SALIX SPP. AS A BIOMASS CROP: INVESTIGATING ITS POTENTIAL ON MINED LANDS AND THE USE OF BIOCHAR AS A SOIL AMENDMENT[1]

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Abstract: Rising energy demands and costs have increased the need to develop alternate sources and markets. Biomass plantations are proposed as part of the renewable energy solution. In West Virginia, over 50,000 acres of previously mined and reclaimed land are suitable for cultivation with bioenergy crops, including woody plants. The feasibility of growing shrub willow (*Salix* spp.) for the dual purpose of restoration and biomass crop production was assessed on reclaimed surface mines and fallow agricultural land in West Virginia. Replicated field trials were established and monitored over one growing season at four sites throughout the state. Within the field trials, biochar was tested as a soil amendment to mitigate soil quality issues associated with mine soils and fallow agricultural land. To characterize *Salix* spp. potential as a feedstock, proximate analysis, ultimate analysis, and heating value were measured. Wood properties for one-year-old material were compared with the specifications required for woody biomass combustion or ethanol production. Relative to these specifications, ash content was slightly higher (2.7% vs. 1.0%) as was nitrogen (0.98% vs. 0.35%), whereas volatile matter was lower (79.8% vs. 82.0%). Based on these standards, *Salix* spp. grown on reclaimed surface mines or fallow agricultural sites appears to be a suitable biomass feedstock for combustion and biofuel production. Biochar improved growth 80.7% and yield 72.4% compared to non-amended plots. Improved growth and yield in biochar-amended plots in the first year of growth gave willow saplings a competitive advantage over weeds. Additionally, biochar has shown long-term positive impacts in field studies, and improved growth and yield during the first year may prove to give higher yields in the long term.

Additional Key Words: mine reclamation, shrub willow, SRWC

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Introduction

At least 200,000 acres of land in West Virginia have been strip/surface mined and at least 50,000 acres of those are suitable for reclamation with cultivation biomass crops (Grushecky et al., 2013). Biomass/bioenergy is derived from living or recently living biological material. Short rotation woody crops (SRWCs) are a type of biomass crop that have been identified as suitable for strip mine reclamation. West Virginia has set a standard of 25% renewable energy from a variety of sources, including biomass, by 2025 (US Department of Energy, 2013). Biomass, specifically SRWCs, grown on previously mined lands would help achieve the goals set forth by legislation regulating coal mining and reclamation with environmental and economic benefits.

Fallow fields and abandoned mine lands are often referred to as marginal lands. These lands usually have limitations that produce lower yields and/or poorer quality crops, making them economically marginal for food production. Limitations can be related to site and soil conditions such as slope, moisture, compaction, rockiness, pH, nutrient deficiencies, salinity, etc. (Wicke, 2011). Growing bioenergy crops on marginal lands is desirable because the prime agricultural lands can, and should be, used for food crops rather than growing bioenergy crops. Additionally, there are economic benefits to landowners who choose to grow bioenergy crops on their marginal lands.

Shrub willows, a type of SRWC, have the potential to improve land value and quality including soil structure, pH, and nutrient cycling. Furthermore, biochar, a stable form of carbon, has been proposed as a soil amendment to improve soil structure and fertility of marginal lands. Its capacity to enhance plant growth and sequester carbon in the soil as a long-term sink has been demonstrated in several field studies (Kwapinski et al., 2010; Lehmann et al., 2006; Major et al., 2010). It retains and releases nutrients that enhance plant growth and yield, increasing soil quality by adding carbon which is resistant to microbial degradation, and increasing water holding capacity (Kwapinski et al., 2010). Therefore, the use of biochar on marginal lands can improve yield of bioenergy crops grown on these lands.

Little work has been done to date on shrub willow as a bioenergy crop in West Virginia. Similarly, there is a lack of literature on impacts of biochar on bioenergy crops. Given the information gap on these topics, a project was designed and carried out to expand the knowledge base for biochar and shrub willow bioenergy development in the state. The project objectives were:

Objective I: Determine the yield differences between shrub willow cultivars on marginal lands through mortality, growth, and yield analysis.

Objective II: Determine the effects of biochar as a soil amendment to shrub willow growth, yield, and quality as a bioenergy crop.

Methods

Site Description

Trials were established in Morgantown, WV at the West Virginia University farm (39°39'29.55"N, 79°55'50.17"W), in Preston County at the Squires Creek No. 1 Mine (39°28'41.03"N, 79°46'59.81"W), in Greenbrier County at the Buck Lilly Surface Mine (38° 1'7.31"N, 80°35'23.05"W), and in Mason County at the West Virginia Division of Forestry Clements State Tree Nursery (38°57'39.83"N, 82° 5'28.58"W) (Fig. 1). Mean annual precipitation is similar; 40-50 inches in Morgantown, in Preston Co., and in Mason Co., while mean annual precipitation is 50-60 inches in Greenbrier Co. Likewise, Morgantown, Preston Co., and Mason Co. are all located within USDA Hardiness Zone 6a, while Greenbrier Co. is in the USDA Hardiness Zone 5b due to its colder winter temperatures and higher elevation. A full analysis of soil properties prior to the application of biochar is available in Table 1. The Morgantown location was historically farmland and has a severe erosion hazard. Squire’s Creek was historically mined and has been abandoned and sealed since 24 April 1986 and there is a severe erosion hazard. The

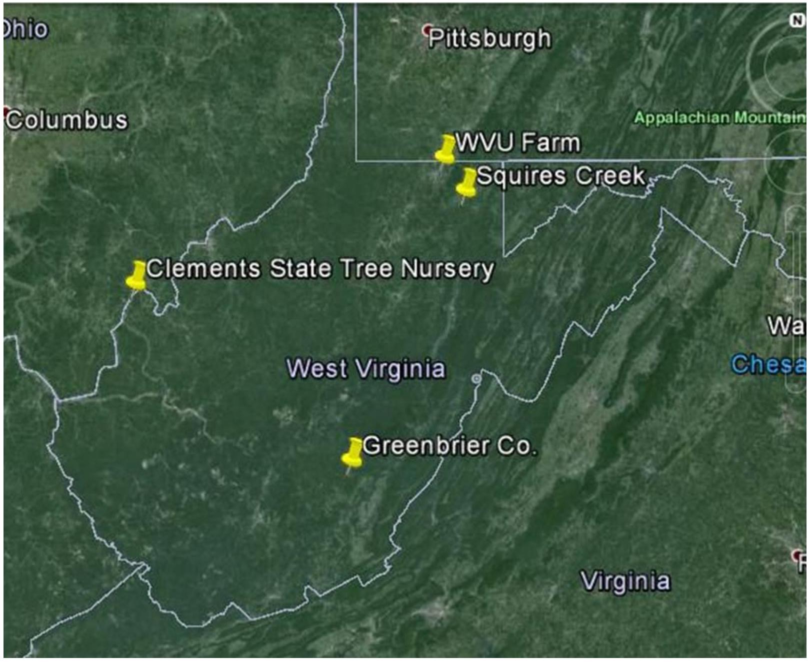

Figure 1. Site map of *Salix* spp. field trials locations in West Virginia, USA.

Greenbrier County site is located at the Buck Lilly Surface Mine and is owned by Plum Creek. It is a non-producing mine and has been classified as such since 12 February 2013. It has steep slopes and severe erosion potential. The Clements State Tree Nursery is located within the Ohio River floodplain and erosion is not a strong concern at this location.

Table 1. Site characteristics of field trial locations. Field trials were located at the WVU Farm in Monongalia Co., WV; Buck Lilly Surface Mine in Greenbrier Co., WV; Squires Creek No. 1 Mine in Preston Co., WV; and Clements State Tree Nursery in Mason Co., WV.

Site characteristics	WVU Farm	Greenbrier	Squires Creek	Clements
Latitude	39°39'29.55"N	38° 1'7.31"N	39°28'41.03"N	38°57'39.83"N
Longitude	79°55'50.17"W	80°35'23.05"W	79°46'59.81"W	82° 5'28.58"W
Elevation (ft.)	1000	3650	1850	575
Soil Type	Ontario	Arnot	Gilpin	Hamlin
Textural Class	silt loam	loam; clay loam; silty clay loam	loam	silt loam
% Sand	18.1	25.2	29.3	26.2
% Clay	16.5	29.3	22.2	17.8
% Silt	65.4	45.5	48.5	56.1
Aggregate Stability (%)	56.7	37.1	32.2	44.3
Available Water Capacity (m/m)	0.23	0.16	0.21	0.25
% Organic Matter	7.12	8	5	4
pH	7.48	6.2	7.3	6.3
Nitrogen (µgN/ gdwsoil/week)	4.9	56	9.9	5.8
Phosphorus (ppm)	3.1	1	1	2
Potassium (ppm)	91.2	96.1	200.6	86.7
Calcium (ppm)	4671.3	1309.2	2046.2	1611
Aluminum (ppm)	9.7	43	29.6	17
Magnesium (ppm)	123.4	186.8	164.2	159.9
Iron (ppm)	0.5	15.7	2.2	1.7
Manganese (ppm)	10.7	19.7	1.4	15.9
Zinc (ppm)	0.5	1.9	0.7	0.5

Source Material

Unrooted willow cuttings were obtained from Double A Willow (Fredonia, NY) in the spring of 2013 and stored in a cooler prior to planting. Six varieties of willow were selected for planting: Oneida (*S. purpurea* x *S. miyabeana*), SX61 (*S. sachalinensis*), Marcy (*S. sachalinensis* x *S. miyabeana*), Preble (*S. viminalis* x (*S. sachalinensis* x *S. miyabeana*)), Fish Creek (*S.*

purpurea), and Fabius (*S. viminalis* x *S. miyabeana*). Cultivars were selected based on recommendations from Double A Willow and researchers at Cornell University.

The biochar used in this study was obtained from a poultry producer located in the eastern panhandle of West Virginia. The producer installed a fixed bed gasifier in 2007 and biochar is created from poultry litter produced on his farms. Poultry litter biochar is rich in P and K with test runs by the International Biochar Initiative yielding results of 1.7-3.2% P and 5.4-9.6% K (2014) and test runs by Novak *et al.* (2009) yielding results of 2.94-4.9% P (2009).

Field Trial Establishment and Harvest

The sites were prepared with a pre-treatment of glyphosate, and the dead plant matter and remaining living material were cut back prior to planting. At each site, six 20 x 20 ft. (400 ft^2) plots were established (Fig. 2).

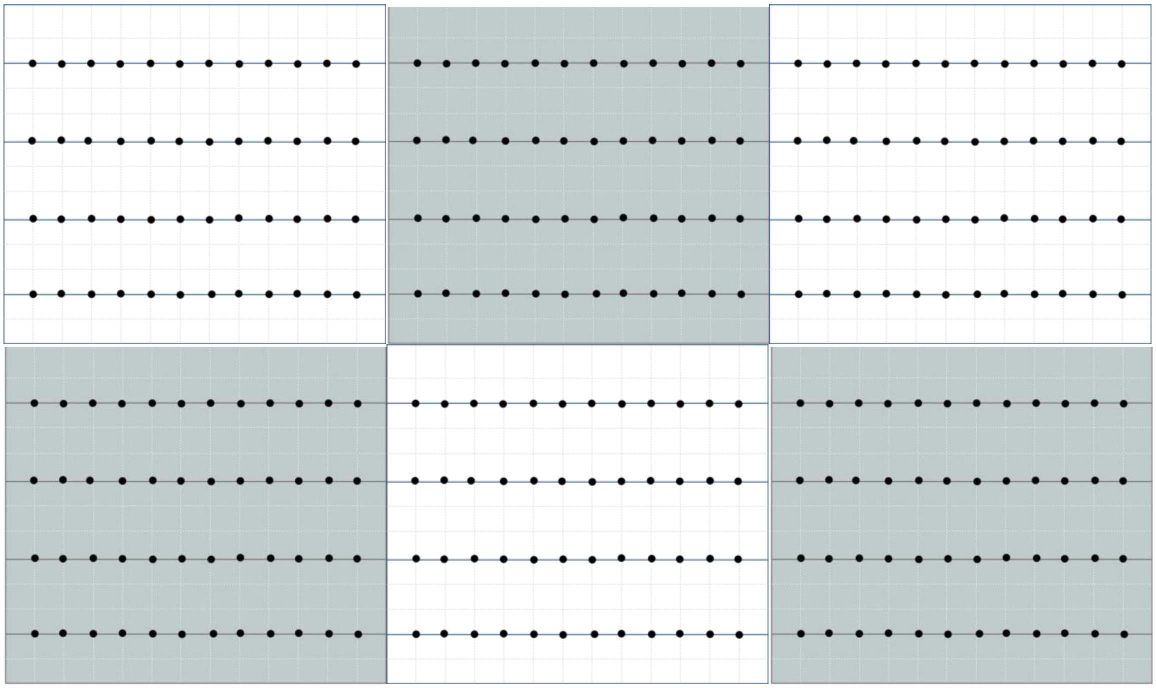

Figure 2. Field trial site and plot layout. Each site consists of 6 plots, 3 of which (grey) receive an application of biochar. Each black dot represents a willow. Four rows of twelve were planted for a total of 48 willows per plot, 288 per site.

A minimum three-foot buffer was maintained between plots. Willows were planted by hand using small shovels to create holes with an approximate diameter of 6 inches and an approximate depth of 6” (~170 in^3). Three plots at each location were selected to receive an application of biochar. Biochar was locally applied at a rate of about 1.5% (~14 tons/acre or ~31.5 metric tons/hectare). Within plots, willows were hand planted in four rows with spacing of approximately 18” between cuttings, for 48 plants per plot between 21 May 2013 and 28 May 2013. Each plot contained at least four cuttings of each variety. Each cutting was approximately 8” and the cutting was inserted into the soil so that about two thirds of the cutting was underground. Soil samples were collected according to the Cornell Soil Health Protocol (http://soilhealth.cals.cornell.edu) from all six replicate plots at each site in June 2013.

Growth and Yield

Willows were measured for growth and noted for survival then coppiced at the end of the first growing season between December 2013 and March 2014. Growth was measured in the field using the length of the longest stem as a proxy for height. To assess dry biomass yield same variety willows were combined for 6 composite samples for each plot, then oven dried to constant weight at 50°C using a Despatch LBB2-18-1 oven. After drying, samples were ground through a 1mm screen using a Wiley Mill, Model ED-5.

Proximate Analysis

Willow biomass samples were analyzed using a Thermogravimetric Analyzer 701 (Leco Corporation, St. Joseph, MI). Each composite sample was analyzed once. A low volatile, bituminous coal standard (Alberta, Canada) was used for quality assurance (Leco Corporation, St. Joseph, MI). Data collected from this analysis include fixed carbon, ash, volatile matter, and moisture content as a percentage of total dry biomass. The method used was ASTM D7582 MVA in Coal.

Ultimate Analysis

Ultimate analysis was performed using a Perkin Elmer 2400 Series II CHNS/O Analyzer (Perkin Elmer Inc., Shelton, CT). Samples were weighed using an AD 6 Auto-balance Controller (Perkin Elmer Inc., Shelton, CT) and data was recorded using EA 2400 Data Manger Version 1.0.0088 software (Perkin Elmer Inc., Shelton, CT). Each composite sample was analyzed once. Traits obtained from this analysis were percent C, H, N, and S as a proportion of total biomass.

Heating Value

Heating value of the samples was determined using a Parr 6300 Bomb Calorimeter (Moline, IL). Each composite sample was analyzed once. Data collected from this analysis include BTU/lb.

Statistical Analysis

All statistical analyses were performed using SAS version 9.3 at a critical α level of 0.05. The examination of the willow samples included thirteen split-plot analyses of variance using randomized blocks. Site type (SiteType), either agricultural or reclaimed mine land, was a method of randomized design testing and the main plot experimental factor. The completely randomized sub-plot experimental factor was biochar (BC) (biochar amended or control), and the sub-sub-plot experimental factor was variety (VAR) (one of the six cultivars listed in the materials and methods section).

Results and Discussion

Mortality

Across all sites and cultivars, mortality was at 47.7% at the end of the growing season. Mortality was lowest at site Greenbrier (32.1%) followed by Squires Creek (46.1%), and Clements (64.8%) (Fig. 3). Mortality data was not collected for the WVU Farm site. Pearson's chi squared test revealed a significant differences in mortality by site (P<0.0001) (Table 2).

Table 2. ANOVA table for mortality of *Salix* spp. by site for three field trial sites in West Virginia. A significant effect was observed using Pearson's chi squared test (P<0.0001).

N	**DF**	**-Log Like**	**R Square (U)**
860	2	31.595628	0.0531

Test	**Chi Square**	**Prob > Chi Sq**
Likelihood Ratio	63.191	<.0001*
Pearson	62.106	<.0001*

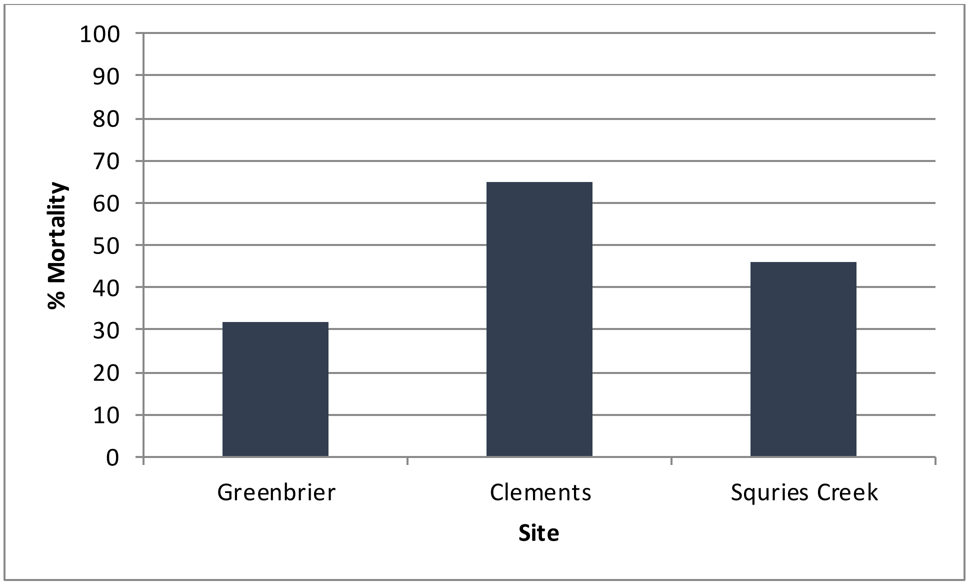

Figure 3. Mortality (%) of *Salix* spp. by site for three field trial sites in West Virginia. Site 'Clements' had the greatest mortality and a significant mortality by site effect was observed (P<0.0001).

Significant differences in mortality were observed between cultivars (P<0.0037) (Table 4). Cultivar 'Oneida' (ONE) demonstrated the least mortality with 67.2% surviving (P<0.0164). Cultivars 'Marcy' (MAR) and 'Preble' (PRE) performed poorest with 46.0% (P<0.0059) and 45.6% (P<0.0047) survivorship, respectively (Fig. 4). Variety 'Oneida' had the highest survivorship of all cultivars. 'Oneida' is a cultivar which has demonstrated a low incidence of rust disease, mammal browsing, or damage by beetle or sawfly in yield trials (Cameron et al., 2007).

Table 4. ANOVA table for mortality of *Salix* spp. by cultivar across all field trial sites in West Virginia. A significance difference was observed using Pearson's chi squared test (P<0.0037).

N	DF	-Log Like	R Square (U)
860	5	8.8876342	0.0149

Test	Chi Square	Prob >ChiSq
Likelihood Ratio	17.775	0.0032*
Pearson	17.478	0.0037*

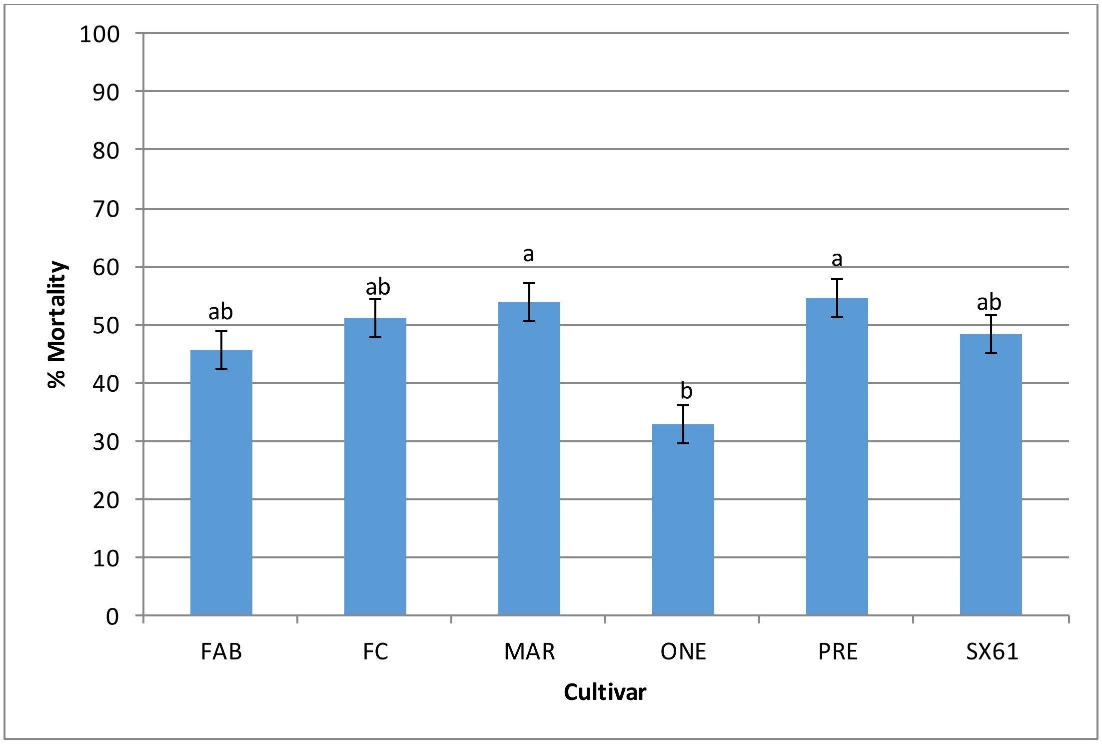

Figure 4. Mortality of *Salix* spp.by cultivar for all field trial sites in West Virginia. A significant cultivar effect was observed (P<0.0037). Cultivar 'Oneida'showed significant differences from cultivars 'Preble' (P<0.0059) and 'Marcy' (P<0.0047)

For all six genotypes planted at the three sites in 2013, survivorship was below the predicted 90% survivorship provided by Double A Willow (Fredonia, NY). Survivorship was highest at site 'Greenbrier' potentially due to the unique conditions at this site, including a lower mean average temperature, a slightly higher annual rainfall, and a higher nitrogen content than the other sites. Site 'Greenbrier' may more closely resemble the geographic origin of the cuttings, thereby resulting in lower mortality at that particular site. However, due to the significant number of environmental variables it is extremely difficult to attribute mortality to any of these factors.

Growth and Yield

Average height growth regardless of site, cultivar, or treatment was 41.4 cm. A statistically significant effect for growth by treatment was observed (P=0.0003) (Table 5; Fig. 5) with plants in the biochar-amended plots growing on average 53.3 cm ± 3.8 cm and plants in reference plots growing on average 29.5 cm ± 3.6 cm.

Table 5. ANOVA table for height growth of *Salix* spp. at four field trial sites in West Virginia. Significant effect was observed for biochar (P=0.0003).

Effect	Num DF	Den DF	F Value	Pr > F
SiteType	1	14	0	0.9943
BC	1	14	23.02	0.0003
SiteType*BC	1	14	0.08	0.7863
Var	5	34	2.31	0.0659
SiteType*Var	5	34	1.84	0.1319
BC*Var	5	24	2.38	0.0684
SiteType*BC*Var	5	24	2.33	0.0738

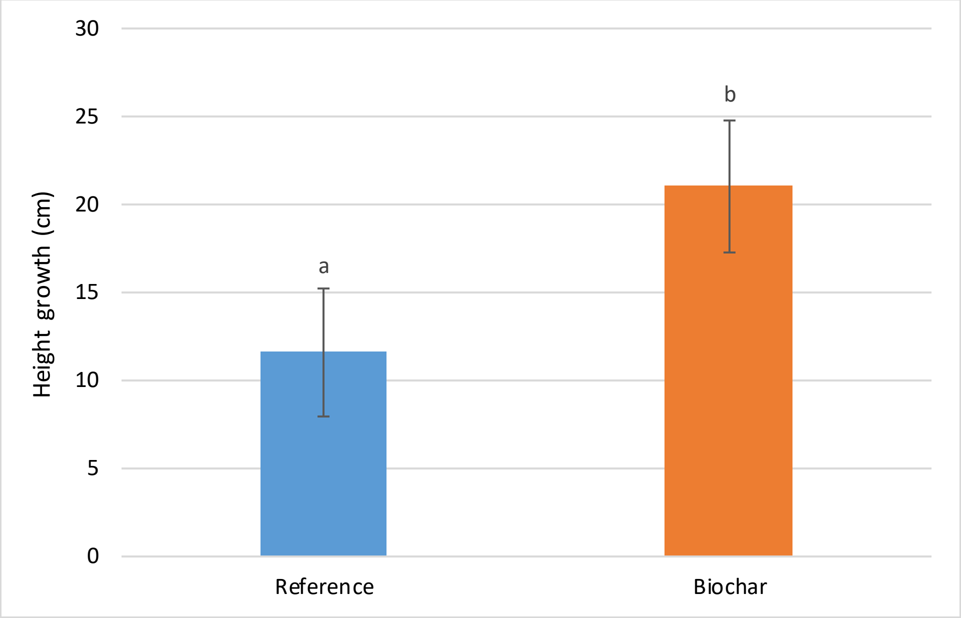

Figure 5. Height growth by treatment for *Salix* spp. at four field trial sites in West Virginia. A significant difference of growth by treatment was observed (P=0.0003).

Average yield regardless of site, treatment, or variety was 3.8 kg/acre. Biochar-amended plots yielded an average of 5.0 kg/acre which was significantly higher than reference plots which yielded 2.9 kg/acre (P=0.0180) (Fig. 6; Table 6).

Table 6. ANOVA table for yield of *Salix* spp. at field trial sites in West Virginia. Significant effects were observed for the interaction of site type, treatment, and variety (P=0.0216), variety (P=0.0046), and treatment (P=0.0180).

Effect	Num DF	Den DF	F Value	Pr > F
SiteType	1	20	0.07	0.792
BC	1	20	6.65	0.018
SiteType*BC	1	20	0.73	0.4028
Var	5	50	3.91	0.0046
SiteType*Var	5	50	1.6	0.1786
BC*Var	5	39	0.63	0.6755
SiteType*BC*Var	5	39	3.01	0.0216

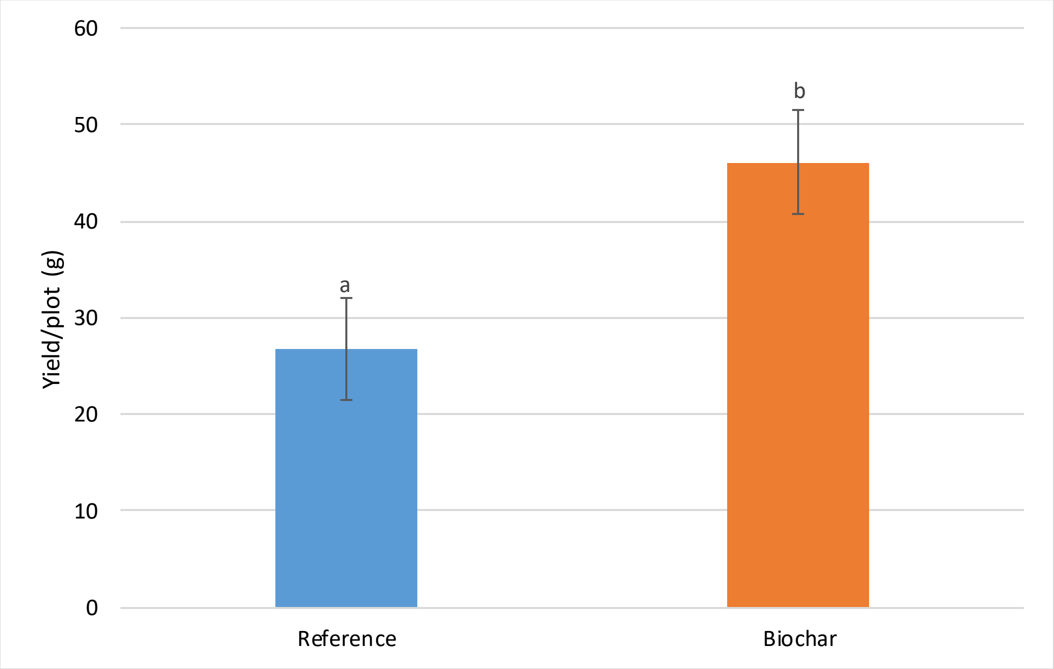

Figure 6. Yield (g/plot) of *Salix* spp. by treatment and field trial site in West Virginia. Biochar-amended plots had statistically significantly higher yield than reference plots at all sites (P=0.0180).

Additionally, a significant variety effect was observed (P=0.0046) (Table 6). Pairwise comparisons indicate that cultivar ‘Fabius’ performed better than all other cultivars with the exception of cultivar ‘Preble’. Furthermore, a significant site type by biochar by variety effect was observed (P=0.0216) (Table 11). For four of the six varieties examined, yield was highest at

Greenbrier ('Fabius,' 'Marcy,' 'Preble,' and 'SX61'). The remaining two varieties ('Fish Creek' and 'Oneida') performed best at the Morgantown site. Varieties 'Oneida' and 'Marcy' had higher yields in biochar-amended plots at reclaimed mine sites and higher yields in reference plots at agricultural sites (Fig. 7). This indicates that biochar may have been more effective at retaining water or essential nutrients for plant growth in depleted soils, while agricultural sites may be more saturated with nutrients thus biochar having a less significant effect.

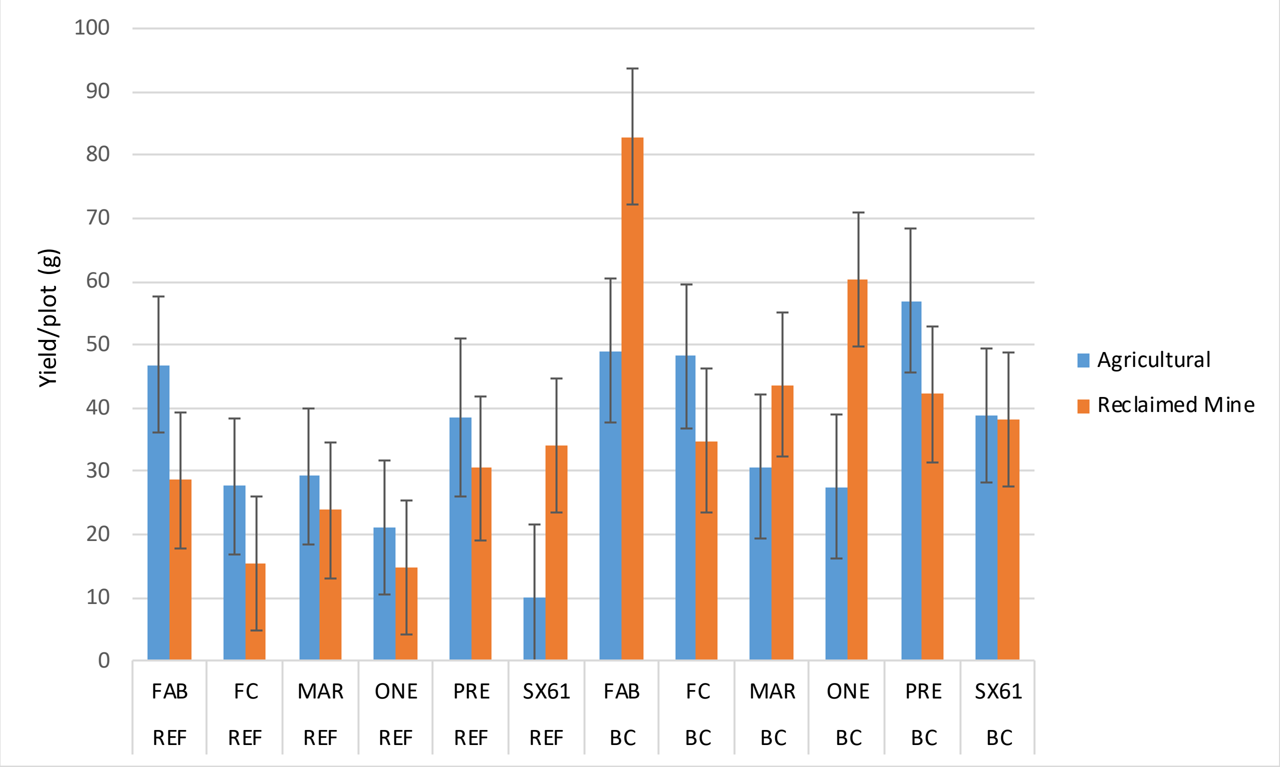

Figure 7. A significant site by biochar by variety effect for yield (P=0.0216) of *Salix* spp. at field trial sites in West Virginia. Due to the complex interaction of biochar, soils/site type, and variety, different varieties performed better on reclaimed mine sites than agricultural sites and/or in the absence of biochar.

Proximate Analysis

Average ash content for all sites was 2.7% by weight. This is higher than the general guideline of 1% ash by weight for woody biomass (McKendry, 2002). The higher ash content may also be explained by the age of the samples. Samples are generally analyzed for ash content at the end of a rotation (3-4 years), however the samples in this study were analyzed after year one. A higher proportion of bark to wood has been associated with higher ash content, thereby explaining the relatively high ash content of these samples.

The average fixed carbon regardless of site type, variety, or treatment was 17.5% by weight, slightly higher than the 17% general guideline provided by Demirbas (2004). Significant fixed effects for fixed carbon were observed for variety (P<0.0148) (Table 7; Fig. 8). Variety 'Fabius' was greatest with 18.1% fixed carbon by percent weight while varieties 'Marcy' and 'SX61' were lowest with 16.9% and 17.0% fixed carbon, respectively. In a least squares means analysis, cultivar 'Fabius' was significantly different from 'Marcy' at α=0.05 level (P<0.0280) and there was a trend toward a significant difference with' SX61' (P<0.0585), however no other trends were observed between varieties. Furthermore, no trends were observed for other fixed effects. Varieties 'SX61' and 'Marcy' are both cultivars of *S. sachalinensis*, while 'Fabius' is a cultivar of *S. viminalis x S. miyabeana*. Differences in hybrid vigor may account for the differences observed between these cultivars.

Table 7. ANOVA table for fixed carbon content of *Salix* spp. at field trial sites in West Virginia. A significant variety effect was observed (P=0.0148).

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
SiteType	1	20	1.31	0.2665
BC	1	20	1.33	0.2622
SiteType*BC	1	20	1.82	0.1927
Var	5	47	3.18	0.0148
SiteType*Var	5	47	0.93	0.4692
BC*Var	5	37	0.26	0.9334
SiteType*BC*Var	5	37	0.64	0.6708

Volatile matter content averaged 79.8% by weight for all samples. Volatile matter content in willows in this study was lower than the general guideline of 82% for woody biomass (Demirbas, 2004). These sites and cultivars are suitable for shrub willow cultivation based on this standard in that lower volatile matter is better suited to combustion systems.

Moisture content in this study was 6.2% by weight. This is slightly higher than the 5% general guideline for coal (Demirbas, 2004). Since moisture content is related to heating value, heating value is expected to be lower than that of coal. Percent moisture is influenced by age, genetic controls, and environmental factors. Moisture content did not vary significantly between sites, variety, treatments, nor were there any interactions among the variables.

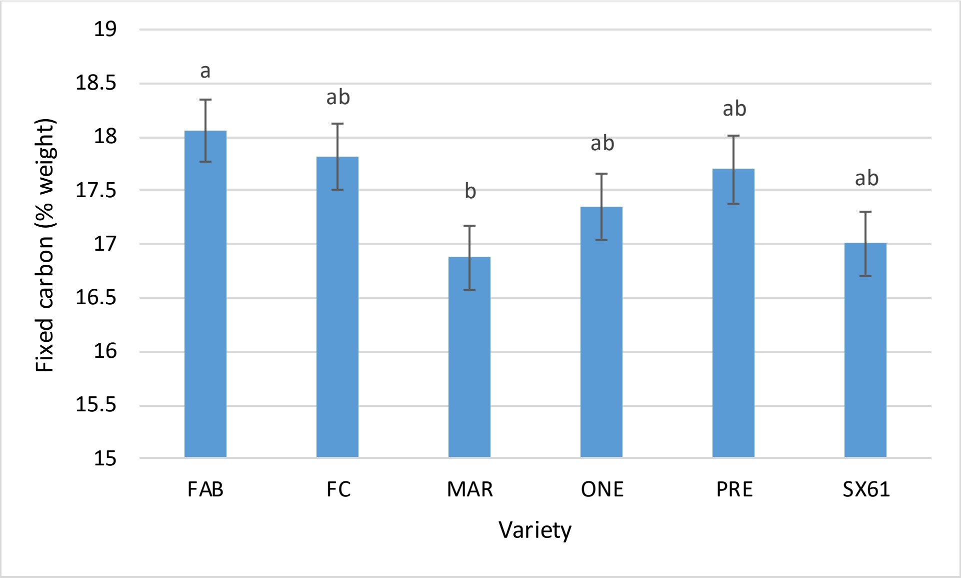

Figure 8. Fixed carbon (% weight) content of *Salix* spp. by variety observed in field trials in West Virginia. A significant effect is observed (P<0.0148).

Moisture content in this study was 6.2% by weight. This is slightly higher than the 5% general guideline for coal (Demirbas, 2004). Since moisture content is related to heating value, heating value is expected to be lower than that of coal. Percent moisture is influenced by age, genetic controls, and environmental factors. Moisture content did not vary significantly between sites, variety, treatments, nor were there any interactions among the variables.

Ultimate Analysis

No significant differences were observed in the elemental analysis of C, H, S, or O by percent weight. Average carbon content of all samples was 47.3% by weight. Average H content was 6.0% by weight, average S content was 0.33% by weight, and average O content was 45.4%. Carbon, H, and S contents were within the general guidelines provided by Demirbas (2004), and O content was just slightly outside the guidelines of 35-45% by weight.

Average N concentration for samples in this study was 0.98% by weight. This is higher than 0.34% and 0.36% observed in similar studies, however lower than the typical 1.2% N found in coal (Demirbas, 2004). Differences were observed in N due to biochar (P=0.0056), variety (P=0.0385), and site type by biochar (P=0.0259) (Table 9). Nitrogen concentrations for wood samples from biochar-amended plots were significantly higher than in reference plots (P=0.0056); 1.0544 (± 0.03687) N by percent weight compared to 0.9080 (± 0.03640) percent N by weight, respectively. This is likely due to biochar's capacity to increase nutrient availability in soils (Lehmann et al., 2006). Nitrogen content also differed significantly in the site by biochar interaction (Fig. 9). Biochar-amended plots were more effective at increasing N availability at agricultural sites than at reclaimed mine sites. The N content at both reclaimed mine sites was higher than for the agricultural sites. The biochar treatment may have been more effective at increasing N availability at agricultural sites due to its initially low availability.

Table 9. ANOVA table for nitrogen content of *Salix* spp. samples in West Virginia field trials. Significant effects were observed for variables biochar (P=0.0056) and variety (P=0.0385), and the interaction site type by biochar (P=0.0259).

Effect	Num DF	Den DF	F Value	Pr > F
SiteType	1	108	3.65	0.0588
BC	1	108	7.98	0.0056
SiteType*BC	1	108	5.1	0.0259
Var	5	108	2.45	0.0385
SiteType*Var	5	108	0.56	0.7296
BC*Var	5	108	0.98	0.4363
SiteType*BC*Var	5	108	1.14	0.3446

Nitrogen also varied due to variety which seemed to be driven by the variety SX61, which had low P-values when compared to the other varieties also producing the only significant difference in pairwise comparisons: varieties 'SX61' (1.14% N by weight) and 'Fabius' (0.87% N by weight) with a P-value of 0.0385 (Fig. 10).

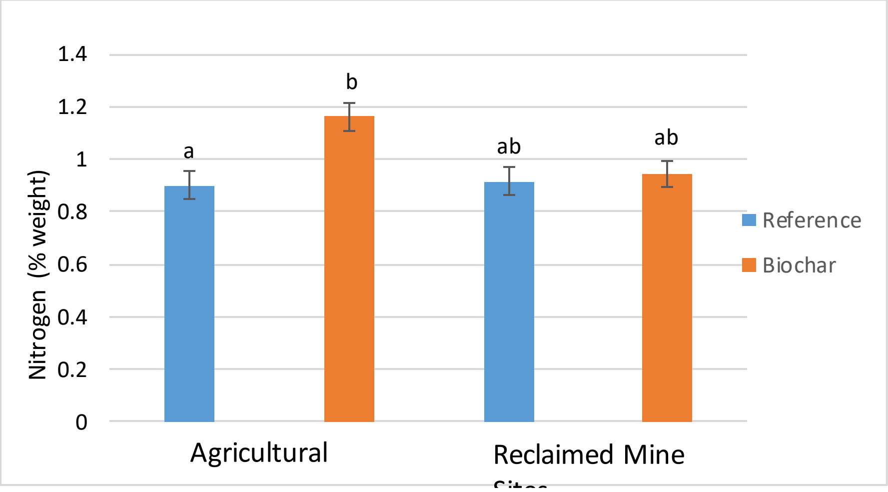

Figure 9. Nitrogen (% weight) of *Salix* spp. samples by site type and treatment in West Virginia field trials. A significant biochar by site type interaction was observed (P=0.0259).

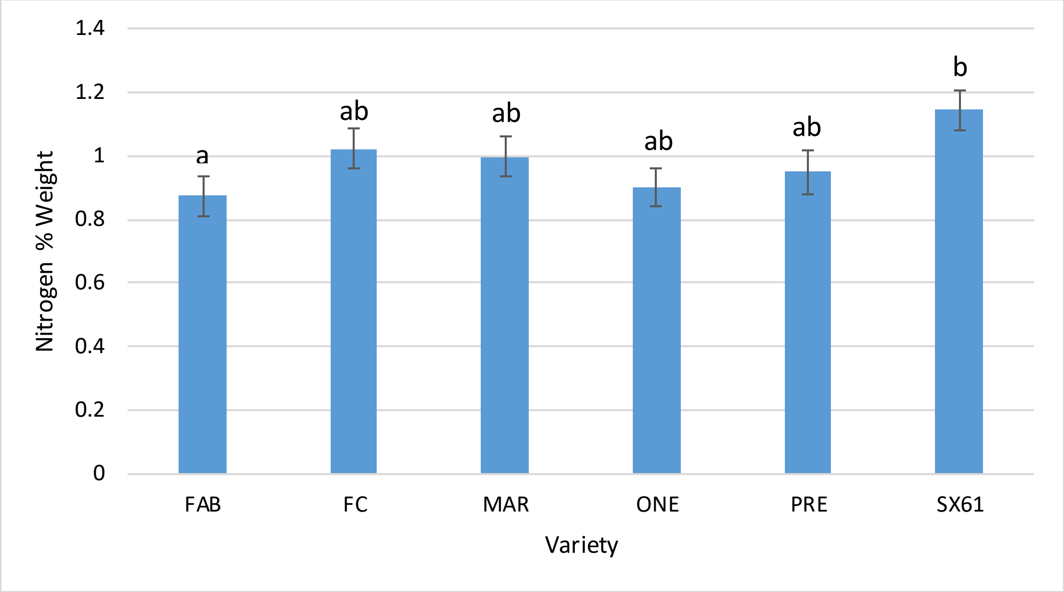

Figure 10. Nitrogen content (% weight) of *Salix* spp. by variety for West Virginia field trials. A statistically significant difference was observed (P=0.0385).

Heading Value

Average BTU/lb for all samples is 7893.8 (18.4 MJ/kg). This falls within the estimates provided by the general guidelines for woody biomass. Those guidelines indicate 14-21 MJ/kg should be expected. Generally speaking, heating value is measured at the end of a rotation (after 3-4 years of growth). Bark is known to lower the average heating value of woody biomass, and since these are samples from year one bark makes up a higher proportion of the biomass, so a lower heating value would be expected; however, this is not what is observed. BTU/lb did not show any correlations with factors that drive heating value such as ash or carbon.

BTU/lb values differed significantly by variety at α=0.05 level (P=0.0045) (Table 10). Differences were driven by variety 'Fish Creek' which had BTU/lb values significantly higher than varieties 'Fabius' (P=0.0348) and 'Marcy' (P=0.0220) (Fig. 11). Variations in heating value for varieties are likely due to the natural variation among cultivars that is expected due to the intentional maintenance of genetic diversity among cultivars.

Table 10. ANOVA table for heating value of *Salix* spp. from West Virginia field trials. A significant variety effect was observed (P=0.0045).

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
SiteType	1	18.46	0.86	0.3654
BC	1	18.46	0.14	0.7146
SiteType*BC	1	18.46	0.46	0.5056
VAR	5	88.34	3.68	0.0045
SiteType*VAR	5	88.34	0.86	0.5122
BC*VAR	5	88.34	1.84	0.113
SiteType*BC*VAR	5	88.34	1.17	0.3297

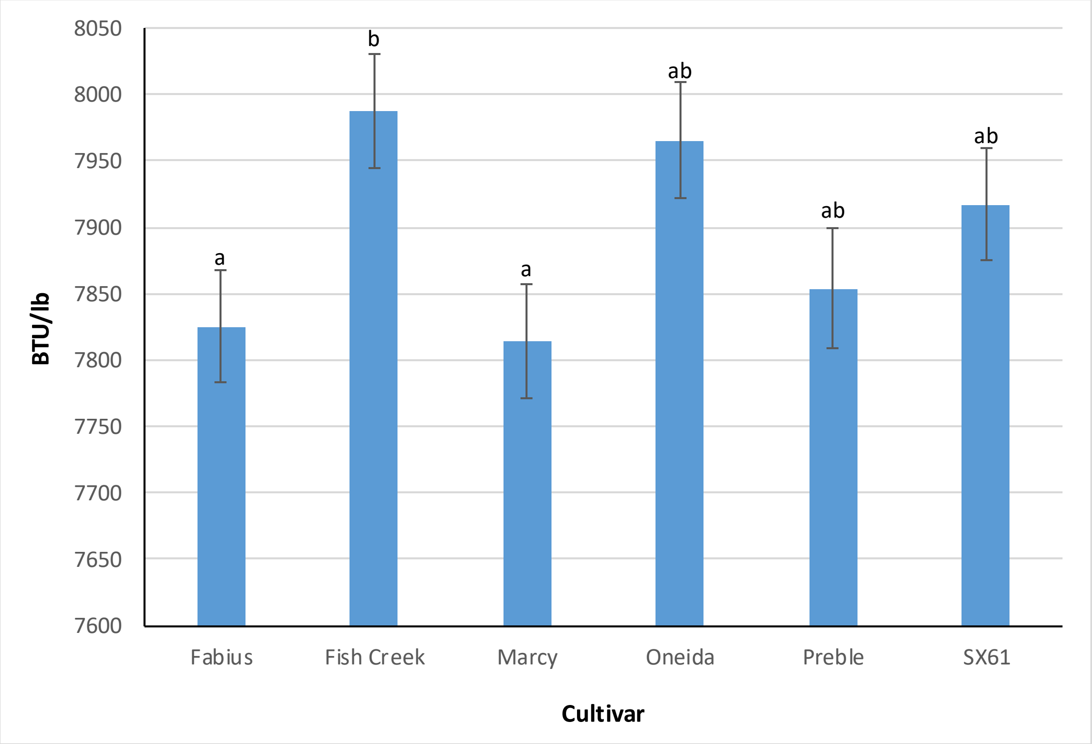

Figure 11. Estimated BTU/lb of *Salix* spp. by cultivar from West Virginia field trials. Significant differences are observed between 'Fish Creek' and varieties 'Fabius' and 'Marcy' (P<0.0045).

Conclusion

Although the results of this study assess only year one data, valuable insights into shrub willow cultivation using biochar on reclaimed mine sites and marginal agricultural sites have been gained.

Survivorship of all cultivars at all sites was lower than the anticipated 90% that has been demonstrated on prime agricultural land. Site ‘Greenbrier’ had the highest growth and yield, and the lowest mortality. This is likely due to the slightly higher mean annual rainfall and lower average temperatures. ‘Greenbrier’ also had more N available in the soils as well as more Fe, Mn, and Zn than the three other sites.

Wood properties were within the general guidelines for woody biomass. Ash content was slightly higher (2.7% vs. 1%) as was N (0.98% vs. 0.35%). Ash content was likely higher than the general guidelines for woody biomass due to the age of the samples. Ash is typically measured at the end of a rotation (3-4 years), whereas in this study ash was measured at the end of the first growing season. The bark to wood ratio is higher at the end of the first growing season thereby raising the percentage of ash in the samples. Volatile matter was lower than the general guidelines (79.8% vs. 82%) which is beneficial for heating values and greenhouse gas emissions.

The insights into the use of biochar on marginal lands were arguably the most important implications of this study. This is suggested through higher growth, yield, and survivorship in biochar-amended plots than reference plots at all sites. Additionally, biochar was more effective at reclaimed mine sites than agricultural sites. This may be due to reclaimed mine sites having a poorer soil structure, and the biochar therefore having a greater positive effect on structure than at agricultural sites. The aggregate stability at both of the reclaimed mine sites was lower than the agricultural sites (34.7% vs. 50.5%). Aggregate stability is influenced by organic matter content, biological activity, and nutrient cycling; biochar likely improved these properties and thus improved growth, yield, and survivorship over non-amended plots. Improved growth and yield in biochar-amended plots in the first year of growth gave willow saplings a competitive advantage over weeds. Additionally, biochar has shown long-term positive impacts in field studies, and improved growth and yield in year one may be an indicator of higher yields in the long term.

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