

RECLAMATION OF MINED LAND WITH SWITCHGRASS, MISCANTHUS, AND ARUNDO FOR BIOFUEL PRODUCTION¹

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Abstract: Use of biomass to supplement the nation's energy needs for ethanol production and green fuel for power plants has created a demand for growing reliable feedstocks. Switchgrass (*Panicum virgatum* L.), miscanthus (*Miscanthus x giganteus*), and giant cane (*Arundo donax* L.) are possible biofuel crops because they produce large amounts of biomass over a wide range of growing conditions, including marginal and reclaimed land. West Virginia's climate and large acreage of available reclaimed mine land provide a land base to generate high amounts of biomass for a biofuel industry. The purpose of this study was to determine the yield of three biomass crops on reclaimed mined land in central West Virginia. A 25-year-old reclaimed site near Alton, WV was prepared using herbicides to eliminate all existing cool-season vegetation on a 5-ha area. Twenty-three plots of 0.4-ha in size were established. Mine soil samples showed an average pH of 7.5 and adequate supplies of plant nutrients. Two switchgrass varieties (Kanlow and BoMaster) were randomly assigned to 10 plots (five replications) and seeds were drilled into the killed sod at a rate of 11 kg ha⁻¹. Two types of miscanthus (sterile public and private varieties) were randomly assigned to 10 plots and planted with seedling plugs on 0.8-m centers. Giant cane was assigned to three plots and rhizomes were planted on 1.5-m centers. Yield measurements were taken in September the second and third years after planting. Yields for Kanlow switchgrass varied from an average of 4,000 kg ha⁻¹ in 2011 to 4,900 kg ha⁻¹ in 2012. BoMaster switchgrass was lower at 2,750 kg ha⁻¹ in 2011 and 3,981 kg ha⁻¹ in 2012. The public variety of miscanthus showed yields 7,500 kg ha⁻¹ in 2011, but decreased to an average of 4,900 kg ha⁻¹ in 2012. The private miscanthus variety was much greater at 21,880 kg ha⁻¹ in 2011 and 15,500 kg ha⁻¹ in 2012. Giant cane yields were low with an average yield of 515 kg ha⁻¹ in 2012. Survival and growth of giant cane was hindered by weed competition and poor establishment. Target yields for reclaimed lands, as established by the WV Department of Environmental Protection of 5,000 kg ha⁻¹ for switchgrass and 15,000 kg ha⁻¹ for miscanthus were not attained with switchgrass and the public variety of miscanthus, but was achieved with the private variety of miscanthus. More time may be needed for these yield goals to be achieved as stands continue to develop over time.

¹ Oral paper presented at the 2013 National Meeting of the American Society of Mining and Reclamation, Laramie, WY **Reclamation Across Industries**, June 1–6, 2013 and accepted for the online Journal of The American Society of Mining and Reclamation, Volume 2, No. 1, R.I. Barnhisel (Ed.). Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502

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Journal American Society of Mining and Reclamation, 2012 Volume 2, Issue 1 pp 177-191

DOI: 10.21000/JASMR13010160

Introduction

West Virginia has thousands of hectares of marginally productive, reclaimed coal mined lands. While these lands were successfully reclaimed to the standards of the day, the existing cover of cool-season grasses and legumes does not realize the productive potential of this area for biomass production. These reclaimed mine lands present an opportunity for sustainable energy production. In 2008, West Virginia leaders encouraged the coal industry to develop reclaimed lands to provide feedstock for alternative transportation fuels that would lessen our dependence on foreign oil. Moreover, the Obama administration has also made known its commitment to the development of alternate energy sources and associated “green jobs” that include expansion of the use of biomass. While fossil fuels will continue to serve the majority of West Virginia’s and the Nation’s energy needs, biomass will help in a carbon-constrained environment by producing energy from sunlight and atmospheric CO₂ while sequestering additional CO₂ in below-ground organic matter thereby improving soil quality. Mined lands offer a unique opportunity since <10% of the total land area in West Virginia is used for agricultural purposes (pasture and cropland). The use of reclaimed mined lands provides the land base that could promote an energy-based economy with the use of agricultural products.

The growth of the corn-based ethanol industry has placed added pressure on conventional crop lands and rising agricultural commodity prices will create an opportunity for states like West Virginia who have large areas of reclaimed land (Diffenbaugh et al., 2012). Compared to traditional food crops, plants used for biomass are low-value, require several years to establish, and therefore they are unlikely to compete economically with corn and soybeans on conventional agricultural lands (Walsh et al., 2003). More likely, plants grown for biomass production will be established on marginal agricultural land where production is limited by poor soil properties, drought, cold, short growing seasons, and long distance to markets. Biomass production for most bioenergy crops is favored by a long, warm, and wet growing season. Biomass crops can be grown in areas such as West Virginia where large areas of reclaimed lands and marginal lands exist, where a suitable climate is present for biomass growth, and where the crops can be transported to a large portion of the USA energy market.

Switchgrass

Switchgrass is a highly-productive, native, perennial warm-season grass that has been promoted for biomass-producing potential (Parrish and Fike, 2005). It was one of the primary components of the American Tall-grass Prairie prior to cultivation. Foliage of mature plants is between 1 to 3 m in height and production on agricultural land can be between 8 to 15 Mg ha⁻¹ depending on soil quality and water availability. A number of trials have demonstrated that switchgrass can be successfully grown for biomass (Lemus et al., 2002; Mulkey et al., 2008; Mulkey et al., 2006; Parrish et al., 2008; Schmer et al., 2006; Tober et al., 2007). Yields vary widely depending on edaphic conditions and the location of conducted trials. Schmer et al. (2008) recorded yields ranging from 10 to 20 Mg ha⁻¹ per year across ten farms in the upper Great Plains states. Switchgrass establishment is slow, generally requiring three years to reach full stand establishment. When it senesces in autumn, most of the nutrients and salts are returned to the soil for next year's growth. It also has a dense root system that can grow to a depth of 2 m or more.

Switchgrass should be ideally suited for reclamation because of its hardiness and inherent tolerance to a number of the limiting soil factors on mined sites. Switchgrass has been used in reclamation studies on roadsides (Skousen and Venable, 2008), surface mines (Skeel and Gibson, 1996; Marra and Skousen, 2012; Dere et al., 2011), sand and gravel mines (Gaffney and Dickerson, 1987), lignite overburden (Skousen and Call, 1987), and Pb and Zn mines (Levy et al., 1999). In 2008, switchgrass trials were established for bioenergy production in West Virginia (Marra and Skousen, 2012). They found that switchgrass on reclaimed land with topsoil produced yields of nearly 7,000 kg ha⁻¹, but yields were three times lower (2,000 kg ha⁻¹) on reclaimed lands with no topsoil. Switchgrass can be a successful reclamation species, but only a few studies are available on the ability of switchgrass to produce adequate amounts of biomass for bioenergy production on mined lands.

Miscanthus

Miscanthus is a genus of 15 species of perennial grasses native to Asia and Africa (Hecht, 2011). Certain species have been used in Japan for thousands of years primarily for forage and thatching. Specimens were first collected in the 19th century as ornamental plants and are still planted today because of their aesthetic value. Following the oil crisis of the 1970s, the search for bioenergy crops began (Heaton et al., 2012), and miscanthus was identified for its high-

energy yield per hectare and relative low energy input cost compared to other bioenergy crops (Hastings et al., 2008). The type most commonly grown for biomass is *Miscanthus x giganteus*, which is a sterile hybrid between *M. sinensis* and *M. sacchariflorus* (Heaton et al., 2012). Large stems emerge from rhizomes annually reaching a maximum height of 3 to 4 m and stands persist and remain productive for 15 to 20 years (Hopwood, 2010). The canes themselves sprout from underground rhizomes, which are perennial and tough, and survive in all but the coldest areas of Europe. Giant miscanthus is best suited for areas with at least 70 cm of rainfall per year, but yields will improve with more rainfall up to 170 cm per year. Like switchgrass, the cane senesces in autumn, with most of the nutrients and salts being returned from the canes to the rhizomes below ground for next year's growth. The standing cane's dry matter content will increase over winter, reaching 60 to 90% by the time it is ready to be harvested in February to April. The main feature distinguishing giant miscanthus from other biomass crops is its high lignocellulose content. However, giant miscanthus has traits that make it better suited for thermochemical conversion processes than biological fermentation (Heaton et al., 2012). Miscanthus yield trials were undertaken at 16 locations throughout 10 European countries resulting in yields ranging from 10 to 40 Mg ha⁻¹ (Heaton et al., 2008). Yields in the USA (Illinois) have reached >40 Mg ha⁻¹. Giant miscanthus has the potential to yield more annual biomass than any other major biomass crop except *Saccharum* and *Arundo* species. In small trials at three separate sites in Illinois, giant miscanthus yielded 10 to 16 Mg ha⁻¹, which was two to four times more biomass than switchgrass (Heaton et al., 2008).

Fallen leaf material from miscanthus provides a mulch layer which helps to suppress weeds. The fallen leaf material also recycles nutrients and returns organic matter to the soil (Hopwood, 2010). A study in Germany investigated the long-term effect of cropping 6- to 8-yr-old stands of *Miscanthus x giganteus* to levels of soil organic matter (SOM) in arable soils. The results showed a 0.5% SOM increase on sandy soils and a 0.2% increase on silty soils. Besides an increase in SOM, there was also an increase in cation exchange capacity and carbon content of the soils (Beuch et al., 2000). Miscanthus has a soil carbon equilibrium that is similar to prairie grasslands, which is between 80 to 90 Mg ha⁻¹. However, if grown on soils with a lower initial organic carbon content, miscanthus growth will result in a net accumulation of soil organic carbon (Hastings et al., 2008).

Giant Cane

Giant cane (*Arundo donax* L.) is a tall, perennial cane 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, miscanthus, and giant cane on a reclaimed surface mine in central West Virginia.

Materials and Methods

Field plots were established at the Alton site, a previously surface mined area of approximately 160 ha located in Upshur County, West Virginia (38°49'0074"N 80°11'4283"W). The site was mined for the Kittanning coal seams with truck-shovel equipment spreads. 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. Of the total land area, about 30 ha were suitable for biomass production. 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.

The experimental design was an incompletely randomized design. Two varieties of switchgrass, two varieties of miscanthus, and one variety of giant cane were randomly assigned

and established in 0.4-ha plots, and replicated five times (except for giant cane with only three) for a total of 23 plots. On June 22, 2010, Kanlow and BoMaster switchgrass varieties were drilled into the killed sod by the use of an agricultural sod-seeding drill at the rate of 11 kg ha⁻¹ pure live seed (PLS). The switchgrass seed 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 15,000 plugs per ha (0.8-m spacing). Giant cane rhizomes were obtained from White Technologies, LLC (Clinton, IN) and planted at a rate of 4,500 rhizomes per ha (1.5-m spacing). Both sprigs and rhizomes were planted at a depth of 5 to 7 cm in the mine soil. Plot configuration is shown in Fig. 1.

Clippings of switchgrass and miscanthus were taken in October 2011 and 2012 to determine yield two and three growing seasons after establishment at a cutting height of 8 cm in six randomly-placed 0.25-m² quadrats in each plot. Giant cane biomass was clipped similarly but only in 2012. Biomass was dried and weighed to determine DM yield and converted to Mg ha⁻¹. Rainfall was 155 cm in 2011 and 130 cm in 2012 at the nearest weather station to the site. Precipitation during 2011 and 2012 was within 10% of the average precipitation of 140 cm per year.

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 (<2 mm) 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 M HCl and 0.025 M H₂SO₄). 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).

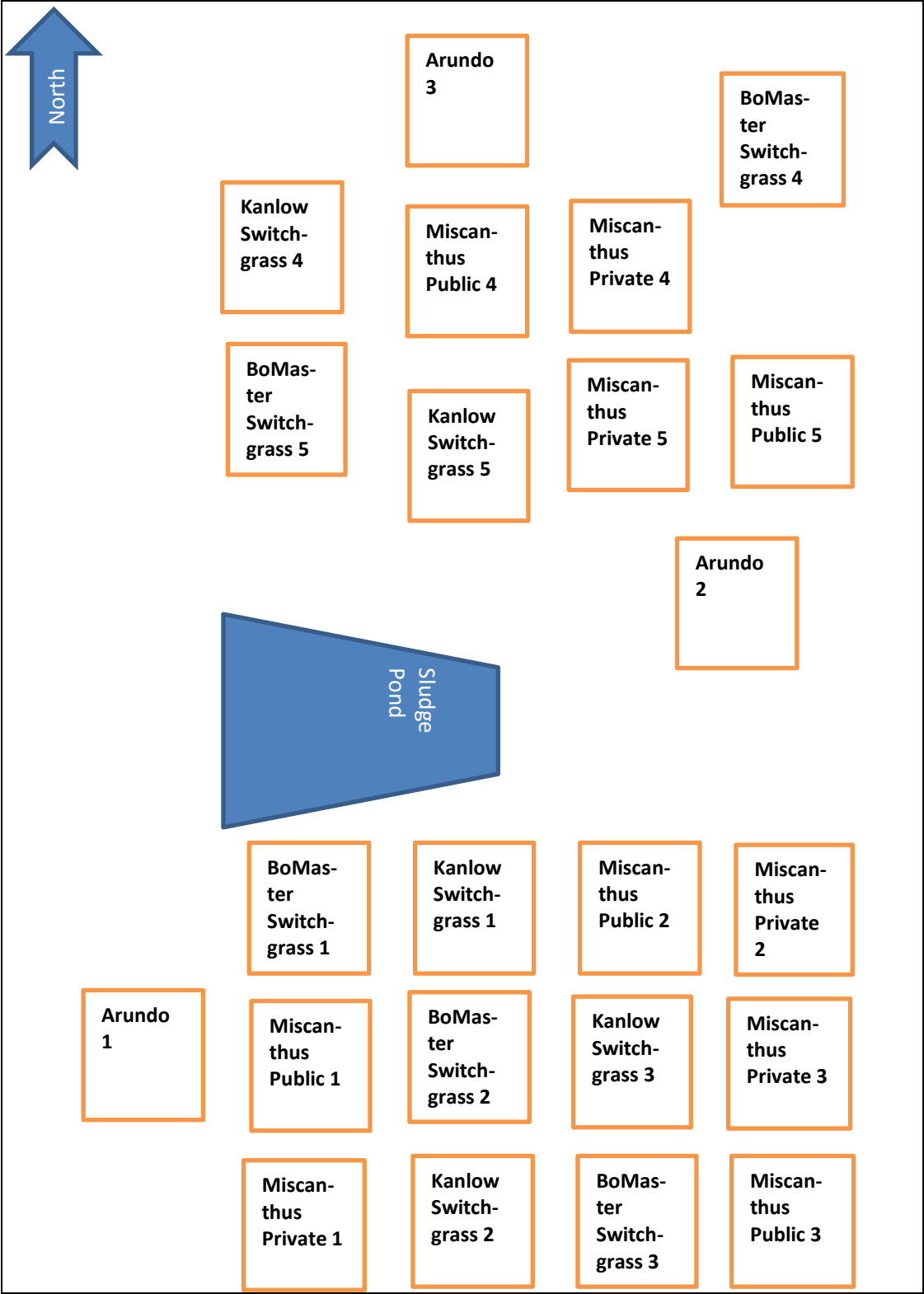


Figure 1. Plot layout for the yield trials at Alton, WV with two varieties of switchgrass, two varieties of miscanthus, and giant cane.

Results

Soil sampling and analysis showed the mine soils at this site to have neutral pH of 6.7 to alkaline pH of 8.0 (Table 1). These mine soils also showed good fertility with medium to high levels of P, K, Ca, and Mg. Soil testing revealed that herbaceous crops like switchgrass and miscanthus should not be hindered by poor soil fertility at this site.

Switchgrass and miscanthus stands were well established after the second growing season and increased to a consistent stand in the third growing season (Pictures 1-3). Kanlow switchgrass produced from 20 to 40% more yield than BoMaster during 2011 and 2012. Dry matter yields for Kanlow varied from 4,000 to 4,900 kg ha⁻¹, while BoMaster produced 2,750 to 4,000 kg ha⁻¹ (Table 2). Both varieties demonstrated during the second and third years after planting that they are suited to this area in West Virginia for good growth and productivity.

Table 1. Chemical properties of mine soils at the Alton site where switchgrass, miscanthus and giant cane were established.

Sample	pH	P	K	Ca	Mg	Base Sat
		mg kg ⁻¹	-----	cmol ⁺ kg ⁻¹	-----	%
1	7.4	25	0.2	2.3	1.1	100
2	6.8	16	0.2	0.9	0.8	98
3	6.7	35	0.2	1.3	0.7	95
4	7.7	21	0.2	2.0	0.5	100
5	7.7	30	0.2	5.0	1.0	100
6	7.6	23	0.2	3.1	0.8	100
7	7.4	14	0.1	4.5	1.8	100
8	7.4	18	0.2	1.4	0.9	100
9	7.3	18	0.1	1.3	1.0	100
10	7.7	18	0.2	4.9	1.6	100
11	7.7	9	0.2	5.6	1.9	100
12	8.0	11	0.2	5.6	1.5	100
13	7.9	15	0.2	5.6	1.3	100
14	7.6	21	0.2	3.9	1.7	100
15	7.4	27	0.1	1.3	1.0	100
Ave	7.5	40	0.2	3.2	1.2	100



Picture 1. Growth of Kanlow switchgrass after the third growing season at Alton, WV.



Picture 2. Tremendous growth of the private variety of miscanthus at Alton, WV, after the third growing season.



Picture 3. Clipping one plant of the private variety of miscanthus at Alton, WV in 2012.

While yields were not quite at the 5,000 kg ha⁻¹ target level for economic feasibility established by the West Virginia Department of Environmental Protection, the target yield will likely be achieved in succeeding years. Weeds were found in appreciable quantities in the stands during the first and second years after planting, but they declined in 2012 as the switchgrass shaded and out-competed the weeds. Switchgrass stands do not develop fully until after the third growing season (Marra and Skousen, 2012). Therefore with less competition from weeds and greater stand density and growth, target yields are anticipated to be reached. These 25-yr-old soils have had organic matter additions from previous vegetation growth, and nutrient cycles have re-established in these soils which has helped to improve soil fertility for these low-maintenance grasses.

Miscanthus yields for the public variety were between 5,000 and 7,500 kg ha⁻¹ and interestingly the yield for 2012 was lower than for 2011 (Table 2). A similar trend was observed with the private variety, showing a yield decline between the second and third years, but it had almost tripled the biomass of the public variety. The tremendous yield of the private variety was similar to miscanthus growth on good agricultural soils (Heaton et al., 2008), which indicates

this variety has great promise to produce high yields on marginal lands like these reclaimed surface mined lands. We are interested to see if the decline in yield from 2011 to 2012 will continue with clippings in 2013.

Table 2. Average dry matter yields (with standard deviations) of switchgrass, miscanthus, and giant cane at Alton, WV in October 2011 and 2012.

Plant Species	2011	2012
	----- kg ha ⁻¹ -----	
Switchgrass		
Kanlow	4,040 (2,643)	4,887 (1,138)
BoMaster	2,752 (1,381)	3,981 (3,136)
Miscanthus		
Public	7,507 (8,254)	4,905 (3,002)
Private	21,880 (22,840)	15,467 (10,447)
Arundo	NA	515 (180)

Giant cane showed much lower yield at only 515 kg ha⁻¹ in 2012 (Table 2). Giant cane did not establish nearly as well as the other two species although height growth was good (Picture 4). Weed competition inhibited the growth of giant cane and the number of stems was reduced as a result of competition. It is also possible that these mine soils are too compact or too clayey for good growth of giant cane since it prefers loose sandy soils. Clippings in 2013 and beyond will confirm whether this species can grow and compete on these reclaimed mine soils.

Conclusions

After the third year, switchgrass and miscanthus showed good growth potential on reclaimed lands. These crops with more time and increasing stand establishment may achieve target yields established by the WV Department of Environmental Protection for economic feasibility. Yields of switchgrass after the third year were nearly 5,000 kg ha⁻¹ for Kanlow switchgrass, and the goal of 5,000 kg ha⁻¹ seems to be attainable in succeeding years. Miscanthus biomass production was three to four times greater than switchgrass, attaining an average of more than 15,000 kg ha⁻¹ with the private variety during the second year, while yields were about one-third with the public variety. Giant cane yield was very low due to poor stand establishment and weed competition. Yields of these three species will be monitored to determine whether sustained yields can be reached with little or no inputs in these mine soils.



Picture 4. Sparse growth of giant cane at Alton, WV after the third growing season.

Acknowledgments

The authors thank Mr. Richard Herd and Dr. Paul Ziemkiewicz, Water Research Institute at West Virginia University, for initiating this project. Thanks also are extended to Mr. Ken Ellison, West Virginia Department of Environmental Protection, for providing funding for this project. We appreciate the help of Mr. Mike Reese and Mr. Bill Snyder for planting seeds/rhizomes and maintenance of the site. We also thank Carol Brown, Trevor Cummings, and Marcus McCartney for field assistance.

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