SWITCHGRASS PRODUCTION ON ABANDONED MINED LAND RECLAIMED WITH MANURE BASED AMENDMENTS[1]

R.C. Stehouwer[2], A.L. Dere, K.E. MacDonald, and Scott Van de Mark

Abstract. Reclaimed mined lands are an underutilized resource that could produce biomass for biofuels. Due to low quality soils on mined lands, biomass yields are likely to be below those of agricultural soils. To determine if manure based soil amendments could be used to rapidly increase soil organic C and nutrient pools and their effect on biomass yields, we conducted an experiment on an acidic abandoned mined land soil in which switchgrass was planted following soil amendment with composted poultry layer manure (67 and 134 Mg ha^{-1}, 30 and 60), layer manure mixed with paper mill sludge (PMS) (manure N equivalent to 67 Mg ha^{-1} compost, mixed at C:N ratios of 20 and 30), or with lime and inorganic fertilizer. The experiment was established in 2006 and soil pH, total C and N, switchgrass yield, and tissue N, P and K were measured. By 2009 soil organic C in the upper 5 cm of soil increased from 3.2% before reclamation to 5.9 to 6.9% with manure based amendments, and to 4.2% with lime and fertilizer amendment. Soil N in the upper 5 cm was 0.09% before reclamation and in 2009 had doubled with lime and fertilizer, tripled with manure+PMS, and quadrupled with compost amendments. In each year of switchgrass production the manure based amendments produced more biomass than the lime and fertilizer amendments. In 2009 yields ranged from 4 to 5 Mg ha^{-1} (1.8 to 2.2 ton $acre^{-1}$)for the manure based amendments, and just over 2 Mg ha^{-1} (0.9 ton $acre^{-1}$) for lime and fertilizer amendment. Harvest removal of N suggests yields may not be sustainable without periodic addition of N. These results show that amendment with manure based materials can improve mine soil quality and nutrient supply to substantially increase switchgrass yield potential.

Additional Key Words: compost, paper mill sludge, carbon, nitrogen, biomass

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Introduction

The convergence of several environmental, economic and energy issues in Pennsylvania and other states in the Eastern US coal production region presents a unique opportunity to utilize mined land reclamation (both active surface mining and abandoned mined land sites) to help resolve these issues and convert these lands into sustainable biomass production areas. These issues include:

1. Increasing costs for energy coupled with increasing demand for coal.
2. The need for large land areas not already dedicated to food production to facilitate the transition to renewable bio-based energy sources.
3. Excess manure nutrients generated by intensive animal production and potential degradation of air and water quality,
4. The negative environmental impact of abandoned mined lands (AML) and the need to stimulate additional economic development in coal mining regions.

An analysis of the potential impact of the increased production and use of biofuels in Pennsylvania projects the production of 1200 million liters (315 million gallons) of ethanol annually from cellulosic materials by 2017 (Urbanchuk, 2006). This is in addition to 1280 million liters (338 million gallons) annually from grain feedstocks. Using a conversion rate of 375 L Mg^{-1} (90 gal ton^{-1}) and biomass production of 6.7 Mg ha^{-1} y^{-1} (3 tons $acre^{-1}$ y^{-1}) would indicate a need for 0.4 million ha (1 million acres) of land for cellulosic ethanol production. Direct combustion of biomass will further increase the demand for biomass production in Pennsylvania. With just over 1.6 million ha (4 million acres) of harvested crop land in the state in 2006, it is clear that this demand for additional land area devoted to biomass production cannot be supplied from current agricultural lands. Other land resources must be utilized.

Mined lands in Pennsylvania provide a unique opportunity to help supply this need for land area. Throughout the coal mining regions of the Eastern US there are hundreds of thousands of acres of (AML). Pennsylvania alone has more than 80,000 ha (200,000 acres) of abandoned mined lands (AML) and present day surface mining reclaims approximately 2,000 ha (5,000 acres) of additional lands annually. However the soil resources on these sites are either non-existent or severely degraded in the case of AML areas or, where soils have been conserved during mining operations, they are often limited in quantity, quality and natural productivity. In order to achieve sustainable biomass production on mined lands, the soils on these sites must first be effectively ameliorated to greatly increase their long-term production potential. Secondly, suitable biomass species, species mixes, establishment and management techniques must be identified.

Most AML sites and many active mining or re-mining sites lack any true topsoil and consist primarily of mine spoil or overburden whose properties can range from loose, course textured material with many rock fragments, to highly compacted high clay material (Ciolkosz, 1983). Mine spoils often have limited ability to store plant available water, and are usually very low in N and P fertility, low organic matter content, and low biological activity (Sutton and Dick, 1987).

Mine reclamation research and practice has demonstrated that organic amendments such as biosolids can support revegetation of mine spoil materials rather than relying on imported natural topsoil or the use of inorganic amendments such as limestone and fertilizer (Pichtel et al., 1994, Pietz et al., 1989 a, b; Sopper, 1993; Stehouwer, 1997). A largely untapped source of organic nutrients in Pennsylvania is animal manure. Pennsylvania produces just over 1.8 million Mg (2 million tons) of poultry manure annually and an estimated 75% of this manure must find off-farm uses in order for those farms to comply with Pennsylvania phosphorous-based nutrient management planning requirements (personal communication from D. Goodlander, Pennsylvania State Conservation Commission). A large amount of this manure could potentially be utilized in mine reclamation. In addition farmers can generate nutrient reduction credits by exporting more manure than is required by their respective nutrient management plans and thereby earn income through the sale of those credits under the Pennsylvania nutrient trading program. The combination of the regulatory cap and the economic incentive can provide for a large annual supply of manure and offset costs to transport of this excess manure to receiving sites.

However, current reclamation practices with organic materials do not effectively sequester the added nutrients and carbon. For example, in Pennsylvania the maximum (and most often used) reclamation rate for biosolids is 134 Mg ha^{-1} (60 tons $acre^{-1}$) on a dry weight basis. Stehouwer et al. (2006) documented that during two years following biosolids application 44% of the added nitrogen was lost via leaching. Thus the improvements in soil quality essential to move from revegetation to sustained, intensive production of biomass crops on reclaimed mined lands are not realized.

Economically accomplishing the rapid and sustained soil quality improvement essential for biomass production necessitates a large one-time additions of organic carbon and nutrients. The problem with making such large additions with manures is that they have low C/N ratios. The nitrogen is rapidly mineralized and rapidly lost from the soil rather than being sequestered for future plant production. This is not only a loss of future production potential but also has possible adverse effects on water quality. We have investigated two methods for stabilizing manure nutrients and reducing leaching of N and P; composting the manure or mixing manure with a high organic C material to increase the overall C:N ratio of the amendment material. An initial greenhouse experiment showed that composting was very effective and nearly eliminated nutrient leaching. Mixing poultry layer manure with short fiber paper mill residuals at a C:N ratio of 30 greatly reduced N leaching relative to manure alone though it was not as effective as composting. Compared to amendment with lime and fertilizer, compost produced almost a 4-fold increase and manure+PMS up to a 14-fold increase in switchgrass growth (unpublished data).

In 2006 we established a field experiment on an AML site in Schuylkill County, Pennsylvania to test these amendments under field conditions. The objectives of the experiment were to determine the effects mine soil amendment with composted layer manure or layer manure mixed with PMS or conventional lime and fertilizer on:

1. Leaching of N and P,
2. Soil sequestration of C and N, and
3. Switchgrass growth.

With lime and fertilizer amendment leaching of NO_3^- + NH_4^+ was minimal, amounting to just 25 kg N ha^{-1} (22 lb N acre^{-1}) during 3 years following reclamation (Dere et al., 2008). Compost amendment resulted in similar amounts of leaching despite application of 13 and 26 times more total N. Combined manure and PMS application leached 171 and 339 kg N ha^{-1} (153 and 302 lb N acre^{-1}) at C:N ratios of 20 and 30, respectively. The leaching losses were 8 and 16% of applied total N. With all treatments 67 to 89% of total N leaching occurred in the first year following reclamation, and less than 2% in the third year. There were no differences in P leaching among any of the treatments and all leached less than 3.8 kg P ha^{-1} (3.4 lb P $acre^{-1}$) during 3 the three years following reclamation.

In this manuscript we report on the second two objectives of the experiment.

Materials and Methods

A multi-year field experiment was initiated in the spring of 2006. The field site is an abandoned coal surface mine from the 1950s located in Schuylkill County, Pa (Fig 1.). The soil is classified as an Udorthent strip mine. Initial site texture was a very channery sandy loam, with an average soil pH of 5.1(1:1 in water) (Eckert and Sims, 1995). Bulk density was estimated at 1.4 g cm^{-3} and initial total soil carbon was measured at 3.1% (Nelson and Sommers, 1996) reflecting the presence of coal fragments in the mine spoil.

Figure 1. View of the AML area in Spring 2006 prior to establishment of the experiment.

Five reclamation treatments were each replicated four times in a randomized complete block design with each plot measuring 6.1 m x 9.1 m (20 x 30 ft). The treatments included the standard reclamation (control) of lime and inorganic fertilizer amendment (112 kg N ha^{-1} as NH_4NO_3; 196 kg P ha^{-1} as triple super phosphate; 186 kg K ha^{-1} as KCl), two rates of composted poultry layer manure, and poultry layer manure blended with paper mill sludge (manure+PMS mixes) to give C:N ratios of 20 and 30. Table 1 gives treatment quantities and compositions, along with their respective soil additions of N and P.

Carbon and N were measured using the combustion method on a Fisons NA 1500 Elemental Analyzer (Nelson and Sommers, 1996). Initial pH of the manure and paper mill sludge was 8.3 and 7.3, respectively. The poultry layer manure was composted by mixing with leaves, shredded wood and water and placed in an open windrow. During active composting the windrow was turned every 7 to 14 days depending on when windrow temperature began to decrease. Following active composting the compost was matured for two months in a static pile. The fresh manure and paper mill sludge treatments were hauled to the experiment site and mixed on site to produce the desired C:N ratio blends. All amendments were surface applied and then incorporated into the upper 5 to 8 cm of the soil using the teeth on a front-end loader bucket. Due to the extremely rocky nature of the site, it was not possible to achieve deeper incorporation.

Table 1. Reclamation treatments used and quantities of material, C and nutrients added with each soil amendment.

	Additions to minespoil				
Treatment	Material	C	N	P	K
	—— Mg ha^{-1} ——		—————— kg ha^{-1} ——————		
Lime and fertilizer					
Limestone	13.4	1.61	—	—	—
NH_4NO_3	1.28	—	112	—	—
TSP	4.00	—	—	196	—
KCl	1.50	—	—	—	186
Compost 1	78	27.0	2117	1052	81.3
Compost 2	156	54.1	4234	2104	163
20:1 manure+PMS					
layer manure	50	15.5	2117	1052	216
paper mill sludge	103	27.0	—	—	—
30:1 manure+PMS					
layer manure	50	15.5	2117	1052	216
paper mill sludge	184	48.2	—	—	—

All plots were initially planted with a combination of 11.2 kg ha^{-1} (10 lbs ac^{-1}) of switchgrass v. Cave-in-Rock (*Panicum virgatum* L.) and 2.2 kg ha^{-1} (2 lbs ac^{-1}) of an annual ryegrass (*Lolium rigidum* Gaud.) immediately following amendment application; the ryegrass was included as a nurse crop to provide some rapid cover prior to switchgrass establishment. Following seeding, one bale of straw mulch was applied to each plot. Vigorous ryegrass growth prevented the establishment of switchgrass in the first year after planting; therefore, plots were reseeded with switchgrass in spring 2007. To minimize ryegrass competition in the first year, the plots were mowed at approximately 15 cm (6 in) in May and June of 2007. Biomass yield was measured by clipping all vegetation present in one 1.0-m^2 quadrat randomly located within each plot in October of each year. Harvested plant material was dried at 60C for 48 h and weighed to determine biomass yield. The entire plot area was then mowed and cut biomass was raked off the plot area.

Figure 2. Experiment area in Spring 2006 following application of soil amendments and planting switchgrass and annual ryegrass. In the foreground is a compost amended plot, and center left is a manure+PMS amended plot.

Soil in each plot was sampled at a depth of 0-5 cm prior to reclamation and again in the fall of each year of the study. Sampling was done by compositing 5 cores from each plot and collecting an approximately 1 kg subsample. Soil material was air-dried and passed through a 2-mm sieve prior to analysis for pH and for total C and N by combustion.

Data were analyzed using analysis of variance and single degree of freedom contrasts for planed comparisons using a significance level of $\alpha = 0.05$. All statistical analysis was performed using SAS software (SAS Institute, 2003).

Results and Discussion

Mine soil quality.

Compared to pre-reclamation levels, all soil amendments increased soil pH and C and N pools (Table 2). The smallest increases were given by the lime and fertilizer amendment as expected since this treatment added no organic C and only a small amount of N. The magnitude of the increase in soil N content with lime and fertilizer addition was not expected. Increases in soil C concentration in all treatments reflect addition of C in the amendments along with subsequent input of plant root biomass. The larger increases in C with compost addition reflect the more stable nature of the added C compared to that added with manure+PMS. Compost amendment also gave the largest increases in N. The larger increase with compost 2 was expected since twice as much N was added with this treatment than with the other manure based treatments. The compost 1 amendment and both manure+PMS amendments all added the same amount of N, but more compost N than manure N was retained in the upper 5 cm of soil. The manure based amendments clearly improved mine soil quality to a greater extent than limestone and fertilizer amendment. However, the apparently smaller increase in soil N pool with manure+PMS has implications for long term sustainability of switchgrass production.

Biomass production.

The annual ryegrass that was planted in 2006 and was intended to serve as a nurse crop for the more slowly establishing switchgrass, instead out-competed the switchgrass and was by far the dominant species in all treatments (Fig. 3). No switchgrass could be found in any plots in the fall of 2006. While the high fertility in the compost and manure+PMS plots likely contributed to the rapid growth of ryegrass, the same effect was observed with the lower fertility lime and fertilizer amendment. In the fall of 2006 there was no effect of soil amendment on biomass yield (Fig. 4).

Table 2. Soil pH and total C and N concentration in the 0 – 5 cm depth.

Sample Date and Soil Amendment	pH	Total C	Total N
		g kg^{-1}	g kg^{-1}
Spring 2006 (before reclamation)			
Plot area	5.10	31.8	0.9
Spring 2009 (3 years after reclamation			
Lime and fertilizer	6.99c†	48.1c	2.1b
Compost 1	7.28b	94.2a	6.8a
Compost 2	7.34ab	99.5a	7.5a
Manure+PMS (20)	7.30ab	60.5bc	3.0b
Manure+PMS (30)	7.50a	81.3ab	3.7b

†Within columns values followed by different letters are statistically different at the α=0.05 level.

Figure 3. Experiment area in July, 2006 showing dense cover of annual ryegrass.

Switchgrass was reseeded in the spring of 2007, and annual ryegrass was mowed twice in early summer of 2007 to remove seed heads before seed could mature. Switchgrass was established during the 2007 growing season, but the mowing and transition from ryegrass to switchgrass resulted much less biomass production in 2007 than in 2006. Despite the reduced yields, there were small differences among treatments with the 2x compost rate producing greater biomass than the lime and fertilizer treatment (Fig. 5).

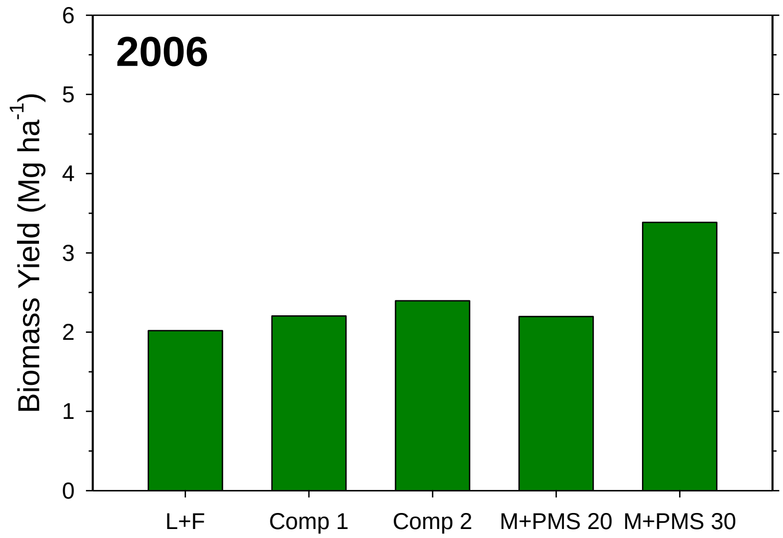

Figure 4. Effect of conventional lime and fertilizer amendment (L+F) and manure based amendments (Comp1, compost 1; Comp2, compost 2; M+PMS20, manure+PMS 20:1; M+PMS30, manure+PMS 30:1) on biomass production in 2006. There were no significant treatment effects on biomass yield in 2006.

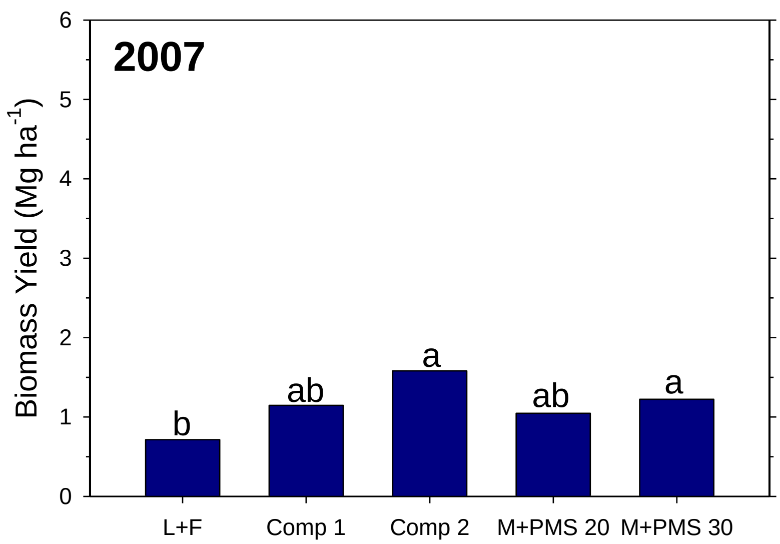

Figure 5. Effect of conventional lime and fertilizer amendment (L+F) and manure based amendments (Comp1, compost 1; Comp2, compost 2; M+PMS20, manure+PMS 20:1; M+PMS30, manure+PMS 30:1) on biomass production in 2007. Bars marked by the same letter are not significantly different.

In 2008, the second year of switchgrass growth, overall biomass production was greater than in the previous two years, and all of the manure based amendments produced greater yields than lime and fertilizer amendment (Figs. 6 and 7). Although some annual ryegrass was present in the early summer, switchgrass was the dominant species from mid-summer onward.

Figure 6. View of experimental plots in July, 2008 showing 2-year stands of switchgrass.

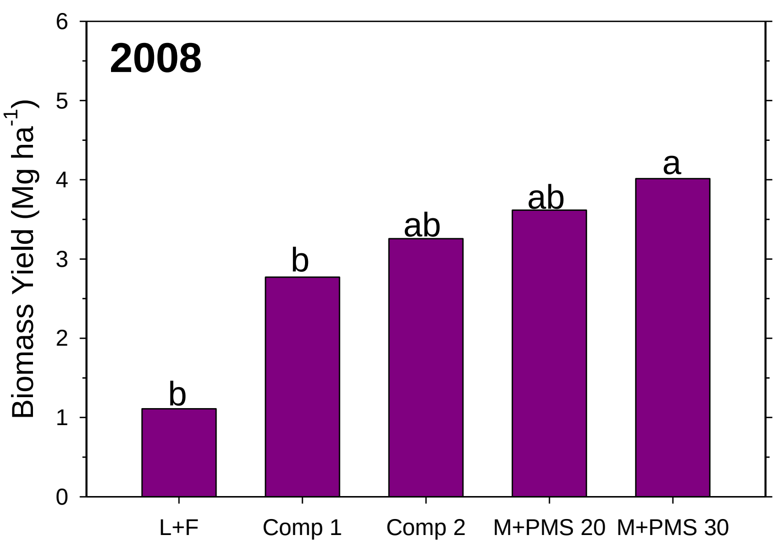

Figure 7. Effect of conventional lime and fertilizer amendment (L+F) and manure based amendments (Comp1, compost 1; Comp2, compost 2; M+PMS20, manure+PMS 20:1; M+PMS30, manure+PMS 30:1) on biomass production in 2008. Bars marked by the same letter are not significantly different.

In 2009 vegetation in all plots was predominantly switchgrass (Fig. 8). Biomass production with the third year switchgrass stand was greater than in any previous year and again, yield with the manure based amendments were nearly twice that of the lime and fertilizer amendment (Fig. 9). By comparison, Adler et al. (2006) reported yields of fertilized, mature switchgrass stands on agricultural production soils in central Pennsylvania ranging from 6.7 to 8.6 Mg ha^{-1} (3.0 to 3.8 tons acre^{-1}), and yields of mature switchgrass stands on lower quality conservation reserve lands of 2.9 to 5.1 Mg ha^{-1} (1.3 to 2.3 tons acre^{-1}). Although yields on this AML site with manure based reclamation have not attained agronomic yield potential, it is possible that production could increase further as the stand matures. No plant nutrients have been added since reclamation and it is possible that topdressing with agronomic rates of inorganic fertilizer or manure could result in further yield increases. We hope to split the existing plots in 2010 to allow testing of yield sustainability without additional nutrients and yield potential with added nutrition.

Figure 8. View of experimental plots in October, 2009 showing 3-year stands of switchgrass.

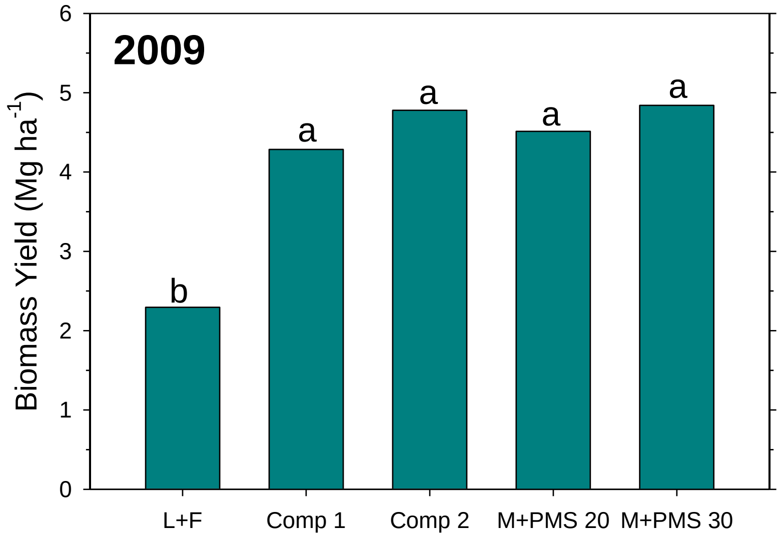

Figure 9. Effect of conventional lime and fertilizer amendment (L+F) and manure based amendments (Comp1, compost 1; Comp2, compost 2; M+PMS20, manure+PMS 20:1; M+PMS30, manure+PMS 30:1) on biomass production in 2009. Bars marked by the same letter are not significantly different.

Tissue analysis.

There were no differences among treatments for tissue N, P or K concentrations (Table 2). Our measured concentrations for N were very close to the critical value of 10 g kg^{-1} reported by Lewandoski and Kircherer (1997). Tissue concentrations in our study were somewhat larger than those reported by Adler et al. (2006) who measured N, P and K concentrations ranging from 3.28 – 6.21, 0.80 – 0.89, and 3.33 – 3.45 g kg^{-1} respectively. In our study we measured similar P removal and somewhat lower N removal (Table 2). Even though the manure amendments added over 2,000 kg N ha^{-1} (1785 lb N $acre^{-1}$), at some point labile N produced from this soil N pool will no longer supply the annual harvest removal of 40 – 50 kg N ha^{-1} (36 to 45 lb N $acre^{-1}$) and additional N input will be needed to maintain yields. Future research should identify the frequency and quantity of N application needed sustained production.

Conclusions

Four years after reclamation, manure based mine soil amendments, compared to conventional lime and fertilizer amendment, have provided greater increases in soil quality (as indicated by pH and soil C and N concentration) and have produced twice as much switchgrass biomass. With either composted layer manure or layer manure mixed with PMS amendment the third year biomass yield of switchgrass yields ranged from 4.3 – 4.8 Mg ha^{-1} (1.9 to 2.1 tons acre^{-1}); approximately 0.5 – 0.7 of yields for mature switchgrass stands on agricultural soil in central Pennsylvania. Yields have increased in each year of growth, and if this trend continues the gap between production on reclaimed mined land and agricultural soil may narrow. Despite substantial increases in soil N content with the manure based amendments, harvest removal of N and other nutrients suggests it will be necessary to periodically apply additional fertility to maintain high levels of production.

Table 2. Concentrations and harvest removal of N, P and K in switchgrass grown in 2009 on mine soil amended in 2006 with lime and fertilizer or manure based amendments.

	Tissue concentration			Harvest Removal		
Soil Amendment	N	P	K	N	P	K
	------------ g kg^{-1} -----------			------------ kg ha^{-1} -----------		
Lime and fertilizer	10.6	2.88	8.30	24.3	6.6	19.0
Compost 1	10.4	2.33	8.78	44.6	10.0	37.6
Compost 2	12.2	3.58	10.2	58.3	17.1	48.7
Manure+PMS 20:1	9.25	2.48	8.70	41.7	11.2	39.3
Manure+PMS 30:1	8.95	2.13	7.90	43.3	10.3	38.2

Literature Cited

Adler, P.R., M.A. Sanderson, A.A. Boateng, P.J. Weimer, and H.G. Jung. 2006. Biomass Yield and Biofuel Quality of Switchgrass Harvested in Fall or Spring. Agron. J. 98:1518-1525. http://dx.doi.org/10.2134/agronj2005.0351.

Ciolkosz, E.J. 1983. Characteristics, interpretations and uses of Pennsylvania minesoils. Pennsylvania State University, College of Agriculture, Agricultural Experiment Station, University Park, PA.

Dere, A.L., R.C. Stehouwer, and K.E. McDonald. 2008. Nutrient fluxes from abandoned mine soil reclaimed with poultry manure and paper mill sludge. Proceedings America Society of Mining and Reclamation, 2008 pp 298-315. http://dx.doi.org/10.21000/JASMR08010298.

Eckert, D. and J. Thomas Sims. 1995. Recommended soil pH and lime requirement tests. p. 11-16. In J. Thomas Sims and A. Wolf (eds.) Recommended Soil Testing Procedures for the Northeastern United States. Northeast Regional Bulletin #493. Agricultural Experiment Station, University of Delaware, Newark, DE.

Lewandowski, I., and A. Kicherer. 1997. Combustion quality of biomass: Practical relevance and experiments to modify the biomass quality of Miscanthus × gigantus. Eur. J. Agron. 6:163-177. http://dx.doi.org/10.1016/S1161-0301(96)02044-8.

Nelson, D. W. and L. E. Sommers. 1996. Total Carbon, Organic Carbon, and Organic Matter. p 961-1010. In D.L. Sparks (ed). Methods of Soil Analysis, Part 3. Chemical Methods. Soil Science Society of America Book Series Number 5. American Society of Agronomy, Madison, WI.

Pichtel, J.R., W.A. Dick, and P. Sutton. 1994. Comparison of amendments and management practices for long-term reclamation of abandoned mine lands. J. Environ. Qual. 23:766-772. http://dx.doi.org/10.2134/jeq1994.00472425002300040022x.

Pietz, J.R., C.R. Carlson Jr., J.R. Peterson, D.R. Zeng, and C.Lue-Hing. 1989a. Application of sewage sludge and other amendments to coal refuse material: I. Effects on chemical composition. J. Environ. Qual. 18:164-169. http://dx.doi.org/10.2134/jeq1989.00472425001800020006x

Pietz, J.R., C.R. Carlson Jr., J.R. Peterson, D.R. Zeng, and C.Lue-Hing. 1989b. Application of sewage sludge and other amendments to coal refuse material: II. Effects on revegetation. J. Environ. Qual. 18:169-173. http://dx.doi.org/10.2134/jeq1989.00472425001800020007x.

SAS Institute. 2003. The SAS system for Windows. Release 9.1. SAS Inst., Cary, N.C.

Sopper, W. E. 1993. Municipal Sludge Use in Land Reclamation. 163 p. Lewis Publishers, Boca Raton, FL.

Stehouwer, R.C. 1997. Amendment of acidic coal refuse with yard waste compost and alkaline materials: Effects on leachate quality and plant growth. Compost Science and Utilization. 5(3):81-92. http://dx.doi.org/10.1080/1065657X.1997.10701889.

Stehouwer, R.C., R.L. Day and K.E. Macneal. 2006. Nutrient and trace element flux following surface mine reclamation with biosolids. J. Environ. Qual. 35:1118-1126. http://dx.doi.org/10.2134/jeq2005.0134.

Sutton, P. and W.A. Dick. 1987. Reclamation of acidic mined lands in humid areas. Advances in Agronomy 41:377-405. http://dx.doi.org/10.1016/S0065-2113(08)60809-3.

Urbanchuk, J.M. 2006. Economic impact of the increased use of biofuels and coal derived transportation fuels for the commonwealth of Pennsylvania. Prepared for Citizens for Pennsylvania's Future. John M. Urbanchuck, Director, LECG LLC