Survival and Growth of Chestnut Backcross Seeds and Seedlings on Surface Mines

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Some scientists consider the loss of the American chestnut from forests in the eastern United States as one of the greatest forest ecological disasters in the 20th century. The American Chestnut Foundation has been attempting to restore chestnut by backcrossing blight-resistant Chinese chestnut to American chestnut and selecting those strains with blight resistance. Third-generation backcross seeds and seedlings have been produced and planted by researchers. Surface-mined lands provide a land base where these backcross chestnut seedlings may be introduced back into forests. In 2008, seeds of two parent species of chestnut (100% American and 100% Chinese) and three breeding generations (B_1F_3, B_2F_3, and B_3F_2 backcrosses) were planted into loosely graded mine soils with and without tree shelters. First-year establishment from seeds averaged 81%. After the fourth year, survival without shelters declined for all chestnut stock types except for Chinese (80%): American 40%, B_1F_3 70%, B_2F_3 40%, and B_3F_2 55%. Survival with shelters was only slightly better after the fourth year (average, 60% with shelters and 57% without). Height growth was not different among stock types, and average height after the fourth year was 43 cm without shelters and 56 cm with shelters. In 2009, seeds and seedlings of the same chestnut stock types were planted into brown (pH 4.5) or gray (pH 6.6) mine soils. Only six out of 250 seeds germinated, which was very poor considering 81% average seed germination in 2008. Transplanted chestnut seedling survival was much better. After the third year, seedling survival was 85% in brown and 80% in gray soil, but significant differences were found with stock types. Survival was significantly higher with American, Chinese, and B_1F_3 stock types (75%) than with B_2F_3 and B_3F_2 (60%). Height after the third season averaged 90 cm on brown and 62 cm on gray soil. Chestnut backcrosses displayed no hybrid vigor and were not better in survival and growth than the parent stock. All five stock types grew on mine soils in West Virginia, and we found surface mines to be promising sites for introducing blight-resistant chestnut backcross trees into the Appalachian forest.

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Surface coal mining has been conducted on about 2.5 million ha since 1930 in the United States (Paone et al., 1978; Plass, 2000), which has disrupted vast areas of eastern deciduous forest. Since the late 1970s, with the passage of a national surface mining law, most surface-mined land in Appalachia was reclaimed to pasture and hay land or wildlife habitat postmining land uses (Plass, 1982, 2000; Angel et al., 2005) rather than forestland. When maintained with fertilizer and lime, pasture and hay land postmining land uses provided landowners with consistent income. However, when neglected, these lands collapse to weedy plant communities that gradually can return to a woody forest community, but valuable hardwood species require more time to recolonize these unmanaged lands (Zipper et al., 2011).

Since the early 2000s, many operators have returned to reforestation as a preferred postmining land use option with the development of practical technology and regulatory incentives. The Forestry Reclamation Approach was developed to help operators be successful in reforestation efforts. The Forestry Reclamation Approach uses the following five steps to reclaim coal-mined land to forestland. Step 1: Create a suitable rooting medium for good tree growth that is no less than 1.2 m (4 ft) deep and comprised of topsoil, weathered sandstone, and/or the best available material; Step 2: loosely grade the topsoil or topsoil substitutes established in Step 1 to create a noncompacted growth medium; Step 3: use ground covers that are compatible with growing trees; Step 4: plant two types of trees (early succession species for wildlife and soil stability and commercially valuable crop trees); and Step 5: use proper tree planting techniques (Burger et al., 2005).

Recent research has demonstrated successful establishment of native hardwood trees when applying this five-step process (Angel et al., 2008; Emerson et al., 2009), which has resulted in increases in reforestation of surface mined lands (Angel et al., 2009).

Regulations require replacing topsoil materials on surface mines, but salvaging topsoil before mining is expensive and dangerous due to steep slopes and is not often feasible given the thin horizons and small amounts available. Substitute materials, such as brown and gray unweathered sandstone materials, can

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Abbreviations: TACF, The American Chestnut Foundation.

be used to supplement or replace topsoil. Gray unweathered materials are available in much larger quantities than brown weathered spoils or native soils (Zipper et al., 2011). Gray materials have higher amounts of coarse fragments and soluble salts and have higher pH levels (Haering et al., 1993, 2004; Emerson et al., 2009). Survival of hardwood tree seedlings was shown to be very good (>80%) during the first several years after planting in brown and gray sandstone mine soils (Burger et al., 2007; Emerson et al., 2009). However, trees planted into brown sandstone have much greater growth than trees planted in gray sandstone (Emerson et al., 2009; Thomas and Skousen, 2011). As reviewed by Skousen et al. (2011a, 2011b), studies have found that weathered rocks, especially sandstones, produce better mine soil materials for plant growth compared with unweathered materials. Working in Kentucky, Angel et al. (2008) found that weathered sandstone mine soils supported faster tree growth and more rapid colonization by native plants than unweathered gray sandstone or a mixture of the two materials.

Tree shelters have generally been shown to increase survival and growth of hardwoods (Potter, 1988), particularly where deer and rodent populations exist. However, Ponder (2003) showed that three species of hardwoods (*Quercus rubra* L., *Juglans nigra* L., and *Fraxinus pennsylvanica* Marsh.) were not significantly different in survival or growth with tree shelters after 10 yr.

Before the 1900s, the eastern hardwood forests of the United States were composed of 30 or 40 hardwood species. One of the most important species was the American chestnut [*Castanea dentata* (Marsh.) Borkh.], and this species was estimated to occupy up to 25% of the forest (Russell, 1987). American chestnut trees were up to 50 m in height and produced tremendous volumes of timber because they grew straight and fast and often produced three or four 4-m logs before the first branch was reached. Chestnut trees were also valued for their consistent annual nut production, which were eaten by humans and animals, and natural tannin for tanning leather (Freinkel, 2009).

Chestnut blight, discovered in 1904 in New York, which is caused by a fungus [*Cryphonectria parasitica* (Murr.) Barr.], quickly spread through the eastern U.S. forests (Jacobs, 2007). By 1950, about 4 billion chestnut trees had perished, thereby eliminating an exceptional wildlife and timber tree and causing the loss of nearly one fourth of the canopy cover of the eastern U.S. deciduous forest. Many scientists consider the loss of the American chestnut to be the greatest forest ecological disaster of the 20th century. The blight fungus infects American chestnut through cracks or wounds in the bark, creating a canker that cuts off circulation to the branches above the canker. The roots, however, remain alive. The ability to sprout has enabled American chestnut to persist in eastern forests but only as an occasional understory shrub. For a broader description of the blight fungus and other diseases of the chestnut, see Anagnostakis (1995) and Brewer (1995).

The American Chestnut Foundation (TACF), formed in 1983, is breeding surviving American chestnut with blight-resistant Chinese chestnuts (*Castanea mollissima*) (Burnham et al., 1986). Highly blight-resistant progeny of the backcrosses were selected for further backcrossing to American chestnut (Hebard, 2005). Through careful selection, these backcrosses incorporated Chinese chestnut's blight resistance while retaining the desirable timber and nut-producing characteristics of the American chestnut. In 2009, TACF produced tree seedlings that are approximately 7/8 American chestnut and 1/8 Chinese chestnut (the B_3F_2 backcross is the third backcross to American chestnut and the second generation hybrid). The American Chestnut Foundation has begun testing this B_3 product in many eastern US states.

The use of reclaimed surface mines for chestnut reestablishment has recently gained momentum (French et al., 2007b). The factors that affect survival and growth of native hardwoods on surface mines, such as mine soil properties, compaction, and organic matter content, will probably affect survival and growth of chestnut. Because the Appalachian coal region overlays the former range of the American chestnut, TACF has been planting American chestnut and backcross chestnut on surface-mined lands in various Appalachian states since 2002. In cooperation with the University of Kentucky, chestnut seeds were planted in 2005 on end-dumped spoil in eastern Kentucky composed of gray sandstone and brown sandstone spoil materials. Better growth was found in brown sandstone (Adank et al., 2008; French et al., 2007a). Researchers in Ohio have been examining chestnut direct seeding versus planted seedlings, mycorrhizal inoculation treatments, and protection of seedlings on surface mine lands (McCarthy et al., 2008, 2010). A breeding orchard of backcross chestnut seedlings on mined land was established in Jefferson County, Pennsylvania, and harvesting of nuts was performed in 2010 (Phelps, 2002). Based on preliminary findings, reclaimed surface mines appear to provide a promising land base alternative for introducing blight-resistant chestnut backcross into the former range of the American chestnut rather than planting chestnut seeds or seedlings back into native forests with competing resources and pathogens.

The objectives of this research were to determine the establishment and growth of seeds and seedlings of two chestnut parental species and three breeding generations, hereafter called "stock types" (American, Chinese, B_1F_3, B_2F_3, and B_3F_2; see Hebard [2005] for descriptions of backcross chestnuts) in mine soils in West Virginia. In Experiments 1 and 2, seeds were planted with and without shelters in a mixed brown/gray mine soil. In Experiments 3 and 4, seedling establishment and growth of the same chestnut stock types were evaluated in two distinct mine soils: a loosely dumped brown sandstone material and a compacted gray sandstone material.

Materials and Methods

Experiments 1 and 2 (2008–2011): Seeds

Experiments 1 and 2 were established at the Glory surface mine, which is located in Boone County, West Virginia (37°57′45.48″ N, 81°45′01.04″ W). Overburden from the 5-Block and Clarion coal seams was used to construct a 1-ha plot for this study, which was comprised of 75% brown sandstone and 25% gray sandstone. The material was end dumped by trucks, and a large bulldozer pushed the tops of the piles to create a roughly level surface. Precipitation is about 112 cm, with 60% falling between April and September, which is the recognized growing season (Wolf, 1994). The average annual temperature during the growing season is 20°C.

On a 1-ha area, two experiments were established at Glory. Experiment 1 was a randomized complete block design with four blocks. Five plots in each block were randomly assigned a chestnut stock type, and five seeds of the assigned seed stock type were planted in each plot at 2.4 × 2.4 m spacing (4 blocks × 5 stock type seeds × 5 replications = 100 seeds). The chestnut seeds were produced from open-pollinated seed orchards of TACF in Meadowview, Virginia. Wooden stakes were driven into the soil at each seed location. Chestnut seeds were planted by digging a 5-cm hole about 5 cm from the base of the wooden stake. Each seed was inoculated with mycorrhizal fungi provided by TACF before planting.

Experiment 2 was established in the same way as Experiment 1 (four blocks with five stock types and five replications), except a 45-cm-tall, blue, plastic tree shelter (Blue-X) with perforations was placed over each planted seed and secured to the stake with twine. Shelters were removed during the second growing season in June 2009 because many chestnut seedlings were observed to be wilting with leaf die-off in the shelters. In both experiments, survival was noted, and height of each live chestnut seedling was measured in August 2008 to 2011.

Statistical analyses were performed using SAS 9.1 software (SAS Institute, 2005). For each year (2008–2011), data for tree survival and height for each experiment were analyzed by ANOVA (Proc GLM) with stock type as the main effect variable. An α level of 0.05 was considered significant.

Experiments 3 and 4 (2009–2011): Seeds/Seedlings

Experiments 3 and 4 were established in 2009 at the Nicholas Energy site about 15 km west of Summersville, West Virginia (38°19′45.22″ N, 80°58′31.25″ W). Nicholas Energy produces about 2.4 million metric tons of high-quality coal per year using large shovels, trucks, and dozers to extract coal from the 5-Block, Clarion, Stockton, and Coalburg seams. Two mine soil types (brown and gray) were available for planting at this site. The brown sandstone materials came from the surface overlying the 5-Block coal seam, which was end dumped by trucks with no striking off or flattening of the piles. The gray sandstone topsoil substitute material came from the overburden above the Clarion coal seam. This gray sandstone material was dumped and graded smooth and was composed of unweathered, coarse-textured materials. Precipitation at the site is about 118 cm, with 55% falling between April and September, the recognized growing season (Carpenter, 1992).

Experiment 3 was a randomized complete block design with five blocks. Chestnuts in Experiment 3 were planted in brown mine soils. Ten plots in each block were randomly assigned a chestnut stock types and one of two planting materials (seeds or seedlings) (5 blocks × 5 stock types × 2 seeds or seedlings × 5 replications = 250 chestnuts). Wooden stakes were driven in where seedlings or seeds were planted on 2.4 by 2.4 m spacing. Chestnut seedlings and seeds were provided by TACF. The planting procedure involved digging holes large enough to place the roots of the seedlings, and the seeds were planted approximately 3 to 4 cm deep in the soil and covered.

Experiment 4 was established the same as Experiment 3 with the same number of seeds and seedlings planted, except the chestnuts were planted in compacted gray mine soils. Survival was noted, and the height of each live chestnut seedling was measured from August 2009 to 2011.

Statistical analyses were performed using SAS 9.1 software (SAS Institute, 2005). For each individual year, data for tree survival and height for each experiment were analyzed with ANOVA (Proc GLM) with stock type and seed/seedling material as main effects. An α level of 0.05 was considered significant.

Soil Sampling

For all experiments, soil samples were extracted at five locations (at the four corners and the center) to a depth of 15 cm to evaluate chemical properties. Samples were analyzed for pH (1:1 soil:water) with a Beckman 43 pH meter (Beckman Coulter). Elemental content was determined by the West Virginia University Soil Testing Laboratory with a Mehlich 1 extract, which is composed of approximately 0.05 mol L^{-1} HCl and 0.025 mol L^{-1} H_2SO_4. The leachate from the extraction was analyzed with a PerkinElmer Plasma 400 emission spectrometer for H, Al, P, K, Ca, and Mg. Cation exchange capacity was calculated by summing the above elements, and base saturation was calculated as the sum of base cations divided by total cations. Statistical analyses were performed for each parameter with ANOVA (Proc GLM), and means were separated with Tukey's honest significant difference tests (SAS Institute, 2005) using an α level of 0.05.

Results and Discussion

Experiments 1 and 2 (2008–2011): Seeds

Soil analysis revealed a pH range of 5.5 to 5.8 for mine soils in Experiments 1 and 2 (Table 1). Because the mine soils were a mixture of brown and gray materials for Experiments 1 and 2, the properties were very similar between experiments, and no significant differences were found for chemical properties. The mine soils of Experiments 1 and 2 were intermediate between Experiments 3 and 4 for pH, P, cation exchange capacity, and base saturation. We expected variation in mine soil properties among these experiments, and these values are within anticipated ranges of mine soil chemical values (Haering et al., 2004).

During the first year in Experiment 1 without shelters, chestnut seed establishment was highest with the backcross stock

Table 1. Chemical properties of soils for four experiments where five chestnut stock types were planted on surface mines in West Virginia.

Experiment	pH	EC†	P	K	Ca	Mg	CEC‡	BS§
		dS m^{-1}	mg kg^{-1}		cmol⁺ kg^{-1}			%
1 (no shelters)	5.5ab¶	0.14	33ab	0.14b	2.1b	2.0b	10ab	44ab
2 (shelters)	5.8ab	0.17	30ab	0.15b	3.4b	1.9b	10ab	55ab
3 (brown sandstone)	4.5b	0.16	6b	0.33a	2.9b	3.6b	13b	28b
4 (gray sandstone)	6.6a	0.23	56a	0.40a	9.5a	6.2a	8a	100a

† Electrical conductivity.

‡ Cation exchange capacity.

§ Base saturation.

¶ Values within columns with different letters are significantly different at $p < 0.05$. If no letters, the values are not significantly different.

types (85%) compared with American (75%) (Table 2). After the fourth year, all stock types had declined except for Chinese, which maintained a survival rate of 80%. American and the B_2F_3 decreased to 40% survival. Height increased from an average of 7 cm across stock types to 43 cm after the fourth year.

For Experiment 2 with shelters after the first year, the highest survival rate was found for Chinese and B_1F_3 (90%), with American and B_3F_2 at 70% (Table 3). After the fourth year, Chinese survival did not decline (90%), compared with 20 to 30% decreases in survival for all other stock types. Height increased from an average of 11 cm to 56 cm across stock types. Survival of stock types in Experiment 2 performed more like one would expect; Chinese and the single backcross hybrid with more Chinese genes (B_1F_3) should behave similarly, whereas second- and third-backcross hybrids with increasingly more American genes would behave more like American. However, the added vigor that comes from hybrids was not apparent.

Chestnut seed survival was very similar between Experiments 1 and 2 (82 vs. 80%), an effect that persisted through 2011 (60 vs. 57%). Between the first and second years after planting, an average of 8% of trees were lost with shelters compared with 9% without. This result is quite different from McCarthy et al. (2010), who found that the survival rate of chestnut seedlings doubled with tree shelters. Tree shelters are known to protect seeds and seedlings from predators, but there was little evidence of browsing or girdling by deer or small mammals at our site, so shelters probably were not needed for this purpose. We noticed some heat stress and burning of leaves in shelters at the end of the first growing season, and many of the seedlings were crowded in the shelters. Therefore, in June of 2009, in the middle of the second growing season, we removed the tree shelters, which eliminated possible high temperatures within the shelter tube (Bergez and Dupraz, 1997).

Some seedlings were lost between the second and third years after shelters were removed (5–20%) (Table 3), but 5 to 20% of trees were also lost with unsheltered trees (Table 2). Across both experiments, 81% of chestnut seeds germinated and established during the first year, which gradually declined to about 58% by the fourth year. Hebard (2005) reported more than 75% germination and establishment for chestnut seeds, which is similar to our results the first year. Skousen et al. (2009a) found that survival of transplanted hardwood species declined during the first 5 yr, but after the fifth year few additional trees died. We saw a similar trend of fewer and fewer trees dying through the first 4 yr of this study with chestnuts.

The rate of tree growth in Experiment 1 (no shelters) was similar for the five stock types with an average of 43 cm after 4 yr, whereas Experiment 2 had an average height of 56 cm. Seedlings from Chinese seeds tended to show better growth during the first and second years than the other stock types. This probably suggests that the larger seed size of Chinese seeds provided greater reserves for early growth. After the fourth year, seedling height among stock types with no shelters was very similar, but differences in height were beginning to appear among stock types with shelters. After 4 yr, height of planted red oak seedlings was around 50 cm on a variety of mine soil types (DeLong and Skousen, 2009; Showalter et al., 2007), which is similar to height of the chestnut seedlings in this study. McCarthy (2008) reported height of backcross stock types (B_1 and B_2) to be 60 cm, versus 35 cm for American. Future growth measurements will document whether the chestnuts from seeds will continue to grow at rates similar to other hardwoods or at least until the blight slows growth of the non–blight-resistant trees. In fact, the rate of growth for all trees seemed to be slowing down (Tables 1 and 2), which may have been a consequence of blight or of dry climatic conditions during the 2010 and 2011 growing seasons.

Experiments 3 and 4 (2009–2011): Seeds/Seedlings

Soil chemical properties were significantly different for most parameters between Experiments 3 and 4 (Table 1). Soil pH in Experiment 4 (brown) was much lower at 4.5, compared with pH 6.6 for Experiment 2 (gray). Most gray sandstone mine soil substitutes in West Virginia have a higher pH, sometimes nearly pH 8.0 (Emerson et al., 2009). The almost 10-fold greater P in the gray versus brown mine soil has also been documented in studies of West Virginia mine soils (Emerson et al., 2009; Thomas and Skousen, 2011), but this P may not be plant available, as shown by a leaching study (Skousen and Emerson, 2010). Significantly

Table 2. Seed germination/survival and height of five chestnut stock types in Experiment 1 (no shelters) from 2008 to 2011.

Stock type	2008	2009	2010	2011
		Survival, %		
American	75b†	70a	50c	40b
Chinese	80ab	80a	80a	80a
B_1F_3	85a	75a	70ab	70a
B_2F_3	85a	70a	50c	40b
B_3F_2	85a	75a	65bc	55ab
Avg.	82	74	63	57
		Height, cm		
American	5	20	32	40
Chinese	8	28	35	41
B_1F_3	7	28	39	45
B_2F_3	7	28	39	47
B_3F_2	6	26	40	45
Avg.	7	27	38	43

† Values within columns with different letters are significantly different at $p < 0.05$. If no letters, values are not significantly different.

Table 3. Seed germination/survival and height of five chestnut stock types in Experiment 2 (with shelters) from 2008 to 2011.

Stock type	2008	2009	2010	2011
		Survival, %		
American	70b†	70b	50b	50b
Chinese	90a	90a	90a	90a
B_1F_3	90a	65bc	60b	60b
B_2F_3	80ab	60c	50b	50b
B_3F_2	70b	70b	60b	50b
Avg.	80	71	62	60
		Height, cm		
American	9	34	52	59
Chinese	13	47	56	61
B_1F_3	12	40	52	51
B_2F_3	11	40	47	59
B_3F_2	10	39	51	51
Avg.	11	40	52	56

† Values within columns with different letters are significantly different at $p < 0.05$. If no letters, values are not significantly different.

greater quantities of Ca and Mg were found in gray versus brown mine soils, which caused much higher base saturation values. Chestnut trees prefer soils with pH from 5 to 6, but they have been shown to grow on a wider range of soil pH (French et al., 2007a; McCarthy et al., 2008).

A surprising finding in this study of seeds and seedlings during the first year was that only a handful of the 250 seeds planted in either experiment germinated and established. In total, only six seeds germinated: 4 out of 125 in gray and 2 out of 125 in brown. The six germinated seeds were not just one seed type: two were B_1F_3, two were Chinese, one was B_2F_3, and one was B_3F_2. Because no other information could be gathered about seed germination and establishment with these chestnut stock types, the planting material effect was not further analyzed. Chestnut seeds are generally very hearty, and germination and establishment is normally >75% (Hebard, personal communication, 2011; Hebard and Rutter, 1991). In Experiments 1 and 2 done the previous year, the germination rate averaged 80%. The reasons for exceptionally poor germination and survival of our planted chestnut seeds in Experiments 3 and 4 were unknown. There was some evidence that rodents had removed and eaten some seeds. When digging to find planted seeds after the first year, we found no seed in many places but found rotted seeds in other places.

For transplanted seedlings after the first year, survival rates were >90% in Experiment 3 (brown) for American, Chinese, and B_1F_3 and 68% for B_2F_3 and B_3F_2 (Table 4). These survival rates declined to between 56 and 84% after three growing seasons. In Experiment 4 (gray), comparable survival was found the first year with the same stock types, and after the third year survival declined to about 45% for B_2F_3 and B_3F_2 (Table 5). The 100% Chinese survival in gray sandstone was exceptional, and it was surprising that all 25 seedlings survived for 3 yr. For B_1F_3 seedlings, 23 of the 25 planted seedlings survived with no decline during 3 yr, similar to Chinese. The poor performance of B_2F_3 and B_3F_2 to around 45% survival was slightly lower than other hardwood seedling survival studies and considerably lower than the >80% survival rate with the other stock types after 3 yr. The reason for a higher survival rate for 2011 than 2010 was that some seedlings did not appear to be alive in 2010, but plants resprouted from roots in 2011. Overall, survival between brown and gray mine soils for all stock types was very similar (74 vs. 73%). We found hardwood tree survival to be between 60 and 70% after 3 yr on brown and gray mine soil materials in other West Virginia studies (Emerson et al., 2009; DeLong and Skousen, 2009), so the survival results with our chestnut stock types fell within this range.

Chinese seedlings were significantly greater in height initially than the other chestnut seedling stock types, and height was generally higher for Chinese after 3 yr (Tables 4 and 5). Again, the backcross stock types should presumably have performed better due to hybrid vigor or at least intermediate to Chinese and American, but they were shorter in both experiments. The height growth rates between 2010 and 2011 were not as great as between 2009 and 2010 partly due to the small size of seedlings that resprouted between 2010 and 2011. Height differences occur due to growing conditions and mine soil properties rather than due to initial seedling size differences. In other studies on mine soils, tree growth is much greater on brown mine soils than on gray mine soils (Emerson et al., 2009; Thomas and Skousen, 2011), and these differences were beginning to show in this study. Average height of all chestnut seedlings in Experiment 3 (brown) was 90 cm, compared with 62 cm in Experiment 4 (gray) after the third year.

The combined results of these experiments showed that all five stock types established and grew on reclaimed mine soils in West Virginia. In the first two experiments, 80% of chestnut seeds germinated and established, whereas in Experiments 3 and 4 only a few seeds germinated. Transplanted seedling survival after the first year was >90% with Chinese, American, and B_1F_3 but was only 50 to 70% for B_2F_3 and B_3F_2. Growth rates were similar among stock types, and height growth appeared to be greater on brown versus gray mine soils, which is comparable to studies with other hardwood trees on these mine soils types in the Appalachian Region. Hybrid vigor did not increase survival or growth for backcrosses compared with the parents. With these results, continued planting of chestnut backcrosses on mined lands is recommended. These plantings along with others throughout the mined area in Appalachia will provide an

Table 4. Seedling survival and height of five chestnut stock types in Experiment 3 (brown sandstone) in 2009 to 2011.

Stock type	2009	2010	2011
		Survival, %	
American	92a†	80ab	80a
Chinese	100a	96a	84a
B_1F_3	96a	72ab	72ab
B_2F_3	68b	56b	56b
B_3F_2	68b	68ab	64b
Avg.	85	74	74
		Height, cm	
American	25b	82b	92ab
Chinese	40a	101a	112a
B_1F_3	15c	56c	85ab
B_2F_3	14c	48c	68b
B_3F_2	14c	52c	82ab
Avg.	23	71	90

† Values within columns with different letters are significantly different at $p < 0.05$.

Table 5. Seedling survival and height of five chestnut stock types in Experiment 4 (gray sandstone) in 2009 to 2011.

Stock type	2009	2010	2011
		Survival, %	
American	92a†	72a	80a
Chinese	100a	80a	100a
B_1F_3	92a	72a	92a
B_2F_3	48c	32b	44b
B_3F_2	68b	48b	48b
Avg.	80	61	73
		Height, cm	
American	23b	61b	71a
Chinese	31a	90a	79a
B_1F_3	16c	42bc	52b
B_2F_3	13c	46bc	53b
B_3F_2	8d	25c	39c
Avg.	20	57	62

† Values within columns with different letters are significantly different at $p < 0.05$.

opportunity to re-establish blight-resistant chestnuts in eastern U.S. forests.

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