ESTABLISHMENT AND GROWTH OF SWITCHGRASS AND OTHER BIOMASS CROPS ON SURFACE MINES[1]

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Abstract: Biomass crops are being grown on agricultural and marginal lands to provide feedstock for co-firing in power plants and conversion to transportation fuels. Switchgrass (*Panicum virgatum* L.), Miscanthus (*Miscanthus x giganteus)*, and giant cane (*Arundo donax* L.) are three biofuel feedstocks that have been planted on reclaimed surface-mined land to determine their establishment and potential for biomass production. This study documents the establishment and dry matter (DM) yield of these biomass crops on several mined sites in West Virginia. The Alton site has all three species planted, and DM yield after the fourth growing season averaged 5,200 kg ha^{-1} for switchgrass (Kanlow and Bomaster varieties) and 9,000 kg ha^{-1} for two varieties of Miscanthus. Giant cane had less than 1,000 kg ha^{-1}. Cave-In-Rock switchgrass was planted on 8 ha at the MeadWestvaco (MWV), WV, site and at The Wilds, OH, site in 2013. After the first growing season, switchgrass production was 752 kg ha^{-1} at MWV and 1,045 kg ha^{-1} at The Wilds site. Miscanthus was also planted on these two latter sites, and biomass production after one year was 200 and 600 kg ha^{-1}, respectively. These biomass averages at The Wilds and MWV were lower than averages produced at Alton after the first growing season. At the Coal Mac site, an average of 10,000 kg ha^{-1} of Arundo was produced after the third growing season. As demonstrated in these and other studies, two to three years are required for these bioenergy plants to establish and expand to produce suitable amounts of biomass.

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Introduction

Switchgrass

Switchgrass was first researched in the early 1900s as one of the important species of native perennials in the Midwestern USA's tall-grass prairies (Parrish et al., 2012). It was only until the middle of the 20th century that switchgrass was grown as a monoculture and intensively researched as a forage crop (Casler and Vogel, 2014; Parrish et al., 2012; Waramit et al., 2012). This early agronomic work focused on factors related to forage value and yield with similar work continuing today (Anderson, 2000), and many of the commercially-available cultivars today have been chosen for their forage characteristics. The first reports for switchgrass as a bioenergy crop were seen at the end of the 1980s, making it a relatively new research subject in the bioenergy field (Parrish et al., 2012; Schmer et al., 2012).

Switchgrass was chosen as a 'model' bioenergy crop because of its ability to grow sufficient amounts of biomass to be a potentially profitable, large-scale agricultural system (Wright and Turhollow, 2010). Initially, the main attraction to switchgrass as a bioenergy crop was its ability to be grown on many different soil types and climates throughout the USA (Parrish et al., 2012). It is a warm-season bunchgrass species, but it has short rhizomes that allow it to form a sod over time. It is a long-shooted species and can grow up to 3 m in height (Zegada-Lizarazu et al., 2012). The ability to grow with low or little fertilizer and pesticide application means it is a more profitable biomass system with lower inputs than other bioenergy feedstocks (Wright and Turhollow, 2010). It can be harvested using standard agricultural equipment for hay (Parrish et al., 2012).

As their name suggests, warm-season grasses are able to grow well during periods of warm temperatures due to their C4 photosynthetic pathway. When temperatures are high, plants respond by reducing stomata openings to minimize water loss while maintaining photosynthesis. Unique to C4 plants, initial photosynthetic reactions occur in the mesophyll cells and the Calvin cycle occurs in the bundle sheath cells. This structure prevents O_2 from reacting with the C3 photosynthetic enzyme Rubisco and out-competing CO_2 for active enzyme sites. Therefore, C4 plants greatly reduce photorespiration and have higher photosynthetic efficiency than their C3 counterparts have. Being able to efficiently carry out photosynthesis with reduced stomatal openings is the reason warm-season grasses are more water-use efficient than cool-season grasses.

Switchgrass is divided into lowland and upland ecotypes that differ primarily in the environment in which they grow, their morphological characteristics, and the number of chromosomes they exhibit (Zegada-Lizarazu et al., 2012; Zhang et al., 2011). Upland ecotypes are more suited to be grown in West Virginia as they can be found growing north of 40°N latitude, while lowland varieties are generally only found below 40°N latitude (Casler, 2012). Lowland types are more adapted to floodplains and the wetter soils that characterize these landscapes, while upland types are more adapted to dry to moderate soil moisture regimes (Koff and Tyler, 2011).

The many studies on switchgrass as a forage crop give evidence of the DM yields that can be achieved with this species in forage strategies, but the data can also be used to evaluate switchgrass as a crop for bioenergy production. For example, Sanderson et al. (1999) saw no difference between DM yield between Cave-in-Rock, Shawnee, and Trailblazer switchgrass cultivars planted in Southeastern PA. Yields were 6.0 Mg ha^{-1} averaged over the three cultivars during the first two years of growth for a 2-cut system (harvests in mid-July, then again after senescence in October). Herbage from the 2-cut system contained lower concentrations of crude protein than in a 3-cut system. More nitrogen (N) in switchgrass biomass is advantageous when it is used as a forage crop because of the relationship between protein content and forage quality as feed. But high N concentrations in forage are not advantageous for bioenergy feedstock purposes because N is seen as an undesirable element in ethanol production (Parrish and Fike, 2005), plus it must be replenished to maintain soil fertility. Therefore, it makes sense to use a 3-cut system when the biomass is used for forage because of higher crude protein and digestible energy concentrations. This study did not consider a 1-cut system (harvesting only once after senescence in October) which Parrish and Fike (2005) argue is the best harvesting system based on lower amounts of N in biomass.

Ample research has shown that switchgrass grown in the Midwestern USA can produce high DM yields when managed as a biofeedstocks. Switchgrass grown in Nebraska, North Dakota, and South Dakota had DM yields ranging from 5.2 to 11.2 Mg ha^{-1} averaged over the 3^{rd} to 5^{th} harvest years (Schmer et al., 2008). Near Chariton, IA, 20 switchgrass cultivars yielded an average of 9.0 Mg ha^{-1} over a period of five years (Lemus et al., 2002). Fike et al. (2006) showed DM yields averaged over treatments and sites within the upper Southeastern USA were 14.2 Mg ha^{-1} for 10-year-old switchgrass stands managed for biomass production. Averaged over four cultivars and two management treatments, switchgrass planted in Morgantown, WV, yielded approximately

13.8 Mg ha^{-1}, while two sites in Blacksburg, VA, averaged 16.6 Mg ha^{-1} (Fike et al., 2006). Three cultivars grown in Rock Springs, PA, and harvested in the fall had an average DM yield of 7.9 Mg ha^{-1} (Adler et al., 2006).

Growing switchgrass on reclaimed surface mines in the Appalachian region could potentially be an alternative to growing biofeedstocks on agricultural lands. Surface mining for coal is estimated to affect approximately 5 million hectares of land across West Virginia, Kentucky, and a few counties in Tennessee (U.S. EPA, 2005). The goal for reclamation of these areas is to develop a suitable post-mining use of the land for landowners, to meet ground cover regulations, and to minimize erosion as inexpensively and effectively as possible. A current, popular post-mining land use is hay land and pasture, which is relatively inexpensive to establish with agricultural grasses and provides quick ground cover that is necessary to meet regulations.

Growing bioenergy feedstocks on reclaimed mine land rather than agricultural lands is an opportunity to lessen competition with food production and protect the nation's fertile agricultural soils while simultaneously restoring degraded lands into productive, economically viable uses. Extensive coal mining in Appalachia produces large expanses of surface-mined lands that were reclaimed to a designated post-mining land use. To meet standards by the Surface Mining Control and Reclamation Act of 1977 (SMCRA), these areas have historically been reclaimed with cool-season perennial grasses and legumes. If switchgrass was grown instead of the cool-season grasses, it would be a potential economic benefit to the area by selling the switchgrass biomass for bioenergy. Unfortunately, full biomass production potential of switchgrass often is not achieved until the second or third growing season following establishment (Marra et al., 2013). However, once mature switchgrass stands have established, they can produce consistent biomass over 10 to 20 years with relatively low nutrient inputs (Kering et al., 2012).

Although there is much research on switchgrass production on productive USA agricultural land, very little research is available for switchgrass grown on reclaimed mine areas. Previous research that may be comparable involves switchgrass grown on marginal lands. Marginal lands are those with low crop productivity due to inherent land or climatic limitations or because they are located in areas that are vulnerable to erosion (Gelfand, 2013). Switchgrass planted on marginal lands along newly constructed highways was able to achieve good cover and soil stabilization after two years (Skousen and Venable, 2008). Schmer et al. (2008) produced annual average DM yields of 5.2 to 11.1 Mg ha^{-1} of switchgrass when managed as a biomass energy crop on marginal cropland in the Midwestern USA. Even greater yields on marginal lands were shown by Kering et al. (2012), with switchgrass producing 16.0 Mg ha^{-1} during the fifth year of production in south central USA. Marra et al. (2013) showed switchgrass to produce 7 Mg ha^{-1} on reclaimed mined lands in West Virginia. The site with high yields had topsoil and sewage sludge amendments to the soil, so growing conditions for the switchgrass were likely optimized. At another site with no topsoil or amendment, yields were much lower at <1 Mg ha^{-1}.

Miscanthus

Miscanthus is a genus comprised of about 15 species. It is a warm-season perennial grass native to Asia and Africa (Hecht, 2011). Certain species have been used in Japan for thousands of years for forage and thatching, but also as ornamental plants with aesthetic value. In the 1970s, Miscanthus was identified as a bioenergy crop because of its high energy yield per hectare and relative low energy input cost compared to other bioenergy crops (Hastings et al., 2008).

Giant Miscanthus (*Miscanthus x giganteus*) is the most commonly grown Miscanthus species for biomass production. It is a sterile hybrid between *M. sinensis* and *M. sacchariflorus* (Heaton et al., 2012). It grows from rhizomes that reach a maximum height of 3–3.5 m and stands have a useful life of 15 to 20 years (Hopwood, 2010). Giant Miscanthus is best suited for areas with at least 75 cm of rainfall per year, with better results as rainfall increases.

Miscanthus DM yield ranged from 10 to 40 Mg ha^{-1} at 16 locations throughout 10 European countries (Heaton et al., 2008). The main feature distinguishing Giant Miscanthus from other biomass crops is its high cellulose content. However, Giant Miscanthus has traits that make it better suited for thermochemical conversion processes than biological fermentation (Heaton et al., 2012). To maintain low input cost, harvesting should be done after frost to allow nutrients to return to the soil, thereby minimizing fertilizer inputs. Pesticides are not normally needed which further reduces input cost. Herbicides to control competition from weeds are not needed if fallen leaf material is left to provide a mulch layer that helps to suppress weeds. The fallen leaf material also recycles nutrients and returns organic matter to the soil (Hopwood, 2010).

Giant Miscanthus has the potential to yield a higher annual DM yield than any other major biomass crop except *Saccharum* species. In small trials at three separate sites in Illinois, Giant Miscanthus yielded two to four times more than native switchgrass (Fig. 1, Heaton et al., 2008).

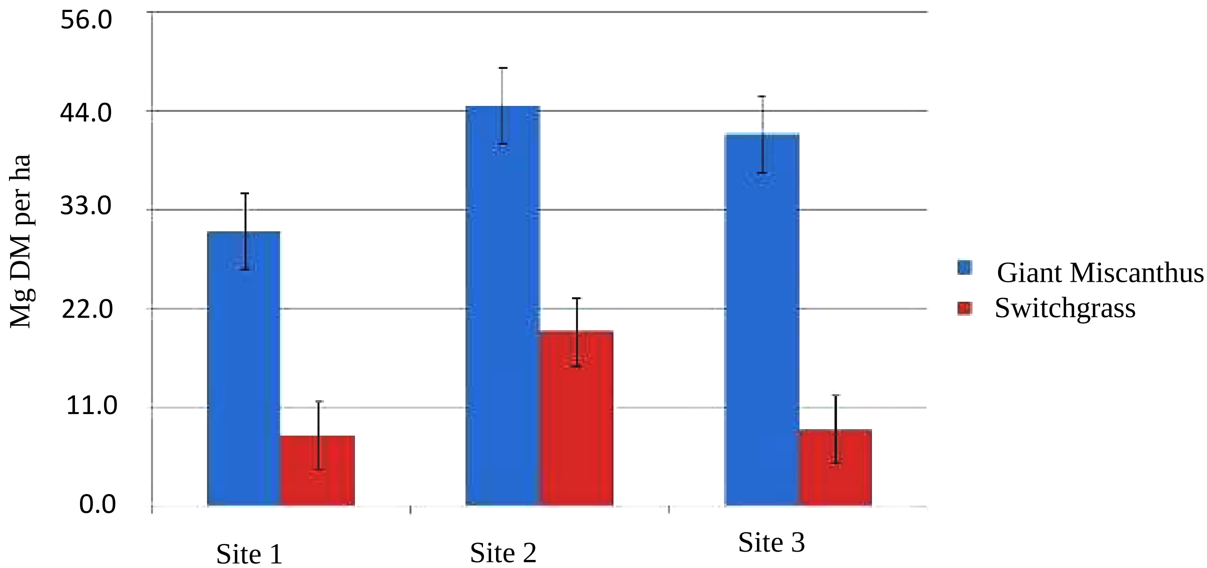


Figure 1. The average annual biomass yields of Giant Miscanthus and switchgrass harvested from three locations in Illinois.

With the average yield rates seen in the Illinois trials, Giant Miscanthus has the potential to supply all the advanced biofuel required under the 2007 Energy Independence and Security Act (Table 1). Consequently, Giant Miscanthus could meet biofuel goals without bringing new land into production or displacing food supply (Heaton et al., 2008).

Miscanthus can have enormous environmental benefits. For example, research work in Illinois showed that production of Miscanthus for biofuel had lower concentrations of nitrates in runoff than corn-based biofuel production, but had higher concentrations of nitrates in runoff switchgrass (McIssac et al., 2010). Since Miscanthus has mainly been tested in Europe and switchgrass in the US, biomass yields from mature stands of Miscanthus and switchgrass grown side-by-side are limited in peer-reviewed literature. This is an area where more research is needed (Heaton et al., 2008).

Table 1. Biomass production, potential ethanol production, and land area needed for different potential bioenergy systems to reach the 132 billion L (35 billion gallon) US renewable fuel goal in 2017 (Heaton et al., 2008).

Feedstock	Harvestable Biomass[a] ($Mg\ ha^{-1}$)	Ethanol ($L\ ha^{-1}$)[b]	Million ha Needed for 132 Billion L of Ethanol	Harvested US Cropland (%) in 2006

Corn grain	10.2	4,260	31.0	24.4
Corn stover	7.4	2,801	47.2	37.2
Corn total	17.6	7,061	18.7	14.8
Switchgrass	10.4	3,931	33.7	26.5
Miscanthus	29.6	11,189	11.8	9.3

[a] Based on DM yield in Illinois.
[b] Assuming conversion of DM yield into ethanol of 420 L Mg^{-1}.

Giant Cane

Giant cane (*Arundo donax* L.) is a tall, perennial grass that grows in damp soils of either fresh or moderately saline water. It is native to eastern and southern Asia, but it has been widely planted and naturalized in temperate, subtropical and tropical regions of both hemispheres (Angelini et al., 2009). It forms dense stands on disturbed sites, sand dunes, wetlands, and riparian habitats. It can grow from 6 to 10 m in height with hollow stems. Giant cane needs to be established by vegetative propagation (rhizomes) due to a lack of viable seed production. It is capable of growing on a wide range of soils and can provide very high biomass yields with low environmental impact and low inputs from fertilizer, tillage, and pesticides. Heating value is similar to other biomass crops at 3.3 to 3.8 MJ kg^{-1} (7,000 to 8,000 BTU lb^{-1}). Dry matter yields varied from 13 to 40 Mg ha^{-1} in central Italy (Angelini et al., 2005). Comparable studies have not been published in the United States on *Arundo* yields because it is viewed as an invasive plant, but similar yields of 20 to 25 Mg ha^{-1} dry matter (DM) are anticipated with stands of giant cane in the USA.

The objective of this project was to determine DM yields of switchgrass, Giant Miscanthus and giant cane on reclaimed surface mines in West Virginia and Ohio.

Site Descriptions, Materials and Methods

Alton

Field plots were established at the Alton site, a previously surface-mined area of approximately 160 ha located in Upshur County, WV (38°49’01”N 80°11’42”W). The site was mined for the Upper, Middle, and Lower Kittanning coal seams with truck-shovel equipment spreads. Of the total land area, about 30 ha were selected as suitable for potentially producing bioenergy crops. The site was reclaimed in 1985 with less than 15 cm of soil being replaced over the mixed overburden, and standard reclamation practices were employed. Grass and legume species planted were tall fescue (*Festuca arundinacea* L.), orchardgrass (*Dactylis glomerata* L.), birdsfoot trefoil (*Lotus corniculatus* L.) and clovers (*Trifolium* spp.), and the soils were fertilized and limed according to regulations. The site supported a 100% ground cover of herbaceous plants during the ensuing 25 years. The test area of about 10 ha was sprayed with glyphosate herbicide (Roundup®) at recommended rates the previous fall and again in the spring before planting in 2010.

Two varieties of switchgrass, two varieties of Miscanthus, and one variety of giant cane were randomly assigned to 0.4-ha plots in a completely randomized design and replicated five times (except for giant cane with only three) for a total of 23 plots. On June 22, 2010, Kanlow and Bowmaster switchgrass varieties were drilled into the killed sod with an agricultural sod-seeding drill at the rate of 11 kg PLS ha^{-1}. Switchgrass seed (historically certified) was purchased from Ernst Conservation Seeds (Meadville, PA). Two sterile varieties (public and private clonal varieties) of *Miscanthus x giganteus* were obtained from Mendel Bioenergy Seeds (Hayward, CA) and planted as sprigs at a rate of 12,300 plugs ha^{-1} (0.9-m spacing). Giant cane rhizomes were obtained from White Technologies, LLC (Clinton, IN) and planted at a rate of 4,500 rhizomes ha^{-1} (1.5-m spacing). Plot configuration is shown in Fig. 2.

Clippings of switchgrass were taken in October of years 2011 to 2013, two to four growing seasons after planting, at a cutting height of 10 cm in six randomly-placed 0.21-m^2 quadrats in each plot. Miscanthus was also clipped at the same height and times with each clipping being one plant in a 0.81-m^2 area (0.9 x 0.9 m). Giant cane biomass was clipped similarly but only determined in 2012 and 2013, and individual plants were clipped in a 2.25-m^2 area (1.5 x 1.5 m). Biomass was dried at 60°C and weighed to determine DM yield.

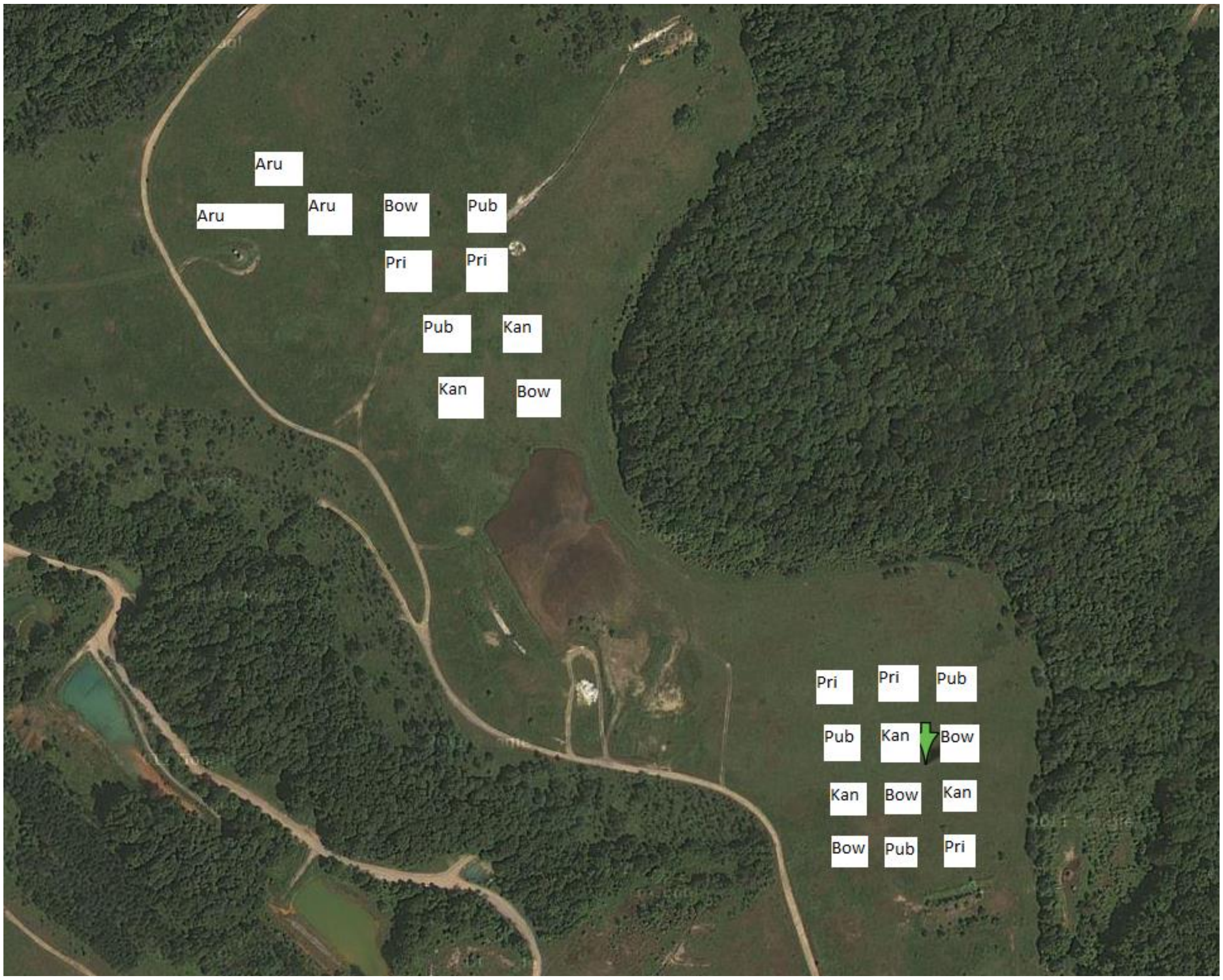


Figure 2. Location of 0.4-ha plots of switchgrass (Kanlow and Bomaster), Miscanthus (public and Private), and giant cane at Alton, WV.

Soil samples were taken in 2009 to a depth of 10 cm at 20 m intervals along a transect that passed through the middle of the 10 ha area. 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).

MeadWestvaco (MWV)

The MeadWestvaco site was chosen as a site where switchgrass was planted on about 8 ha and a small plot of Miscanthus was planted (1117 msle, 38°01'11.87"N 80°35'13.78"W). The cool-season existing vegetation was killed with Glyphosate herbicide in April 2013 and drilled with Cave-in-Rock switchgrass at 12 kg ha^{-1} PLS on June 10, 2013. This site had been reclaimed for approximately 10 years. The switchgrass area was again divided into three sections (Fig. 3) and six soil samples were taken to a depth of 15 cm, while three samples were extracted from the smaller Miscanthus-planted area. Aboveground biomass was clipped as described above: six 0.21 m^2 quadrats in each of the switchgrass sections, and six Miscanthus plants on 11 October 2013. Clipped biomass was dried for three days in large convection ovens at 60°C and weighed to determine dry weight.

The Wilds

The Wilds is a conservation and research center located on nearly 4,000 ha of reclaimed surface-mined land in Ohio donated by American Electric Power in 1984 (323 msle, 39°48'39.78"N 81°43'40.72"W). A large part of the area at The Wilds is used as a wildlife preserve in partnership with the Columbus Zoo and Aquarium. Animals from all over the world, including threatened and endangered species, are brought to The Wilds and allowed to roam on the large expanse of land (Bauman and Cavender, 2011).

Another conservation focus of The Wilds includes restoration of native grass prairies, including grasses for bioenergy production. An 8 ha area was selected for a switchgrass and Miscanthus planting. Soils were composed of dumped overburden material that was graded to approximate contour. A cool-season grass-legume mix of tall fescue, orchardgrass and clovers was seeded. The area was mowed during succeeding decades and soil has developed over time with additions of organic matter that helped to re-establish an organic matter pool and nutrient cycles. In April 2013, the existing vegetation was killed with Glyphosate herbicide at recommended rates. Cave-in-Rock switchgrass was drilled into the killed sod on June 6, 2013 at a rate of 12 kg PLS ha^{-1}. Miscanthus rhizomes from Aloterra Energy (Conneaut, OH) were planted on 0.9-m centers. Excellent stand establishment for both species was noted because of suitable rainfall during the succeeding two months. The 8-ha switchgrass plot was divided into three sections corresponding to aspect and slope (Fig. 4) and six soil samples were withdrawn from each of these three sections to a depth of 15 cm and kept separate for analysis. Samples were analyzed for nutrient elements as stated above. Three soil samples were taken from the area where Miscanthus had been planted with the same procedures and analyzed. Aboveground biomass was taken as described above on October 9, 2013, dried, and weighed.

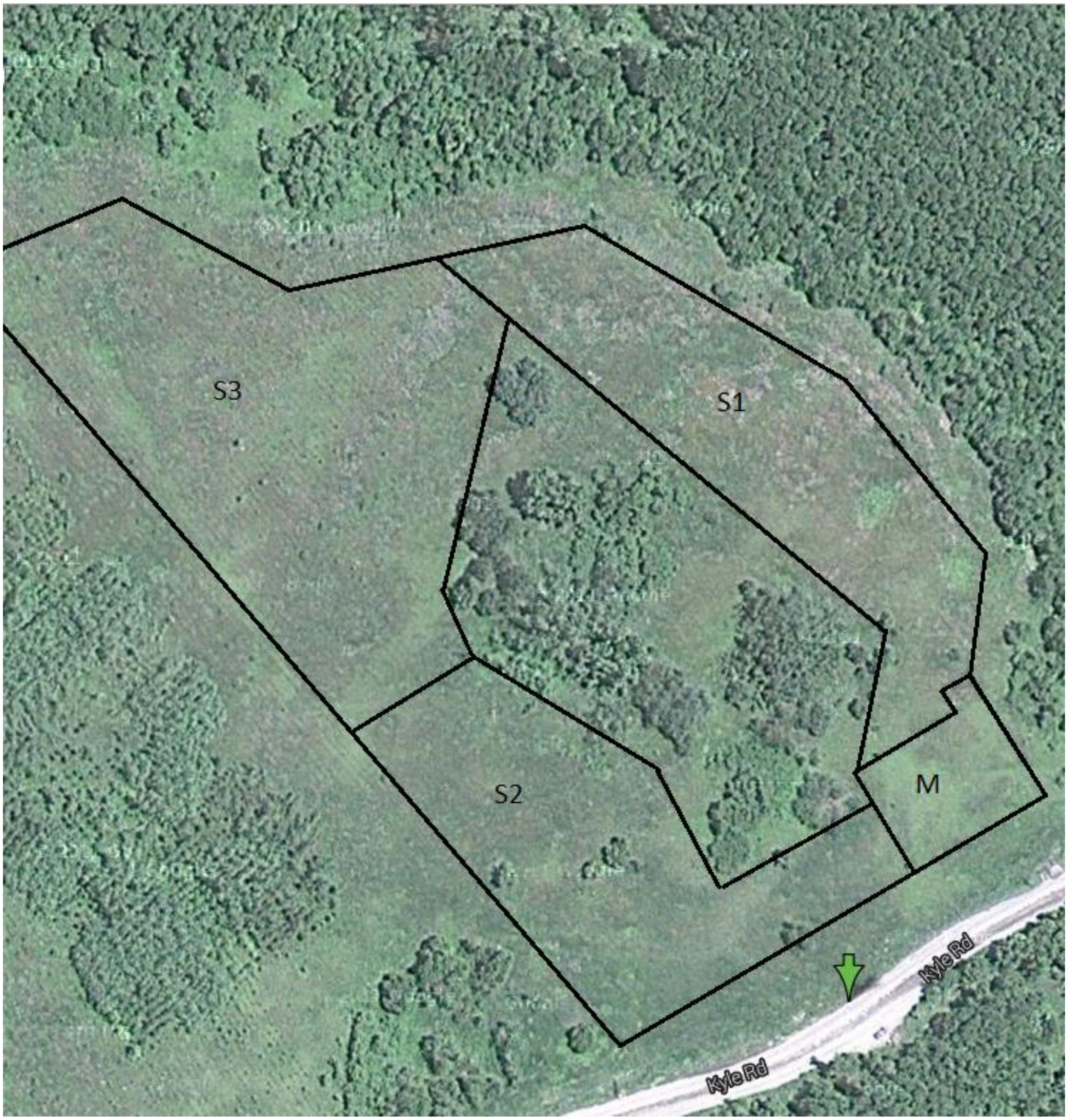


Figure 3. Location of 8-ha switchgrass plot (divided into three sections, S1-S3) and Miscanthus plot (labelled M) at the MeadWestvaco site near Rupert, WV.

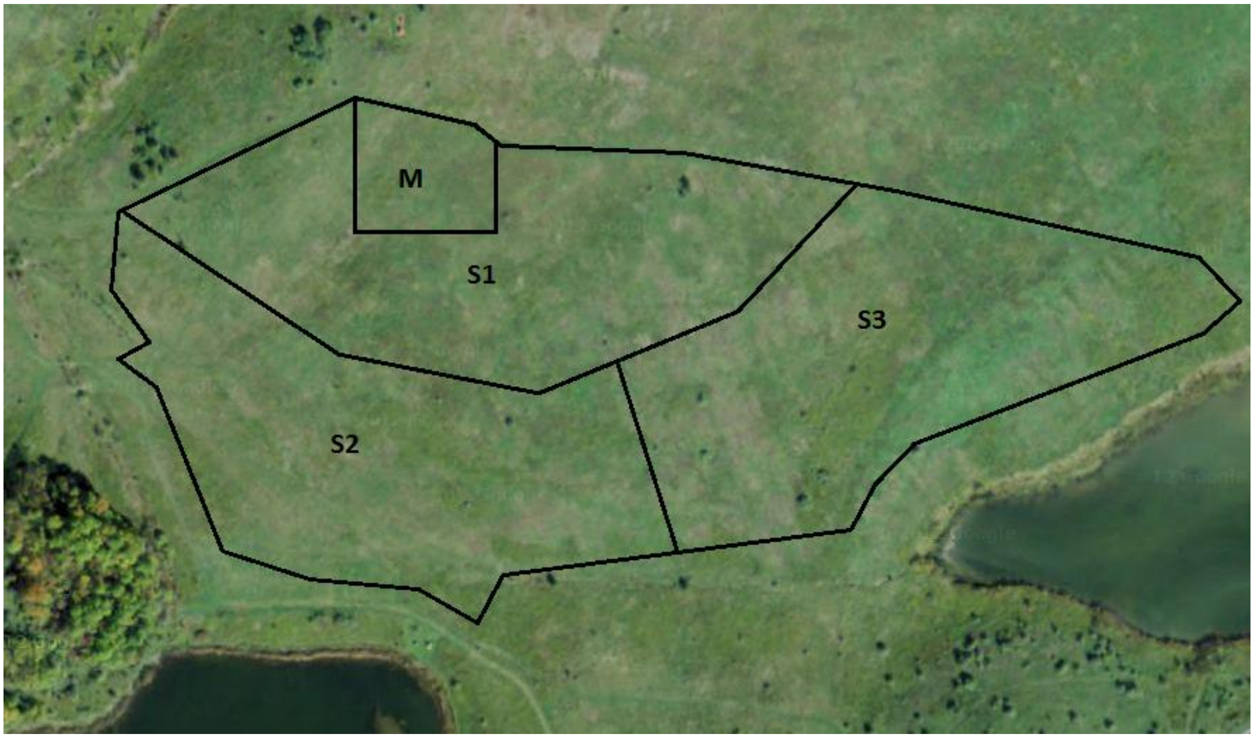


Figure 4. Location of 8-ha switchgrass plot (divided into three sections, S1-S3) and Miscanthus plot (labelled M) at The Wilds site near Cumberland, OH.

Coal Mac

Coal Mac is located on a large surface mine in Mingo, Logan, and Boone counties operated by Coal-Mac, part of Arch Coal, Inc. (37°43'51.81"N 82°04'29.95"W). The site of the planting was leveled and reclaimed with 60 to 90 cm of topsoil and weathered sandstone mixture that was placed over gray sandstone overburden. Miscanthus rhizomes from White Technologies were planted in 0.9 m centers in three 20 x 30 m plots in June 2012. In October 2013, aboveground biomass was clipped from six plants (0.81 m^2) in each of the three plots at 10 cm height. The material was collected, dried at 60°C, and weighed to determine DM yield. Three soil samples were also collected from each plot and composited for analysis.

Results and Discussion

Alton

Soil analysis showed the mine soils at Alton with pH values ranging from 6.5 to 7.2 (Table 2). These mine soils also showed good fertility with 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.

Switchgrass and Miscanthus stands were well established by the end of the second growing season and increased to a consistent stand in the third growing season (Skousen et al., 2013). Kanlow switchgrass produced from 20 to 40% more yield than BoMaster during 2011 and 2012, and DM yields were similar for Kanlow in 2013 compared to 2012. Yields for Kanlow varied from 4,000 to 4,900 kg ha^{-1}, while BoMaster had 2,750 in 2011 and doubled to 5,400 kg ha^{-1} in 2013 (Table 3). Both varieties demonstrated good growth and productivity on surface mines in this area.

Table 2. Average values of chemical properties of mine soils at the Alton site where switchgrass, Miscanthus, and giant cane 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
Arundo	7.3	25.2	0.48	3.4	0.18	7

Table 3. Average DM yields (with standard deviations) of switchgrass, Miscanthus, and giant cane at Alton, WV in October 2011, 2012, and 2013.

Plant Species	2011	2012	2013
		kg ha^{-1}	
Switchgrass			
Kanlow	4,040 (2,643)	4,887 (1,138)	4,963 (3,541)
BoMaster	2,752 (1,381)	3,981 (3,136)	5,415 (9,829)
Miscanthus			
Public	2,248 (2,006)	4,905 (3,002)	7,029 (6,613)
Private	6,553 (5,847)	15,467 (10,447)	11,058 (6,811)
Giant Cane			
Arundo	NA	515 (180)	797 (1,204)

Miscanthus DM yields for the public variety were between 2,000 and 7,000 kg ha^{-1} (Table 3). The private variety of Miscanthus doubled in yield between 2011 and 2012, with a slight decline in 2013. These high yields of 6 to 15 Mg ha^{-1} for the private variety are getting close to yields of 15 to 20 Mg ha^{-1} measured on good agricultural soils (Heaton et al., 2008). These high yields show that marginal lands, like these reclaimed surface mined lands, can grow large quantities of biomass for bioenergy.

Giant cane showed much lower yield at only 515 kg ha^{-1} in 2012, which increased slightly to 800 kg ha^{-1} in 2013 (Table 3). Giant cane did not establish and grow nearly as well as the other two species. Weed competition inhibited the growth and density of giant cane stems. Yield measurements in future years will determine whether this species can expand and produce large amounts of biomass.

<u>MeadWestvaco and The Wilds</u>

Soils at MeadWestvaco had pH values somewhat lower than optimal for switchgrass and Miscanthus growth with values below 6.0 (Table 4). All other nutrients were at suitable concentrations for grass growth. The Wilds had slightly higher pH values in the soils due to the more alkaline overburden that had been brought to the surface during mining. Subsequent leaching and plant growth moderated the pH to levels of around 5.8 to 6.7, which are good for grass growth. Similar to MeadWestvaco, The Wilds soils had good fertility.

Switchgrass at both sites showed good establishment success (Pictures 1 and 2). At the end of the first growing season, DM yields of switchgrass were low with an average of only 752 kg ha^{-1} at MeadWestvaco and slightly higher with an average of 1,045 kg ha^{-1} at The Wilds (Table 5). MeadWestvaco is a much colder and wetter site located at an elevation of almost 1100 meters, while The Wilds is at 323 meters, and so it would be expected that the warmer Wilds site would probably produce greater amounts of biomass with other site factors being equal.

Miscanthus at the end of one growing season showed the same trend with low yields. As mentioned, three growing seasons are needed before switchgrass begins to reach its full potential for biomass, while Miscanthus needs at least two years to produce high yields. These two sites have a good start for biomass growth potential.

Picture 1. Successful establishment of switchgrass at the MeadWestvaco site three months after planting. Milkweeds (*Asclepias* spp.) and ragworts (*Senecio* spp.) were common weeds.

Picture 2. Successful establishment of switchgrass at The Wilds three months after planting.

Table 4. Average values of chemical properties of mine soils at the MeadWestvaco, The Wilds and Coal Mac sites where switchgrass, Miscanthus and giant cane (Arundo) were established.

Site and Plant Species	pH	CEC	Mg	Ca	K	P
		μS cm^{-1}	----- cmol^{+} kg^{-1}		-----	mg kg^{-1}
MeadWestvaco						
Switchgrass						
Plot 1	5.5	11.0	0.54	2.6	0.28	11
Plot 2	5.6	6.6	0.54	1.6	0.17	22
Plot 3	5.8	6.9	0.54	2.1	0.21	35
Miscanthus	5.4	8.2	0.56	1.6	0.20	12
Site Average	5.6	8.2	0.55	2.1	0.22	23
The Wilds						
Switchgrass						
Plot 1	6.7	18.0	0.82	2.5	0.18	13
Plot 2	5.7	11.4	0.48	2.9	0.22	16
Plot 3	6.6	13.0	0.44	2.4	0.15	26
Miscanthus	5.8	20.2	0.45	3.2	0.19	19
Site Average	6.3	14.1	0.58	2.6	0.18	18
Coal-Mac						
Giant Cane	5.5	1.2	0.18	5.1	0.06	35

Table 5. Average DM yields (with standard deviations) of switchgrass and Miscanthus at MeadWestvaco and The Wilds at the end of the first growing season of establishment (2013).

Plant Species	MWV	Wilds
	---------------- kg ha^{-1}	--------------
Switchgrass		
Plot 1	1,111 (887)	258 (169)
Plot 2	473 (390)	1,235 (413)
Plot 3	671 (442)	1,641 (657)
Ave	752 (595)	1,045 (738)
Miscanthus	201 (179)	559 (504)

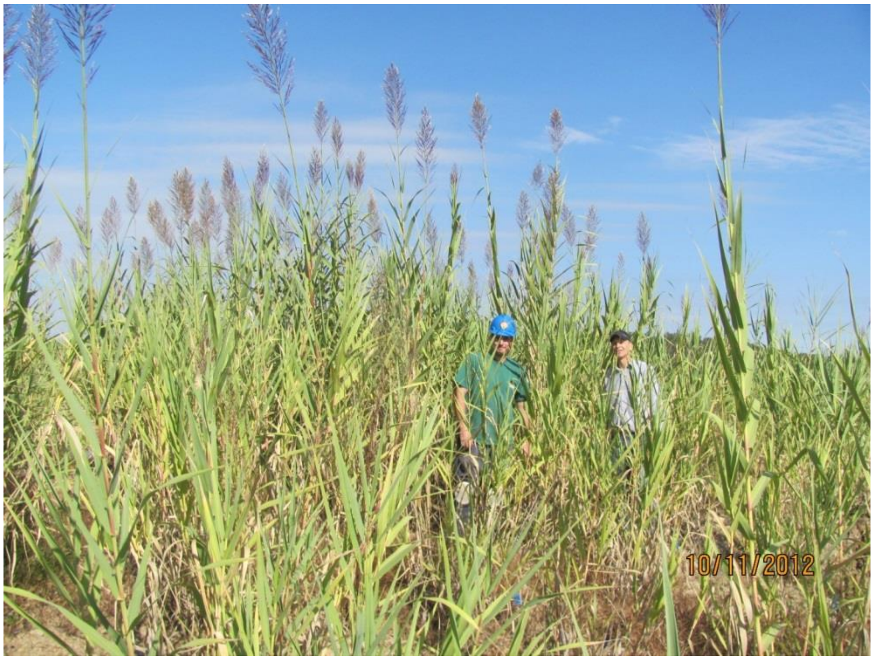
Coal Mac

Soils at Coal Mac had a pH of 5.5 due to the soil being made primarily from sandstone parent material that was slightly acid (Table 4). The coarse texture of the soil is demonstrated by the low CEC of this soil.

Yields of giant cane were modest during the second year of growth in 2011, ranging from 1,900 to 4,100 kg ha^{-1} (Table 6). However, substantial growth occurred during the third year with increases from three to four times, reaching an average of 12.5 Mg ha^{-1} (Table 6 and Picture 3). Very little competition from other weed species have colonized the site due to the poorer soil conditions related to texture, nutrient-supplying capacity, and moisture relations.

Table 6. Average DM yields (with standard deviations) of giant cane (*Arundo*) after the second growing season at Coal Mac. Each value is the mean of six clipping taken in the three plots.

Plant Species	Coal-Mac	
	---------------- kg ha^{-1} ---------------	
	2012	2013
Giant Cane		
Plot 1	2,669	13,266 (7,290)
Plot 2	1,986	7,529 (3,299)
Plot 3	4,113	16,785 (12,031)
Ave	2,930 (1621)	12,527 (8,532)



Picture 3. Giant cane growth after the second growing season at Coal Mac.

Conclusions

Yields of switchgrass at the end of the fourth year at Alton averaged 5,200 kg ha^{-1} for Kanlow and BoMaster switchgrass varieties. Miscanthus DM yield was two times greater than switchgrass during the fourth growing season with an average of about 9,000 kg ha^{-1}. Giant cane DM yield was very low, probably due to weed competition during both years. The newly planted sites at MeadWestvaco and The Wilds showed successful stand establishment after seeding, but low biomass values. Yield increases are expected during subsequent years since it takes up to three years for switchgrass stands to reach 5,000 kg ha^{-1}. Giant cane DM yield at Coal Mac increased by four times to 12.5 Mg ha^{-1} between the second and third growing season.

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