SWITCHGRASS AND MISCANTHUS YIELDS ON RECLAIMED SURFACE MINES FOR BIOENERGY PRODUCTION[1]

Steffany Scagline[2], Jeff Skousen, and Thomas Griggs

Abstract. Legislation passed by the U.S. Congress in 2007 mandates that 25% of transportation fuels must be made from renewable sources by 2022. Two bioenergy crops that have the potential to meet this mandate are switchgrass (*Panicum virgatum*) and Miscanthus (*Miscanthus x giganteus*). Both species are warm-season perennial grasses and have high biomass production potential under low soil fertility requirements. Biofeedstocks for transportation fuels should be grown on marginal lands rather than prime agricultural land best suited for growing food crops. West Virginia provides an abundance of reclaimed surface mine lands that could be used to produce bioenergy crops. In 2010, two varieties each of switchgrass and Miscanthus were planted in 0.4-ha plots with five replications. This study determined dry matter yields of switchgrass varieties Kanlow and BoMaster and Public and Private varieties of Miscanthus after five growing seasons. All species and varieties were established at Alton, a reclaimed surface mine in central West Virginia. This site was reclaimed in 1985 with 15 cm of soil being placed over mixed overburden. Grass and legume species were planted and soils were initially fertilized and limed according to recommendations. Miscanthus yields after the 5th year averaged 13.7 Mg ha^{-1} for Private and 14.4 Mg ha^{-1} for Public. Switchgrass yields after five years averaged 7.9 Mg ha^{-1} for Kanlow and 7.3 Mg ha^{-1} for BoMaster, which is approaching the yields of switchgrass on agricultural soils in the region. With these recorded biomass yields, switchgrass and Miscanthus are able to provide alternative, more sustainable energy sources, whilst providing a more profitable post-mining land opportunity for surface mined land-owners.

Additional Key Words: Biomass, warm-season perennial grass, renewable energy sources, alternative energy.

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Introduction

Changes in climate and increases in environmental risks have been attributed to the combustion of fossil fuels due to global industrialization. The use of nonrenewable energy sources and their impacts on the environment and society are driving the demand for development of renewable energy sources. In 2013, the United States consumed an average of 18.9 million barrels of oil per day (U.S. E.I.A., 2014). In 2012, the United States consumed 838 thousand barrels of ethanol per day for fuel (U.S. E.I.A., 2014). The Energy Independence and Security Act (EISA) signed into law on December 19, 2007, set specific standards on goals to help reduce dependence on fossil fuels and to increase use of alternative energy sources that would reduce emissions related to global climate change (U.S. E.P.A., 2014). By the year 2022, the United States goal was to increase renewable fuel production from biofuels to 36 billion gallons (U.S. EISA, 2007).

The most widely used biofuel currently comes from corn-grain (*Zea mays* L.) conversion to ethanol. Ethanol cannot be used as a sole source fuel and the maximum allowable percentage of ethanol for non-flex cars made before 2001 is 10% (E10) (U.S. EIA, 2012). Flex-fuel cars can use up to 85% ethanol in the fuel. With a demand for increased agricultural production to meet the food needs of a growing population, the continued use of corn as a bioenergy feedstock is being debated. Corn is an annual crop that has large soil nutrient requirements and grows mostly on prime agricultural lands, all of which make it an undesirable choice for fuel production. Other crops have been evaluated for bioenergy production capabilities that have lower cropping and management requirements. Switchgrass (*Panicum virgatum*) and Miscanthus (*Miscanthus x giganteus*) are C_4 warm-season perennial grasses that provide model biofuel production capabilities due to their ability to produce large amounts of biomass on a wide-range of growing conditions such as reclaimed mine lands (Skousen et al., 2013). West Virginia, Kentucky, and four counties in Tennessee have been affected by an estimated 4.9 million ha of land due to surface mining (U.S. E.P.A., 2005). These reclaimed surface mine lands could be used to produce bioenergy crops.

Switchgrass (*Panicum virgatum*)

Switchgrass is a warm-season perennial, which is native to most of North America except for the areas west of the Rocky Mountains and north of 55°N latitude (Vogel, 2004). As it is dispersed from tropical origins across Central and North America over time, distinct populations came to genetic-ecologic equilibrium in many distinct niches (Parrish and Fike, 2005), resulting in two discrete ecotypes, lowland and upland varieties. Lowland varieties grow better in deep moist soils, while upland varieties tend to be better adapted to thinner soils and drier sites (Parrish and Fike, 2005).

Switchgrass is considered to be a "model biofuel" crop because of its ability to produce large quantities of biomass on marginal soils. Another characteristic of C_4 perennial species such as switchgrass is their ability to senesce and store nutrients. This translocation of nutrients from aboveground tissues to crowns and roots in late fall provides the plant with stored carbohydrates and other nutrients that it uses for regrowth in the spring (Coyne et al., 1995). Without the need for seeding and fertilizing every year, switchgrass reduces tillage, associated erosion to local waterways, and reduces costs associated with seeding and fertilization. Switchgrass has low soil fertility requirements and is highly tolerant to acidity. These attributes benefit growth on mine soils, which tend to be more acidic with lower nutrient contents than agricultural soils (Bona and Belesky, 1992). Studies have shown switchgrass to grow in soils with pH as low as 3.7 (Stucky et al., 1980). Another characteristic of switchgrass is a dense rooting system that can reach depths up to 2.5 m, which can help break up compacted soils and increase water infiltration to increase production capability for future uses.

Studies have shown switchgrass stands can produce average yields of 5.2 to 11.1 Mg ha^{-1} when grown on marginal lands in the northern Great Plains (Schmer et al., 2008). With switchgrass' potential ability to produce high yields of biomass on reclaimed surface mines, disturbed lands can develop a profitable and sustainable post-mining land use for owners while benefiting from increased energy independence.

Miscanthus (*Miscanthus x giganteus*)

Miscanthus is a warm-season C_4 perennial grass native to Asia and Africa (Hecht, 2011). The most widely used Miscanthus species for biomass production is *Miscanthus x giganteus*, which is a sterile hybrid (Skousen et al., 2014). Miscanthus shares similar growth characteristics as switchgrass and other warm-season perennial species with growth from rhizomes that reach a maximum height of 3 to 3.5 m (Skousen et al., 2014). Characteristic of almost all C_4 perennial species, senescence takes place in the late fall-early winter and stores nutrients and carbohydrates in crowns and roots for regrowth in spring. Miscanthus stands have life spans that can reach up to

15 to 20 years with minimal cultural inputs, which makes them beneficial to grow on marginal lands (Hopwood, 2010).

Miscanthus is a promising bioenergy crop because it produces high yields that exceed switchgrass (Heaton et al., 2008). Studies show Miscanthus DM yields ranged from 10 to 40 Mg ha^{-1} throughout Europe (Lewandowski et al., 2003). Besides producing greater DM yields of biomass, Miscanthus produces higher lignocellulose contents (Skousen et al., 2013).

Both Miscanthus and switchgrass are able to produce high yields of biomass with low fertility requirements and are viable options for post-mining land uses such as bioenergy production. The primary objective of this study was to determine yields of two varieties of Miscanthus ('Public' and 'Private') and two varieties of switchgrass ('BoMaster' and 'Kanlow') on a reclaimed surface mine for potential biofuel production. The secondary objective of this study was to determine which species was capable of producing greater biomass yields on the same amount of land on a reclaimed surface mine.

Materials and Methods

Site Location

Biomass plots were established at the Alton site, a previously surface mined area of 160 ha located in Upshur County, WV (38°49'N 80°11'W). Coal seams that were mined at this site were the Upper, Middle, and Lower Kittanning coal seams. This site was reclaimed in 1985 with about 15 cm of soil placed over mixed overburden. Grass and legume species planted were tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh], orchardgrass (*Dactylis glomerata* L.), birdsfoot trefoil (*Lotus corniculatus* L.), serecia lespedeza (*Lezpedeza cuneate* G. Don), and clovers (*Trifolium spp*.). Soils were fertilized and limed according to recommendations at the time. Of the 160-ha total land base, about 60 ha were suitable for biomass production. In 2010, after 25 years of herbaceous growth, roughly 10 ha were chosen for the switchgrass and Miscanthus study site and sprayed with glyphosate herbicide (Roundup) at recommended rates the previous fall and again before planting in the spring of 2010.

Experimental Design and Analysis

A completely randomized design was chosen for this study. Lowland varieties of switchgrass ('Kanlow' and 'BoMaster') and varieties of Miscanthus ('Private' and 'Public') were randomly assigned and established in 0.4-ha plots. Each variety was replicated five times for a total of 20 plots. Existing herbaceous cover was killed with herbicide and then Kanlow and BoMaster switchgrass varieties were no-till drilled in at the rate of 11 kg ha^{-1} PLS (Pure Live Seed). Ernst Conservation Seeds (Meadville, PA) supplied the switchgrass seed and, while the seed was not certified, it had been certified during the past 5 yrs. Two sterile varieties (Public and Private) of *Miscanthus x giganteus* were obtained from Mendel Biotechnology (Hayward, CA) and planted as sprigs at a rate of 12,300 plugs per ha (0.9-m spacing) (Fig. 1).

Clipping of switchgrass and Miscanthus plots began in October of 2011, two years after establishment, and each year thereafter. Switchgrass was clipped by hand to a 10-cm cutting height in six randomly located 0.21-m^2 quadrats in each plot. Miscanthus was clipped at the same cutting height from a randomly-selected single plant in a 0.81-m^2 area (0.9 x 0.9 m area). All biomass was dried at 60^{o}C for 48 hours to a constant weight and weighed to determine DM yield and converted to Mg ha^{-1}.

Figure 1. Alton site location of 0.4-ha plots of switchgrass (Kanlow and BoMaster) and Miscanthus (Public and Private).

Soil samples were taken in 2009 to a depth of 10 cm at three randomly located places in each plot. Soil samples were dried and rocks were removed through dry sieving. The fine material (< 2mm) was dried and used for analyses. Soil pH was determined on a 1:1 mixture with deionized distilled water with a pH meter (Mettler Toledo SevenEasy pH Meter). Soils were extracted with a Mehlich 1 solution (0.05 mol L^{-1} HCl and 0.025 mol L^{-1} H_2SO_4). The resulting solution was analyzed with an emission spectrophotometer (Perkin Elmer Optima 2100 DV) for P, K, Ca, Mg, Al, Ba, Fe, and Mn (Wolf and Beegle, 1995). Mean values were determined for each plot and averaged for each species.

Biomass data were Ln-transformed to meet normality criteria. Biomass data were analyzed for all four years using repeated measures ANOVA in mixed procedure of SAS (Version 9.3, SAS Institute Inc., Cary, NC, Copyright © 2002-2010). Main fixed effect analysis for species, cultivar within species, and the year was followed by Tukey-Kramer multiple comparison on least squares. In addition, biomass data were analyzed by years. Significance criterion was 0.05.

Results and Discussion

Alton soil analysis showed pH values ranging from 6.5 to 7.2 (Table 1). These mine soils had medium to high levels of P, K, Ca, and Mg. Bioenergy crops like switchgrass and Miscanthus should grow well at these soil pH and nutrient levels (Skousen et al., 2014).

Table 1. Average values of chemical properties of mine soils at the Alton site where switchgrass and Miscanthus were established.

Plant Species	pH	CEC	Mg	Ca	K	P
		μS cm^{-1}	-----	$cmol^{+}$ kg^{-1}	-----	mg kg^{-1}
Switchgrass						
Kanlow	6.5	23.7	0.55	2.6	0.18	37
BoMaster	6.8	19.9	0.21	3.9	0.13	23
Miscanthus						
Private	6.7	15.9	0.18	3.9	0.16	23
Public	7.2	16.7	0.43	3.4	0.13	19

Switchgrass and Miscanthus stands were well established by the end of the second growing season and increased to a consistent stand after the third growing season (Skousen et al., 2013). It is characteristic of switchgrass and Miscanthus species to reach full stand establishment by the end of the third year (Fig. 2). Kanlow switchgrass almost doubled from 2011 to 2014 from 4.0 Mg ha^{-1} to 7.9 Mg ha^{-1} (Table 2). BoMaster increased from 2.7 Mg ha^{-1} to 7.3 Mg ha^{-1} (Table 2). Both varieties produced well over the 5.0 Mg ha^{-1} limit set to show economic viability for growth of switchgrass biofeedstocks on mined lands.

Figure 2. Kanlow switchgrass growth on a reclaimed surface mine at Alton, WV.

Table 2. Average DM yields (with standard deviations) of switchgrass and Miscanthus at Alton, WV in October 2011, 2012, 2013, and 2014.

	Year of Production			
Plant Species	2011	2012	2013	2014
	------------------ Mg ha^{-1} ------------------			
Switchgrass				
Kanlow	4.0 a[1] (2.6)	4.9 a (1.1)	4.9 a (3.5)	7.9 a (2.6)
BoMaster	2.7 b (1.4)	4.0 a (3.1)	5.4 a (9.8)	7.3 a (3.5)
Miscanthus				
Public	2.2 y (2.0)	5.0 y (3.0)	7.0 x (6.6)	14.4 x (7.8)
Private	6.5 x (5.8)	15.5 x (10.4)	11.1 x (6.8)	13.7 x (5.7)

[1] Means for switchgrass and miscanthus cultivars within years with the same letter are not significantly different at $p \leq 0.05$.

Miscanthus DM yields for the Public variety increased from 2.2 Mg ha^{-1} in 2011 to 7.0 Mg ha^{-1} in 2013 and then doubled to 14.4 Mg ha^{-1} from 2013 to 2014 (Table 2). The Private variety had an increase from 6.5 Mg ha^{-1} in 2011 to 15.5 Mg ha^{-1} in 2012 but then declined in 2013 (Table 2). From 2013 to 2014, Private increased to 13.7 Mg ha^{-1}. Repeated measurements each year using ANOVA analysis revealed significant effect of year ($p = 0.0003$). Biomass increased with each year. Biomass for species and cultivar within species were not significantly different over the years ($p = 0.11$ and 0.17, respectively). Both Miscanthus varieties were similar or higher than studies on agricultural lands (Heaton et al., 2008). Yearly biomass analysis showed Miscanthus yields were significantly larger than switchgrass (Fig. 3). These results confirm that Miscanthus grown on marginal lands such as reclaimed surface mines are comparable to growth on agricultural lands (Fig. 4). An example done by Heaton et al. (2008), shows Miscanthus yields on agricultural soils at 15.0 to 20.0 Mg ha^{-1}.

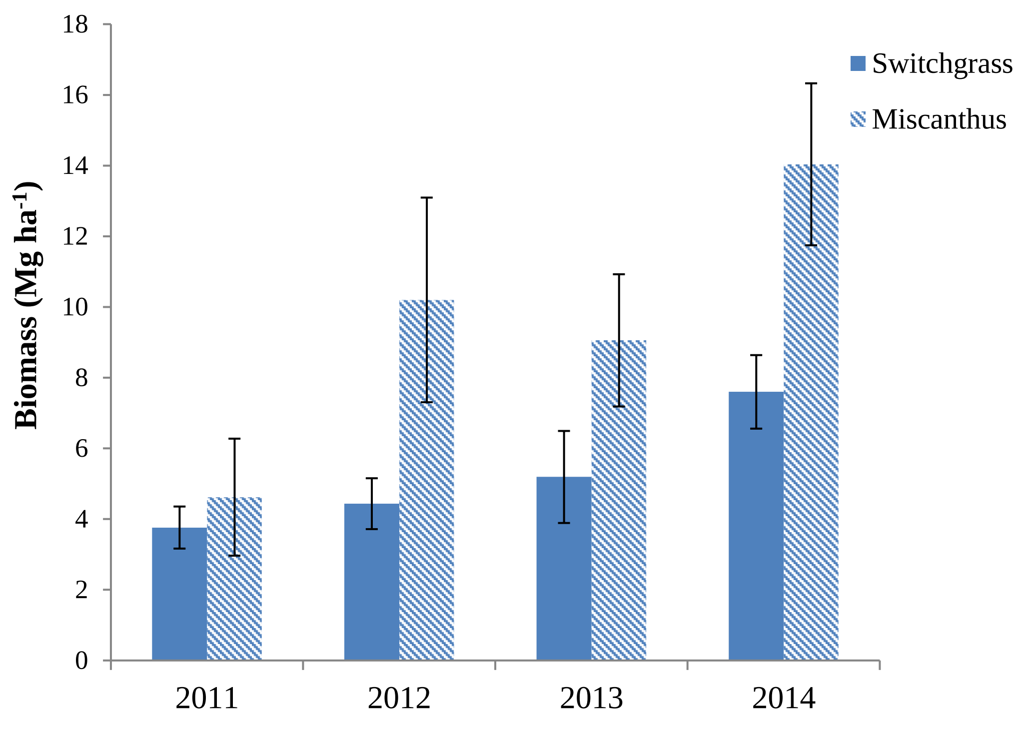

Figure 3. Biomass (Mg ha^{-1}) averages of switchgrass and Miscanthus varieties from 2011, 2012, 2013, and 2014.

Figure 4. Private variety of Miscanthus grown on a reclaimed surface mine at Alton, WV.

Conclusion

The result of biomass production from this study indicates that two varieties of switchgrass and Miscanthus have successfully established on a reclaimed surface mine in WV and produced comparable yields as those on other marginal lands and agricultural soils. Switchgrass variety Kanlow produced 7.9 Mg ha^{-1} by 2014 and BoMaster produced 7.3 Mg ha^{-1}, both producing over the 5.0 Mg ha^{-1} economically viable standard (Skousen et al., 2013). Private Miscanthus yielded 13.7 Mg ha^{-1} and Public yielded 14.4 Mg ha^{-1} during the fifth growing season in 2014. Switchgrass and Miscanthus demonstrated high yields of biomass production on reclaimed surface mined land, thus making them profitable and sustainable alternatives to corn for future biofeedstocks.

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