Evaluation of Small Trees and Shrub Plantings on Reclaimed Surface Mines in West Virginia

Final Report
Cooperative Agreement S15AC20022
July 2015 – April 2017
Applied Science Program
Office of Surface Mining, Reclamation, and Enforcement

Submitted to:
Office of Surface Mining, Reclamation, and Enforcement
Mid-Continent Region
Program Support Division
Program & Tech Support Branch
501 Belle Street, Suite 216
Alton, IL 62002
Phone: (618) 463-6463 x5113 or x5114

Submitted by:
Jeffery Skousen, PhD
Alexis Monteleone
West Virginia University
333 Evansdale Drive
Morgantown, WV 26505
Phone: (304) 293-2667

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or presents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Abstract

The Forestry Reclamation Approach recommends that two tree types be planted during reforestation. While valuable crop trees such as oaks, maples and poplars are successfully planted, small trees and shrubs which occur in understories of native forests are often not planted. These species add floral and structural diversity to the forest and can provide habitat and food for wildlife. The goal of this study was to determine the survival and growth of 20 small tree and shrub species planted on four surface mines in West Virginia. Initial survival and height data were collected at the end of the first growing season after planting, and then survival and height were determined after 6 years at Fola and ICG, and after 8 years at Elk Run and Hobet. Soil properties varied widely among sites with pH ranging from 3.4 at Fola to 7.5 at ICG, fines ranged from 58% at ICG to 82% at Hobet, and elemental concentrations showed large variability. In general, 18 of the 20 species included in this study were successful in establishing and growing on the reclaimed surface mine sites in West Virginia. The exceptions were pawpaw (*Asimina triloba* L.) on the sites planted in 2008 and blueberry (*Vaccinium corymbosum* L.) on the sites planted in 2010. The best performing species overall were black chokeberry (*Aronia melanocarpa* Michx.) at 56% survival, black cherry (*Prunus serotina* Ehrh.) at 55%, Washington hawthorn (*Crataegus phaenopyrum* L. f.) at 54%, nannyberry (*Viburnum lentago* L.) at 52%, and hazelnut (*Corylus avellana* L.) at 50%. The two species that experienced the highest mortality were flowering dogwood (*Cornus florida* L.) at 10% and pawpaw at 9%.

List of Tables

List of Figures

Executive Summary

Hundreds of acres of mined land are reclaimed annually in West Virginia (WV) and are planted with hardwood tree species. Forestry and wildlife post-mining land uses require the planting of specific tree species designated by the individual mine permit and planting plan, which generally includes planting of commercially-valuable hardwood species. Establishment and growth of fruit- and nut-producing small tree and native shrub species has not been studied for reforestation plantings on surface mines. Though these species are not generally planted as part of forestry reclamation, they are commonly found in forest ecosystems of WV and are often an important component, contributing to both structural and floral species diversity. Survival and growth of 20 species of mast- and fruit-producing shrubs and small trees were evaluated to better understand their suitability for reclamation plantings. Seedlings were planted in graded overburden material during 2008 and 2010 on four reclaimed surface coal mines in WV. The selected sites were reclaimed using some FRA methods including reduced grading, end-dumped piles, steep slopes, and the use of tree-compatible herbaceous covers. The experiment was a completely randomized block design with four replicated blocks per site, two east-facing and two west-facing. Each block was comprised of 20 monoculture species plots, and within each plot 25 individuals were planted on 2.4 m x 2.4 m spacing. Initial data on survival and growth of these species was collected in 2008 and 2010 a growing season after establishment. Survival and growth of these species were measured again in 2015 and 2016 to determine individual species performance over time.

In general, 18 of the 20 species included in this study were successful in establishing and growing on the reclaimed surface mine sites in West Virginia. The exceptions were pawpaw (*Asimina triloba* L.) on the sites planted in 2008 and blueberry (*Vaccinium corymbosum* L.) on the sites planted in 2010. The best performing species overall were black chokeberry (*Aronia melanocarpa* Michx.) at 56% survival, black cherry (*Prunus serotina* Ehrh.) at 55%, Washington hawthorn (*Crataegus phaenopyrum* L. f.) at 54%, nannyberry (*Viburnum lentago* L.) at 52%, and hazelnut (*Corylus avellana* L.) at 50%. The two species that experienced the highest mortality were flowering dogwood (*Cornus florida* L.) with only 10% survival and pawpaw with 9% survival. Across all species, Elk Run showed the highest survival percentage at 51%, Fola and

ICG were between 40 and 45%, while Hobet had the lowest at 25%. Although survival and some height measurements were found to be greater for some trees on west-facing aspects when compared with east-facing aspects in this study, the differences between aspects were not critical and the results were skewed by a few species that performed particularly well on west-facing aspects at one site. The effect of aspect for the majority of species in this study and at most sites was not significant at the individual species level. Soil properties varied widely among sites with pH ranging from 3.4 at Fola to 7.5 at ICG, fines ranged from 58% at ICG to 82% at Hobet, and elemental concentrations showed large variability. When compared to the growth rates exhibited by these species in horticultural, forestry, or agricultural settings, the growth rates were considerably less in this project with these mine soil conditions.

In order to correlate average heights observed with soil properties in the mine soils, principle component analysis and principle component regression were used. The analysis showed potassium, phosphorus, and aluminum as being the most strongly correlated (R^2 of 0.20) with plant height when all species' average heights at all four sites were considered.

The results of this study demonstrated that several small tree and shrub species have potential for planting on surface mines in West Virginia. Species like black chokeberry, black cherry, Washington hawthorn, and nannyberry, which had greater than 50% survival after 6 or 8 years, are the most likely candidates. Other species which are adapted to better soil conditions did not perform well and should not be considered for plantings.

Introduction

The Appalachian Regional Reforestation Initiative (ARRI) is a cooperative effort by the States of the Appalachian Region with the USDI, Office of Surface Mining to encourage restoration of high quality forests on reclaimed coal mines in the eastern USA (Angel et al., 2005). The Forestry Reclamation Approach (FRA) has been developed by consensus of a broad group of academic researchers, industry, and regulatory personnel as the most suitable way to establish commercially valuable tree species on mined sites and to assure their rapid growth and development.

The FRA approach is described in five steps (Burger et al., 2005). Step 1 of the FRA involves creating a suitable rooting medium that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material. Growth media with low to moderate levels of soluble salts, equilibrium pH of 5.0 to 7.0, low pyritic sulfur content, and textures conducive to proper drainage are preferred. A mixture of brown weathered and gray sandstones, when loosely graded, can form a soil medium suitable for trees. Step 2 of the FRA states that operators should loosely grade the topsoil or topsoil substitutes because excessive soil compaction can have a major negative effect on survival and growth of trees. Step 3 of the FRA involves using ground covers that are compatible with growing trees. Ground-cover vegetation used in reforestation requires a balance between erosion control and competition for the light, water and space required by trees. Ground covers should include grasses and legumes that are slow-growing, have sprawling growth forms, and are tolerant of a wide range of soil conditions. Steps 4 and 5 encourage planting early-successional species and commercially valuable crop trees in the correct manner on reclaimed sites.

One of the areas that has not been studied in the Forestry Reclamation Approach is which early-successional species should be planted with the commercially valuable crop trees in Step 4. Because the soil or soil substitute has been placed in a non-compacted manner and the herbaceous ground cover has been reduced, the opportunity exists for recruitment and colonization of native and unplanted species from surrounding forests to re-inhabit the site. But many foresters know that planting a diversity of tree types at the start will more rapidly and greatly enhance the functional and structural diversity of the ecosystem. The intent of FRA reclamation is to develop a forest plant community with all the ecological components necessary for maximizing multiple-use of the reclaimed area. A diverse plant community composed of early-successional and later-successional species enhances the wildlife habitat potential, recreational, aesthetic, and productive value of the reclaimed land.

The overall goal of land reclamation is to return it to a condition equal to or better than the land's original condition before mining. One of the ways to do this is reforestation, which aims to return the land back into a sustainable forest after disturbance. Early-successional trees and shrubs are said to be ecological enhancers that provide many benefits to the ecosystem. This project will help determine additional species that could be planted during reclamation in order to enhance ecosystem development.

Experimental Design and Methods

Williams Forestry established shrub and small tree plantings on surface mines in West Virginia. Two sites (Elk Run and Hobet) were planted in 2008 and two other sites (ICG and Fola) were planted in 2010. The study was designed as a completely randomized block design. At each site, four blocks, each measuring 0.42 ha (4,160 m^2), were established (Figures 1 to 4). Two blocks were located on east-facing slopes, while the other two blocks were oriented on west-facing slopes. In each block, plots measuring 208 m^2 (14.4m x 14.4m) were delineated. In each plot, one of 20 different small tree or shrub species were randomly selected and planted with 25 individuals of each species on a 2.4 m x 2.4 m spacing (Table 1). The sites planted in 2008 only possess 19 species plots due to the absence of hazelnut, which was included in the 2010 plantings.

Block 7 East

14	1	18	2	3
4	20	15	13	19
11	7	9	6	12
17	10	8	16	5

Block 8 East

5	16	18	11	20
4	1	8	10	7
15	14	17	19	12
9	3	6	13	2

Block 7 West

10	5	9	4	18
7	11	14	3	13
2	19	8	16	15
1	6	20	17	12

Block 8 West

7	11	17	14	8
2	10	13	12	4
18	9	19	3	16
6	1	5	20	15

Figure 1. The randomized complete block design used at ICG. Numbers within plots represent different tree and shrub species (Table 1). Twenty-five individuals of each species were planted in each plot on 2.4 x 2.4 m spacings.

Block 3 East

empty	12	17	5	2
18	4	19	15	1
14	16	9	11	6
13	7	10	8	3

Block 4 East

8	19	12	1	empty
13	4	17	10	2
5	9	6	15	3
14	11	7	16	18

Block 3 West

18	2	3	Empty
1	10	15	16
12	17	6	7
19	4	9	11
8	13	5	14

Block 4 West

14	13	12	17	5	2
empty	18	4	19	15	1
	empty	16	9	11	6
	empty	7	19	8	3

Figure 2. The randomized complete block design at Elk Run. Numbers within plots represent different tree and shrub species (Table 1). Twenty-five individuals of each species were planted in each plot on 2.4 x 2.4 m spacings.

Block 1 East

empty	18	10	13	9
15	16	11	17	3
1	4	14	6	12
19	5	2	7	8

Block 2 East

empty	14	6	3	1
18	2	11	17	13
7	9	16	12	19
15	5	8	4	10

Block 1 West

empty	17	19	16
14	9	2	1
8	12	5	7
11	18	3	10
13	4	15	6

Block 2 West

18	5	13	empty
19	4	3	17
9	1	16	6
8	12	10	11
15	7	2	14

Figure 3. The randomized complete block design used at Hobet. Numbers within plots represent different tree and shrub species (Table 1). Twenty-five individuals of each species were planted in each plot on 2.4 x 2.4 m spacings.

Figure 4. The randomized complete block design at Fola. Numbers within plots represent different tree and shrub species (Table 1). Twenty-five individuals of each species were planted in each plot on 2.4 x 2.4 m spacings.

Table 1. List of tree and shrub species used in trials. Growth forms were determined using the USDA Plants Database.

Growth Form	Common Name	Scientific Name
Trees	American Crabapple	*Malus coronaria* L.
	Black Cherry	*Prunus serotina* Ehrh.
	Choke Cherry	*Prunus virginiana* L.
	Common Apple	*Malus pumila* Mill.
	Common Pear	*Pyrus communis* L.
	Eastern Redbud	*Cercis Canadensis* L.
	Elderberry	*Sambucus Canadensis* L.
	Flowering Dogwood	*Cornus florida* L.

	Pawpaw	*Asimina triloba* L.
	Persimmon	*Diospyros virginiana* L. f.
	Serviceberry	*Amelanchier arborea* Michx. f. Fernald
	Red Mulberry	*Morus rubra* L.
	Washington Hawthorn	*Crataegus phaenopyrum* L. f.
	Wild Plum	*Prunus Americana* Marshall
Shrubs	Black Chokeberry	*Aronia melanocarpa* Michx.
	Blueberry	*Vaccinium corymbosum* L.
	Gray Dogwood	*Cornus racemose* Lam.
	Hazelnut	*Corylus avellana* L.
	Highbush Cranberry	*Viburnum trilobum* L.
	Nannyberry	*Viburnum lentago* L.

Study Sites

2008

Elk Run and Hobet were planted in 2008, each with four blocks. They are located in the Appalachian Plateau physiographic region of southwestern West Virginia (Figure 5). The Elk Run mine is located in central Boone County, WV, and covers roughly 2,000 ha. The mine was operated by Alpha Natural Resources. The tree and shrub planting block locations at Elk Run are located at approximately 38° 04’ 20” N, 81° 43’ 27” W (Figure 6). The Hobet mine near Madison, WV, covers approximately 5,000 ha in Boone and Lincoln counties. The mine was operated by several companies: Hobet, Arch, Magnum, and now is held by the Virginia Conservation Legacy Foundation. The Hobet block locations are located at approximately 38° 07’ 38.76” N, 81° 52’ 37.83” W and are a part of the S-0128-78 permit in the Long Branch area of the mine (Figure 7).

Figure 5. The Appalachian Plateau physiographic region in Boone County of southwestern West Virginia where the Hobet and Elk Run Mine are located.

Figure 6. Satellite image of research block locations on Elk Run Mine, Boone County, WV in 2008.

Figure 7. Satellite image of research block locations on Hobet Mine, Boone County, WV in 2008.

The mine soil on the research area at Elk Run is characterized by a mixed brown and gray sandstone substrate. The blocks were located on slopes that averaged 14 and 20 percent. The research plots had a wide range of ground cover from 0 to 100 percent. There was evidence of gully erosion, particularly where the ground was bear with little to no vegetative cover. Common groundcover species that existed at Elk Run include birdsfoot trefoil (*Lotus corniculatus* L.*)*, orchardgrass (D*actylis glomerata* L.*)*, tall fescue (*Schedonardus arundinacea* Schreb.*)*, perennial ryegrass (*Lolium perenne L*.), sericea lespedeza (*Lespedeza cuneate* Dum. Cours.*)*, knotweed (*Polygonum aviculare* Siebold & Zucc.*)*, white aster (*Symphyotrichum ericoides* L.*),* casper spurge (*Euphorbia lathyris* L.*)*, and broomsedge bluestem (*Andropogon virginicus* L.*)*. In areas where the groundcover was good, survival of woody growth was poor. Natural encroachment of woody plants onto the mine site was observed from the surrounding dense forest and those species commonly found encroaching included autumn olive (*Elaeagnus umbellata* Thumb.*)*, black locust (*Robinia pseduoacacia* L.*)*, sycamore *(Platanus occidentalis* L.), and princess trees (P*aulownia tomentosa* Thumb.*).*

A mix of brown and gray sandstone characterized the Hobet mine soil with many rock fragments ranging in size from small pebbles to cobble size. The site had extensive gully erosion, due to both the steep slope and absence of sufficient herbaceous cover to slow water runoff. The average slope of the area was between 18 and 25 percent depending on the research block. The groundcover existing in the research area ranged from having a 0% cover to a 100% ground cover. The most common species found in the area included birdsfoot trefoil, orchardgrass, tall fescue, perennial ryegrass, sericea lespedeza, knotweed, white aster, caper spurge, and broomsedge bluestem. The east facing research blocks (E1 and E2) at Hobet were partially bulldozed after establishment. Forest encroachment from the existing forest that surrounds the research blocks was starting to occur. There is some natural colonization by black locust, autumn olive, princess trees, and sycamore species into the plot.

2010

ICG and Fola mine sites were planted each with four blocks in 2010. These sites are also located in the Appalachian Plateau physiographic region of WV (Figure 8). ICG is located in Nicholas and Webster Counties and the mine was operated by several companies over the years: Shell, Evergreen, and International Coal Group. The mine covers approximately 2,000 ha. The two east-facing ICG blocks are located at approximately 38° 26’ 08.45” N, 80° 37’ 05.74” W, and the two west-facing ICG blocks are located at approximately 38° 27’ 21.95” N, 80° 36’ 36.96” W (Figure 9). These research blocks are a part of permit number S-235-76. Blocks 7W and 7E were established in a Clarion shale substrate. This mine soil consists of numerous shale channers or small chips that absorb thermal radiation, thereby making the surface very hot during summer. This site had slopes ranging from 25 to 30 percent. The mine soil produced almost no herbaceous cover, which allowed the planted woody growth to grow free from herbaceous cover competition. The most common herbaceous species that occurred included sericea lespedeza, knotweed, caper spurge, birdsfoot trefoil, Queen Anne’s lace *(Daucus carota* L.*)*, coltsfoot *(Tussilago farfara* L.*)*, thistle (*Onopordum acanthium* L.*)*, and yarrow *(Achillea millefolium* L.*)*. There was an established forest surrounding both 7W and 7E blocks and encroachment by autumn olive, princess trees, and black locust was apparent. The other two research blocks at ICG, 8W and 8E, were planted in a mixed brown and gray sandstone mine soil. The slopes of these remaining blocks were not as steep as 7E and 7W and there was more competition from both herbaceous and woody plant types. The common encroaching species here were the same as those in the other two blocks.

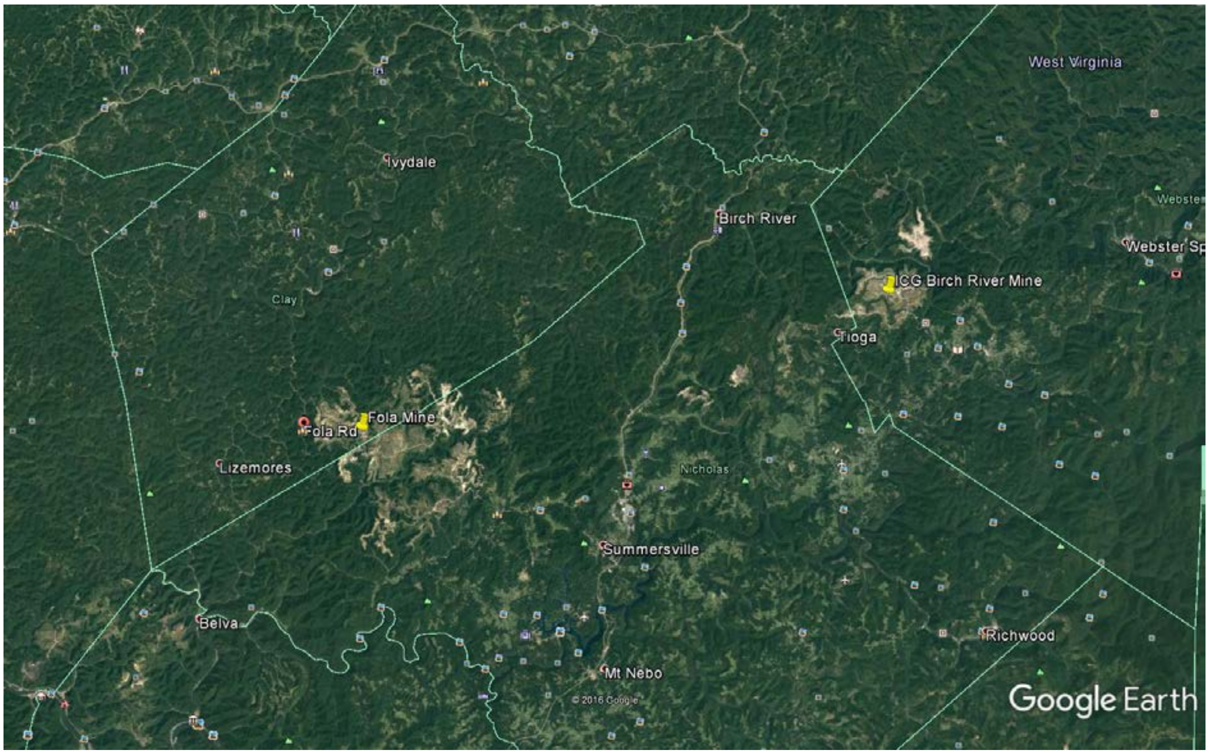

Figure 8. The Appalachian Plateau physiographic region in Clay, Nicholas, and Webster Counties of West Virginia where the Fola and ICG Mine are located.

Figure 9. Satellite image of research block locations on ICG Mine, Webster and Nicholas County, WV in 2010.

Fola is located in Clay County and was owned and operated by Fola Coal Company and then by Consolidation Coal Company. Fola covers approximately 4,000 ha. The research blocks are located at approximately 38° 35’ 24.66” N, 81°08’94.19”W (Figure 10). Due to the high and dense vegetation growing at the site in 2015, only two of the four research blocks could be found. One block, F2W, is close to a road and has an average slope of 24 percent. The mine soil of this block is a mixed brown and gray sandstone materials with gray being more dominant, which included numerous large rocks on the surface. The very dense and almost impassable vegetation was comprised of sericea lespedeza and bramble (*Rubus spp.)*, Goldenrod (*Solidago canadensis)*, and broomsedge bluestem along with volunteer woody growth from black locust and autumn olive. The east-facing block had less percent herbaceous groundcover than the west-facing block. Ground cover percentages were generally less than 100% and included large bare patches of ground. Common herbaceous and woody species that occupied the area included the same species found on the other block.

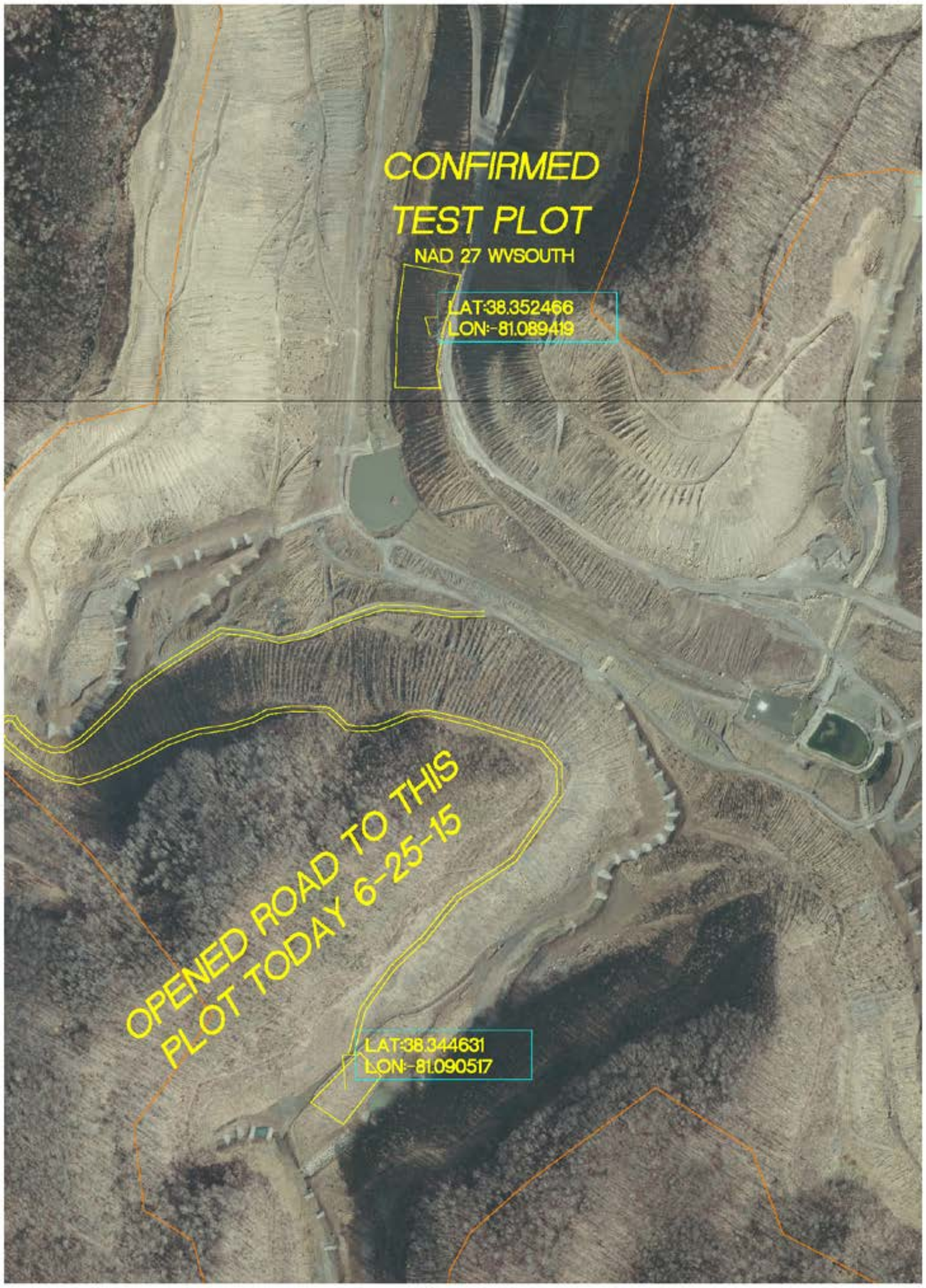

Figure 10. Satellite image of research block locations on Fola Mine, Clay County, WV in 2010.

Tree-planting and Early Measurements

All seedlings were planted by workers of Williams Forestry as bareroot 1-0 stock and were kept refrigerated at approximately 36°F (2.2°C) with the roots contained in bags until the day of planting, with the exception of the highbush blueberry, which were transplanted from containers. Approximately 300 of each species were purchased each year even though only 200 would be used for the study. Bareroot seedlings were separated into bundles of 25 with the largest and smallest individuals being culled during separation, so that moderately-sized individuals would be planted in the study plots. The bagged seedlings were removed from refrigeration the morning of planting and the roots of all bare root seedlings were dipped in a water and TerraSorb™ suspension. The TerraSorb™ suspension was used to protect the roots from dessication during the time between storage in the planting bags and planting. Root pruning was kept to a minimum and was only allowed when root length exceeded blade length (>20 cm). Each planted seedling was marked with a colored pin flag to aid in subsequent location and measurement.

2008 and 2010 Data Collection

Blocks were assigned a number followed by a letter, which corresponds to the aspect of the block. For example, block 2W would represent block 2, west-facing. Every seedling within a species plot was assigned a number (from 1 to 25) so that individuals could be tracked for survival, growth, and health over time.

A survey of all planted trees and shrubs was conducted for survival, growth, and health at the end of the first growing season. In reclamation plantings, the first year often produces the highest woody plant mortality, with less mortality in year two and beyond (Burger et al., 2005).

Height was measured from ground level to the height of the highest living tissue, and was recorded to the nearest cm using a standard meter stick. As seedlings were planted on a slope, the meter stick was placed on the higher side of the hill for all measurements. When an individual suffered from stem dieback, the height measurement was taken at the highest point of the stem that was determined to be living at the time of measurement. Diameter was measured at ground level, using digital calipers, and was recorded to the nearest millimeter. Only the dominant stem was measured for height and diameter on individuals exhibiting multiple stems. Other measured variables included herbivory, dieback, chlorosis, etc. These measurements were done by workers employed by Williams Forestry. The data collected during the first year after planting were made available for analysis in this study.

2015 and 2016 Data Collection

A survey of all trees and shrubs was conducted in 2015 and 2016. Survival, growth, and health of each individual was assessed. Due to the increased size and growth of the trees, modifications of the sampling techniques from the original sampling design in 2008-2010 were adopted. To better assess the height achieved by each individual plant, height was measured using a meter stick and read to the nearest 0.1 meter instead of cm. Diameter was taken at 2.5 cm above ground level where possible. With multi-stemmed shrubs and trees, crown cover was measured instead of a single stem diameter. Crown cover consisted of measuring the average spread of the shrub to the nearest cm. In the field, this consisted of obtaining the shortest and longest values of spread and averaged.

In addition to tree and shrub measurements, soil sampling was also performed in order to correlate the success of the species with mine soil properties. For this, at three random locations within each plot, a soil sample was collected to a depth of 15 cm. These three samples were composited into one sample and used as a representative sample for each plot. Therefore, 20 soil sample composites were collected for each block and 80 samples were collected per site for a total of 320 samples for analysis.

Herbaceous ground cover was also estimated to allow an assessment of competition and its effect on tree and shrub survival and growth. Ground cover was evaluated visually using a ¼-m^2 quadrat in the field. The quadrat was randomly placed in three places in each species plot. At each of these three points, the species occupying the space in the quadrat were recorded as well as their percent cover. Using this information, herbaceous cover competition was correlated to species success.

Samples were dried, weighed and sieved into coarse and fine fractions (2-mm sieve). The percentage of fine material and coarse material for each soil was determined. The soil fine fraction was analyzed for chemical properties including soil pH using a 1:1 soil:water ratio, soluble salts (as electrical conductivity using 2:1 soil:water ratio). Phosphorus (P), potassium

(K), magnesium (Mg), calcium (Ca), sodium (Na) and other elements (Fe, Al, Mn, Zn, Cu, and Ni) were analyzed using the Mehlich 1 extraction solution. From this chemical analysis, soil properties were correlated to shrub and tree growth through regression analyses and principle component analysis.

Statistical Analysis

The survival data was left-skewed and transformations did not work well to correct the lack of normality in the data. Therefore, the parametric methods could not be used, rather, the data was treated as categorical and Mantel-Haenszel frequency analysis was used. Chi-square analysis of survival by species was done to compare survival by year (2015 and 2016). The effect of aspect on survival was explored through frequency analysis (Chi-square) for all species combined and separately by species. Chi-square frequency analysis was also used to quantify the association of site and survival status with all species and aspects combined, and additionally was completed separately by species and by aspect. Repeated frequency analysis using the ridit scores of the Mantel-Haenszel procedure measuring the nonzero correlation of age and survival was done to test the effect of age on survival, utilizing the first year after establishment and the ages 7 and 8 for the older plots (Elk Run and Hobet), and 5 and 6 for the younger plots (Fola and ICG).

To test the effect of age on plant height, a repeated measures ANOVA was done. Due to the irregular timing of sampling, the ANOVA was adjusted to account for the irregular spacing between sampling times. Two separate ANOVAs were used for two different age site groups, Elk Run with Hobet and Fola with ICG so that no site had an advantage and was only compared against the site of the same age. Age was used as the repeated measure factor in a model with effect of age, site, aspect, and their interactions as independent variables on height as a response. After finding significant main effect(s) or interaction(s) in the repeated measure ANOVAs, Tukey-Kramer adjustments were applied to multiple comparisons to control type 1 errors.

In order to relate site properties (physical and chemical soil properties) with average height, a stepwise regression, principle component analysis and principle component regression were used. First, stepwise regression was performed to regress the height of individual species on all site properties. The two different aged site groups were analyzed separately, with regression only performed on sites that were the same age. Selection criteria for any variable entering the multiple regression model was 0.3 and the criteria for staying in the model was 0.05. In order to analyze all sites (older and younger) by principle component analysis, the average height of each plot and species was normalized using the difference between minimum and maximum average height. Specifically, for each species, the minimum height minus 0.01 m was subtracted from each average height measurement. Then the new height was multiplied by 100 and divided by the new maximum height (maximum height minus the minimum height). In this final step, the normalized height of each species and plot is expressed as a percentage of the maximum height for the respective species.

$$Normalized\ Height = \frac{(original\ height - min)(100)}{maximum\ height - min} = \frac{(new\ ind.height)(100)}{new\ maximum\ height}$$

Once height was normalized, all sites could be used in one analysis. A principle component analysis (PCA) was utilized to find the uncorrelated site variables among all 16 physical and chemical variables. The principle component analysis produced a number of principle component groups with different contributions from each input variable in the PCA. Those variables with the highest eigenvector value (greater than 0.3) represented the variables with the most contribution to each principal component. Principle component regression (PCR) was a next step, where the PCs and later, the corresponding variables selected in the PCA were utilized to predict the normalized height.

Statistical analyses were performed using SAS 9.4 software (SAS®, Version 9.4, SAS Institute Inc., Cary, NC, Copyright ©2002-2012). Significance criterion alpha for all tests was 0.05.

Results

Soil Properties

Soil conditions were very variable across the four sites included in this study (Table 3). Elk Run and Fola had a lower average slope (around 15%) compared to about 22% at Hobet and ICG. It was observed that some soils were more compacted than others, and the differences were largely related to slope. Compaction was not measured on these sites with probes or meters, but appeared to be lower on those sites with steeper slopes based on walking and extracting soil samples. The assumed lower compaction at Hobet and ICG could have influenced species growth. But as noted, Hobet generally had the lowest average heights for most of the shrub and tree species compared to the other sites, and Elk Run had the highest average heights.

The sites had different average soil pH values, which impacted the growth of the planted species. ICG and Elk Run soils had the highest pH values (above 6.0), while Fola and Hobet soils were below 5.0 (Table 2). Soluble salts were very high at Fola, being three times higher than the average EC values at other sites. The low pH condition of the soil at Fola probably allowed for solubilization of elements, which contributed to the high EC levels at that site. ICG had the lowest percent fines at 58%, while the other sites had higher levels. A higher level of percent fines usually improves water relations and nutrient holding capacity.

Table 2. Average values for site parameters for soils at each site measured in 2015.

	Sites			
Soil Properties	**Elk Run**	**Hobet**	**ICG**	**Fola**
Average slope (%)	14	22	23	16
Average Groundcover (%)	27	39	50	67
Fines (%)	74	82	58	66
Average pH (range)	6.4 (4.9 – 7.9)	4.5 (3.9 – 6.2)	7.5 (7.3 – 7.6)	3.4 (3.3 – 3.5)
EC (µS/cm)	85	73	84	261
K	0.11	0.06	0.16	0.12
Ca	7.21	0.06	0.16	0.12
Mg	2.56	0.28	0.16	0.12
P	36.71	12.58	36.30	6.48
Al	62.72	71.77	35.98	235.60
Zn	1.99	0.94	4.79	1.85
Ni	0.80	0.31	0.78	1.46
Cu	1.79	0.47	2.96	2.92
Mn	38.91	13.82	47.12	10.67
Fe	0.04	0.02	0.03	0.04
Na	0.04	0.02	0.03	0.04

The site with the lowest pH, low percent fines value, and highest EC was the Fola site, which should have made this site the poorest in terms of shrub and tree growth. But Fola generally had better average growth for planted species than Hobet. The ICG site was found to have the highest pH value overall and the lowest percent fines. ICG had a unique mine soil material with a mix of broken sandstone and Clarion shale materials, and was characterized by shale channers that were found in many places on the surface. This material also inhibited the amount of herbaceous competition growing on the site (Table 2). The Hobet site had a low pH of 4.5, and the largest percentage of fines. Gully erosion was a common occurrence noted at this site due to the fine material in soils and steep slopes. Elk Run had the largest pH range. This substrate was similar to that of Hobet, and gully erosion and bare soil conditions were common sights on the research blocks.

Other chemical properties of the soils at the four different sites were also variable (Table 2). Elk Run had the highest concentrations of calcium, magnesium, and phosphorus. ICG had the highest amount of potassium, zinc, copper, and manganese. Fola had the most competing groundcover, and had the highest concentrations of aluminum and nickel. The Hobet site did not possess any of the highest concentrations of any chemical parameter, but generally had the lowest concentration of many chemicals out of any of the sites including potassium, calcium, phosphorus, zinc, nickel, copper, iron, and sodium.

Tree and Shrub Survival

The four sites included in the study were planted at different times: the older plants were established in 2008 at Elk Run and Hobet, and younger plants were established in 2010 at Fola and ICG. Due to the two-year difference in survival and growth times, survival after 8 years could be very different from survival after only 6 years, so these sites were separated into older and younger plantings. There were also 14 trees and six shrubs. To make the figures more readable, the species figures were generally separated into three figures, the first seven trees (alphabetically A-E), the second seven trees (alphabetically F-W), and the six shrubs on the third figure.

No significant difference was found between the survival percentages between 2015 and 2016 ($p = 0.51$, Table 3). Due to the insignificant difference between 2015 and 2016 data, the 2016 data were chosen to represent survival percentages in further detail.

Table 3. Average survival values for all species in 2015 and 2016.

Species	**% Survival 2015**	**% Survival 2016**
American Crabapple	41	40
Black Cherry	52	55
Black Chokeberry	56	56
Blueberry	31	30
Chokecherry	44	44
Common Apple	41	41
Common Pear	38	47
Eastern Redbud	48	45
Elderberry	27	27
Flowering Dogwood	11	10
Gray Dogwood	45	44
Hazelnut	51	50
Highbush Cranberry	47	47
Nannyberry	53	52
Pawpaw	9	9
Persimmon	37	37
Red Mulberry	41	41
Serviceberry	47	44
Washington Hawthorn	57	54
Wild Plum	45	44
TOTAL	41	40

Significant differences in survival were found among the different species across sites, and this proved to be highly significant ($p < 0.0001$) (Figures 11 A-C, Table 4). Clearly, some species established and survived better than others due to the individual's health and quality at planting, the stresses the individual plants experienced in the soils and environment at each site and block, and to the differences in the species' adaptation to the stressful conditions of mine soils. A comparison will be made among species about first year survival and then to subsequent survival after 6 or 8 years on these sites. For the entire study including all species and all sites, the survival was 40% (Table 3).

The best performing species overall was black chokeberry, having 56% survival (Table 4). Four other species had survival percentages at or above 50% including black cherry (55%), Washington hawthorn (54%), nannyberry (52%), and hazelnut (50%). The most median survival percentages for species in this study were between 40 and 50%. The 10 species in this group included common pear (47%), highbush cranberry (47%), eastern redbud (45%), chokecherry (44%), gray dogwood (44%), serviceberry (44%), wild plum (44%), common apple (41%), red mulberry (41%), and American crabapple (40%). Blueberry and persimmon had survival percentages between 30 and 40%. Elderberry was the only species between 20 and 30% survival. Two species in the study had survival percentages at or below 10%, flowering dogwood (10%) and pawpaw (9%).

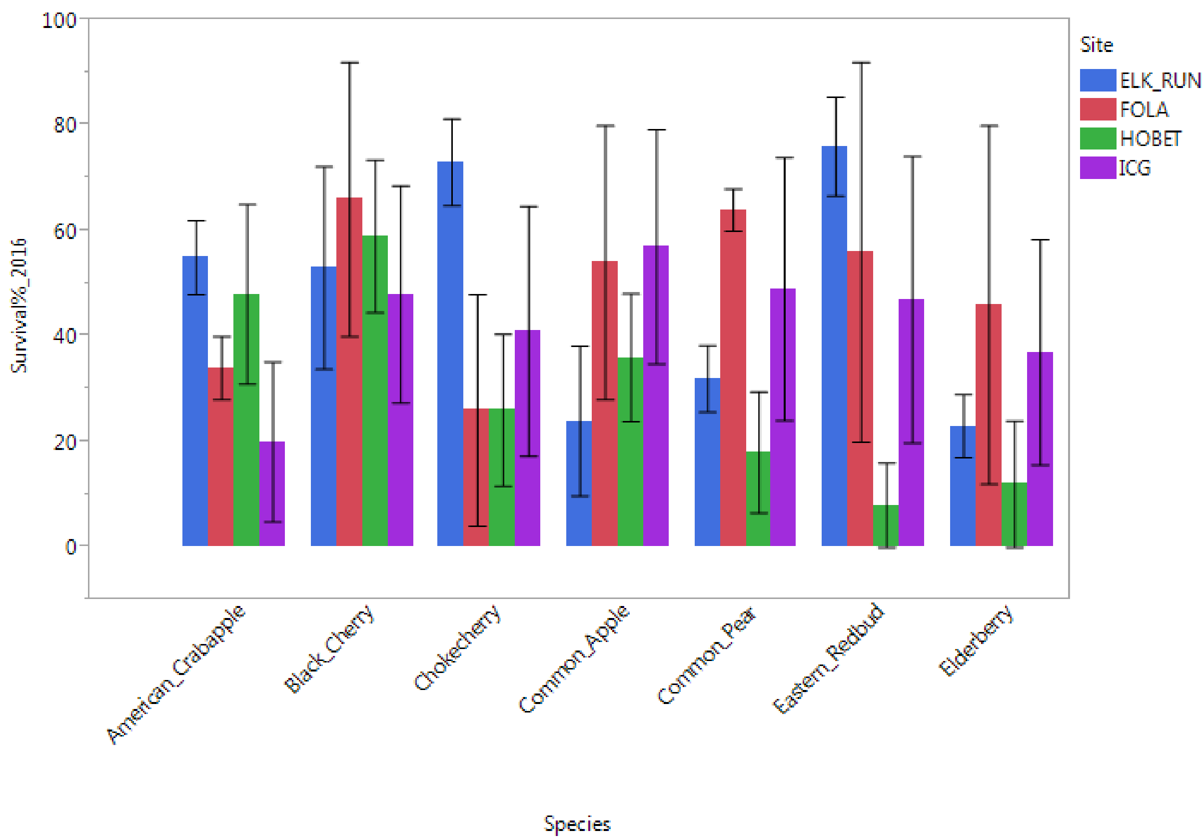

Figure 11A. Average survival percentages of seven tree species (A-E) by site in 2016 with error bars.

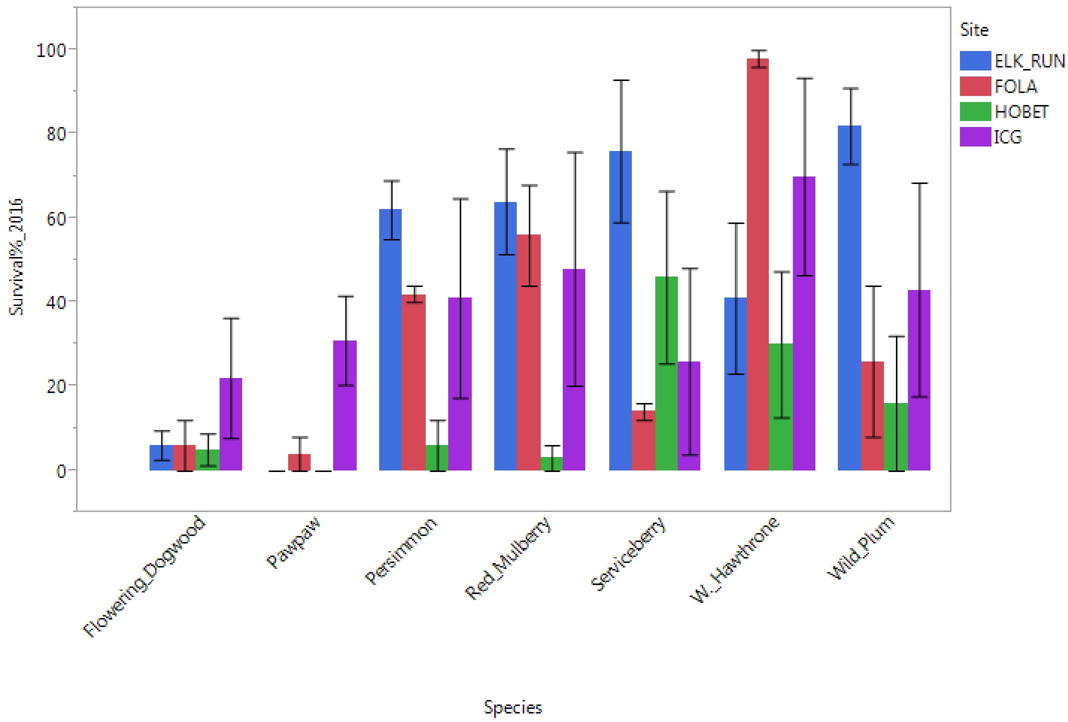

Figure 11B. Average survival percentages of seven tree species (F-W) by site in 2016 with error bars.

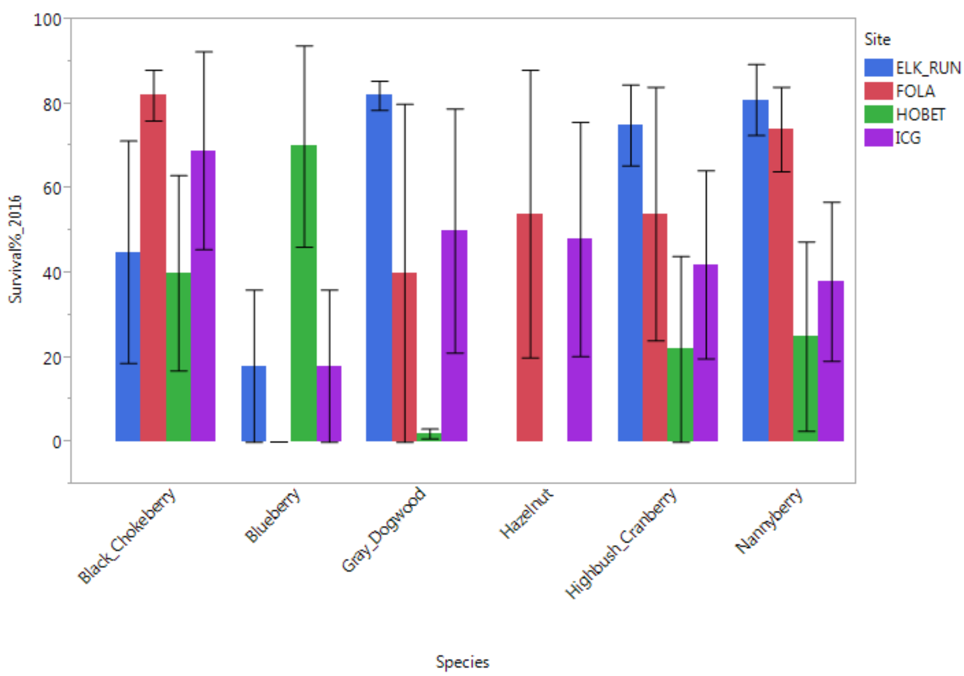

Figure 11C. Average survival percentages of shrub species by site in 2016 with error bars.

Table 4. Species survival by site. The Chi-square probability of significant difference between sites is shown.

Species	Elk Run	Hobet	ICG	Fola	Chi-Square p-value	Average
American Crabapple	55	48	20	34	<0.0001	40
Black Cherry	53	59	48	66	0.17	55
Black Chokeberry	45	40	69	82	<0.0001	56
Blueberry	18	70	18	0	<0.0001	30
Chokecherry	73	26	41	26	<0.0001	44
Common Apple	24	36	57	54	<0.0001	41
Common Pear	32	18	49	64	<0.0001	37
Eastern Redbud	76	8	47	56	<0.0001	45
Elderberry	23	12	37	46	<0.0001	27
Flowering Dogwood	6	5	22	6	<0.0001	10
Gray Dogwood	82	2	50	40	<0.0001	44
Hazelnut	N/A	N/A	48	54	0.56	50
Highbush Cranberry	75	22	42	54	<0.0001	47
Nannyberry	81	25	38	74	<0.0001	52
Pawpaw	0	0	31	4	<0.0001	9
Persimmon	62	6	41	42	<0.0001	37
Red Mulberry	64	3	48	56	<0.0001	41
Serviceberry	76	46	26	14	<0.0001	44
Washington Hawthorn	41	30	70	98	<0.0001	54
Wild Plum	82	16	43	26	<0.0001	44
TOTAL	51	25	42	45		40

The Elk Run site showed the overall highest survival at 51%, Fola and ICG were intermediate at 45 and 42%, respectively, and the Hobet site had the lowest at 25%. Species survival significantly ($p < 0.0001$) varied among sites for all species except black cherry and hazelnut. Both of these species had relatively good survival compared to other species across all sites.

Aspect had a significant effect on survival (p <0.0001). The west-facing blocks had an overall greater survival of 44% than the east-facing blocks of 36%. The effect of aspect on the individual species level was analyzed (Figures 11A-C).

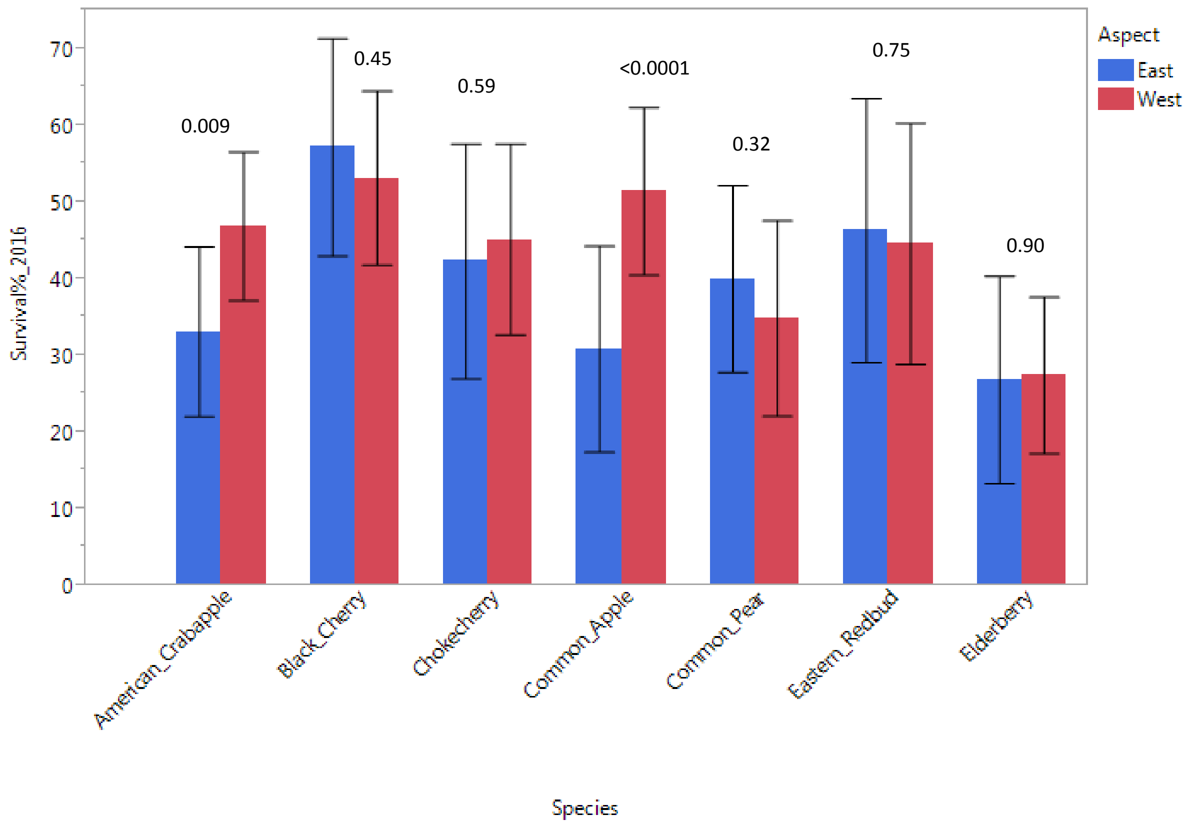

Figure 12A. Survival percentages in 2016 of seven tree species (A-E) by aspect with error bars and Chi-square p-values shown.

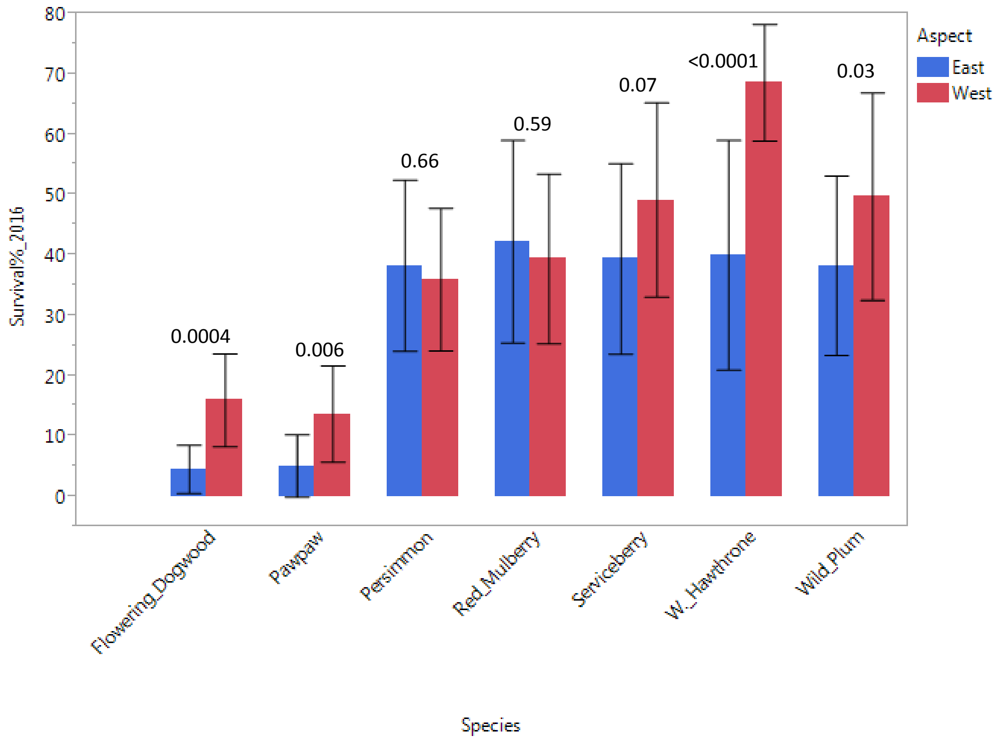

Figure 12B. Survival percentages in 2016 of seven tree species (F-W) by aspect with error bars (p <0.0001).

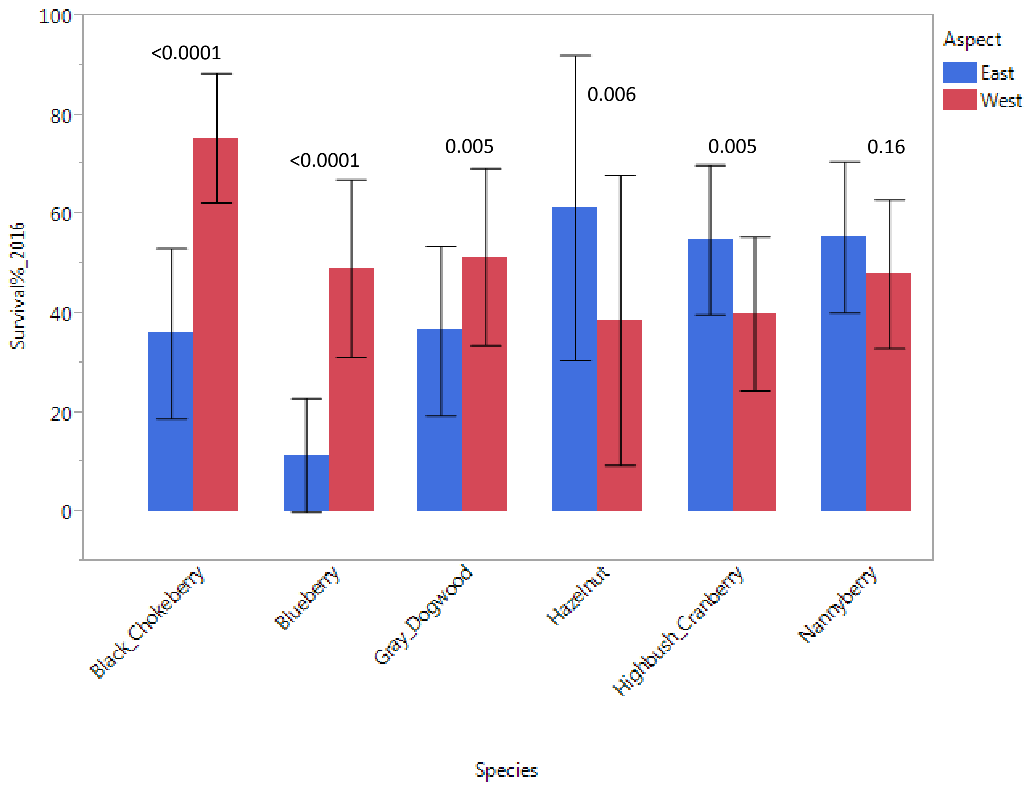

Figure 12C. Survival percentages in 2016 of shrub species by aspect with error bars (p <0.0001).

Black cherry and hazelnut were the only species that did not exhibit a significant difference in survival between the two aspects included in the study (Figures 12A-C). Many species exhibited the same trend as the trend observed in the study overall, with the west-facing blocks having better survival than the east-facing blocks. The exceptions to this included black cherry, common pear, eastern redbud, hazelnut, highbush cranberry, nannyberry, persimmon, and red mulberry which showed greater survival on east-facing blocks. Survival percentages for planted woody species were significantly different between the sites with Elk Run starting between 70-100% and arriving at 50% in 2016, while Hobet had only between 50-75% survival the first year and 25-50% survival in 2016.

Shrub survival after the first year was usually about 5 to 10% higher than tree survival after the first year (Table 5). For example, Elk Run had 87% shrub survival and 76% tree survival after the first year, which dropped to 60% for shrubs and 48% for trees after the 8th year. Many species did not survive well after the first year, and survival continued to decline with time. Other species, like wild plum and persimmon, had good survival the first year and showed good survival after the initial transplanting shock period.

Table 5. The nonzero correlation of age and survival of species on the older sites (Elk Run and Hobet) planted in 2008. Significance was determined by p-value <0.05. P-values derived from the repeated frequency analysis using the ridit scores of the Manel_Haenszel procedure. The nonzero correlation value was used because of the repeated measures.

	Survival with respect to year planted (years)			**Nonzero correlation; Q_{CSMH} p-value**
Species	**1**	**7**	**8**	
American Crabapple	56	55	52	0.56
Black Cherry	67	51	56	0.38
Black Chokeberry	84	43	43	0.02
Blueberry	73	45	44	0.15
Chokecherry	91	51	50	0.005
Common Apple	81	30	30	0.005
Common Pear	44	26	25	0.15
Eastern Redbud	61	46	42	0.27
Elderberry	48	18	18	0.11
Flowering Dogwood	12	6	6	0.15
Gray Dogwood	45	44	42	0.64
Highbush Cranberry	75	49	49	0.09
Nannyberry	86	55	53	0.02
Pawpaw	64	0	0	0.0002
Persimmon	80	35	34	0.007
Red Mulberry	55	34	34	0.23
Serviceberry	80	67	61	0.40
Washington Hawthorne	71	40	36	0.02
Wild Plum	84	51	49	0.05

Of the 19 species included in the study, eight of them showed a significant decline in survival between ages 1 and 8. Significance was determined by the Q_{CSMH} values found in the Cochran-Mantel-Haenszel test. If the probability was found to be <0.05 they were considered significant. The severity of the decrease in survival was specific with some species like Washington hawthorn having a severe decline in survival from 72 to 36%, while others declined but not at such a precipitous rate. Pawpaw had the lowest survival percentage at age 1 and at age 8, and most of the individuals of this species died. This was the most dramatic decline among all the species. Chokecherry had the highest average survival after the first year (92%) and survived well to 50% after year 8. Common apple, persimmon, and Washington hawthorn also experienced significant declines in survival after the first year. Species with survival percentages under 50% in the later years may indicate that they may not be species that operators should plant during reforestation projects. This large mortality in the year seedlings were planted is possible because either the planting stock was of poor quality, planting conditions and techniques were poor, or that the species were not suited or adapted to the conditions of the site.

Other species did not experience such an intense survival decline after planting and during the first growing season. These species may be better suited to the growing environment than those that had greater than 50% mortality in the first year. Serviceberry had the highest survival at 80% after the first year, and ended up having a high survival after 8 years of 61%. Gray dogwood started out with 46% survival and ended with survival at 42%, demonstrating that this species, once established, persisted on mine sites. Blueberry and highbush cranberry experienced dramatic mortality.

The same analysis was conducted for the younger sites (Fola and ICG) which were established in 2010. Again, the data were not normally distributed and exhibited a left-skewedness that could not be fixed by using transformations. As a result, frequency analysis was used in order to test the effect of time on survival on ICG and Fola.

Unlike the two older sites, Fola and ICG had similar survival percentages in year 1 between the two growth forms. At Fola at the end of year 1, the shrubs had 87% survival while trees had 76%. By year 6, the percent survival was reduced to 51% for shrubs and survival followed the same trend at Fola and ICG as shown at the other sites (Elk Run and Hobet) with survival diminishing with age. A few species experienced a die-out during 2010, the year of establishment, and they began with low survival percentages in year 1 and continued to decline with age. The majority of species did not have a dramatic die off during year 1, but instead experienced mortality after the first year and in between later sampling times. This was different from what was the most prevalent situation on the older sites, where the most severe mortality occurred during the first growing season.

Table 6. The nonzero correlation of age and survival of species on the younger sites (Fola and ICG) planted in 2010. Significance was determined by p-value <0.05. P-values derived from the repeated frequency analysis using the ridit scores of the Manel_Haenszel procedure. The nonzero correlation value was used because of the repeated measures.

	Survival with respect to year planted (years)			Nonzero correlation; Q_{CSMH} p-value
Species	1	5	6	
American Crabapple	35	22	25	0.46
Black Cherry	91	54	54	0.05
Black Chokeberry	100	73	73	0.01
Blueberry	43	12	12	0.03
Chokecherry	87	36	36	0.01
Common Apple	97	56	56	0.009
Common Pear	97	54	54	0.008
Eastern Redbud	87	50	50	0.28
Elderberry	48	39	40	0.96
Flowering Dogwood	71	17	17	0.008
Gray Dogwood	89	47	47	0.31
Hazelnut	93	51	50	0.06
Highbush Cranberry	83	46	46	0.10
Nannyberry	73	50	50	0.29
Pawpaw	73	22	22	0.005
Persimmon	94	41	41	0.005
Red Mulberry	95	51	51	0.06
Serviceberry	65	22	22	0.03
Washington Hawthorne	99	79	79	0.12
Wild Plum	95	37	37	0.03

Of the 20 species planted at Fola and ICG, the survival of 10 species significantly changed over time. Survival leveled off as time progressed, showing the number of surviving plants persisted with time. Black chokeberry began with the highest survival percentage at year 1 at 100%, and this species had the highest overall shrub survival percentage after year 6 with 73%. Blueberry started out with the lowest survival at 43% and finished with the lowest survival percentage of 12%. The survival percentage achieved by each species heavily depended on the survival success in the year of establishment.

Comparing these species and survival averages to those found to be significant on the older sites, time was significant to more species' survival on the younger sites than the older sites. It is clear that the younger sites had higher survival percentages after year 1, with many above 90%. Blueberry, chokecherry, flowering dogwood, persimmon, serviceberry, and wild plum all fell below 50% survival after year 6. American crabapple and elderberry had less than 50% surviving after the first year. Nannyberry had better survival without a severe drop in survival in year 1 with 73% surviving, but survival at the end of year 6 was reduced to 50%. Washington hawthorn showed the best overall survival, starting with the highest (100%) alive after year 1 and finishing with around 80% in year 6. For some of the species, a significant p-value was not found. These species, including hazelnut and red mulberry, had low mortality rates after year 1 and remained above 80% survival. The average survival in years 5 and 6 was similar for all species in this group, around 50%.

Height

The average height of all shrubs was 1.26 m, while trees averaged 1.40 m. As expected, the trees tended to grow straight upward with a dominant meristem, rather than shrubs which tended to spread and not have a dominant main stem. However, the height differences were not significantly different between the two growth forms in 2016 more than 6 or 8 years after establishment.

Two of the four sites, Elk Run and Hobet, were planted in 2008 while the other sites in the study, Fola and ICG, were not planted until 2010. Due to the two-year difference in growth times, the four sites were separated into two age groups for analysis based on the year they were planted. The height of the older plants of the same species were expected to be taller than those of the younger species so the comparison across sites would not be appropriate.

When comparing the height differences between the shrubs and trees at the sites planted in 2008, Elk Run and Hobet, no significant difference was found between the two (Figure 13). The tree group was slightly taller than the shrub group on average, but the difference was not significant. Trees were again greater in height numerically than shrubs at the sites planted in 2010, however the difference was not great enough to be considered significant. Hobet had the lowest average heights for both trees and shrubs and Elk Run and Fola trees were taller than Hobet and ICG trees. Elk Run was found to have the tallest shrubs, and Fola was found to host the tallest trees. At ICG, the average shrub and tree heights were very similar.

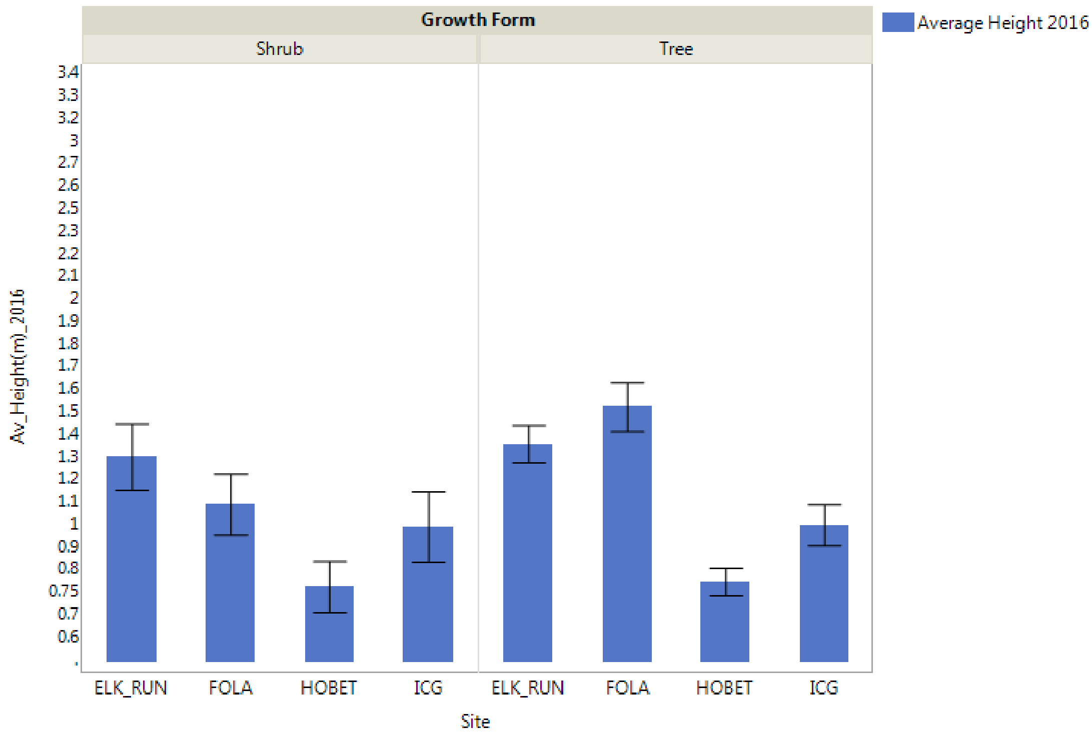

Figure 13. Average height of shrubs and trees on each site in 2016.

To further explore the effect of site on height, each species was analyzed separately so that the differences in average height in 2016 were compared within species across sites. Height differences across species were not analyzed because of inherent differences in growth rates and general height conditions among the species even within growth forms. There were significant differences in average heights within a species across sites. In order to make comparisons, the 20 species were separated as detailed above: 2 figures for the two groups of trees ordered alphabetically, and one figure for the six shrubs.

As mentioned, Fola generally had the tallest plants, while Hobet consistently had the smallest plants of any site (Figure 13). This result was surprising considering that the plants at Hobet were 2 years older than those at Fola, but the low survival percentages at Hobet were reflected in the poor growth conditions. This similarity in heights was found for all species in Figure 14A at Elk Run and Fola except for common apple, where Fola apple trees were found to be significantly taller. The seven trees at ICG and Hobet were not significantly different from each other within species and were generally shorter than those at Elk Run and Fola.

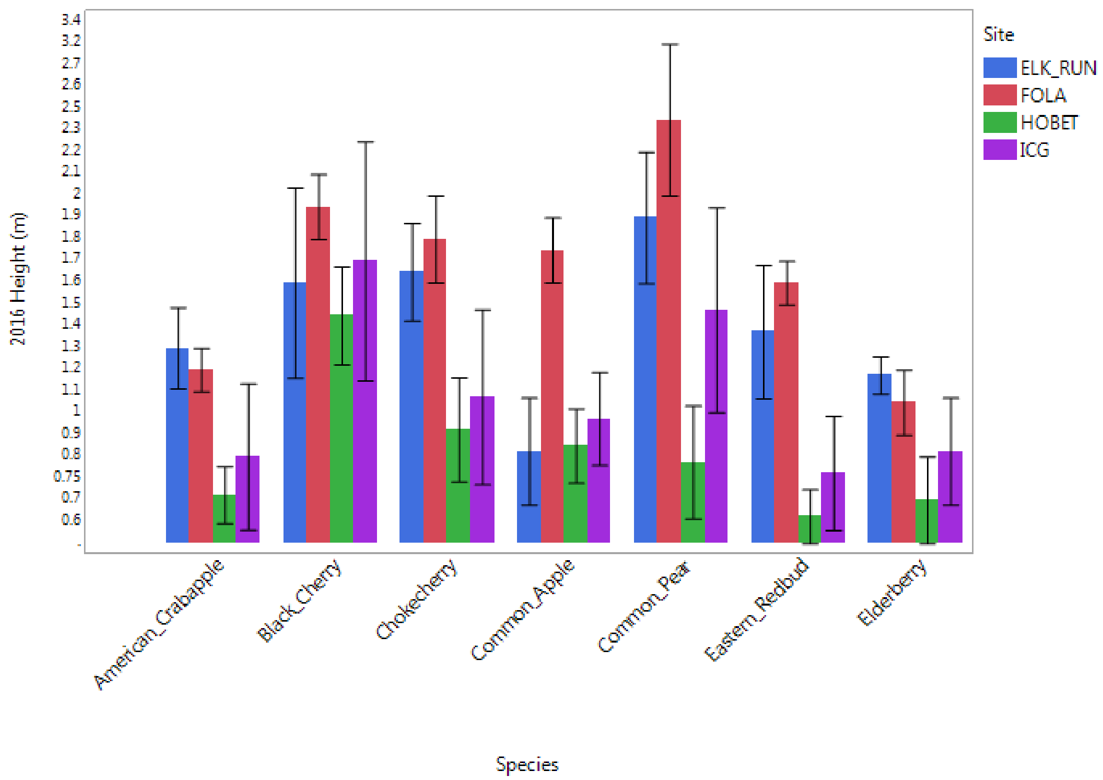

Figure 14A. Average height of seven trees (A-E) on all four sites in 2016.

The second group of trees (Figure 14B) followed the same overall trend that was displayed in Figure 14A, with the Fola site having the tallest plants for most species. However, even though Fola had the tallest plants, the average heights for trees at Elk Run and Fola were not significantly different in most cases. Persimmon and Washington hawthorn were found to be the exceptions, with significant differences between heights at Elk Run and Fola. Serviceberry achieved the greatest height on average of any species on this figure, and pawpaw was found to be the shortest. The average height of pawpaw was a reflection of the poor survival and overall poor growth of this species.

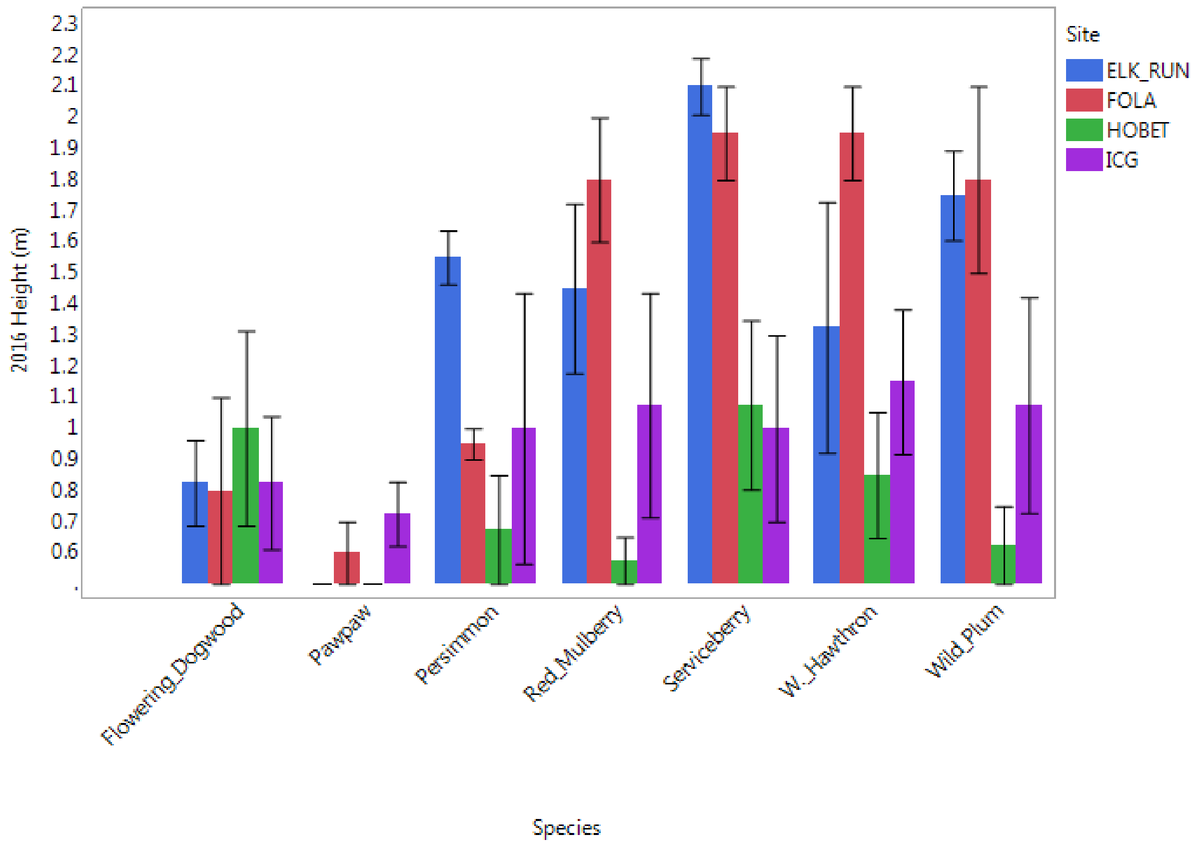

Figure 14B. Average height of seven trees (F-W) on four sites in 2016.

Average height of the shrub species across sites are shown in Figure 14C. The growth of black chokeberry and hazelnut were significantly higher at Fola when compared to other sites (Figure 14C). Gray dogwood grew well at Elk Run, as did highbush cranberry and nannyberry. Hobet was the site of worst performance for many of the species except for blueberry, where Hobet showed the best growth. Hazelnut was not planted at Elk Run and Hobet.

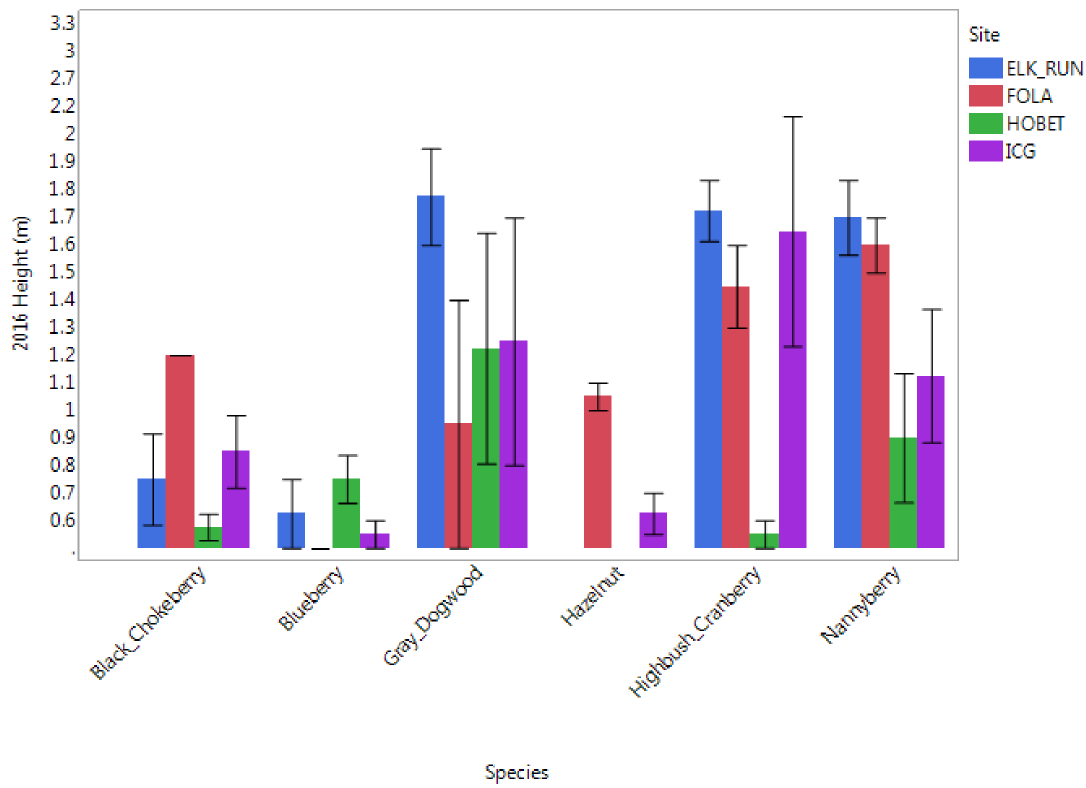

Figure 14C. Average height of six shrubs on all four sites in 2016.

The effect of aspect on height for shrubs and trees were tested against average height of each growth form and were not shown to be significantly different between aspects (data not shown). More clear height differences were observed when the average heights were separated by site and aspect (Figure 16). For both growth forms, Hobet had the shortest plants. The shrubs exhibited no significant difference between aspects on any site. Significant differences were found for tree height between Hobet and the two sites, Fola and Elk Run, on the west-facing aspects. For the trees species in this study, signficant differences were found between the east- and west-facing aspects at Hobet and ICG. ICG and Hobet were more similar in average tree heights compared to the other sites, but the trend observed between the two sites was different. At Hobet, the west-facing blocks had significantly taller trees, and at ICG the east-facing blocks had significantly taller trees. Fola and Elk Run showed no height differences between aspects.

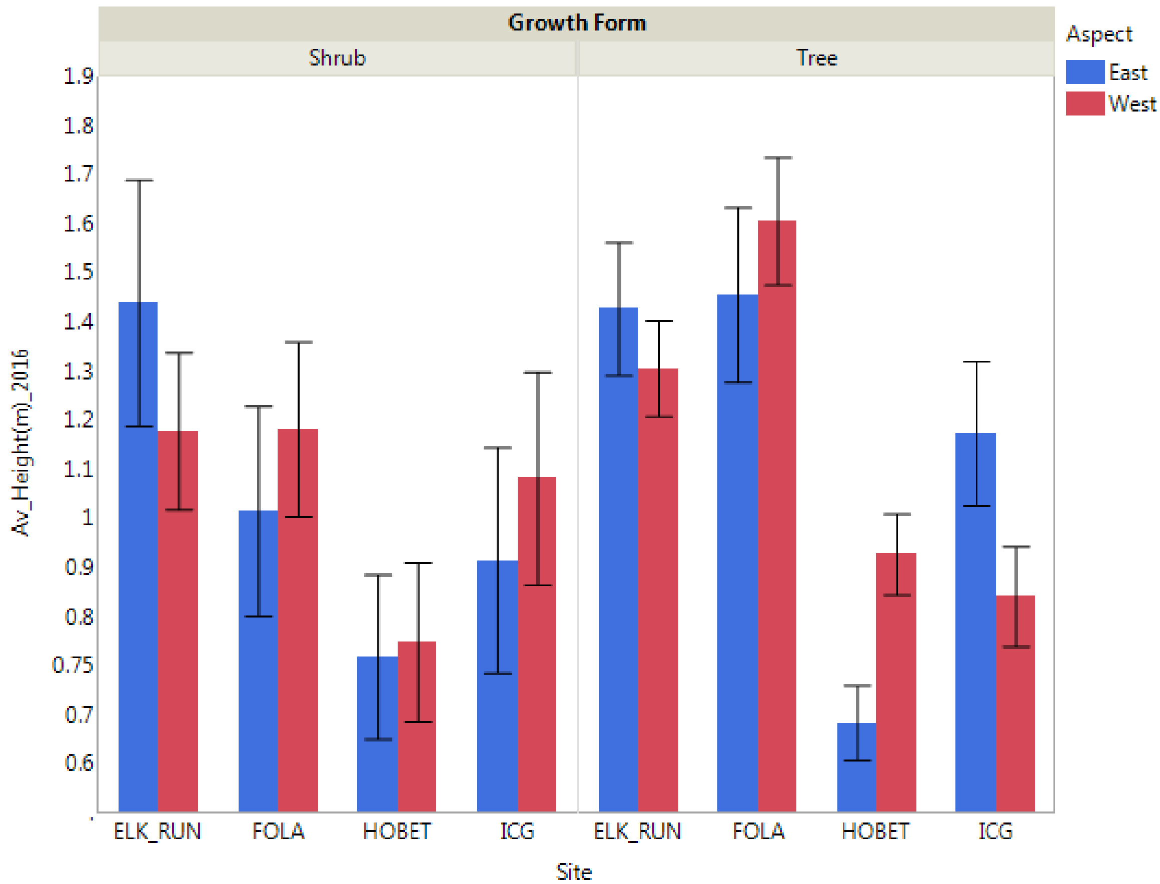

Figure 15. Average height in 2016 for shrubs and trees between the east- and west-facing aspects by site.

The effect of aspect on the average height of each species is shown in Figures 23A-C. Again, due to the quantity of species included in this study they were separated into three groups, two tree groups (alphabetically ordered A-E and F-W) and the shrubs. It was hypothesized that trees growing on east-facing aspects would have greater heights since these aspects normally result in cooler and wetter soil conditions than west-facing aspects. For some species, tree and shrub heights tended to be greater on the west-facing aspect than the east-facing aspect. The exceptions were black cherry, chokecherry, and common pear (Figures 16A and 16B). But the differences in average height between the two aspects was found to be mostly insignificant. The exceptions were common apple, flowering dogwood, and Washington hawthorn where the west-facing blocks had taller trees than the east-facing ones.

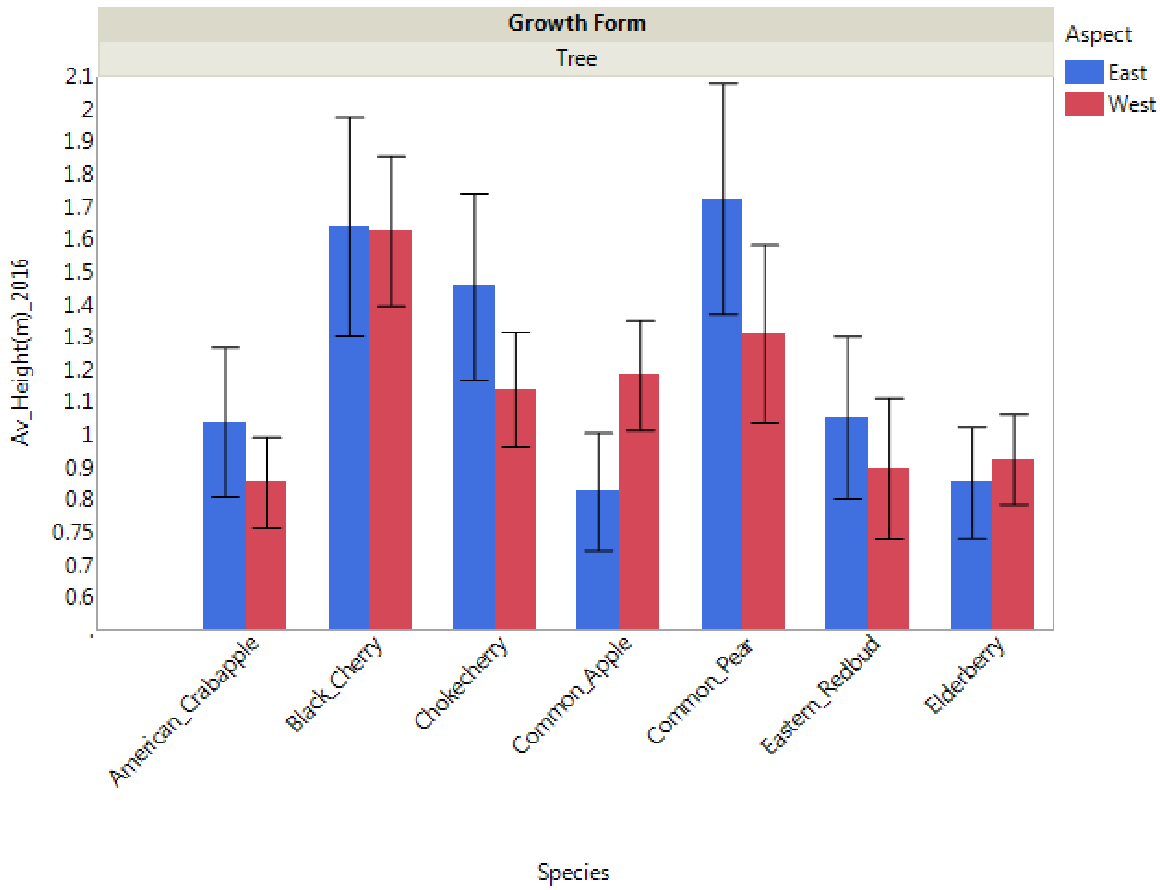

Figure 16A. Average height of selected tree species (A-E) in 2016 at all sites between the east- and west- facing aspects.

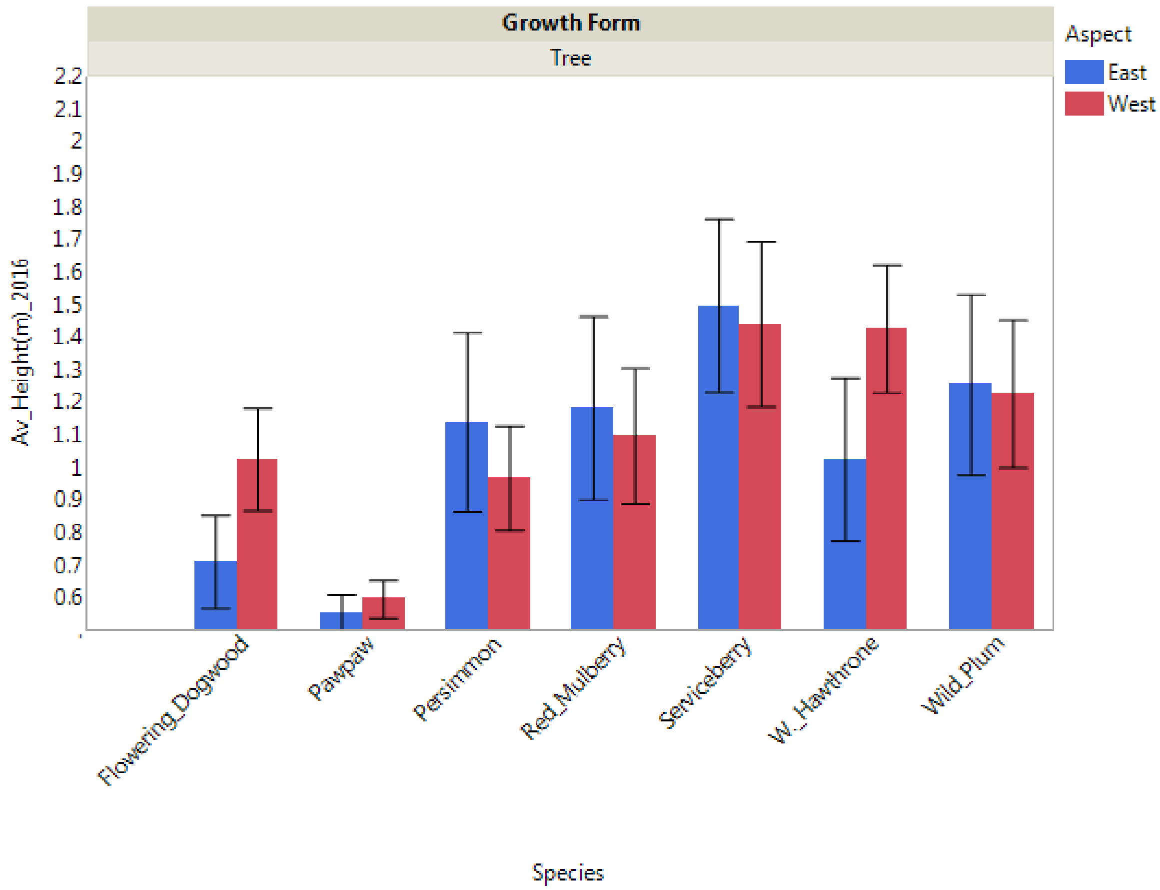

Figure 16B. Average height of selected tree species (F-W) in 2016 at all sites between the east- and west-facing aspects.

The shrub species showed similar results to the tree species with aspect. The shrubs on west-facing aspects had higher average height values than the east-facing aspects, but significant differences between aspects within the same species were not found.

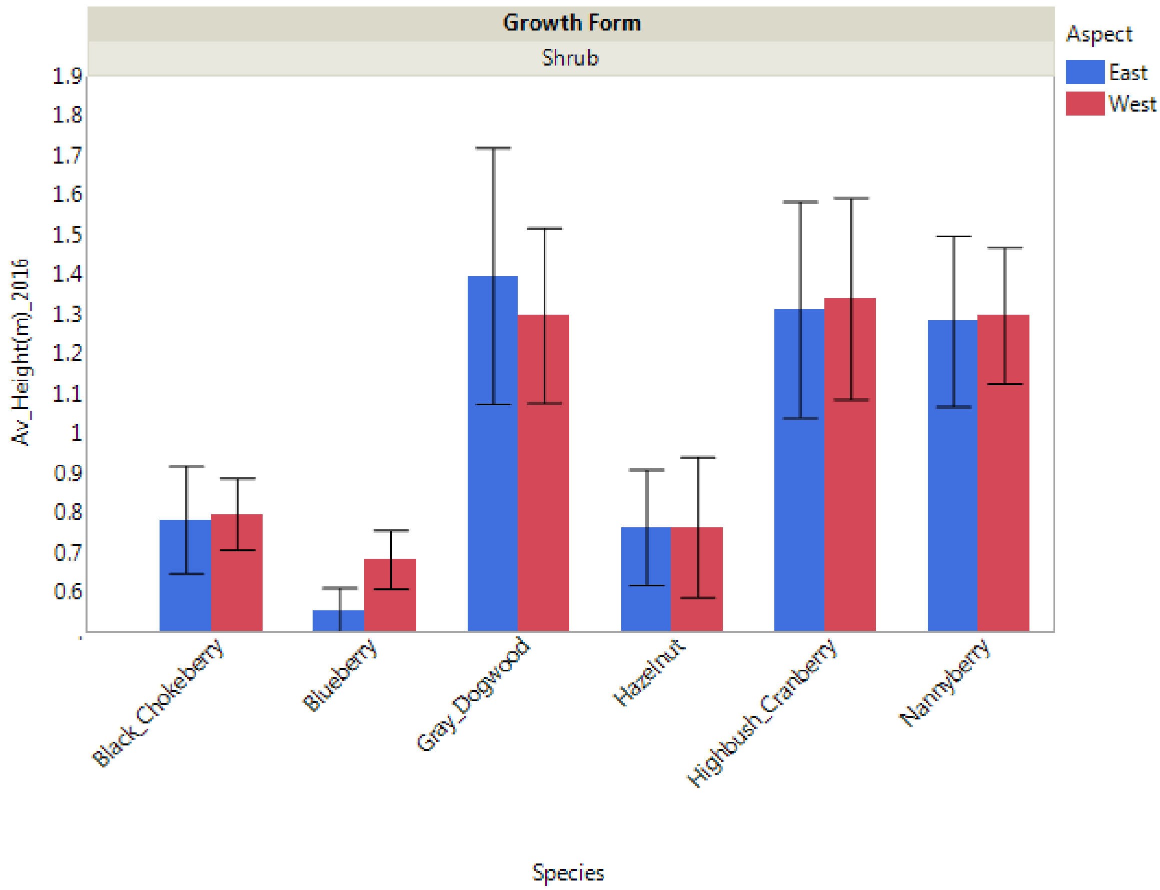

Figure 16C. Average height of shrubs in 2016 at all sites between the east- and west-facing aspects.

The interaction of aspect and site was also analyzed for the average heights of each individual tree species (graphs not shown). At Elk Run, the trees on east-facing blocks were generally taller than those on west-facing blocks. Common apple was the only species where the trees on west-facing aspects grew better than the east-facing aspects. At Fola, the trees on west-facing aspects overall had taller plants than east-facing aspects, with exceptions being black cherry, chokeberry, and common pear. Hobet showed the most dramatic difference in average heights between aspects. This is due to the partial demolition of the east-facing blocks at Hobet in the year of establishment, 2008. At ICG, most trees grew taller on east-facing aspects, but even though numerically higher, the differences weren't significant.

The shrub species showed similar results to the tree species when testing the interaction of aspect by site for each species (graphs not shown). Elk Run showed the east-facing blocks having greater average height than the west-facing blocks with the exception of blueberry. No significant differences were observed between aspects within species at Elk Run. Shrubs at Fola did not show a strong trend for either aspect. Within species at Fola, the only significant difference in height between aspects was found for gray dogwood, where the west-facing block had significantly taller trees. Hobet showed a less dramatic difference between aspects compared to the tree species. No significant differences between aspects were found within species at Hobet. Average heights for individual species were not significantly different between aspects at ICG.

As expected, trees and shrubs on these sites showed significant growth during the time between the first year after planting and either 6 or 8 years later (Tables 7 and 8). The height data were more normally distributed than the survival data, and as a result an ANOVA was run to test the effect of age, site, aspect, and their interactions using age as a repeated measure.

Table 7. Average height of each species after one growing season and after 8 growing seasons on the sites planted in 2008, Elk Run and Hobet, using age as a repeated measure. The Tukey-Kramer adjustment was made to the calculated p-values in order to make the test more conservative and control type I errors from occurring.

	Height (m)		**P-value**
Species	**Year 1**	**Year 8**	
American Crabapple	0.20	1.07	<0.0001
Black Cherry	0.76	1.70	0.0003
Black Chokeberry	0.36	0.83	0.007
Blueberry	0.19	0.87	<0.0001
Chokecherry	0.39	1.42	<0.0001
Common Apple	0.31	1.10	<0.0001
Common Pear	0.22	1.65	0.0001
Eastern Redbud	0.44	1.29	0.004
Elderberry	0.23	1.12	<0.0001
Flowering Dogwood	0.47	1.16	0.01
Gray Dogwood	0.41	1.91	<0.0001
Highbush Cranberry	0.37	1.53	0.0002
Nannyberry	0.39	1.57	<0.0001
Pawpaw	0.36	-	-
Persimmon	0.37	1.48	<0.0001
Red Mulberry	0.50	1.30	0.005
Serviceberry	0.38	1.74	<0.0001
Washington Hawthorn	0.39	1.47	0.0004
Wild Plum	0.71	1.59	0.0005

Table 8. Average height of each species after the first growing season and after 6 growing seasons on sites planted in 2010, Fola and ICG, using age as a repeated measure. The Tukey-Kramer adjustment was made to the calculated p-values in order to make the test more conservative and control type I errors from occurring.

	Height (m)		**p-value**
Species	**Year 1**	**Year 6**	
American Crabapple	0.18	1.22	0.01
Black Cherry	0.38	2.20	0.0005
Black Chokeberry	0.43	1.05	<.0001
Blueberry	0.12	0.65	0.003
Chokecherry	0.28	1.78	<.0001
Common Apple	0.58	1.42	0.002
Common Pear	0.42	2.16	0.0003
Eastern Redbud	0.30	1.34	0.0005
Elderberry	0.04	1.15	<.0001
Flowering Dogwood	0.15	1.14	0.0002
Gray Dogwood	0.38	2.04	0.006
Hazelnut	0.35	0.90	0.0003
Highbush Cranberry	0.23	2.00	0.0004
Nannyberry	0.30	1.43	<.0001
Pawpaw	0.13	0.78	<.0001
Persimmon	0.25	1.23	0.02
Red Mulberry	0.32	1.73	0.003
Serviceberry	0.20	1.74	<.0001
Washington Hawthorn	0.63	1.60	0.0003
Wild Plum	0.37	1.72	<.0001

The age shown is the time at which tree height was sampled. Age 1 represents tree height after one growing season after transplanting in 2008. Age 7 represents the height measured 7 years later, in the summer of 2015 at Elk Run and Hobet. Age 8 represents height measurements collected in the summer of 2016 8 years after establishment. The ANOVA was adjusted to account for the irregular spacing of the sampling ages for analysis.

The plants at Elk Run were taller on average in years 7 and 8 than those at Hobet in the same years of growth, regardless of growth form (Figure 17). At age 1, the plants did not significantly differ in height between sites. A significant difference was found in average height between ages 1 and 7 and ages 1 and 8. However, no significant difference in growth was found between ages 7 and 8 for either growth form.

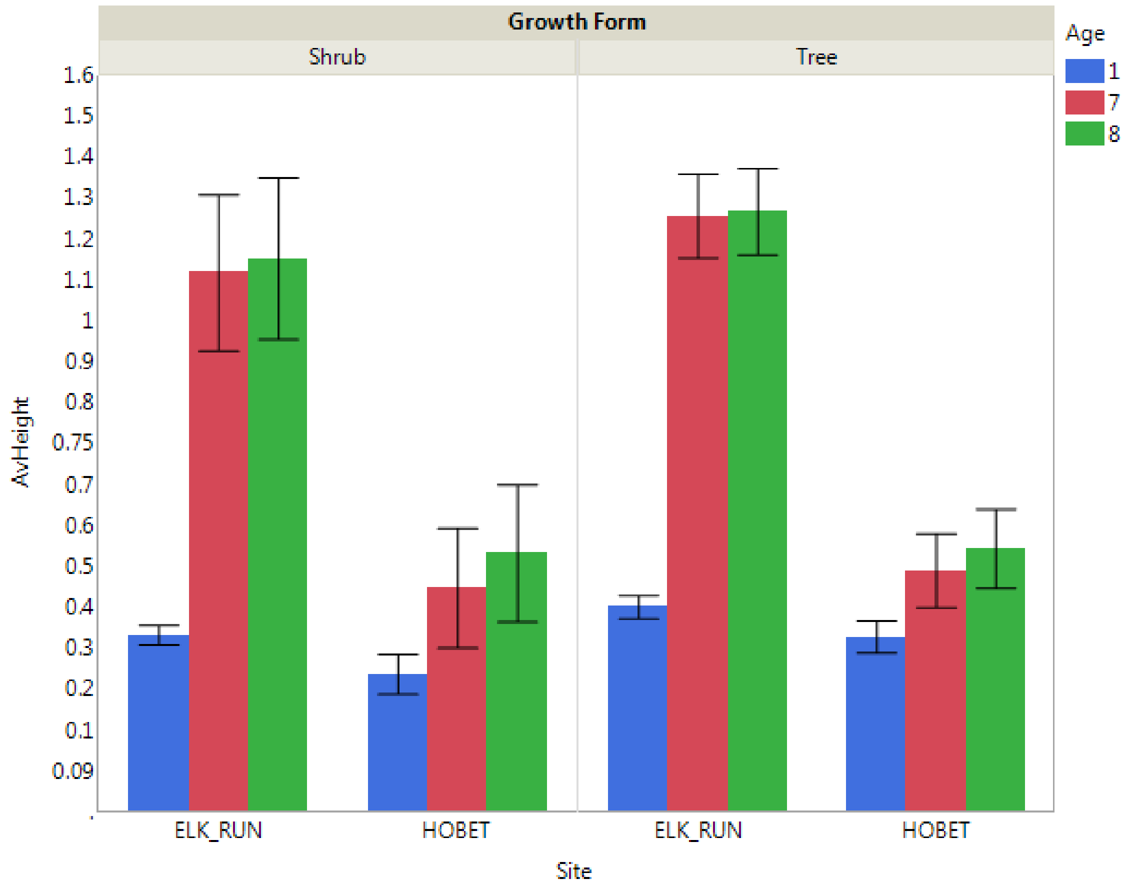

Figure 17. Average height of different growth forms separated by site (Elk Run and Hobet) after 8 years of growth.

When looking at individual species, all were found to be growing over time except for pawpaw, which experienced complete mortality on these two sites. Most species showed a significant difference in growth between age 1 and ages 7 and 8, excluding black chokeberry, blueberry, flowering dogwood, and wild plum (Table 9). These species still showed growth but it was slow and not significantly different from the original height, which was mostly due to poor survival of those species.

To further explore the effect of time on performance in the study, the two growth forms were separated by site so that site performance can be more closely examined and explained.

Table 9. ANOVA results testing the effect of site on species height and the effect of the site*age interaction on the sites planted in 2008, Elk Run and Hobet, using age as a repeated measure. The Tukey-Kramer adjustment was made to the calculated p-values in order to make the test more conservative and control type I errors from occurring.

	Prob F	Means by site		p-value	Prob F showing the effect of SITE * AGE						p-value		
					Elk Run			Hobet			Elk Run and Hobet		
Species		Elk Run	Hobet		1	7	8	1	7	8	1	7	8
American Crabapple	0.04	0.94	0.53	0.03	0.08	<.0001	<.0001	0.24	0.0009	0.0003	0.9992	0.04	0.09
Black Cherry	0.07	1.60	1.26	0.07	0.0004	<.0001	<.0001	0.0002	<.0001	<.0001	0.9990	0.32	0.20
Black Chokeberry	0.02	0.80	0.51	0.02	0.0005	<.0001	<.0001	0.002	0.0004	0.0001	0.9972	0.11	0.23
Blueberry	0.004	0.73	0.58	0.004	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.95	0.01	0.0986
Chokecherry	0.08	1.21	0.86	0.08	0.02	<.0001	<.0001	0.02	<.0001	<.0001	1.00	0.21	0.21
Common Apple	0.010	0.95	0.70	0.010	<.0001	<.0001	<.0001	0.0006	<.0001	<.0001	0.91	0.03	0.23
Common Pear	0.17	1.33	0.83	0.17	0.36	<.0001	<.0001	0.41	0.008	0.006	1.00	0.33	0.36
Eastern Redbud	0.20	1.08	0.66	0.20	0.04	<.0001	<.0001	0.07	0.10	0.04	1.00	0.52	0.79
Elderberry	0.62	0.77	0.83	0.62	0.06	<.0001	<.0001	0.03	<.0001	<.0001	0.9962	0.9886	1.00
Flowering Dogwood	0.07	0.74	1.1	0.07	0.003	0.0002	<.0001	0.005	0.002	<.0001	0.9850	0.55	0.25
Gray Dogwood	0.71	1.40	1.31	0.71	0.04	<.0001	<.0001	0.13	0.0001	<.0001	1.00	0.92	1.00
Highbush Cranberry	0.0004	1.23	0.61	0.0004	0.0007	<.0001	<.0001	0.0003	0.0005	0.0005	0.88	0.004	0.002
Nannyberry	0.03	1.23	0.98	0.03	0.0005	<.0001	<.0001	0.0003	<.0001	<.0001	0.99	0.16	0.12
Pawpaw	0.05	0.33	0.40	0.05	<.0001	-	-	<.0001	-	-	0.01	-	-
Persimmon	0.02	1.16	0.86	0.02	0.001	<.0001	<.0001	0.003	<.0001	<.0001	1.00	0.01	0.24
Red Mulberry	0.13	1.14	0.59	0.13	0.02	0.0003	0.0002	0.17	0.10	0.07	0.99	0.43	0.54
Serviceberry	0.01	1.49	0.96	0.01	0.02	<.0001	<.0001	0.03	<.0001	<.0001	1.00	0.02	0.01
Washington Hawthorn	0.26	1.18	0.89	0.26	0.08	<.0001	<.0001	0.06	0.002	0.0007	0.99	0.49	0.76
Wild Plum	0.004	1.4	0.81	0.004	<.0001	<.0001	<.0001	<.0001	0.002	0.0004	0.99	0.02	0.06

When comparing the two sites established in 2008, a clear difference in average height was shown (Table 9). Hobet had a much lower average height and fewer significant differences were observed between ages 1 and ages 7 and 8. There are also some species at Hobet including eastern redbud, flowering dogwood, pawpaw, and wild plum that had a higher average height at age 1 than at age 7. This is due to the change in survival percentage that occurred between ages 1 and 7. Elk Run showed only one species that had a higher average height at age 1 than at later ages, and that was pawpaw. Like Hobet, the reason was mortality.

The shrub species showed similar results to the tree species when comparing average height over time (Table 9). The average heights achieved by three of the shrubs were much greater at Elk Run than they were at Hobet. Gray dogwood, highbush cranberry, and nannyberry all showed a significant increase in height between age 1 and ages 7 and 8. Blueberry and black chokeberry still showed signs of growth, but at a much slower rate probably due to a large mortality of those species at Elk Run. Hobet showed a significant height difference between age 1 and ages 7 and 8 for only one species, gray dogwood. Blueberry, black chokeberry, and nannyberry all displayed signs of slow growth. Highbush cranberry survival was very low at Hobet, and as a result the average height was highest at age 1 and decreased over time.

The same ANOVA models were run for the effects of age and site at the younger sites (Fola and ICG) for the two growth forms and individual species. The two different growth forms showed a more significant effect on the sites planted in 2010, particularly at Fola (Figure 18). At Fola, a significant difference was found between the growth forms at ages 5 and 6. This relationship was not mirrored at ICG, where the difference in average height between growth forms was not significant. Plants growing at ICG did not grow as well over the same time period as those at Fola. Different survival rates between the sites may have influenced the average height numbers.

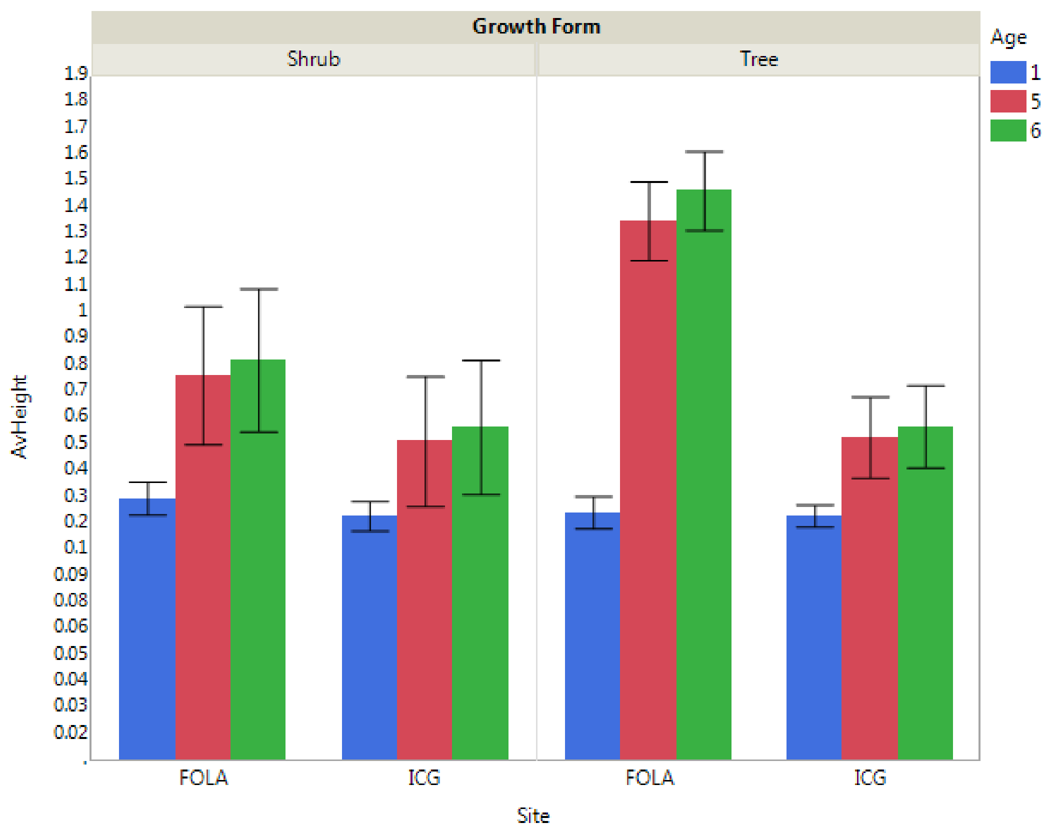

Figure 18. Average height of different growth forms separated by site (Fola and ICG) after 6 years of growth.

Age proved to be significant for most of the species included in the study. This indicates that the planted species had been growing successfully on the sites planted in 2010. Exceptions where age was not significant included blueberry, eastern redbud, flowering dogwood, gray dogwood, hazelnut, pawpaw, and persimmon. These species did not have high survival percentages at these sites, and as a result the plants that survived had reduced average height.

Table 10. ANOVA results testing the effect of site on species height and the effect of the site*age interaction on the sites planted in 2010, Fola and ICG, using age as a repeated measure. The Tukey-Kramer adjustment was made to the calculated p-values in order to make the test more conservative and control type I errors from occurring.

	Prob F	**Means by site**		**p-value**	**Prob F**	**Least square means showing the effect of SITE * AGE**						**p-value**		
Species		**Fola**	**ICG**	**p-value**		**Fola**			**ICG**			**Fola and ICG**		
						1	**5**	**6**	**1**	**5**	**6**	**1**	**5**	**6**
American Crabapple	0.95	0.78	0.80	0.95	0.53	0.35	0.80	1.20	0.07	1.10	1.25	0.96	0.97	1.00
Black Cherry	0.56	1.40	1.67	0.56	0.78	0.40	1.85	1.95	0.38	2.27	2.37	1.00	0.97	0.97
Black Chokeberry	0.04	0.95	0.74	0.04	0.74	0.55	1.10	1.20	0.38	0.87	0.97	0.33	0.17	0.18
Blueberry	0.42	-	0.46	-	-	0.08	-	-	0.14	0.56	0.67	0.79	-	-
Chokecherry	0.80	1.25	1.21	0.80	0.99	0.30	1.65	1.80	0.27	1.60	1.75	1.00	0.99	0.99
Common Apple	0.05	1.33	0.97	0.05	0.12	0.55	1.70	1.75	0.60	1.12	1.18	0.99	0.14	0.15
Common Pear	0.22	1.90	1.33	0.22	0.58	0.55	2.55	2.60	0.35	1.78	1.87	0.99	0.63	0.69
Eastern Redbud	0.07	1.18	0.76	0.07	0.56	0.45	1.50	1.60	0.23	0.96	1.11	0.86	0.35	0.43
Elderberry	0.40	0.68	0.76	0.40	0.47	0.05	0.95	1.05	0.04	1.00	1.25	1.00	0.99	0.70
Flowering Dogwood	0.96	0.79	0.78	0.96	0.84	0.15	1.11	1.11	0.15	1.05	1.15	1.00	0.99	0.99
Gray Dogwood	0.16	1.03	1.66	0.16	0.40	0.40	1.30	1.40	0.37	2.26	2.36	1.00	0.59	0.60
Hazelnut	0.01	0.80	0.60	0.01	0.07	0.35	1.00	1.05	0.35	0.70	0.75	1.00	0.07	0.07
Highbush Cranberry	0.16	1.03	1.62	0.16	0.23	0.25	1.40	1.45	0.22	2.26	2.36	1.00	0.44	0.39
Nannyberry	0.17	1.15	0.94	0.17	0.63	0.35	1.50	1.60	0.27	1.22	1.32	0.99	0.61	0.61
Pawpaw	0.15	0.43	0.56	0.15	0.36	0.09	0.50	0.90	0.15	0.94	0.80	0.98	0.46	0.94
Persimmon	0.29	0.67	1.08	0.29	0.65	0.20	0.85	0.95	0.27	1.46	1.51	0.99	0.78	0.83
Red Mulberry	0.71	1.25	1.37	0.71	0.58	0.25	1.70	1.80	0.35	2.10	1.65	0.99	0.95	0.99
Serviceberry	0.12	1.28	1.06	0.12	0.03	0.03	1.85	1.95	0.27	1.41	1.51	0.52	0.19	0.19
Washington Hawthorn	0.03	1.43	1.13	0.03	0.02	0.55	1.80	1.95	0.67	1.36	1.36	0.91	0.11	0.03
Wild Plum	0.44	1.32	1.18	0.44	0.99	0.45	1.70	1.80	0.33	1.56	1.65	0.98	0.99	0.98

In general, growth rates for trees were better at Fola compared to ICG. The effect of site was not significant for every tree species. Chokeberry, common apple, common pear, and eastern redbud displayed significant differences in average height between Fola and ICG. Red mulberry, serviceberry, Washington hawthorn, and wild plum all showed a difference in height between sites (Figure 18). The species which did not show a difference between sites was due to poor survival and poor growth in general. Unlike the trees, Fola did not appear to have greater shrub growth than ICG (Table 10). Hazelnut and nannyberry showed a significant effect with Fola having taller plants for these two species than ICG.

Site and Soil Property Correlations to Height

Principle component analysis (PCA) followed by principle component regression (PCR) were used to determine which soil properties, both physical and chemical, most strongly correlated with plant height. First the soil conditions and normalized plant heights at all sites were analyzed together so as to represent the total variability of soil conditions experienced by plants in the study. The results of the PCA show the eigenvalues for the model and the score and loading plots of principle components 1 (PC1) and 2 (PC2), which together explained 58.4% of the variability in the data. This variability is shown in the score plot on the left in Figure 19. The loading plot shows the scatterplot matrix of the loadings for each soil variable taken pairwise. The loading plot shows pH, K, Mn, Mg, P, and Cu loading positively on PC1. Percent fines displayed a negative correlation on PC1. Figure 19 also displays those site factors that loaded on PC2 which are EC, Al, and Cu.

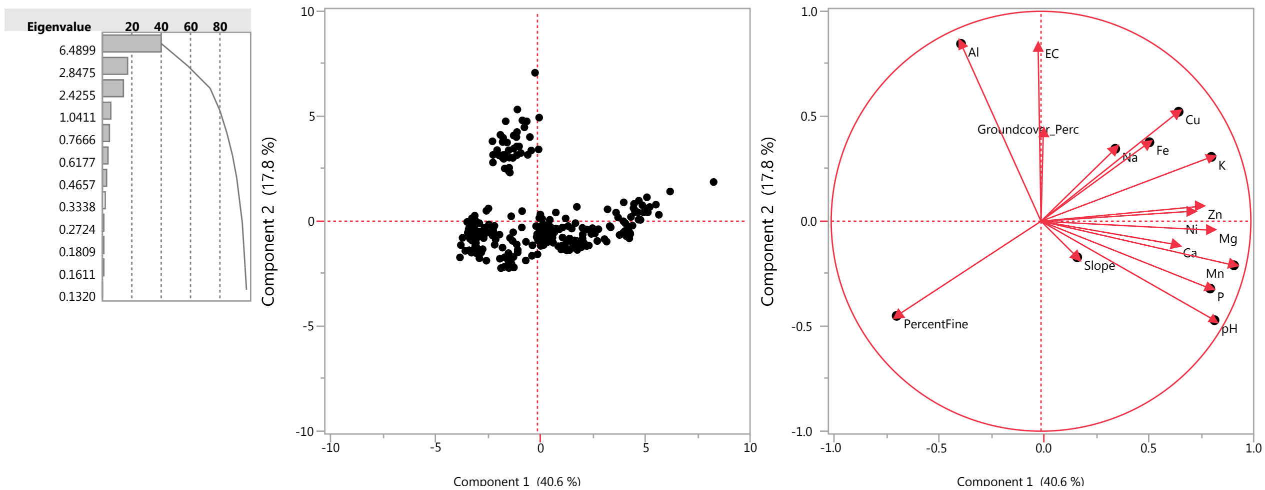

Figure 19. Principle components and correlation depictions on all sites.

The principle components (PC1-PC4) were then regressed against the average height. Four principle components were chosen based on the eigenvalues being > 1, the percentage of variability accounted for by the first principle components, and the results of the scree plot which displayed significant bends at the first four points in the graph.

The regression results showed that the two strongest principle component groups were those on PC1 and PC2. These two groups showed significant p-values less than 0.05 (Table 11). The elements with the strongest eigenvector values for PC 1 were pH, K, Mg, P, and Mn. The soil properties with the strongest eigenvector values for PC2 were EC and Al. A regression was then run with these elements against average height to determine those soil properties most correlated with average height overall.

Table 11. Results of PCR of height at all sites in study. The R^2 value of 0.15 was obtained.

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**	**VIF**
Intercept	46.04	2.19	21.04	<.0001*	.
Prin1	3.14	0.79	3.97	0.0001*	1.02
Prin2	4.71	1.18	3.99	<.0001*	1.00

Prin3	-1.45	1.19	-1.23	0.2212	1.00
Prin4	-2.25	2.02	-1.11	0.2670	1.01

The results of the principle components regression showed that the soil properties K, P, and Al as being significantly correlated to plant height considering all site conditions (Table 12). The R^2 value, 0.20, was fairly low.

Table 12. Results of PCR of all significant soil properties in PC 1 and 2 on average height for all sites. The R^2 value of 0.20 was obtained. Only three properties were significant.

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**	**VIF**
Intercept	29.65	20.82	1.42	0.1561	.
pH	-4.48	4.43	-1.01	0.3137	13.48
EC	-0.05	0.04	-1.25	0.2129	3.03
K	149.76	73.75	2.03	0.0438*	3.86
Mg	3.20	2.59	1.23	0.2191	4.08
P	0.77	0.26	2.96	0.0035*	5.89
Al	0.14	0.06	2.27	0.0247*	5.10
Mn	-0.26	0.22	-1.16	0.2462	7.29
Ni	3.68	7.33	0.50	0.6162	2.86
Zn	0.21	1.66	0.13	0.9000	3.19

The variability across sites was recognized both in the field and in the data collected from laboratory analysis of soil samples. The goal of the PCA in this study was to correlate certain soil properties or conditions with plant height, which was easier to do across sites with the same conditions. In order to determine how plants might grow in response to specific soil conditions experienced in the study, the data were separated by site. The data for each site was analyzed in the same way as when the data were analyzed when all site data were combined, with a PCA followed by a PCR.

Discussion

Survival

No significant difference was found between the survival data collected in 2015 and 2016. Significant differences were found for survival among different species included in the study, indicating that the response to growing in the reclaimed coal mine soils was species specific. Survival in 2016 across all species was 40%. The species with the best survival 6 or 8 years after planting was black chokeberry with 56% survival. Only four other species had survival percentages over 50%, and they were black cherry, Washington hawthorn, nannyberry, and hazelnut. Ten species had survival percentages between 40-49%. Flowering dogwood and pawpaw had survival percentages ≤10%, with significantly lower survival than the other species. Survival percentage significantly varied among sites overall; Elk Run showed the highest survival percentage (51%) while Hobet had the lowest (25%). Survival of the same species at the four different sites significantly varied for all species except black cherry and hazelnut. Both of these species were considered to be two of the best surviving species overall, and performed well across all sites. A significant effect was shown between survival for plants on the east- and west-facing aspects with the west (44%) having overall greater survival than the east (36%). The difference in survival between east- and west-facing aspects was very different for a few species in the study with the west-facing aspects having greater survival, which strongly influenced the statistical analysis. Black cherry, common pear, eastern redbud, hazelnut, highbush cranberry, nannyberry, persimmon, and red mulberry, however, showed a greater percentage alive on east-facing blocks. Due to the conflicting results between the two aspects at the species level, the overall significant effect when all are combined is not very meaningful.

The effect of time on survival was tested for sites that were planted in the same year. On the older sites, Elk Run and Hobet, the shrubs had higher survival than the trees, with shrubs having about 5-10% higher survival than trees, which effect persisted for the ensuing 8 years. Elk Run showed significantly higher survival (70-100%) than Hobet (50-75%) after the first year, and Elk Run had higher survival than Hobet 8 years later. Survival at both sites decreased over time, but the severity in survival decline over time varied among species. This result indicated that percent survival in the long run in reforestation and reclamation plantings is very dependent on the survival after the first growing season in the year of establishment. All species had greater than 50% survival after the first year, however only nannyberry, serviceberry, black cherry, and black chokeberry remained above 50% in 2016. Pawpaw did not have good survival in the study overall, and this poor survival is attributed to the species' need for deep and moist soil conditions in coves and under the canopy positions (Burns and Honkala, 1990). All of the best-surviving species belong to the *Rosaceae* family except for nannyberry, but all are considered to be semi-drought tolerant and can survive in high solar conditions. The large percentage of mortality in other species was possibly due to poor planting stock, improper planting techniques, drought, or soil conditions experienced.

Shrubs were found to have higher survival than trees overall. Black chokeberry was found to have the best survival at year 1 (100%) and in year 6 (73%) for the shrubs while Washington hawthorn survived best out of the tree species with 100% survival in year 1 and 80% remaining in year 6. Both black chokeberry and Washington hawthorn belong to the Rose family, thrive in full-sun conditions, and are considered to be drought tolerant. Blueberry experienced the most severe mortality of any species, and chokecherry, flowering dogwood, persimmon, serviceberry, and wild plum also fell below 50% survival by year 6. The average site pH at ICG was 7.5, which is not conducive with blueberry's affinity for acidic soils. Flowering dogwood did not survive well on any site because of the need for moist and well-drained soils, and a requirement for shady conditions. Persimmon is most commonly found along moist floodplains, and the lack of soil moisture and organic matter in the reclaimed mine soils was probably responsible for the poor overall survival percentage. Serviceberry and chokecherry are commonly found in Appalachian forest ecosystems and in a variety of soil conditions, and the poor performance could not be directly correlated with species characteristics. Wild plum is found in a variety of soil conditions, but the species is notably drought intolerant and therefore would have difficulty surviving the dry mine soil conditions.

Weather conditions experienced by the plants in their year of establishment may have greatly influenced survival. In this study, Elk Run and Hobet were planted in 2008, while ICG and Fola were planted in 2010. The weather in the spring of 2008, the time of establishment, was described as normal for the season and state (NOAA, 2009). The summer of 2008 was warmer than normal for the country, but West Virginia experienced temperatures below normal. Fall of 2008 was described as cooler than normal in West Virginia, and the winter of 2008 was described as near normal for West Virginia. Rainfall received in the year 2008 was considered to be above normal in the spring, near normal in the summer, and below normal in the fall (NOAA, 2009).

The sites planted in the spring of 2010 experienced a much warmer than normal spring with normal precipitation (NOAA, 2011). The summer of 2010 was warmer than normal with a normal amount of precipitation. The fall of 2010 was hotter than average for West Virginia, while the amount of precipitation received during that time was below normal (NOAA, 2011). Stem girdling by rodents and browsing by wildlife could also have had a negative effect on survival. On the other hand, some species survived overall very well and had high survival rates across all sites. Chokecherry had the highest and most consistent survival across sites after the first growing season.

Survival percentages for this study were low compared to other reforestation studies in the past. Reasons for this may be due to planting stock quality, planting techniques, moisture conditions, soil conditions, or other site parameters. The absence of a shade canopy in the study area, which is required for some small tree and shrub species, may have also influenced the success of species survival in this study, especially those described as having a partial-shade requirement like pawpaw and flowering dogwood. The development of a canopy or shading of some type would be beneficial to many of these species by decreasing the amount of solar radiation received, decreasing soil temperature, and increasing the amount of moisture. Most of those species that require shade also require moist soil conditions to thrive.

Species which consistently experienced severe mortalities in the year of planting should not be included in reclamation plantings. These were flowering dogwood, blueberry, and pawpaw. For flowering dogwood and pawpaw, as described above, these species require more shade and moisture than can be expected or provided in reclamation plantings. Blueberry was successful at Hobet, but could not thrive at other places due to the requirement of very specific soil conditions. Species with greater than 50% survival in this study should be considered as potential candidates in future reclamation woody species plantings and include black chokeberry, black cherry, Washington hawthorn, nannyberry, and hazelnut. Greater survival was shown on west-facing aspects compared to the eastern facing aspects overall, but on the individual species level the results of the effect of aspect were conflicting. This effect was study specific, because greater survival was more commonly found on east-facing aspects where soil is thought to be moister and the amount of solar radiation received is more conducive with plant growth.

Height

In general, 18 of the 20 species included in this study were successful in growing on the reclaimed surface mine sites in West Virginia. The exceptions were pawpaw on the sites planted in 2008 and blueberry on the sites planted in 2010. When compared to the growth rates exhibited by these species in horticultural, forestry, or agricultural settings, the growth rate is considerably less in this project with these mine soil conditions. Growth between the two growth forms in 2016 after 6 and 8 years respectively was found to be not significantly different at Hobet and Elk Run, but was significantly different at ICG and Fola. At these sites planted in 2010, the tree species were significantly taller than the shrub species. Growth between sites differed, and plants at Hobet exhibited the worse overall growth when compared with Elk Run. When comparing the sites planted in 2010, Fola showed better growth than ICG. When all sites were compared together, Hobet had the smallest plants while Fola hosted the tallest. Heights between sites were not significantly different between Elk Run and Fola, which displayed significantly better height than the other two sites (Hobet and ICG). This result was surprising considering the two-year difference in planting times between Elk Run and Hobet and ICG and Fola, with Elk Run and Hobet planted in 2008. The Hobet site did have the worst survival percentages, which undoubtedly was reflected in average height as well. Most species displayed greater average heights on west-facing aspects when compared with east-facing aspects, but the difference in height was mostly insignificant and were masked by a couple of species having much greater height on the west-facing aspect. Only three species were found to have a significant aspect effect; common apple, flowering dogwood, and Washington hawthorn. For these species, height was significantly greater on west-facing blocks. The site with the most dramatic difference in aspect was Hobet, where the east-facing blocks were partially demolished in their first year of establishment. Elk Run and Fola both show the majority of trees being taller on the west-facing blocks compared to the east-facing blocks, but the effect is not significant. Contrarily at ICG, most tree species grew taller on the east-facing blocks but again the effect was not proven significant. For shrubs, Elk Run showed taller plants growing on east-facing blocks, while no significant difference was found at any other site.

Soil and Site Conditions on Height

Site and soil conditions examined in this study included slope, groundcover, percent fines, pH, electrical conductivity, and macro- and micronutrients. The variation in these values across sites gave some perspective on how differences in these site qualities affected growth and survival at a species specific level.

Species survival and growth were affected by these site conditions although correlations between site and soil properties to tree and shrub height were difficult to interpret. For example, blueberry prefers acidic soils and will not thrive in alkaline conditions. Both conditions existed in this project, but the most acidic site, Fola, had the poorest blueberry survival with the highest blueberry survival at Hobet. The dry, upland conditions of the research blocks also affected the success of certain selected species including pawpaw and choke cherry, which generally prefer moist soil conditions. Additionally, growth of some of the selected species was affected by their degree of shade tolerance. Because this project was designed in a way that the planted species received direct solar radiation and had no canopy cover, species that require more shading did not thrive as well. And the east- or west-facing aspects at each site could also have impacted survival and growth of the planted species.

The Elk Run site had a moderate slope of 14% (lower than ICG and Hobet), a neutral pH of 6.4 (higher than Hobet and Fola), and a low EC. It had the best survival for chokecherry, nannyberry, and American crabapple, but the lowest survival for flowering dogwood and a complete die-out of pawpaw.

The Hobet mine site exhibited the worst overall survival and growth. Hobet had a slope of 22%, a low pH of 4.5, low EC, and high fines of 74%. These soil characteristics are perceived to be compatible with tree and shrub growth; however, Hobet had the lowest survival for most of the species included in this study including red mulberry, black cherry, common apple, common pear, eastern redbud, gray dogwood, pawpaw, persimmon, Washington hawthorn, and wild plum. Like Elk Run, it also had a complete die-out of pawpaw. But, this site had the highest survival for blueberry and highbush cranberry.

The Fola mine site possessed a moderate slope, the lowest pH range, and the highest EC value of any site included in the study. This site achieved the highest survival for black chokeberry, hazelnut, Washington hawthorn, elderberry, common pear, and black cherry. Fola had the largest common pear trees of any site. Fola also showed the lowest survival for blueberry, choke cherry, and serviceberry.

The ICG site had a slope of 23%, the highest overall pH of 7.5, low EC, and the lowest percent fines (58%) of any site. ICG also had the least amount of groundcover competition overall. This site showed the highest survival for black cherry, common apple, common pear, eastern redbud, flowering dogwood, gray dogwood, pawpaw, persimmon, and Washington hawthorn. This same site exhibited the lowest survival for hazelnut, American crabapple, and black cherry.

The soil properties at these sites were extremely variable and the PCA model correlating the site properties to average height of all plant species predicted only 58.4% of the variability. The PCR showed potassium, phosphorus, and aluminum as being the most strongly correlated with plant height when all four sites were considered.

Conclusions

The survival of small trees and shrubs on surface mines in this study was lower than commercial tree plantings in many reforestation reclamation studies, which are often in the 60 to 80% range. Black chokeberry, black cherry, Washington hawthorn, nannyberry, and hazelnut were the only species out of the 20 included in this study with over 50% surviving in 2016. These species successfully established and persisted in this growing environment and should be considered in future reclamation reforestation plantings. In this study, survival in the year of establishment was a critical factor to the overall success of the species in later years. The difference in survival may be derived from the difference in species selection in this project when compared to other reforestation plantings. In most reforestation studies in Appalachia, hardwood tree species, with known survival success on surface mines, are used. This study evaluated small tree and shrub species that have not been planted on surface mines in a large scale and therefore knowledge and experience was not known about these species survival and growth on surface mines. Major reasons for these species high mortality were related to the conditions into which they were planted: high solar radiation, low levels of moisture, the absence of an existing forest canopy, and large amounts of browsing by wildlife during the first year of establishment when plants are most vulnerable. Some of the species in this study with high mortality were species more commonly found in moist cove environments like pawpaw and flowering dogwood. Other reasons for low survival in this study included a planting stock that may have been of poor quality and improper planting techniques may have been used. Other un-identified reasons for poor success could also be responsible.

Although survival and some height measurements were found to be greater on west-facing aspects when compared with east-facing aspects in this study, the results were not strongly supported by statistical analyses and highly influenced by just a few species with better survival and growth on the west-facing aspect. The effect of aspect for the majority of species in this study was not significant at the individual species level. Most other reforestation studies document better survival and growth on east-facing aspects (Gorman, 2001; Chazdon, 2008; Fekedulegn 2002).

K, P and Al were found to be soil properties correlated with average plant height across all sites and for all species. These results are not surprising because potassium and phosphorus are macronutrients, which are important for plant growth. Aluminum was a more surprising result, but it is closely connected with low pH.

The results of this study will aid species selection for future reclamation plantings. Planting some of the more successful species in this study including black chokeberry, Washington hawthorn, black cherry, nannyberry, gray dogwood, hazelnut, and serviceberry would potentially encourage and accelerate ecological succession and benefit wildlife. Poor survival after 6 or 8 years as seen with some of the species on these sites provided strong evidence that planting may not be practical and a waste of resources. Additionally, to increase the survival of the species that are more adapted to shade and other more mature soil conditions and to save money, it may be advisable to delay transplanting of some of these species or to allow native recruitment of these species after a canopy has been established from the planted trees. Species that prefer cove environments and rely heavily on moist soil conditions and shade, like pawpaw, should not be included in these plantings. Therefore, based on the results of this study, careful attention should be taken when selecting species and sites where such plantings should occur.

References

Angel, P., V. Davis, J. Burger, D. Graves, and C. Zipper. 2005. The Appalachian Regional Reforestation Initiative. Forest Reclamation Advisory No. 1, December 2005.

Burger, J., D. Graves, P. Angel, V. Davis, C. Zipper. 2005. The forestry reclamation approach. ARRI forest reclamation advisory number 2. U.S. Office of Surface Mining, Department of Interior, Washington. http://arri.osmre.gov/FRA/Advisories/FRA_No.2.7-18-07.Revised.pdf. Accessed 17 November 2016.

Burns, R.M. and B.H. Honkala. 1990. Silvics of North America, Vol. 2, Hardwoods. Washington DC: U.S.D.A. Forest Service Agriculture Handbook 654. **http://www.na.fs.fed.us/pubs/silvics_manual/table_of_contents.shtm**, last accessed 12.15.2016.

Chazdon, R. 2008. Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science 320: 1458-1460. DOI: 10.1126/science.1155365

Fekedulegn, D., R. Hicks, J.J Colbert. 2002. Influence of topographic aspect, precipitation, and drought on radial growth of four major tree species in an Appalachian watershed. Forest Ecol. Manage. 6064: 1-17.

Gorman, J., J. Skousen, J Sencindiver, P. Ziemkiewicz. 2001. Forest productivity and minesoil development under a white pine plantation versus natural vegetation after 30 years. p. 1-9. In: Proceedings, 2001 American Society of Mining and Reclamation. June 3-7, 2001. Lexington, KY.

NOAA National Centers for Environmental Information, State of the Climate: National Overview for Annual 2010, published online January 2011, retrieved on February 28, 2017 from http://www.ncdc.noaa.gov/sotc/national/201013.

NOAA National Centers for Environmental Information, State of the Climate: National Overview for Annual 2008, published online January 2009, retrieved on February 28, 2017 from http://www.ncdc.noaa.gov/sotc/national/200813.

Statistical Analysis System. 2011. SAS/STAT systems for windows v.9.3. SAS Institute, Cary, NC.

USDA, NRCS. 2016. The PLANTS Database. http://plants.usda.gov. 15 Dec 2016. National Plant Data Team, Greensboro, NC 27401-4901 USA.