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

Final research report

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I. Introduction:

The broad aim of this research project was to evaluate the potential for value-added utilization of SMC through application to degraded mine soils on mined land (both abandoned and active) for the production of biomass from grass species. Grass feedstock can in turn serve as an input in mushroom substrate 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.

The primary tasks in evaluating the potential for SMC-based feedstock production were 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, 15, 30 T A^{-1} of spent mushroom compost (SMC) on each of these experiments and collected data on biomass yield and monitored soil nutrient levels. These rates were based on the nitrogen requirements of crops. We also sought to determine the amount of mined land area in the Anthracite coal mining region that is potentially suitable for SMC-based biomass production.

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. Estimate the amount of mined land suitable for grass biomass production in the anthracite region.

III. Grass biomass production with SMC amendment

Methods and Procedures:

Study sites & grass species:

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) (Fig. 1). 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 allowed for the evaluation of potential reclamation combinations including SMC and their effects on switchgrass yields and soil nutrients.

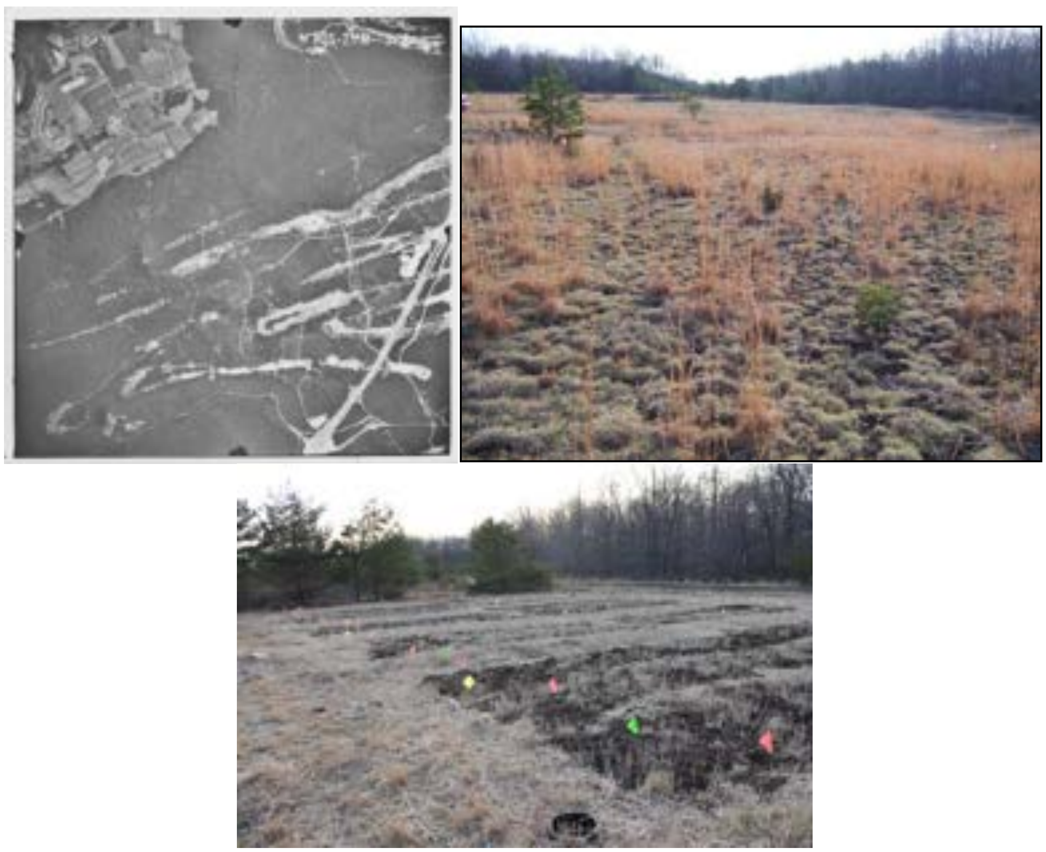

Figure 1. The Barry experiment site. Upper left in a 1971 aerial photo showing strip mining at the site, upper right in 2006 prior to establishment of the experiment, and lower center showing broadcast application of SMC in April 2014.

The second site, Blackwood, was established on a coal refuse dump adjacent to former underground mine (Fig. 2). 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 10 tons/acre of lime kiln dust 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*).

Figure 2. The Blackwood experiment site. The 1939 aerial photo above shows long-term mining disturbance at the site. Below, left shows the cleared, graded coal refuse on which the experiment was established. Below right shows the site after initial seeding in the Fall of 2012.

Prior to reclamation both soils were characterized by moderate to high acidity and low-nutrient levels with poor potential for pastures or farming.

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

<u>Measurements:</u>

We 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
- Plant macronutrient tissue analysis

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).

Research Results:

<u>Yields:</u>

Switchgrass was initially planted at the Barry site in 2006 thus the stand was relatively mature at the outset of this experiment in 2011. Figure 3 shows the site in 2013 and Fig. 4 shows the stand in 2014.

Figure 3. Barry switchgrass stands in July 2013 (left) and November 2013 (right).

Figure 4. Switchgrass stand at the Barry experiment on September 5, 2014.

At the Barry site average switchgrass yields have increased by approximately one ton per acre annually from 2011 to 2014 (Fig. 5). SMC application did affect switchgrass yield in 2011, produced a very small increase in 2012, and notably larger increases in 2013 and 2014. In 2013 and 2014 an interactive effect of SMC with initial reclamation was observed, with a larger SMC response on the lime+fertilizer plots than on the manure+PMS plots. This difference in yield response is likely due to the much lower fertility in the lime+fertilizer soil.

We experimented with double cutting switchgrass in 2013, harvesting first in July and again in November. While the two harvests likely increased total yield, regrowth was relatively small and also appeared to be highly favored by deer as late summer browse. Therefore the second cutting yield was too small to be economically feasible and two cuttings may weaken the stand. Thus a single cutting appears to be the best strategy.

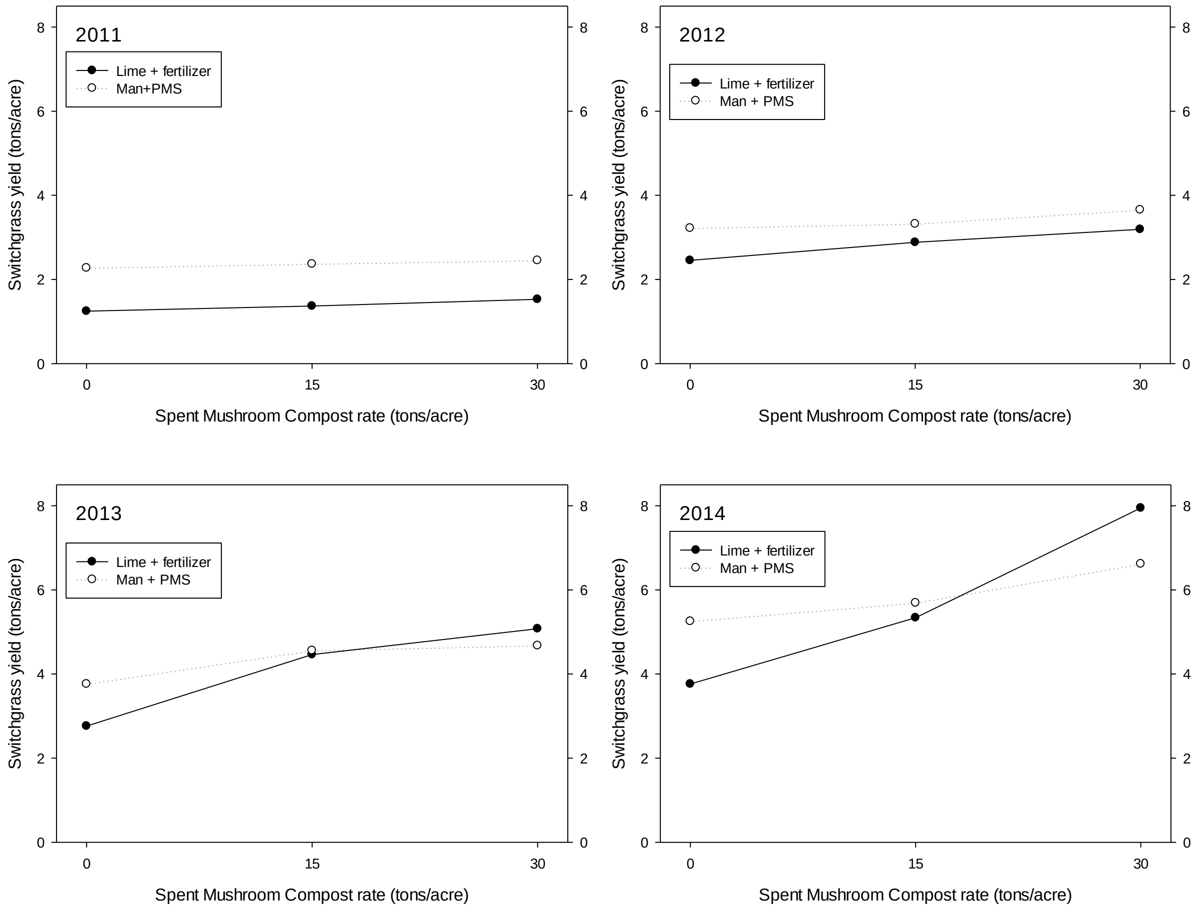

Figure 5. Effect of initial reclamation treatment and SMC application on switchgrass yield from 2011 – 2014 in the Barry experiment.

At the Blackwood site the warm-season grasses, switchgrass and giant miscanthus, have produced several fold greater yields than the cool-season grasses site in each year of the study (Figs. 6-9). Thus although the cool season grasses were quick to establish and provide ground cover, the slower establishing warm season grasses produced more biomass even before the stands were fully established and mature. As was observed with switchgrass in the Barry experiment, yields have increased in each year of the experiment as stands have matured. Establishment of miscanthus has been difficult because rhizomes must be hand planted. Where rhizomes failed to establish we have replanted in both 2013 and 2014.

Where miscanthus rhizomes did establish, plants performed well producing stalks 7 – 8 feet high in 2014. Similar to what we observed in the Barry experiment, grass yields did not respond to SMC application the first time it was applied in 2013, but did respond to the second annual application in 2014.

Figure 6. Switchgrass (foreground) and miscanthus (background) stands at the Blackwood experiment on July 1, 2014.

Figure 7. Miscanthus stand at the Blackwood experiment on September 5, 2014.

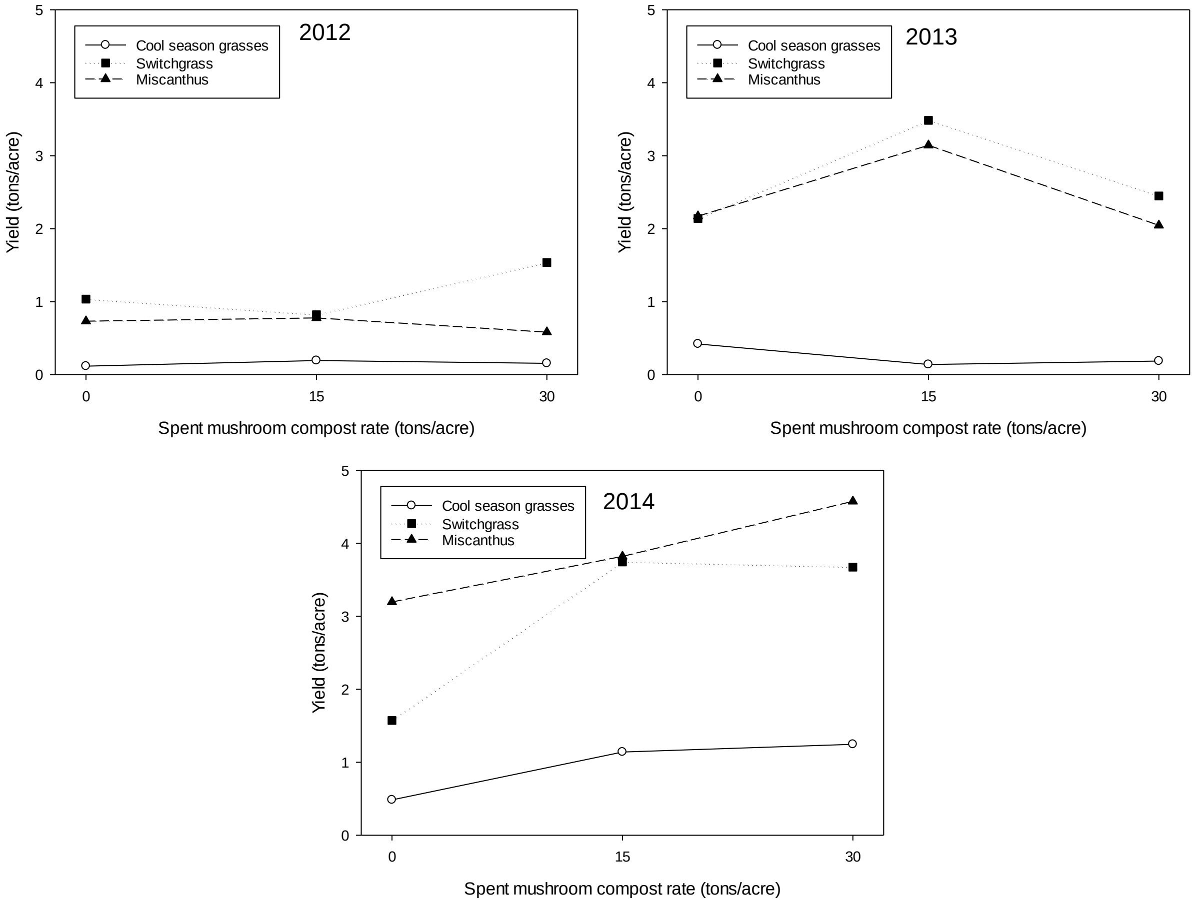

Figure 8. Effect of SMC application on cool season grass (average of 3 species), switchgrass and miscanthus yields in the Blackwood experiment.

Figure 9. Giant miscanthus with person for scale at Blackwood (left) and comparisons with poor performing cool-season grass (right).

Soil nutrients:

Top-dress application of SMC has increased available macronutrients levels (P, K, Ca, Mg) relative to controls in the mine soil surface layer, reduced soil aluminum levels, and maintained near neutral to slightly alkaline pH. The effects of SMC application on Mehlich-3 nutrient levels and soil pH are presented in Table 1 for the Barry experiment and Table 2 for the Blackwood experiment.

Non-reclaimed coal mine soils in Appalachia typically have a moderately low pH and low soil fertility, especially phosphorus. SMC applications have provided phosphorus beyond annual plant needs, thereby mitigating a common nutrient deficiency in mine soils. However, continued annual application of SMC will clearly increase soil P levels far beyond optimum for plant growth and could increase the potential for P loss from these soils. However, due to the perennial grass cover and the chemistry of the underlying mine soil, such losses would be expected to be far less than on agronomic soils. Further research would be required to assess such loss potential.

Nutrient content of harvested warm season grass biomass was relatively unaffected by SMC application (Tables 3 and 4). This is likely because nutrients taken up during the active growth phase are largely translocated to below-ground storage tissues at plant senescence in the Fall. Thus relatively little of the nutrients added with SMC is removed in harvested biomass. Some leaching loss of N and K can be expected. Such losses were not measured in this research project.

Table 1. Effect of SMC applications on 2012 and 2014 soil pH and nutrient levels (Mehlich3 extraction) at the Barry site.

Year	Reclamation	SMC	pH	P	K	Mg	Ca
		tons/acre		------------------------ mg/kg	---------------------		
2012	Lime + Fertilizer	0	6.92	126	121	120	2190
		15	7.32	289	150	208	3064
		30	7.24	375	162	222	3219
	Manure + PMS	0	7.84	615	124	160	11584
		15	7.69	607	138	225	11069
		30	7.58	667	126	232	7629
2014	Lime + Fertilizer	0	7.22	103	111	130	2221
		15	7.63	369	210	234	4604
		30	7.46	485	203	250	6905
	Manure + PMS	0	7.88	415	90	113	8554
		15	7.76	451	161	222	10220
		30	7.57	555	179	290	9340

Table 2. Effect of SMC applications on soil pH and nutrient levels (Mehlich3 extractions) at the Blackwood site.

Year	SMC tons/acre	pH	P	K	Mg	Ca
			mg/kg			
2012	-	7.32	164	172	261	2978
2013	0	7.51	222	157	278	3268
	15	7.59	328	276	325	3642
	30	7.59	400	345	388	3961
2014	0	7.61	284	140	201	4825
	15	7.48	419	232	322	5745
	30	7.47	576	237	394	6560

Table 3. Effect of initial reclamation treatment and SMC application on switchgrass tissue nutrient content in Fall 2013 at the Barry experiment.

Reclamation	SMC tons/acre	C	N	P	K	Ca	Mg
		mg/kg					
Lime+fertilizer	0	455	6.36	1.20	2.70	5.40	1.36
	15	456	6.58	1.32	3.85	4.83	1.26
	30	461	7.34	1.32	4.02	4.82	1.32
Manure+PMS	0	458	7.34	1.36	3.16	5.47	1.28
	15	461	7.51	1.34	3.39	5.45	1.29
	30	458	8.65	1.30	4.12	4.60	1.31

Table 4. Effect SMC application on switchgrass and miscanthus tissue nutrient content in Fall 2013 at the Blackwood experiment.

Grass	SMC tons/acre	C	N	P	K	Ca	Mg
		mg/kg					
Switchgrass	0	465	6.58	1.05	6.58	3.12	1.25
	15	464	6.46	0.91	8.01	3.20	1.24
	30	462	7.54	1.13	8.81	2.84	1.58
Miscanthus	0	466	5.30	0.65	5.22	3.37	0.80
	15	462	10.0	1.22	8.57	4.32	1.22
	30	465	5.60	0.70	5.82	3.17	1.07

IV. Determination of Anthracite region mined land suitable for biomass production

Materials and Methods

A number of data sets are available for the Anthracite coal mining region which are instructive to identifying suitable areas for SMC-based reclamation and grass biomass production, however, a specific regional inventory which includes active mine sites, reclaimed mined land, and abandoned mined land (AML) does not exist for Pennsylvania's Anthracite coal region. The National Land Cover Database (NLCD) has produced land use land cover (LULC) maps of the entire nation at resolution of 30-meters (MRLC, 2014). However the relatively course resolution of NLCD datasets limits their ability to accurately distinguish inter-site topography and fragmentation of mined areas. The Pennsylvania Department of Environmental Protection (DEP) and Office of Surface Mining (OSM) have produced detailed AML inventories, however, these do not provide details of surface groundcover. Likewise, The Eastern Pennsylvania Coalition for Abandoned Mine Reclamation (EPCAMR) has produced shapefiles of "AML Problem Areas" specific to Pennsylvania, but this does not discriminate between LULC within these areas. Data layers delineating mined soils based on the National Soil Cooperative Survey (1956-1977) are now outdated due to continued mining and lack information on current land use and land cover. The Pennsylvania State University Mine Map Atlas provides aerial imagery and United State Geological Survey maps are more suited for site-specific use than for a regionally extensive inventory. The need for a more detailed map of suitable lands for SMC application in the region warranted the creation of a new inventory based on project data and recent imagery.

In recent years, the availability of high-resolution imagery has allowed for more detailed mapping of mine sites in the Appalachian in comparison to Landsat. Commercial platforms include Quickbird and RapidEye are ideal for landscape analysis at both the site-specific and regional level, but come with significant costs. In contrast, free-platforms such as Google Earth and Bing Maps are useful for [looking at sites] but have limited values in landscape based analysis. The National Agricultural Inventory Program (NAIP) provides high-resolution 1-meter spectral data for free, representing a compromise between commercial imagery and other free imagery. NAIP imagery has been used to map mining, mine reclamation, and disturbances caused by gas extraction.

High resolution imagery also allows for textural analysis. Texture can be smooth for areas without much differentiation such as bodies of water or grass fields, intermediate, as in the case of low-lying brush among grasslands, or rough or course as in the case of forests. Mottled and/or stripped may occur across vegetation/landscape gradients or because of anthropogenic patterns such as city planning, irrigation, or fallowing. Textural methods in high-resolution imagery have been commonly employed in the classification of forests, including specific species of trees, urban environments, and the identification of individual and/or small groups of trees within the urban environment. These techniques can be valuable on non-forested former mine sites which can vary between relatively flat pasture like conditions to dense shrub land covered interspersed with trees.

The objective of GIS analysis was to determine the extent and nature of a theoretical SMC to mined land system based on project results and experience in conjunction with a combination of remote sensing techniques. Additional details of the GIS and NAIP-image processing methodology are not included in this report but are available upon request.

Results

Total area

Total acreage of core areas was calculated at 18,030 ha (44,536 acres) and was a mix of AML, previously reclaimed and active mine sites (Table 5). This area is consistent with Frank (1964) who estimate the area of total disturbed lands in the region at 43,500 ha of which roughly half had not been reforested. It is reasonable to assume that although reforestation has progressed on former mine sites since the 1960's active mine sites, active mining has also cleared new land. An area of 18,030 ha is a fraction of all mined lands in Pennsylvania. To provide context and a relative comparison, the amount of AML in Pennsylvania is estimated at approximately 80,000 ha (200,000 acres).

Table 5. Land area suitable for SMC-based reclamation and grass biomass production by county in the Anthracite region of PA.

County	Ha	Acres	% of total
Schuylkill	7,790	19,241	43.19
Luzerne	5,532	13,663	30.67
Lackawanna	2,007	4,958	11.13
Northumberland	1,528	3,773	8.47
Carbon	702	1,734	3.89
Columbia	476	1,175	2.64
Dauphin	0	0	0
Total area	18,035	44,546	100%

Area by county

Area of suitable lands for SMC-application differed considerably between the seven counties of the Anthracite coal region (Table 6.2). Schuylkill County had the largest amount of at 7,790 ha (19,241 acres) or 43.19 % of total lands in the inventory. The Southern Anthracite field runs SE to NE along the central axis of Schuylkill County. The second largest was Luzerne County at 5,532 ha (13,663 acres) followed by Lackawanna County at 2,007 ha (4,958 acres), both of which contain the bulk of the Northern Anthracite field. Northumberland County had 1,528 ha (3,773 acres), while Carbon and Columbia counties had 702 ha (1,734 acres) and 476 ha (1,175 acres), respectively. In the extreme northeast of Dauphin County forests have effectively covered the small portion of formally mined land, resulting in 0 ha of land for biomass production.

Landscape fragmentation and management implications

Although substantial amount of land suitable for SMC application exists across the Anthracite region, suitable lands were highly fragmented spatially. The causes of fragmentation in the Anthracite region varied across the area. In the Southern Anthracite field mine lands were largely fragmented by forest and shrub regrowth, while urban development in the proximity of Wilkes-Barre accounted for fragmentation in the Northern Anthracite field. The majority of LFA-classified core areas were of the smallest core category and smaller than nearby agricultural lands in adjacent areas.

The fragmented nature of available mined lands presents a potential limitation to the extensive agronomic production of biomass with SMC (or other alternative amendments). Establishment, management, labor, and transportation will increase where available lands are of relatively small acreage and/or widely geographically dispersed. In the Anthracite region, both are true, especially of AML sites. Older AML sites in the Appalachian region are often partially reforested with limited transportation (unpaved or unimproved roads). The presence of differential local government, management, and ownership regimes across the region further complicates renting or acquisition of large tracts of open land. For these reasons, improvement of individual AML tracts is an unlikely option for SMC-based biomass production.

Where trees or shrub land fragment large flat areas tree removal could expand production sites, but would require the use of heavy equipment at increased costs. Preference for low-intensity management of marginal land would likely make this an unattractive option, except in cases where timber is harvestable quality. Forest quality on reclaimed mine land is typically poor due to traditional preference for early successional species to achieve rapid ground cover.

A more attractive alternative for mushroom producers for biomass production may be recently disturbed sites on active mine sites. Partnerships with mine operations could provide a number of attractive considerations including access to heavy equipment and the potential to consolidate and improve larger tracts of land in comparison to AML. In addition, newly mined barren lands have maintained access roads, on-site heavy equipment for regarding and hauling, and storage areas for stockpiling amendments.

V. <u>Summary of Major Findings:</u>

- Mined land reclamation using 30 tons/acre of SMC as an initial mine soil amendment allowed for successful establishment and both cool and warm season grasses.
- Cool-season grasses, although quick to establish ground cover on mine soil, produced low-yields relative to warm-season grasses and are not an economically feasible option for SMC based feedstock biomass production on mine lands
- Warm-season grasses (switchgrass and miscanthus) were successfully established on SMC amended mine soil. Warm season grass yields increased during each year of production as the grasses became more fully established and the stands matured.
- Warm season grass yield was increased by annual application of SMC at rates of 15 and 30 tons/acre. However, yield responses to the first, and sometimes also the second SMC application were very small or not significant. Yield response became greater with each subsequent SMC application.

- Maximum switchgrass yields with SMC amendment were in the range 5 – 8 tons/acre. Maximum miscanthus yields with SMC were in the range 3.5 – 4.5 tons/acre. Miscanthus yields are expected to increase in subsequent years as the stand matures.
- Annual SMC applications are capable of building soil fertility on degraded mine land. Continued annual applications will increase soil P levels to levels far in excess of optimum. Although the potential for P loss from mine soils covered with perennial grasses is small, such accumulations should be avoided. We expect that after 3 – 4 annual SMC applications, alternate year application of 15 tons/acre of SMC will likely sustain warm season grass production.
- GIS and remote sensing data indicate there is 44,500 acres of mined land suitable for grass biomass production in the Anthracite region. However this substantial land area is highly fragmented and some may be difficult to access. The best option for SMC based mine soil reclamation and warm season grass biomass production appears to be lands that are actively being surface mined. During the reclamation process these lands could be contoured to facilitate agronomic production of warm season grasses.