NETL AAD DOCUMENT CONTROL BLDG. 921
U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
P. O. BOX 10940
PITTSBURGH, PA 15236-0940

Technical Progress Report

**“Restoring Sustainable Forests on Appalachian Mined Lands for Wood Products,
Renewable Energy, Carbon Sequestration, and Other Ecosystem Services”**

Quarterly Report

Report Period: January-March, 2004

Principal Author: James A. Burger

Principal Investigators: J. Burger, J. Galbraith, T. Fox, G. Amacher, J. Sullivan, and C. Zipper

June 4, 2004

Instrument No: DE-FG26-02NT41619

Department of Forestry (0324)
228 Cheatham Hall
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ABSTRACT

The overall purpose of this project is to evaluate the biological and economic feasibility of restoring high-quality forests on mined land, and to measure carbon sequestration and wood production benefits that would be achieved from forest restoration procedures. In this quarterly report, we present a preliminary comparison of the carbon sequestration potential of forests growing on 14 mined sites in a seven-state region in the Midwestern and Eastern Coalfields. Carbon contents of these forests were compared to adjacent forests on non-mined land. The study was installed as a 3 x 3 factorial in a random complete block design with three replications at each location. The treatments include three forest types (white pine, hybrid poplar, mixed hardwood) and three silvicultural regimes (competition control, competition control plus tillage, competition control plus tillage plus fertilization). Each individual treatment plot is 0.5 acres. Each block of nine plots requires 4.5 acres, and the complete installation at each site requires 13.5 acres. The plots at all three locations have been installed and the plot corners marked with PVC stakes. GPS coordinates of each plot have been collected. Soil samples were collected from each plot to characterize the sites prior to treatment. Analysis of soil samples was completed and these data are being used to prepare fertilizer prescriptions. Fertilizer prescriptions will be developed for each site. Fertilizer will be applied during the second quarter 2004. Data are included as appendices in this report. As part of our economic analysis of mined land reforestation, we focused on the implications of a shift in reforestation burden from the landowner to the mine operator. Results suggest that the reforestation of mined lands as part of the mining operation creates a viable and profitable forest enterprise for landowners with greater potential for carbon sequestration.

TABLE OF CONTENTS

Title Page	1
Disclaimer	2
Abstract	3
List of Graphical Materials	4
Introduction	5
Executive Summary	6
Task 1 Report	8
Task 2 Report	20
Task 3 Report	21
Task 4 Report	25
Task 5 Report	31
Project Timetable	32

LIST OF GRAPHICAL MATERIALS

Figure 1. Total carbon captured in forest ecosystem components (tree, litter layer, soil) of 14 forested mined sites (pine and hardwood forests) and corresponding natural non-mined reference sites (carbon values for the non-mined sites were projected to the age of the mined sites) located in the Midwestern and Appalachian Coalfields of the U.S.	10
Table 1. Carbon sequestered by ecosystem component of even-aged stands on eight non-mined (natural) and 14 mined sites in the Midwestern and Appalachian Coalfields	11
Figure 2. Average total ecosystem carbon sequestered on eight non-mined reference sites (left) and 14 mined sites (right) located in the Midwestern and Appalachian coalfields of the U.S.	12
Figure 3. Multivariate regression models for total forest ecosystem carbon storage based on average site data for forested non-mined (darker surface) and forested mined sites (lighter surface) located in the Midwestern and Appalachian Coalfields of the U.S.	15
Figure 4. Average total ecosystem carbon sequestered on 14 mined sites located in the Midwestern and Appalachian coalfields of the U.S. The figure depicts a carbon storage response surface generated by using a multivariate regression model, with site index and stand age as independent variables	16
Figure 5. Map of field sites in Lawrence County, Ohio	22
Figure 6. Map of field sites in Nicholas County, West Virginia	23
Figure 7. Map of field sites in Wise County, Virginia	24
Table 2. Comparison of mixed hardwood LEV ranges for scenarios where landowner pays reforestation costs vs. where coal company pays reforestation costs	28
Table 3. Comparison of white pine LEV ranges for scenarios where landowner pays reforestation costs vs. where coal company pays reforestation costs	29

INTRODUCTION

Public Law 95-87 mandates that mined land be reclaimed in a fashion that renders the land at least as productive after mining as it was before (Torbert et al. 1995). Research has shown that restored forests on mined lands can be equally as or more productive than the native forests removed by mining (Burger and Zipper 2002). Given that most land surface-mined for coal in the Appalachians was originally forested, forestry is a logical land use for most of the reclaimed mined land in the region (Torbert and Burger 1990). However, since implementation of the SMCRA, fewer forests are being restored in the eastern and Midwestern coalfield regions (Burger et al. 1998). In several states, most notably Virginia, the majority of mined land is now being restored to forests. Over eighty percent of Virginia's mined land has been reclaimed to forested post-mining land uses since 1991. However, region-wide, the majority of mined land that was originally forested is not being reclaimed in a way that favors tree establishment, timber production, carbon sequestration, and long-term forest productivity (Torbert and Burger 1990).

We believe that these reclaimed mined lands are producing timber and sequestering carbon at rates far below their potential for reasons that include poor mine soil quality, inadequate stocking of trees, lack of reforestation incentives, and regulatory disincentives for planting trees on previously forested land (Boyce 1999, Burger and Maxey 1998). A number of these problems can be ameliorated simply through intensive silvicultural management. Through established site preparation techniques such as ripping, weed control, fertilizing, and liming, the quality of a given site can be improved. Other management and silvicultural techniques such as site-species matching, correct planting techniques, employing optimal planting densities, post-planting weed control, and thinning can also improve normal development of forest stands, and improve timber production and carbon sequestration.

Similar to the much-debated topic of converting agricultural land to forests, the conversion of reclaimed mined lands to forests carries with it many economic implications. The primary difference between converting agricultural lands to forests and converting reclaimed mined lands to forests is the absence of any obvious extrinsic opportunity cost in the latter scenario; this, of course, assumes that the reclaimed mined land has been abandoned and is not being utilized for any economically beneficial purpose.

A fair amount of research has been conducted regarding the amounts and values of timber produced on reclaimed mined lands. The effect that a carbon market may have on decisions pertaining to the reclamation of mined lands has also been researched. According to previous research, it appears that mined lands are capable of sequestering carbon and producing harvest volumes of equal or greater magnitude to similar non-mined lands. This fact alone, however, does not render afforestation of mined lands economically profitable or feasible in all cases. There appears at this stage to be a lack of research pertaining specifically to the conversion of reclaimed mined lands from their current uses to forests and the economic implications of such a land use conversion. Furthermore, the potential for an incentive scheme aimed at promoting the conversion of reclaimed mined lands to forests has yet to be explored in depth.

This study ultimately addresses the potential for increasing carbon sequestration on surface-mined land. The overall research objective of this study is to determine the economic feasibility of carbon sequestration through converting reclaimed mined lands to forests using high-value tree species, and to demonstrate the economic and decision-making implications of an incentive scheme on such a land use conversion.

EXECUTIVE SUMMARY

The overall purpose of this project is to evaluate the biological and economic feasibility of restoring high-quality forests on mined land, and to measure carbon sequestration and wood production benefits that would be achieved from forest restoration procedures.

In the previous quarter, we refined carbon sequestration estimates as a function of species-specific biomass based on new algorithms. During this quarter, we used the carbon sequestration models generated in this study and showed that the natural forest stands that were growing well on medium- to highly-productive forest sites (SI greater than 50 ft) produced more tree biomass and sequestered more carbon than mined sites across the same spectrum of stand age (15 to 60 years). This work was based on 14 forests growing on mined land and eight forests growing on undisturbed land. These forest stands were located in a seven-state area of the Midwestern and Eastern Coalfields. The amount of carbon captured across mined sites was largely a function of forest stand age and forest and site productivity, quantitatively expressed as site index (SI) of white oak at base age 50 years. Ecosystem carbon prediction models on natural and mined sites were generated for a wide spectrum of SI and age, including carbon sequestered in tree biomass, litter layer, and soil. The natural sites' multivariate regression model ($P = 0.002$) explained about 68% of the total variation among natural sites and the mined site model ($P = 0.064$) explained 28% of the total variation in measured carbon among mined sites. This study showed that current reclamation procedures and techniques restore carbon sequestration potential on low-quality sites, but carbon sequestration potential is degraded on medium- to high-quality sites. Better reclamation techniques might increase the potential of forests and forest soil systems to sequester carbon at pre-mining levels for the entire spectrum of SI and stand age. These results were presented recently at the 2004 National Meeting of the American Society of Mining and Reclamation and The 25th West Virginia Surface Mine Drainage Task Force, April 18-24, 2004.

At three mined land reforestation experimental areas in Ohio, West Virginia, and Virginia, we completed plot preparation by constructing deer-proof fencing and overseeing ripping (site preparation) and planting of the tree seedlings in each study site. Post-planting herbicides were applied to control competing vegetation. Lab analyses of soil materials taken from the experimental plots were completed using the same materials and methods as described in the previous report.

An economic analysis was conducted to evaluate the effect of reforestation costs on reforestation success and the potential for sequestering carbon. Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA), mandates that mined land be reclaimed to its pre-mining use, and in a fashion that renders the land at least as productive after mining as it was before mining. According to SMCRA requirements, mine operators are responsible for reclaiming mined land. Until recently, mine operators commonly reclaimed previously forested land to hayland/pasture or wildlife habitat. This left the landowner with the option or necessity of converting these reclaimed mined lands to forests at a later stage, in order to make them economically viable. Such a land-use conversion, however, comes at a substantial cost to the landowner, which makes the financial feasibility of such a conversion a questionable issue. The economic implications of this shift in reforestation burden from the landowner to the mine operator are critical for reforestation success. Results suggest that the reforestation of mined lands as part of the mining operation creates a viable and profitable forest enterprise for landowners and the likelihood of significant carbon sequestration is high. On the other hand, if the landowner must bear the cost of reforestation, only the highest quality sites growing conifer

forests would be profitable. These results were also presented at the 2004 National Meeting of the American Society of Mining and Reclamation and The 25th West Virginia Surface Mine Drainage Task Force, April 18-24, 2004.

TASK 1: Estimate forest productivity and carbon sequestration potential on mined lands supporting abandoned grasslands. (Burger et al.)

Executive Summary

In the previous quarterly report, we refined carbon sequestration estimates as a function of species-specific biomass based on new algorithms. During this quarter we used the carbon sequestration models generated in this study and showed that the natural forest stands that were growing well on medium- to highly-productive forest sites (SI greater than 50 ft) produced more tree biomass and sequestered more carbon than mined sites across the same spectrum of stand age (15 to 60 years). This work was based on 14 forests growing on mined land and eight forests growing on undisturbed land. These forest stands were located in a seven-state area of the Midwestern and Eastern Coalfields. The amount of carbon captured across mined sites was largely a function of forest stand age and forest and site productivity, quantitatively expressed as site index (SI) of white oak at base age 50 years. Ecosystem carbon prediction models on natural and mined sites were generated for a wide spectrum of SI and age, including carbon sequestered in tree biomass, litter layer, and soil. The natural sites' multivariate regression model ($P = 0.002$) explained about 68% of the total variation among natural sites and the mined sites' model ($P = 0.064$) explained 28% of the total variation in measured carbon among mined sites. This study showed that current reclamation procedures and techniques restore carbon sequestration potential on low quality sites, but carbon sequestration potential is degraded on medium to high quality sites. Better reclamation techniques might increase the potential of forests and forest soil systems to sequester carbon at pre-mining levels for the entire spectrum of SI and stand age.

Experimental

Carbon captured in tree biomass, including biomass in the above-ground and coarse-root components, was estimated on each site by randomly choosing measurement points at four of the 20 x 20-m grid intersections. Trees in the main canopy greater than 13.0 cm in diameter at breast height (dbh) were tallied within a 404 m² circular plot.

Site index of each tree species on all sites was standardized to the site index of a single species, white oak at base age 50 years (Doolittle, 1958). Similar to the site index conversion procedure used by Rodrigue (2001), we used site index tables and graphs that were most suitable for each site's location (Wenger, 1984).

We estimated above-ground and coarse-root biomass (kg dry weight) from species-specific tree diameter data for each tree tallied. These estimates were based on regression equations from the most recent literature (Jenkins et al., 2003). The above-ground and coarse-root weights were summed to produce an estimate of the total tree biomass in dry weight units. Total forest biomass included stem wood, stem bark, foliage, treetops, branches, stumps, and coarse roots. Total forest biomass was converted to kilograms of carbon with a conversion factor for different regional species groups (Birdsey, 1992). Carbon in ground layer woody or herbaceous biomass was not included because carbon estimates could not be generated for this portion of the forest community. However, carbon contained in these understory components is often ignored in biomass estimates because it only amounts to 1 to 2% of the above-ground carbon content (Birdsey, 1992; Bormann and Likens, 1979).

A soil pit was dug to a depth of 1.5 m at the four plot centers on each site to develop estimates of soil carbon. Pits were described using standard soil survey techniques to obtain total depth, horizon depth, and percent coarse fragments greater than 7.6 cm. Loose samples and duplicate bulk density samples were collected from each horizon. Soil samples were air-dried, sieved (2 mm), and weighed to determine coarse fragments (< 7.6 cm). All soil carbon determination procedures were performed on the sieved 2-mm fraction. Soil properties were analyzed on samples from all horizons found in the profiles. Bulk density, corrected for coarse fragment content, was determined using soil cores. Organic carbon was determined by the Walkley-Black wet oxidation procedure (Nelson and Sommers, 1982). This procedure is used to better discriminate between recently plant-derived pedogenic carbon and geologically-derived geogenic carbon in coal. Litter layer estimates were generated from four 0.25-m² random samples at each measurement plot and bulked to form a 1-m² sample. Bulk samples were dried, ground, and total carbon was determined with a LECO carbon analyzer. Litter layer estimates were corrected for ash and the mineral material that the samples contained. Total forest carbon, litter layer carbon, and soil organic carbon in kilograms per hectare were converted to metric tons per hectare (Mg ha⁻¹). Results from regression analyses termed significant in this paper have a confidence level of $\alpha = 0.1$.

Results and Discussion

In all cases, the carbon distribution among tree, litter, and soil components was more variable on mined sites. The lower variation within the natural sites reflects the uniformity that develops in the tree community, litter layer, and soil during millennia of development, while mined site variation reflects a variety of site and stand conditions including age, tree species, mine soil construction, and site productivity. The tree carbon of natural sites varied between 57% and 66% of the total. On mined sites the range was 42% to 71%, and it was 54% to 72% for pine and hardwood stands, respectively. Litter layer carbon varied between 3% and 7% on natural sites, between 2% and 6% for hardwoods on mined sites, and between 4% and 16% for pines on mined sites. Soil carbon on natural sites varied between 27% and 40% of the total; on mined sites the range was 24% to 40% for hardwood sites and 14% to 46% for pine sites.

Tree Carbon

Carbon sequestered in tree biomass is a function of stand age, soil quality, and site and forest quality. The ratio of carbon on mined versus natural sites $\{(C_{\text{Mined_Sites}}/C_{\text{Natural_Sites}})*100\}$ was used as a statistic for comparing mined site carbon sequestration potential of each forest ecosystem component with that of the natural sites. We assumed that natural site carbon estimates depicted a logical reference for carbon capture on undisturbed forested sites. Percent ratio greater than 100% means that mined sites sequestered carbon quantities that were greater than those on natural, non-mined, adjacent sites.

The ratio for the tree component of pine stands ranged between 39% (VA-1) and 145% (KY-4), with an average ratio of 89% (Fig. 1). The ratio for hardwoods ranged from 67% (IN-1) to 135% (OH-1), with an average of 95%. On average, hardwoods had a slightly greater carbon sequestration potential than pines.

Carbon recovery was greater than 100% for some hardwood (KY-2, OH-1, and OH-2) and pine (WV-2, KY-4, and KY-3) stands (Fig. 1). Carbon recovery levels on these mined sites indicated that reclamation procedures created growth conditions similar to or better than those on

the adjacent non-mined sites. Properly reclaimed mined sites appeared to ameliorate growth-limiting conditions such as soil fragipans (OH-1 and OH-2) and shallow depths to bedrock (KY-2, KY-3, KY-4, and WV-2). Mining operations and the proper reclamation of the sites in Ohio, West Virginia, and Kentucky created more productive sites by eliminating root-limiting conditions.

Figure 1. Total carbon captured in forest ecosystem components (tree, litter layer, soil) of 14 forested mined sites (pine and hardwood forests) and corresponding natural, non-mined reference sites (carbon values for the non-mined sites were projected to the age of the mined sites) located in the Midwestern and Appalachian Coalfields of the U.S. Study site locations are arranged on the horizontal axis in age-increasing order. State abbreviations denote the location of each site.

Carbon present within the developing tree biomass (stem wood, stem bark, foliage, treetops, branches, stumps, and coarse roots) on natural sites ranged from 97 to 156 Mg ha^{-1} (Table 1). Mined-site tree carbon ranged from 76 to 128 Mg ha^{-1} (hardwood) and ranged from 43 to 139 Mg ha^{-1} (pine). Carbon found in tree biomass was comparable to other natural forests in the East, though tree carbon pools vary from study to study depending on site productivity, site age, tree species, management impacts, and local topography and climate. Little has been done to quantify the carbon pools associated with tree biomass of mature, planted forests on mined sites (Ashby et al., 1980; Burger et al., 2003).

Table 1. Carbon sequestered by ecosystem component of even-aged stands on eight non-mined (natural) and 14 mined sites in the Midwestern and Appalachian Coalfields. State abbreviations denote the location of each site.

Site*		Tree Carbon**		Litter Layer Carbon**		Soil Carbon**		Total Carbon Sequestered
----- Mg ha ⁻¹ -----								
<i>Natural Sites:</i>								
IN-C	(40)	113	(59)	5	(3)	74	(39)	192
IL-C	(43)	156	(58)	7	(3)	108	(40)	271
KY-C	(52)	102	(57)	11	(6)	66	(37)	179
OH-C	(59)	97	(61)	9	(6)	53	(33)	159
WV-C2	(60)	137	(61)	8	(4)	81	(36)	226
PA-C	(62)	120	(66)	13	(7)	49	(27)	182
WV-C1	(62)	132	(61)	10	(5)	73	(34)	215
VA-C	(72)	148	(65)	15	(7)	66	(29)	229
<i>Average:</i>		126	(61)	10	(5)	71	(34)	207
<i>Mined Sites:</i>								
<u>Pine:</u>								
VA-1	(20)	43	(42)	16	(16)	44	(43)	103
WV-2	(31)	139	(67)	20	(10)	48	(23)	207
KY-4	(33)	131	(68)	23	(12)	39	(20)	193
WV-1	(38)	81	(70)	18	(16)	16	(14)	115
KY-3	(40)	106	(63)	7	(4)	55	(33)	168
PA-1	(40)	87	(71)	19	(15)	17	(14)	123
IN-2	(50)	56	(44)	13	(10)	58	(46)	127
<i>Average:</i>		92	(61)	17	(12)	40	(28)	148
<u>Hardwood:</u>								
KY-1	(35)	76	(54)	8	(6)	57	(40)	141
KY-2	(35)	93	(66)	4	(3)	44	(31)	141
IL-2	(43)	122	(71)	8	(5)	42	(24)	172
OH-1	(50)	125	(64)	4	(2)	67	(34)	196
OH-2	(50)	114	(72)	5	(3)	39	(25)	158
IL-1	(54)	128	(70)	7	(4)	48	(26)	183
IN-1	(55)	80	(60)	21	(16)	32	(24)	133
<i>Average:</i>		106	(65)	8	(5)	47	(29)	161

*Numbers in parentheses indicate average stand age.

**Numbers in parentheses indicate carbon distribution as a percent of the site total.

Tree carbon averaged 126 Mg ha⁻¹ for our natural sites and 106 Mg ha⁻¹ and 92 Mg ha⁻¹ for mined site hardwood and pine stands, respectively. Carbon associated with tree biomass of hardwood forests in Indiana were measured by Kaczmarek et al. (1995). Our estimates for both natural and mined hardwood sites in Indiana and western Kentucky are well within the range of their carbon estimates, which were between 61 and 117 Mg ha⁻¹.

Richter et al. (1995) found 140.6 Mg ha⁻¹ carbon in the tree biomass of a 35-year-old loblolly pine site in South Carolina. Within our study, sites KY-3 and KY-4 both contained loblolly pine. They had 106 and 131 Mg ha⁻¹ of carbon in total woody plant biomass at ages 40 and 33, respectively. Pine sites in the Appalachian region (WV-1, WV-2, PA-1, VA-1) were dominated by white pine, averaging 87.5 Mg ha⁻¹. These pine sites compared favorably with carbon estimates for mixed pine and hardwood canopies on southern and western aspects in North Carolina (Vose and Swank, 1993).

Overall, these mined sites were new forest communities that, in some cases, accumulated nearly as much carbon in the tree biomass as that sequestered in trees on the natural sites. Most of these new forests contained valuable species, trees were well spaced, and especially on low quality sites, these new forest systems had the potential to develop greater amounts of tree carbon per unit area than understocked, high-graded forests commonly found in the eastern U.S.

Litter Layer Carbon

Natural-site litter layer carbon pools ranged from 5 to 15 Mg ha⁻¹ (Table 1). Litter layer carbon pools on mined sites ranged from 4 to 8 Mg ha⁻¹ (excluding IN-1 site) and ranged from 7 to 23 Mg ha⁻¹ for hardwood and pine stands, respectively. The IN-1 (21 Mg ha⁻¹) Indiana site had a unique tree species composition, including a significant pitch pine component that may be the reason for its relatively high litter layer carbon accumulation.

Litter layer carbon estimates compared favorably with other investigations. Overall, our litter layer carbon estimates from natural sites averaged 10 Mg ha⁻¹ and those from mined sites averaged 8 Mg ha⁻¹ (hardwood) and 17 Mg ha⁻¹ (pine). Litter decomposition rates differ with litter type, a result of variation of litter quality, litter chemical composition, availability of nutrients, particularly nitrogen, from other site resources, and climatic factors (Vogt et al., 1986).

The mined to non-mined litter layer carbon ratio ranged from 64% (KY-3) to 260% (IN-2) and ranged from 36% (KY-2) to 114% (IL-2) (excluding IN-1 site with 420% ratio) for pine and hardwood stand, respectively (Fig. 1). The average for pine stands (173%) was almost 1.5 times greater than the average for hardwood sites (120%). A ratio greater than 100%, particularly in pine stands, may indicate failure to recycle C and other nutrients, causing significant litter layer build-up.

Litter layer carbon pools from other studies in the eastern U.S. ranged from 4 to 14.4 Mg ha⁻¹ depending on age and forest species composition (Hoover et al., 2000; Kaczmarek, 1995; Van Lear et al., 1995; Vose and Swank, 1993). However, sites with higher conifer components tend to develop greater carbon pools within the litter layer. In Ohio, Vimmerstedt et al. (1989) found that hardwood litter layer carbon pools (3 Mg ha⁻¹) were significantly lower than litter layer carbon pools under pine sites (8 Mg ha⁻¹). On a 35-year-old loblolly pine site in the piedmont of South Carolina, litter layer carbon averaged 32.8 Mg ha⁻¹ (Richter et al., 1995). Our 33-year-old loblolly pine mined site in western Kentucky (KY-4) averaged 23 Mg ha⁻¹. Mined site litter layers also appeared to be approaching a steady state relative to carbon accumulation. Van Lear et al. (1995) found that pine litter layers in the southeast tend to reach a steady state 15 to 20 years after a disturbance such as logging. Yanai et al. (2000) found that litter layers in logged northern hardwood forests increased with age after disturbance until about 50 to 55 years. However, over the chronosequence of their study, litter accumulation was also related to the logging practice used on each site.

Soil Carbon

Unlike tree and litter layer carbon, soil carbon contents on mined sites were consistently lower than the natural soil carbon pool. The average mined to non-mined ratio was 57% (range from 22% to 83%) and was 68% (range from 39% to 126%) for pine and hardwood stands, respectively (Fig. 1). Of the three ecosystem components, the soil has the greatest potential for sequestering and storing additional carbon.

Natural site soil carbon ranged from 49 to 108 Mg ha⁻¹ (Table 1). The amount of carbon in the mine soils ranged from 24 to 40 Mg ha⁻¹ under hardwoods, and ranged from 14 to 46 Mg ha⁻¹ under pines. Average natural site soil carbon levels were similar to estimates for temperate forest soil carbon levels reported in the literature. Post et al. (1982) reported average soil carbon levels of 79 and 60 Mg ha⁻¹ within 1 m for dry and moist warm temperate forests, respectively. Researchers in the eastern U.S. reported carbon levels for depths from 0.5 m to bedrock ranging between 36 and 130 Mg ha⁻¹ (Hoover et al., 2000; Johnson et al., 1995; Kaczmarek, 1995). Our natural sites averaged 71 Mg ha⁻¹ and mined sites averaged 40 Mg ha⁻¹ and 47 Mg ha⁻¹ for hardwood and pine stands, respectively (Table 1).

The mined site average soil carbon was comparable to that of a degraded natural pine site on the Piedmont of South Carolina (Van Lear et al., 1995) that had 37.2 Mg ha⁻¹ carbon within 1 m. Prior to pine establishment, poor farming practices severely eroded this site, resulting in loss of the surface horizons. Mined soil carbon pools also correlated well with carbon pools reported in other investigations. Akala and Lal (1999) reported that 30-year-old reforested mined sites (to 0.5 m) contained 51.5 Mg ha⁻¹ of soil carbon; 50-year-old sites contained 54.9 Mg ha⁻¹. Sites approximately 30 years old in our study contained 47 Mg ha⁻¹, while 50-year-old mined sites contained an average of 55 Mg ha⁻¹.

Total Ecosystem Carbon

Total carbon sequestered on natural reference sites ranged from 159 to 271 Mg ha⁻¹, with an average of 207 Mg ha⁻¹ (Table 1). Total carbon sequestered on mined sites ranged from 103 to 207 Mg ha⁻¹ in pine stands and ranged from 141 to 196 Mg ha⁻¹ in hardwood forests. The average across sites planted to pine (148 Mg ha⁻¹) was lower than that of sites planted to hardwoods (161 Mg ha⁻¹).

Most of the carbon present on both reference and mined sites was associated with the total tree biomass (Table 1). Generally, the relative carbon allocation in trees was greater than that in soil with the exception of two mined-site pine stands (VA-1 and IN-2). These two exceptions are examples of the significant effect of stand age as a factor in pine stand development and tree growth. The white pine stand (VA-1) was 20 years old at time of measurement and the pitch pine stand (IN-2) was 50 years old. At an early age, trees are in the initial phase of accumulating biomass, hence carbon sequestration is accelerating. However, in the second case, tree biomass is likely being relocating to the soil carbon pool as the old pine stand deteriorates. The tree carbon contained an average of 61% of the total sequestered carbon on natural sites. Equally, on mined-site pine stands, the tree carbon represented 61% of the total ecosystem carbon. For hardwood stands the ratio was 65%. Natural forest litter layers contained 5% of the total carbon, and mined site litter layers contained 5% (hardwood) and 12% (pine). The soils of natural and mined sites contained 34% and 29% (hardwood) and 28% (pine) of the sequestered carbon, respectively.

Total Carbon Inventory Models

Multivariate regression models for total carbon as a function of stand age and SI were created for both natural and mined sites. Carbon content response surfaces built upon statistically significant regression equations are shown in three-dimensional perspective for a better visualization (Fig. 2).

Figure 2. Average total ecosystem carbon sequestered on eight non-mined reference sites (left) and 14 mined sites (right) located in the Midwestern and Appalachian coalfields of the U.S. Multivariate regression models were used to create the corresponding carbon response surfaces using site index and stand age as independent variables. The eight non-mined sites were projected to the specific age of each of their corresponding adjacent mined sites, thus yielding 12 projected non-mined reference carbon values.

The regression model for the natural sites ($P = 0.0021$) explained about 68% ($\text{Adj-R}^2 = 0.68$) of the total variation among the observed average total carbon amounts captured on natural sites (Fig. 2). This model form is well-established and widely used to represent biomass production as a function of age and site quality. All regression components for our natural site data were statistically significant ($P < 0.1$). This model was also applied to the mined-site data. The model was also significant ($P = 0.0642$) and explained 28.3% ($\text{Adj-R}^2 = 0.28$) of the total variation among observed total carbon on mined sites (Fig. 2). Both models appeared to be good representations of stand dynamics and biomass accumulation in forest ecosystems across the spectrum of SI and stand age. An example of the good integrity of both models is the representation of biomass accumulation rates for low SI (poor) and high SI (good) natural and mined sites. At early stages of stand development (< 30 years) on fertile sites ($\text{SI} > 100$ ft), both natural and mined sites accumulate biomass, hence accumulate carbon, at much faster rates

(steeper slopes) than on poor sites. In fact, on poor sites (for ages beyond 15 years), the rate of carbon accumulation is minimal.

Site index and stand age affected differently the carbon sequestration rates on both mined and natural sites. Carbon accumulation on both mined and natural sites increased exponentially with increases in site index (SI), and increased asymptotically with stand age increases (Fig. 2). However, the rates of increase differed between the natural and mined sites. As shown in Fig. 2, an increase in SI on natural sites resulted in a steeper response surface relative to the response surface for the mined sites.

Combining both the mined and natural site response surfaces from Fig. 2 shows the influence of mined land site quality on carbon sequestration compared to the undisturbed reference condition. Clearly depicted in Fig. 3 is the convergence of both regression planes at approximately SI 45. This corroborates the observations and reports of several researchers that forest productivity of pre-SMCRA mined sites is as good or better than the productivity of poor-quality sites prior to mining (Ashby et al., 1980; Burger et al., 2003). Improved forest productivity as a result of mining is usually attributed to the breakup of natural soil fragipans, bedrock and other root-impeding layers. On the other hand, the models show that forests growing on mined sites that had SI > 50 prior to mining are not as productive after mining. The higher the original forest site quality, the less likely productivity is restored, and the greater the disparity between pre- and post-mining carbon sequestration potential.

Figure 3. Multivariate regression models for total forest ecosystem carbon storage based on average site data for forested non-mined (darker surface) and forested mined sites (lighter surface) located in the Midwestern and Appalachian Coalfields of the U.S. The mined site response surface is below that of the non-mined sites across the entire range of site index and age, except for the region confined between site index 40 and 50 for stand age greater than 20 years.

Because of the limited fit ($\text{Adj-R}^2 = 28.3\%$) of the natural site model to the mined site data, we explored the possibility that a different regression model would better represent total ecosystem carbon accumulation on mined sites. Mined sites are very different from natural sites due to the elimination of natural soil, changed hydrology, and different distributions of flora and fauna; therefore, it is not unreasonable to believe that carbon would accumulate differently as a function of forest age and mine site quality. We used the base model in Eq.2 and re-analyzed the mined site data using the same steps as previously described. The new model, as well as each of the model components, was statistically significant ($P < 0.1$). The goodness of fit of the new model nearly doubled, increasing the r-squared value from 28.3% to 48.6% (Fig. 4).

Figure 4. Average total ecosystem carbon sequestered on 14 mined sites located in the Midwestern and Appalachian coalfields of the U.S. The figure depicts a carbon storage response surface generated by using a multivariate regression model, with site index and stand age as independent variables.

Biologically, the new model is very reasonable. The response surface depicted similar patterns of carbon accumulation across the spectrum of SI and age. However, the increase in stand age affected carbon sequestration rates differently than previously discussed. Carbon sequestration peaked at an approximate age of 35 years across any level of site index, after which it decreased as the stands aged (Fig. 4). We attribute this response to the significant component of older pine stands in the mined site data set. Pine stands tend to deteriorate at ages greater than 40 years, characterized by tree mortality and carbon efflux to the atmosphere and the soil carbon pools. This response was particularly evident in our 50-year-old Indiana pitch pine mined site (IN-2).

Given our limited data set, species- and management-specific inferences can not be made. However, our goal is to include additional forested mined sites and their corresponding non-mined natural sites that would allow for species-specific estimates of carbon sequestration potential. We will also measure carbon sequestration potential of post-SMCRA mined sites and

determine the influence and value of different forest management practices, including hybrid tree species, tillage, weed control and fertilization on long-term restoration of site productivity and carbon sequestration.

We will also refine our measurement and monitoring techniques to maximize the precision of our carbon estimates. Evidence from the literature suggests that the best current organic carbon determination techniques, including both wet and dry combustion methods, invariably include some amount of geogenic carbon in the estimate (Thurman and Sencindiver, 1986; Indorante et al., 1981; Pederson et al., 1978; Cummins et al., 1965). If this is the case, then mine soil pedogenic carbon estimates are actually lower than projected, and replenishment of soil carbon levels may take longer than indicated.

Conclusions

The development of productive forests on reclaimed land satisfies multiple goals. Successful reforestation on productive minelands meets SMCRA guidelines that require the return or enhancement of pre-mining productivity levels. Reforestation also establishes a long-term sink for atmospheric carbon. Land that has been mined for coal increases atmospheric carbon via land use change and by producing a carbon-based fuel. Considering that very little organic carbon is present on a recently reclaimed mined site, there is great potential for sequestering carbon by restoring the forest to a level of productivity equal to or greater than that present before mining.

Mined soil organic carbon levels were lower than average natural sites due to the pre-law mining process, which disrupts the biogeochemical cycle of all elements, including C. By removing the forest and soil fauna and flora, the carbon cycle is breached and sequestration is interrupted. Reincorporating organic matter into the soil requires establishment of a biological community, including plants for primary production, and soil fauna and flora to process the detritus.

Our results indicate that pre-SMCRA surface coal mining procedures used in the Midwestern and the Appalachian coalfields of the USA degraded forest site quality and the potential to sequester carbon at pre-mining levels. Based on the carbon sequestration models generated in this study, the natural forest stands that were growing well on medium- to highly-productive forest sites (SI greater than 50 ft) produced more tree biomass and sequestered more carbon than mined sites across the same spectrum of stand age (15 to 60 years). Research investigating the effects of different forest management techniques on carbon sequestration potential of mined lands planted to forests is currently underway on three mined sites in Ohio, West Virginia, and Virginia.

References

- Akala, V. A., and R. Lal. 1999. Mineland reclamation and soil organic carbon sequestration in Ohio. p. 322-329 *In* Mining and Reclamation for the Next Millennium. Vol. 1. Proc., Amer. Soc. for Surface Mining and Reclam. Ann. Natl. Mtg., Aug. 13-19, 1999, Scottsdale, AZ.
- Anderson, J. M. 1991. The effects of climate change on decomposition processes in grasslands and coniferous forests. *Ecol. Appl.* 1:326-347.

- Ashby, W. C., C. A. Kolar, and N. R. Rogers. 1980. Results of 30-year-old plantations on surface mines in the central states. P. 99-107 *In: Trees for Reclamation*. USDA. For. Serv. Tech. Rep. NE-61.
- Birdsey, R. A. 1992. Carbon storage and accumulation in the United States forest ecosystems. USDA For. Serv. Gen. Tech. Rep. WO-59. 51pp.
- Bormann, F. H., and G. E. Likens. 1979. *Pattern and Process in a Forested Ecosystem*. Springer, New York.
- Burger, J. A., W. E. Auch, R. G. Oderwald, and M. Eisenbies. 2003. White pine growth and yield on a mined site in Virginia: Response to thinning and pruning. p. 226-240 *In: R. I. Barnhisel (ed.). Working Together for Innovative Reclamation*. 20th National Conf. Amer. Soc. of Mining and Reclamation. June 3-6, 2003. Billings, MT.
- Cummins, D. G., W. T. Plass, and C. E. Gentry. 1965. Chemical and physical properties of spoil banks in the eastern Kentucky coal fields. Central States For. Exp. Sta., Columbus, OH. 11pp.
- Doolittle, W. T. 1958. Site index comparisons for several forest species in the southern Appalachians. *Soil Science Soc. Am. Proc.* 22:455-458.
- Hoover, C. M., R. A. Birdsey, L. S. Heath, and S. L. Stout. 2000. How to estimate carbon sequestration on small forest tracts. *J. For.* 98:13-19.
- Indorante, A. J., I. J. Jansen, and C. W. Boast. 1981. Surface mining and reclamation: initial changes in soil character. *J. Soil and Water Conservation* 36:347-350.
- Jenkins, J. C., D. C. Chojnacky, L. H. Heath, and R. A. Birdsey. 2003. National-scale biomass estimators for United States tree species. *Forest Science* 49(1):12-35.
- Johnson, C. E., C. T. Driscoll, T. J. Fahey, T. G. Siccama, and J. W. Hughes. 1995. Carbon dynamics following clear-cutting of a northern hardwood forest. p. 463-488 *In: W. W. McFee and J. M. Kelly (eds.). Carbon Forms and Functions in Forest Soils*. Soil Sci. Soc. Amer., Madison, WI.
- Kaczmarek, D. J., K. S. Rodkey, R. T. Reber, P. E. Pope, and F. Ponder Jr. 1995. Carbon and nitrogen pools in oak-hickory forests of varying productivity. p. 79-93 *In: K. W. Gottschalk and S. L. C. Fosbroke (eds.). 10th Central Hardwood Forest Conf.* March 5-8, Morgantown, WV. USDA For. Serv. Gen. Tech. Rep. NE-197, Northeast Exp. Sta., Radnor, PA.
- Nelson, D. W., and L. E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p. 539-580 *In: A. L. Page et al. (eds.). Methods of Soil Analysis, Part 2*. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.
- Pederson, T. A., A. S. Rogowski, and R. Pennock Jr. 1978. Comparison of morphological and chemical characteristics of some soils and minesoils. *Reclamation Review* 1:143-156.
- Post, W. M., W. R. Emanuel, P. J. Zinke, and A. G. Stangenberger. 1982. Soil carbon pools and world life zones. *Nature* 298:156-159.
- Richter, D. D., D. Markewitz, J. K. Dunsomb, P. R. Heine, C. G. Wells, A. Stuanes, H. L. Allen, B. Urrego, K. Harrison, and G. Bonani. 1995. Carbon cycling in a loblolly pine forest: implications for the missing carbon sink and for the concept of soil. p. 233-251 *In: Carbon Forms and Functions in forest Soils*, Ch. 11. Soil Sci. Soc. Amer., Madison, WI.

- Rodrigue, J. A. 2001. Woody species diversity, forest and site productivity, stumpage value, and carbon sequestration of forests on mined lands reclaimed prior to the passage of the Surface Mining Control and Reclamation Act of 1977. M.S. Thesis. Dept. of Forestry, Virginia Polytechnic Institute and State University. 299pp.
- Thurman, N. C., and J. Sencindiver. 1986. Properties, classification, and interpretations of mine soils at two sites in West Virginia. *Soil Sci. Soc. Am. J.* 50:181-185.
- Van Lear, D. H., P.R. Kapeluck, and M. M. Parker. 1995. Distribution of carbon in a piedmont soil as affected by loblolly pine management. p. 489-50 *In: Carbon Forms and Functions in Forest Soils*, Ch. 22. Soil Sci. Soc. Amer., Madison, WI.
- Vimmerstedt, J. P., M. C. House, M. M. Larson, J. D. Kasile, and B. L. Bishop. 1989. Nitrogen and carbon accretion on Ohio coal minespoils: influence of soil forming factors. *Landscape and Urban Planning* 17:99-111.
- Vose, J. M., and W. T. Swank. 1993. Site preparation burning to improve southern Appalachian pine-hardwood stands: aboveground biomass, forest floor mass, and nitrogen and carbon pools. *Can. J. For. Res.* 23:2255-2262.
- Wenger, K. F. 1984. *Forestry Handbook*. 2nd ed. John Wiley & Sons, NY.
- Wright, J. A., A. Dinicola, and E. Gaitan. 2000. Latin American forest plantations, opportunity for carbon sequestration, economic development, and financial returns. *J. For.* 98:20-23.
- Yanai, R. D., M. A. Arthur, T. G. Siccama, and C. A. Federer. 2000. Challenges of measuring forest floor organic matter dynamics: repeated measures from a chronosequence. *For. Ecol. Manage.* 138:273-283.

TASK 2: Develop classification and inventory criteria and procedures for mined land. (Galbraith et al.)

Executive Summary

During the reporting period (Jan.-Mar. 2004), we have continued a literature search about classification criteria for reforestation on mine soils, and continued lab analysis on field samples collected in earlier reporting periods.

Experimental

During the reporting period (Jan.-Mar. 2004), two graduate students completed experimental plot preparation by constructing deer-proof fencing and overseeing ripping (site preparation) and planting of the tree seedlings in each study site. Lab analysis was conducted using the same materials and methods as described in the previous reporting period.

Results and Discussion

Updated results of the individual plot laboratory analysis are included as a spreadsheet file in Appendix A. The results indicate that we achieved our task of identifying groups of plots with similar soil properties within each plot, but differing soil properties between the groups of plots. The results have not been compared statistically because the data was used only to provide background information to assess the validity of our plot layout at each study site. Appendix B contains results of analysis at the soil pit description and sampling sites that represent the entire soil profiles at each study area. Statistical analysis has not been conducted on any of the soil information because it will be used as background site information and cannot be compared to tree growth until the seedlings have grown.

Conclusion

The surface soils in the plots contained the desired traits as outlined in the proposal materials and methods for Task 2.

References

The references for the literature review will be updated continuously during the study. No new references have been added since the previous reporting period.

TASK 3: Develop reforestation methods and procedures for mined land. (Fox et al.)

Executive Summary

Installation of the field sites designed to evaluate reforestation methods and procedures was completed. Site preparation was completed at the sites in West Virginia and Virginia. Seedlings were planted. Post-planting herbicides were applied to control competing vegetation.

Experimental

Installation of the field sites designed to evaluate reforestation methods and procedures was completed. There are three separate field locations in the study. The first site is located in Lawrence County, Ohio, on land owned by the Nature Conservancy (Figure 5). This site was previously owned by MeadWestvaco Corporation. A meeting has been set for June 2004 with The Nature Conservancy to discuss its participation as a partner in the project. The second site is located in Nicholas County, West Virginia, on land owned by Plum Creek Timber Company (Figure 6). The third site is located in Wise County, Virginia, on land owned by PennVirginia Company (Figure 7).

The study was installed as a 3 x 3 factorial in a random complete block design with 3 replications at each location. The treatments include three forest types (white pine, hybrid poplar, mixed hardwood) and three silvicultural regimes (competition control, competition control plus tillage, competition control plus tillage plus fertilization). Each individual treatment plot is 0.5 acres. Each block of nine plots requires 4.5 acres, and the complete installation at each site requires 13.5 acres. The plots at all three locations have been installed and the plot corners marked with PVC stakes. GPS coordinates of each plot have been collected.

Soil samples were collected from each plot to characterize the sites prior to treatment. Analysis of soil samples was completed, and these data are being used to prepare fertilizer prescriptions. Fertilizer prescriptions will be developed for each site. Fertilizer will be applied during the second quarter 2004.

Site preparation was completed. At the site in Ohio, two of the blocks were tilled with a single shank ripper. The third block was tilled with a single shank ripper that was also equipped with twin disks. The site in WV was tilled with a single shank ripper that was also equipped with twin disks. At the site in Virginia, two of the blocks were tilled with a single shank ripper. The third block was tilled with a multiple shank ripper.

Tree seedlings were hand planted at each site. Three species mixtures were planted: (1) white pine; (2) hybrid poplar; and (3) mixed Appalachian hardwoods. The species of hardwood included at each of the three sites varied. The species mixture selected was intended to mimic the species distribution of native hardwood stands in the adjacent forests.

The pre-emergent herbicide Pendulum was sprayed on all the plots after the seedlings were planted.

Deer fencing was installed at the site in Ohio and is scheduled to be installed at the site in West Virginia during the second quarter of 2004. The deer population at the site in Virginia is low enough that we do not anticipate significant deer browse damage at that site.

Results and Discussion

None to date. The installation phase of the project has just been completed.

Conclusions

None to date.

References

None.

Figure 5. Map of field sites in Lawrence County, Ohio.

Figure 6. Map of field sites in Nicholas County, West Virginia.

VIRGINIA site locations. DOE project.
 Coordinates are UTM (z17) meters in NAD'83
 Prepared by Beyhan Amichev.12/08/2003.

Figure 7. Map of field sites in Wise County, Virginia.

TASK 4: Conduct economic analyses of reforestation and forest management activities for carbon sequestration and a variety of forest products and services. (Amacher and Sullivan)

Executive Summary

Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA), mandates that mined land be reclaimed to its pre-mining use, and in a fashion that renders the land at least as productive after mining as it was before mining. According to SMCRA requirements, mine operators are responsible for reclaiming mined land. Until recently, mine operators commonly reclaimed previously forested land to hayland/pasture or wildlife habitat. This left the landowner with the option or necessity of converting these reclaimed mined lands to forests at a later stage, in order to make them economically viable. Such a land-use conversion, however, comes at a substantial cost to the landowner, which makes the financial feasibility of such a conversion a questionable issue. In this quarter, Task 4 progress has focused on the economic implications of this shift in reforestation burden from the landowner to the mine operator. Results suggest that the reforestation of mined lands as part of the mining operation creates a viable and profitable forest enterprise for landowners. These results were presented recently at the 2004 National Meeting of the American Society of Mining and Reclamation and The 25th West Virginia Surface Mine Drainage Task Force, April 18-24, 2004.

Experimental

Land expectation value (LEV) has previously been calculated under Task 4 for three silvicultural options on five site classes of reclaimed mine lands that address incompatible ground cover, soil compaction, and site productivity. These financial calculations have been extended this quarter to examine the burden that forest landowners bear when they have to pay the costs of returning the land to a forested condition. Our analysis is based on an idealized model of forest landowner who is facing the decision to reforest previously reclaimed mine land that was reclaimed into grass cover.¹ Suppose that in the absence of a reforestation option, the landowner possesses an *indirect* utility function given by,

$$V(r, I, L_0) = V[r(L_0), I] + \phi(L_0) \quad (1)$$

where $V()$ is indirect utility, r is the revenue generated from the property (which could be considered land rents, and consequently include the market value of the land), I is exogenous landowner income, L_0 is the current condition of the property, Φ measures non-market benefits (utility) derived from owning the land. The utility function indicates that land condition may be important to utility in multiple ways, including financial returns (first term on the RHS) and amenities that the landowner derives from the condition of the land (second term on the RHS). Moreover, each component of the indirect utility function could without loss be expressed as a stream of rents generated from using the land from grazing or hunting, or production of non-market benefits. That is, we could define discounted annual revenues and non-market benefits from the reclaimed land as follows:

¹ Owners of reclaimed mine lands are quite diverse, including mine operators, land-holding companies, and small private owners. Our representative landowner model is intended to be only a generalized depiction, and all elements of the model may not be applicable to a given owner.

$$r(L_0) = \int_0^{\infty} a[L_0(z)]e^{-iz} dz; \quad \phi(L_0) = \int_0^{\infty} b[L_0(z)]e^{-iz} dz \quad (2)$$

where i is the interest rate, $a(\cdot)$ are annual revenues generated from the land (perhaps grazing or hunting leases), $b(\cdot)$ are non-market benefits derived from owning land each period, z is a variable of integration representing time periods $1, \dots, t$, and $L_0(z)$ is land condition at each point in time.

Suppose now the landowner represented by (1) is offered the opportunity to reforest previously mined land that was reclaimed into grass cover. Not only will the reforestation provide potential harvest revenues when the timber matures, but the stream of non-market benefits may also be different than those identified in (2) above. Thus, the new indirect utility function can be written:

$$V(r, I, L_f) = V[r(L_f), I] + \phi(L_f) \quad (3)$$

where L_f is the condition of the land after reforestation, and discounted revenues and non-market benefits are calculated as follows:

$$r(L_f) = \frac{pQ_f(t)e^{-it} - c_f e^{it}}{(1 - e^{-it})} - c_0 + \int_0^{\infty} a[L_f(z)]e^{-iz} dz \quad (4)$$

and

$$\phi(L_f) = \int_0^{\infty} b[L_f(z)]e^{-iz} dz \quad (5)$$

where p is the unit price of timber, Q_f is the volume of timber produced from reforested land at age t , c_f is regular reforestation costs after timber harvest, and c_0 is initial reforestation costs incurred when converting grassland into forest². This formulation is similar to the standard Hartman (1976) model of a forest with amenities that is used commonly in forest landowner analyses (e.g., Conway *et al.* 2003, Sullivan *et al.* 2004).

Reforestation of the reclaimed land involves a welfare improvement only if:

$$V(r, I, L_f) > V(r, I, L_0) \Leftrightarrow \quad (6)$$

$$V[r(L_f), I] - V[r(L_0), I] + \phi(L_f) - \phi(L_0) > 0$$

or

² Note that this representation of the problem is slightly simplified for presentation, depicting reforestation cost as a single, one-time expense. In actuality, there may be multiple costs associated with site conversion (especially the control of established, competing vegetation) that occur over the first few years of initial forest stand establishment, which we address in our empirical analysis.

$$\begin{aligned}
& V \left[\frac{pQ_f(t)e^{-it} - c_f e^{it}}{(1 - e^{-it})} - c_0 + \int_0^{\infty} a[L_f(z)]e^{-iz} dz, I \right] - V \left[\int_0^{\infty} a[L_0(z)]e^{-iz} dz, I \right] \\
& + \int_0^{\infty} b[L_f(z)]e^{-iz} dz - \int_0^{\infty} b[L_0(z)]e^{-iz} dz > 0
\end{aligned} \tag{7}$$

Net discounted revenues of timber harvesting in this calculation could be positive or negative, depending on conversion and regular reforestation costs, prices, interest rates and timber volumes produced. Annual revenues and non-market benefits may differ from pre-reforestation values, due to differing land attributes (L_f v. L_0), though it is difficult to imagine these annual values not increasing when the land is reforested. It should be noted that a major component of our calculation is the conversion cost c_0 in (4) and (7) above. This undiscounted cost must be paid up front, at the time of reforestation, without any offsetting revenues until the timber reaches maturity in t years. Hence, it is likely to play a major role in determining landowner welfare and, ultimately, the likelihood of reforestation occurring. In our work under Task 4 in the preceding quarter, we have examined the magnitude of the difference in net discounted revenues under a range of site conditions and reforestation options, and especially the importance of identifying who pays the conversion costs in the profitability of forestry on these reclaimed grasslands.

Results and Discussion

Our results indicate that indeed there are significant economic implications associated with changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for mixed hardwood. For example, for the “middle” site class scenario, mixed hardwood LEV increases by \$2045.76/ha in favor of the landowner, when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs (Table 2). It is also evident from our results that all of the proposed land use conversion scenarios for mixed hardwoods become financially profitable when the coal company pays the costs of forest establishment, whereas, under the assumption that the landowner pays these costs, none of the scenarios are financially profitable.

Table 2. Comparison of mixed hardwood LEV ranges for scenarios where landowner pays reforestation costs vs. where coal company pays reforestation costs.

Site Class		Mixed hardwoods (landowner pays costs)	Mixed hardwoods (coal company pays costs)
Low	<i>LEV (\$/ha)</i>	-2416.71	15.38
	<i>Rotation</i>	80 years	80 years
	<i>Site class</i>	V	V
	<i>Site preparation</i>	High	High
	<i>ARR</i>	7.5%	7.5%
Middle	<i>LEV (\$/ha)</i>	-1710.16	335.60
	<i>Rotation</i>	60 years	60 years
	<i>Site class</i>	III	III
	<i>Site preparation</i>	Medium	Medium
	<i>ARR</i>	5%	5%
High	<i>LEV (\$/ha)</i>	-145.58	2057.96
	<i>Rotation</i>	40 years	40 years
	<i>Site class</i>	I	I
	<i>Site preparation</i>	Low	Low
	<i>ARR</i>	3.5%	3.5%

Our results also indicate that there are significant economic implications associated with changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for white pine scenarios. For example, for the “middle” site class, white pine LEV increases by \$1951.57/ha in favor of the landowner, when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs (Table 3). Under the assumption that the landowner pays the costs of forest establishment, our results indicate that land-use conversion to white pine only becomes financially profitable under the most favorable environmental and economic conditions, e.g. best sites and low alternative rate of return. However, when the costs of forest establishment are paid by the coal company, it appears that land-use conversion to white pine becomes profitable even under the most unfavorable environmental and economic conditions.

Table 3. Comparison of white pine LEV ranges for scenarios where landowner pays reforestation costs vs. where coal company pays reforestation costs.

Site Class		White pine (landowner pays costs)	White pine (coal company pays costs)
Low	<i>LEV (\$/ha)</i>	-2330.53	220.93
	<i>Rotation</i>	20 years	20 years
	<i>Site class</i>	V	V
	<i>Site preparation</i>	High	High
	<i>ARR</i>	5%	5%
Middle	<i>LEV (\$/ha)</i>	-316.06	1635.51
	<i>Rotation</i>	30 years	30 years
	<i>Site class</i>	III	III
	<i>Site preparation</i>	Medium	Medium
	<i>ARR</i>	5%	5%
High	<i>LEV (\$/ha)</i>	2697.98	4731.66
	<i>Rotation</i>	30 years	30 years
	<i>Site class</i>	I	I
	<i>Site preparation</i>	Medium	Medium
	<i>ARR</i>	3.5%	3.5%

Conclusions

For a landowner, it would obviously be preferable, from a financial point of view, to leave initial site preparation and reforestation up to the coal company, and in so doing, spare him/her - self the initial costs of reclaiming the mined land. Were the coal company to assume the costs of reclaiming the mined lands, from a landowner's perspective, it would be most profitable to invest in high intensity site preparation on the best quality sites. However, in reality, the coal company would seek to reclaim the mined land in such a way that bond release is achieved at the least cost possible. This least cost option would most likely entail low intensity site preparation, regardless of site quality or other market factors. As an example of how this least cost reforestation scenario (coal company assumes costs) would impact the landowner economically, mixed hardwood LEV on a site class I site, under low intensity site preparation (rotation age 60 years, 5% ARR) would increase by approximately 164% from the corresponding scenario in which the landowner assumed the costs of reforestation. Thus, under this least cost reforestation scenario, the landowner (who assumes no costs) would still benefit.

Recent Task 4 work demonstrates that converting reclaimed mined lands back to their original forested state, as part of the coal mining enterprise, and in compliance with the law, is needed to ensure an economically viable forestry land use. If the costs of site preparation and planting are borne by the forestry enterprise after mining and bond release, and these costs are carried for decades until harvest, the forest land use is usually not profitable given current price and cost assumptions.

References

- Conway, M. C., Amacher, G. S., J. Sullivan, and D. Wear. 2003. Decisions nonindustrial forest landowners make: an empirical examination. *J. For. Econ.* 9:181-203.
- Hartman, R. 1976. The harvesting decision when a standing forest has value. *Econ. Inquiry* XIV:52-58.
- Sullivan, J., G.S. Amacher, and S. Chapman. 2004. Forest banking and forest landowners: forgoing management rights for guaranteed financial Returns. *J. Forest Policy and Econ.* In press.

TASK 5: Determine the potential of large-scale SMCRA grassland restoration to sequester carbon and create other societal benefits. (Zipper et al.)

Executive Summary

Because of our inability to identify a graduate student who would conduct the work required by Task 5, a search for a post-doctoral research associate to conduct this work was initiated during Fall, 2003. A candidate was selected in January, 2004, and hired to begin in April 2004.

Report

Activity during the reporting period consisted of concluding the search for a post-doctoral research associate who will conduct research activities related to reclaimed coal mine soils capability to support forests and sequester atmospheric carbon with support provided jointly by NASA (Wynne et al. 2003) and the U.S. Department of Energy (Burger et al 2002). The DOE-supported activities would locate and characterize mine sites available for reforestation, while the NASA-supported project component would support additional site characterization work necessary to assess spectral characteristics, and acquisition and analysis of remote sensing data.

An offer was extended to Joshua McGrath, a Ph.D. student in environmental soils at the University of Delaware. Dr. McGrath accepted the offer, contingent upon completion of his Ph.D. degree requirements as expected in April, 2004. Mr. McGrath has excellent experience in soil analysis in the field and in the lab, and has knowledge of environmental policy issues. Dr. Zipper is pleased to have been able to obtain the involvement in the project by Dr. McGrath, who (subsequent to this reporting period) completed his Ph.D. successfully as scheduled and began work on April 19, 2004.

References

- Burger, J.A., T. R. Fox, G. S. Amacher, B. J. Sullivan, C. Zipper, and J. Galbraith. 2002. Restoring Sustainable Forests on Appalachian Mined Lands for Wood Products, Renewable Energy, Carbon Sequestration, and Other Ecosystem Services. Research proposal to U.S. Department of Energy. 10/02 - 10/05. (funded).
- Randolph H. Wynne, James B. Campbell, Carl E. Zipper, and Layne T. Watson. 2003. Remote Sensing for Forest Productivity, Carbon Management and Monitoring. National Aeronautics and Space Administration / George Mason University. 10/03 – 9/04 (renewal through 10/05 anticipated).

PROJECT TIMETABLE

		Planned				Completed						
Year:	2002	2003				2004				2005		
Quarter:	4th	1st	2nd	3rd	4 th	1st	2nd	3rd	4th	1st	2nd	3rd
Task 1												
Subtask 1.1	Baseline Carbon Sequestration Potential											
Subtask 1.2	Mine Soil Productivity											
Subtask 1.3						Carbon Sequestration by Forest Practice						
Subtask 1.4						Accounting Procedures						
Task 2												
Subtask 2.1	Classification Criteria											
Subtask 2.2				GIS Mapping								
Subtask 2.3				Test Remote Sensing								
Subtask 2.4						Experimental Plots						
Subtask 2.5							Soil Analyses					
Subtask 2.6											Validate classification criteria	
Task 3												
Subtask 3.1	Locate sites											
Subtask 3.2			Establish experiment									
Subtask 3.3			Silvicultural recommendations									
Subtask 3.4					Reforestation costs							
Subtask 3.5						Evaluate survival & growth						
Subtask 3.6						Estimate growth potential						
Subtask 3.7							Estimate timber & carbon value					
Task 4	Economic feasibility											
Subtask 4.1				Evaluation								
Subtask 4.2								Government policies				
Subtask 4.3												
Task 5												
Subtask 5.1			Identify SMCRA grassland									
Subtask 5.2				Use characteristics of permits								
Subtask 5.3						Soil properties by permit						
Subtask 5.4								Est. quantity grassland				
Subtask 5.5								Est. C sequ. by site quality class				
Subtask 5.6											Est. C sequ. by policy scenario	

DOE Composite Sample Site	Plot	Sample 0=0-10cm 1=10-30 TS SS=subsoil 2=10-30 +SS	# of samples in composite	Lab #	pH	P	ppm in soil (mg/kg)									
							Mehlich I (dilute double acid procedure)									
							K	Ca	Mg	Zn	Mn	Cu	Fe	B		
WV-1	1	0	5	1	5.59	50	128	818	261	2.9	58.5	1.1	33	0.3		
WV-1	1	1	5	2	6.27	69	65	805	251	2.6	72.4	2.1	39.2	0.2		
WV-1	2	0	5	3	5.9	67	87	1032	274	3.5	57.8	1.5	35.2	0.3		
WV-1	2	1	5	4	6.65	112	64	1057	256	2.9	79.9	2.5	42.9	0.2		
WV-1	3	0	5	5	5.88	48	88	934	290	3.4	62.1	1.8	39	0.3		
WV-1	3	1	5	6	6.88	91	56	1088	276	2.6	84.9	1.9	44.3	0.2		
WV-1	4	0	5	7	5.84	65	122	1141	298	3.7	79.1	1.1	34.4	0.3		
WV-1	4	1	5	8	6.85	87	56	1034	244	4.1	76.5	2	40.7	0.2		
WV-1	5	0	5	9	5.83	57	104	975	264	3.3	76.7	1.5	35.3	0.3		
WV-1	5	1	5	10	6.59	67	61	868	227	1.9	74.5	1.6	37.8	0.2		
WV-1	6	0	5	11	6.02	62	108	901	268	2.6	67.7	1.3	38.1	0.2		
WV-1	6	1	5	12	6.54	99	56	932	263	2.6	84	1.9	42.8	0.2		
WV-1	7	0	5	13	5.98	82	80	1010	275	3	83.6	1.6	41.9	0.3		
WV-1	7	1	5	14	6.72	113	56	1003	238	2.2	74.7	1.7	46.7	0.2		
WV-1	8	0	5	15	6.08	82	97	1032	246	2.4	78.5	1.4	41.9	0.3		
WV-1	8	1	5	16	7.03	120	72	1295	257	1.9	81	1.7	43.1	0.2		
WV-1	9	0	5	17	6.07	84	95	998	246	3.2	80.1	1.7	38.8	0.3		
WV-1	9	1	5	18	6.95	107	56	1249	238	2.9	83.9	2	42.6	0.2		
WV-2	1	0	5	19	5.73	66	100	861	275	3.4	55.5	1.4	53.5	0.4		
WV-2	1	1	5	20	5.01	77	61	761	267	2.6	81.1	1.7	68.8	0.2		
WV-2	2	0	5	21	5.64	72	97	854	269	3.2	60.1	1.6	50.7	0.2		
WV-2	2	1	5	22	6.24	102	72	825	261	2.7	70.1	1.8	49.7	0.2		
WV-2	3	0	5	23	5.57	73	73	852	270	3.2	69.6	1.4	53.1	0.2		
WV-2	3	1	5	24	6.24	137	75	1021	287	2.7	93.8	1.5	54.9	0.2		
WV-2	4	0	5	25	5.9	80	100	955	286	3.4	52.7	1.2	44.2	0.3		
WV-2	4	1	5	26	6.78	116	101	1041	290	2.6	76	1.9	48.9	0.2		
WV-2	5	0	5	27	5.7	65	93	919	283	3.9	53.3	1.4	48	0.3		
WV-2	5	1	5	28	5.89	94	46	750	258	3	76.5	2	56.1	0.2		
WV-2	6	0	5	29	5.8	82	87	830	261	2.7	56.4	1.3	50.2	0.2		
WV-2	6	1	5	30	6.24	104	76	790	272	2.6	73.7	1.6	48.3	0.2		
WV-2	7	0	5	31	5.65	43	96	864	289	4.8	49.7	1.2	44.4	0.3		
WV-2	7	1	5	32	5.85	53	61	587	260	3.1	66.2	2.5	48	0.1		
WV-2	8	0	5	33	5.68	63	107	839	266	3.9	50	1.2	53.6	0.2		
WV-2	8	1	5	34	5.63	89	87	833	259	3	73.1	2	57.4	0.2		
WV-2	9	0	5	35	5.79	65	76	846	283	3.1	51.3	1.5	48.6	0.2		
WV-2	9	1	5	36	6.42	110	63	883	287	2.7	73.8	2	48.8	0.2		
WV-3	1	0	5	37	5.18	49	111	716	220	3.1	53.3	1.9	55.3	0.2		
WV-3	1	1	5	38	5.06	76	60	733	221	3.1	67.5	2.7	52.5	0.1		
WV-3	2	0	5	39	5.68	39	84	848	272	4.1	50.3	1.2	34.7	0.3		
WV-3	2	1	5	40	5.92	68	62	712	245	3	70.8	2.3	50	0.1		
WV-3	3	0	5	41	5.54	26	88	688	261	4.2	48.9	1.3	36.2	0.2		
WV-3	3	1	5	42	5.81	43	49	598	270	2.7	62.9	2.3	42.8	0.1		

DOE Composite Sample Site	Plot	Sample 0=0-10cm 1=10-30 TS SS=subsoil 2=10-30 +SS	# of samples in composite	Lab #	pH	ppm in soil (mg/kg)											Mehlich I (dilute double acid procedure)			
						P	K	Ca	Mg	Zn	Mn	Cu	Fe	B						
WV-3	4	0	5	43	5.83	30	133	722	282	4.7	58.4	1.8	37.6	0.2						
WV-3	4	1	5	44	5.44	19	45	432	231	2	46.5	2.3	36.3	0.1						
WV-3	5	0	5	45	5.67	44	93	897	298	4	54.4	1.7	34.7	0.3						
WV-3	5	1	5	46	5.94	63	55	699	254	2.5	56.1	2.4	44.2	0.1						
WV-3	6	0	5	47	5.54	26	123	684	231	3	53.3	1.3	40.7	0.2						
WV-3	6	1	5	48	5.95	27	65	651	268	2.6	54.8	2.5	43.2	0.1						
WV-3	7	0	5	49	5.49	31	111	777	232	3.3	51.6	1.6	43.7	0.2						
WV-3	7	1	5	50	6.63	75	66	1222	273	2.9	66.9	2.3	45.1	0.2						
WV-3	8	0	5	51	5.27	26	104	750	244	3.8	52.8	1.6	53.6	0.2						
WV-3	8	1	5	52	5.95	49	52	662	236	2.1	59.7	2.1	42.4	0.1						
WV-3	9	0	5	53	5.5	24	101	640	235	3.6	54.1	1.6	53.2	0.2						
WV-3	9	1	5	54	6.1	55	55	565	215	2.2	44.3	2	41.8	0.1						
OH-1	1	0	5	55	5.12	47	87	1134	158	1.5	22.2	1.7	37.2	0.3						
OH-1	1 SS		4	177	7.45	165	74	2115	274	3.3	53.5	3	57.8	0.8						
OH-1	2	0	5	58	5.04	17	98	870	159	1.4	20.8	1.5	26.5	0.2						
OH-1	2 SS		5	59	5.46	70	104	1366	251	3.3	20.1	3.2	68.3	0.9						
OH-1	3	0	5	60	4.95	30	85	1002	178	1.7	26.5	1.8	49.5	0.2						
OH-1	3 SS		5	61	6.59	116	82	1478	250	3.8	33.7	4	98.8	1.1						
OH-1	4	0	5	62	4.74	10	89	898	154	1.3	25.8	1.4	49.7	0.2						
OH-1	4 SS		5	63	6.18	107	91	3141	287	4.3	48.6	3	71.3	1						
OH-1	5	0	5	64	4.74	29	77	831	143	1.4	23.4	1.3	47.7	0.2						
OH-1	5 SS		5	65	7.27	96	60	4906	262	2	49.8	0.8	17	0.7						
OH-1	6	0	5	66	4.78	18	71	948	200	1.8	23.7	1.1	40.7	0.2						
OH-1	6 SS		5	67	7.19	3	37	5000	187	0.2	27.2	0.1	1.5	0.4						
OH-1	7	0	5	68	5.15	40	66	1035	158	1.4	24	1.3	37.2	0.2						
OH-1	7 SS		5	178	7.84	90	63	5000	255	1.5	50.3	0.3	5.9	0.8						
OH-1	8	0	5	70	4.78	14	84	898	177	1.7	32.7	1.8	44.7	0.2						
OH-1	8 SS		4	71	6.78	26	50	5000	234	1.6	55.9	0.2	6.5	0.6						
OH-1	9	0	5	72	4.71	15	79	754	198	1.5	22.3	1.3	37.6	0.2						
OH-1	9 SS		4	73	6.96	148	65	3034	250	2.9	46.3	1.8	63.7	0.6						
OH-2	1	0	5	74	5.18	9	74	661	147	1.3	48.3	0.9	28	0.2						
OH-2	1 SS		5	75	5.96	48	46	1385	241	2.4	60.7	2.2	58.1	0.4						
OH-2	2	0	5	76	5	6	73	584	137	1.5	44.7	0.9	34.1	0.2						
OH-2	2 SS		5	77	6.57	89	42	2609	216	2.2	59.1	1.8	54.1	0.6						
OH-2	3	0	5	78	4.9	9	62	899	176	2.1	43.4	2.1	30.9	0.2						
OH-2	3 SS		5	179	5.62	49	55	1270	224	2.3	48.6	2.2	62.2	0.3						
OH-2	4	0	5	81	5.03	17	73	956	198	1.5	40.9	1.1	40.6	0.2						
OH-2	4 SS		5	180	5.96	56	53	1709	306	2.7	66	2.5	83.5	0.5						
OH-2	5	0	5	83	5.23	8	82	667	248	1.2	34.2	1.1	36.4	0.2						
OH-2	5 SS		5	84	5.46	75	63	2515	341	2.1	35.9	2.5	76.6	0.5						
OH-2	6	0	5	85	5.94	7	87	785	166	1.1	24.8	1	34.2	0.3						
OH-2	6 SS		4	86	5.96	154	71	2674	178	2.4	25.8	3.1	83.6	0.7						

DOE Composite Sample Site	Plot	Sample 0=0-10cm 1=10-30 TS SS=subsoil 2=10-30 +SS	# of samples in composite	Lab #	pH	P	ppm in soil (mg/kg)										Mehlich I (dilute double acid procedure)			
							K	Ca	Mg	Zn	Mn	Cu	Fe	B						
OH-2	7		0	5	87	5.19	10	63	1065	274	1.6	40.6	1.2	36.1	0.2					
OH-2	7	SS		5	88	7.01	141	84	2925	279	2.9	41.7	3	93	1					
OH-2	8		0	5	89		5	60	881	207	1.5	51.2	1.1	41	0.2					
OH-2	8	SS		5	90	6.38	60	61	4233	218	2.5	45.5	2	88.5	0.7					
OH-2	9		0	5	91	5.27	6	69	843	165	1.3	30.6	1.4	39.6	0.2					
OH-2	9	SS		5	92	6.42	117	88	3095	240	2.3	39.5	2.6	72.2	0.8					
OH-2	10		0	5	93	5.45	12	67	1224	171	1.2	28.8	1.1	35.3	0.3					
OH-2	10	SS		4	94	7.16	62	95	5000	231	1.7	55.5	1	22.2	1					
OH-2	11		0	5	95	5.2	8	95	917	316	1.8	45.5	1.3	27.9	0.3					
OH-2	11	SS		5	96	7.24	77	68	5000	307	1.9	53.3	1.6	46.6	0.8					
OH-2	12		0	5	97	5.27	17	73	973	183	1.6	47.3	1.1	27.8	0.3					
OH-2	12	SS		5	98	7.31	14	55	5000	225	1.4	38.5	0.2	9.1	0.8					
OH-3	1		0	5	99	6.39	70	86	1936	165	2.3	44.6	1.6	49	0.5					
OH-3	1	SS		5	100	6.84	195	78	2096	215	3.4	43.5	3.1	78.6	1.1					
OH-3	2		0	5	101	5.82	26	84	1283	166	1.5	30.4	1.1	44.8	0.3					
OH-3	2	SS		5	102	6.98	99	78	3739	271	3.3	45	2.4	75.8	1.1					
OH-3	3		0	5	103	6.51	43	82	1519	158	1.8	44	1.6	61.5	0.4					
OH-3	3	SS		5	104	7.11	95	75	4156	277	2.5	40.7	2.2	74.9	1					
OH-3	4		0	5	105	5.95	13	100	1090	145	1.1	33.2	1.5	50.4	0.3					
OH-3	4		1	2	181	6.19	22	83	2091	183	1.9	35.6	2.7	57.1	0.5					
OH-3	4	SS		3	182	7.43	56	77	2806	239	1.8	52.3	3.4	25.9	0.7					
OH-3	5		0	5	107	6.14	20	79	1371	182	1.5	41.4	1.5	45.1	0.4					
OH-3	5		1	3	108	6.43	57	47	2362	213	2.3	51.6	2.7	44.5	0.7					
OH-3	5	SS		2	109	6.95	59	58	2149	297	2.5	47.5	3.5	39.6	1.1					
OH-3	6		0	5	110	6.52	27	79	1331	170	1.6	39.1	1.4	34.5	0.4					
OH-3	6	SS		5	111	6.52	100	67	1702	198	2.5	42.9	2.3	69.2	0.7					
OH-3	7		0	5	112	6.3	20	82	1254	203	1.7	38.1	2.1	37.5	0.5					
OH-3	7	SS		4	113	6.22	100	90	2731	317	2.1	44.4	2.1	73.6	0.7					
OH-3	8		0	5	114	5.45	10	111	787	154	1	28	1.3	39.6	0.2					
OH-3	8	SS		5	115	6.64	102	72	1443	236	2.4	48.2	3	51.3	0.9					
OH-3	9		0	5	116	5.4	13	91	785	153	1	30.6	1.2	40.2	0.3					
OH-3	9		1	2	183	7.02	39	70	1144	253	1.7	37	2.8	29.8	0.7					
OH-3	9	SS		3	184	7.48	77	86	2351	371	2	45.5	3.6	48.2	1					
VA-1	1		0	5	118	4.39	26	91	542	220	1.7	66.6	2	42.3	0.1					
VA-1	1		1	4	119	4.86	31	81	873	295	2.3	66.9	2.6	59.4	0.1					
VA-1	2		0	5	120	4.59	24	74	419	155	1.5	52.1	1.6	40.2	0.1					
VA-1	2	SS		4	121	7.13	41	79	1666	164	4.7	59.5	2.8	109.7	0.1					
VA-1	3		0	5	122	4.62	13	92	281	132	1.1	46.6	1.1	26.7	0.1					
VA-1	3	SS		5	123	7.44	54	66	1540	183	5.5	66.8	2.8	118.8	0.1					
VA-1	4		0	5	124	4.8	18	109	356	147	1.7	47.8	1.4	35.6	0.1					
VA-1	4	SS		5	125	7.31	52	88	1334	234	6.8	83.5	3.1	119.1	0.1					
VA-1	5		0	5	126	4.8	34	66	625	215	1.9	66	2.3	58.1	0.1					

DOE Composite Sample Site	Plot	Sample 0=0-10cm 1=10-30 TS SS=subsoil 2=10-30 +SS	# of samples in composite	Lab #	pH	ppm in soil (mg/kg) Mehlich I (dilute double acid procedure)										
						P	K	Ca	Mg	Zn	Mn	Cu	Fe	B		
VA-1	5		1	3	127	5.08	44	80	863	267	2.8	62.3	3.1	73.1	0.1	
VA-1	5	SS		2	128	5.89	49	65	1211	171	5.1	60.3	2.8	88.2	0.1	
VA-1	6		0	5	129	4.47	22	64	430	200	2.1	61.8	2.7	43.3	0.1	
VA-1	6		1	3	130	4.41	15	65	393	190	2.1	59.8	2.5	42.5	0.1	
VA-1	6	SS		2	131	5.81	43	74	1193	261	3.6	64	2.9	78.1	0.1	
VA-1	7		0	5	132	5.17	22	69	627	211	1.4	62.7	1.5	39.9	0.1	
VA-1	7	SS		4	133	6.98	49	84	1500	211	4.7	68.3	2.9	108	0.1	
VA-1	8		0	5	134	4.93	32	74	596	226	1.9	78.6	2.2	56	0.1	
VA-1	8	SS		2	135	6.8	54	75	1479	213	5.1	70.6	3	97.4	0.1	
VA-1	9		0	5	136	4.97	51	73	734	263	2.3	68	2.4	50.7	0.1	
VA-1	9		1	4	137	5.44	52	69	997	351	2.9	48.1	2.9	49.7	0.1	
VA-2	1		0	5	138	6.08	55	91	886	245	2.9	64.6	2.4	63.7	0.1	
VA-2	1		1	2	139	5.98	52	70	1187	262	3	58.9	2.5	74.7	0.1	
VA-2	1	SS		3	140	7.36	57	108	1519	309	9	78	5.3	145.7	0.2	
VA-2	2		0	5	141	6.05	73	76	1112	281	3.5	80.5	2.8	76.1	0.1	
VA-2	2	SS		4	142	7.65	52	92	1952	398	6.6	95.8	4	201.5	0.1	
VA-2	3		0	5	143	6.36	70	108	933	227	3.9	71.1	2.7	84.5	0.2	
VA-2	3		1	3	144	7.06	62	73	1211	302	4.6	81	3.5	106.8	0.1	
VA-2	3	SS		2	145	7.5	88	102	1519	390	7.2	63.3	5.3	217.8	0.2	
VA-2	4		0	5	146	6.17	55	92	1012	295	2.9	76.8	3.2	79.8	0.2	
VA-2	4	SS		4	147	7.63	98	121	1473	384	7.4	74.9	5.8	151.8	0.2	
VA-2	5		0	5	148	6.31	62	73	864	236	2.9	65.8	2.9	71.7	0.1	
VA-2	5	SS		5	149	7.75	58	81	1861	443	7.3	90.5	5	224.3	0.2	
VA-2	6		0	5	150	6.13	62	76	941	254	3.1	63.9	3	65.7	0.1	
VA-2	6	SS		4	151	7.72	38	96	2093	414	7.8	78.7	4.6	237	0.1	
VA-2	7		0	5	152	6.8	85	77	1166	268	3.8	69.2	3.2	70.5	0.1	
VA-2	7	SS		4	153	7.64	73	110	1829	458	10.7	77.3	7.2	224.4	0.2	
VA-2	8		0	5	154	6.95	89	87	1077	222	3.9	69.1	3.1	75.4	0.1	
VA-2	8		1	3	155	7.2	75	67	1498	288	4.2	55.1	3.7	84.3	0.1	
VA-2	8	SS		2	156	7.26	93	115	1829	428	6.7	69.9	5.1	153	0.2	
VA-2	9		0	5	157	5.81	47	89	718	240	2.4	63.4	3	71.7	0.2	
VA-2	9	SS		4	158	7.46	53	97	1586	414	6.2	82.6	4.9	191.6	0.1	
VA-3	1		0	5	159	5.3	44	70	367	213	4	41.2	2	67.1	0.1	
VA-3	1		1	5	160	5.23	24	72	218	166	3.9	30.5	1.8	38.8	0.1	
VA-3	2		0	5	161	5.85	71	74	500	212	3.6	46.3	1.8	76.1	0.1	
VA-3	2		2	5	162	5.89	56	64	545	219	3.3	57.8	1.9	104.9	0.1	
VA-3	3		0	5	163	6.47	89	87	784	265	3.1	63.8	2	104.8	0.1	
VA-3	3		1	5	164	6.2	72	82	739	268	3.2	78.6	2	133.1	0.1	
VA-3	4		0	5	165	6.58	93	84	709	244	4.7	50.2	2.1	101.3	0.1	
VA-3	4		1	5	166	6.56	62	73	685	233	4.3	50.7	2.1	100.6	0.1	
VA-3	5		0	5	167	6.95	143	103	1016	312	6.9	49.2	2.8	125.2	0.2	
VA-3	5		1	5	168	7.01	84	101	818	291	6.5	57.7	2.8	152.3	0.2	

DOE Composite Sample Site	Plot	Sample 0=0-10cm 1=10-30 TS SS=subsoil 2=10-30 +SS	# of samples in composite	Lab #	pH	P	ppm in soil (mg/kg)										Mehlich I (dilute double acid procedure)			
							K	Ca	Mg	Zn	Mn	Cu	Fe	B						
VA-3	6	0	5	169	6.61	109	106	959	300	4.2	74.6	2.2	125.4	0.1						
VA-3	6	2	5	170	6.77	80	94	783	262	3	71.7	2	116.6	0.1						
VA-3	7	0	5	171	6.83	119	118	934	303	4.4	55.2	2.5	124.3	0.2						
VA-3	7	1	5	172	6.35	68	88	774	262	2.8	65.3	1.7	146.6	0.1						
VA-3	8	0	5	173	7	105	123	977	324	5	56.3	2.8	122.3	0.2						
VA-3	8	2	5	174	6.93	79	80	935	317	3.8	67	2	169.5	0.2						
VA-3	9	0	5	175	6.3	69	86	808	276	3.9	69.6	2.1	124.1	0.1						
VA-3	9	2	5	176	5.89	50	71	551	216	3.9	69.1	2	96.7	0.1						

DOE Composite Sample Site	Analyte Wavelength (nm) Detection limit	Mg 279.079 0.0242	K 766.491 0.0821	Ca 373.690 0.0066	Mn 257.610 0.0001	Na 589.592 0.0286	Sr 421.552 0.0001	Rb 420.185 5.20	Exchangeable Al ³⁺ (meq/100g)
-----ppm in solution (1N NH ₄ OAc extract)-----									
WV-1		42.33	24.18	105.4	2.333				0.05
WV-1		28.99	8.07	71.5	0.526				0.00
WV-1		35.51	13.3	95.3	1.101				0.05
WV-1		29.47	9.07	80.1	0.51				0.00
WV-1		41.73	15.45	107.5	1.6		0.4243	<5.20	0.05
WV-1		35	8.56	100.9	0.232	0.692			0.00
WV-1		44.81	19.38	132.7	2.902		0.4753	<5.20	0.10
WV-1		29.07	7.77	87.7	0.397				0.00
WV-1		38.91	15.51	106.3	2.243		0.3909	<5.20	0.05
WV-1		25.11	7.6	68.1	0.4815				0.00
WV-1		39.68	14.82	96	1.602		0.3463	<5.20	0.10
WV-1		28.35	7.26	63.7	0.4145				0.00
WV-1		37.57	13.31	92.2	2.139		0.3511	<5.20	0.15
WV-1		29.48	8.07	76.4	0.3493				0.05
WV-1		35.7	17.01	94.9	1.743				0.10
WV-1		25.52	7.09	92.4	0.3034				
WV-1		33.26	14.26	92.7	2.279		0.342	<5.20	0.10
WV-1		25.65	7.33	92.7	0.4079				
WV-2		41.55	16.35	91.5	1.212				0.15
WV-2		32.57	8.39	55.4	1.217				0.35
WV-2		39.48	15.09	87.8	1.938		0.4028	<5.20	0.15
WV-2		34.42	11.03	64.1	0.582				0.05
WV-2		38.44	11.98	82.4	2.108		0.3781	<5.20	0.20
WV-2		31.35	8.87	61.3	0.536				0.05
WV-2		43.9	19.07	99.3	1.085		0.4155	<5.20	0.20
WV-2		31.32	11.08	69.2	0.3622				0.05
WV-2		41.67	15.27	100.1	1.806				0.20
WV-2		30.89	6.48	52.7	1.037				0.15
WV-2		38.14	13.54	85.1	1.431		0.4184	<5.20	0.10
WV-2		32.94	9.45	58.4	0.564				0.00
WV-2		40.84	17.29	93.6	1.62		0.351	<5.20	0.20
WV-2		29.29	7.31	45.41	0.696				0.00
WV-2		41.36	19.52	91.7	1.618				0.20
WV-2		31.78	11.38	65.2	1.305				0.05
WV-2		36.43	10.78	79.9	1.14		0.3194	<5.20	0.15
WV-2		32.63	7.96	61.2	0.629				0.00
WV-3		28.64	16.05	69.6	1.61				0.25
WV-3		25.93	7.85	57.3	0.762				0.65
WV-3		41.53	15.39	102.1	1.823		0.3448	<5.20	0.15
WV-3		30.68	8.27	62.5	0.892				0.00
WV-3		38.69	14.32	84.3	2.377		0.2795	<5.20	0.15
WV-3		32.88	7.03	53.1	0.965				0.05

DOE Composite Sample Site	Analyte Wavelength (nm) Detection limit	Mg 279.079 0.0242	K 766.491 0.0821	Ca 373.690 0.0066	Mn 257.610 0.0001	Na 589.592 0.0286	Sr 421.552 0.0001	Rb 420.185 5.20	Exchangeable Al ³⁺ (meq/100g)
-----ppm in solution (1N NH ₄ OAc extract)-----									
WV-3		43.72	20.56	93.9	2.783				0.30
WV-3		27.05	6.2	41.39	1.616				0.25
WV-3		36.61	12.57	85.7	1.446		0.2919	<5.20	0.20
WV-3		32.23	7.42	62.2	0.785				0.05
WV-3		32.98	17.45	79.2	2.683				0.25
WV-3		31.71	8.75	62.5	0.832				0.10
WV-3		31.3	19.12	85.7	1.994		0.3019	<5.20	0.30
WV-3		29.73	9.28	93.1	0.4444				0.05
WV-3		34.63	18.15	86.6	2.649		0.3002	<5.20	0.35
WV-3		30.89	8.01	65.6	1.65				0.10
WV-3		33.58	17.6	74.9	2.548		0.2599	<5.20	0.35
WV-3		27.66	7.04	53.3	0.652				0.05
OH-1		23.44	12.53	164.8	0.918				0.55
OH-1		26.55	8.56	180.2	0.1627				
OH-1		24.05	13.3	130.9	1.833				1.10
OH-1		34.47	12.38	183.9	0.4251				0.05
OH-1		28.37	13.17	140.6	1.663		0.507	<5.20	0.90
OH-1		30.39	12	152.1	0.1501				0.00
OH-1		22.17	13.18	123.4	2.037		0.3959	<5.20	1.50
OH-1		31.8	13.22	300.6	0.618				0.05
OH-1		17.16	12.3	84.1	1.727		0.3125	<5.20	1.70
OH-1		25.22	10.1	318.6	0.402	0.939			
OH-1		29.11	13.74	115.4	1.583		0.4269	<5.20	1.50
OH-1		20.99	8.96	395.4	0.3817				
OH-1		21.2	11.44	113.8	1.313		0.3668	<5.20	0.40
OH-1		22.61	9.94	358.2	0.4434				
OH-1		24.74	14.85	106.9	2.862				1.80
OH-1		23.58	10.19	385.6	1.033				0.30
OH-1		27.23	14.83	82.4	1.709		0.3842	<5.20	
OH-1		25.95	9.94	195.8	0.2963				
OH-2		16.87	10.85	66.6	2.708		0.2849	<5.20	0.85
OH-2		26.79	6.66	135.9	1.096				0.05
OH-2		18.72	12.61	69.9	2.861		0.303	<5.20	0.85
OH-2		22.83	6.37	185.3	0.319	1.183			0.15
OH-2		23.63	11.23	104.6	2.406				0.90
OH-2		22.61	6.03	122.5	0.3447				0.00
OH-2		27.72	12.7	109.6	2.478		0.4565	<5.20	
OH-2		32.21	6.28	185.5	0.617				0.00
OH-2		34.95	11.85	93.6	2.048				0.45
OH-2		32.96	7.83	209.7	0.534				0.10
OH-2		20.06	12.42	90.4	0.582		0.4996	<5.20	0.10
OH-2		18.46	9.33	218.3	0.2144				0.10

DOE Composite Sample Site	Analyte Wavelength (nm) Detection limit	Mg 279.079 0.0242	K 766.491 0.0821	Ca 373.690 0.0066	Mn 257.610 0.0001	Na 589.592 0.0286	Sr 421.552 0.0001	Rb 420.185 5.20	Exchangeable Al ³⁺ (meq/100g)
-----ppm in solution (1N NH ₄ OAc extract)-----									
OH-2		35.68	9.92	124.1	2.181				0.45
OH-2		31.18	11.01	237	0.1764				
OH-2		28.98	10.45	104.1	3.086		0.4955	<5.20	0.70
OH-2		22.57	10.07	410.2	0.3891				0.10
OH-2		22.98	10.48	101.7	1.561		0.578	<5.20	0.25
OH-2		24.37	10.13	226.3	0.4237				0.15
OH-2		20.81	10.69	142.2	0.808				0.20
OH-2		21.31	11.48	342.3	0.216				
OH-2		41.22	12.51	111.9	2.052				0.30
OH-2		30.25	10.72	377.6	0.2299				
OH-2		21.97	12.36	96	2.106				0.35
OH-2		23.61	10.05	440.5	0.2555				
OH-3		20.58	14.31	178.1	0.461		0.824	<5.20	0.05
OH-3		23.43	10.41	163.3	0.1524				
OH-3		22.53	14.77	143.7	0.717		0.65	<5.20	0.05
OH-3		29.71	11.39	273.1	0.2	1.2			
OH-3		19.66	12.56	165.7	0.4649		0.687	<5.20	0.05
OH-3		33.36	12.32	341.9	0.1996				
OH-3		17.55	16.04	112.6	0.611		0.3943	<5.20	0.10
OH-3		19.21	9.82	180.4	0.3283				0.05
OH-3		25.14	9.55	262.8	0.2108				
OH-3		21.24	12.55	123.2	0.481	0.4319	0.4696	<5.20	0.00
OH-3		27.82	10.07	209.5	0.586				0.00
OH-3		40.5	10.77	226.5	0.1291				
OH-3		23.58	15.62	149.6	0.3646				0.00
OH-3		23.16	10.02	158.3	0.1635				0.00
OH-3		29.48	15.29	155.7	0.501				0.05
OH-3		33.41	9.4	260.6	0.302				0.05
OH-3		21.93	18.08	110.3	1.211				0.35
OH-3		25.24	8.58	136.8	0.1227				0.05
OH-3		17.26	11.81	91	0.856		0.3175	<5.20	0.15
OH-3		30.72	8.28	148.4	0.1062				
OH-3		40.41	9.98	215.8	0.1429				
VA-1		28.37	10.66	63.4	5.27	1.451			0.65
VA-1		30.41	7.73	82.2	3.158	1.545			0.20
VA-1		16.71	7.93	40.23	3.451	0.881			0.85
VA-1		12.06	6.47	111.5	0.4866	0.997			
VA-1		16.78	11	32.21	4.052	0.726			1.45
VA-1		12.22	5.56	92.7	0.491	0.776			
VA-1		18.23	12.41	42.1	2.898	0.634			1.00
VA-1		17.22	6.3	88.8	0.337	0.706			
VA-1		23.8	7.83	61.6	3.495	0.65			0.35

DOE Composite Sample Site	Analyte Wavelength (nm) Detection limit	Mg	K	Ca	Mn	Na	Sr	Rb		Exchangeable Al ³⁺ (meq/100g)
		279.079	766.491	373.690	257.610	589.592	421.552	420.185		
		0.0242	0.0821	0.0066	0.0001	0.0286	0.0001	5.20		
		-----ppm in solution (1N NH ₄ OAc extract)-----								
VA-3		28.58	9.55	66.2	0.795	1.396				0.00
VA-3		23.65	6.93	50.6	0.3111	1.005				0.00
VA-3		25.37	9.43	61.2	0.3585	1.05				
VA-3		26.94	7.87	58.4	0.875	1.435				0.00
VA-3		26.21	8.7	66.6	0.2627	1.222				
VA-3		23.27	6.52	53.7	0.3218	1.408				
VA-3		27.24	7.85	62.5	0.982	1.694				0.00
VA-3		22.17	6.56	41.21	2.291	1.444				0.00

Lab #	Pit	Horizon	H ₂ O pH	EC S m-1	CaCl pH	P	ppm in soil (mg/kg)							Mehlich I (dilute double acid procedure)				
							K	Ca	Mg	Zn	Mn	Cu	Fe	B				
185	OH1-1	A	4.8	0.32	4.97	15	164	507	116	2.5	39.7	0.5	23.4	0.3				
186	OH1-1	Bw	5	0.09	4.68	7	111	653	132	1	19.4	1.6	68.6	0.2				
187	OH1-1	2BC	7.6	0.96	7.47	212	92	4460	283	3	53.7	1.6	22.3	1.4				
188	OH1-1	3C1	7.9	0.3	7.66	156	59	3905	536	1.2	49.1	0.7	9	0.9				
189	OH1-1	3C2	7.8	0.5	7.76	222	68	3478	570	1.9	38.9	1.5	12.4	1.1				
190	OH1-2a	A	5.6	0.4	5.45	19	219	1181	179	2.9	30.2	0.9	20.9	0.4				
191	OH1-2a	Bw	5.9	0.11	5.74	35	106	1070	182	2.2	23.9	2.6	69.1	0.2				
192	OH1-2a	2BC	7.8	0.19	7.36	164	86	1838	215	5.4	42.3	2.8	75.2	0.6				
193	OH1-2a	3C1	7.6	0.15	7.47	131	65	1911	221	2.4	37.5	2	41.9	0.5				
194	OH1-2a	4C2	8.1	0.22	7.72	223	103	2669	277	2.1	41.5	1.7	50	0.9				
195	OH1-2b	A	5.8	0.39	5.89	24	126	1135	141	3.2	25.4	0.3	13.4	0.4				
196	OH1-2b	Bw1	5.6	0.1	5.29	16	125	938	152	1.3	14.5	1.6	42.6	0.2				
197	OH1-2b	Bw2	8	0.15	7.73	153	78	2133	244	2.7	56.8	2.4	54.2	0.7				
198	OH1-2b	2BC	8.2	0.19	7.87	164	92	1934	265	2.8	35.2	2.3	85.9	1				
199	OH1-2b	2C1	7.7	0.55	7.65	154	127	2139	340	2.9	29.2	2.5	82.4	1.2				
200	OH1-2b	2C2	7.8	0.52	7.6	139	93	2182	373	2.6	30.6	1.8	104	1				
201	OH1-3	A	5.7	0.49	5.64	22	143	1302	157	2.3	44.7	0.4	12.4	0.5				
202	OH1-3	Bw	5.2	0.09	4.83	5	98	714	162	0.9	14.8	1.6	47.7	0.1				
203	OH1-3	2BC	8.1	0.22	7.8	119	81	4422	316	1.8	52.9	0.8	17.6	0.9				
204	OH1-3	2C1	7.8	0.55	7.55	146	99	3893	411	3.6	46.4	2.9	28.1	1.2				
205	OH1-3	2C2	7.7	0.95	7.55	140	106	3726	426	1.8	37.5	1.6	61.1	1.1				
206	OH2-1	A	5.4	0.52	5.47	13	152	1370	260	5.3	78.5	0.2	7.2	0.5				
207	OH2-1	Bw	5.4	0.1	5.19	2	30	405	170	0.7	21.2	0.6	20.1	0.1				
208	OH2-1	2BC	7.5	0.35	7.37	272	88	1931	342	2.3	33.6	2.6	67.9	1				
209	OH2-1	2C1	7.3	1	7.04	480	94	2730	461	2.6	35.5	2.8	87	1				
210	OH2-1	2C2	7.2	1.15	6.89	327	83	2529	410	3.1	43.6	2.5	68	1.2				
211	OH2-1	2C3	7.5	1.25	7.23	165	139	2791	276	2.6	25.5	4.2	137	1.1				
212	OH2-1	3C4	7.1	1.9	6.57	3	120	5000	266	5.4	26.9	0.8	13.2	1.1				
213	OH2-2	A	4.9	0.32	4.98	7	116	645	130	2.5	38.3	0.2	12	0.3				
214	OH2-2	Bw1	4.8	0.1	4.57	2	54	405	154	0.8	6.7	0.9	16.9	0.1				
215	OH2-2	2Bw2	6	0.5	5.79	31	53	936	248	1.7	36.2	2	48.1	0.3				
216	OH2-2	2BC	7.1	1.45	6.85	48	63	2153	255	4.1	48	5.2	59.1	0.6				
217	OH2-2	3C	7.6	2.3	7.41	2	77	5000	325	0.3	20.8	0.1	0.9	1.3				
218	OH2-2	3Cd	7.7	2.2	7.45	2	75	5000	323	0.6	27.3	0.1	5.7	1				
219	OH3-1	A	7	0.65	7.07	42	108	3003	163	3	38.5	0.4	12.7	1.2				
220	OH3-1	Bw	7.4	0.41	7.35	42	65	2667	172	1.6	35.7	2.1	59	0.5				
221	OH3-1	2BC	7.6	1.1	7.57	69	69	4863	234	1.8	30.8	1.6	48.6	0.8				
222	OH3-1	2C1	7.5	1.55	7.57	38	99	5000	414	1.3	30.8	0.3	27.4	1.1				
223	OH3-1	3C2	7.7	0.5	7.65	2	28	5000	120	0.6	45.8	0.1	1.1	0.3				
224	OH3-1	4C3	7.6	2.3	7.48	2	80	5000	287	0.1	15.6	0.1	0.1	0.4				
225	OH3-1	4C4	7.6	1.6	7.32	2	71	5000	221	0.2	20.9	0.1	0.4	0.4				
226	OH3-2	A	6.4		6.64	27	156	2275	270	4.6	51.5	0.7	4.6	1.1				
227	OH3-2	Bw	6.6	0.65	6.88	31	64	1473	273	1.7	27.5	3.4	23.7	0.8				

Lab #	Pit	Horizon	H ₂ O pH	EC S m-1	CaCl pH	P	ppm in soil (mg/kg)							Mehlich I (dilute double acid procedure)			
							K	Ca	Mg	Zn	Mn	Cu	Fe	B			
228	OH3-2	2BC	5.6	2.1	5.55	83	67	2630	299	2.6	49.2	2.1	94.3	0.7			
229	OH3-2	2C	6.4	2.6	6.3	91	91	3934	395	3.8	43	3.1	103.3	0.9			
230	OH3-2	2Cd	6.4	1.1	6.02	201	114	2425	327	2.7	23.9	6.4	112.6	1			
231	VA1-1	A	5.2	0.11	4.82	8	66	338	132	1	51	0.8	25.2	0.1			
232	VA1-1	C	7.2	0.6	7.09	43	100	1382	259	3.8	104.6	3.3	103.2	0.1			
233	VA1-1	Cd1	6.5	0.5	6.5	33	84	1163	234	4	67.4	5.2	79.5	0.1			
234	VA1-1	Cd2	6.6	0.4	6.6	38	58	1098	210	1.9	74.1	2.2	87.2	0.1			
235	VA1-1	C'	6.8	0.59	6.8	31	63	1349	210	3.6	68.3	2.1	73.5	0.1			
236	VA1-2	A	6.7	0.3	6.65	38	44	950	218	2.3	45.2	1.9	56.4	0.1			
237	VA1-2	C1	6.6	0.33	7.81	49	59	1996	176	6.9	50.1	2.8	122.1	0.1			
238	VA1-2	C2	7.3	0.35	7.57	52	58	2003	304	4.9	82	2.7	92.7	0.2			
239	VA1-2	C3	7.1	0.35	7.72	75	79	1496	176	8.5	37.2	5	134.1	0.1			
240	VA2-1	A	7.6	0.1	7.57	65	53	964	195	4.2	50.5	2.9	73	0.1			
241	VA2-1	C1	7.8	0.25	7.12	20	66	3209	503	7.3	90.6	4.2	367.6	0.2			
242	VA2-1	C2	8	0.2	7.52	12	61	3515	473	8.7	110.8	3.7	288.3	0.2			
243	VA2-2	A	6.4	0.4	6.16	46	87	999	239	3.5	72.9	2.8	79	0.2			
244	VA2-2	C1	5.5	0.42	5.3	31	63	823	247	3.1	50.1	3.5	85.3	0.1			
245	VA2-2	C2	8	0.21	7.25	47	79	2099	483	9	68.3	4.8	364.6	0.1			
246	VA2-2	C3	7.9	0.3	6.84	40	80	2409	495	10.3	74.8	5.5	371.5	0.2			
247	VA3-1	A	5.5	0.31	5.65	34	72	654	295	2.3	90.2	2.5	84.9	0.1			
248	VA3-1	C1	6.8	0.2	6.97	45	74	645	225	3	54.3	2.3	112.5	0.1			
249	VA3-1	C2	6.2	0.25	5.83	41	75	437	220	4.3	46	3.9	96.5	0.1			
250	VA3-2	A	7.2	0.39	7.11	134	105	1184	341	6.9	48	3.5	156.6	0.2			
251	VA3-2	Cd	7.2	0.3	6.68	108	98	1130	361	6.8	42.4	3.8	198.9	0.2			
252	VA3-2	C	6.4	0.29	6.87	64	55	511	188	3.7	38.3	1.5	113.5	0.1			
253	WV-1	A	5.6	0.45	5.9	59	126	1036	283	3.5	55.3	0.8	34.4	0.4			
254	WV-1	Bw	7	0.09	6.91	123	56	1437	246	2.4	73.1	1.8	42.8	0.2			
255	WV-1	BC	7.3	0.15	7.23	121	53	1396	294	2.5	74.4	1.4	45.4	0.2			
256	WV-1	C1(<3/4)	7.4	0.15	7.61	103	71	1937	306	2.4	66	1.7	39.9	0.2			
257	WV-2	A	5.5	0.39	5.28	21	107	815	303	5.7	53.3	0.8	24.5	0.3			
258	WV-2	Bw	5.8	0.09	5.57	16	61	483	273	3	54.1	3.3	55.5	0.1			
259	WV-2	BC	6.4	0.1	6.41	70	65	702	273	2.8	51.2	2.1	46.9	0.2			
260	WV-2	C1	7.2	0.15	6.96	133	66	1710	290	3.4	62.8	2.4	45.2	0.2			
261	WV-3	A	5.7	0.45	5.62	55	148	1188	340	5	52.6	0.5	31.2	0.4			
262	WV-3	Bw	5.2	0.17	4.9	45	50	568	199	1.9	48.9	1.9	82.7	0.2			
263	WV-3	BC	5.3	0.2	5.1	129	70	1003	278	2.7	75.7	0.8	63	0.2			
264	WV-3	C1	6.4	0.21	6.04	273	81	1593	297	1.5	77.9	0.3	59.3	0.3			
265	WV-3	C2	7.4	0.29	7.07	150	91	2727	417	3.4	64	0.8	27	0.5			
266	WV-1	C2	8.2	0.25	7.43	2	61	4915	477	0.2	15.1	0.1	1	0.2			
267	white pine	topsoil	4.6	0.11	4.44	4	48	198	51	2.4	81.3	0.6	49.9	0.1			
268	white pine	subsoil	4.6	0.15	4.42	2	51	535	102	7.1	41	2	64	0.1			

Lab #	Analyte Wavelength (nm) Detection limit	-----ppm in solution (1N NH ₄ OAc extract)-----					Exchangeable Al ³⁺ (meq/100g)
		Mg 279.079 0.0242	K 766.491 0.0821	Ca 373.690 0.0066	Mn 257.610 0.0001	Na 589.592 0.0286	
185		28.77	43.65	127.3	5.52	1.757	1.00
186		17.18	13.29	88.3	0.94	0.604	1.75
187		22.8	10.64	336.5	0.3233	0.912	
188		52.6	8.56	279.6	0.602	1.793	
189		57.6	9.36	256.8	0.49	2.805	
190		29.03	33.38	185.7	1.81	0.924	0.30
191		23.17	11.9	138.7	0.616	0.778	0.10
192		21.89	10.24	170.4	0.3231	1.697	
193		21.85	9.02	189.2	0.1453	0.933	
194		27.86	11.82	193.2	0.1654	1.382	
195		42.06	40.24	307.2	2.786	0.765	0.30
196		20.83	12.83	139.4	0.3753	0.513	0.30
197		25.15	11.1	213.5	0.2442	0.839	
198		28.95	11.54	181.4	0.204	0.845	
199		35.41	12.64	206.4	0.2319	2.379	
200		39.2	11.31	199.9	0.235	4.997	
201		38.39	34.49	297.2	4.634	1.171	0.35
202		18.65	8.74	94.5	0.632	0.895	1.95
203		30.67	10.89	333.9	0.4371	1.047	
204		40.73	10.52	292.5	0.516	2.397	
205		46.07	12.73	323.6	0.4721	5.03	
206		72.1	40.53	337.7	12.84	1.941	0.75
207		17.98	3.108	44.95	1.179	0.976	0.30
208		39.31	11.9	164.1	0.1652	2.044	
209		48.67	11.8	208.1	0.1676	3.005	
210		43.06	9.68	207	0.2136	3.301	
211		33.06	15.27	259.6	0.2867	2.947	
212		37.79	21.06	961	1.4	3.331	0.35
213		28.12	29.07	118.5	5.18	1.372	0.70
214		18.99	7.78	51.4	0.3442	0.548	2.15
215		28.28	6.43	107.6	0.4189	1.128	0.00
216		26.32	7.14	246.2	0.2623	1.447	
217		41.12	15.84	1441	0.2001	2.493	
218		36.48	13.32	552	0.3839	2.324	
219		28.47	24.11	429.9	1.346	1.514	
220		16.95	9.11	227.7	0.1731	1.278	
221		28.69	11.2	397.6	0.2042	2.029	
222		44.49	14.75	475.6	0.199	3.569	
223		7.76	2.514	261.3	0.788	1.763	
224		33.37	13.25	843	0.1797	3.157	
225		25.28	11.49	513	0.4497	2.441	
226		55.5	42.04	388	3.663	1.722	0.30
227		34.82	9.85	201.6	0.2458	1.493	

Lab #	-----ppm in solution (1N NH4OAc extract)-----						Exchangeable Al3+ (meq/100g)
	Analyte	Mg	K	Ca	Mn	Na	
	Wavelength (nm) Detection limit	279.079 0.0242	766.491 0.0821	373.690 0.0066	257.610 0.0001	589.592 0.0286	
228		35.96	8.88	364.2	0.3682	1.898	0.00
229		43.71	11.66	608	0.1839	2.286	0.00
230		41.01	16.07	263.7	1.081	2.989	0.00
231		15.87	7.27	37.01	4.837	1.476	0.95
232		20.51	8.81	106.4	0.623	1.945	
233		24.04	8.81	116.7	1.814	1.68	0.00
234		21.3	7.55	113	1.796	1.475	0.00
235		18.76	6.17	121.1	0.4496	1.7	0.00
236		22.39	4.924	98.2	0.3362	1.867	0.00
237		13.52	5.02	124.5	0.572	1.089	
238		17.99	5.43	116	0.4056	1.492	
239		13.59	5.99	88.1	0.371	1.361	
240		18.78	5.06	84.2	0.1463	0.567	
241		14.19	6.18	129.4	0.925	0.665	
242		15.03	5.78	128.4	0.684	1.022	
243		25.04	10.24	92.5	0.888	1.097	0.00
244		28.72	8.19	78.2	0.4113	1.009	0.05
245		18.43	7.72	88	0.4624	0.752	
246		15.91	6.09	81.3	0.4585	0.848	
247		29.87	8.29	55.7	4.157	1.021	0.10
248		24.56	6.47	42.26	0.1712	0.866	
249		24.34	5.74	33.14	1.372	0.983	0.05
250		25.77	9.54	71.3	0.2744	0.982	
251		27.98	10	71.6	0.2577	1.267	0.05
252		17.15	4.398	30.25	0.736	0.642	
253		42.45	20.85	133.5	1.891	0.88	0.10
254		24.71	6.89	106.2	0.3294	0.831	
255		28.89	7.51	83.9	0.0589	0.819	
256		27.46	8.7	146.2	0.0232	0.816	
257		45.26	17.25	106	2.88	0.573	0.15
258		29.03	6.91	44.47	1.57	0.617	0.10
259		31.38	7.05	57.9	0.4424	0.72	0.00
260		27.05	7.93	119.6	0.0535	0.609	
261		55.4	32.16	145.8	1.916	0.568	0.10
262		26.42	7.38	54.1	1.948	0.823	1.20
263		35.44	12.07	75.2	1.536	0.979	0.40
264		37.96	14.5	95.1	0.2589	1.143	0.05
265		44.96	16.13	165.1	0.1381	1.09	
266		42.16	9.68	268.2	0.0468	0.906	
267		5.06	5.7	17.6	7.98	0.632	
268		12.81	8.28	52.2	2.443	0.757	

Appendix A and B References:

- Gee, G.W. and Bauder, J.W. 1986. Particle Size Analysis. pp. 383-410. *In* Klute, Arnold. (ed.) Methods of Soil Analysis. Part 1. 2nd ed. SSSA. Inc. Madison, WI.
- McLean, E.O. 1965. Aluminum. p. 978-998. *In* C.A. Black et al. (ed.) Methods of soil analysis, Part 2. Agron. Monogr. 9. ASA, Madison, WI
- Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. p. 961-1010. *In* J.M. Bigham (ed.) Methods of soil analysis. Part 2. 2nd ed. SSSA. Madison, WI.
- Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403-431. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. Agron. Monogr. 9. ASA and SSSA. Madison, WI.
- SCS. 1972. Soil survey laboratory methods and procedures for collecting soil samples. USDA. SSIR 1. U.S. Government Printing Office, Washington, D.C.