Powell River Project Report 2011
Tree Species, Density, and Fertilizer Effects on Woody Biomass Production on Mined Lands: Year Three Report

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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 report summarizes the establishment procedure, growth of trees after three years, and the effects of a fertilizer treatment applied after year two. At year three, black locust continues to have the highest volume and biomass of any treatment and high density treatments have greater per-ha volume and biomass compared to low density treatments. For black locust, sycamore, and hybrid poplar, year three per-tree volume growth increments were greater than year two and fertilizer nominally increased growth in year three.

Introduction

More than 6,000 km^2 in Appalachia have been mined for coal since 1980 under the USA's national coal mine reclamation law, the Surface Mining Control and Reclamation Act (SMCRA), and an additional >100 km^2 are being mined each year. Some mining firms today are using reclamation methods intended to re-establish native forest on active reclamation areas (Burger et al. 2005; Angel et al. 2009), but large acreages reclaimed in the past and using other methods remain unused, unmanaged, and often unproductive.

These lands constitute a resource with potential for improved management and utilization. As demand for energy increases in association with global climate concerns, demand for carbon-neutral fuels such as woody biomass products may increase. Additional potential demands for woody biomass will arise if technologies for conversion of such materials to liquid fuels are commercialized. If they prove capable of producing biomass fuels in an economically viable fashion, mined lands may help to provide these needed biomass materials in the coal fields of Virginia and surrounding coal producing states. Unlike many other lands with potential to produce biomass, existing mined lands could be placed in biomass production uses without displacing agriculture, other managed uses, or natural ecosystems. Conversion of unused mined lands to biomass production would create societal benefits as marketable products and as and enhancements of ecosystem services such as watershed protection. Mined lands often have deep soils with abundant supplies of essential nutrients Ca, Mg, K, and S. However, past mining practices have left many sites with compacted soils, competitive vegetation, and other limitations that require cost to mitigate. Little information is available about potential productivities of post-SMCRA mined lands if converted to biomass production.

This report summarizes our methods for planting and maintenance of 6 ha of operational biomass plantation at three sites. It also summarizes results after three 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, planting densities, and fertilizer treatments.
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 report presents the tentative results for the first three objectives at year three.

Methods

Three sites in Wise County, Virginia were included as replicate blocks (Figure 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 (Figure 2), 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 (Figure 3), 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 (Figure 4), was dominated by grasses, with sparse trees that had survived the initial reforestation in the late 1990s. The original reclamation was 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.

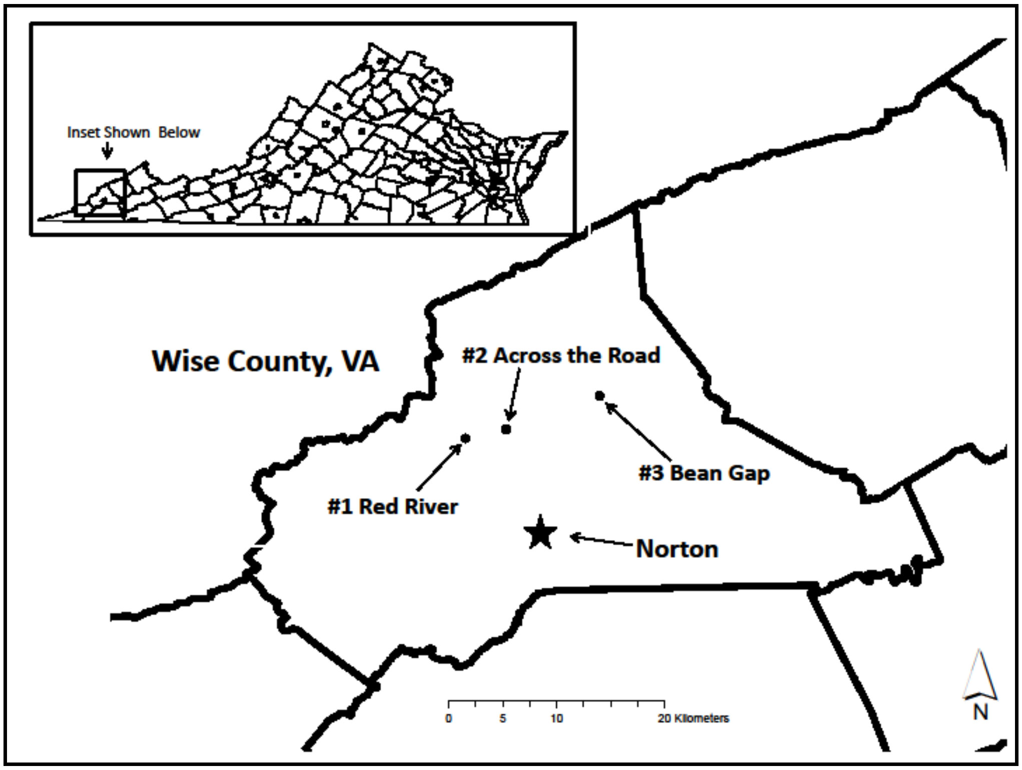

Figure 1. Biomass study block locations on ripped mine sites in Wise County, Virginia.

Each of the three blocks was divided into 4 species treatment areas of approximately 0.5 ha (Figures 2,3,4). 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} (Figure 5). 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.

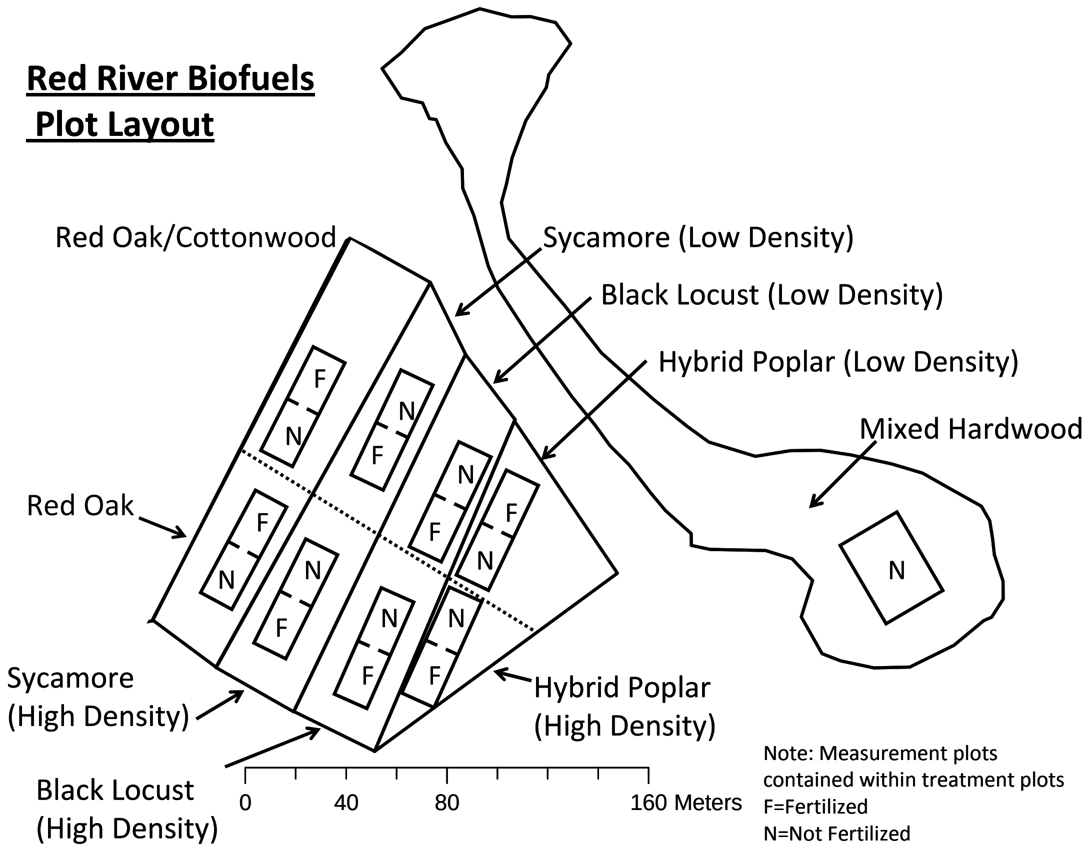

Figure 2. Red River (Block 1) biofuels treatment and measurement plot layout including black locust trial. For the black locust trial: I=improved. U= un-improved. F=fertilized. NF= no fertilization.

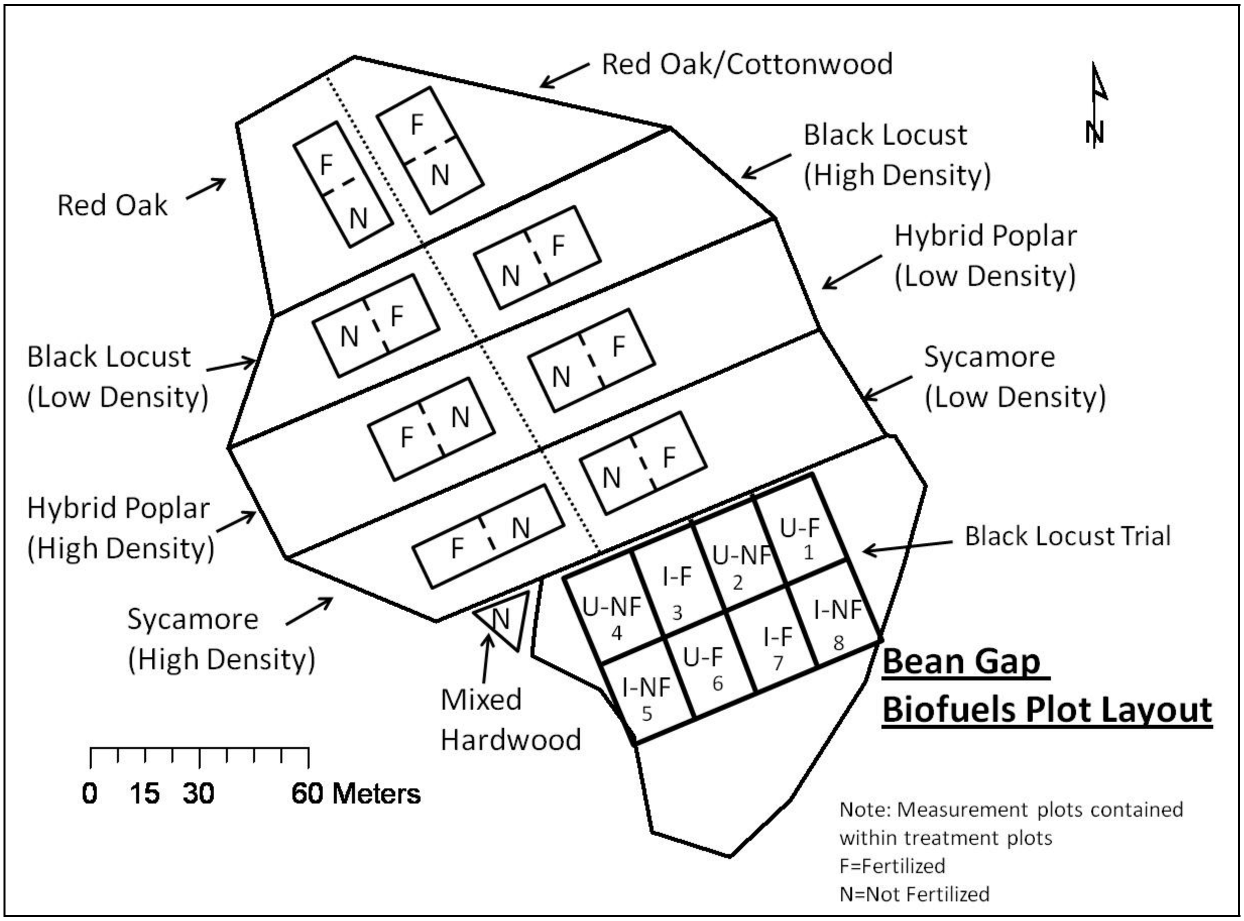

Figure 3. Bean Gap (Block 3) biofuels treatment and measurement plot layout including black locust trial. For the black locust trial: I=improved. U= un-improved. F=fertilized. NF= no fertilization.

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 (Figure 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.

In the late spring of both 2008, 2009 and 2010 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, December of 2009, and September of 2010 (after 2008, 2009, and 2010 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 (Figures 2,3,4). In December of 2009, 118 ml 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.

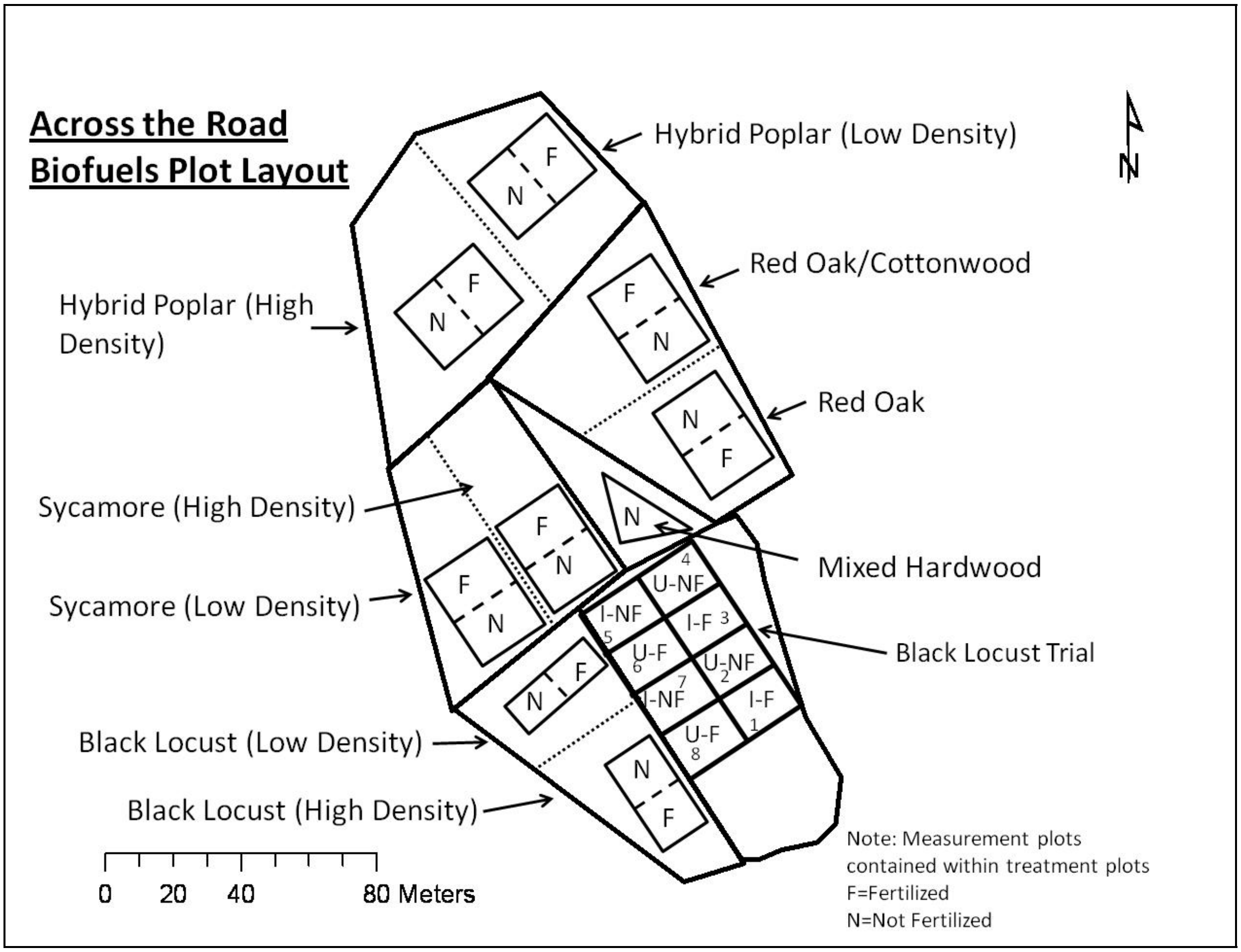

Figure 4. Across the Road (Block 2) biofuels treatment and measurement plot layout including black locust trial. For the black locust trial: I=improved. U= un-improved. F=fertilized. NF= no fertilization.

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. For this report, analysis of variance was used to test for differences in per-tree volume using the Tukey HSD test for differences between the fertilized and unfertilized treatments at our nine planting treatments. Additional analysis was conducted to test for density, species, fertilizer, and block effects on volume growth of sycamore, hybrid poplar and black locust. A

3x3x2x2 model was used to test for these effects. All analysis was conducted in SAS 9.1. An $\alpha = 0.05$ was used for significance in all analyses.

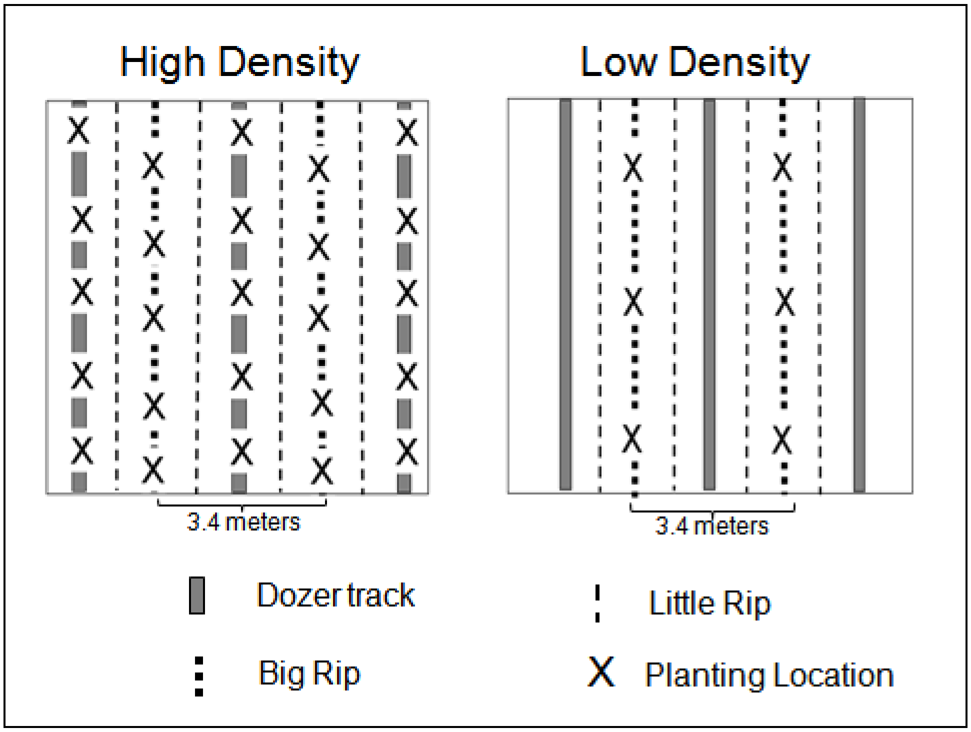

Figure 5. Planting layout for high (1.7 m by 1.7 m) and low (3.4 m by 3.4 m) density planting at biomass study on ripped mined sites in Wise County, VA.

Results

Stocking

Stocking at year three is 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 (Table 1). There is also variation in stocking between fertilized and un-fertilized treatments. Seven treatment plots across the blocks had more than a 500 trees ha^{-1} difference in stocking between the fertilized and un-fertilized plots (Table 1). These differences in stocking bias per-ha volume or biomass values that are calculated using stocking. Averaging stocking between the blocks reduces some of this effect and has a range from 53 to 400 tree ha^{-1} difference between fertilized and un-fertilized treatment plots. We therefore provide mean biomass estimates to reduce the effect of the variable stocking at each block on biomass per-ha (Table 2) and focus our analysis on per-tree volume for this report.

High density second year stocking for hybrid poplar, black locust and sycamore ranged from 1177 to 3624 trees ha^{-1}. While low density stocking for these species ranged from 488 to 1493 trees ha^{-1}. The red oak and red oak/cottonwood treatments were highly variable between blocks after the second planting (Table 1), with 1177 to 2024 trees ha^{-1} for the red oak and 1378 to 2956 trees ha^{-1} for the red oak/cottonwood treatment. The hardwood treatment stocking was also variable between blocks with block 3 having three times higher stocking than blocks 1 and 2.

Table 1. Year three height, volume, and biomass per tree at biomass production trial on ripped mine sites in Wise County, Virginia.

	Stocking (tree ha^{-1}) **NF(F)**	**Mean Height NF (cm)**	**Mean Height F (cm)**	**Volume Index NF** (cm^3 $tree^{-1}$)	**Volume Index F** (cm^3 $tree^{-1}$)	**Biomass Index NF** (g $tree^{-1}$)	**Biomass Index F** (g $tree^{-1}$)
Block 1 (Red River)							
Black Locust (HD)	3444 **(2641)**	191	**222**	1774	**2682**	1064	**1609**
Black Locust (LD)	1062 **(1062)**	198	**212**	2069	**2708**	1242	**1625**
Hybrid Poplar (HD)	2612 **(2727)**	154	**166**	630	**925**	214	**315**
Hybrid Poplar (LD)	1091 **(1493)**	114	**128**	419	**408**	143	**139**
Sycamore (HD)	2440 **(2469)**	102	**124**	390	**506**	179	**233**
Sycamore (LD)	488 **(631)**	80	**92**	242	**334**	111	**154**
Red Oak	1177 **(1234)**	50	**59**	37	**72**	21	**40**
Red Oak/ Cottonwood	1579 **(1378)**	54	**58**	38	**54**	18	**25**
Mixed Hardwood	1033	48		45		21	
Block 2 (Across the Road)							
Black Locust (HD)	2906 **(3624)**	228	**239**	2769	**3229**	1661	**1937**
Black Locust (LD)	1292 **(1076)**	282	**297**	5464	**6030**	3279	**3618**
Hybrid Poplar (HD)	2095 **(1177)**	194	**236**	1571	**2470**	534	**840**
Hybrid Poplar (LD)	488 **(574)**	171	**174**	968	**1387**	329	**472**
Sycamore (HD)	3387 **(2813)**	150	**150**	942	**1030**	433	**474**
Sycamore (LD)	775 **(689)**	158	**217**	1184	**3258**	545	**1499**
Red Oak	1686 **(1292)**	51	**52**	34	**94**	19	**53**
Red Oak/ Cottonwood	2727 **(1722)**	100	**80**	247	**153**	116	**72**
Mixed Hardwood	1378	138		658		309	
Block 3 (Bean Gap)							
Black Locust (HD)	3215 **(2899)**	268	**279**	4655	**4673**	2793	**2804**
Black Locust (LD)	1148 **(1206)**	259	**279**	5724	**7087**	3434	**4252**
Hybrid Poplar (HD)	3071 **(2727)**	143	**194**	427	**1003**	145	**341**
Hybrid Poplar (LD)	1177 **(1320)**	191	**250**	1013	**2149**	344	**731**
Sycamore (HD)	3031 **(2377)**	188	**152**	1487	**842**	684	**387**
Sycamore (LD)	1119 **(1148)**	128	**169**	802	**1554**	369	**715**
Red Oak	1550 **(2024)**	66	**68**	80	**113**	45	**63**
Red Oak/ Cottonwood	2842 **(2956)**	70	**77**	115	**136**	54	**64**
Mixed Hardwood	5511	83		195		91	

Note: NF= No Fertilizer. F= Fertilizer. Bold type indicates fertilized treatment plots.

Growth

At year three, black locust, hybrid poplar, and sycamore have all attained a 'free to grow' status and are generally above the competing herbaceous vegetation and deer browse effects at both high and low density at all blocks, with a few minor exceptions (Table 1). Mean height was nominally greater at all but three of the fertilized plots for all species, densities, and blocks (Table 1). However, when averaged across blocks, none of these differences are significant at an a= 0.05 (Tukey HSD).

Black locust had the highest mean per-tree volume index (Table 2). Both high and low density fertilized black locust had greater mean per-tree volume (3528 and 5275 cm^3 respectively) than the unfertilized black locust and all other treatment combinations. Both high and low density unfertilized black locust had significantly greater mean volume (3066 and 4419 cm^3 respectively) than the remaining species and density combinations, often by greater than an order of magnitude. When averaged across the blocks the nominal differences between the mean per-tree volume for fertilized and unfertilized plots were not significant at an a= 0.05 (Tukey HSD).

On a per-tree basis, high and low density fertilized black locust had the greatest biomass (2117 and 3165 g $tree^{-1}$ respectively) (Table 2) with unfertilized black locust slightly lower (1840 and 2651 g $tree^{-1}$ respectively). 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 high and low density fertilized black locust had greater biomass than all other treatments by an order of magnitude (6.57 and 3.53 Mg ha^{-1} respectively) with unfertilized black locust slightly lower (5.87 and 3.10 Mg ha^{-1} respectively). For the fertilized and unfertilized black locust, sycamore, and hybrid poplar treatments, the high density treatments had approximately two to four times more estimated per-ha biomass than the low density treatments. The red oak and red oak/cottonwood treatments had the lowest biomass on a per-ha basis, by one to two orders of magnitude.

Table 2. Year three volume and biomass per-tree and per-ha on three ripped mine sites in Wise County, Virginia.

Treatment	Mean Volume Index NF (cm^3 $tree^{-1}$)	Mean Volume Index F (cm^3 $tree^{-1}$)	Mean Biomass Index NF (g $tree^{-1}$)	Mean Biomass Index F (g $tree^{-1}$)	Mean Biomass Index NF (Mg ha^{-1})	Mean Biomass Index F (Mg ha^{-1})
Black Locust (HD)	3066	**3528**	1840	**2117**	5.87	**6.47**
Black Locust (LD)	4419	**5275**	2651	**3165**	3.10	**3.53**
Hybrid Poplar (HD)	876	**1466**	298	**498**	0.77	**1.10**
Hybrid Poplar (LD)	800	**1315**	272	**447**	0.25	**0.50**
Sycamore (HD)	940	**793**	432	**365**	1.28	**0.93**
Sycamore (LD)	743	**1715**	342	**789**	0.27	**0.65**
Red Oak	50	**93**	28	**52**	0.04	**0.08**
Red Oak/ Cottonwood	133	**114**	63	**54**	0.15	**0.11**
Mixed Hardwood	299		141		0.34	

Note. NF= No fertilizer. F= Fertilizer.

The results from the multiple comparison procedure comparing fertilized to unfertilized indicating that mean per-tree volumes were not significantly different for any treatment species or density are supported by the mixed model ANOVA. Results from the mixed model analysis addressing species, fertilization, density, and block effects on mean per tree volume show that fertilizer is not a significant effect at a=0.05. Block, species, and density were all found to be significant effects in the model, indicating that block location, species selection, and planting density had an effect on mean per-tree volume growth.

Table 3. Analysis of variance of per-tree volume index for black locust, sycamore, and hybrid poplar at three ripped mine sites in Wise County, VA.

Source	Degrees of Freedom	Sum of Square	Mean Square Error	F statistic	Pr>F
Fertilizer	2	1278504	1278504	1.51	0.228
Block	2	15428556	7714278	9.14	0.008
Species	1	69735243	34867621	41.29	<.0001
Density	2	5218200	5218200	6.18	0.0189
Model	6	93202645	15533774	18.39	<.0001
Error	29	24489611	844469		
Total	35	117692257			

Mean per tree volume growth increment of black locust, sycamore, and hybrid poplar increased from year two to year three for all density and fertilizer treatment combinations. However, these species showed variation in patterns of growth increment from year two to three and response to fertilizer (Figure 6). Black locust per-tree volume growth increment increased from year two to three with the fertilized plots having almost two times greater growth increments for both densities (Figure 6). The fertilized and un-fertilized low density black locust treatments had the greatest third year volume growth increment of any treatment (3358 and 2502 $cm^3 tree^{-1} yr^{-1}$, respectively) with the high density black locust treatments slightly lower (2217 and1755 and $cm^3 tree^{-1} yr^{-1}$, respectively). Sycamore and hybrid poplar also had increases in mean volume growth increment from year two to three in both the fertilized and unfertilized and high and low density treatments (Figure 6). The fertilized hybrid poplar treatments and the fertilized low density sycamore treatment had third year volume increments that were almost an order of magnitude greater than second year.

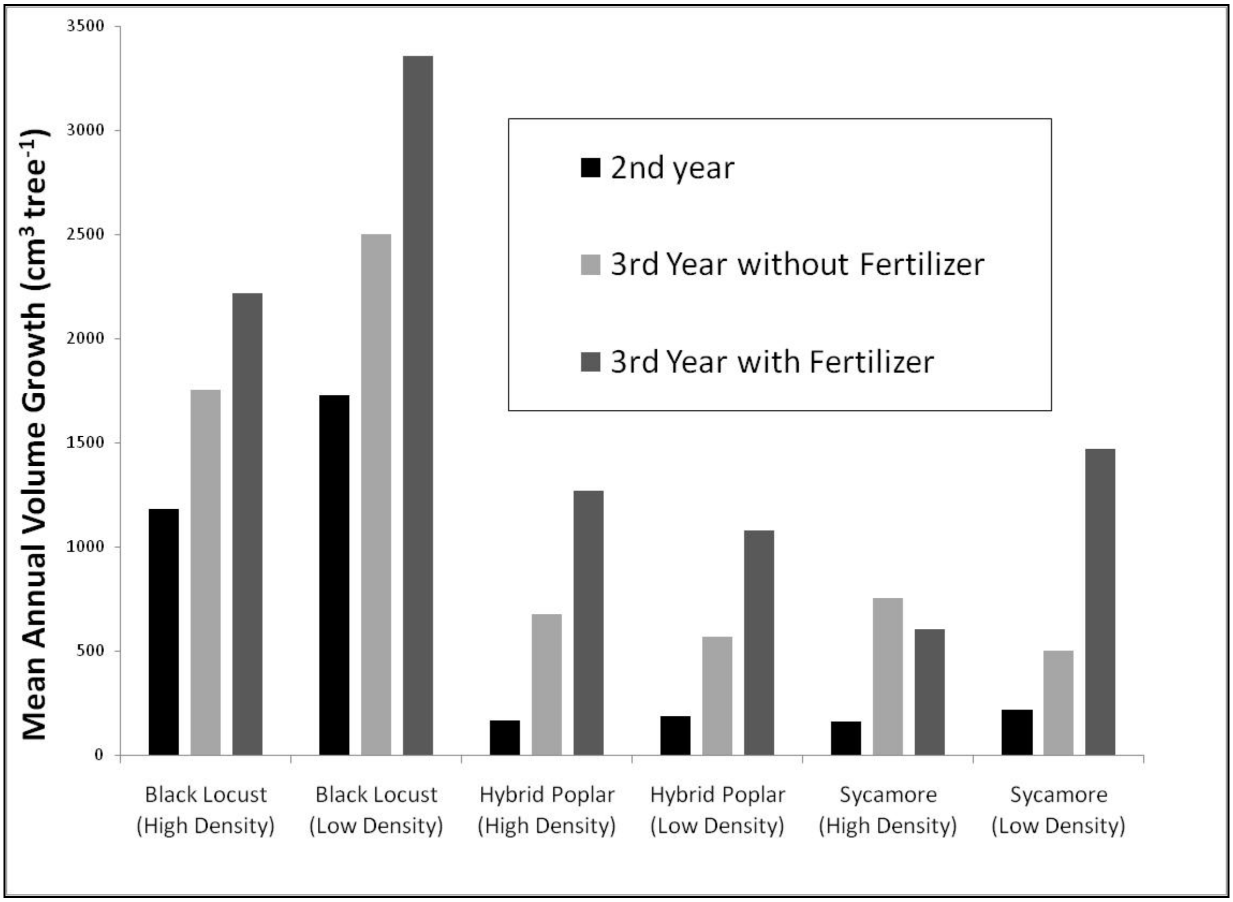

Figure 6. Mean annual per-tree volume growth increment by planting density and fertilizer treatments for black locust, hybrid poplar, and sycamore at three ripped mine sites in Wise county, VA.

Discussion and Conclusions

At year three we have achieved successful stocking for all of the treatment combinations. However, there is high variability in the stocking levels at the three blocks and stocking levels between the fertilized and unfertilized treatments are not consistent. Future analysis on volume or biomass per-ha will have to address the different stocking levels for fertilized and un-fertilized treatments.

The year three volume and biomass estimates have similar patterns between species and density treatments as year two (Evans et al. 2010). Black locust continues to have the greatest per-tree volume, per-ha volume, and per-ha biomass. Hybrid poplar and sycamore continue to be secondary in volume and biomass growth behind black locust. The red oak, red oak/cottonwood, and hardwood treatments are successfully stocked but are growing substantially slower than the black locust, hybrid poplar, and sycamore treatments. The red oak, red oak/cottonwood, and hardwood treatments make a useful comparison with the faster growing species in this trial and are good species choices for reforestation after mining. However, based on their slower growth in this trial, we cannot recommend them for operational biomass production at this time.

At year three the high density treatments continue to have the greatest biomass per-ha for the sycamore, hybrid poplar, and black locust. However, the per-tree volume and biomass for the low density treatments are greater than the high density treatments for these species and density is a significant variable in the mixed model analysis. This is likely due to resource competition effects in the high density treatments. We expect to see the low density treatment volume and biomass per-ha continue to increase while the high density growth may slow due to resource competition effects.

We did not find statistical differences between fertilized and un-fertilized plots at this time. This may be due to the species and density treatments over-powering the effects of the fertilizer or the fertilizer not having enough time to create large enough differences in height and volume to be significant. Additionally, it is possible that high variability between blocks and the lack of replication at each block has reduced our statistical ability to detect differences.

The volume growth increments for black locust, hybrid poplar, and sycamore increased from year two to three, indicating that the trees are growing faster and they have not reached their biological rotation age. Fertilization nominally increased the volume growth increments for each of these species and density treatments. Future analysis will be conducted to determine the biological rotation age for each of the treatment combinations with a focus on testing if fertilized plots continue to grow faster than non-fertilized plots and if they reach biological rotation faster or slower. We will also address total biomass growth over the rotation and examine the maximum potential biomass production for each of the treatment combinations.

Acknowledgements

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Other Activities

This work was reported at the 2011 National Meeting of the American Society of Mining and Reclamation, and a paper was published in the Conference Proceedings:

Zipper C.E., D.M. Evans†, J.A. Burger, C.W. Fields-Johnson*, A. Brunner, B. Stanton. 2011. Woody biomass production on post-SMCRA mined lands over three years and comparisons with other studies. in: Proceedings, National Meeting of the American Society of Mining and Reclamation. June 11-16, Bismarck ND.

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