

MINE SOIL RECLAMATION WITH SWITCHGRASS FOR BIOFUEL PRODUCTION ¹

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Abstract: Climate change mitigation and the high cost of transportation fuels have created an interest in utilizing biofuels to supplement the nation's energy portfolio. Switchgrass (*Panicum virgatum* L.) has been suggested as a possible biofuel feedstock crop because of its ability to produce large amounts of biomass over a wide range of growing conditions and its ability to sequester atmospheric carbon into stable soil organic carbon. Appalachia has the potential to become a center of biofuel production with its large expanses of reclaimed mine lands that are central to the U.S. energy market. Our intention with this study is to identify the best varieties of switchgrass for mined lands in northern Appalachia, their planting and management requirements, yields, biofuel feedstock potential, capacity for carbon capture and sequestration and other revenue streams. Three mine sites in West Virginia were selected for switchgrass demonstration plots and each had unique minesoil characteristics. The Hobet 21 mine was reclaimed with mostly topsoil substitute mixed with some original top soil; soil pH was 7.2 and total C was 1.5%. The Coal-Mac mine was reclaimed with mostly original topsoil mixed with some topsoil substitute; soil pH was 6.1 and total C was 1.5%. The Hampshire Hill mine was reclaimed almost entirely with original top soil amended with municipal biosolids; soil pH was 7.2 and total C was 7%. Three varieties of switchgrass (Carthage, Cave-in-Rock and Shawnee) were randomly assigned and planted into 0.4 ha plots, which were replicated three times for a total of nine plots at each site. Planting was conducted in May of 2008. At the end of the 2009 growing season, biomass yields were highest for the Cave-in-Rock variety in plots that were well established. The Hampshire Hill plots that received high amounts of municipal biosolids outperformed other plots with no organic amendments.

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Introduction

Surface mining for coal has created many thousands of hectares (ha) of reclaimed mine lands across Appalachia. Though these lands are reclaimed to regulatory standards, pasture and hay land using cool season grasses and legumes is perhaps not the most productive use of these lands. As wildlife habitat or rangeland, the future economic potential of these lands are often underutilized. However, the production of switchgrass (*Panicum virgatum* L.) on these lands for biofuel production and carbon sequestration could create new and advantageous post mining land uses.

Switchgrass is a warm-season perennial grass native to North America. Typically recognized as a dominant grass species native to the prairie, switchgrass populations exist, or once occurred, from Central America to Southern Canada and from the Atlantic Coast to the Rocky Mountain front in the United States (Hitchcock, 1935). As a managed crop, switchgrass has gained a great deal of attention as a warm-season forage species, and more recently as a biomass feedstock for renewable energy. In addition to biofuel feedstock and forage, other major uses for switchgrass include conservation plantings to control erosion, sedimentation and nutrient runoff. Finally switchgrass stands can also offer valuable wildlife habitat, especially for game birds like wild turkey, quail and pheasant. Switchgrass in general is efficient at utilizing resources and is well adapted to sites with limited to moderate fertility.

A number of trials have proven that switchgrass can be successfully grown for biomass (Lemus *et al.*, 2002; Mulkey *et al.*, 2008; Mulkey *et al.*, 2006; 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 5.2 to 11.1 Mg ha⁻¹ across ten farms in the upper Great Plains states. These yields equated to an average net energy yield of 60 GJ ha⁻¹y⁻¹ for switchgrass. They went even further to estimate that cellulosic ethanol from switchgrass would theoretically produce 94% less green house gasses than the equivalent amount of petroleum based gasoline. Many authors also point out that switchgrass grown for biofuels is a relatively new crop and that advances in plant breeding and agronomics could substantially increase yields (Lewandowski *et al.*, 2003; Parrish and Fike, 2005; Vogel, 2000; Vogel and Jung, 2001).

Because of switchgrass' adaptation over a variety of limiting edaphic conditions, there has been some research done on switchgrass as a species to reclaim drastically disturbed lands, whether as a monoculture or as part of a mixed species sward. There are a number of physical and chemical soil limitations to mine soils that can inhibit the growth of plants, including, but not limited to, poor structure and moisture regimes, compaction, restricted rooting, nutrient deficiencies and toxicities, high electrical conductivity, and soil acidity (Shrestha and Lal, 2006; Bendfeldt *et al.*, 2001). Switchgrass should be ideally suited for reclamation because of its hardiness and inherent tolerance to a number of these limiting factors. Switchgrass has been used in reclamation studies on roadsides (Skousen and Venable, 2008), strip mines (Rodgers and Anderson, 1995; Skeel and Gibson, 1996), sand and gravel mines (Gaffney and Dickerson, 1987), lignite overburden (Skousen and Call, 1987), and lead and zinc mines (Levy *et al.*, 1999). No trials have been conducted with switchgrass on mine lands of any type specifically for the purpose of biofuel production. It has been proven that switchgrass can be a successful reclamation species, but research is lacking on whether it can also complete the dual duty of successfully providing adequate amounts of biomass for economic conversion into fuel.

This project seeks to test the feasibility of establishing switchgrass for biofuel production on recently mined lands as part of the reclamation process. Mined lands offer the unique opportunity to increase the land acreage devoted to fuel production without subtracting from the acreage already in food and feed production. Issues that need to be resolved over this long term study include establishing the best method of planting switchgrass, the best varieties of switchgrass to utilize in WV and the best management techniques to optimize biomass production. This project also seeks to track switchgrass productivity and chemical and physical changes in mine soil as the result of reclamation with switchgrass. Many of these issues have previously been resolved by researchers studying switchgrass on agricultural soils, however there is a definite lack of information concerning managing switchgrass on mined lands.

To examine these issues on mine lands, switchgrass was established on three different mines across the state of West Virginia. Three varieties of switchgrass were chosen and each variety was planted in 0.4 ha plots at each site. The objective of this study was to examine switchgrass establishment success and productivity, and to measure changes in soil chemical and physical properties.

Materials and Methods

The switchgrass establishment portion of this project took place on three different surface coal mines in West Virginia (Figure 1). Each of these mine sites has three varieties of switchgrass replicated three times in 0.4-ha plots. Two of these mines are large mountain top removal mines in southern WV. The third site is on a contour mine located in the eastern panhandle of WV.

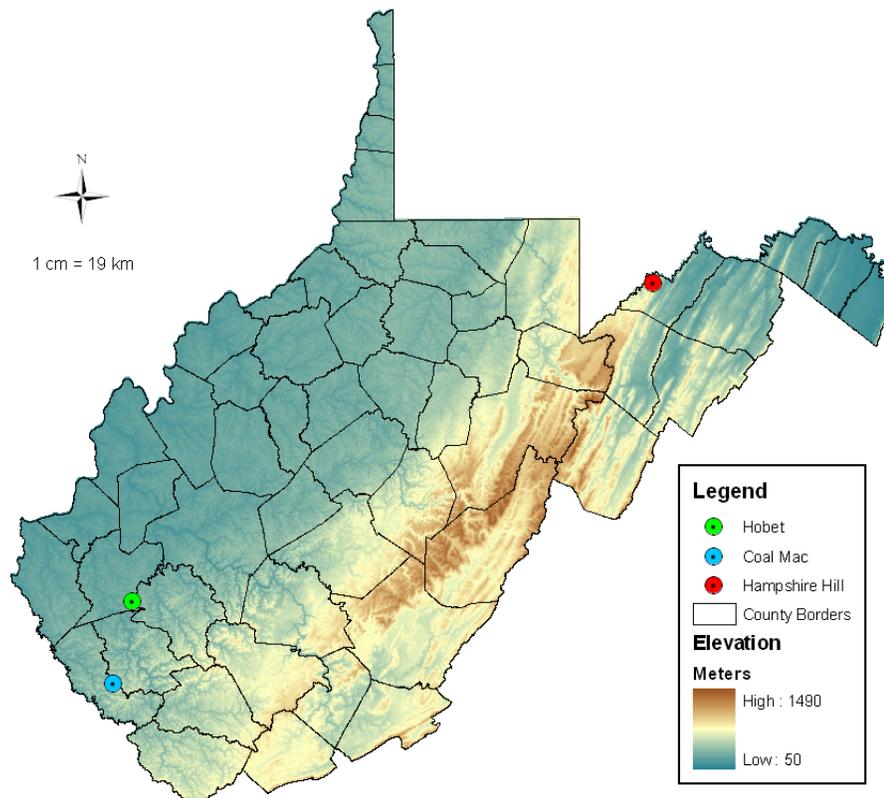


Figure 1: Location of the three study areas

Hobet 21

Operated by the Hobet Mining Company, a subsidiary of Magnum Coal, the Hobet 21 mine in Boone and Kanawha counties consists of some 4,800 ha of operating and reclaimed mine lands. This mine utilizes a large dragline for overburden removal. The site planted with

switchgrass was constructed by grading out topsoil and topsoil substitute consisting of weathered rock material over compacted overburden material with a bulldozer. This site was tracked in by a dozer and allowed to sit unvegetated for some time before establishing switchgrass. Subsequently, before planting, the hard soil crust had to be broken to ensure proper seed to soil contact. A large earthmoving offset disk harrow was pulled across the site with a bulldozer to till the soil before planting.

Nine 0.4-ha plots were laid out by hand with a tape measure and marked at the corners with steel T-posts. A minimum buffer of at least 3-m was left between all plots. Each of the three varieties was randomly assigned to one plot until each variety had been replicated three times (Table 1). Planting was conducted on May 28, 2008 using an Earthway Ev-N-Spred hand broadcast spreader.

Table 1: Switchgrass variety by plot number and mine site.

	Hampshire Hill	Hobet 21	Coal-Mac
	----- switchgrass variety -----		
Plot 1	Carthage	Cave-in-Rock	Cave-in-Rock
Plot 2	Shawnee	Cave-in-Rock	Shawnee
Plot 3	Shawnee	Shawnee	Shawnee
Plot 4	Cave-in-Rock	Shawnee	Carthage
Plot 5	Shawnee	Carthage	Carthage
Plot 6	Carthage	Carthage	Cave-in-Rock
Plot 7	Carthage	Shawnee	Shawnee
Plot 8	Cave-in-Rock	Carthage	Cave-in-Rock
Plot 9	Cave-in-Rock	Cave-in-Rock	Carthage

Our goal was to seed 4.54 kg of pure live seed (PLS) on all plots across all three sites. After seeding, a light covering of hydromulch was applied over the plots to prevent seed washing and to ensure seed to soil contact. On July 29, 2008, approximately 50 kg ha⁻¹ of urea was applied to each plot. On July 9, 2009, approximately 200 kg ha⁻¹ of 19-19-19 fertilizer was applied to one half of each plot.

Coal-Mac Phoenix Surface #4

The Coal-Mac Phoenix Surface #4 mine is located in Mingo and Logan counties in southern WV. The mine is a subsidiary of Arch Coal, Inc. It is a large mountain top removal mine that utilizes large power shovels for overburden removal. The site was constructed by rolling out soil and weathered rock material over compacted overburden material. Topsoil was tracked in by a bulldozer and then a small agricultural offset disk harrow and tractor were used to prepare the site for planting.

The nine 0.4-ha plots were established as before. To test the viability of several seeding methods, planting was done with a hydroseeder (Figure 2). Planting was conducted on May 29, 2008. After seeding, a light covering of hydromulch was applied over the plots to prevent seed washing and to ensure seed to soil contact. Plots were fertilized at the same time and at the same rates as the Hobet 21 site.



Figure 2: Hydroseeding at Coal-Mac.

Hampshire Hill

The Hampshire Hill Mine is located in Mineral County, West Virginia. The property is currently managed by the Upper Potomac River Commission. This site was a small contour mine that utilized smaller mining equipment and trucks. Coal production on the site ceased in April of 1998. Reclamation was completed with rolled out topsoil and a top dressing of lime treated sludge from the Westernport, MD municipal wastewater treatment facility which treats industrial wastewater from the nearby New Page paper mill and municipal wastewater from the town of Westernport. Sludge consisting of sewage waste and paper mill pulp was again applied in 2003 and directly before planting in 2008 at a rate of 225 Mg (dry) ha⁻¹. A small bulldozer and offset disk harrow were used to prepare the site for planting.

Nine 0.4-ha plots were laid out as already described and assigned switchgrass varieties. Planting was conducted on June 13, 2008, using an Earthway Ev-N-Spred hand broadcast spreader. To try a third method of establishment, a no-till drill was first tried unsuccessfully due to the overly wet conditions. No fertilizer was applied at this site. Herbicide was applied in June of 2009 to control weeds. Atrazine (2-chloro-4-(ethylamine)-6-(isopropylamine)-s-triazine) was applied at a rate of 0.75 L ha⁻¹ along with Banvel (3,6-dichloro-o-anisic acid) at a rate of 25 mL ha⁻¹.

Soil Sampling Strategy

In 2008 at the three switchgrass establishment sites in West Virginia, five points were randomly located in each plot and marked with a landscaping flag. Each landscaping flag was kept at least 2-m from the plot boundaries. A soil sample was randomly taken from a 1-m radius around each landscaping flag. This made a total of five soil samples for each 0.4 ha plot, or 45 samples for each mine site.

Beginning in 2009, plots at the Coal-Mac and Hobet 21 mine sites were split into halves based on whether or not fertilizer was applied. Three points were randomly placed into each half plot using the same method as in 2008 and were kept at least 2-m from the plot boundary. If possible, sampling locations from 2008 were reused. An extra point was placed in each plot at the Hampshire Hill site so that every plot has a total of six randomly placed sampling points.

Each of these locations was located with a GPS to limit the further need for often difficult to locate landscaping flags. Soil samples were carefully dug with a shovel. A vertical slice of soil and rocks 10 cm deep was taken and placed into a labeled bag. Starting in 2009, a stand vigor rating (Table 2) was used at each sampling location based on the relative switchgrass performance in a 1-m radius around the sampling point because of the variability in switchgrass stand performance at the Hobet 21 and Coal-Mac mines.

Table 2: Switchgrass vigor ratings.

Vigor Rating	Criteria
Very Poor	Seedlings shorter than 5cm. Most seedlings brown and senesced. Poor cover.
Poor	Seedlings between 5 – 10 cm. Seedlings green but poor cover.
Moderate	Grass between 10 – 20 cm. Better cover. Green plants.
Good	Grass greater than 20 cm. Good cover but some gaps. Green plants.
Very Good	Grass greater than 20 cm. Nearly 100% cover. Very best performance.

All samples were air dried, weighed and sieved with a 2 mm sieve into a fine (<2 mm) and coarse (>2 mm) fraction. During sieving any visible roots were discarded. Both portions were retained for chemical and physical analysis.

Soil Chemical Analysis

All chemical analyses were conducted with the fine (<2 mm) portion of the soil samples unless otherwise noted. Electrical conductivity and pH were determined using a 2:1 and 1:1 solution:soil slurry respectively.

A 5:1 solution:soil ratio of Mehlich 1 double dilute acid was used to obtain the extractable elements in the soil. The Mehlich solution was analyzed for Al, Fe, Mg, Ca, Na, K, P, Ni, Zn, and Cu using a Perkin Elmer Plasma 400 emission spectrometer.

Total soil C was determined using a LECO TruSpec CNH carbon analyzer. Soil was lightly ground to pass a 0.25 mm sieve. Each sample was weighed into foil cups and combusted to determine total C. The amount of C in the form of evolved CO₂ was measured.

Vegetation Measurement

Both frequency and percent cover by switchgrass were measured on our sites in 2008. Yield and cover were measured in 2009. Percent cover was determined by placing four 0.25 m² quadrats at each randomly placed landscape flag on each plot. Each of the four quadrats placed around the flag were situated at one of the cardinal directions. A visual estimate of the percent of the soil surface covered by switchgrass was recorded. Frequency in 2008 was estimated by calculating what proportion of the 20 quadrats in a field had at least one switchgrass plant.

Yield was determined in 2009 by randomly placing a 43.2 cm² quadrat around each of six flag locations in each of the plots. All the switchgrass in the quadrat was clipped and collected (Figure 3). Then it was oven dried at 60°C for 48 hrs to determine dry weight.



Figure 3: Quadrat used to clip switchgrass biomass for yield determination.

Results and Discussion

All three mine sites where switchgrass was established showed rocky soil characteristics that are consistent and within the range of those expected on mountain top mine soils in southern West Virginia (Table 3). Noteworthy differences include the small amount of rock fragments at Hampshire Hill compared to Coal-Mac and Hobet 21. Hampshire Hill also had very high EC, total carbon and Ca due to the heavy application of lime treated municipal solids and paper mill sludge. EC decreased for all three sites from 2008 to 2009 and pH increased slightly. Percent total C also increased.

Table 3: Selected physical and chemical characteristics of mine sites.

	Hobet 21		Coal-Mac		Hampshire Hill	
	2008	2009	2008	2009	2008	2009
pH	7.3	7.9	6.1	6.2	7.2	7.3
Electrical Conductivity ($\mu\text{S}/\text{cm}$)	187	69	258	55	1245	382
% Total Carbon	1.0	1.6	1.5	1.9	6.8	7.1
% Fines [†]	50		44		26	

[†] Calculated as the percentage dry weight of sample material >2mm in size.

Elemental concentrations in soils across these three sites reflected the general soil pH and EC characteristics already shown (Table 4). Calcium concentrations were very high at Hampshire Hill, with lower concentrations at Coal Mac and Hobet 21.

Table 4: Mehlich 1 extractable elements.

	Hobet 21		Coal-Mac		Hampshire Hill	
	2008	2009	2008	2009	2008	2009
	----- mg/kg soil -----					
Al	59	40	95	96	104	86
Fe	123	126	91	76	59	21
Mn	46	51	50	30	173	63
Mg	169	205	212	195	221	201
Ca	634	606	605	49	6159	5118
K	42	45	48	46	102	97
Na	11	8.6	27	8.9	91	14
P	53	33	15	14	4.6	2.8
Ni	1.3	1.0	0.6	0.7	0.4	0.5
Cu	2.3	2.2	2.0	2.2	2.6	1.7
Zn	2.7	3.2	1.5	1.5	8.6	7.4

Fertilizer application appears to have had some effect on soil properties and switchgrass growth. At the Hobet site there was no significant difference in measured K and P levels, however there was a significant difference for biomass production and percent cover between fertilized and unfertilized plots (Table 5). At the Coal Mac site there was a significant statistical difference in measured K and P levels between fertilized and unfertilized plots, however this difference did not manifest itself into significant differences for biomass production or percent cover.

Table 5: Comparison of Fertilized and Unfertilized Plots

		Fertilized	Unfertilized	P-value
Hobet 21	K (mg/kg soil)	9	8	0.36
	P (mg/kg soil)	6	6	0.46
	Biomass (kg/ha)	382	52	0.043
	% Cover	19.7%	7.2%	0.021
Coal-Mac	K (mg/kg soil)	10	8	<0.001
	P (mg/kg soil)	3	2	<0.001
	Biomass (kg/ha)	861	703	0.712
	% Cover	29.3%	30.4%	0.900

At the end of 2008, no significant trends in vegetation were evident in either percent ground cover or the frequency of switchgrass seedlings. All three mine sites showed even distributions of germinated plants with a density that would support a full mature stand (Table 6). Although the frequency was less at the Hampshire Hill mine, this was an artifact of not using guides to ensure even coverage of seed with the spinner spreader as was done at the Hobet 21 site. By the end of 2009, most of these areas had filled in. When cover data was collected in July of 2008, most areas showed only small amounts of growth which is evidenced by the relatively small amount of switchgrass ground cover (Table 7). This was not unexpected since, during the first year of growth, switchgrass spends most of its energy developing roots. Percent cover was much better in October of 2009. There was a significant difference between the three sites. The only significant difference between varieties within a site was at Coal-Mac where Cave-in-Rock was the best.

Table 6: Average percent frequency across mine site and switchgrass variety in 2008.

	Hobet 21	Coal Mac	Hampshire Hill
	----- % -----		
Carthage	98	98	90
Cave-in-Rock	98	97	92
Shawnee	97	98	78
Average for site	98	98	87

Table 7: Average percent cover of switchgrass across mine site and switchgrass variety.

	Hobet 21		Coal Mac		Hampshire Hill	
	2008	2009	2008	2009	2008	2009
	----- % -----					
Carthage	2.2	14	1.8	22	1.6	96
Cave-in-Rock	2.7	8.6	2.0	40	3.3	100
Shawnee	2.3	17	1.6	28	1.9	97

By 2009, significant differences in biomass were observed between the three mine sites (Table 8). At Hampshire Hill and Coal-Mac, areas that had before shown little growth in 2008, greatly improved and produced large amounts of biomass in 2009. While most of the area at Hobet was green and presumably still growing, only a few areas were fully established and performing vigorously. The Hampshire Hill mine was the greatest biomass producer followed by Coal-Mac and then Hobet. It was also interesting to note that the Cave-in-Rock variety produced a statistically significant higher amount of biomass at Hampshire Hill and Coal-Mac. Both these sites are more established than Hobet and it appears that on these two sites, Cave-in-Rock is the best biomass producer.

Table 8: Switchgrass biomass at three sites for three varieties in West Virginia, 2009.

	Hobet 21	Coal Mac	Hampshire Hill
	----- kg/ha -----		
Cave-in-Rock	72	1219	6501
Shawnee	456	725	3448
Carthage	124	417	3604

While the biomass harvested at Hobet and Coal-Mac was much less, it should be noted that the variability of performance was much higher at these two mines. Every area sampled at the Hampshire Hill mine scored the highest vigor rating while the other two mines were lower and more variable (Figure 4). The Hobet site averaged a vigor yield between very poor and poor while the Coal-Mac site averaged between poor and moderate (Table 9). There was no significant statistical difference in vigor between any of the varieties at any of the mine sites.

Table 9: Average vigor for 2009 between mine sites and variety.

Variety	Hobet 21	Coal Mac	Hampshire Hill
Cave-In-Rock	Very Poor to Poor	Poor to Moderate	Very Good
Shawnee	Very Poor to Poor	Poor to Moderate	Very Good
Carthage	Very Poor to Poor	Poor to Moderate	Very Good



Figure 4: Spatial variability of switchgrass performance at the Coal-Mac mine.



Figure 5: Switchgrass growth during second growing season at Hampshire Hill.

Conclusions

At the end of two growing seasons, we found that switchgrass can indeed be successfully established on mine lands with planting techniques typically employed by mine operators. However, while established switchgrass plants are tolerant of marginal soils, the small size of switchgrass seed limits the amount of stored reserves available to the plant to become established. Accordingly, switchgrass establishment may take much longer on very marginal soils. So far, mine soils reclaimed with biosolids completely out performed those soils that were mostly comprised of topsoil substitutes. This is easily attributed to the organic material's ability to supply a steady stream of nutrients and moisture to the switchgrass seedlings. At Coal-Mac and Hobet 21, the reason for the spatially variable performance of the switchgrass stand remains unclear. However, the Coal-Mac mine received more original topsoil during reclamation and perhaps this is the reason for its better performance than Hobet. This is just the beginning of a

decade-long project to test the feasibility of growing switchgrass on mine lands in West Virginia. A great deal of data remains yet to be collected and interpreted.

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