WOODY BIOMASS PRODUCTION ON POST-SMCRA MINED LANDS OVER THREE YEARS AND COMPARISONS WITH OTHER STUDIES[1]

Carl E. Zipper,[2] Daniel M. Evans, James A. Burger, Christopher W. Fields-Johnson, Amy Brunner, Brian Stanton

Abstract. Lands mined for coal and reclaimed under the Surface Mining Control and Reclamation Act (SMCRA) can be used to produce woody biomass. This study evaluates woody biomass production on SMCRA-reclaimed lands after ripping to reduce soil compaction. Four species treatments were established at two planting densities on three Wise County, Virginia, mine sites. Here, we review experimental treatment effects on biomass production after three years, and we compare results to those of two other current studies that are also evaluating biomass production on post-SMCRA mined lands. After three growing seasons, black locust produced more volume and biomass than other planted species. High-density plantings produced greater per-hectare biomass than low-density plantings. For black locust, sycamore, and a hybrid poplar clone (*Populus trichocarpa x P. deltoides,* clone 52-225), per-tree volume growth increments were nominally greater in year three than in year two, and fertilizers applied after year two nominally increased growth. A low-density red oak planting and a mix of red oak and eastern cottonwood planted at high density produced low amounts of biomass compared to other species. The Wise County study's hybrid poplars are growing less rapidly than hybrid poplars of the same clonal variety growing on VA, WV, and OH mine sites in a multi-state study, and its black locust biomass production is comparable to the best performing of the multi-state study's hybrid poplars. In a third study, ninety-eight hybrid poplar genotypes of three taxons (*P. deltoides x P. trichocarpa* (DT and reciprocal), *P. deltoides x P. nigra* (DN), and *P. deltoides x P. maximowiczii* (DM)) completed two years of growth on a VA mine site. Average biomass production by the DM clones exceeded production on the multi-state trial's best performing site and is comparable to the Wise County study's black locust production over comparable time periods. Within each taxon including DM, growth by the fastest growing genotypes is exceeding taxon means by factors of >2x. In both the Wise County and the multi-state study, significant effects by site and other non-species factors on biomass production are apparent, but which factors are driving performance differences is not clear. In order for biomass production on post-SMCRA mine sites to achieve commercial potential, factors causing the major growth differences observed in these studies must be understood and managed.

Additional Key Words: Hybrid poplar, black locust, sycamore

---

[1] Paper was presented at the 2011 National Meeting of the American Society of Mining and Reclamation, Bismarck, ND ***Reclamation: Sciences Leading to Success*** June 11 - 16, 2011. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] Carl E. Zipper is Associate Professor and Chris Fields-Johnson is a graduate student, Crop and Environmental Sciences Dept, Virginia Tech. Daniel M. Evans is Research Associate James A. Burger is Professor Emeritus, and Amy Brunner is Associate Professor, Forest Resources and Environmental Conservation Dept. Virginia Tech, Blacksburg VA 24061. Brian Stanton is Managing Director for Tree Improvement at Greenwood Resources, Portland, OR. 97201.

Proceedings America Society of Mining and Reclamation, 2011 pp 768-786
DOI: 10.21000/JASMR11010768
http://dx.doi.org/10.21000/JASMR11010768

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 (US OSMRE 2011). 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 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 along with global climate concerns, use of carbon-neutral fuels such as woody biomass for energy production may increase. Additional demands for woody biomass may occur if technologies for their conversion into liquid fuels are commercialized. Mined lands in the Appalachian coalfields may help to provide these materials if they prove capable of producing biomass in an economically viable fashion. Unlike many other lands with potential to produce biomass, mined lands can be converted to biomass production without displacing agriculture, other managed uses, or valued natural ecosystems. Conversion of unused mined lands to biomass production can create societal benefits as marketable products and as enhancements of ecosystem services such as watershed protection. Mined lands often have deep soils with abundant supplies of the essential nutrients Ca, Mg, K, and S. However, past mining practices have left many mine sites with compacted soils, competitive vegetation, and other limitations that are costly to mitigate. Little information is available about potential productivity of post-SMCRA mined lands if used for biomass production.

We are conducting studies to evaluate the capability of previously mined and reclaimed lands to support woody biomass production. One study on three mine sites in Wise County, Virginia, evaluates biomass production for differing tree species and planting densities after ripping to improve soil physical properties (Evans et al. 2010). Study goals are to evaluate effects of tree species, planting density, and fertilization on biomass production. Here, we report results of that Wise County study after its third year, and we compare those results with two other current studies that are also evaluating woody biomass production on ripped post-SMCRA mine sites.

Methods

Wise County Study Sites

Three mine sites in Wise County, Virginia were developed as replicate experimental blocks (Fig. 1). This mountainous area of VA receives approximately 120 cm of mean annual precipitation, approximately half during the growing season, and has a mean annual temperature of 12°C. The native vegetation is mixed hardwood forest. Prior to study installation, vegetation at all three sites was unmanaged grasses and woody shrubs. The study sites had no known problems with salts, acids, or metalloids. Site W1, at 806 m in elevation, was reclaimed in the early 2000s with reclamation grasses and *Pinus sp.* Pine survival was poor, as remnant pines occupied ~10% of the site, and herbaceous vegetation was sparse. Site W2, at 686 m, was reclaimed with grasses in the mid-1980s. Vegetation immediately prior to biomass conversion was a dense mixture of early successional volunteer species of varying stature, but with few trees. Site W3, at 616 m and reclaimed in the mid-1990s, was dominated by grasses but also supported sparse trees, a mixture of native hardwoods and eastern white pine (*Pinus strobus*), as remnants of the original reclamation.

Each site provided ~2 ha of relatively flat ground (<15% slope) without large established woody vegetation. Each site was disked and ripped in December 2007 and planted in early 2008. Site preparation procedures are described with more detail by Evans et al. (2010).

Wise County Study Treatments

One experimental block was established at each site. Each block was divided into 4 species treatment areas of approximately 0.5 ha. These 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*) seedlings, and black locust (*Robinia pseudoacacia*) seedlings, each at two planting densities. The low-density treatment was planted along the ~3 m spaced furrows created by the soil ripping operation with an intended 3.4 m by 3.4 m spacing or 860 trees ha^{-1} (Fig. 2). The high density treatment was planted in parallel rows both on the furrows and between furrows at an intended spacing of 1.7 m by 1.7 m or 3400 trees ha^{-1}. A fourth species treatment included a low-density planting of northern red oak (*Quercus rubra*) (3.4 m by 3.4 m) seedlings, paired with a high-density interplanting of red oak on the furrows at 1.7 m spacing with parallel rows of eastern cottonwood (*Populus deltoides*) between the furrows and also at 1.7 m spacing. The high-density interplanted treatment was included to test the fast-growing eastern cottonwood's ability to "train" the red oak to develop straighter-growing and higher valued stem form with less branching than the low-density open-grown form while also developing as a harvestable biomass crop.

Each mine site also had ripped areas that were not established as any of the four species treatments. These were irregularly shaped areas between or adjacent to the primary experimental plantings but ripped and prepared similarly. Mixed hardwoods were established in these areas at densities typical of non-biomass reforestation plantings and equivalent to the low-density biomass plantings. The mixed hardwoods were a mix of black cherry (*Prunus serotina)*, oaks (*Quercus* sp,), sugar maple (*Acer saccharum)*, American sycamore (*Platanus occidentalis)*, black locust (*Robinia pseudoacacia)*, ash species *(Fraxinus* sp.), and dogwoods (*Cornus* sp.). Although not established as an experimental treatment, these hardwood plantings were also measured and evaluated as a control for comparison with the experimental treatments. The hybrid poplars were purchased from a grower in Oregon as 23 cm cuttings with 0.95 cm minimum diameter, while all other trees obtained by a planting contractor as seedlings from commercial sources. A commercial contractor planted all seedlings and cuttings. At the time of planting, trees received no fertilizer, tree protectors, mycorrhizal treatments, or watering.

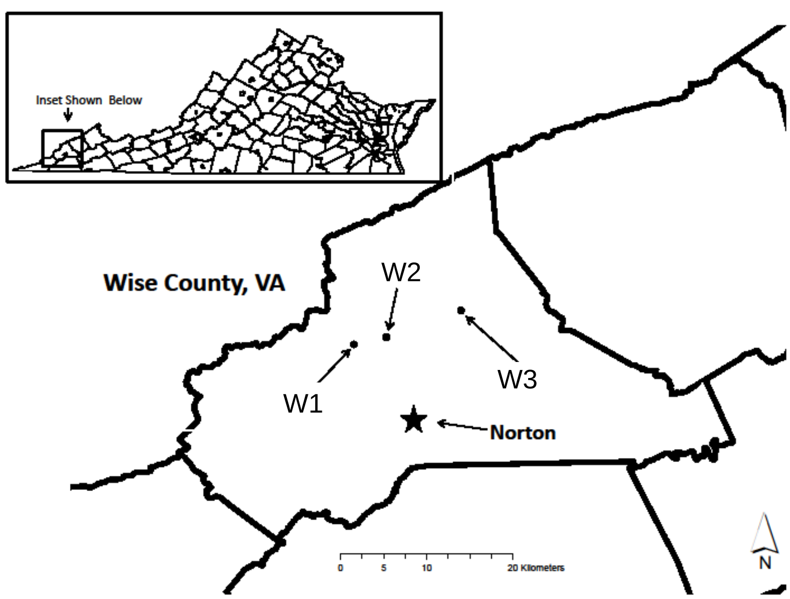

Figure 1. Biomass study locations on ripped mine sites in Wise County, Virginia. Three experimental blocks (W1, W2, and W2), were established, one at each location.

Within each treatment area (species x planting density), permanent measurement plots of approximately 700 m^2 were installed. A few treatment areas contained non-homogenous land conditions, so these measurement plots were reduced in size to attain relatively homogenous ground throughout the measurement areas of each experimental block.

In the late spring of 2008, 2009 and 2010, an herbicide spray (2% glyphosate) was used in the treatment areas to reduce competition from weeds within a 2 m diameter circle around each tree. This spray was hand-applied using backpack sprayers. Because of a droughty summer in 2008 and the low viability of seedling stock documented by the planting contractor, red oak and cottonwood survival was poor. Therefore, the red oaks and cottonwoods were replanted in the late winter of 2008 to bring stocking back to desired levels. In December 2009, 118 ml of granular 19:19:19 commercial fertilizer was applied to the soil surface in a 0.5 m diameter circle around each tree in one half of each measurement plot, establishing a split-plot treatment of fertilization versus no fertilization within all species and planting density treatments. The mixed hardwood control areas were not fertilized. In February 2009, December 2009, and September 2010, living trees within all measurement plots were assessed for survival, and measured for height (H) to highest live bud and ground line diameter (GLD).

Wise County Study Data Analysis

A volume index (VI) was used to estimate the volume of each measured tree:

$$VI = H*GLD^2$$

Oven dry wood density was estimated for each species using the Global Wood Density Database (Zanne et al. 2009), and VIs were converted to aboveground stem biomass indices using these factors. Analysis of variance was used to test for differences in stocking, per-tree volume, per-tree biomass, and per-hectare biomass due to planting density, fertilization, species, and block effects. Data analyses were performed using SAS 9.1 and JMP 9.0 (SAS Institute, Cary NC).

Comparison Studies

To enable a broader view of potential biomass production on post-SMCRA mined lands, Wise County study results are compared to results from two other current field studies that are also evaluating biomass production on similarly prepared post-SMCRA mine sites.

Multi-State Study: In early 2004, mined land sites in OH, VA, and WV were prepared for tree establishment (Casselman et al. 2006; Fields-Johnson et al. 2008; Fields-Johnson 2011). Cultural treatments were weed control only; weed control plus subsoil ripping; and weed control plus ripping plus fertilization. Three replications of the same experimental design were established in each state. Three species treatments were planted (mixed hardwoods, eastern white pine (*Pinus strobus*), and hybrid poplar) but we report here only the results for hybrid poplar which was clearly the highest biomass producer. The hybrid poplars used in this study were of the same clonal variety and obtained from the same source as for the Wise County study. In OH and VA, the ripped and fertilized treatments produced the most hybrid poplar biomass, as expected. In WV; however, the ripped and unfertilized treatment produced more biomass than the fertilized treatments; these study areas were established on a mined area that had previously been grazed by livestock and had greater measured N and P levels than the VA and OH other sites. The multi-state study plantings were measured after their second, third, fourth, and fifth growing seasons using techniques identical to those applied for the current trial.

Hybrid Poplar Genotype Study: In early 2009, a hybrid poplar genotype comparison study was established at Powell River Project Research and Education Center in Wise County, VA. The site had been ripped in late 2007. In early 2009, it was prepared for planting by removing competing vegetation, liming, and fertilizing with N and P (Brunner et al. 2009). Ninety-eight hybrid poplar genotypes of three taxa (*Populus deltoides x P. trichocarpa* (DT and reciprocal TD, DT/TD), *P. deltoides x P. nigra* (DN), and *P. deltoides x P. maximowiczii* (DM) were installed, with 4 replications. Clones were planted on 0.6 m spacings over subsoil rips that were spaced ~3m, using the same ripping equipment as the Wise County trial. Clones were measured in late 2010, after their second year. Measurements included height for all planted clones, and diameter at breast height (DBH) for those individuals that had reached breast height.

In order to convert these measurements to a basis that would enable comparisons to data generated by other studies that measured tree diameter at ground level, a regression relationship was developed using data recorded by the multi-state study in Year 4, when both DBH and GLD were measured for all hybrid poplars taller than breast height (636 individuals). An ordinary least-squares regression, computed from these data using JMP 9.0 yielded the following expression: GLD (cm) = 2.3306176 + 1.239331*DBH (cm) [$R^2 = 0.79$; $p<.0001$]

This expression was applied to each measured DBH as a means of estimating comparable GLDs; a volumetric index was then calculated using that estimated GLD and the same function as was applied in the other trials.

For those trees with heights <1.3 m, DBH was not measured but height was measured. For these trees, volumetric index was estimated using the following expression:

$$VI\ (cm^3) = 0.0605963*H^2$$

where H is height expressed in cm. This expression was estimated by fitting a quadratic curve, constrained to a zero intercept, to the H vs. VI data for those trees in this trial where VIs were estimated as described above. The curve fit yields an R^2 of 0.975. ($p<.0001$). This expression is applied to estimate VIs only for individual trees that have not grown to breast height.

Volumetric indices were converted to a biomass index using an identical procedure to that applied for the other trials. Results were averaged by genotype, and then by taxon.

Results

The fertilization that was applied prior to the Year 3 growing season in the Wise County study, although nominally increasing stocking and growth for across most treatments (Table 1), did not have a statistically significant influence (at $p<0.05$) on any of the 4 biomass production indicators: stocking, volumetric index per tree, biomass index per tree, and biomass index per hectare. At $p<.10$, fertilizer significantly influenced volume index but not the other three production-indicator variables.

Stocking

Stocking at year three for the Wise County trial is generally lower than intended 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 considerable variation in stocking between fertilized and non-fertilized treatments. Seven treatment plots across the blocks had more than a 500 trees ha^{-1} difference in stocking between the fertilized and non-fertilized plots. Average stocking difference between fertilized and non-fertilized treatment plots ranged from 53 to 400 trees ha^{-1}.

Table 1. Year three stocking, volume, per-tree biomass, and per-hectare biomass on three ripped mine sites in Wise County, Virginia.

Species†	Planting Density	Stocking (trees ha^{-1})		Mean Volume Index (cm^3 $tree^{-1}$)		Mean Biomass Index (g $tree^{-1}$)		Mean Biomass Index (Mg ha^{-1})	
		NF	F	NF	F	NF	F	NF	F
BL	High	3188	**3055**	3066	**3528**	1840	**2117**	5.87	**6.47**
BL	Low	1167	**1115**	4419	**5275**	2651	**3165**	3.10	**3.53**
HP	High	2593	**2210**	876	**1466**	298	**498**	0.77	**1.10**
HP	Low	919	**1129**	800	**1315**	272	**447**	0.25	**0.50**
S	High	2953	**2553**	940	**793**	432	**365**	1.28	**0.93**
S	Low	794	**823**	743	**1715**	342	**789**	0.27	**0.65**
RO/C	High	2383	**2019**	133	**114**	63	**54**	0.15	**0.11**
RO	Low	1471	**1517**	50	**93**	28	**52**	0.04	**0.08**
MH		2641		299		141		0.34	

Note. BL = Black Locust; HP = Hybrid Poplar; S = Sycamore; RO/C = Red Oak – Cottonwood; RO = Red Oak; MH = Mixed Hardwoods. NF= No fertilizer. F= Fertilizer.

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 among blocks despite the replanting after Year 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 mixed hardwoods' stocking was also variable between blocks, with W3 having three times greater stocking than W1 and W2.

Growth

At year three in the Wise County study, black locust, hybrid poplar, and sycamore have all attained a "free to grow" status; they are generally taller than competing herbaceous vegetation and above deer-browse at both high and low density, but with a few exceptions. Mean height for the fertilized plots was generally and nominally greater than for the corresponding non-fertilized plots.

Mean per-tree volume index and biomass index were greatest for black locust (Table 2). Both high- and low-density black locust showed significantly greater mean volume and biomass than the remaining species - density combinations. Per-tree volume and biomass production by black locust exceeded red oak, red oak-cottonwood, and mixed hardwoods by more than an order of magnitude. Hybrid poplar and sycamore had less biomass per tree than black locust by nearly an order of magnitude, with red oak and red oak/cottonwood lower by almost an additional order of magnitude (Table 2).

Table 2. Mean volume index per tree, and mean biomass index per tree and per ha after 3 growing seasons for each of species and species group, at high density (HD) and low density (LD) spacings.

	Volume Index (cm^3 $tree^{-1}$)		Biomass Index (g $tree^{-1}$)		Biomass Index (Mg ha^{-1})	
Species	HD	LD	HD	LD	HD	LD
BL	3297 a	4847 a	1978 a	2908 a	6.1 a A	3.4 a B
HP	1171 b	1057 b	398 b	360 b	0.8 b A	0.4 b B
SY	866 bc	1229 b	398 b	566 b	1.1 b	0.5 b
RO (/C)	124 c	72 b	58 b	40 b	0.14 b A	0.06 b B
MH		299		140		0.3

Note. BL = Black Locust; HP = Hybrid Poplar; S = Sycamore; RO/C = Red Oak – Cottonwood; RO = Red Oak; MH = Mixed Hardwoods. Results are means for fertilized and non-fertilized treatments combined. Small letters within columns indicate significant differences among species (Tukeys HSD, alpha = 0.10). Caps across columns indicate significant differences among planting densities (t test, alpha = 0.10). MH were not included in the statistical comparisons.

On a per-hectare basis, both high- and low-density black locust had greater biomass than all other treatments, again by nearly an order of magnitude compared to sycamore and hybrid poplar. For black locust, hybrid poplar, and red oak (compared to red oak/cottonwood), estimated per-hectare biomass on the high-density treatments was significantly greater than, and approximately double, that of the low-density treatments. For sycamore, high-density per-hectare biomass was approximately double the low-density biomass but the difference was nominal. For black locust, greater nominal growth at low densities partially offset the planting-density effect on per-hectare biomass.

Growth Rates

Mean per-tree volume growth increments of black locust, sycamore, and hybrid poplar increased from year two to year three for all density and fertilizer treatment combinations. However, patterns of incremental growth from year two to three and fertilizer responses varied among these species (Fig. 2). Black locust per-tree volume growth increment increased from year two to three, with the increments for the fertilized plots more than doubling for both densities. The fertilized and non-fertilized low-density black locust treatments had the greatest third year volume growth increment of any treatment, with the high density black locust treatments slightly lower. Sycamore and hybrid poplar also produced increased incremental mean volume growth in both the fertilized and non-fertilized, and in high- and low-density treatments (Fig. 2). 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 increments.

Site effects on performance were evident, as site W1 demonstrated consistently poor performance relative to the other two sites although being prepared similarly and within the same time frame. All species treatments, including black locust (Fig. 3) produced less biomass, per tree and per hectare, on site W1 than on other sites; but those differences were nominal.

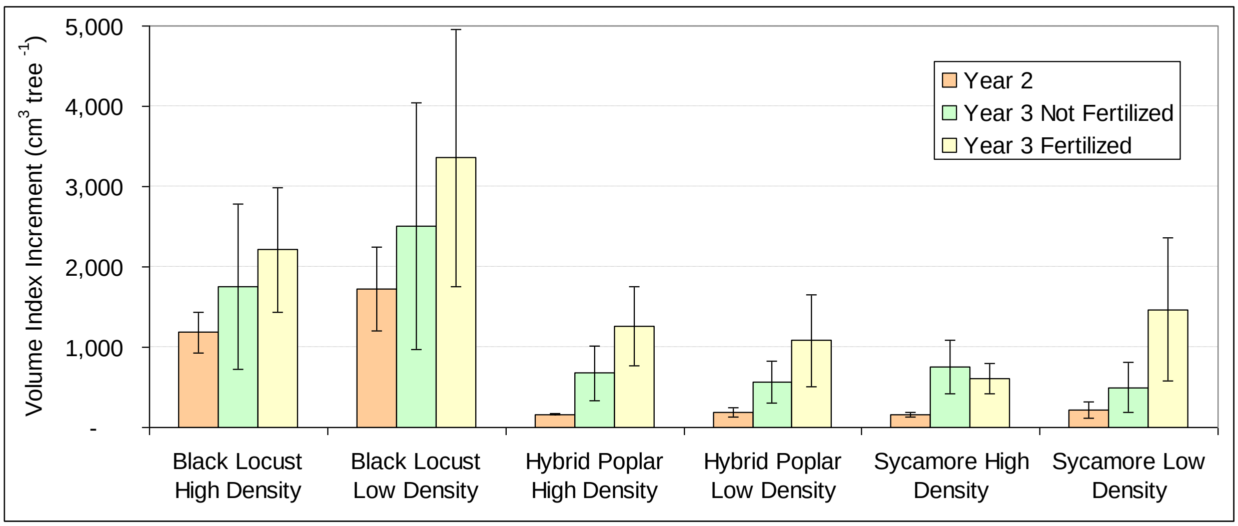

Figure 2. Mean annual per-tree volume growth increments, with standard errors, by planting density and fertilizer treatments for black locust, hybrid poplar, and sycamore at three ripped mine sites (W1, W2, and W2) in Wise County, VA.

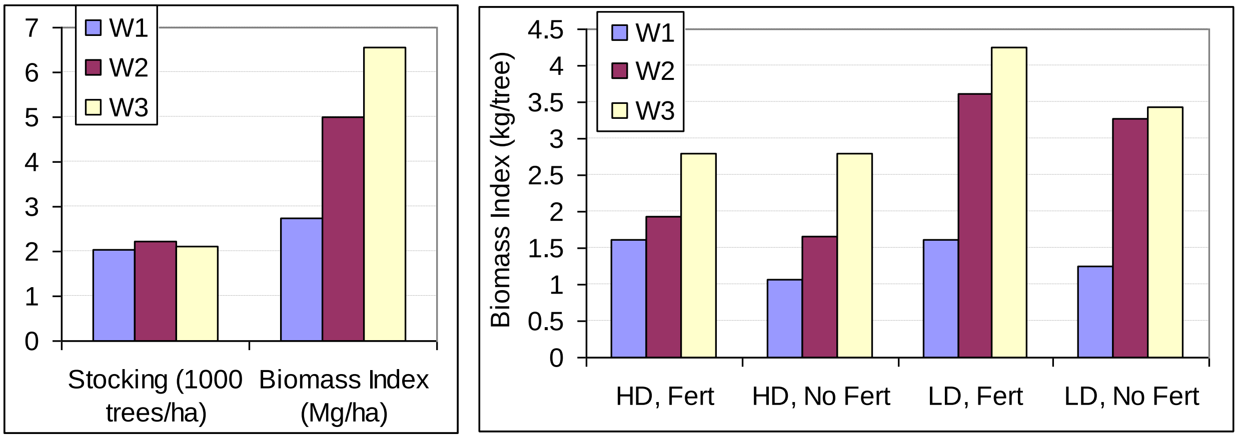

Figure 3. Black locust stocking and growth in the Wise County biomass trials (Left) Third-year stocking and biomass index per hectare averaged over the 4 treatment combinations. (Right) Site effects on black locust per-tree biomass growth over 3 years on the Wise County biomass trials for high density (HD) and low density plantings (LD), and for fertilized (Fert) and unfertilized treatments.

Study Comparisons

Comparison of the three biomass studies is exploratory. Due to differences among experimental designs, results are compared using descriptive statistics only.

Over the first two years of growth, the black locust in the Wise County trial produced more biomass per tree, on average, than the hybrid poplar TD clone growing in the multi-state trials, both collectively and at the WV sites where they were growing most rapidly (Fig. 4). DM clones in the hybrid poplar genotype study grew faster than DN and DT/TD clones, on average; and those DM clones grew faster than the DT/TD clones growing in the multi-state trials, both collectively and at all individual sites. The DM clones' production was comparable to that of the Wise County trial's black locust. These comparisons must be considered as conditional, however, because of differences among sites, soils, fertilization, and similar factors. Site characteristics have major influence on these species' growth potentials, but we are unable to compare site qualities among experimental trials directly.

Unlike the genotypes and the hybrid poplars growing in fertilized multi-state VA and OH sites, the Wise County trial hybrid poplars were not fertilized at establishment; and, unlike the hybrid poplars growing on the multi-state trial's WV site being reported in Fig. 4 and 5, they were not grown on lands with residual N and P from prior grazing uses. These factors may explain the Wise County study hybrid poplars' slow growth (Fig. 4). The Wise County black locust, although also not fertilized at establishment, appeared to produce biomass more rapidly over its first two years than any other experimental unit except, possibly, the DM clones.

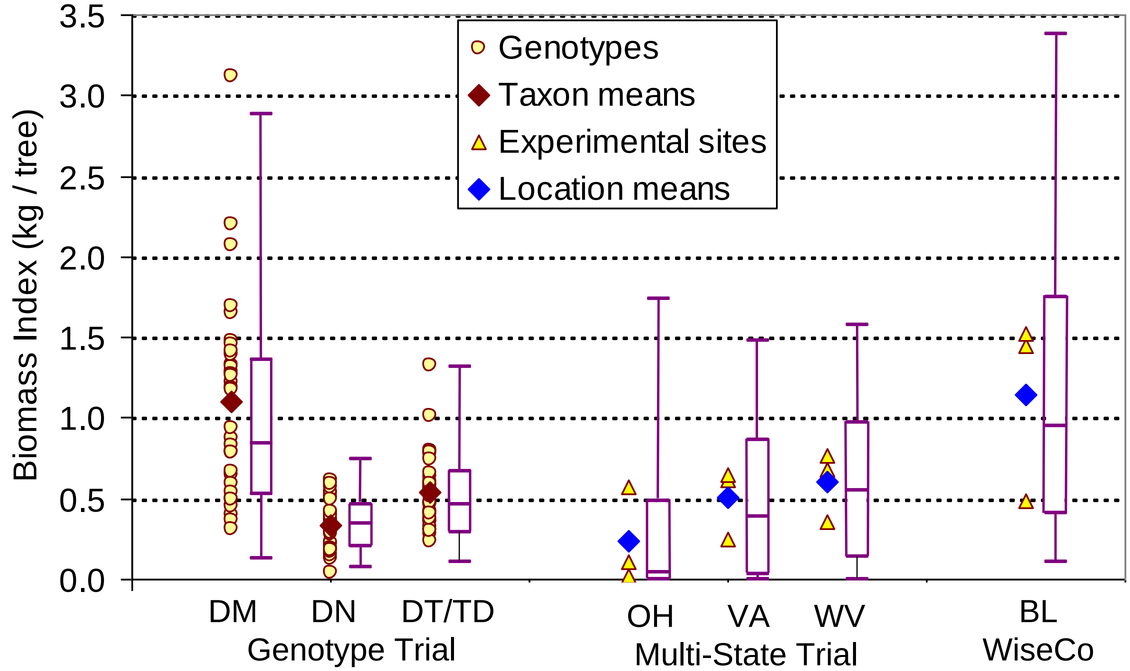

Figure 4. Comparison of growth over two years among hybrid poplar genotypes of three taxa established on a single mine site; a single hybrid poplar clone that was established on 9 mine sites in three states in the Multi-State trial; and low-density black locust plantings on three mine sites in the Wise County biomass trial. Results are represented for individual clones in the genotype trial; for individual experimental sites in multi-state and Wise County trials; and as experimental unit means for all trials. Box plots of growth by individual trees within each experimental unit are also represented as 5th, 25th, 50th, 75th, and 95th percentiles.

During a third growing season, the multi-state study's WV hybrid poplars added biomass more rapidly than either the fertilized or the unfertilized black locusts in the Wise County study (Fig. 5). The WV poplars continued their growth in Years 4 and 5, with more rapid growth-rate increases on the more productive sites. At the conclusion of Year 5, the WV hybrid poplars' per-tree biomass was more than three times measured levels for hybrid poplars on the OH blocks in the multistate trial.

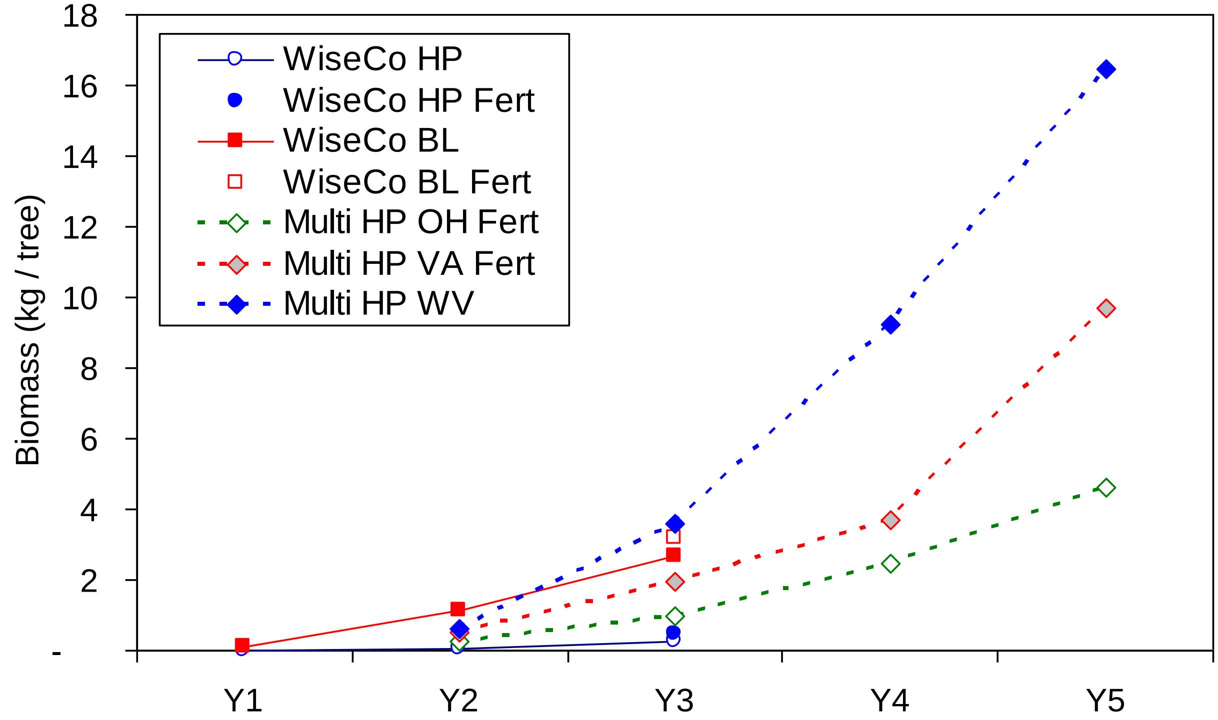

Figure 5. Comparison of Wise County trial per-tree biomass index for black locust and hybrid poplar, low-density spacings, unfertilized and fertilized (FERT) treatments over their first three years of growth, to the Multi-State trial's hybrid poplars in years 2 through 5.

Unfertilized hybrid poplars established on Virginia mine sites at similar planting densities also exhibited substantial growth differences (Fig. 6). Within both the Wise County and multi-state trials over three years, the best-performing site produced >2x more biomass per tree than the lowest-producing site, but the multi-state trial sites produced, on average, ~5x the amount of biomass produced by the Wise County trial sites over same-length growth periods. Both sets of sites were prepared using similar methods and planted with what identical hybrid poplar genetic stock, although the three-year periods being compared were not coincident. As noted by Fig. 2, the Wise County trial's hybrid poplars' growth accelerated markedly in their third year, especially for the fertilized treatments.

Like hybrid poplar, black locust also exhibited obvious growth differences among sites (Fig. 3), despite its well-known adaptability and tendency to proliferate on mine sites.

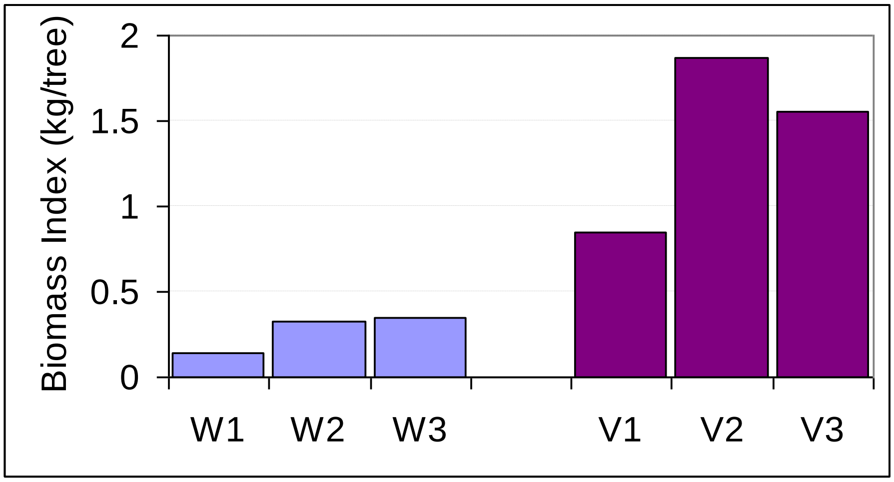

Figure 6. Third-year hybrid poplar biomass, ripped and unfertilized treatment only, on Virginia mine sites: The three low-density plantings in the Wise County trial (W1, W2, and W3), and the multi-state trial's 3 Virginia sites (V1, V2, V3). Sites W1 and V1 are within a few hundred meters of one another on the same mine bench.

Discussion

Wise County Study

At year three, the Wise County study has achieved successful stocking for all of the treatment combinations. However, stocking levels throughout the experimental plots are quite variable.

The third-year volume and biomass estimates showed patterns of response to species and density treatments similar to second-year results (Evans et al. 2010). Black locust continued to have the greatest per-tree volume, per-hectare volume, and per-hectare biomass, while hybrid poplar and sycamore remained secondary in volume and biomass. The red oak and red oak/cottonwood treatments are successfully stocked but are growing slowly relative to other planted species, as are the mixed hardwoods. Black locust's ability to fix atmospheric N is likely aiding its performance on mine soils.

At year three, black locust's high-density treatments continued to produce biomass per-hectare than sycamore, hybrid poplar, and low-density black locust, but per-tree volume and biomass differences due to planting densities are not statistically significant ($p<.10$). Given that high-density treatments are approaching crown closure for sycamore and hybrid poplar and have achieved crown closure for black locust, density effects on per-tree volume and biomass may become significant, as expected, as resource competition effects intensify with passage of additional time.

We did not find statistically significant differences between fertilized and non-fertilized plots in the first year after fertilization. Given the tendency of mine soils to be low in bioavailable N and P, we expect fertilization will produce significant differences in growth measures with time. The volume growth increments for black locust, hybrid poplar, and sycamore increased from year two to three (Fig. 2), indicating that these species are accelerating growth and have not reached their biological rotation age. Fertilization nominally increased the volume growth increments for most of these species and density treatments.

As noted, substantial differences between sites were evident (Fig. 3). Differences among the sites included the amount and vigor of competing vegetation, as thick and vigorous *Sericea lespedeza* that emerged on site W1 after ripping provided stiff competition for the growing trees. Competing vegetation at the other two sites, although requiring effort to control, was not as vigorous and challenging.

Another possible influence on growth differences among sites could be site age. Site W1, at approximately 7 years of age, was the youngest of the 3 Wise County trial sites and it performed poorly. Sites W2 and W3 were ~13 and ~25 years old, respectively, when replanted for the biomass study. Fresh mine soils are commonly deficient in N and P, and this was likely the case for site W1 as existing vegetation was sparse prior to ripping and replanting. However, it is possible that the pre-existing vegetation communities on the older sites had sequestered and were cycling greater amounts of N and P (Li and Daniels, 1984; Howard et al. 1988); and that the older sites' higher bioavailable nutrient levels helped to support faster growth.

Another possible influence on growth differences could be the nature of the spoil materials. As noted by Skousen et al. (2011), mine spoil characteristics influence tree growth rates on reclaimed mine sites. It is possible that the sites W2 and W3 supported more rapid tree growth and greater biomass production than site W1 because their soils were more suitable for growth by the planted species.

Study Comparisons

The study comparisons are intended to support general inference concerning the production potentials of biomass plantings on post-SMCRA mine sites. The studies occurred on different sites, with different soil properties, and the growth-years being compared are not coincident. Growth and production differences observed between species and treatments evaluated in different trials are not intended to support inference concerning comparative biomass production potentials of various species and treatments more generally.

Black locust's growth in the Wise County study during the first two years exceeded that of all hybrid poplar treatments in the multi-state study over their first two years (Fig. 4). During Year 3, however, hybrid poplar's growth on the multi-state study's most productive site, in WV, accelerated more rapidly (Fig. 5). This finding raises concern about black locust's capability to continue increasing its growth rate beyond the first few years, a concern that is amplified by this species' known susceptibility to infestation by locust leafminer (*Odontota dorsalis* (Thunb.)).

Substantial differences are apparent in results achieved among similar treatments at different planting sites, both within and between trials. Per-tree growth in all trials showed considerable variability (Fig. 4). Within some experimental units, the growth represented by the 95th percentile of individual trees exceeded the 75th percentile by a factor of 2x or more. Both genetic differences (for the genotype trial, Fig. 4), and intra-site quality differences, and inter-site-differences (Fig. 6) contribute to growth variability.

Establishing biomass plantings on mine sites requires significant investments for soil mitigation, fertility enhancement, competing vegetation control, and planting (Burger and Zipper 2011). If such investments are to be considered as viable, better understanding of site factors that cause these dramatic productivity differences is essential. Such understanding can inform both site selection and management decisions, and would enhance the potential for using reclaimed coal mines for biomass plantings.

The hybrid poplar genotype trials showed substantial differences in biomass production both among and within taxons. Early results indicate that DM taxon is performing best, but individual genotypes of DT/TD and DN are also performing well. These trials are in their early stages and, unlike the other biomass treatments, were only established on a single mine site. Nonetheless, this finding highlights the potential for hybrid poplars' genetic improvements to enhance this species' biomass production, and for genetic selection to serve as a biomass production management tool.

Conclusions

In both the Wise County and the multi-state studies, significant effects by site and other non-species factors on biomass production are apparent but it is not clear which of these factors are driving performance differences. Possible influences include soil properties, fertility, competing vegetation, and other effects. Planting density affected biomass production. These studies show hybrid poplar and black locust as species that have potential to produce substantial biomass quantities if properly established and managed. The current screening trials with a large number of hybrid poplar genotypes of three taxa indicate that through breeding and testing, hybrid poplar taxa and genotypes that perform well on mined lands can be selected. In order for biomass production on post-SMCRA mine sites to become a commercial enterprise, factors causing production differences must be better understood so as to enable more informed and effective management.

Acknowledgements

The authors extend thanks to Alpha Natural Resources and Powell River Project for funding this research. Thanks also to Forestland Group, Penn Virginia Resource Partners, and Red River Coal for their assistance, including grants of access to the experimental sites. Thanks to Amy Villamagna and Chris Jackson for field assistance. Thanks to US Department of Energy for funding the multistate trial. Thanks to Virginia Tobacco Commission for funding and to cooperators for the hybrid poplar genotype trial. Thanks to GreenWood Resources for providing the hybrid poplar clones being tested in genotype trial. Thanks to Jennifer Gagnon, John Munsell, Chris Jackson, Zach Addington, Dan Early, Amy Gail Fannon, and others whose efforts were establishing and maintaining the genotype trial.

Literature Cited

Angel, P., J.A. Burger, V.M. Davis, C.D. Barton, M. Bower, S.D. Eggerud, P. Rothman. 2009. The Forestry Reclamation Approach and the measure of its success in Appalachia. p. 18-36, in: 26th: National Meeting of the American Society of Mining and Reclamation. http://dx.doi.org/10.21000/jasmr09010018.

Brunner, A, J. Munsell, J. Gagnon, H. Burkhart, C. Zipper, C. Jackson, A. Fannon, B. Stanton, R. Shuren. 2009. Hybrid poplar for bioenergy and biomaterials feedstock production on

Appalachian reclaimed mine land. In: Powell River Project Research and Education Program Progress Reports. Virginia Tech, Blacksburg.

Burger, J.A., J. D. Graves, P. Angel, V. Davis, and C. Zipper. December 2005. The Forestry Reclamation Approach. Forest Reclamation Advisory No. 2. U.S. Office of Surface Mining. 4p.

Burger, J.A., and C. Zipper. 2011. Reforestation Guidelines for Unused Surface Mined Lands in the Eastern United States. Virginia Cooperative Extension Publication 460-144. http://pubs.ext.vt.edu/460/460-144/460-144.html

Casselman, C.N., T.R. Fox, J.A. Burger, A.T. Jones, and J.M. Galbraith. 2006. Effects of silvicultural treatments on survival and growth of trees planted on reclaimed mine lands in the Appalachians. Forest Ecology and Management. 223:403-414. http://dx.doi.org/10.1016/j.foreco.2005.12.020.

Evans, D.M., C. Zipper., J.A. Burger. C. Fields-Johnson. 2010. Tree species and density effects on woody biomass production on mined lands: Establishment and two year results. Proceedings America Society of Mining and Reclamation, 2010 pp 276-291 http://dx.doi.org/10.21000/JASMR10010276

Fields-Johnson C. 2011. Coal Surface Mine Reforestation Techniques: Grading, Cultural, and Species Selection Effects. M.S. Thesis. Virginia Tech, Blacksburg.

Fields-Johnson C., T.R. Fox, D.M. Evans, J.A. Burger, and C. Zipper. 2008. Fourth-year Tree Response to Three Levels of Silvicultural Input on Mined Land. Proceedings America Society of Mining and Reclamation, 2008 pp 389-402. http://dx.doi.org/10.21000/JASMR08010389.

Howard, J., D.F. Amos, W.L. Daniels. 1988. Phosphorous and potassium relationships in southwestern Virginia coal-mine spoils. J. Environ. Qual. 17:695-700. http://dx.doi.org/10.2134/jeq1988.00472425001700040029x00.

Li, R.S., W.L. Daniels. 1994. Nitrogen accumulation and form over time in young mine soils. J. Environ. Qual. 23:166-172. http://dx.doi.org/10.2134/jeq1994.00472425002300010026x.

Skousen, J., C. Zipper, J. Burger, P. Angel, C. Barton. 2011. Selecting topsoil substitutes for forestry mine soils. Proceedings America Society of Mining and Reclamation, 2011 pp 591-609 http://dx.doi.org/10.21000/JASMR11010591

US Office of Surface Mining (US OSMRE). 2011. Annual Reports. http://www.osmre.gov/Reports/AnnualReport/AnnualReport.shtm

Zanne, A.E, G Lopez-Gonzalez, D.A. Coomes, J. Ilic,S. Jansen, S.L. Lewis, R.B. Miller, N.G. Swenson, M.C. Wiemann, and J. Chave. 2009. Global wood density database. Dryad. Identifier: http://hdl.handle.net/10255/dryad.235.