growth of Pt inoculated northern red oak seedlings (Ruehle 1980). An interaction between N fertilization, drought, and mycorrhizal colonization of Norway spruce (*Picea abies* L. (Karst)) was identified by Nilsen et al. (1998). Hunt (1989) found that addition of CRF influenced the percent colonization and species of mycorrhizae on Engelmann spruce (*Picea engelmannii* Parry ex. Engelm).

The objectives of this study were to (1) compare the effectiveness of four different stocktypes and (2) assess the contribution of controlled-release fertilizer (CRF) and mycorrhizal inoculation (MI) to survival and performance of northern red oak on reclaimed mined lands.

Materials and Methods

Study sites

Two study sites were selected for outplanting in Clay County (latitude 39.5 N × longitude 87.1 W), Indiana. The first site, AML132, was mined in the 1930s and did not regenerate naturally. The original spoil was graded to the natural contour in 1984. Efforts have been made by the Division of Reclamation to limit erosion, but there is little development of vegetation on the site. Soil pH (~ 4.10) is lower than surrounding forests and pH in runoff from this site is quite low (3.05). Segments of exposed shale throughout the site may limit the successful establishment of seedlings on some areas of the site. The second site, HM001, was mined in 1989, and is a typical post Surface Mining Control and Reclamation Act (SMCRA) site. As is dictated by the act, the site has been graded to the original contour of the land and had topsoil replaced to an approximate depth of 45 cm. Portions of this site are heavily compacted. The site was first planted in 2000, after having a deep ripping the previous fall. Deep ripping is a common practice used to break up hardpan layers to facilitate root penetration and movement of water (Bateman and Chanasyk 2001). The measured depth to the hardpan at both sites was approximately 30 cm. There were no distinct soil horizons, which is common for reclaimed mined lands (see Bussler et al. 1984).

Stocktypes

Four northern red oak (*Quercus rubra* L.) stocktypes were used: (1) standard-density bareroot seedlings (grown at a nursery density of 75 seedlings/m2), (2) low-density bareroot seedlings (grown at a nursery density of 21 seedlings/m2), (3) containerized summer-grown seedlings (June-sown 2002), and (4) containerized early-season seedlings (January-sown 2003). Within each stocktype, each of three treatments were applied: (1) MI, (2) addition of CRF, or (3) a combination of MI and addition of CRF. A control was also established within each stocktype, where neither MI nor addition of CRF fertilizer were employed.

Both standard-density and low-density bareroot seedlings were grown at the Indiana Department of Natural Resources Division of Forestry Vallonia nursery (Vallonia, IN). A bulk seedlot, consisting of a mixture of northern red oak families, was used. Seedlings were sown in March of 2002, and were lifted in March 2003, and placed into cold storage (2°C). Seedlings were removed from cold-storage prior to out-planting.

Containerized seedlings were produced at the Purdue University Department of Horticulture greenhouse facilities, also from bulk seedlots. The containers measured 7.25 cm in top-width (square), 6.5 cm in bottom-width (square), and 14.25 cm in depth, for a volume of 650 cm^3 and were filled with Scott’s Metro Mix® 510, consisting of 20 – 25 % pine bark, 15 – 30 % medium grade vermiculite, 20 – 35% sphagnum peat moss, and 5 – 25 % bark ash. Two different treatments of containerized seedlings were used, with one sown in June 2002 and the other in January 2003. The June-sown seedlings were germinated in 50 cm × 70 cm flats (as per Davis et al. *in prep.*), grown for 6 weeks, transplanted into containers, and grown in the greenhouse until November. Seedlings were then hardened-off from November to January, at which time they were placed into cold storage. Supplementary lighting was used from 5 September 2002 until the seedlings were hardened-off. The January-sown seedlings were germinated in flats (50 cm × 70 cm), grown for 6 weeks under supplemental lighting, transplanted into containers (650 cm^3), grown in the greenhouse until April, and were then transplanted directly into the field without a dormant period. All seedlings received irrigation as needed in the nursery, which included periodic fertilization with 30-30-30 (N-P-K) at 200 ppm in the irrigation water.

Mycorrhizal Inoculation

Ectomycorrhizal fungi, obtained from Mycorrhizal Applications Inc. (Grand Pass, OR), used for this study consisted of *Pisolithus tinctorius*, a *Rhizopogon* species, and four species of the genus *Scleroderma*. As a means of ensuring that both bareroot and container stocktypes had equal likelihood of being colonized, both bareroot and containerized stock were inoculated with mycorrhizae immediately following planting. A 5 mL solution containing approximately 2500 spores was applied sub-basally to each seedling using a syringe, with the tip of the syringe approximately 0.5 cm below the soil surface and 1 cm from the base of the stem, angled towards the seedling at approximately 45°. Re-inoculation, using the same method, occurred in August 2003, with the aim of increasing colonization rates and likelihood of successful inoculation prior to late-season seedling root development (Lyr and Hoffman 1967).

Controlled-release fertilizer

Osmocote® Exact® Lo-Start 15-8-10 plus micros, a CRF with a 16 to 18 month release rate (at a media temperature of 21°C) was selected for use. Containerized seedlings received 9 g/seedling incorporated into the growing media of 50% of the seedlings during nursery cultivation. The same rate of fertilizer (9 g/ planting hole) was placed at the bottom of the planting hole for 50% of the bareroot stock immediately before planting the seedling.

Plantation establishment

Seedlings were planted using a tractor-hauled coulter with trencher and packing wheels, and a crew of three people, as is typical for bareroot plantings across Indiana (Jacobs et al. *in press*). Both sites were planted 17 April 2003. At HM001, 4 blocks were established and 3 blocks were established at AML 132. Each block contained one 10-tree row per treatment. With a combination of 16 different treatments including controls, a total of 70 trees per treatment were planted. Within-row (between seedling) spacing was approximately 1.5 m, while spacing between rows was approximately 2.4 m. In total, 1120 seedlings were planted. Immediately following planting, seedling height and diameter were measured.

Given the high deer population levels in Indiana, 4.45 cm × 4.45 cm grid mesh fencing (2.29 m high) was erected surrounding both plantations as a means of excluding deer from the study sites to protect the seedlings from browse. While fencing is not a common browse protection method in Indiana due to the prohibitive cost, eliminating deer browse was necessary to limit external variation such that true treatment effects could be assessed.

At planting, herbicide was applied in 1 m bands centered along the planting rows. A combination of a pre-emergent (Oust™, active ingredient: Sulfometuron) and a post-emergent (GlyproPlus ™, active ingredient: Glyphosate), was applied at a rate of approximately 53.16 g/ha and 1.5 % solution, respectively. Subsequent vegetation control consisted of a mid-summer (1 July 2003) herbicide application of 1.5% solution GlyproPlus™. Effective vegetation control leads to reduced damage by rabbits and rodents, as with lower cover they are more visible to predators. Furthermore, high light intensity increases the likelihood of successful mycorrhizal colonization (Garrett et al 1979.)

Measurements

First-year seedling survival was assessed 19 October 2003. Seedling survival percentage was calculated by dividing the number of surviving seedlings by the number of planted seedlings and multiplying by 100.

Soil samples were collected from each site and analyzed for differences in chemical and physical properties. Bulk density was determined by removing eight 250 mL soil cores from each site, and drying them in an oven at 72°C for 48 hrs. Dried samples were then weighed and divided by the initial volume (250 mL) to determine bulk density. Chemical properties, including % organic matter (OM), and PPM for phosphorus, potassium, magnesium, and calcium, as well as soil pH and cation exchange capacity (CEC) were analyzed at A & L Great Lakes (Ft. Wayne, IN), a professional soil analysis laboratory.

Weather data (Fig. 1) was obtained from the Purdue Applied Meteorology Group (2003).

Statistical analyses

Data were analyzed using analysis of variance (ANOVA) for a randomized complete block design (4 × 2 × 2, stocktype × MI × CRF) to identify differences between treatments for seedling survival percentage. ANOVA was also used to identify differences in soil physical and chemical properties between the sites. Significant differences ($\alpha = 0.05$) were identified with using Tukey's mean separation test. The experiment was established as a randomized complete block design, with three replications at one site and four at the other. The experimental unit was each row of 10 seedlings, and the observational unit was each individual seedling. SAS® software (Cary, NC) was used for all data analyses.

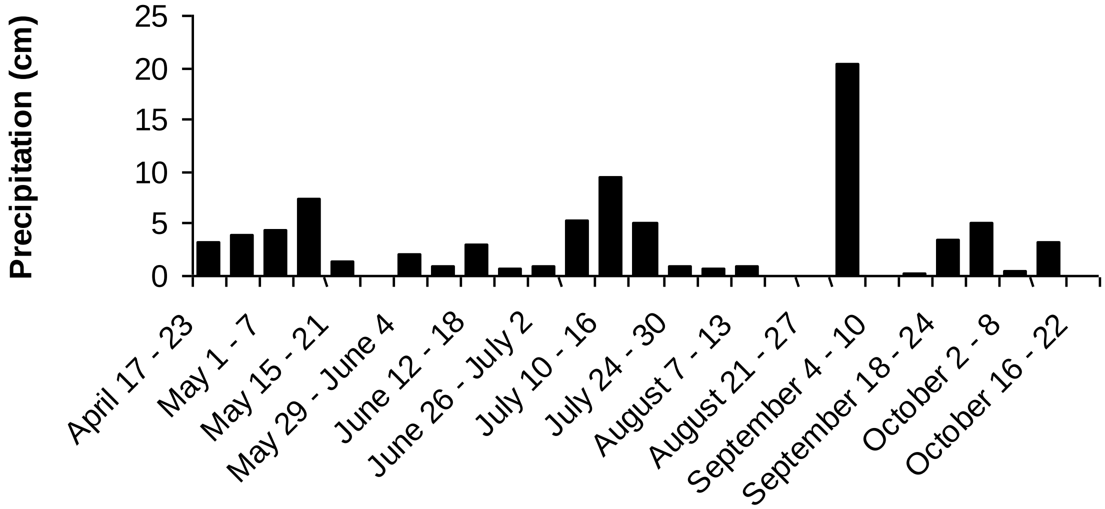

Figure 1. Estimated weekly precipitation.

Results

Soil properties

Site was not a significant factor in terms of seedling survival ($p = 0.6538$). Therefore, data from both sites were pooled for analyses.

Seedling Survival

Seedling survival differed significantly by stocktype ($p < 0.0001$). As well, there was a significant stocktype × CRF interaction ($p = 0.0215$), where addition of CRF to the media of June-sown containers negatively affected seedling survival (Fig. 2). Neither MI ($p = 0.789$) nor addition of CRF ($p = 0.3404$) were significant as main effects.

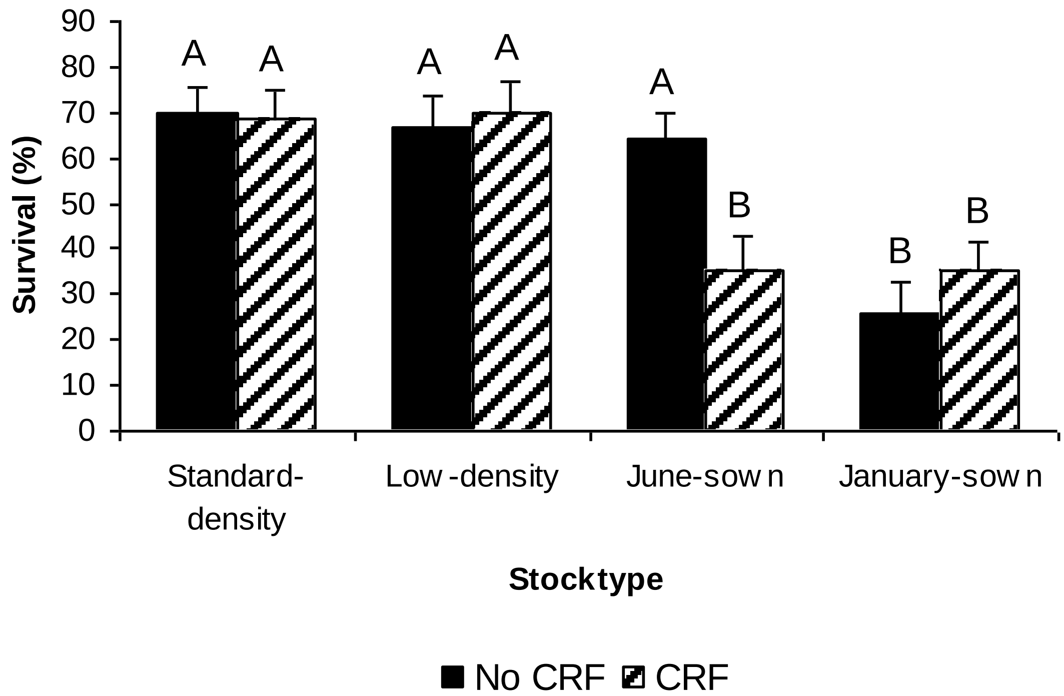

Figure 2. Seedling survival as influenced by stocktype × CRF. Data points are means, error bars are SE. Treatments with the same letter did not differ significantly at $\alpha = .05$.

Discussion

Seedling Survival

Seedling survival may have been negatively influenced by weather. The 2003 growing season yielded approximately 36% more rainfall than normal (Purdue Applied Meteorology Group 2003). Unfavorable environmental conditions in the form of periodic heavy rainfall intermixed with extended dry conditions may have resulted in lower seedling survival, particularly for smaller seedlings.

The influence of stocktype on seedling survival is counter to that which was hypothesized. This indicates that the container stocktypes selected for this study were not well suited to the site conditions in which they were planted; had more robust containerized seedlings been produced, the seedling survival may have been higher. In the case of the January-sown stocktype, the lack of a dormant period may have negatively influenced seedling survival. For plantation establishment success to be maximized, a target seedling for a specific site, species, and anticipated silvicultural regime should be developed (Landis 2002, Bainbridge 1994, Hobbs 1984, Tinus 1978). The initial differences in seedling size (data not shown) may have influenced seedling survival, as seedling size and quality can affect northern red oak establishment (Struve et al. 2000, Ward et al. 2000). The survival of both bareroot stocktypes was close to the average of those planted on former agricultural lands in Indiana (Jacobs et al. *in press*), but lower than the > 80 % of the same stocktypes planted in gap openings in southern Indiana (Jacobs and Davis *unpublished data*). While this may imply that seedling survival is acceptable compared to agricultural lands, past studies of former mine lands suggest that survival decreases beyond the first year (Chaney et al. 1995, Kost and Vimmerstedt 1994, Anderson et al.1989), while on former agricultural lands in Indiana it does not (Jacobs et al. *in press*). Anderson et al. (1989) found that container-grown northern red oak had higher survival than bareroot seedlings during the first four years of establishment. However, 12-year survival of those seedlings did not differ between containerized seedlings and bareroot stocktypes (Chaney et al. 1995).

While it is known that MI may improve seedling survival (Anderson et al. 1983, Marx 1977), Pope (1993) reported that inoculation did not improve northern red oak seedling survival, which corresponds to the first-year survival results in this study. In an examination of shortleaf pine (*Pinus echinata* Mill.), containerized seedlings had higher survival and growth than bareroot seedlings on a good site, but the reverse was found on a poor site (Rhuele et al. 1981). In that case, inoculation with mycorrhizae increased survival of bareroot seedlings but not containerized seedlings. That difference was attributed to differences in root architecture between stocktypes limiting the successful colonization of containerized seedlings.

In the present study, it is possible that either inoculation was ineffective or conditions were not those that would allow for the seedling to benefit from inoculation, either the result of inherently poor soil conditions or unfavorable weather conditions. It is also possible that colonization of the seedling may have been detrimental to establishment, as the initial stage of mycorrhizal development is saprophytic, drawing on the seedlings' nutrient reserves to establish. In this instance, the seedlings with the lowest internal nutrient reserves would likely be damaged most. While the lack of significant influence of inoculation on survival indicates that any damage that occurred did so across all stocktypes and treatments, mycorrhizal colonization was not assessed after the first growing season, limiting our ability to draw conclusions on this matter.

While the addition of CRF did not affect seedling survival, implying that nutrient demands for survival were met internally or through uptake from the soil, there was a significant stocktype × CRF interaction, which identified that CRF negatively influenced survival of June-sown containerized seedlings. This could be due to restricted seedling root proliferation, a problem associated with seedling fertilization (Jacobs et al. 2003). It is expected that future survival will benefit from both continued release of nutrients from the CRF and from potential higher internal nutrient reserves of those seedlings that received fertilizer. However, in the case of loblolly pine (*Pinus taeda* L.) planted on a reclaimed surface coal mine in Tennessee, survival was significantly lower in seedlings that received fertilizer (Walker et al. 1989). The lower survival was attributed to increased growth of competing vegetation.

Conclusion

The results of this study indicate that different stocktypes may influence the establishment of northern red oak seedlings on reclaimed mined lands. Bareroot seedling stocktypes yielded higher survival than containerized seedlings, except in the case of June-sown containerized seedlings that did not receive controlled-release fertilizer. Future studies to increase our understanding of the interactions between CRF, soil chemistry, and seedling development are necessary.

Inoculation with mycorrhizae and CRF did not benefit first-year seedling survival, and in the case of June-sown containerized seedlings, CRF had a negative impact on seedling survival. However, increased nutrient availability to the seedlings which received CRF may benefit second-year growth, as the seedling would be acclimated to the site conditions, allowing greater allocation of resources to above-ground growth. Successful mycorrhizal colonization should increase the availability of water and nutrients to seedlings, further enhancing establishment success.

A single container configuration was able to provide equal survival to traditional bareroot seedlings. Development of container configurations suited to specific site conditions, cost constraints, and future silvicultural practices could improve seedlings survival. Given the expected decrease in survival beyond the first year following planting, plantation establishment may yet benefit from MI and the addition of CRF, and from using containerized seedlings.

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