SURVIVAL AND GROWTH OF FIVE CHESTNUT SEED TYPES ON A MOUNTAINTOP SURFACE MINE IN WEST VIRGINIA[1]

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Abstract : Reforestation of mined lands has become a preferred post-mining land use in some parts of Appalachia since the Appalachian Regional Reforestation Initiative began. With this new emphasis, attention has been focused on replanting the American chestnut on these areas, which was decimated by Chestnut blight during the last century. The American Chestnut Foundation has developed potential blight-resistant hybrids through a series of backcrosses between American and Chinese chestnut. Therefore, the objective of this study was to evaluate the survival and growth of five seed types of chestnut (100% American, 100% Chinese, and three hybrids [B1F3, B2F3, and B3F2]) into loosely-graded minesoils at the Glory surface mine in Boone County, West Virginia. The five seeds types were randomly planted in eight blocks (four with tree shelters and four without shelters) and each block was split into randomly assigned peat or no peat treatments. Average seedling survival from seeds after the first growing season was 72% across all treatments, with survival of Chinese 82%, American 67%, and the hybrids at between 69 and 74%. Seeds with tree shelters showed a significantly higher survival at 81% compared to non-sheltered seeds at 63%. Peat treatment generally reduced seed survival but especially so on the non-sheltered seeds. Height growth of trees showed similar results as that of survival, with Chinese seeds and sheltered trees being greatest in height. Additional plantings of seeds and seedlings will be conducted in spring 2009 in West Virginia.

Additional Keywords: chestnut hybrids, Forestry Reclamation Approach, minesoils, tree seedlings, tree seeds

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Introduction

About 78% of West Virginia is forested and, with the prevailing climate, almost all land in this region will naturally revert to forestland eventually if disturbed by fire, farming, or mining. The climate and soil/geology of the central Appalachians is conducive to very good hardwood forest growth.

Surface coal mining has been conducted on about 2.5 million ha (6 million ac) since 1930 in the USA (Paone et al., 1978; Plass, 2000). In Appalachia, the vast majority of surface mined land was originally covered by eastern deciduous forest. The earliest laws governing reclamation of surface mines were passed in Ohio, Pennsylvania, and West Virginia during the 1940s, and these early reclamation laws prescribed soil, subsoil, and overburden (the geologic material overlying the coal) be used to refill the excavated area. Leveling the land was often specified, and conifers and some hardwood trees species were planted to replace the forest that had been removed (Ashby, 2006; Brown, 1962; Limstrom, 1960; Plass, 2000). Reforestation was chosen because the land had been originally forested and reforested sites provided long-term site stabilization, wildlife habitat, and future economic value when trees are harvested (Torbert and Burger, 2000).

Since the late 1970s with the passage of a national surface mining law, a large amount of surface mined land in Appalachia has been reclaimed to pasture and hay land or wildlife habitat post-mining land uses (Plass, 1982; 2000), rather than forestland. The reasons for this land use change are related to: 1) quick economic returns to landowners by grazing and haying systems, 2) predictable bond release because the consistent ground cover gave good erosion control and water quality, and 3) better land stability compared to pre-law mined landforms where no grading was performed (Boyce, 1999). When maintained with fertilizer and lime, these pasture and hay land uses provide landowners with consistent income. When neglected, these lands collapse to weedy plant communities that gradually can return to a woody forest community, but long time periods are necessary for valuable hardwood species to invade and mature.

Forest post-mining land uses have gradually emerged during the early 2000s as a preferred post-mining land use option. A recent approach to deal with obstacles of forest re-establishment on mined lands is the Forestry Reclamation Approach of the Appalachian Regional Reforestation Initiative (ARRI). ARRI encourages a 5-step process to reclaim coal mined land to forestland:

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;
2. Loosely grade the topsoil or topsoil substitutes established in step one to create a non-compacted growth medium;
3. Use ground covers that are compatible with growing trees;
4. Plant two types of trees – 1) early succession species for wildlife and soil stability, and 2) commercially valuable crop trees;
5. Use proper tree planting techniques (Burger et al., 2005).

Prior to the 1900s, the eastern hardwood forests of the United States were comprised of an assemblage of 30 or 40 hardwood species. One of the most important species was the American chestnut (*Castanea dentata* (Marsh.) Borkh.), and foresters estimated that this species occupied up to 25% of the forest. American chestnut produced great volumes of timber because it grew straight, fast, and often produced three or four 16-foot logs before the first branch was reached.

In 1904, a forester in New York discovered a disease on chestnut trees, which is caused by a fungus, *Cryphonectria parasitica* (Murr.) Barr., originating in Asia. It quickly spread through the forests and by 1950 the entire range of the chestnut was affected. Approximately 4 billion trees had perished, nearly one-fourth of the canopy cover of the eastern deciduous forest was gone, and an important wildlife and timber tree was lost. Many scientists consider the loss of the American chestnut to be the greatest ecological disaster of the 20th century.

The blight fungus infects American chestnut through wounds in the bark, creating a canker, which effectively 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.

The American Chestnut Foundation (TACF) was formed in 1983 with the goal to restore this once dominant tree throughout its native range. By crossing surviving American chestnut flowers with blight-resistant Asiatic chestnuts, TACF is producing hybrid chestnuts that incorporate Asiatic chestnuts' blight resistance, while retaining the desirable timber and nut-producing characteristics of the American chestnut. In this manner, TACF is currently producing trees that are approximately 15/16 American chestnut and 1/16 Chinese chestnut. TACF hopes to begin widespread testing of their final product around 2010.

The use of reclaimed surface mines for chestnut reestablishment has recently gained attention. The same factors that affect survival and growth of native hardwoods on surface mines will probably affect survival and growth of American chestnuts. Since the Appalachian coal region overlays the former range of the American chestnut, the establishment of blight-resistant hybrids would coincide with TACF's goal of restoring the chestnut in the eastern USA (French et al., 2007b).

Since 2002, TACF has been planting American chestnut and hybrid chestnut on mined lands in various Appalachian states. In cooperation with the University of Kentucky, chestnut seeds were planted in 2005 on end-dumped spoil in eastern Kentucky composed of gray sandstone, brown sandstone, and run-of-mill spoil materials. Better growth was found in brown sandstone (French et al., 2007a; Adank et al., 2008). Researchers in Ohio have been examining chestnut direct seeding versus planted seedlings, mycorrhizal inoculation treatments, and protection of seedlings on mine lands (McCarthy et al., 2008). A breeding orchard of 1/16 Chinese and 15/16 American chestnut seedlings on mined land was established in Jefferson County, PA, and it is anticipated that selections and harvesting of nuts will be performed by 2010 (Phelps, 2002).

The objective of this study is to determine the survival and growth of five seed types of chestnut in a growth media mixture of brown and gray sandstone in West Virginia. Treatments of peat and tree shelters were also incorporated into the planting design.

Materials and Methods

The Glory surface mine is located near Van, in Boone County, West Virginia. Glory produces about 1 million metric tons of high quality coal per year using multiple hydraulic excavators, trucks, dozers, and one highwall miner system. With this equipment, operators mine the Number 5 Block, Clarion, Stockton, and Coalburg coal seams. Overburden from the Number 5 Block and Clarion coal seams was used to construct a 1-ha plot for this experiment, which was comprised of 75% brown sandstone and 25% gray sandstone. The material was end dumped by trucks and a large bulldozer flattened the tops of the piles to create a rough level surface (Fig. 1). Precipitation at the site is about 112 cm with 60% falling between April and September, the recognized growing season (Wolf 1994). The average annual temperature during the growing season is 20 degrees C.

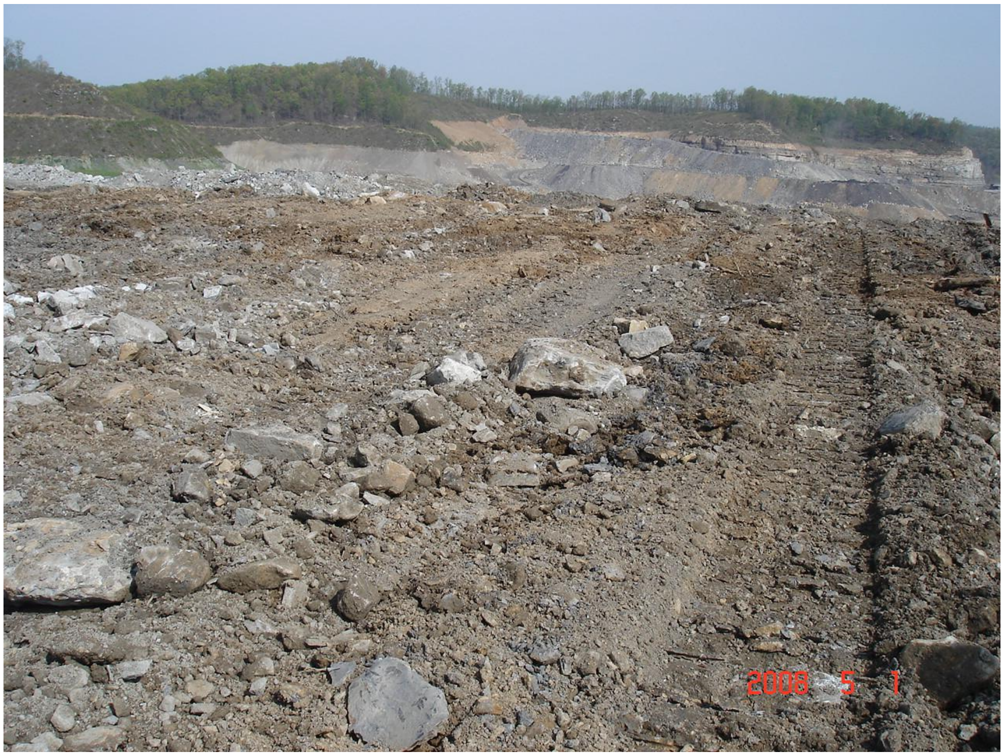


Figure 1. The 1-ha experimental area was constructed with primarily brown sandstone substrate, end-dumped with trucks, and the piles were flattened by one or two passes of a bulldozer.

On this 1-ha site, the experimental setup consisted of two, split plot designs with tree shelters (with or without) being the whole plot factor. Each whole plot (shelters or no shelters) was composed of four blocks (blocks 1, 2 5, and 6 were assigned tree shelters, and blocks 3, 4, 7 and 8 had no tree shelters). One-half of each block was randomly assigned a peat or no peat treatment. In each half block, five subplots were randomly assigned a seed type (Fig. 2). Five seeds of the assigned seed type were planted in each subplot at 2.4 x 2.4 m spacing. The chestnut seeds were provided by Fred Hebard and Bob Paris of the American Chestnut Foundation in Meadowview, VA. Wooden stakes were driven into the soil at each seed location. Fifty seeds were planted in each block. In total, 80 seeds of each seed type were planted for a total of 400 seeds (5 seed types x 8 blocks x 2 peat treatments x 5 replications = 400 seeds).

Seeds were planted by digging a small 5-cm-deep hole about 5 cm from the base of the wooden stake. Each seed was inoculated with mycorrhizal fungi before planting. In peat treatments, about 5 cm^3 of commercial peat from a local gardening store was placed in the hole and the seed was placed on the peat and covered with soil. In the no peat treatment, only soil

BLOCK 1

B2F3	B3F2
AMERICAN	CHINESE
B1F3	B2F3
B3F2	B1F3
CHINESE	AMERICAN
np	p

BLOCK 5

AMERICAN	CHINESE
CHINESE	B2F3
B3F2	AMERICAN
B2F3	B3F2
B1F3	B1F3
np	p

BLOCK 2

B2F3	B2F3
CHINESE	AMERICAN
AMERICAN	B1F3
B1F3	CHINESE
B3F2	B3F2
p	np

BLOCK 6

B1F3	AMERICAN
AMERICAN	B1F3
CHINESE	B2F3
B2F3	B3F2
B3F2	CHINESE
np	p

BLOCK 3

CHINESE	AMERICAN
AMERICAN	B1F3
B2F3	CHINESE
B1F3	B3F2
B3F2	B2F3
p	np

BLOCK 7

B2F3	AMERICAN
B1F3	B2F3
B3F2	B3F2
AMERICAN	B1F3
CHINESE	CHINESE
p	np

BLOCK 4

B2F3	AMERICAN
B3F2	B2F3
B1F3	CHINESE
AMERICAN	B1F3
CHINESE	B3F2
np	p

BLOCK 8

B1F3	CHINESE
B3F2	B3F2
AMERICAN	AMERICAN
CHINESE	B1F3
B2F3	B2F3
np	p

Figure 2. Split plot design experiments with 1) seeds with shelters (blocks 1, 2, 5 and 6) and 2) seeds with no shelters (blocks 3, 4, 7 and 8) being the whole plot component, and peat treatment being the subplot. Seed types were considered treatments randomly assigned in each peat subplot. Seed types were American, Chinese, B1F3, B2F3, and B3F2. Blocks were located at the Glory Mine in Boone County, WV.

was used to cover the seed. After planting, we placed 45-cm-tall, plastic tree shelters on top of each planted seed in blocks 1, 2, 5 and 6 (200 seeds), and no tree shelters were placed on planted seeds in blocks 3, 4, 7 and 8 (Fig. 3 and 4). The tree shelters were secured to the stakes with twine. No fertilizer was applied at the time of planting. Survival was noted and height of each live chestnut seedling was measured on August 29-30, 2008, about four months after planting.

Figure 3. Plastic tree shelters were placed on four of the blocks (1, 2, 5 and 6).

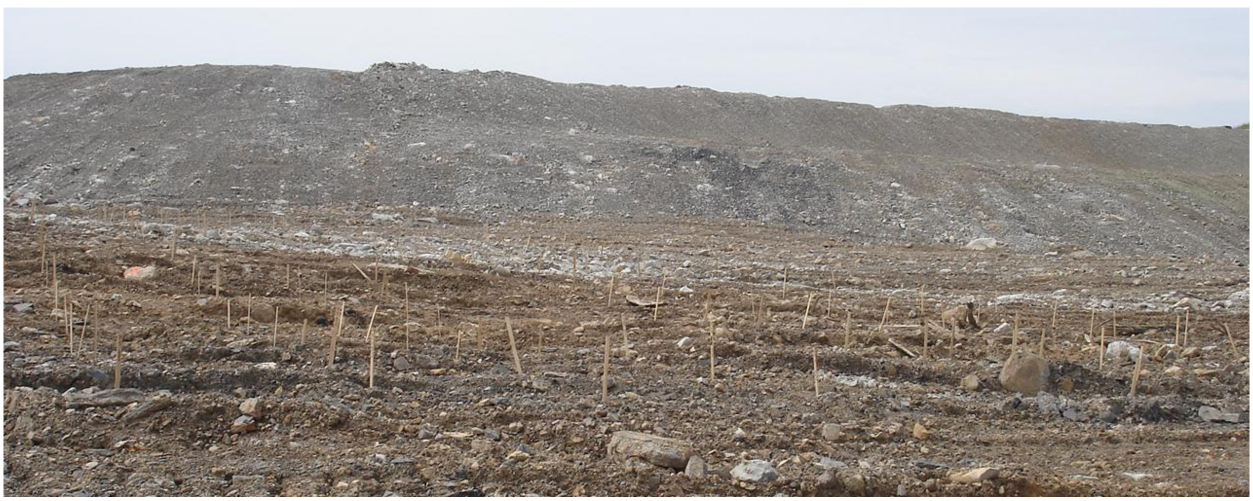


Figure 4. Planted area where tree shelters were not placed over the seeds on four blocks (3, 4, 7 and 8).

Statistical analyses were performed using SAS 9.1 software (SAS Institute, 2005). Using Proc GLM means statement, Fisher's t-tests were applied to test for differences in mean survival and growth between whole plots (shelters and no shelters). Significant differences in means were separated by the LSD test at an alpha level of 0.05. Within whole plots, ANOVA was used to evaluate the split plot experimental design and statistically assess the differences in survival and growth between peat treatments and among seed types. An alpha level of 0.05 was considered significant.

Two weeks after planning, soil samples were extracted at five locations in each block (at the four corners and center) to a depth of 15 cm to evaluate chemical properties at the site. Samples were analyzed for pH (1:1 soil:water) with a Beckman 43 pH meter and elemental content by the West Virginia University Soil Testing Laboratory by extracting each sample with a Mehlich 1 extract, which is composed of approximately 0.05N HCl and 0.025N H_2SO_4. The extract was analyzed with a Perkin Elmer 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 analysis was performed with ANOVA (completely randomized block design) to determine significant differences among blocks for soil parameters and the LSD test was used to separate means when significant (SAS Institute, 2005).

Results and Discussion

Soil analysis revealed a pH range from 5.2 to 6.7 across blocks (Table 1). Blocks 5, 7 and 8 had pH above 6.2, while the others were < pH 5.6. Blocks 2, 5 and 6 had significantly higher Ca content than other blocks, which translated into higher base saturation values. No other soil parameters were statistically significant among blocks. When comparing Blocks 1, 2, 5 and 6 (where tree shelters were placed) to Blocks 3, 4, 7 and 8 (no tree shelters), the tree shelter blocks appear to be slightly more acidic than the no tree shelter blocks based on pH, Ca, and base saturation. Soil differences between blocks were not statistically significantly between sheltered and non sheltered trees. We expected some variation in soils among blocks and these values are within anticipated ranges of soil chemical values.

Chestnut seeds established and survived at a significantly higher rate where tree shelters were placed on top of the seed compared to those that did not have a tree shelter (81 vs 63%) (Table 2). The tree shelters may have protected the seed from predators but there was no evidence that small mammals or deer had visited the plot. The chestnut planting area is near an active mining area with loud machinery operating within 1000 m of the site. In addition, the site is toward the center of the ridge and not close to undisturbed forest, which should hinder visitation by animals because of the distance from the edge of the forest to the planted area. Tree shelters may also slightly change the climate and environment within the shelter. In one way, the shelter could be a detriment by keeping temperatures high inside the shelter during summer, which could heat up the seedling and cause stress. However, during cold and windy times, the tree shelter could protect the seedling from frost or wind damage or tree shelters may have helped minimize transpirational demand of protected foliage associated with drying winds (Bergez and Dupraz, 1997).

Table 1. Chemical properties of soils where five chestnut seed types were planted at the Glory surface mine in West Virginia. Seeds were planted in 8 blocks and tree shelters were placed on blocks 1, 2, 5 and 6 and no shelters were placed on blocks 3, 4, 7 and 8.

Block	pH	P	K	Ca	Mg	CEC	BS
		mg kg^{-1}	---------------	$cmol^{+}$ kg^{-1}	----------------		%
1	5.3b	25	0.15	0.76b	1.85	9	30b
2	5.6ab	26	0.17	4.32a	2.08	12	53ab
3	5.2b	23	0.14	0.84b	1.78	12	28b
4	5.5ab	33	0.15	1.05b	2.30	12	40b
5	6.7a	41	0.15	3.86a	2.09	8	79a
6	5.5ab	30	0.12	3.50a	1.70	10	55ab
7	6.2a	35	0.11	2.59ab	1.97	10	64ab
8	6.6a	40	0.15	2.93ab	1.78	7	80a
Shelters	5.4	27	0.15	1.74	1.93	11	38
No shelters	5.7	36	0.14	3.22	1.96	9	70

Table 2. Chestnut seed survival with and without tree shelters across all five seed types and peat treatments at the Glory surface mine.

	Survival		
	Shelters	No Shelters	Total
	----------------------	%	----------------------
All Trees	**81a***	**63b**	**72**

*Shelter treatments with different letters are significantly different with an LSD test at $p<0.05$

Surprisingly, seeds planted with peat showed lower seed survival and establishment than seeds without peat (63% vs 81%, Table 3) and it is not clear as to why this might be the case. Rainfall during May through July was normal for this time of year with good distribution throughout these months. Average monthly rainfall total for this period is 44 cm (Wolf 1994), and 51 cm were received in 2009 (rainfall data from coal company rainfall gauges). However,

Table 3. Chestnut seed survival with and without peat treatment across all five seed types and tree shelter treatments at the Glory surface mine.

	Survival		
	Peat	No Peat	Total
	----------------------	%	----------------------
All Trees	**63b***	**81a**	**72**

*Peat treatment values with different letters are significantly different with an LSD test at $p<0.05$

August was drier than normal (9 cm) compared to 3 cm in 2009. We expected that the seeds planted with peat would experience less moisture stress and have better survival, but this was not true. There may, however, be other explanations such as pH or chemical effects of the peat rather than only those related to soil moisture availability for seeds.

On seeds with shelters, the peat treatment had no significant effect on survival (Table 4). However, blocks 1 and 2 were significantly lower in survival than blocks 5 and 6. Without shelters, peat treatment significantly lowered seed survival (44%) compared to no peat treatments (82%) (Table 5).

Table 4. Chestnut seed survival with shelters (blocks 1, 2, 5 and 6) with and without peat treatment across all trees at the Glory surface mine.

	Survival - Shelters		
Block	Peat	No Peat	Total
	-----------	%	-----------
1	72	76	74b*
2	72	60	66b
5	84	92	88a
6	96	88	92a
Ave	**82a****	**79a**	**81**

*Block totals with different letters are significantly different with an LSD test at $p<0.05$
**Peat treatment values with different letters are significantly different with an LSD test at $p<0.05$.

Table 5. Chestnut seed survival without shelters (blocks 3, 4, 7 and 8) with and without peat treatment across all trees at the Glory surface mine.

	Survival – No shelters		
Block	Peat	No Peat	Total
	-----------	%	-----------
3	48	56	52a*
4	40	96	68a
7	52	96	74a
8	36	80	58a
Ave	**44b****	**82a**	**63**

*Block totals with different letters are significantly different with an LSD test at $p<0.05$
**Peat treatment values with different letters are significantly different with an LSD test at $p<0.05$

Table 6. Chestnut seed survival for five seed types across shelter and peat treatments.

Seed Type	Survival
	----------- % -----------
American	67b*
Chinese	82a
B1F3	74b
B2F3	69b
B3F2	72b
Totals	**72**

*Values with different letters are significantly different with an LSD test at p<0.05

Table 7. Chestnut seed survival for five seed types without tree shelters with peat treatments. Statistically significant differences were assessed using split plot ANOVA analysis (α=0.05).

	Survival – No shelters		
Seed Type	Peat	No Peat	Total
	---------------	%	---------------
American	40	75	58a*
Chinese	60	80	70a
B1F3	45	85	65a
B2F3	35	85	60a
B3F2	50	85	68a
Totals	**44b****	**82a**	**63**

*Seed type totals with different letters are significantly different with an LSD test at p<0.05
**Peat treatment values with different letters are significantly different with an LSD test at p<0.05

Where tree shelters were placed on seeds, survival was not significantly different between peat and no peat treatments, but again Chinese seed survival was significantly higher than American and the hybrids (Table 8).

Tree height was significantly higher on seeds with shelters compared to no shelters (Table 9). Peat treatment had reduced height of seedlings in both the sheltered and unsheltered trees, but the reduction was not significant (Tables 10 and 11). On seedlings without shelters, Chinese showed significantly higher growth than American, but the hybrids were intermediate (Table 10). With tree shelters, Chinese was significantly higher than the B1F3 and B3F2 hybrids, and both were significantly taller than B2F3 and American seedlings (Table 11). We will continue to monitor survival and height growth of these seedlings during subsequent years.

Table 8. Chestnut seed survival for five seed types with tree shelters with peat treatments. Statistically significant differences were assessed using split plot ANOVA analysis (α=0.05).

	Survival – Shelters		
Seed Type	Peat	No Peat	Total
	---------------	%	---------------
American	80	70	75b*
Chinese	95	90	93a
B1F3	75	90	83b
B2F3	75	80	78b
B3F2	80	70	75b
Totals	**82a****	**79a**	**81**

*Seed type totals with different letters are significantly different with an LSD test at $p<0.05$
**Peat treatment values with different letters are significantly different with an LSD test at $p<0.05$

Table 9. Chestnut seed height with and without tree shelters across all five seed types and peat treatments at the Glory surface mine.

	Height		
	Shelters	No Shelters	Total
	----------------------	cm	----------------------
All Trees	**27a***	**16b**	**22**

*Shelter totals with different letters are significantly different with an LSD test at $p<0.05$

Table 10. Chestnut seed survival for five seed types without tree shelters with peat treatments. Statistically significant differences were assessed using split plot ANOVA analysis (α=0.05).

	Height – No Shelters		
Seed Type	Peat	No Peat	Total
	---------------	cm	---------------
American	13.4	12.7	13.1b*
Chinese	17.8	20.3	19.1a
B1F3	15.2	16.5	15.9ab
B2F3	15.4	16.5	16.0ab
B3F2	14.2	18.3	16.3ab
Totals	**15.2a**	**16.9a**	**16.1**

*Seed type totals with different letters are significantly different with an LSD test at $p<0.05$
**Peat treatment values with different letters are significantly different with an LSD test at $p<0.05$

Table 11. Chestnut seed height for five seed types with tree shelters with peat treatments. Statistically significant differences were assessed using split plot ANOVA analysis (α=0.05).

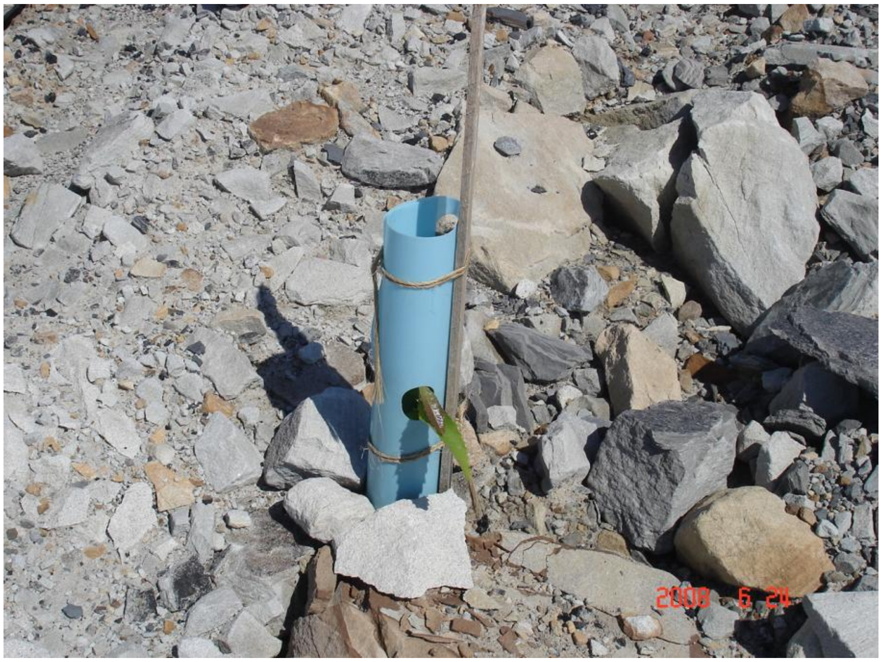
	Height – Shelters		
Seed Type	Peat	No Peat	Total
	---------------	**cm**	---------------
American	16.5	27.9	22.2c*
Chinese	32.5	32.0	32.3a
B1F3	30.5	26.7	28.6b
B2F3	25.4	21.6	23.5c
B3F2	24.6	32.0	28.3b
Totals	**25.9a****	**28.0a**	**27.0**

*Seed type totals with different letters are significantly different with an LSD test at p<0.05
**Peat treatment values with different letters are significantly different with an LSD test at p<0.05

A new study was initiated at a different site in West Virginia where seeds and seedlings of these five seed types were planted. No peat or tree shelter treatments were applied in this study, but ½ of the eight blocks of the experiment were placed on a loosely-dumped soil material with no strike off or dozer leveling, while the other ½ of the experiment used graded materials.

Summary and Conclusions

Five chestnut seed types (American, Chinese, B1F3, B2F3, and B3F2 hybrids) were planted into a mixed brown sandstone substrate material in 8 blocks with and without peat and with and without tree shelters on a surface mine in southern West Virginia. The mixed brown sandstone soil material had a pH that varied across the blocks from pH 5.3 to 6.7, with the tree sheltered blocks being slightly more acidic than the non-sheltered blocks. Germination and survival after the first year was significantly higher for seeds with tree shelters (81%) compared to 63% for seeds without tree shelters. Peat treatment also reduced survival and especially on the blocks without tree shelters (44% compared to about 80%). Chinese seeds had significantly higher survival at 82% compared to 67 to 74% survival for American and hybrid seeds. Height of trees showed a similar pattern as that of survival. Seedlings with tree shelters were significantly greater in height, but seeds with peat treatment were not significantly lower than no peat. The average soil conditions where tree shelters were placed on seeds had a slightly lower pH and base saturation compared to the blocks where no tree shelters were placed, which might account for the higher survival and growth of chestnut seedlings. Further monitoring over the subsequent years will assess whether these trends from first year growth will continue.



Picture 4. A Chinese chestnut seedling within a tree shelter.

Picture 5. A Chinese chestnut seedling with no peat and no tree shelter treatments.

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