SWITCHGRASS POTENTIAL ON RECLAIMED SURFACE MINES FOR BIOFUEL PRODUCTION IN WEST VIRGINIA[1]

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Abstract: The high cost and environmental risks associated with non-renewable energy sources has caused an increased development of renewable biofuels. Switchgrass (*Panicum virgatum* L.), a warm-season perennial grass, has been investigated extensively as a source of biofuel feedstock due to its high biomass production on marginal soils. Additionally, the plant's high tolerance to adverse growing conditions and its ability to provide habitat for wildlife makes it a widely used species for conservation cover. West Virginia contains vast expanses of reclaimed surface mine lands and could potentially benefit from the production of switchgrass as a biofuel feedstock. Furthermore, switchgrass production could satisfy Surface Mining Reclamation and Control Act of 1977 (SMCRA) requirements for reclamation bond release to mine operators. This study examined yield of switchgrass stands grown on reclaimed surface mines during the third and fourth years of production. Three varieties were tested on two mine sites to determine which produces the highest yields on reclaimed surface mines in West Virginia. The Hamphire Hill mine site which was reclaimed in the early 1990s using top soil and treated municipal sludge consistently had the highest yields of the two sites (2,566 kg/ha averaged across three years). The other mine site, Hobet 21, was prepared using crushed, unweathered sandstone as the soil material, and yields of switchgrass were 975 kg/ha averaged over three years. Cave-in-Rock variety produced more biomass than the other two varieties, Shawnee and Carthage. A second study to determine optimal nitrogen rates for switchgrass established on newly reclaimed surface mines was launched in June 2011 on two new surface mine sites. Both sites were seeded at a rate of 11.2 kg pure live seed (PLS) ac^{-1} on replicated treatments of 0, 33.6 and 67.0 kg N ha^{-1}. Results showed that a fertilizer treatment of 33.6 kg ha^{-1} and 67.0 kg ha^{-1} at seeding produced a higher yield compared to yields from plots with no fertilizer and the plants looked more vigorous and provided greater ground cover. Plots fertilized with 0, 33.6, and 67.0 kg ha^{-1} produced average yields of 67, 367 and 777 kg ha^{-1}, respectively. No significant difference was found between the high and low N applications.

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Introduction

Use of plants as energy and fuel sources has gone on for millennia. Practices range from the use of wood for heating, cooking and light to more advanced technologies such as converting starch and cellulosic crops to transportation fuels. Currently, energy production from biomass, or plant and other organic materials, has gained considerable interest. In 2010, approximately 1.7% of the energy in the United States was provided by biomass fuels (U.S. Energy Information Administration, 2011). Waning petroleum production, which makes up 94% of consumed transportation fuel in the United States (U.S. Energy Information Administration, Oct 2011), as well as increased environmental concerns associated with fossil fuels have sparked abundant research in the development of bioenergy. This recent growth of renewable energy, in particular, biofuel created from the conversion of plant based material to ethanol, has increased demand for reliable feedstocks.

The majority of the United States' current biofuel demands are met by conversion of corn grain (*Zea mays L.*) to ethanol. Concerns associated with food demands, use of quality farm land to produce fuel rather than food, and energy and carbon balance of bioenergy production has led researchers to examine other biofuel feedstock options. Many perennial herbaceous plants have been evaluated as sources of cellulosic material to be converted to biofuel. Switchgrass (*Panicum virgatum* L.), a warm-season perennial grass native to North America and commonly used as a conservation and forage species, has been investigated extensively as a source of biofuel feedstock. An assessment of several herbaceous feedstocks initiated in the 1980's and conducted by the U.S. Department of Energy (USDOE) led to selection of switchgrass as a "model" bioenergy feedstock (Lynd et al., 1991; McLaughlin and Kszos, 2005).

Switchgrass is a tall, warm-season grass which can grow up to 3 m and forms dense sods over time. It was originally adapted to the tall grass prairie and native stands were most abundant east of 100° longitude (Vogel, 2004). Varieties or cultivars of switchgrass are placed in two distinct ecotypes: upland and lowland. Lowland ecotypes are found on areas prone to flooding and upland ecotypes typically favor drier soils and more semiarid climates. Lowland ecotypes are typically more fibrous and taller than upland (Vogel, 2004). In general, switchgrass tolerates low fertility, persists in acid to moderately alkaline soils, and is tolerant of drought and heat. It is considered the model feedstock of herbaceous energy crops because of its high productivity, wide geographic range, ability to grow on marginal land, and low water and nutrient requirements.

Growing hardy perennial herbaceous energy crops such as switchgrass compared to annual energy crops, such as corn, also offers many environmental benefits. These include: reduced erosion and runoff, which reduces loss of nutrients and organic matter, increased incorporation of soil carbon, which improves soil properties, and reduced use of agricultural chemicals such as herbicides and pesticides (McLaughlin and Walsh, 1998). Switchgrass also has considerably low nutrient requirements because it is a very efficient user of soil nutrients, including N and P.

Along with its ability to provide environmental benefits, switchgrass has potential to produce high yields across a wide range of growing environments. A three-year study conducted by Fike et al. (2006a) showed yields of 14.1 Mg ha^{-1} averaged across four cultivars from eight sites in five southeastern U.S. States, including West Virginia. Similarly, yields as high as 14.9 Mg ha^{-1} were reported from three states located in the Midwestern U.S. (Vogel and Masters, 1998). Yields of over 22.4 Mg dry matter ha^{-1} have also been reported west of the Rocky Mountains on irrigated research plots in Washington (Fransen, 2009). In research plots, switchgrass has potential to produce 22 to 33 Mg ha^{-1} per year, but on a commercial scale 11 to 22 Mg ha^{-1} per year is a more reasonable expectation (Lemus and Parrish, 2009).

The previously mentioned studies, as well as many others, have shown switchgrass can be successfully grown as a biomass feedstock in normal agronomic conditions. Furthermore, because of its characteristics, it has potential to grow on marginal land as well. In fact, studies conducted on switchgrass established and grown on marginal land have shown biofuel production is achievable. Skousen and Venable (2008) established switchgrass along newly-constructed highways in West Virginia, where it achieved good cover and soil stabilization after two years. Schmer et al. (2008) managed switchgrass as a biomass energy crop on marginal cropland on 10 farms and produced annual average yields of 5.2 to 11.1 Mg ha^{-1}.

Growing switchgrass on marginal lands offers a unique opportunity to serve two purposes: biofuel production without offsetting land used for food production and conservation of soil resources. Extensive coal mining in the state of West Virginia produces large expanses of reclaimed surface mines. To encourage proper reclamation practices, the Surface Mining Control and Reclamation Act of 1977 (SMCRA) requires mine operators to post sufficient bond to cover the complete cost of reclamation should a mining operation fail to properly reclaim the land themselves or declare bankruptcy because of coal market conditions. SMCRA also requires mine operators to specify how land will be used after reclamation. Bonds are only released to the mine operator when the land is properly reclaimed and utilized for the specified land use. Mine operators commonly grow cool-season grasses and legumes on disturbed lands because of their quick establishment and aggressive growth for ground cover and erosion control. Reclamation of mined land with cool-season grasses and legumes meets regulation standards to produce a productive post-mining land use, but production of switchgrass as biofuel feedstock could be a more efficient and economical post-mining land use.

Using switchgrass for biofuel feedstock production could be of economic value, especially in West Virginia due to the many acres of land disturbed per year from coal mining and its central location to the U.S. energy markets. Research and information in the area of establishment and management methods, as well as long term production potential of switchgrass grown explicitly on reclaimed surface mines could be a useful commodity to mine operators interested in biofuel production as a post-mining land use. In order for switchgrass to be a viable and economically sound post-mining land use, these research areas require close examination.

Switchgrass is relatively slow to establish. It will typically reach only 33-66% of its production capacity during the first and second years of production (McLaughlin and Kszos, 2005). However, once established switchgrass can grow very well under normal agronomic conditions. Two common problems with switchgrass establishment are seed quality and weed competition (Schmer et al., 2006; Vogel, 2004). Switchgrass seeds are very small compared to annual grains and therefore switchgrass seeds have little reserves for germination. Planting seeds of good quality and with a high percentage of germinable seeds are important when establishing stands. Wolf and Fiske (1995) recommend seeding rates of 8.9 to 11.2 kg pure live seed (PLS) ha^{-1}. Teel and Barnhart (2003) recommend slightly lower rates of 5.6 to 6.7 kg PLS ha^{-1}. Seedbeds should be firm and seeds should be planted at a depth of 0.6 to 1.2 cm to ensure good soil to seed contact (Teel and Barnhart, 2003; Wolf and Fiske, 1995). Coarse textured and low fertility mine soils are typically considered to have poor physical and chemical soil properties for plant growth. Besides purchasing seed with a high germination rate and minimizing weed competition, sound establishment practices need to be developed in order to successfully produce switchgrass on reclaimed mine soils.

When managed as a biomass feedstock, maximum yields while maintaining long-term stands with few inputs is desirable for switchgrass. This leads to the need for understanding harvest management requirements for switchgrass grown on reclaimed mine soils. Switchgrass has potential to be harvested several times during the growing season or once at the end of the season. Maximum yields of 10.5 to 12.6 Mg ha^{-1} per year were recorded in the Midwest when the variety Cave-in-Rock was harvested once per growing season during anthesis (flowers are shedding pollen) (Vogel, 2004). Conversely, Fike et al. (2006b) found yields increased with a two-harvest management system compared to a one-harvest management system when data were averaged across eight switchgrass sites in five states. In fact, this study also showed the two upland cultivars used in the study (Cave-in-Rock and Shelter) had a 38% increase in yield when harvested twice per year. Vogel et al. (2002) found the optimal time to harvest switchgrass for biomass in the Midwest was during the reproductive stage at the R3 to R5 stage of maturity (panicles fully emerged to post-anthesis; Moore et al., 1991) and sufficient regrowth may be obtained for a second harvested after a killing frost.

Switchgrass is capable of producing high yields from long term stands. Yields from production years six though nine conducted by Fike et al. (2006b) averaged 14.2 Mg ha^{-1}. Once established, switchgrass has potential to produce stands up to 10 years old, however multiple harvests per growing season may decrease stand longevity. Harvesting at the end of the growing season when minimal regrowth is likely to occur will preserve carbohydrate reserves used for tiller production the following growing season (Casler and Boe, 2003). Late in the growing season, N is remobilized from the above ground biomass to the stem bases, crowns, or roots of switchgrass plants harvested after a killing frost (Vogel et al., 2002). Determining appropriate harvest management techniques and knowledge of production potential over time for switchgrass grown on reclaimed mine soils could help mine operators maximize yields and increase stand longevity.

This project was designed to study biomass production and soil physical and chemical properties of switchgrass stands grown on reclaimed surface mines in West Virginia. The first and second years of growth on two mine sites were used to determine the feasibility of establishing three switchgrass varieties on recently-mined lands. Results of these first two years of research showed switchgrass was successfully established with both a hand broadcast seeder and by hydroseeding techniques. Switchgrass grown on older reclaimed land and amended with lime-treated municipal sludge had higher yields compared to switchgrass grown on fresh mine spoil with no amendments (Keene and Skousen, 2009).

Biomass production results of the two previous years of study also showed that Cave-in-Rock was the most productive for the study areas. In fact, Cave-in-Rock continually produced highest yields at both sites and switchgrass grown on finer-textured soil amended with biosolids produced higher yields than switchgrass grown on mine soils composed of unweathered materials with high rock fragment content. Using this information from the two original switchgrass studies, additional research experiments were established to examine harvest management and new establishment techniques.

This paper reports on yields of three switchgrass varieties in years two through four of switchgrass production planted on two reclaimed surface mines in West Virginia. One- and two-harvest management systems for switchgrass production on reclaimed surface mines were compared. Soil chemical and physical properties on these sites were determined to examine relationships to production on these sites. Studies established on two other sites determined the effects of fertilizer and mulch applied during seeding of switchgrass on newly-reclaimed surface mines. These studies will help evaluate best practices in establishing switchgrass on reclaimed surface mines.

Methods

Site Locations:

Two mine sites were used to determine yields of three varieties of switchgrass and both were established in 2008, Fig. 1. The Hobet 21 site, located on a large surface mine in Boone and Kanawha counties operated by Hobet Mining Company, was prepared by planting the varieties on 1-m of crushed, unweathered rock material overlaying compacted overburden material. The Hampshire Hill site is located on a small contour mine in Mineral County. Mining at Hampshire Hill stopped in 1998 and the site is currently managed by the Upper Potomac River Commission. The site was reclaimed by overlaying the mined overburden with a 30-cm layer of top soil. Lime-treated municipal sludge from the Westernport, MD municipal wastewater treatment facility was then placed over the topsoil at a rate of 225 Mg (dry) ha^{-1} (Keene and Skousen, 2009). Additional treatments of sludge from the wastewater treatment facility were applied in 2003 and again in 2008 before planting.

For the second study, two new sites were selected and planted in June 2011. The first site is located on the Coal-Mac Phoenix #5 surface mine located in Mingo and Boone Counties and operated by Coal-Mac, a subsidiary of Arch Coal, Inc. This mine is a large mountaintop removal mine that utilizes large power shovels to remove overburden. The site location was leveled and prepared by Coal-Mac operators prior to planting. A 60- to 90-cm layer of top soil and weathered sandstone mixture was placed on leveled gray sandstone overburden. The second new site is the Black Castle surface mine operated by Black Castle Mining Company and owned by Alpha Natural Resources. Black Castle is also a large mountaintop removal mine and is located in Boone County, WV. This site was leveled and prepared by Black Castle operators by placing a 20- to 30-cm layer of topsoil mixed with crushed weathered rock over unweathered overburden.

Figure 1. Locations of research sites in West Virginia.

Experimental Design:

In 2008, three varieties of switchgrass were planted at Hampshire Hill and Hobet 21 mine sites. The varieties, Cave-in-Rock, Carthage, and Shawnee, were planted in 0.4-ha plots replicated three times for a total of nine plots per site. Each 0.4-ha plot was randomly assigned one switchgrass variety and seeded at a rate of 11.2 kg PLS ha^{-1} using a hand broadcast seeder (Keene and Skousen, 2009). These same plots will continue to be used for the first study.

Biomass was collected from each plot to determine annual yields at Hobet 21 and Hampshire Hill. Biomass was determined by randomly placing a 0.21-m^2 quadrat within 1 m of each sampling location and clipping all switchgrass within the quadrat. In a critical review of publications examining the biology and agronomy of switchgrass conducted by Parrish and Fike (2005), clipping height or stubble height was one of many management practices summarized. In the review, stubble heights ranged from 5 to 30 cm. In general, the review indicated that 1) more biomass was collected when clipped to a lower stubble height, 2) more regrowth in multiple harvest systems occurred when stubble height was higher, and 3) clipping at a lower stubble height typically resulted in better stand persistence. For this experiment, switchgrass within the 0.21-m^2 quadrat was clipped at approximately 10 cm with the goal to collect the maximum amount of biomass without clipping at ground level. Stand persistence is not a concern since samples will be taken from a small proportion of the entire plot. The clipped samples were then oven dried at 60º C to a constant weight to determine dry weight.

Beginning in 2011, at Hobet 21 and Hampshire Hill, biomass was collected to represent two harvest management types. Switchgrass was clipped from six locations in each plot at the midpoint of the growing season (mid-July before flowering) at six randomly-selected points. At the end of the growing season (early-October), the regrowth was clipped from the same points. Total yield was determined by combining the oven-dried weights of both biomass samples. The one-harvest system samples were collected at the end of the growing season only (post-anthesis). One- and two-harvest system clipping locations were within 3 m of each other. All samples were collected by clipping all switchgrass to 10 cm stubble height within a 0.21-m^2 quadrat, oven dried at 60º C to constant weight, then weighed.

For the second study, four treatments were examined to determine establishment methods for growing switchgrass (Cave-in-Rock) on freshly reclaimed surface mines in West Virginia at

Coal-Mac and Black Castle mine. A randomized complete block design with five replications was used as the experimental design. Each block was 0.4 ha with four treatments randomly assigned in each block. The corners and center of each 0.4-ha plot were marked with steel T-posts. Additionally, the halfway point of each side were marked with flags, which divided each 0.4-ha plot into four sections.

West Virginia Surface Mining Reclamation Regulations require a minimum of 67 kg N ha^{-1} and 560 kg ha^{-1} of mulch be applied to disturbed areas (WVDEP §38-2-9., 2002). The four treatments used for this experiment are based on two levels of N fertilizer and two application rates of a wood cellulose hydromulch. The four treatments are: 33.6 kg N ha^{-1} and a light application of hydromulch; 67 kg N ha^{-1} and a light application of hydromulch; 33.6 kg N ha^{-1} and a heavy application of hydromulch; and a control which received no N fertilizer and a light application of hydromulch.

Using a Solo 421-S Portable Spreader, seed was applied at a rate of 11.2 kg PLS ha^{-1} to each plot. Fertilizer was spread evenly by hand. The hydromulch was applied by mine operators after each plot had been fertilized and seeded. Once an entire 0.4-ha plot received an even coat of hydromulch, additional mulch was spread on the subplot assigned to receive the heavy hydromulch treatment. Light mulch treatments received approximately 1.7 Mg ha^{-1} and heavy mulch treatments received approximately 3.0 Mg ha^{-1}. Biomass samples were taken at the end of the growing season in order to determine total yield after one full growing season. Frequency and percent cover of switchgrass were measured in 2011. The percent ground covered by switchgrass was estimated using a modified Daubenmire method (Daubenmire, 1956) and a specific class was assigned by placing a 1.0-m^2 quadrat at each randomly selected sampling point, Fig. 2. Seven coverage classes were used (0-1%, 2-5%, 5-25%. 25-50%, 50-75%, 75-95% and 95-100%). Frequency was estimated by placing a 0.25-m^2 quadrat at each cardinal direction of each random sample point. Frequency was calculated by determining the proportion of quadrats within a treatment that have at least one switchgrass plant.

Soil Sampling and Analysis:

Soil samples were collected at all four sites and analyzed for soil chemical and physical properties. Samples were collected once annually during the growing season. Soil samples were collected from six sample locations within each plot at Hobet 21 and Hampshire Hill.

Figure 2. Percent cover measured using modified Daubenmire Method.

Three soil samples were collected from each subplot at Black Castle and Coal Mac sites. Soil sample locations were randomly selected and soils were collected to a depth of approximately 15 cm. Using the collected coordinated data and a GPS receiver, soil samples can collected from approximately the same location annually.

Samples were air dried, weighed, and sieved with a US #10 2 mm sieve. The fine fraction (sample fraction <2-mm) was collected and used for chemical analysis. The rock fraction (>2-mm) was collected, washed through a US #10 2 mm sieve, air dried and reweighed to determine the portion of the sample made up of rock fragments on a dry weight basis.

Using the fine portion of each sample, the following soil chemical data were determined on all sites: pH, electrical conductivity (EC), and available nutrients. To determine pH, 5 g of soil were combined with 5 mL of distilled de-ionized (DDI) water. The mixture was placed on an orbital shaker table and mixed for 15 minutes, then allowed to equilibrate for at least 1 hour. A Mettler Toledo SevenEasy pH Meter was used to take the pH readings. EC was determined by combining 5 g of soil with 10 mL DDI water. The mixture was placed on an orbital shaker table and mixed for 15 minutes, then allowed to equilibrate for at least 1 hour. An Amber Science Inc. Digital Conductivity Meter was used to take EC readings.

Mehlich 1 solution, also referred to as Dilute Double Acid solution, composed of 0.0025 *N* H_2S0_4 + 0.05 *N* HCL was used to extract available elements from the soil (Wolf and Beegle, 1995). For the extraction, 25 mL of the Mehlich 1 solution was added to 5 g of soil, mixed on an orbital shaker for 5 minutes, then allowed to equilibrate. The samples were then filtered through Whatman No. 2 filter paper. Using a Perkin Elmer inductively coupled plasma emission spectrometer, the filtrate was analyzed for available nutrients: Al, Fe, Mn, Mg, Ca, K, P, Ni, Cu, and Zn.

Results

Soil Physical and Chemical Properties

Hampshire Hill and Hobet 21 both had soils with low contents of % fines and high rock fragment contents (material >2mm in size), which is typical for mine soils in West Virginia (Table 1). However, Hobet 21 contained significantly lower % fines than Hampshire Hill. Both sites consistently had a pH slightly above neutral and Hampshire Hill consistently had a higher electrical conductivity compared to Hobet 21, which was due to multiple applications of lime treated municipal sewage sludge prior to planting.

Table 1. Physical and chemical soil characteristics at Hobet 21 and Hampshire Hill.

	Hobet 21				Hampshire Hill			
	2008	2009	2010	2011	2008	2009	2010	2011
% Fines†	55	58	59	55	77	81	76	74
pH	7.3	7.8	7.8	8.0	7.2	7.3	7.5	7.4
EC (µS)	187	69	218	109	1245	381	785	421

† Calculated as the percentage dry weight of sample material <2mm in size.

Concentrations of available nutrients (Table 2.) revealed that Hampshire Hill had higher Ca levels compared to Hobet, which were due to the multiple treatments of lime treated municipal sewage sludge. However, extractable P at Hobet was consistently higher than Hampshire Hill.

Table 2. Mehlich 1 extractable soil nutrients at Hobet 21 and Hampshire Hill.

	Hobet 21				Hampshire Hill			
	2008	2009	2010	2011	2008	2009	2010	2011
	----------cmol charge/kg soil ----------							
Mg	1.4	1.7	1.4	1.3	1.8	1.6	1.5	1.3
K	0.1	0.1	0.1	0.1	0.3	0.2	0.4	0.2
Na	0.05	0.04		0.03	0.4	0.06		0.03
Ca	3.1	3.0	2.5	2.0	30.7	25.5	22.2	22.7
	----------mg/kg soil----------							
Al	59	40	44	31	104	86	132	98
Fe	123	126	73	52	59	21	25	22
Mn	46	55	39	29	173	63	78	49
P	53	33	53	50	4.6	2.7	11.8	8.0
Ni	1.3	1.0	1.1	0.9	0.4	0.5	0.6	0.4
Cu	2.3	2.2	1.8	1.9	2.7	1.7	1.8	1.4
Zn	2.7	3.2	2.7	2.4	8.6	7.4	7.8	6.7

Black Castle was slightly more acidic than Coal-Mac with a pH of 5.7 compared to 6.0, respectively (Table 3.). Both sights contained about 55% fines, with relatively high rock fragments, which is expected at newly reclaimed mine sites. Additionally, Black Castle had a higher EC.

Table 3. Physical and chemical soil characteristics at Black Castle and Coal Mac.

	Black Castle	Coal-Mac
% Fines†	53	56
pH	5.7	6.0
EC (μS)	843	166

† Calculated as the percentage dry weight of sample material <2mm in size.

With the exception of sodium, Black Castle contained greater levels of all measured extractable nutrients compared to Coal-Mac (Table 4), which is consistent with the higher EC values. Greater extractable nutrient content and EC could be due to differences in top soil quality added to the Black Castle mine site during site preparation.

Table 4. Mehich 1 extractable soil nutrients at Black Castle and Coal-Mac

	Black Castle	Coal-Mac
	----cmol charge/kg soil ----	
Mg	1.95	0.17
K	0.27	0.10
Na	0.05	0.05
Ca	3.10	0.20
	----mg/kg soil----	
Al	56.5	5.72
Fe	34.2	1.95
Mn	79.5	1.91
P	10.9	0.51
Ni	0.82	0.02
Cu	1.29	0.18
Zn	1.97	0.14

Vegetation Measurement

The results of a repeated measures analysis of variance (ANOVA) used at Hamshire Hill and Hobet determined the main effect, site, was significant (p<001) for yield. Across three years and including variety, the Hampshire Hill site produced 5760 kg ha^{-1} compared to 803 kg ha^{-1} at Hobet 21. Results also determined year was a main effect indicating yield changed year to year from 2009 to 2011, which was expected. Yield data, averaged across site and variety, increased from 2359 kg ha^{-1} in 2009 to 4457 kg ha^{-1} in 2010, but decreased to 3028 kg ha^{-1} in 2011 (Table 5).

Table 5: Switchgrass biomass yield by year averaged across sites and varieties.

Year	Yield (kg ha^{-1})†
2009	2359 ^{A*}
2010	4457 ^{B}
2011	3029 ^{C}

† Year contrasts were based on square root transformed data.
* Different letters within a column denote significance at p<0.05 level.

The main effect, variety, also showed a significant effect (p=0.0025) with Carthage appearing to be the worst performer when comparing average biomass yields across site and year

(Table 6). No significant difference was found when comparing Shawnee to Cave-in-Rock (Table 6). However, a site*variety interaction indicated that switchgrass production varied between the Hampshire Hill and Hobet 21 sites.

Table 6: Switchgrass yield by variety averaged across sites and years.

Variety	Biomass Yield (kg ha^{-1})†
Cave-in-Rock	3130 ^{A*}
Carthage	1850 ^{B}
Shawnee	2516 ^{A}

† Variety contrasts were based on square root transformed data.
* Different letters within a column denote significance at p<0.05 level.

Cave-in-Rock outperformed Carthage and Shawnee, and no significant difference was found between Carthage and Shawnee at the Hampshire Hill mine site (Table 7). Hobet 21 differed from Hampshire Hill in that Shawnee was the top performer and Cave-in-Rock and Carthage showed no significant difference (Table 7).

Table 7. Switchgrass yield by variety and site averaged across years.

Variety	Hampshire Hill†	Hobet 21†
	-----------------------------kg ha^{-1}	---------------------------
Cave-in-Rock	7853 ^{A*}	743 ^{A}
Carthage	4377 ^{B}	581 ^{A}
Shawnee	5051 ^{B}	1086 ^{B}

† Variety contrasts were based on square root transformed data.
* Different letters within a column denote significance at p<0.05 level.

Examining averages within years and within the one- and two- cut system for 2011; Cave-in-Rock produced the most biomass at both sites, while Carthage produced the least. Cutting once at the end of the growing season at Hobet 21 produced more biomass than utilizing a two-cut system (Table 8). The first cut taken in July produced the majority of the two-cut system total yield, and the second cut added very little.

Table 8. 2011 one- and two- cut system biomass totals for Hobet 21.

Hobet 21				
	1st Cut	2nd Cut	2-cut system total	1-cut system total
	--	--kg ha^{-1}	--	
Cave-In-Rock	592	85	677	1094
Carthage	494	108	602	893
Shawnee	490	115	605	838

No statistical difference was found between varieties within harvest treatments at Hobet.

Yield collected in the two-cut system proved to be advantageous at Hampshire Hill, specifically for Cave-in-Rock and Shawnee (Table 9). Both varieties produced more biomass when harvested with a 2-cut system compared to harvesting once at the end of the growing season. Similar to the results found at Hobet 21, biomass collected from the second harvest of the 2-cut system was very low compared to the biomass collected from the first harvest.

Table 9. 2011 one- and two- cut system biomass totals for Hampshire Hill.

Hampshire Hill				
	1st Cut	2nd Cut	2-cut system total	1-cut system total
	--	--kg ha^{-1}	--	
Cave-In-Rock	7227^{A}	1219^{A}	8446^{A}	7822^{A}
Carthage	1869^{B}	374^{A}	2243^{B}	2964^{B}
Shawnee	4278^{AB}	599^{A}	4877^{AB}	4476^{B}

Letters denote statistical difference at ($p<0.5$) between varieties within harvest management system.

For the second study, we established new switchgrass plantings at two sites. Percent cover and frequency after the first growing season at Black Castle and Coal Mac both showed adequate cover and frequency with application of fertilizer. Plots treated with fertilizer, at either application rate, had, on average, higher frequency compared to control plots. Plots receiving no fertilizer and a light hydromulch application had a cover and frequency of <1% and approximately 63%, respectively. Frequency of plots receiving either 33.6 or 67.0 kg ha^{-1} fertilizer had a frequency ranging from 78 to 93%. Percent ground covered by switchgrass varied between 0.5 to 20%, likely due to the patchy growth habits of immature switchgrass stands.

A two-way ANOVA was used to examine yield response to main effects, site and treatment. Both main effects were significant at p-value <0.05 and there was no interaction between main effects. Averaged across treatment, Black Castle experienced higher yields compared to Coal-Mac with yields of 570 kg ha^{-1} and 248 kg ha^{-1}, respectively. Examination of treatments, which consisted of varying levels of N fertilizer and hydromulch application, revealed yields improved N fertilizer amendments. Averaged across sites, yields for the 0 fertilizer, 33.6 kg N ha^{-1} (plus light mulch), 67 kg N ha^{-1} and 33.6 kg N ha^{-1} (plus heavy mulch) were 67 kg ha^{-1}, 362 kg ha^{-1}, 777 kg $ha^{-1}$and 375 kg ha^{-1}, respectively. The treatment receiving no fertilizer and a light application of hydromulch was significantly different than the other treatments receiving N application. No significant difference was found between means of the three treatments which received N.

Table 10. Treatment yields at Black Castle and Coal-Mac.

Treatment	Yield		
	Black Castle	Coal Mac	Average Across Site
	--------------------------------- kg ha^{-1} ----------------------------------		
No fertilizer; light mulch	17	116	67^{B}
33.6 kg N ha^{-1}; light mulch	447	278	362^{A}
33.6 kg N ha^{-1}; heavy mulch	495	255	375^{A}
67 kg N ha^{-1}; light mulch	1212	341	777^{A}

Letters denote statistical difference at (p<0.5) between varieties within harvest management system.

Discussion

Yield production from three and four year old switchgrass stands showed that mine sites can provide adequate yields for biofuel production. Hampshire Hill, an older reclaimed mine site which utilized lime-treated municipal sludge as an input, outperformed Hobet 21 mine site. Hampshire Hill, which contained a higher percentage of fine material as well as higher extractable nutrients, more resembles normal agronomic conditions compared to Hobet 21. Significance within the interaction of the main effects, site and variety, showed that site characteristics at each site were more suited for a certain variety than another when grown on reclaimed surface mines. The three upland varieties used in this study are common and commercially available, but Cave-in-Rock produced the highest yield at the more fertile Hampshire Hill site. Shawnee, an improved variety of Cave-in-Rock, outperformed the other varieties at the less fertile and coarser textured Hobet 21 site. The Carthage variety was the worst performer at both sites.

Less anticipated was the decline of yield between the years 2010 and 2011. From 2009 to 2010, yields increased at both sites. A brush hog was used to mow all plots at Hampshire Hill in spring 2011. All cut debris was left on the surface. Mowing switchgrass after the third growing season should not have had a detrimental effect on total yield at Hampshire Hill and rainfall was above average, so it is not clear why it decreased. Further monitoring may give an indication of the problem for decreasing yield. We did observe that the heavy growth simply layed on the surface and may have had a negative impact due to covering the new growth and hence hindered regrowth of switchgrass in 2011. If this material had been removed from the site as in a conventional haying operation, the heavy cover of debris and dead material on the surface would not have hampered the regrowth of switchgrass at Hampshire Hill.

The two-cut harvest system had greater yields at the more fertile Hampshire Hill site compared to Hobet 21. The less fertile and more coarse textured Hobet 21 mine site had decreased yield when harvesting twice per growing season. Since Hobet 21 was reclaimed in a manner more typical to mining practices in West Virginia, it indicates that a multiple harvest system may not give the greatest yield for switchgrass stands grown on reclaimed surface mines.

In the second study, results showed establishment of switchgrass on a newly-reclaimed mine site can be improved with an N fertilizer amendment. Increased frequency and yield were observed when applying fertilizer at a rate of 33.6 kg ha^{-1} and 67 kg ha^{-1} compared to the control which received no fertilizer. No significant difference was found between the different levels of fertilizer treatment indicating that a minimum level of fertilizer may suffice for switchgrass establishment. Additionally, this objective examined high and low hydromulch treatments and found no increase in yield by applying a heavier application of mulch after seeding.

Conclusion

Based on findings from this study and previous research, switchgrass is capable of producing adequate yields on reclaimed surface mines. Along with site preparation and seeding rate, special attention to variety selection, N application as well as the use of hydromulch will improve chances of good establishment and persistent yields. As seen in the first study, variety selection can affect yield. Out of the varieties selected for this study, Cave-in-Rock and Shawnee were the best performers on mine sites in this area. Originally, Cave-in-Rock was selected to be used for the second study based on its outperformance of Shawnee and Carthage during the first two years of growth at Hobet and Hampshire Hill. However, based on findings from 2011, it appears Shawnee may be better suited for lower fertility sites. Further investigation of growth at Hobet 21 and Hampshire Hill will determine long term yields. The second study determined that higher levels of N (67 kg ha^{-1}) were not required to produce adequate frequency and yield compared to 33.6 kg N ha^{-1}. Although no effect was found between high and low levels of hydromulch application , mulching likely improves seed to soil contact, covers the soil, and helps to provide moisture to the seed during establishment.

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References:

Casler, M.D. and A.R. Boe. 2003. Cultivar x environment interactions in switchgrass. Crop Science 43: 2226-2233. http://dx.doi.org/10.2135/cropsci2003.2226.

Daubenmire, R. 1956. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

Fike, J.H., D.J. Parrish, D.D. Wolf, J.A. Balasko, J.T. Green, Jr., M. Rasnake and J.H. Reynolds. 2006a. Long-term yield potential of switchgrass-for-biofuel systems. Biomass and Bioenergy 30:198-206. http://dx.doi.org/10.1016/j.biombioe.2005.10.006.

Fike, J.H., D.J. Parrish, D.D. Wolf, J.A. Balasko, J.T. Green, Jr., M. Rasnake and J.H. Reynolds. 2006b. Switchgrass production for the upper southeastern USA: Influence of cultivar and cutting frequency on biomass yields. Biomass and Bioenergy 30:207-213. http://dx.doi.org/10.1016/j.biombioe.2005.10.008.

Fransen, S. 2009. Agronomics of switchgrass for biofuel in the west. *In* Proceedings, 2009 Western Alfalfa and Forage Conference, December 2-4, 2009. Reno, Nevada.

Keene, T. and J. Skousen. 2009. Switchgrass production potential on reclaimed surface mines in West Virginia. Abstract In R.I. Barnhisel (ed.) Proceedings, 26th meeting, American Society for Mining and Reclaimation, May 30 –June 5, 2009. Billings, Montana.

Lemus, R. and D.J. Parrish. 2009. Herbaceous crops with potential for biofuel production in the USA. CABI Reviews: Perspective in Agriculture, Veterinary Science, Nutrition and Natural Resources 4:1-23. http://dx.doi.org/10.1079/pavsnnr20094057.

Lynd, L.R., J.H. Cushman, R.J. Nichols and C.E. Wyman. 1991. Fuel ethanol from cellulosic biomass. Science 251:1318-1323. http://dx.doi.org/10.1126/science.251.4999.1318.

McLaughlin, S.B. and L.A. Kszos. 2005. Development of switchgrass (Pancium virgatum) as a bioenergy feedstock in the United States. Biomass and Bionergy 28: 515-535. http://dx.doi.org/10.1016/j.biombioe.2004.05.006.

McLaughlin, S.B. and M.E. Walsh. 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy. Biomass and Bioenergy 14.4: 317-324. http://dx.doi.org/10.1016/S0961-9534(97)10066-6.

Moore, K.J., L.E. Moser, K.P. Vogel, S.S. Waller, B.E. Johnson and J.F. Pedersen. 1991. Describing and quantifying growth stages of perennial grasses. Agronomy Journal 83: 1073-1077. http://dx.doi.org/10.2134/agronj1991.00021962008300060027x.

Parrish, D.J. and J.H. Fike. 2005. The biology and agronomy of switchgrass for biofuels. Critical Reviews in Plant Sciences 24:423. http://dx.doi.org/10.1080/07352680500316433.

Schmer M.R., K.P. Vogel, R.B. Mitchell, L.E. Moser, K.M. Eskridge, R.K. Perrin. 2006. Establishment stand thresholds for switchgrass grown as a bionergy crop. Crop Science 46: 157-161. http://dx.doi.org/10.2135/cropsci2005.0264.

Schmer, M.R., K.P. Vogel, R.B. Mitchell and R.K. Perrin. 2008. Net energy of cellulosic ethanol from switchgrass. Proceedings of the National Academy of Sciences 105: 464-469. http://dx.doi.org/10.1073/pnas.0704767105.

Skousen, J.G. and C.L. Venable. 2008. Establishing native plants on newly-constructed and older-reclaimed sites along West Virginia highways. Land Degradation and Developement 19:388-396. http://dx.doi.org/10.1002/ldr.846.

Teel, A. and S. Barnhart. 2003. Switchgrass seeding recommendation for the production of biomass fuel in southern Iowa. Iowa State University Extension, Ames, IA.

U.S. Energy Information Administration. 2011. Biomass Explained. http://www.eia.gov/energyexplained/index.cfm?page=biomass.home (Lasted updated: June 1, 2011). U.S. Department of Energy, Washington, DC.

U.S. Energy Information Administration; Office of Statistics. October 2011. Annual Energy Review 2010. http://www.eia.gov/totalenergy/data/anual/pdf/aer.pdf. U.S. Department of Energy, Washington, DC. DOE/EIA-0384 (2010).

Vogel, K.P. 2004. Switchgrass. p. 561-583. *In* Moser, L.E., B.L. Burson and L.E. Sollenberger (ed.) Warm Season (C4) Grasses, Agronomy Monograph no. 45. ASA, CSSA, and SSSA, Madison, WI.

Vogel, K.P., J.J. Brejda, D.T. Walters and D.R. Buxton. 2002. Switchgrass biomass production in the Midwest USA: harvest and nitrogen management. Agronomy Journal 94: 413-420. http://dx.doi.org/10.2134/agronj2002.0413.

Vogel, K.P. and R.A. Masters. 1998. Developing switchgrass into a biomass fuel crop for theMidwestern USA. *In* Proceedings BioEnergy 1998: Expanding Bioenergy Partnerships, Madison, WI. 4-8 Oct. 1998.

West Virginia Department of Environmental Protection. 2002. West Virginia Surface Mining Reclamation Regulations (July 15, 2002). (http://www.dep.wvu.gov/dmr/codes). §38-2-9. Revegetation.

Wolf, A. and Beegle, D. 1995. Recommended soil tests for macronutrients: Phosphorus, Potassium, Calcium and Magnesium. p. 30-38. *In* Sims, J.T. and A.M. Wolf (ed.). Recommended soil testing procedures for the Northeastern United States. Northeastern

Regional Pub. No. 493 (2nd edition). Agricultural Experiment Station Univ. of Delaware, Newark, DE.

Wolf, D.D. and D.A. Fiske. 1995. Planting and managing switchgrass for forage wildlife, and conservation. Virginia Cooperative Extension Pub. no. 418-013. Virginia Cooperative Extension, Blacksburg, VA.