Mushroom Compost Feedstock Production on Degraded Mined Land Reclaimed with Spent Mushroom Compost

Project PI: Richard Stehouwer
Project Co-PIs: Marvin Hall, David Beyer, Mena Hautau, Jayson Harper

This research project was initiated in the Fall of 2011 with seed grant funding from MFPA and was continued with funding from the Giorgi grant from July 2012 to May 2014. We are now in the final, and in some respects the most critical year of the project. We are requesting funding from MFPA to allow us to complete the final year of the project.

Introduction

As Pennsylvania's mushroom industry seeks to increase and intensify production their need for high quality mushroom compost similarly increases. However, the high fiber and cellulosic biomass materials essential for high quality mushroom compost production are increasing in cost and are often in limited supply. Grass hay, wheat straw, and corn stover feedstocks are being sourced from across Pennsylvania and from neighboring states resulting in large haul distances and significant transport cost increases. Increased mushroom production also means increased generation of spent mushroom compost (SMC) that must be moved and utilized in an environmentally sound manner. Markets for SMC in concentrated mushroom producing areas are nearly saturated and new markets are needed.

Our research project addresses both of these issues by utilizing SMC to produce grass straw and hay on marginal, underutilized lands. Within the anthracite coal mining region of eastern PA are thousands of acres of land degraded by mining that potentially could be used for production of perennial grass hay, and utilize SMC for fertility. Much of this land is 30 to 100 miles from intensive mushroom production areas which would mean significantly shorter biomass hauls than many currently utilized sources. Transportation costs could be further reduced by establishing back-haul networks where trucks carry SMC to the grass production sites and return with loads of grass straw or hay. Developing biomass production on these degraded lands would also not compete with food, feed and biomass production on existing agricultural land. The system would establish a natural recycling of the carbon and nutrients in the mushroom industry's major by-product material (SMC) to produce new essential raw materials for mushroom production.

However, this potential grass production and SMC recycling system contains several uncertainties and questions that must be addressed before it can be widely adopted by the industry and landowners. Our ongoing research is investigating the following questions:

1. To what extent can soil amendment with SMC overcome the low quality and very limited crop production potential of degraded mined land soils?
2. What species of grass are best suited for production on reclaimed mined lands, and what is their production potential?
3. How does straw and hay from these grasses perform as feedstocks for mushroom compost production?
4. What are the economics of this biomass production system?

To address these questions we have been focusing on the following objectives:

1. Determine production potential of various warm and cool season grasses on degraded mined land reclaimed using SMC.

2. Determine annual SMC application rates needed for sustained production of these grasses on reclaimed mined land.
3. Quantify soil sequestration of C and N in mine land soils being used for biomass production with SMC application.
4. Evaluate warm and cool season grasses as fiber based bulk ingredients for composting mushroom substrate.
5. Conduct an assessment of the amount of degraded land suitable for biomass production within an economically feasible hauling distance from current mushroom production capacity.
6. Conduct an economic assessment of biomass production on mined lands using SMC and use of biomass for production of fresh mushroom substrate.

Research Plan

To accomplish these objectives we utilized an existing switchgrass experiment on an abandoned mined land site near the intersection of I-81 and route 25 in Schuylkill County, and we established a second small plot experiment on mined land located near Tremont in Schuylkill County.

The existing experiment was established in 2006 and includes six reclamation treatments: lime and fertilizer, and two rates each of composted manure and manure+paper mill sludge. No fertilizer has been added since 2006. In Spring 2011 we split the existing plots into 3 subplots each. One subplot received no added fertility and the other two received SMC at 1x and 2x the agronomic N rate. These treatments were applied again in Spring 2012-14. We have been measuring switchgrass production and soil C and nutrients in response to the SMC applications.

Figure 1. Partial view of the small plot experiment established at the *Blackwood* site in August, 2011, showing cool season grass growth, dark strips of newly planted miscanthus and bare strips where switchgrass was planted the following week. Photographed on April 26, 2012.

A second small plot experiment was established in August, 2011 on non-reclaimed mined land at the *Blackwood* site, a 2,300 acre tract owned by Mr. Nolan Perin. Mr. Perin provided use of land and his business associate, Mr. Jeffrey LeBlanc of *WeCare Organics, LLC* has provided heavy equipment and labor needed for site preparation and spreading and incorporate SMC. The Blackwood experiment area was reclaimed with 30 tons SMC/acre (approximately 500 lb N/acre). We installed a split plot experiment in which the main plots received either no additional fertility, or annual SMC applications at 1x and 2x the agronomic N rate. Each main plot is split into 5 subplots planted with 2 warm season grasses (switchgrass and miscanthus) and 3 cool season grasses (tall fescue, orchardgrass and timothy). This will allow comparison of the mined land production potential of the grasses and their yield response to SMC as a nutrient source. We expect to make 2 harvests per year once the grass stands are established. We will also sample soils and analyze for organic C and nutrients to monitor their retention in the reclaimed soil.

Research for Objective 4 was conducted at PSU's Mushroom Research Center (MRC) and the Mushroom Test Demonstration Facility (MTDF). This research focused primarily on substituting miscanthus and switchgrass in mushroom substrate formulas and comparing to a standard formula. Alternative methods and materials were used to pre-condition these materials before mixing in the other supplements. Phase I and II composting temperatures were monitored, and physical and chemical analysis of the finished compost were made. The substrate was spawned with a commercial spawn and supplement and grown under a controlled environment for 12-15 days before a layer of pH buffered peat moss (casing) was applied. Differences in mushroom yield and size were determined.

We are currently working on Objectives 5 and 6 by obtaining data from the Eastern PA Coalition for Abandoned Mine Reclamation (EPCAMR), PADEP bureaus of Surface Mining and Abandoned Mines and individual landowners to assess the quantity and geographic location of mined land suitable for biomass production. We are utilizing cost and production data from the research project to conduct the economic assessment of this biomass production and SMC utilization system.

Project findings will be communicated to the mushroom industry and mined land owners by holding field days at the demonstration site and dissemination of project reports and fact sheets.

The overall project timeline is shown below. We are seeking funding from MFPA to complete soil and plant tissue analysis and to complete the 3rd and 4th year harvests at the Blackwood and Barry experiments respectively. It takes at least 3 and sometimes 4 years for warm season grasses to become fully established and reach their maximum yield potential, and it is only after several repeated annual applications of SMC that we can begin to assess the effect on soil organic matter, soil nutrients and plant productivity. Thus this final year of the project in many respects will provide the most valuable and most important data for assessing mined land production of grass hay using SMC. It is critical that these data be collected.

Project Timeline

Activity	Year and Season													
	2011		2012				2013				2014			
	Su	Fa	Wi	Sp	Su	Fa	Wi	Sp	Su	Fa	Wi	Sp	Su	Fa
Prep Blackwood experiment site	C*													
Prep Blackwood 4 acre demo site							C							
Plant cool seas. grasses on new exp.	C*													
Plant warm seas. grasses on new exp.				C*										
Plant cool seas. grasses on demo. site								C						
Plant switchgrass on demo. site								C						
Annual agronomic SMC application			C*					C				C		
Harvest and biomass sampling		C*				C			C	C			X	X
Soil sampling		C*				C			C				X	
Soil and biomass analysis			C*				C				C	X	X	X
Mushroom compost tests			C*	C	C		C	C	C		C	C	X	
Land area assessment									C	C				
Economic assessment										C	C	C	X	
Extension field day														X
Project reports							C				C			X

C=completed, X=planned, *These objectives were accomplished with seed grant funding provided by MFPA.

Budget

CAC Seed grant budget request

Direct Costs	Period: July 2014 – Dec. 2014
Salaries	
Summer Salary for Graduate Assistant	2925
Undergraduate wages $10/hr x 250 hrs	2500
Fringe @ 7.9%	429
Total salaries and wages	5854
Soil and plant sampling & Econ analysis	1000
Purchased services (Ag Anal Lab)	500
Hauling/use of biomass harvester	1500
Travel	1000
Total	**9854**

Appendix A. Progress Report 2014

Mushroom Compost Feedstock Production on Degraded Mined Land Reclaimed with Spent Mushroom Compost (SMC)

Richard Stehouwer, Marvin Hall, David Beyer, Mena Hautau, James Banfill
The Pennsylvania State University and Berks County Cooperative Extension

I. Introduction:

2014 marks the third year of the Mushroom Compost Feedstock Production on Degraded Mined Land Reclaimed with Spent Mushroom Compost (SMC) project between Giorgi Mushrooms and researchers at the Pennsylvania State University. The broad aim of the project is to evaluate the potential for value-added disposal of SMC through application to degraded mine soils on abandoned mine land (AML) for the production of bio-feedstock from quick growing grass species. Grass feedstock can in turn serve as an input in mushroom production, thereby contributing to more efficient resource and nutrient management.

If realized, a SMC-to-feedstock cyclical system linking the mushroom producing counties of Berks and Chester counties and the nearby Anthracite coal region would support the economic development and environmental sustainability of two of Pennsylvania's important industries.

A primary task in evaluating the potential for SMC-based feedstock has been the establishment of two experimental field sites, called Barry and Blackwood, on degraded coal mine soils in Schuylkill County. Since 2011-2, we have applied annual agronomic rates of 0, 34, and 67 Mg ha^{-1} (0, 15, 30 T A^{-1}) of spent mushroom compost (SMC) on each site and collected data on biomass yield and monitored soil nutrient levels. These rates were based on the nitrogen requirements of crops.

In this report we briefly summarize the objectives and methods for our field study, results to-date, and on-going tasks as of April 2014.

II. Objectives:

1. Evaluate and compare the production potential of warm-season and cool-season grasses on SMC-amended mine soils in the Anthracite coal region of Pennsylvania.

2. Determine the annual SMC applications required for sustained production of grasses on mined land.

3. Interpret project experience and data to assist in economic assessment of SMC-based grass production, transport, and cost-benefit to stakeholders.

4. Test effects of inclusion of warm season grass species in mushroom compost formula on compost quality and mushroom yield.

III. Methods and Procedures:

Study sites & grass species:

Figure 2: The Barry site in 2006 prior to initial reclamation.

The Barry site is a former strip mine located on private land near the junction of Interstate 81 and State Route 25 near Hegins (40°40'30.27"N, 76°24'20.43"W). Barry was the site of a previous experiment which established switchgrass (*Panicum virgatum L.*) on five different reclamation treatments of lime and fertilizer, two rates of compost, and two blends of paper mill sludge mixed with poultry manure in 2006. Subsequent application of SMC on this site allows the evaluation of potential reclamation combinations including SMC and their effects on grass yields and soil nutrients.

Figure 3: Blackwood site before study (left) and after initial seeding (right) in 2012.

The second site, Blackwood, was established on a coal refuse dump adjacent to former underground mine. Blackwood is located near Tremont (40°38'13.85"N, 76°19'29.19"W). Initial reclamation was carried out using a one-time application of 158 Mg SMC ha^{-1} (70 T/A) mixed with 26 Mg lime kiln dust ha^{-1} (10 T/A) to neutralize acidity. Five grass species, including two-warm season grasses and three cool-season grasses, were established at the Blackwood site. The warm-season grasses include switchgrass and giant miscanthus (*Miscanthus x giganteus*). The cool-season grasses include timothy-grass (*Phleum pratense*), orchardgrass (*Dactylis glomerata*), and tall fescue (*Festuca arundinacea*).

Prior to reclamation both soils were characterized by moderate to high acidity and low-nutrient levels with poor potential for pastures or farming (National Cooperative Soil Survey, 1977).

Both field sites are visible on Google Earth at the above coordinates.

Measurements:

Researchers have undertaken a number of methods to evaluate the treatment effect of SMC on grass production at each site. These have included:

- Annual dry matter yields
- Annual soil macronutrient (P, K, Ca, Mg) analysis
- Soil micronutrient analysis (2013 only)
- Plant macronutrient and micronutrient tissue analysis (2013 only)

A biomass harvester was used to measure yields each November. In 2013, double cuttings, one in July and one in November, were conducted for switchgrass at the Barry site and cool-season grasses at the Blackwood site. Soil and tissue analyses were conducted at the Pennsylvania State University Agricultural Analytical Services Laboratory (AASL).

Mushroom compost testing:

Mushroom Test Demonstration Facility (MTDF) compost was prepared using standard methods, with Phase I taking place in an environmentally controlled aerated bunker. The composting formula for the MTDF consists of straw-bedded horse manure, switch grass (SG) straw, poultry manure, gypsum and dried distiller's grain. Two additional treatments containing miscanthus grass (MG) or sorghum stover (SS) were also prepared based on the MTDF formulation by replacing the SG with MG or SS. The aerated Phase I composting period lasted 6 days, with the compost piles turned on day 3 and turned and filled into tubs on day 6. The compost was taken to the Mushroom Research Center (MRC) to complete Phase II (PII). The three compost treatments were placed in the PII room where moisture and temperatures were monitored and maintained according to standards for the MRC for 7 days until conditioning was completed and the composts were ready to be spawned (seeded).

The compost was spawned with a commercial off-white hybrid of *Agaricus bisporus* at a rate of 2% and supplemented with a commercial supplement at a rate of 4%. At spawning, fifty pounds of wet weight compost was layered into 2.75-square foot plastic growing tubs for each replicate and the compost in each tub was pressed tightly. The tubs were placed on metal racks and moved to an environmentally controlled production room at the MRC with monitoring for temperature, relative humidity, and CO_2 for the duration of the 14-day spawn run.

Standard MRC casing consisting of sphagnum peat moss and agricultural limestone (50 lbs. lime per 6 cub ft. bale of peat moss) with a commercial casing inoculum added (CI) was then applied onto crop. The room was flushed with fresh air and temperatures lowered 5 days after casing to initiate primordial development. First break harvest began 10 days after the fresh air flush, 16 days after casing. Mushrooms were harvested for 3 growing cycles, or breaks. Yield data was statistically analyzed for a completely randomized design and was analyzed using the Waller Duncan k-ratio t-test at a significance level of 0.05 to separate the means.

IV. Progress report:

Yields:

Figure 4: Barry switchgrass stands in July (left) and November (right).

At the Barry site average switchgrass yields have increased annually. Average yields for all treatment groups were between 5-6 Mg ha^{-1} in 2011, 7-8 Mg ha^{-1} in 2012, and 9-11 Mg ha^{-1} in 2013. The average yield for the control group was 2.7 Mg ha^{-1}, 5.4 Mg ha^{-1}, and 6.1 Mg ha^{-1} over the same time period. Switchgrass yields of 10 Mg ha^{-1} yields on reclaimed coal mine soils are comparable to similar studies conducted in the region (Marra *et al*., 2013). A 2-3 year period for a stand to reach full productivity is also consistent with previous studies of switchgrass on marginal mine soils (Marra and Skousen, 2012).

SMC application had statistically significant effects on switchgrass yield in the second (2012) and third growing seasons (2013). In 2012 only the highest SMC rate significantly influenced yield in 2012 relative to controls, while both SMC rates had significant effects on yield in 2013. These findings suggest a higher initial input of SMC may contribute to early achievement of higher yields, but may not be necessary to sustain yields in subsequent years (Figure 3).

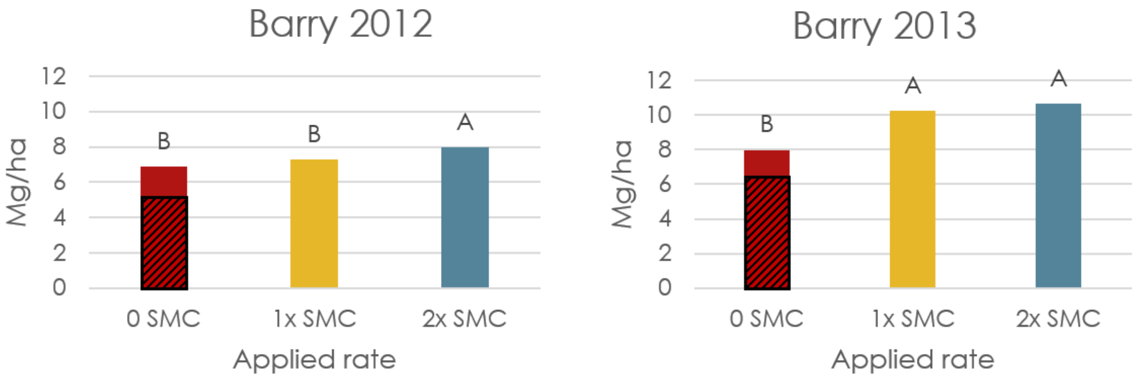

Figure 5: Mean switchgrass yields in 2012 and 2013 by SMC treatment group at Barry. Letter groupings denote statistically similar results. Black cross hatches represent means for control plots which received no SMC application and had no residual fertility from previous experiments.

Double cuttings increased overall yields for the year by 2-3 Mg ha^{-1}. However, second cutting yield was much lower compared to the same year's summer harvest and the previous year's fall harvest. Double-cut switchgrass showed signs of grazing damage by deer, which has not been observed in past-November harvests. Deer may be attracted to new switchgrass regrowth as alternative sources of fresh grazing material decline in late summer.

At the Blackwood site both warm-season grasses, switchgrass and giant miscanthus, have outperformed the cool-season grasses site in terms of annual yield. In 2012, switchgrass produced between 1-3 Mg ha^{-1} and miscanthus produced between 1-2 Mg ha^{-}1. Switchgrass yields reached between 5-8 Mg ha^{-1} in during the second growing season (2013), which were comparable to second year (2012) yields at Barry.

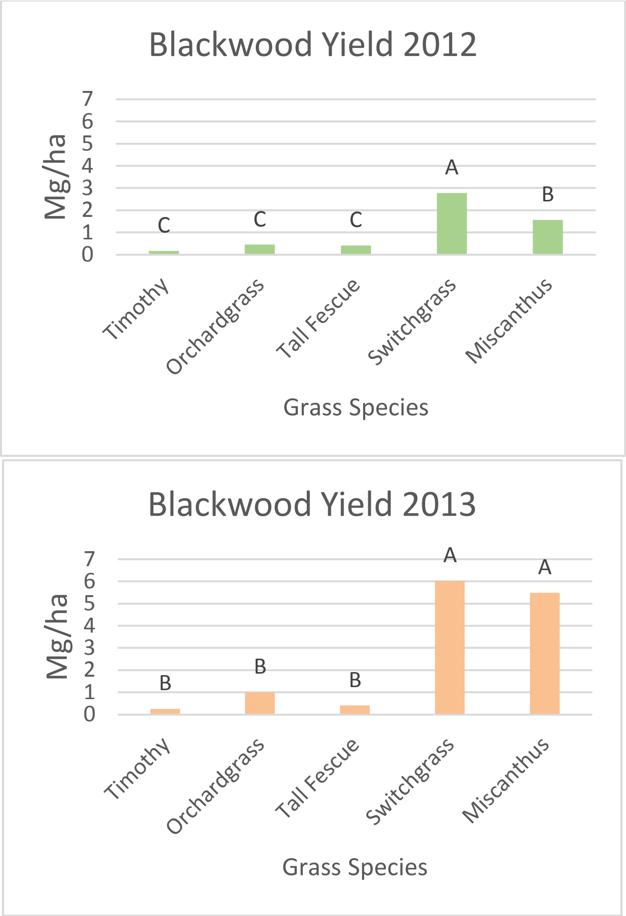

Figure 6: Mean cool-season and warm-season grass yields from 2012 (left) and 2013 (right) for the Blackwood site. Letter groupings denote statistically similar results.

In 2012 giant miscanthus produced between 1-2 Mg ha^{-1} at Blackwood. Yields increased to between 4-6 Mg ha^{-1} in 2013 but were likely reduced due to poor establishment of rhizomes. Fike *et al*. (2008) reported similar difficulty establishing miscanthus on mine sites in Virginia. Where miscanthus rhizomes did establish, plants performed well, producing stalks taller than two meters. Yields were comparable to some miscanthus varieties grown on AML, but well below higher yielding varieties which are capable of producing upwards of 15 Mg ha^{-1} even on marginal soils (Skousen *et al*., 2013).

An additional growing season of yield data in 2014 will help to evaluate the sustained production of switchgrass and giant miscanthus on SMC-amended mine soils.

Figure 7: Giant miscanthus with person for scale at Blackwood (left) and comparisons with poor performing cool-season grass (right).

Cool-season grasses, although quick to establish ground cover, produced low yields below 1 Mg ha^{-1} in the first year of the study. Yields marginally improved during the second growing season, but were still significantly lower than higher producing warm-season grasses. Double cutting did not improve cool-season yields by an appreciable amount. High surface temperature on coal refuse piles may hinder vegetative productivity of heat sensitive cool-season grasses (Daniels *et al*., 2010).

Soil nutrients:

Top-dress application of SMC has raised available macronutrients levels (P, K, Ca, Mg) relative to controls in topsoil, reduced soil aluminum levels, and maintained near neutral to slightly alkaline pH. Table 6 presents Mehlich-3 nutrient levels and pH by SMC rate for the Barry site in 2013.

Unreclaimed coal mine soils in Appalachia are typically moderately to high pH and low soil fertility, especially in terms of phosphorus (Howard *et al*., 1988). SMC applications have provided phosphorus beyond annual plant needs, thereby mitigating a common nutrient deficiency in mine soils.

Tissue analysis in combination with yield data will provide an estimate of harvest nutrient removal from sustained production of grasses and help to guide management choices related to future application rates and frequency. Switchgrass has a relatively high potassium uptake (Kering *et al.* 2013) and potassium removal in the 2013 summer harvest was roughly equivalent to annual inputs from the lower SMC rate. Additional potassium losses from the soil due to weather mean the higher rate of SMC may be more suitable to meet the potassium requirement of switchgrass under summer harvest management. Another management alternative may be to harvest only in the fall when potassium returns to the soil from plant tissue.

Soil data from 2014 will provide insight into the effects of sustained switchgrass production at high yields on soil nutrients.

Table 6: Soil nutrient levels in 2013 at the Barry site by SMC treatments.

SMC rate			**Soil Nutrients at 1-5 cm (Mehlich-3 extraction)**				
T/A	**Mg/ha**	**pH**	**P**	**K**	**Mg**	**Ca**	**Al**
					ppm		
0	0	6.8	100	160	121	1954	597
15	34	7.3	265	281	272	2679	282
30	67	7.3	415	237	292	2835	239

Mushroom compost testing results:

At casing, spawn growth was subjectively assessed and reported the colonization to be good for most replicates for all treatments. However, some replicates did show poorer growth in some areas but this was not related to any treatment. Mycelium growth was moderate and no molds were observed. Compost condition was normal for all treatments.

The yield results suggested that the MG had no significant difference in total yield compared to the SG control, Table 1. No significant difference in yields by break was noted for the miscanthus grass and SG control substrates. Total yield for the sorghum stover substrate was significantly lower that the SG control and MG substrates and the difference appear to be a significantly lower second break. This result suggests that sorghum stover may have to be handled differently during composting to achieve better results.

The percent bio-efficiency is defined as the total fresh weight of mushrooms per lb. of substrate dry weight at spawning. Results reported for this experiment suggest the bio-efficiency for these substrates were slightly lower than the MRC standard of 100% or greater.

Table 1. Fresh mushroom yields by break and total and the bio-efficiency for control and miscanthus grass and sorghum stover replacing switch grass in mushroom compost formula.

	Yield[1] (lbs/ft^2)									% Bio-Efficiency
Treatment	Break 1		Break 2		Break 3		Total		Kg/m^2	
Switchgrass Control	1.82	a	1.73	a	0.95	a	4.50	a	21.96	78.09
Miscanthus Grass	1.94	a	1.62	ab	0.88	a	4.44	ab	21.65	77.95
Sorghum Stover	1.56	a	1.40	b	0.84	a	3.80	b	18.53	67.38

[1] Data in the same column with the same letter(s) are not significantly different.

Summary of Major Findings:

- Warm-season grass yields responded to SMC annual applications and achieved production comparable to similar studies on marginal land.
- Cool-season grasses although quick to establish ground cover have produced low-yields relative to warm-season grasses.
- Annual SMC applications are capable of building soil fertility on degraded mine land.
- Mushroom compost testing results are encouraging that miscanthus can be used as an ingredient in mushroom composting. Further testing using higher quantities of miscanthus and mixtures of miscanthus and switchgrass are proposed for the next year.

On-going work:

This April we will apply another annual treatment of SMC to both field sites. Annual soil sampling will continue in July and be followed by yield harvest in the November, thereby providing four seasons of data for the Barry site and three seasons for Blackwood. We are interested in seeing if yields will improve, remain constant, or decline in the next year, particularly for warm-season grasses. An additional year of soil test levels and tissue analysis will allow us to evaluate the potential impact of continued SMC application on soil nutrients in established grass stands and the sustainability of yearly applications.

We are also investigating the economic feasibility of a SMC to feedstock system based in the context of project experience, collected data, regional geography and economics. Based on 2011-3 yields we are working to estimate grass establishment and production costs, SMC-biomass transport costs, and the potential for backhauling with both materials. Economic analysis will also include an evaluation of potential AML sites for SMC application and feedstock production based on available spatial data.

References

Daniels, W.L., B. Stewart, and C.E. Zipper. 2010. Reclamation of Coal Refuse Disposal Areas. Powell River Project Reclamation guidelines for Surface-Mined Land. Virginia cooperative Extension.

Fike, J., J. Galbraith, C. Teutsch, D. Parrish, C. Zipper, and J. Rocket. 2008. Herbaceous Crops for a Biofuels/Bioproducts Industry on Reclaimed Mine Lands. PRP Research and Education Program Reports 2008.

Howard, J.L., D.F. Amos, and W.L. Daniels. 1988. Phosphorus and Potassium Relationships in Southwestern Virginia Coal-Mine Spoils. Journal of Environmental Quality, 17(4), 695-700.

Kering, M. K., Butler, T. J., Biermacher, J. T., Mosali, J., & Guretzky, J. A. 2013. Effect of potassium and nitrogen fertilizer on switchgrass productivity and nutrient removal rates under two harvest systems on a low potassium soil. BioEnergy Research, *6*(1), 329-335.

Marra, M., T. Keene, J. Skousen, and T. Griggs. 2013. Switchgrass yield on reclaimed surface mines for bioenergy production. Journal of Environmental Quality, 42(3), 696-703.

Marra, M., and J. Skousen. 2012. Switchgrass potential on reclaimed surface mines for biofuel production in West Virginia. In: Barnhisel, R. (ed.), Proceedings, American Soc. Mining and Reclamtion, Tupelo, MS, 8-15 June, 2012.

National Cooperative Soil Survey. 1977. Soil Survey of Schuylkill County, Pennsylvania.

Skousen, J., Keene, T., Marra, M., & Gutta, B. 2013. Reclamation of Mined Land with Switchgrass, Miscanthus, and Arundo for Biofuel Production. Journal American Society of Mining and Reclamation, 2(1).