FACTORS AFFECTING PERFORMANCE OF ARTIFICIALLY REGENERATED AMERICAN CHESTNUT ON RECLAIMED MINE SITES[1]

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Abstract: The use of SMCRA approved practices for mined land reclamation has resulted in arrested succession throughout many areas of central Appalachia. The combination of heavily compacted soils and the addition of aggressive, often non-native, grasses and forbs creates an environment characterized by high soil bulk density and aggressive ground-layer competition. This results in a situation where trees are unable to recruit and thus many lands are unable to return to original forest cover through natural processes of succession. Using the basic principles of the Forestry Reclamation Approach (FRA), we report on two experiments conducted in Ohio: one designed to remediate a 30-yr arrested succession and the other designed to encourage immediate reforestation at the time of reclamation. We conducted these experiments using American chestnut (*Castanea dentata*) to explore the potential for using these sites as part of the national restoration plan under development by the American Chestnut Foundation (ACF). The first experiment utilized deep soil ripping and a combination of plowing and disking treatments. After three years, the results are clear. Simply planting chestnut into untreated existing habitat is ineffective. Some type of surface treatment to reduce soil bulk density and competition is necessary for seedling establishment. The more significant the disturbance, the better the survival and growth of chestnut. The second experiment utilized loose end-dumping at the time of reclamation. Various methods of chestnut deployment and planting were evaluated including direct seeding and bare-root seedlings. Plantings were done with and without protection from predators in different microsites. While survival of seedlings was greater than seeds, the most noticeable enhancement to survival was the addition of a tree shelter, which nearly doubled the survival rate. In summary, American chestnut appears to thrive on mine land reclamation sites—this may prove to be a useful focal point for restoration of the species while aiding in the reforestation of old and new reclamation sites.

Additional Keywords: ARRI, *Castanea dentata*, Ohio, succession

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Introduction

For the past three decades, the standard for mine land reclamation in the United States has been dictated largely by the policies and regulations set forth by the Surface Mining Control and Reclamation Act (SMCRA, 1977). However, after years of observing reclaimed lands employing these principles, several problems have become evident. First and foremost is the problem of *arrested succession*. Succession is a basic theoretical principle of plant community ecology that reflects the natural change in plant species composition over time. These changes are often heavily influenced by the nature of the initial disturbance (anthropogenic or natural) that resets the successional process. SMCRA calls for a number of landscape modifications that ultimately interfere with these natural processes by increasing soil compaction, changing hydrology, and introducing aggressive non-native plant species (e.g., *Lespedeza* spp., *Festuca* spp.) (Casselman et al. 2006).

Throughout the central Appalachians, most areas that have been surface mined originated as forested habitat. This is the natural condition of most of the Appalachian region. Following disturbances (e.g., tornado, fire, mining, etc.) habitats of such areas go through a fairly predictable set of habitat changes. Early plant communities are usually dominated by herbaceous species, with woody species dispersing in and coming to dominate over time (usually < 10-15 years). The goal of reclamation is usually to return land back to its natural condition. However, mined lands reclaimed using the practices set forth by SMCRA has often failed to produce a young forest, even after 20-30 years. Many of these habitats remain arrested at the early successional stage with species that are primarily herbaceous (grasses and forbs) and often non-native to the habitat (species are introduced as part of the reclamation process) (Groninger et al. 2007).

Forests provide a wealth of ecological (carbon storage, hydrologic control, nutrient cycling, biodiversity, etc.) and utilitarian (timber, wildlife, etc.) functions that are not achievable with alternative vegetation types. Thus, the goal of most reclamation projects would be return to forest habitat, if that was the original pre-mining condition. The goal of forest restoration has been the main focus of the FRA proposed by the Appalachian Regional Forest Initiative (ARRI; Angel et al. 2005). To date, six FRA publications have been produced that outline the details of the approach (http://arri.osmre.gov/Publications.shtm).

The goal of this research was to evaluate how restoration of the American chestnut (*Castanea dentata*) could be facilitated by incorporating it into the mined land reclamation using the FRA (McCarthy et al. 2008). American chestnut was once a dominant species throughout the hardwood forest of the eastern United States. Due to a fungal pathogen (*Cryphonectria parasitica*) introduced in the early 1900s, the species has been brought to near extinction in the canopy. Sprouts remain in the understory but become re-infected as they mature, die back, and re-sprout again. Long-term efforts by the American Chestnut Foundation (www.acf.org) have resulted in a potentially blight resistant form of the American chestnut (Jacobs 2007). Plans are underway for disseminating this species and initiating a large-scale reintroduction and restoration of the species. Reclaimed mine lands provide an interesting option for deployment of this species in as much as chestnut is tolerant of the harsh micro-environmental conditions often present on recovering mine lands (e.g., full sun, low pH soils, nutrient poor topsoils, etc.) (Jacobs 2007).

Here we report the response of American chestnut using two different experiments. The objective of the first experiment was to evaluate how to accelerate succession and chestnut establishment on land that was previously mined, reclaimed, and presently in arrested succession (after ca. 30 years). The objective of the second experiment was to evaluate how chestnut would respond and establish on freshly reclaimed areas using a loose end-dump approach advocated by ARRI and to assess different planting techniques (i.e., direct seeding vs. seedlings, herbivore protection vs. none).

Methods

Experiment-1

The site for this experiment was the Tri-Valley Wildlife Management Area (TVWMA), located (largely) in Muskingum County, Ohio and managed by the Ohio Department of Natural Resources (ODNR) identified as the. This 6500 ha area was previously surface mined and reclaimed following the prescriptions of SMCRA in ca. 1980. Thirty years later, natural succession has failed to take place with any resemblance of a typical trajectory (Fig. 1). The habitat remains largely dominated by the original *Festuca* spp. and *Lespedeza* spp. planted as part of the previous reclamation process. Additional herbs have recruited onto the site, as well as some shrubs and occasional trees (especially non-native invasive species like tree-of-heaven; *Ailanthus altissima*).

Figure 1. Tri-Valley Wildlife Management Area (Ohio) in winter condition (2007). Note dominance of herbaceous species on reclaimed areas in foreground and natural hardwood forest (undisturbed) in background. Reclamation was completed in 1980 using SMCRA guidelines.

Within the area shown, three experimental (statistical replicate) blocks were established for study. Within each block (73 × 36 m), four contiguous treatment plots (18 × 36 m) were established. The treatments applied (randomly) to the plots included: (1) cross-ripping at 1.5 m intervals to a depth of 1.0 m using a D-6 sized dozer (Fig. 2), (2) surface plowing and disking to a depth of 0.3 m (Fig. 3), (3) cross-ripping followed by plowing and disking the surface, and (4) an untreated control. Thus, the statistical design of this experiment was a randomized complete block suitable for analysis using ANOVA, with block as random effect and treatment as a fixed effect.

Figure 2. D-6 sized dozer installing ripping treatments.

Figure 3. Tractor installing plow and disk treatments using typical agricultural attachments.

Twelve hundred (1200) bare-root American chestnut seedlings (1-0 stock), obtained from the American Chestnut Foundation (ACF) in Meadowview, VA, were planted into the treatment plots (12 plots, 100 seedlings each). Seedlings were planted at a 2.0 m spacing interval to correspond with the interstices of the cross-rip treatment. Holes for seedlings were excavated with a hand shovel, bare root seedlings were dipped into Terra-Sorb ™ gel for protection from desiccation, two 10 g fertilizer tablets (30-30-30; Scotts ™ Agriform) were added and the hole was back-filled with soil. A 1 × 1 m square fabric weed mat was installed around each seedling (to control competition from weeds) and a shovel of river gravel added around the base of the seedling to deter voles which damage seedlings by bark-stripping. A 1.0 m high poultry wire net tube (30 cm diameter) was affixed around each seedlings and held up with three 1.5 m wooden stakes (Fig. 4).

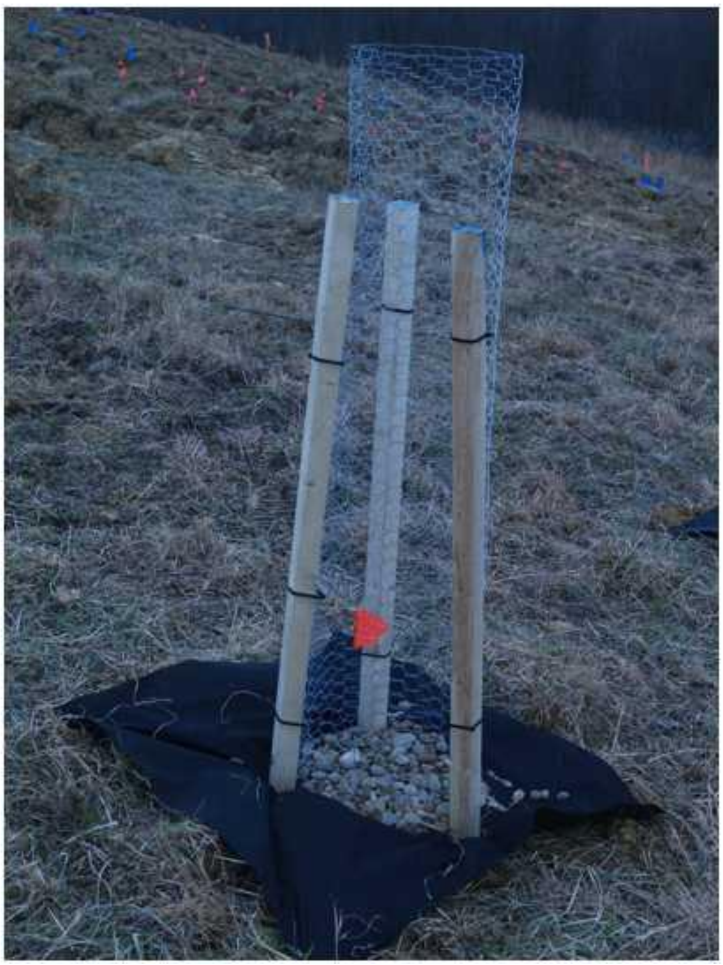

Figure. 4. One of 1200 seedlings planted in experiment. Note weed mat for control of weeds and poultry wire for protection from deer.

Survival data were recorded monthly the first growing season and at the end of both the second and third growing seasons (2007-09). Because chestnuts were planted as one-year-old seedlings, initial measurements were recorded at time of planting. After each growing season, plant height (cm) and basal diameter (mm) were recorded. Cox proportional hazard model was used to determine significant differences in survival among treatments. A two-way analysis of variance (ANOVA) followed by a Tukey's HSD post hoc test was used to detect differences in relative growth rates of the primary shoot growth (cm $month^{-1}$) among the seedlings and total height (cm) after three growing seasons. All statistics were performed using R v2.91 (R Development Core Team 2009).

Experiment-2

The site for this experiment was the Jockey Hollow Wildlife Management Area (JHWMA), located in Belmont and Harrison County, Ohio, managed by the Ohio Department of Natural Resources (ODNR). This 1400 ha area was previously surface mined and reclaimed by end-dumping stockpiled top soil and best quality overburden available in large piles on the surface in a checkerboard pattern (Burger et al. 2005). This site was being actively reclaimed at the time of this experiment and all plantings were done into fresh soil.

The objectives of this study were two-fold: (1) to evaluate the survival and performance of American chestnut seedlings using loose end-dumping and to (2) to evaluate the efficacy of direct seeding vs. planting bare root seedlings. To meet the first objective, 933 1-0 bare-root seedlings were planted over a several acre area of the JHWMA in early March 2007 Fig. 5. To protect seedlings from herbivory, a 1.2 m tall (10 cm diam) vented plastic tube was installed around each seedling and supported with an oak stake (www.plantra.com). To address the second objective, we also planted 876 American chestnut seeds, half with a 0.9 m tall (10 cm diam) tube to protect from herbivores, the other half without (to assess level of survival without protection) Fig. 6.

Seedlings were monitored monthly for survival and height growth. Seeds were monitored for germination and survival monthly for the first field season and then height at the end of each year thereafter. A Cox proportional hazard model was used to determine significant differences in survival among treatments. A one-way analysis of variance (ANOVA) followed by a Tukey's HSD post hoc test was used to detect differences in growth rates among seedlings vs. seeds and protected vs. unprotected material. All statistics were performed using R v2.91 (R Development Core Team 2009).

Figure. 5. Loose end dumping at JHWMA and tree seedlings.

Figure. 6. Planting bare root 1-0 American chestnut seedlings w/protective tubes.

Results

Experiment-1

After three growing seasons, seedling survival in the mechanically treated plots was 79-85% compared to 32% in the control plots (Cox proportional hazard model, Likelihood = 564, df = 3, $P < 0.0001$; Fig. 7). Apparently, any form of surface treatment increased survival of American chestnut.

Likewise, the relative growth rate (RGR; height in cm gained per month) in the treatments was collectively greater than the controls (Fig. 8). The first year proved most detrimental to seedlings in the control plots (C) with a -4.20 (cm month^{-1}) loss in shoot growth (Fig. 8A) and an overall RGR rate significantly less than each treatment plot (one-way ANOVA, df = 3, F = 47.37, $P < 0.0001$; Fig. 8D). Each growing season, the ripped plots (R) had a higher growth rate (cm month^{-1}) than either the C or the plow+disk (PD), particularly the plots that had the combined treatment rip+plow+disk (RPD) (ANOVA, all $P < 0.001$). Overall, the ripped plots, R and RPD, had the highest total RGR over three growing seasons (2.16 and 2.80 cm mo^{-1}, respectively). This was significantly higher than the C and PD plots (-1.35 and 1.44 cm $^{-1}$, respectively; ANOVA, df = 3, F = 135.12, $P < 0.001$). Final mean heights of chestnut seedlings after three seasons were as follows: C (16.30 cm), PD (75.68 cm), R (89.93 cm), and RPD (100.30 cm) (ANOVA df = 3, F = 172.88, $P < 0.0001$; Fig. 9).

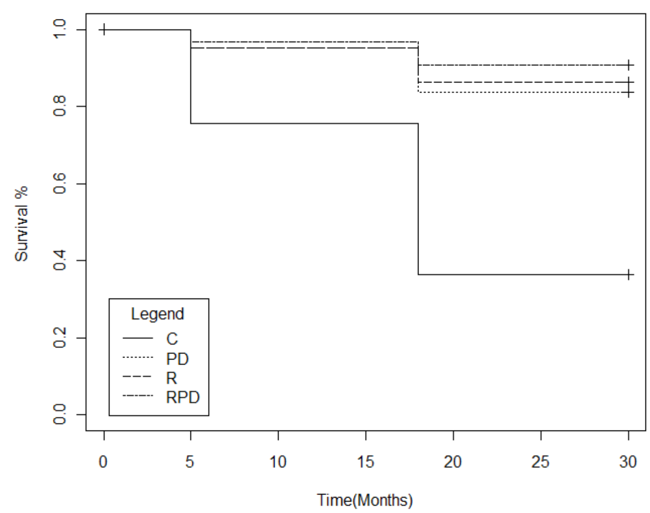

Figure. 7. Cox proportional hazard model for percent seedling survival by months in surface treatments at TVWMA. C = control, PD = plow + disk, R = rip, RPD = ripped + plow + disk

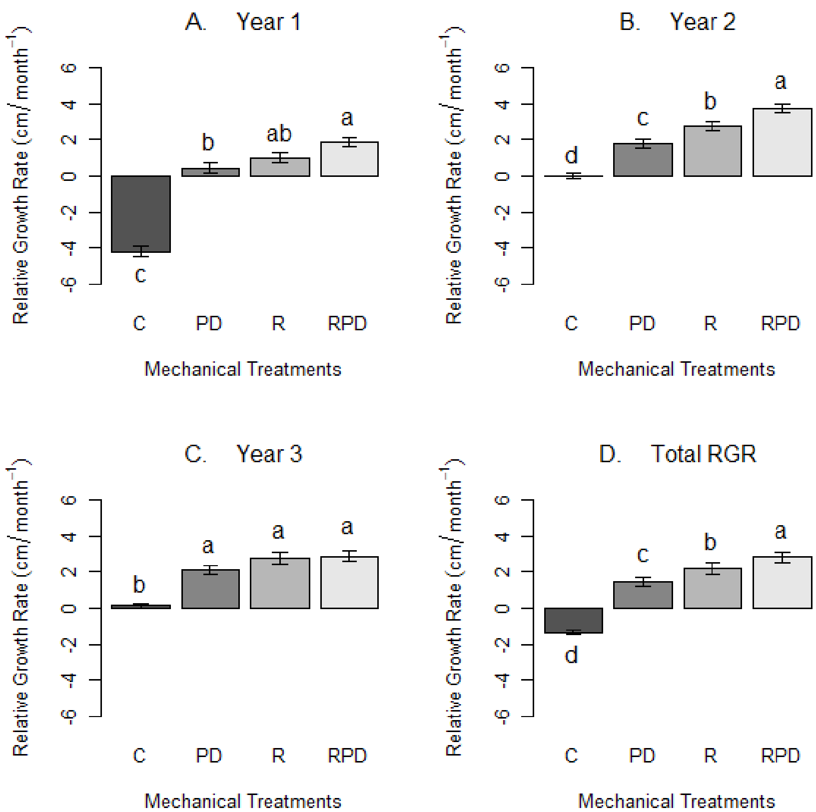

Figure. 8. Relative Growth Rates (RGR) of American chestnut seedlings across four treatment combinations and three years (2007-2009). C = control, PD = plow + disk, R = rip, RPD = ripped + plow + disk.

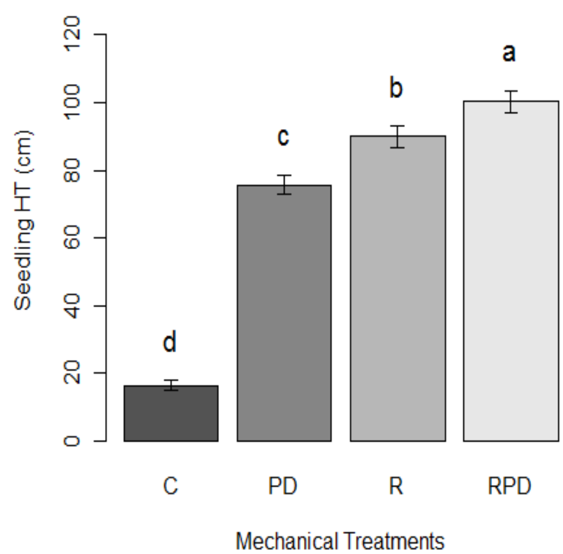

Figure. 9. Final mean seedling height (± SE) of American chestnut after three growing seasons. C = control, PD = plow + disk, R = rip, RPD = ripped + plow + disk.

Experiment-2

Seedlings planted as bare root material showed significantly greater rates of survival (ca. 90%) compared to seedlings originated from direct seeding (ca. 55%; Fig. 10, Survival analysis by Cox Proportional Hazard, likelihood = 103, df = 1, $P < 0.00001$, $n = 1208$). Seeds that did not receive a protective tube suffered a very high rate of predation immediately after planting and a sustained rate of browsing for months thereafter (Fig. 11; Survival analysis by Cox Proportional Hazard, likelihood = 131, df = 1, $P < 0.00001$, $n = 377$).

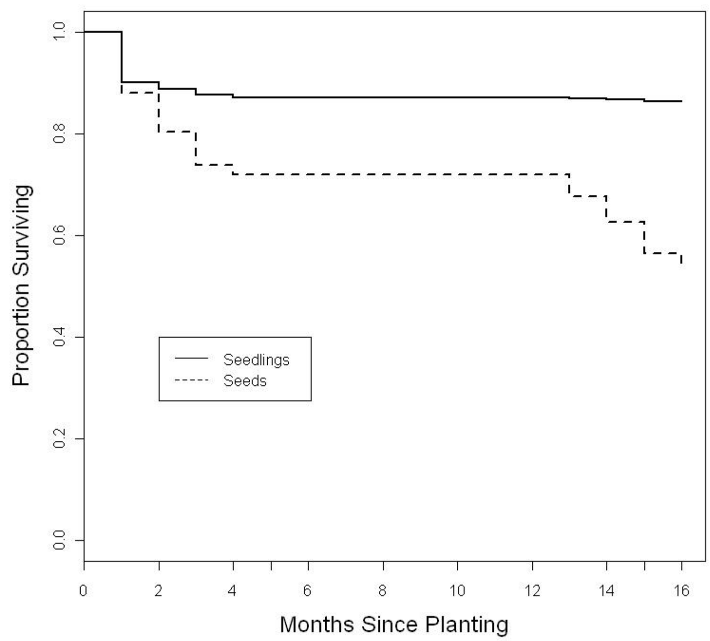

Figure. 10. Survival of seedlings originating from seed ("seed") vs. bare root stock ("seedlings") over two growing seasons (2008 & 2009).

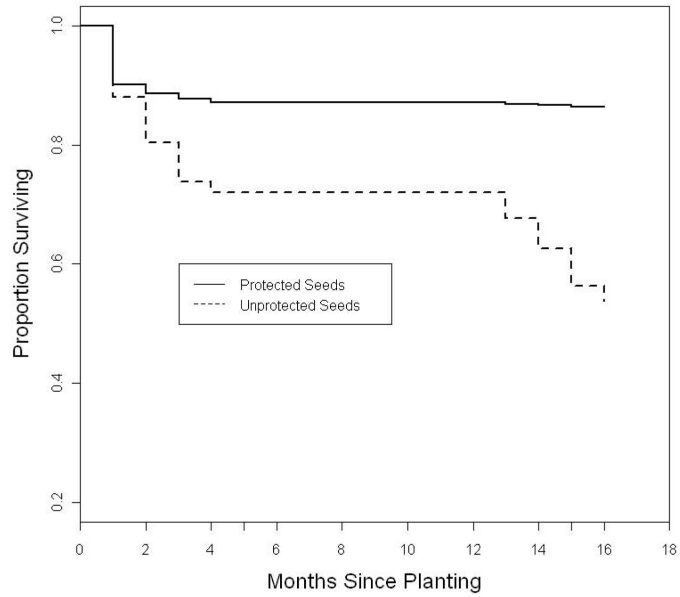

Figure. 11. Survival of chestnut seedlings originating from seed with and without a protective tube over two growing seasons.

In examining relative growth rates, we found that seedlings originating from bare root stock performed well, but slightly less than seedlings with the same protective tube originating from direct seeding (seeds + tall tube). Seedlings originating from direct seeding with a short tube performed on par with bare root stock. Seedlings originating from seed with no protection performed very poorly due to a constant rate of herbivory (Fig. 12; $F = 65.323$, $P < 0.001$, $n = 227$).

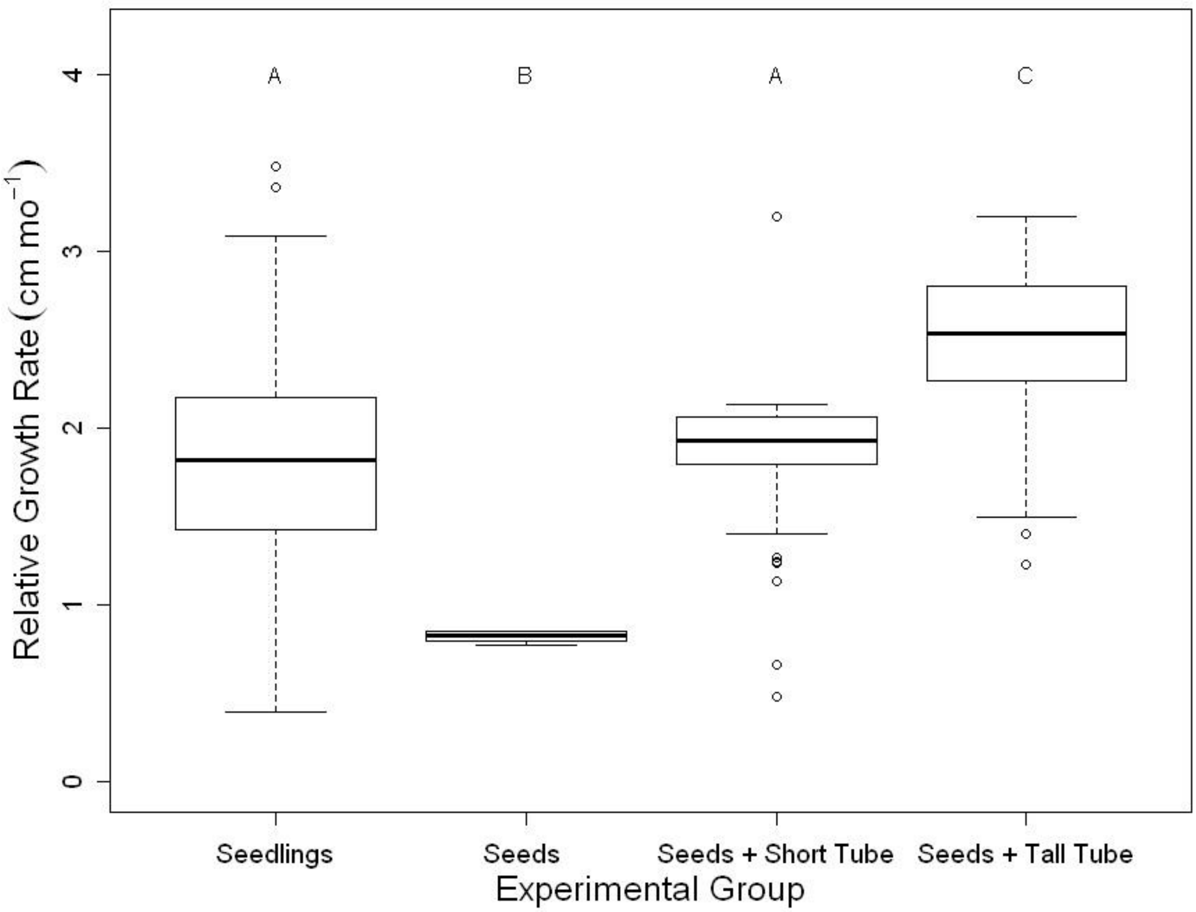

Figure. 12. Relative Growth Rate (RGR) of seedlings originating from bare root planting of 1-0 stock seedlings (with tall protective tubes) vs. direct seeding ("Seeds" without and with short/large protective tubes). Groups with the same letter are not significantly ($P > 0.05$) different.

Discussion

The first experiment dealing with arrested succession suggests that restoration of reclaimed mine land habitat to forest cannot succeed by simply planting seedlings. The control plots exhibited very low levels of chestnut seedling survival and growth. This is most likely related to the very competitive nature of the dominant herb species that were planted there (*Festuca* spp. and *Lespedeza* spp.). These species are well known for their aggressive root systems and ability to usurp space in open habitat (Casselman et al. 2006). In addition, these soils were found to have a high bulk density (data not shown) which combined with the herb roots presents a severe impediment to establishment and survival. In essence, any disturbance in the surface conditions, where competitive interactions were reduced from surrounding vegetation, would appear to provide a window of opportunity for tree seedling establishment. However, over time, the data indicate that this will need to be accompanied by deep ripping to promote better root development (Cleveland and Kjelgren 1994). If a modest tree cover can become established, it can shade out the high light demanding herb species and facilitate additional tree establishment in the future. Thus, our recommendation is to break the arrested succession on reclaimed areas is to use a deep rip and accompany this by a surface plow and disk to further aerate and loosen the topsoil and decrease competition from surrounding vegetation. Bare root seedlings should be direct planted into these conditions. We do *not* recommend the use of poultry netting as a way to protect from herbivores as it is very expensive in manpower, time, and money. The second experiment indicated that vented plastic tubes (only available after the initial experiment) are cheaper and much easier to use. Solid plastic tubes are *not* recommended (previous experiment not reported here; unpublished) as we have observed high mortality in them due to increased fungal pathogen activity (and why poultry netting was used in the first experiment).

Both the first and the second experiment collectively indicate that if American chestnut is provided with the proper rooting conditions and protection from herbivores (primarily white-tailed deer), two-three year survival rates will likely be in the range of 80-90%. These are excellent results by any measure. It was hoped that direct seeding would produce results comparable to the use of bare root seedlings. The rationale for this assumption being that seeds are easier to handle and transport, less expensive, and may require less time, money, and energy to plant. In fact, seedlings originating from seed (with tall tube protection) showed a significantly better growth rate than seedlings starting from bare root. This is most likely due to the seed establishing a better and stronger root system at the time of recruitment than a bare root seedling (which is very susceptible to planting errors). However, seedlings from seed had a much lower survival rate than those from bare root. Usually the goal of reclamation is to demonstrate a survival to a certain density. Thus, initial survival may be more important to reclamation efforts.

An additional piece of information emerges from this research that is quite important. American chestnut, once dominant throughout much of the hardwood forests of the eastern United States, could be restored by using mine reclamation sites as a starting point. Chestnut appears to be well adapted to the environmental conditions found on these sites, and is tolerant of moisture stress, high light, and low pH and often exhibits high growth rates relative to other similar species (McCament and McCarthy 2005, McEwan et al. 2006, Joesting et al. 2007, 2009, Jacobs et al. 2009, Rhoades et al. 2009). The combination of American chestnut restoration and mine land reclamation is an interesting opportunity that permits multiple objectives with constituencies having different goals, but a similar outcome.

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