Powell River Project Report 2013

Fertilizer and Density Treatment Effects on Woody Bioenergy Production on Mined Lands: Year Five Report

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Abstract

Planting woody biomass for energy production can be used as a mine reclamation procedure to satisfy the SMCRA and provide renewable energy for the United States. This study examines the productivity of woody biomass on previously mined lands using five species planted at two densities, with and without fertilizer. This report summarizes the current volume of these species as well as the effect of planting density and fertilizer application. After five years of growth, black locust has the highest volume of any treatment. Low density treatments out-produce high density treatments on a per-tree basis and significant differences were found between the species as well as treatments.

Introduction

The Surface Mining control and Reclamation Act (SMCRA) of 1977 requires all surface-mined lands to be restored at a minimum to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood (30 U.S.C., 1977). When applying for a permit to extract coal from a parcel of land, mine operators are required to submit a plan for how they intend to follow regulations for restoring the land to a useable state. Land is generally reclaimed to hayland/pasture, traditional forestry production, or development (typically industrial or commercial).

Growing bioenergy crops is an emerging issue in discussions of the United States' energy future. The Annual Energy Outlook (2011) predicts a 72% increase in electricity generated by renewable sources over the next 20 years, with most growth coming from wind and biomass facilities. A majority of the states in the US have Renewable Portfolio Standards, requiring a portion of their energy to be generated from renewable sources. Woody biomass can be used to help meet these goals and the increasing energy demand of the United States by growing bioenergy crops on mined lands as a reclamation procedure.

Woody bioenergy cropping as a mine reclamation procedure can offer many environmental benefits. Biomass can be burned alongside coal in existing power plants in small percentages (5-20%) with minimal (if any) plant upgrades and negligible efficiency losses. Studies have found efficiency losses of burning 15% biofuel (85% coal) to be in the range of 0.9%-1.5% when compared to burning only coal (Gold and Tillman, 1996; Mann, 2001). Coal-based carbon emissions are greatly reduced by burning woody biomass; one ton of CO_2 emissions are avoided for every ton of biomass cofired (Tillman, 2000). Other environmental benefits of growing woody biomass on previously mined lands include decreased runoff and erosion, nutrient retention, and increased carbon sequestration (Brinks et al., 2011). Reforesting mine sites provides benefits to the ecosystem that the likely alternative reclamation, hayland/pasture, does not. In addition to hydrologic and soil benefits, forested areas (including woody biomass crops) can provide habitat for native plants and animals (Zipper et al., 2011a).

Planting woody bioenergy crops on lands previously mined for coal has the potential to keep energy revenue coming from the land following coal extraction, thereby providing renewable energy and employment for Appalachian communities while restoring ecosystem services. Experimental sites on previously reclaimed mine lands were established in southwestern Virginia to determine biomass production potential. This report summarizes the first five years of growth data.

Methods

In spring of 2008, three experimental plots were established in the coal fields of Wise County, Virginia on the Powell River Project for examining opportunities to grow biomass on reclaimed mine lands as a potential post-mining land use (Figure 1). After mining, all three sites had been reclaimed with grasses and woody shrubs. The coal companies achieved bond release, although the lands were left without potential to return to forest. To prepare the experiment for planting the land was ripped, creating furrows spaced approximately 2.5 meters apart. Five tree species were planted, including: hybrid poplar (*Populus trichocarpa* L. (Torr. And Gray ex Hook) x *Populus deltoids* (Bartr. Ex Marsh.) hybrid 52-225), American sycamore (*Platanus occidentalis)*, black locust (R*obinia pseudoacacia)*, and northern red oak (*Quercus rubra*) coupled with eastern cottonwood (*Populus deltoides*), along with a group of mixed hardwoods (black cherry (*Prunus serotina*), oaks (*Quercus* sp.), sugar maple (*Acer saccharum)*, American sycamore (*Platanus occidentalis)*, black locust (R*obinia pseudoacacia)*, ash species (*Fraxinus* sp.), and dogwoods (*Cornus* sp.)).

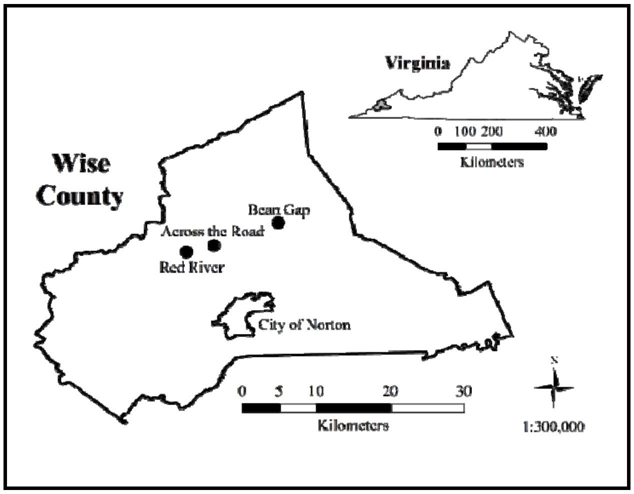

Figure 1: Biomass plots located in Wise County and context within Virginia.

Each of the primary species (hybrid poplar, black locust and American sycamore) was planted on each of the three sites at two different planting densities – high (1.7 meter by 1.7 meter spacing, approximately 1375 trees/acre) and low (3.4 meter by 3.4 meter spacing, approximately 350 trees/acre). Red oak was planted at low density, and was also planted at high density spacing in combination with eastern cottonwood. The group of mixed hardwoods was planted only at low density, which is a typical planting density when reclaiming mines to forest. The plots were further split so that each species at both densities received one of two treatments, either fertilization or no fertilization (no fertilizer was applied to the mixed hardwood control group) (Zipper et al., 2011b). Fertilized trees received 118 ml of granular 19:19:19 in a 0.5 meter diameter surrounding the base of the tree in December 2009. All plots received a 2% glyphosate mix weed control at a 2 meter diameter around each tree, 2008-2010.

Tree growth for each species has been measured at either the beginning or end of every growing season since the sites were established. Height measurements were taken using calipers and a metric Philly rod. Height was determined as the height to the highest live bud; ground line diameter (GLD-basal diameter) was also measured. Measurements were recorded for each tree within the plot, roughly 700-800 stems of each species (eastern cottonwood and northern red oak counted toward one sample of 700-800).

Annual measurements were compiled, analyzed, and reported to the Powell River Project. Oven-dry wood density was estimated (Table 1) for each species using the Global Wood Density Database (Zanne et al., 2009). A volume index incorporating height, diameter, and this oven-dry wood density, was used to estimate growth and give an estimate of dry woody biomass produced using each treatment. Biomass per acre was also estimated using the field-measured diameters and adapting the Clark III and Schroeder (1985) biomass equation, as follows:

$$biomass\ tons = a \times (ground\ line\ diameter^2)^b \times {}^{lbs}/_{ton} \times {}^{trees}/_{acre} \quad (1)$$

Coefficients a and b are determined by tree species, adapted from Clark III and Schroeder (1985). These biomass per acre equations were derived from measurements of trees in larger size classes than the trees being considered here, yet was used because the equation was the best found for this application. Analysis was conducted to determine the effects of planting density and fertilizer on the various species across the three sites.

Table 1: Oven dry wood density (g/cm^3) for each species in trial as depicted by the Global Wood Density Database; source: Zanne et al. (2009).

Species	Oven dry wood density (g/cm^3)
Black locust	0.60
Hybrid poplar	0.34
American sycamore	0.46
Red oak	0.56
Cottonwood	0.47
Hardwood species (other)	0.47

Results and Discussion

Tree growth rate over the first five years varied by species, fertilization, and planting density, with each species responding to fertilizer and planting density in different manners. The unfertilized hybrid poplar and sycamore trees increased their growth rates more in the fifth growing season than any previous year (Figure 2). Unfertilized black locust hit its peak growth rate by the fourth year and for the trees planted at high density, growth rate declined in the fifth year. Growth rate for fertilized trees increased rapidly early on (in the third year) and both high and low density black locust treatments hit their peak growth rate in the fourth year, with the growth rate declining in the fifth growing season.

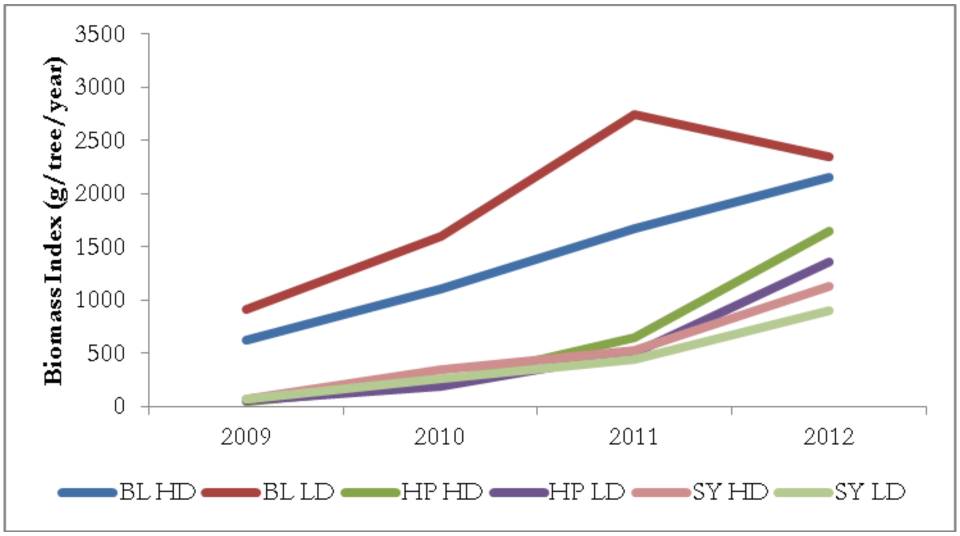

Figure 2: Annual growth increment (g/tree/year) for non-fertilized black locust (BL), hybrid poplar (HP) and sycamore (SY) trees planted at high density (HD) and low density (LD).

Black locusts are nitrogen-fixing trees; perhaps by the fifth growing season the trees have reached a nitrogen threshold after which additional nitrogen inhibits instead of increases growth (Figures 2 and 3). It is also possible that physiological effects caused by locust leaf miner (*Odontota dorsalis)*, an insect pest that infests black locust throughout the region and which has been observed to occur in these plantings, may have interfered with black locust growth. Low density hybrid poplar growth rate is also tapering off but its growth rate had not begun to decline by the fifth year.

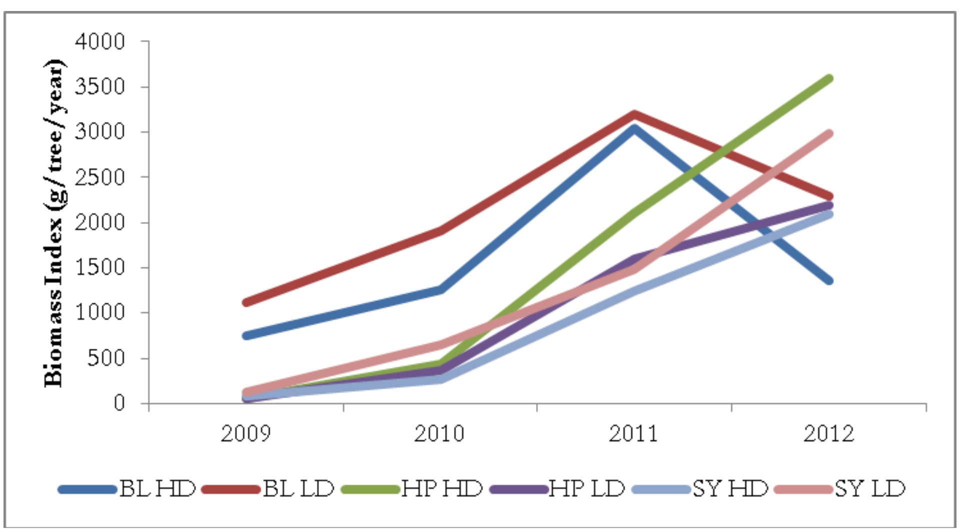

Figure 3: Annual growth increment (g/tree/year) for fertilized black locust (BL), hybrid poplar (HP) and sycamore (SY) trees planted at high density (HD) and low density (LD).

Most of the trees planted survived through the fifth growing season. Red oaks and cottonwoods did not survive as well as the other species, with 73% and 58% survival, respectively, after five years (the next lowest survival is hybrid poplar at 83%) (Figure 4). Additionally, the red oak and cottonwood trees that did survive have much lower biomass accumulation compared to the other species. Stocking levels decreased dramatically during the first season, but have remained relatively stable for the past few years. Bean Gap is the only site that saw significant declines in stocking levels in the fifth year. These declines may be attributed to deer browsing; the low density hybrid poplar plot was especially hard hit. High density fifth year stocking for hybrid poplar, black locust and sycamore ranged from 976 to 3358 trees/ha. Low density stocking for the same species ranged from 344 to 1435 trees/ha. The red oak and red oak/cottonwood treatments continued to be highly variable in stocking with a maximum of 1837 trees/ha and a minimum of 172 trees/ha.

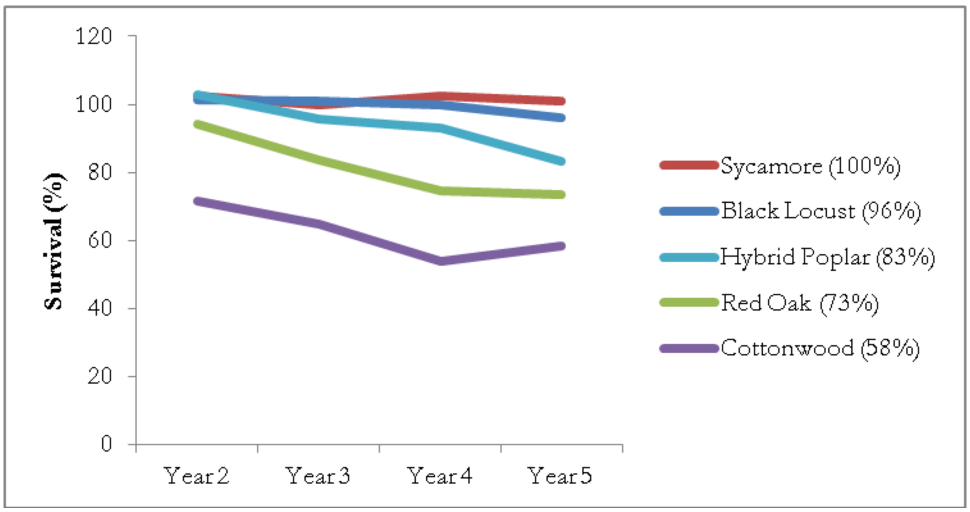

Figure 4: Individual species survival year by year for five years across all three sites, end of season survival reported.

Biomass indices for each species and treatment were compared. After five years of growth, black locust out-produced all other species in the trial, regardless of planting density or application of fertilizer. On average on a per-tree basis, black locust (biomass index= 7671 g/tree unfertilized and 8383 g/tree fertilized) and fertilized sycamore (4799 g/tree) had a higher biomass index after five years when planted at low density than at the high density. High density hybrid poplar produces the most biomass after black locust (5137 g/tree when fertilized and 2273 g/tree unfertilized). When fertilizer was applied, low density sycamore (4799 g/tree) followed hybrid poplar and black locust, but where fertilizer was not applied, high density sycamore preceded (2259 g/tree) the hybrid poplar.

Overall, when considered on a per-tree basis, tree planting density had as a greater effect on biomass index than fertilizer did, with low density trees out-producing trees planted at high density. However, fertilization increased overall biomass index for all species and planting densities, in some cases by a substantial margin (greater than twice as much). Compared on a tons per acre basis (using equation 1), the high density treatments out-produced low density treatments and fertilized treatments out produced unfertilized treatments, except in the case of black locust (Table 2 and Figure 5).

Table 2: Mean biomass (tons/acre) by year, species, planting density, and fertilization; black locust (BL), hybrid poplar (HP), and American sycamore (SY).

NO FERT	2008	2009	2010	2011	2012
BL high density	0.87	4.11	7.64	10.96	14.53
BL low density	0.42	1.95	4.00	6.94	7.38
HP high density	0.10	0.37	1.09	2.76	6.39
HP low density	0.06	0.16	0.37	0.96	2.42
SY high density	0.09	0.43	1.74	3.47	6.78
SY low density	0.04	0.13	0.46	0.76	1.52
FERT					
BL high density	0.87	4.82	8.07	12.25	14.43
BL low density	0.42	3.07	4.46	6.87	8.46
HP high density	0.10	0.31	1.42	6.44	12.53
HP low density	0.06	0.19	0.66	2.82	4.85
SY high density	0.07	0.41	1.28	4.56	9.09
SY low density	0.09	0.23	0.87	2.11	4.88

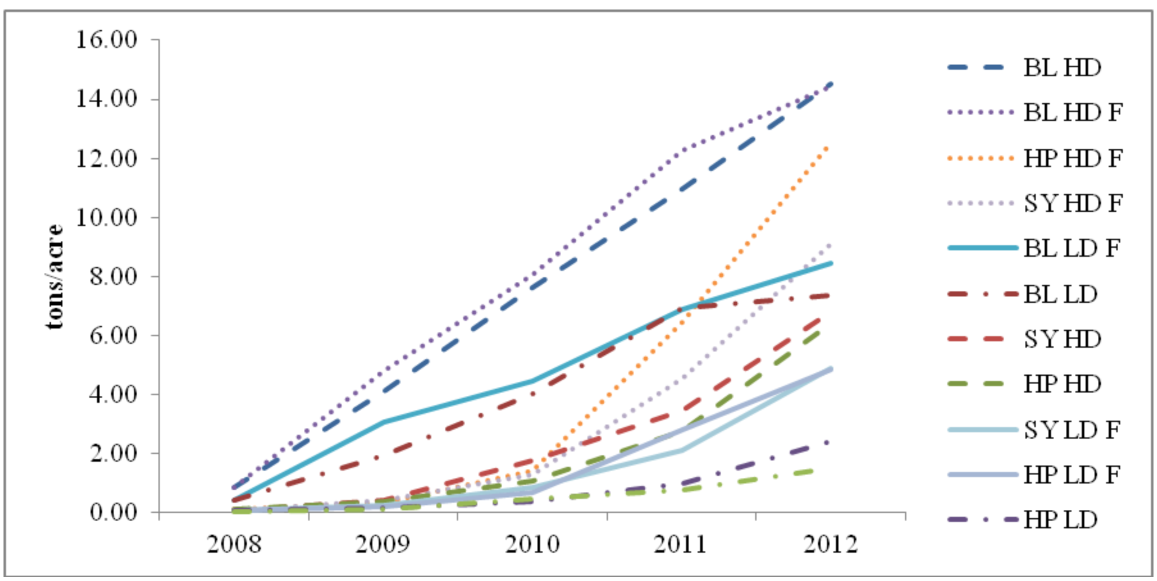

Figure 5: Average biomass (tons/acre) by year, species, and treatment. Black locust (BL), hybrid poplar (HP), sycamore (SY), high density (HD), low density (LD), fertilized (F).

To maintain consistency with previous PRP reports, analysis of variance (ANOVA) was used to test for differences between sites, treatments, and species. A statistically significant difference was found in the average biomass index produced at each site location. On average, trees with the largest biomass index were found on the Red River site, Bean Gap follows closely behind, and Across the Road produced the smallest trees. Low density treatments had significantly larger biomass indices than trees planted at high density. Fertilizer was also a significant treatment, with non-fertilized plots producing trees with smaller biomass index than their fertilized equals. Hardwoods did not produce a significantly different biomass index than red oaks or cottonwoods and the average biomass indices of red oaks and cottonwoods were also not different from each other. All other species had biomass indices that were significantly different from one another (Table 3).

Table 3: ANOVA comparison using Scheffe's method to test differences between biomass indices (g/tree) across species.

Row mean – Column mean	Black locust	Cottonwood	Hybrid Poplar	Hardwoods	Red Oak
Cottonwood	-5315.16*	-	-	-	-
Hybrid Poplar	-2696*	2619.15*	-	-	-
Hardwood	-5783.34*	-468.18	-3087.33*	-	-
Red Oak	-6488.43*	-1173.28	-3792.43*	-705.098	-
Sycamore	-3630.96*	1684.19*	-934.961*	2152.37*	2857.47*

* Significant at $\alpha=0.01$

The fifth year results differ from past reports in that more variables are statistically significant, there is greater disparity between species growth, and growth rates have slowed down for a few species. Fertilizer was applied in the second season, although was not significant until the fourth growing season and was still significant in the fifth season.

Conclusions

The mixed hardwoods, red oaks, and cottonwoods had not achieved successful stocking by the fifth growing season and the trees that did survive were much smaller than the other trees in the trial. It is not likely that the red oak and cottonwoods will catch up to the other trees, therefore it is determined that they are not suitable for bioenergy production on these sites at this time.

Many of the growth patterns stayed the same for the past few growing seasons: black locust continues to out-produce all other species, and fertilized trees and low density treatments produce larger trees than their counterparts. Low density trees produce the greatest per-tree biomass while the high density treatments result in greater biomass on a tons per-acre basis. This is expected to change in the upcoming years as more trees achieve canopy closure and compete for space and sunlight. Total biomass for the fertilized and unfertilized trees may begin to even out as the boost trees received from the fertilizer wanes.

Analysis was conducted to determine the economic viability of each of the species and treatments on a tons per acre basis. At the time of analysis, bioenergy appears to be profitable only in limited scenarios, when the cost of production is low and the sale price of bioenergy is high. It was determined that the unfertilized black locust planted at low density results in the greatest returns for the landowner, and unfertilized low density planting achieves the greatest returns for every species in the trial.

Measurements will continue to be made on an annual basis to monitor growth patterns of the different species and treatments. When the trees reach a size deemed reasonable for harvest, a new treatment will be added to the experimental trial – coppice regrowth. Analysis will be conducted to determine which species and treatments have the greatest capability to coppice on these reclaimed mine lands and to determine optimal rotation lengths for each treatment.

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Related Publications

Sullivan, J. and G.S. Amacher. 2013. Optimal Hardwood Tree Planting and Forest Reclamation Policy on Reclaimed Surface Mine Lands in the Appalachian Coal Region. Resources Policy. 38:1-7.

Leveroos, M.K. 2013. Economic Viability of Woody Bioenergy Planting for Surface Mine Reclamation. M.S. Thesis. Virginia Tech, Department of Forest Resources and Environmental Conservation. 95 p.

Summary Data (on page that follows)

Year five average height, diameter, and biomass index for each site, species, and treatment.

No Fertilizer	gld (cm) - ATR	gld (cm) - BG	gld (cm) - RR	Mean gld (cm)	ht (m) - ATR	ht (m) - BG	ht (m) - RR	Mean ht (m)	Mean Biomass Index (g/tree)
Black Locust (High Density)	3.67	3.94	5.47	4.36	3.08	3.29	4.29	3.55	5279
Black Locust (Low Density)	5.20	4.90	6.24	5.45	3.30	3.70	4.24	3.75	7671
Hybrid Poplar (High Density)	3.15	4.82	3.03	3.67	2.50	3.74	2.27	2.84	2273
Hybrid Poplar (Low Density)	2.09	3.50	4.43	3.34	1.60	2.47	3.34	2.47	1732
Mixed Hardwood	1.50	3.32	2.78	2.54	0.81	2.14	1.70	1.55	761
Red Oak	1.00	0.99	1.64	1.21	0.74	0.53	1.14	0.80	113
Red Oak/Cottonwood	1.07	0.99	1.73	1.27	0.76	0.69	1.08	0.84	103
Sycamore (High Density)	2.38	3.83	4.91	3.70	1.58	2.66	3.02	2.42	2259
Sycamore (Low Density)	2.20	4.18	4.03	3.47	1.34	2.69	2.26	2.10	1545
Fertilizer	gld (cm) - ATR	gld (cm) - BG	gld (cm) - RR	Mean gld (cm)	ht (m) - ATR	ht (m) - BG	ht (m) - RR	Mean ht (m)	Mean Biomass Index (g/tree)
Black Locust (High Density)	4.53	4.34	5.26	4.71	3.52	3.62	4.57	3.90	6334
Black Locust (Low Density)	4.45	5.58	6.43	5.49	3.13	3.96	4.53	3.87	8383
Hybrid Poplar (High Density)	4.28	6.71	4.38	5.12	2.99	5.00	3.44	3.81	5137
Hybrid Poplar (Low Density)	2.25	3.76	6.19	4.07	1.75	2.47	4.80	3.01	3236
Red Oak	1.22	1.23	1.95	1.47	1.12	0.71	1.32	1.05	207
Red Oak/Cottonwood	1.15	1.08	1.94	1.39	0.99	0.83	1.16	1.00	143
Sycamore (High Density)	2.68	3.96	6.10	4.24	2.10	2.82	3.93	2.95	3691
Sycamore (Low Density)	2.16	6.49	5.71	4.79	1.42	3.85	3.05	2.77	4799

Annual average iomass tons per acre for each species and treatment

NO FERT	**2008**	**2009**	**2010**	**2011**	**2012**
Black Locust (High Density)	0.87	4.11	7.64	10.96	14.53
Black Locust (Low Density)	0.42	1.95	4.00	6.94	7.38
Hybrid Poplar (High Density)	0.10	0.37	1.09	2.76	6.39
Hybrid Poplar (Low Density)	0.06	0.16	0.37	0.96	2.42
Mixed Hardwood	0.04	0.22	0.50	0.90	1.73
Red Oak	0.06	0.07	0.12	0.19	0.29
Red Oak/Cottonwood	0.07	0.07	0.26	0.22	0.42
Sycamore (High Density)	0.09	0.43	1.74	3.47	6.78
Sycamore (Low Density)	0.04	0.13	0.46	0.76	1.52
FERT	**2008**	**2009**	**2010**	**2011**	**2012**
Black Locust (High Density) F	0.87	4.82	8.07	12.25	14.43
Black Locust (Low Density) F	0.42	3.07	4.46	6.87	8.46
Hybrid Poplar (High Density) F	0.10	0.31	1.42	6.44	12.53
Hybrid Poplar (Low Density) F	0.06	0.19	0.66	2.82	4.85
Red Oak F	0.04	0.09	0.23	0.33	0.49
Red Oak/Cottonwood F	0.06	0.06	0.30	0.22	0.53
Sycamore (High Density) F	0.07	0.41	1.28	4.56	9.09
Sycamore (Low Density) F	0.09	0.23	0.87	2.11	4.88