TREE SPECIES AND DENSITY EFFECTS ON WOODY BIOMASS PRODUCTION ON MINED LANDS: ESTABLISHMENT AND TWO YEAR RESULTS[1]

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Abstract. Under-utilized, previously mined lands may be used to produce woody biomass materials for energy production and C sequestration. Past research trials have shown that tree growth on mined lands can be highly productive if suitable reclamation practices are used. This study tests the productivity of woody biomass plantations on previously mined lands after ripping to reduce soil compaction, using four species treatments under two planting densities. This paper summarizes the establishment procedure and initial results after two years of growth. Initial results indicate that black locust has the highest mean per tree volume growth under both high (1311 cm^3) and low (1917 cm^3) density planting. Due to good survival and high wood density, it also has the highest dry biomass production by an order of magnitude over other species for both high (2.39 Mg ha^{-1}) and low (1.28 Mg ha^{-1}) density planting. Hybrid poplar and American sycamore are secondary in both volume and biomass growth. Red oak and eastern cottonwood had poor survival, volume growth, and biomass production. At year two, planting density did not have a significant effect on volume growth, likely due to lack of crown/root closure between trees.

Additional Key Words: Appalachian coal fields, carbon sequestration, woody biomass, biofuels.

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Introduction

The extensive hardwood forests of the Appalachian Mountains may help meet current and future demand for biomass materials used for energy production. If demand for energy increases or future government policies limit net carbon (C) emissions from energy production, demand for carbon-neutral fuels such as woody biomass products may increase. Carbon sequestration in the United States, using forest practices, may also become an exchangeable commodity under future C regulation scenarios that may encourage production of biomass materials. Localized demand for woody biomass materials may increase if construction of 'hybrid' power plants in the Appalachian region increases. These plants are contracted to burn a percentage of non-coal materials, which will increase demand for biomass products in former and current coal producing areas. For example, Dominion Resources' Virginia City Hybrid Energy Center, currently under construction in Wise County, Virginia will use up to 20 percent biomass for its fuel (Dominion Resources 2009). Hybrid power plants that include biomass materials in their fuel mix will place pressure on local forest systems to produce acceptable forest products. If they prove capable of producing biomass fuels in an economically viable fashion and in sufficient quantities, under-utilized mined lands may help to provide these needed biomass materials in the coal fields of Virginia and surrounding coal producing states.

There are many advantages and benefits of using mined lands to produce biomass materials. The proximity of mined lands to power plants built in the coalfields will enable provision of biomass products to such plants, while limiting or minimizing transportation costs. If such mined lands can be converted and managed to provide marketable biomass products, it may reduce the impact on native forests, which can be conserved for traditional forest products and ecosystem services. Local economies will also benefit through the production of a renewable forest product on lands deemed unproductive by past generations and largely ignored by the forest products industry.

Research trials have demonstrated that properly reclaimed mine-lands can be highly productive when properly reclaimed and planted with trees (Amichev et al. 2008, Burger and Fannon 2009, Fields-Johnson et al. 2008, Amichev et al. 2004, Burger 2004). Mine soils can offer soil-like materials comprised of freshly fractured rocks at thicknesses far deeper than many of the region's natural soils. These freshly-fractured geologic materials often have chemical characteristics that are favorable to plant growth, including pH levels and nutrient cation availabilities (Anderson et al. 1989). Research on native soils in mountainous areas suggests that productivity (Mg ha^{-1} yr^{-1}) of fast growing woody crops growing on favorable sites can be 3 to 5 times greater than long-rotation natural forests (Amichev 2007). For example, in an analysis of data collected from eight un-mined native hardwood forests adjacent to coal mining areas, Amichev (2007) found that total-tree carbon accumulation averaged 2.1 Mg C ha^{-1} yr^{-1} over 60 year rotations. In contrast, he estimated that hybrid poplar growing on favorable sites with short rotations in a similar climate have the potential to accumulate total-tree C at a rate of 11 Mg C ha^{-1} yr^{-1}. Amichev et al. (2004; 2008) also found that pre-mining C sequestration can be restored on many low-quality forested sites, indicating that these mined lands can be used to produce woody biomass at levels similar to or above those of low-quality native sites. Rodrigue et al. (2002) studied forest growth on older coal mine sites in the eastern and Midwestern United States that were known to support forests, and found that 12 of 14 sites achieved productivities similar to nearby un-mined forests. The capacity of mined lands to produce woody biomass, when prepared and managed specifically for that purpose, has not been explored.

More than 40,000 ha in the southwestern Virginia coalfield, and about 0.7 million ha throughout Appalachia, have been mined for coal and reclaimed under the Surface Mining Control and Reclamation Act of 1977. Many of these areas remain accessible because mining access roads were left in place. However, past mining practices have left many sites with highly degraded site productivity due to soil compaction and lack of tree compatible vegetation. We hypothesize that these degraded mined sites with favorable soil chemical characteristics can be managed for intensive tree biomass production regardless of past soil and vegetation management. Concurrent with the production of biomass materials, we also hypothesize that stands of fast growing trees on formerly mined lands may be a viable C sequestration technique. This study is designed to test the capability of previously mined lands to be used for tree biomass production. It tests biomass production for differing tree species and planting densities on previously mined lands that have been ripped to improve soil physical properties. We used an adaptation of the Forestry Reclamation Approach (FRA), a reclamation method developed for preparing active mine sites to support woody vegetation using forestry techniques (Burger et al. 2005), to prepare these older mine sites. This paper summarizes our methods for planting and maintenance of 6 ha of operational biomass plantation at three sites. It also summarizes initial results from two years of growth, with a focus on production of aboveground biomass. There are four primary objectives for this study.

1. Develop and describe a method for preparing mine sites that have been reclaimed in previous years and are currently unused for biofuels production.
2. Measure and compare production of woody biofuel crops on mined lands using various species and planting densities.
3. Measure and compare optimum harvest cycles of woody crops on mined land.
4. Determine the potential of woody biomass, growing under optimal soil conditions, to sequester atmospheric carbon in above and below-ground forms.

This paper presents the results for the first two objectives. Objectives 3 and 4 will be addressed at future measurement intervals.

Methods

Three sites in Wise County, Virginia were included as replicate blocks (Fig. 1). This mountainous area of Virginia receives approximately 120 cm of mean annual precipitation and has a mean annual temperature of 12°C. The native vegetation types on these mountains are dominated by diverse, mixed hardwood forests. Previous to the study installation, vegetation at all three blocks was unmanaged grasses and woody shrubs, and had no significant issues with salts or metalloids. The sites were not used for agricultural grazing, but did include remnants of the original reclamation tree plantings. Block 1, the Red River site at 806 m in elevation, was reclaimed in the early 2000s with typical reclamation grasses and *Pinus* sp. Remnant pine survival was poor, as pines occupied ~10% of the site, and herbaceous vegetation was sparse. Block 2, the Across the Road site at 686 m, was reclaimed in the mid-1980s. Vegetation was a dense mixture of early successional volunteer species. Block 3, The Bean Gap site at 616 m, was dominated by grasses, with sparse trees that had survived the initial reforestation in the late 1990s. The original reclamation was with a mixture of native hardwoods and eastern white pine. Survival was poor; likely due to physical compaction effects caused by equipment operation on this relatively flat to gently sloping area.

Each site provided 2 ha of relatively flat ground (<15% slope), without large established woody vegetation, that can be reached by heavy equipment for site preparation and harvesting. In December, 2007, each site was disked and ripped to till under existing vegetation and to alleviate possible compaction, leaving loose soil material for tree planting and root growth. This was accomplished with a heavy forestland disc harrow used to break up the soil, followed by a second pass to deep till and mound the tree planting row. The tillage tool had a 1 meter center shank that ripped a deep trench through the compacted mine soil while large disks around the shank produced a mound of loose soil over the rip where the trees were planted. Smaller shanks to the right and left of the center shank broke up the surface to 1 foot on either side of the planting location.

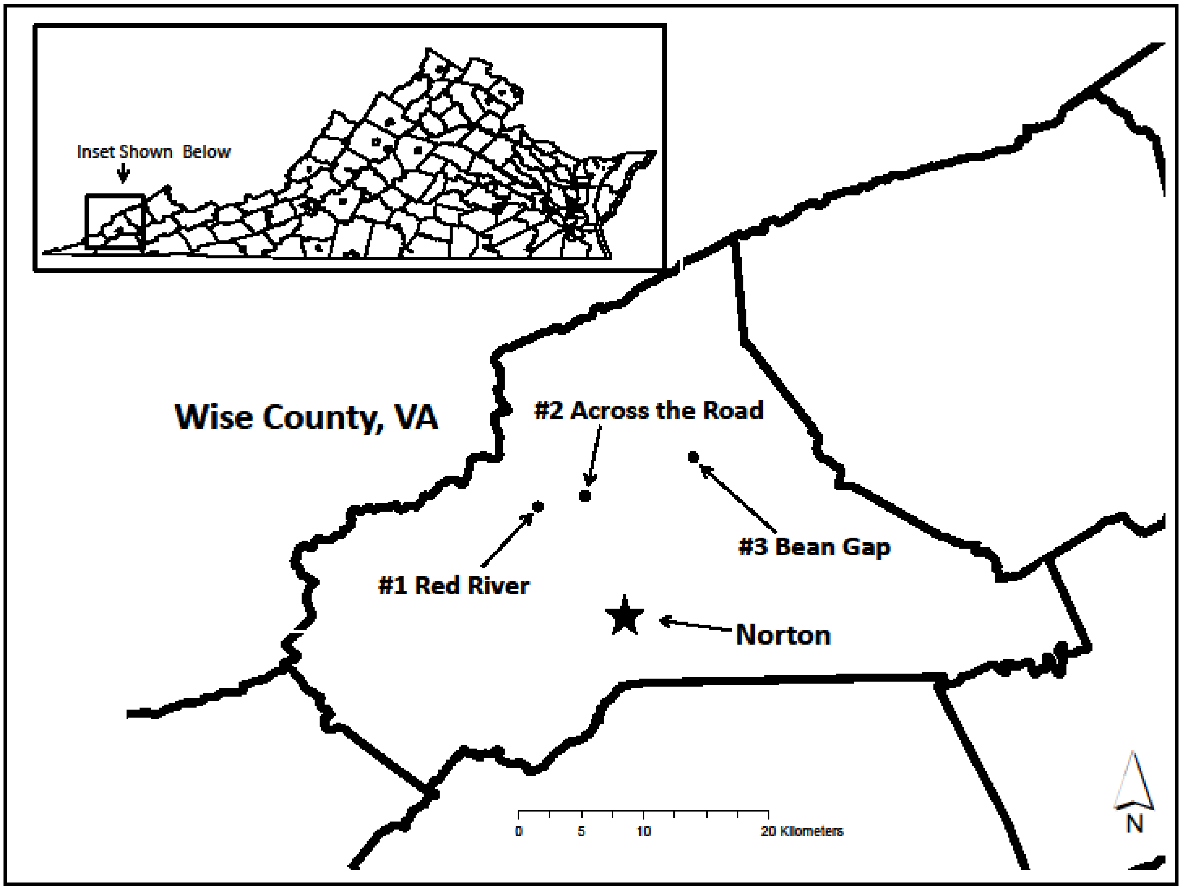

Figure 1. Biomass study block locations on ripped mine sites in Wise County, Virginia.

Each of the three blocks was divided into 4 species treatment areas of approximately 0.5 ha (Fig. 2). Species treatment plots were planted with hybrid poplar cuttings (*Populus trichocarpa* L. (Torr. and Gray ex Hook.) x *Populus deltoides* (Bartr. Ex Marsh.) hybrid 52-225), American sycamore (*Platanus occidentalis*), and black locust (*Robinia pseudoacacia*),each at two planting densities. The low density treatment was planted along the 11 foot furrows with an intended target of 3.4 m by 3.4 m spacing or 860 trees ha^{-1} (Fig. 3). The high density treatment was planted at half the distance between trees both on the furrows and in-between the furrows with an intended target of 1.7 m by 1.7 m spacing or 3400 trees ha^{-1}. A fourth species treatment included an additional low density treatment of northern red oak (*Quercus rubra*) (3.4 m by 3.4 m) interplanted with rows of eastern cottonwood (*Populus deltoides*) (1.7 m within row). This treatment was included to test the fast growing eastern cottonwood's ability to train the slower growing but higher value red oak. Red oak is a high-value sawtimber species that is native to Appalachian forests. The value of red oak as sawtimber may be increased by training its stem form at an early age by interplanting with eastern cottonwood, which can be harvested for biomass products at a relatively short rotation age. A low density red oak treatment (3.4 m by 3.4 m) without cottonwood was included to compare against the interplanted red oaks. A final treatment of low density mixed hardwoods was included, where space allowed, using a planting mix of: *Prunus serotina*, *Quercus* sp, *Acer saccharum*, *Platanus occidentalis*, *Robinia pseudoacacia*, *Fraxinus* sp., and *Cornus* sp. The hybrid poplar cuttings were purchased from a grower in Oregon, while all other trees were planted by a planting contractor, as seedlings, obtained by the contractor from commercial sources. At the time of planting, trees received no fertilizer, tree protectors, mycorrhizal treatments, or watering.

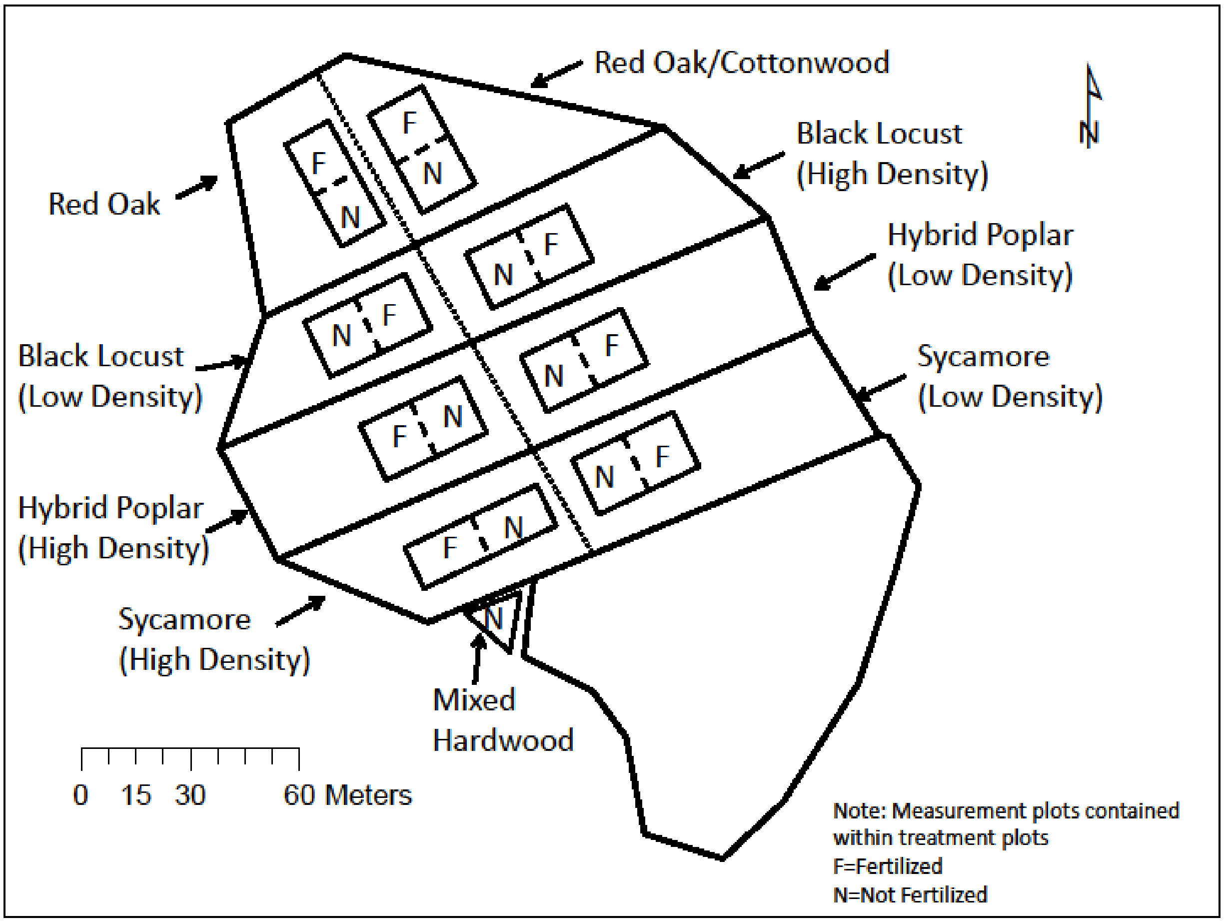

Figure 2. Example of treatment and measurement plot layout at each of three biomass study sites on ripped mined-sites in Wise County, VA. Included diagram is for Block #3 (Bean Gap).

Harvesting methods drove the rationale for the high and low planting densities. The high-density planting is suitable for harvesting at a young age (5-10 yrs) using a "mowing and chipping" type of harvesting equipment with an operating mechanism that resembles agricultural harvest equipment. The low-density planting would be suitable for harvesting with traditional whole-tree forestry equipment after a longer rotation (16-60 yrs). Within each treatment area and planting density we installed permanent measurement plots of approximately 700 m^2 (Fig. 2). A few treatment areas were in non-homogenous land areas, with seasonal or unexpected anthropogenic disturbances, so we reduced the size of these measurement plots to ensure relatively homogenous ground.

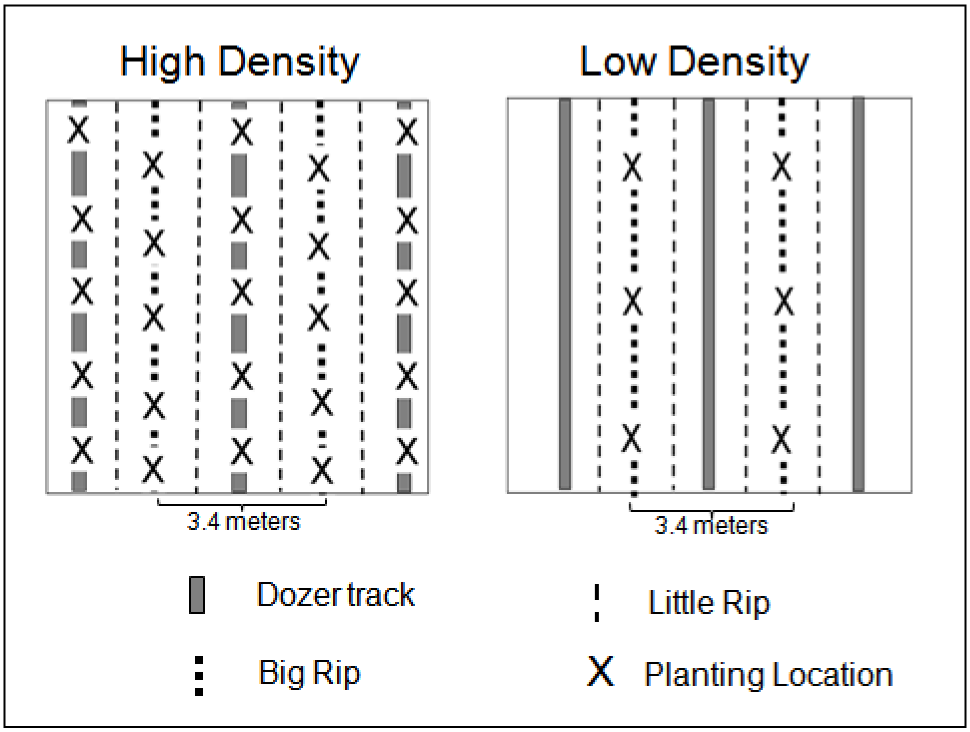

Figure 3. Planting layout for high (1.7 m by 1.7 m) and low (3.4 m by 3.4 m) density planting at biomass study on ripped mined sites in Wise County, VA.

In the late spring of both 2008 and 2009, a release spray of 2% glyphosate was used to reduce competition from weeds in a 2 m diameter circle around each of the trees in the treatment area. This spray was hand applied using backpack sprayers. Because of a droughty summer in 2008 and low viability of seedling stock, red oak and cottonwood survival was poor. Therefore, we replanted the red oaks and cottonwoods in the late winter of 2008 to bring the density back to desired levels. In February of 2009 and December of 2009 (after 2008 and 2009 growing seasons), we measured each of the treatment areas for survival, height (height to highest live bud) and ground line diameter (basal diameter). In order to test for fertility constraints on tree growth, we also applied fertilizer to half of each treatment plot, establishing a split plot treatment of fertilization versus no fertilization on all treatments except for the mixed hardwood plots (Fig. 2). In December of 2009, 118 milliliters of granular 19:19:19 was applied to the soil surface in a 0.5 m diameter circle around each tree in one half of each measurement plot. Because the nutrients in these fertilizer applications will not be available to the trees until the third growing season, analysis of this treatment is not included in this paper.

We used a volume index for an estimate of growth that incorporates both height (h) and diameter (d) growth (d^2h). Ground line diameter was used for diameter growth in the calculations. Oven dry wood density was estimated for each species using the Global Wood Density Database (Zanne et al. 2009). Biomass index per tree and per unit area were calculated using these values to give an estimate of dry woody biomass that has been produced in each treatment. Analysis of Variance was used to test for differences in volume growth using the Tukey HSD test for multiple comparisons between our nine planting treatments. Statistical analysis was not conducted on height and diameter measures, due to the young age of the trees. Additional analysis was conducted to test for density, species and block effects on volume growth of sycamore, hybrid poplar and black locust. A 3x3x2 model was used to test for these effects. All analysis was conducted in SAS 9.1. An $\alpha = 0.1$ was used for significance in all analyses.

Results

Stocking

Our measurements of stocking at year 1 and 2 indicate that planting was successful and survival was adequate (Table 1). However, stocking levels are generally lower than our projected levels of 860 and 3400 trees ha^{-1} for low and high density treatments, respectively, and there is a wide range of stocking at each block and for each treatment. High density second year stocking for hybrid poplar, black locust and sycamore ranged from 1837 to 3401 trees ha^{-1}. While low density stocking for these species ranged from 560 to 1335 trees ha^{-1}. The red oak and red oak/cottonwood treatments were variable between blocks after the second planting (Table 1), with 1507 to 1916 trees ha^{-1} for the red oak and 2067 to 2641 trees ha^{-1} for the red oak/cottonwood treatment. All treatments had generally stable stocking between year 1 and 2, except for the red oak and red oak/cottonwood treatments. These treatments saw declines instocking between year 1 and 2, indicating that the second planting of red oak and cottonwood is also having survival problems. The hardwood treatment stocking was variable between blocks with block 3 having three times higher stocking than blocks 1 and 2. Black locust is the only species that has attained enough mean height growth at all sites and planting densities to be generally above deer browse height and to be generally 'free to grow' (Table 1).

Table 1. Year one and two stocking, tree diameter and height for tree species and density trial on ripped mine sites in Wise County, Virginia.

Block 1 (Red River)	*n* 2008	*n* 2009	Area (m^2)	Trees ha^{-1} 2009	Mean Basal Diameter (cm)	Mean Height (cm)
High Density Black Locust	210	218	697	3129	2.8	189
Low Density Black Locust	69	72	697	1033	3.2	203
High Density Hybrid Poplar	184	201	697	2885	1.2	98
Low Density Hybrid Poplar	83	93	697	1335	1.5	124
Red Oak	102	113	697	1622	0.7	52
Red Oak/Cottonwood	168	144	697	2067	0.7	49
High Density Sycamore	154	170	697	2440	1.5	88
Low Density Sycamore	40	39	697	560	1.4	80
Mixed Hardwood	46	54	697	775	1.0	65
Block 2 (Across the Road)						
High Density Black Locust	164	163	557	2924	2.3	146
Low Density Black Locust	55	53	465	1141	2.1	134
High Density Hybrid Poplar	130	128	697	1837	1.3	99
Low Density Hybrid Poplar	47	47	697	675	1.1	74
Red Oak	87	84	557	1507	0.6	41
Red Oak/Cottonwood	227	184	697	2641	0.6	46
High Density Sycamore	244	237	697	3401	1.2	61
Low Density Sycamore	62	60	697	861	1.1	51
Mixed Hardwood	20	20	261	766	0.7	37
Block 3 (Bean Gap)						
High Density Black Locust	209	214	697	3071	2.3	158
Low Density Black Locust	84	82	697	1177	3.2	204
High Density Hybrid Poplar	216	212	697	3043	1.3	99
Low Density Hybrid Poplar	87	87	697	1249	1.2	92
Red Oak	101	89	465	1916	0.6	43
Red Oak/Cottonwood	225	172	697	2469	0.7	49
High Density Sycamore	136	150	581	2583	1.4	88
Low Density Sycamore	80	77	697	1105	1.8	107
Mixed Hardwood	29	30	116	2583	1.5	91

Growth

Black locust had the highest mean per tree volume (index) in both the high and low density treatments (Table 2). Both high and low density black locust had significantly greater mean volume (1311 and 1919 cm^3 respectively) than all other species and density combinations, often by greater than an order of magnitude. The high and low density black locust volumes were not significantly different from each other, but were greater than all other plantings. Hybrid poplar and sycamore had nominally greater volumes than the red oak and red oak/cottonwood, but these differences were not significant. Volume in the low density treatments was nominally greater than in the high density treatments but this difference was not significant.

On a per-tree basis, high and low density black locust had the greatest biomass (786 and 1150 g, respectively) (Table 2). Hybrid poplar and sycamore had less biomass per-tree than black locust by an order of magnitude, with red oak and red oak/cottonwood lower by an additional order of magnitude (Table 2). Mixed hardwood was generally intermediate for both mean volume index and biomass per tree. On a per-unit area basis, both the high and low density black locust treatments were again greater than all other treatments by an order of magnitude (2.39 and 1.28 Mg ha^{-1} respectively). The high density treatments had approximately double the estimated biomass for black locust, sycamore and hybrid poplar. The red oak and red oak/cottonwood treatments had the lowest biomass on an area basis, by one to two orders of magnitude.

Table 2. Year two volume and biomass index estimates for tree species and density trial on three ripped mine sites in Wise County, Virginia.

Treatment	Mean Volume Index per-tree (cm^3) (*n*=3)	Mean Stocking (trees ha^{-1})	Oven Dry Wood Density (g cm^3)	Mean Biomass Index per-tree (g)	Mean Biomass Index (Mg ha^{-1})
Black Locust (High Density)	1311a (se=263)	3041	0.60	786	2.39
Black Locust (Low Density)	1917a (se=559)	1117	0.60	1150	1.28
Hybrid Poplar (High Density)	199b (se=12)	2588	0.34	68	0.18
Hybrid Poplar (Low Density)	234b (se=74)	1086	0.34	80	0.09
Sycamore (High Density)	186b (se=74)	2808	0.46	86	0.24
Sycamore (Low Density)	244b (se=100)	842	0.46	112	0.09
Red Oak	24b (se=4)	1682	0.56	13	0.02
Red Oak/Cottonwood	29b (se=4)	2392	0.47	14	0.03
Mixed Hardwood	154b (se=69)	1375	0.47	72	0.10

Note. Volume index with same letters are not significantly different at an $\alpha = 0.1$. Oven dry wood density from Global Wood Density Database (Zanne et al. 2009). Oven dry wood density for mixed hardwood estimated from mean of four hardwood species that are major components of this planting mix

The results from the multiple comparison procedure showing that mean per-tree volumes for the high and low density treatments were not significantly different for any treatment species is supported by the mixed model ANOVA. Results from the mixed model analysis addressing species, density, block, and species x density effects on mean per tree volume show that only species is significant at $\alpha = 0.1$ (Table 3). Block, density and species x density did not have significant effects on volume index.

Table 3. Analysis of variance of volume index for species and density trial at three ripped mine sites in Wise County, VA.

Source	Degrees of Freedom	Sum of Square	Mean Square Error	F statistic	Pr>F
Block	2	675317	337658	2.05	0.1797
Species	2	9017009	4508504	27.34	<.0001
Density	1	209239	209239	1.27	0.2863
Species x Density	2	343932	171966	1.04	0.3878
Model	7	10245499	1463642	8.88	0.0013
Error	10	1648805	164880		
Total	17	11894304			

Discussion

At year two, we have achieved adequate stocking for all of our species treatments at three sites. These treatments are at a reasonably large scale and allow for a operational scale study of biomass production on mined lands. We have demonstrated the feasibility of establishing woody biomass plantations on previously mined lands with degraded physical properties using ripping as pre-planting treatment. Though there is variability of stocking between the three sites and stocking is lower than expected, all three sites have densities that will allow for intensive biomass production. Additionally, stocking levels are generally consistent between high and low density planting. This will allow us to test if high density plots reach crown closure and produce more biomass earlier than the low density plots. Mean volume growth per tree has yet to be affected by planting density, but we expect to see changes in volume growth per tree as the trees attain crown/root closure and reach the site resource competition stage of forest development. This study will allow us to test for differences in biomass production and above and below ground C sequestration under our two planting densities. It will also allow us to determine how these two planting densities effect biomass production over time to optimize harvest scheduling.

Total volume per tree was clearly greatest for black locust at year two. Combined with good stocking and the highest wood density of any tree in this study, black locust had the greatest biomass production per unit area. Hence, black locust appears to have great potential for woody biomass production on mined- lands that are not fertilized. However, there are concerns that the locust borer *Megacyllene robiniae* (Forst.), a common insect pest of black locust, will have negative effects on tree growth and production over the harvest cycle (Boring and Swank 1984). Our study will allow for examination of this possible effect over the length of the rotation for black locust. An additional concern for end utilization of black locust is its tendency to produce multiple stems. This may increase harvesting costs if the black locust stems are not large enough to use whole tree harvesting equipment, creating concern that standard chopper-type harvesting equipment may not be able to navigate surfaces that have been ripped.

Hybrid poplar and sycamore are intermediate in biomass index at year two. They also have good stocking, which gives them good potential for future volume. However, sycamore has a greater wood density than hybrid poplar (Zanne et al. 2009), which may lead to greater biomass in the future. Sycamore also has the potential to produce sawlogs that may have higher value per volume than pulp or chip materials. Hybrid poplar yields may have been reduced by lack of fertilization at planting, a common cultural treatment in hybrid poplar plantations on un-mined soils. Future growth measurements will reveal if hybrid poplar responds to the recent fertilizer application. The red oak, red oak/cottonwood, and mixed hardwood treatments do not appear to have good potential for biomass production. We successfully established good stocking for these treatments, but they had generally low to moderate volume growth. In addition, the red oak and red/oak cottonwood treatments were also hard to establish and had poor early survival. Even with a second planting, these treatments have moderate stocking and are continuing to lose trees. Our ability to determine if cottonwood can be used to train red oaks may be compromised by poor growth and survival of both species. At year two, the black locust, hybrid poplar, and sycamore treatments appear to be the best suited species for woody biomass production.

Our treatments also showed stocking variability from block to block that may be due to changes in topography, ripping requirements, soil properties, or herbaceous competition effects. This high variability in stocking appears to be common particularly when there are drastic differences in soil/spoil characteristics between sites as noted (Casselman et al. 2006; Fields Johnson et al. 2008). Growth responses under variable site conditions in mined settings are poorly understood, but must be considered when growing trees for biomass. Future research should be focused on identifying species that do well in various mine soil conditions such as seasonally ponded areas or well drained ridge and shoulder positions. Protocols must also be developed to better schedule final grading of sites with herbaceous planting and tree planting. Biomass production for energy production or C sequestration on mined lands will require advanced understanding of species selection based on site properties and timing of silvicultural activities. This study is an initial step in the understanding of these protocols.

Our estimated rotation ages are 5-10 years for the hybrid poplar, black locust and sycamore biomass crop, with a 16-60 year rotation for the red oak and sycamore saw log crop. Actual rotation ages will be determined by tracking mean annual increment (MAI) over time and harvesting at the peak MAI or the biological rotation age. The hybrid poplar and black locust will be grown strictly for biomass products. Although sycamore is among the fastest growing native Appalachian hardwood species when planted on suitable soils, its growth rate is not as fast as black locust and hybrid poplar. However, its value at rotation age will be much higher if its butt log is used for sawtimber while chipping the rest of the tree for biomass products. At approximately year 12, the interplanted eastern cottonwood will be row-thinned and the red oaks will be left free to grow for a sawtimber rotation. The interplanted treatment will evaluate the silvicultural response of the oaks' stem form due to the presence of the interplanted eastern cottonwoods, as well as total biomass production. This treatment will also help determine the effect of early revenue from biomass on a sawtimber forest enterprise.

This study confronted many of the challenges that need to be addressed to produce biomass on previously mined lands. Though we did not plant herbaceous vegetation, a vigorous cover of volunteer species re-established after ripping. This required the spraying of glyphosate to reduce weed competition around the seedlings, an approach that others have used with success to give planted trees on mined lands higher growth and survival rates (Skousen et al. 2009; Casselman et al. 2006; Ashby 1997; Anderson et al. 1989). Other researchers have had problems with animal browsing (Ashby 1997; Fields-Johnson et al. 2008). After two years, our study has seen little animal damage. At this time, black locust is generally above deer browsing height. All other species, but particularly the red oaks, cottonwoods and mixed hardwoods are still at a height where deer or rodent damage may occur and could set these species back further. Animal browsing control is a factor for successful establishment of biomass plantations and will have to be addressed in many settings. We also included a fertilizer treatment at year 2 to improve soil fertility. The costs of these techniques will vary according to the scale of an operation and the particular conditions at a site. However, successful establishment of woody biomass plantations on past mined lands will often require these additional management techniques and will incur additional costs over the standard FRA protocol on active mine sites.

We plan to track growth over the rotation ages for each treatment with a focus on aboveground biomass production, above and below ground carbon sequestration, and sawtimber production. Analysis will be conducted addressing optimum harvest scheduling timing, as well as per hectare expenditures and possible revenue streams for all of the management scenarios that this study represents.

Conclusions

There are hurdles to overcome in development of techniques to grow woody biomass on both past mined lands and newly mined lands. This study has shown that establishing biomass plantations on past minded lands will require silvicultural practices beyond what is commonly necessary to establish woody vegetation on active mine sites that are being reclaimed under the Surface Mining Control and Reclamation Act of 1977. The foundation for these silvicutural strategies have been developed by foresters and soil scientists, that our now named the Forestry Reclamation Approach (FRA) (Burger 2005). This paper demonstrated the feasibility of installing woody biomass plantations on past mined lands using the FRA, a protocol for reclaiming active mine sites, as a guideline for establishing techniques for soil management, planting, and herbaceous competition control on past mined lands. At year two, our study indicates that black locust, hybrid poplar, and American sycamore are good candidates for biomass plantations on past mined lands. However, future inter-tree competition dynamics, weed competition, species by site interaction effects, and pest impacts will influence which species produces the greatest easily harvestable biomass, in any time-frame.

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