Carbon Sequestration on Surface Mine Lands

2nd Annual Report

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Principal Authors: Donald H. Graves
Christopher Barton
Bon Jun Koo
Richard Sweigard
Richard Warner

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Name and Address of Submitting Organization
University of Kentucky
Department of Forestry
Lexington, Kentucky 40546-0073

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ABSTRACT

The first quarter of 2004 was dedicated to tree planting activities in two locations in Kentucky. During the first year of this project there was not available mine land to plant in the Hazard area, so 107 acres were planted in the Martin County mine location. This year 120 acres were planted in the Hazard area to compensate for the prior year and an additional 57 acres were planted on Peabody properties in western Kentucky. Additional sets of special plots were established on each of these areas that contained 4800 seedlings each for carbon sequestration demonstrations. Plantings were also conducted to continue compaction and water quality studies on the newly established areas as well as continual measurements of the first year's plantings. Total plantings on this project now amount to 357 acres containing 245,960 seedlings.

During the second quarter of this year monitoring systems were established for all the new research areas. Weather data pertinent to the research as well as hydrology and water quality monitoring continues to be conducted on all areas. Studies established to assess specific questions pertaining to carbon flux and the invasion of the vegetation by small mammals are being quantified. Experimental practices initiated with this research project will eventually allow for the planting on long steep slopes with loose grading systems and allow mountain top removal areas to be constructed with loose spoil with no grading of the final layers of rooting material when establishing trees for the final land use designation.

Monitoring systems have been installed to measure treatment effects on both above and below ground carbon and nitrogen pools in the planting areas. Soil and tissue samples were collected from both years planting and analyses were conducted in the laboratory. Examination of decomposition and heterotropic respiration on carbon cycling in the reforestation plots continued during the reporting period. Entire planted trees were extracted from the study area to evaluate carbon accumulation as a function of time on the mine sites. These trees were extracted and separated into the following components: foliage, stems, branches, and roots. Each component was evaluated to determine the contribution of each to the total sequestration value.

The fourth quarter of the year was devoted to analyzing the first two years tree planting activities and the evaluation of the results. These analyses included the species success at each of the sites and quantifying the data for future year determination of research levels. Additional detailed studies have been planned to further quantify total carbon storage accumulation on the study areas. At least 124 acres of new plantings will be established in 2005 to bring the total to 500 acres or more in the study area across the state of Kentucky.

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INTRODUCTION

EXECUTIVE SUMMARY

Field sampling has been completed for the 2004 growing season on all plots established in 2003 and 2004. Planting areas have been identified for next year and will be established in February and March of 2005. Monitoring of all the sites will be continued and analyzed for the final report to be prepared for this project. Most of the data has been evaluated and summaries are presented in this report. It is becoming very evident that the research systems employed are identifying and quantifying the potential that exists for carbon sequestration on surface mine areas. The presently established areas should yield very valuable results for many years to come.

EXPERIMENTAL

A monitoring program to measure treatment effects on above and below ground carbon (C) and nitrogen (N) pools for tree planting areas is currently underway. Sample plots established in 2003 are being assessed to determine biomass, carbon and nutrient changes from the previous year. The plots were designed to both sample planted species and to account for differences related to site preparation activities and micro-topographic variability amongst planting units. Additional plots were developed to assess the 2004 plantings, and these plots will be monitored in a similar fashion as those plots established in 2003 (Graves et al., 2003). Soil and tissue analyses from samples collected in the field have been or are currently being processed in the laboratory. Results from these activities will primarily be presented in the Final Report.

Preliminary Findings

Second growing season seedling surveys have been completed and compiled. At the 17 West –Ripped site (Eastern Kentucky), average survival was greater than 80% for all species except redbud (78%) and black cherry (50%) (Figure 1). Initial seedling height at 17 West was between 30 and 50 cm for all species planted except for black locust, which exhibited an average height of over 100 cm (Figure 2). In 2004, most species exhibited a slight increase in height (5 to 20 cm) except for yellow poplar, which decreased. However, black locust demonstrated significant growth (≈100 cm) during the second growing season (Figure 2). Of the four dominant species at this site, white oak and red oak initially exhibited the highest average leaf area index (>2000 mm^2), but 2004 data indicated a decline in leaf area for these species which is likely attributable to dieback (Figure 3). Black locust and ash exhibited similar average leaf area indices in 2003 at 1000 mm^2, and showed similar increases of approximately 500 mm^2 in 2004 (Figure 3).

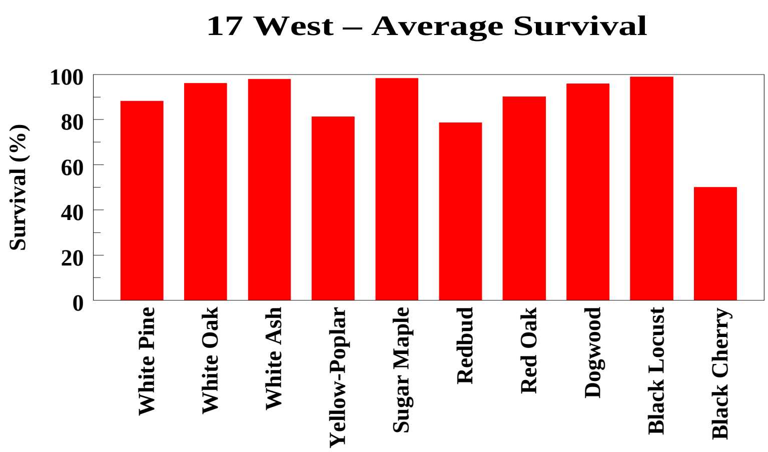

Figure 1. Average survival of planted seedlings at the 17 West mine in Martin Co. KY.

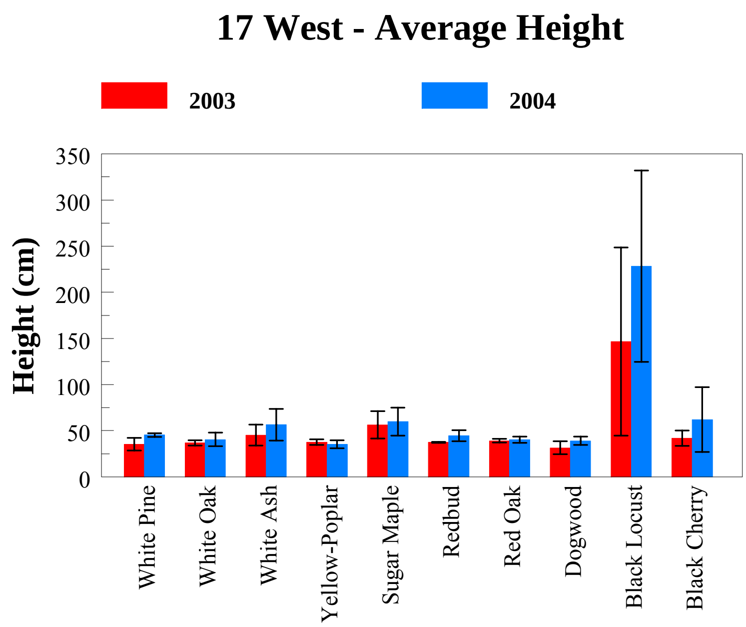

Figure 2. Average seedling height at the 17 West mine in Martin Co. KY.

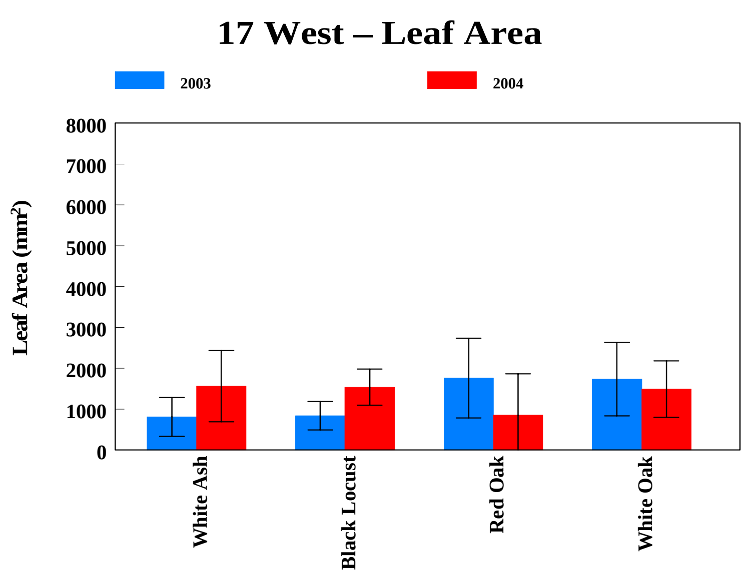

Figure 3. Average leaf area of dominant species at the 17 West mine in Martin Co. KY.

Seedlings at the Gibraltar –Ripped site (Western Kentucky) showed an average initial height between 30 and 60 cm for all species planted (Figure 4). In 2004, ash, dogwood and loblolly pine exhibited slight increases in height, while the oaks, cypress and persimmon showed a decline in height. As with the 17 West site, black locust showed good growth characteristics with an approximate increase in height of 30 cm. Even though the oaks and cypress exhibited a decline in height, all three showed an increase in leaf area from 2003 to 2004, which suggests that growth was occurring and that these species were not stressed (Figure 5). In addition, the ash exhibited a doubling of leaf area between the two years while showing practically no increase in height. Hardwood seedlings (especially oaks) are known to expend a large amount of energy developing an extensive rooting system during the first few growing seasons; thus, the observed response was anticipated.

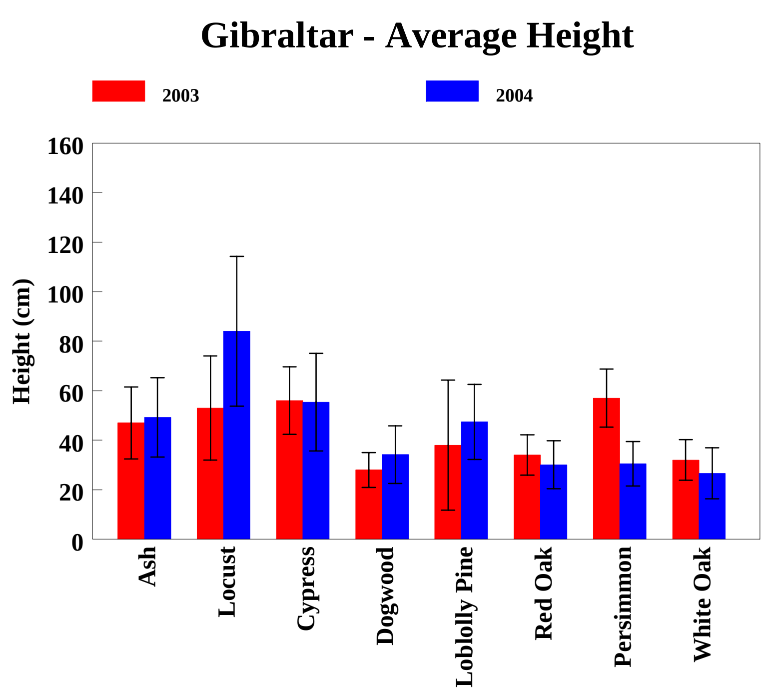

Figure 4. Average seedling height at the Gibraltar mine in Muhlenberg Co. KY.

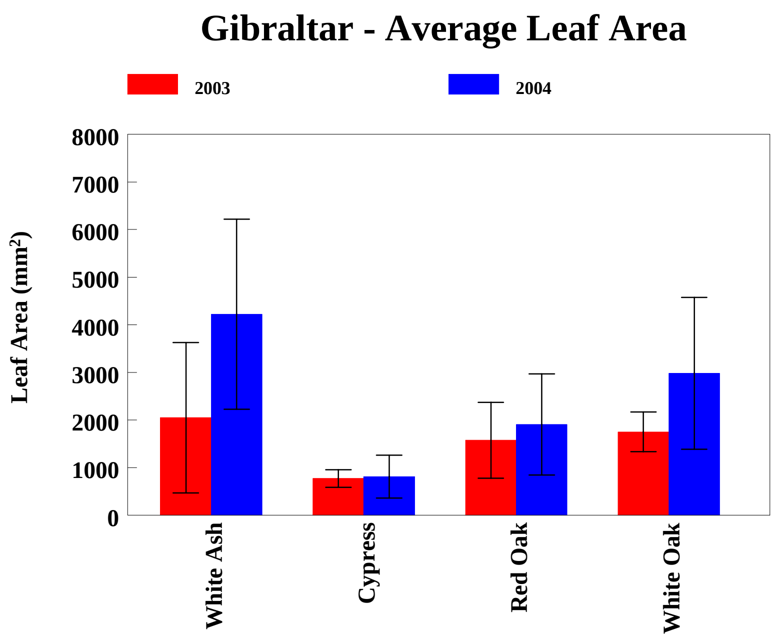

Figure 5. Average seedling height at the Gibraltar mine in Muhlenberg Co. KY.

The Vogue site (Western Kentucky) contained loose graded material and exhibited the lowest species diversity of all sites sampled. The seedlings at this site primarily consisted of yellow poplar and southern red oak. The two species showed an average initial seedling height between 30 and 60 cm and remained that way through 2004 (Figure 6). Initially, we had indicated a small amount of loblolly pine and white oak in the plots at Vogue; however, these species were not present in 2004. It is likely that the pine did not survive, but we are unsure as to the fate of the white oak at this time. The two dominant species exhibited an average leaf area index of ≈ 3000 mm^2 in 2003 and showed a slight increase in 2004 (Figure 7). Leaf area for white ash and white oak (seedlings were not inside sample plot, but still within the planting unit) did not deviate much over that observed in 2003.

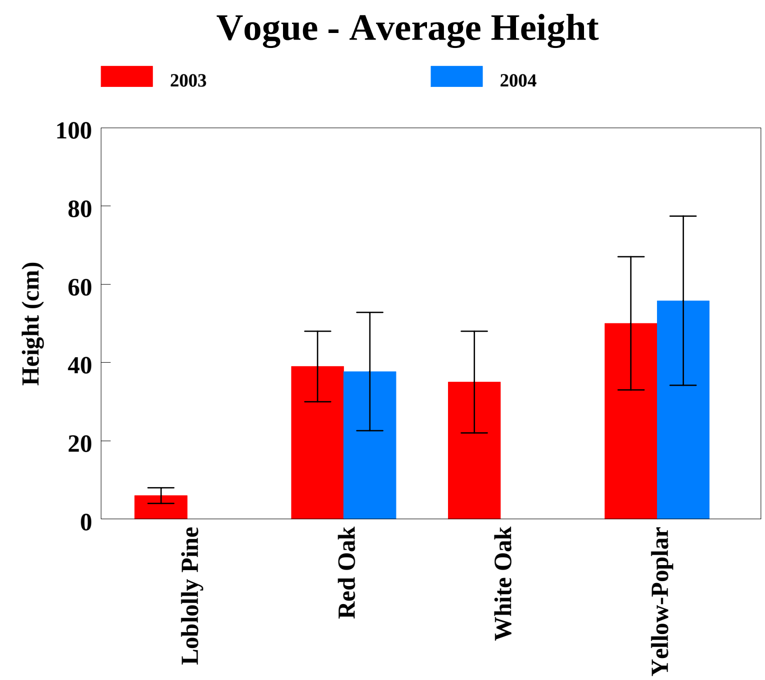

Figure 6. Average seedling height at the Vogue mine in Muhlenberg Co. KY.

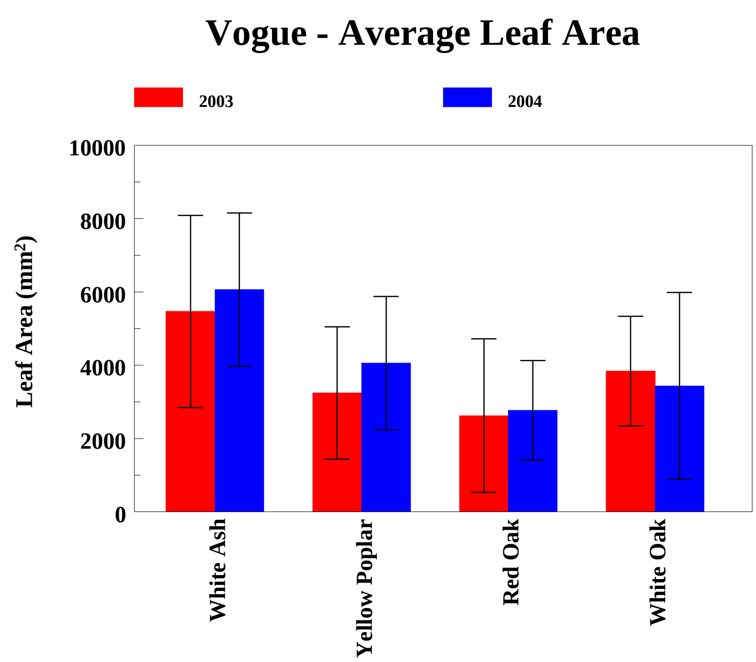

Figure 7. Average leaf area at the Vogue mine in Muhlenberg Co. KY.

Seedlings at the Big Run – Control (compacted) site (Western Kentucky) showed an average initial height between 30 and 60 cm for all species planted (Figure 8). Results from 2004 were very similar to that observed at the Gibraltar site where ash, locust, and cypress showed an increase in height while persimmon and both oak species exhibited a slight decline in height. Of the dominant species, ash exhibited the highest initial average leaf area index of ≈ 4000 mm^2 and showed a modest increase in 2004 to ≈ 6000 mm^2 (Figure 9). Red oak, white oak and cypress showed no increase in leaf area, which is similar to that reported for the ripped areas.

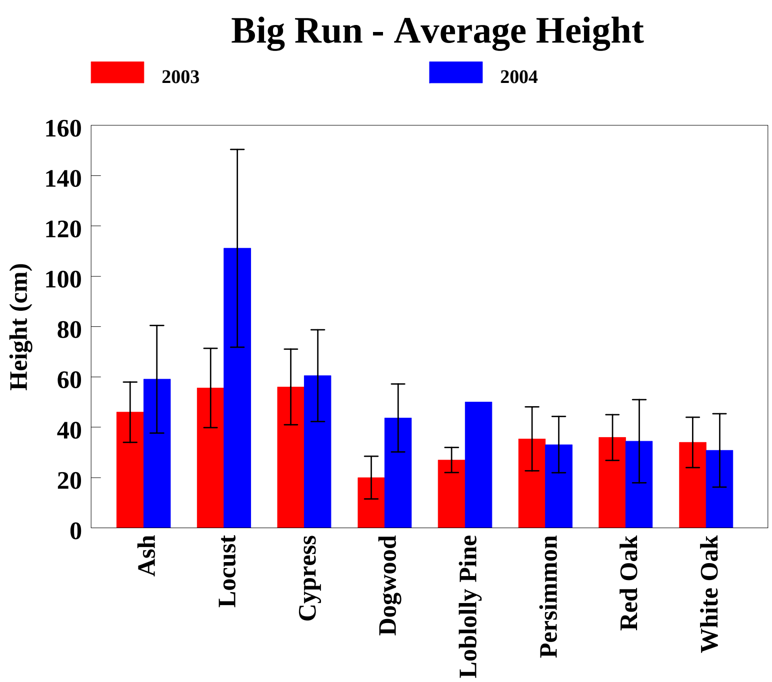

Figure 8. Average seedling height at the Big Run mine in Muhlenberg Co. KY.

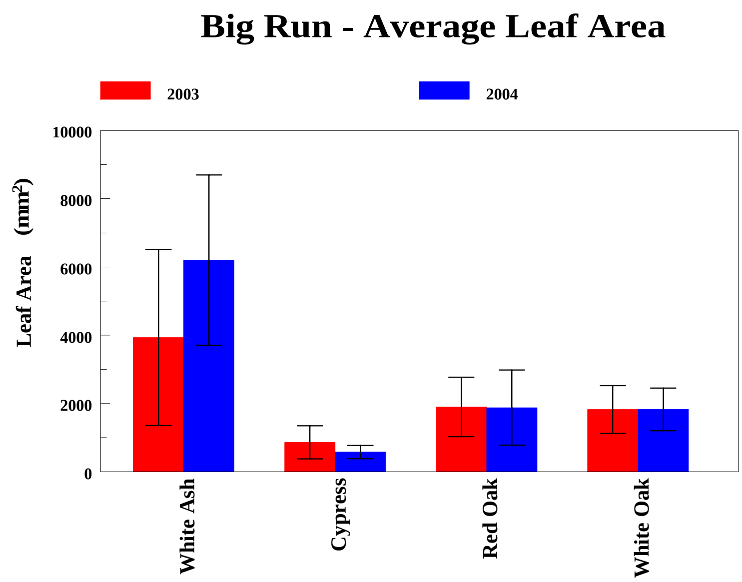

Figure 9. Average leaf area at the Big Run mine in Muhlenberg Co. KY.

Figure 10 displays a comparison of leaf area by reclamation treatment for sites in western Kentucky that were planted in 2003. For red and white oak, the highest leaf area was observed in seedlings planted in the loose spoil (end dump), followed by the ripped then the compacted. Alternatively, white ash exhibited the highest average leaf area in the compacted site, followed by the end dumped and ripped treatments.

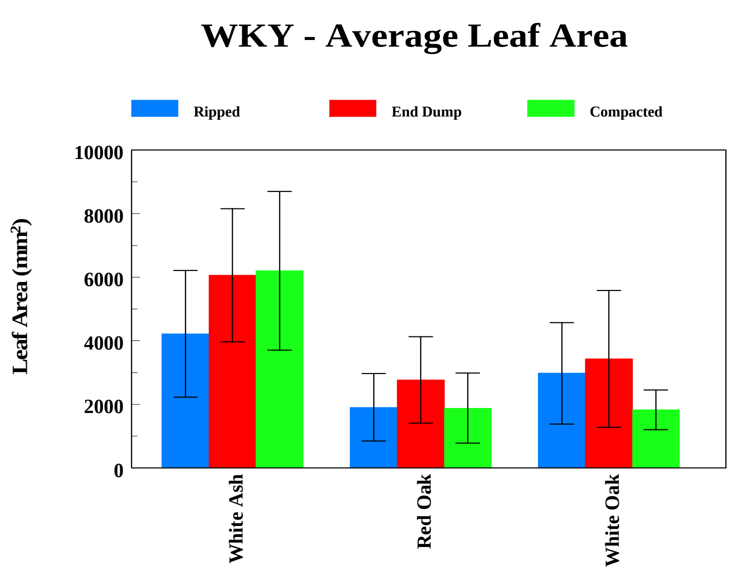

Figure 10. Average 2004 leaf area of seedlings in Muhlenberg Co. KY for three reclamation techniques.

Seedling information from sites developed during 2004 is currently being compiled and will be presented in a future report. Soil and vegetation samples collected during the surveys are currently being processed, analyzed and/or interpreted and will also be presented in a future report.

Mineland Reforestation Mycorrhizae Study

Detailed studies to address specific questions pertaining to carbon cycling have been initiated with the development of additional manipulative plots to examine the influence of mycorrhizae, spoil chemical, and mineralogical properties, and use of amendments on forest establishment and carbon sequestration. A factorial experiment using inoculated vs. non-inoculated species in non-fertilized, fertilized only, amended (organic mulch) only, and fertilized + amended plots was initiated in 2004 and described in the 6th Quarter Report (Graves et al., 2004).

The research plots were established on mined sites in Knott and Muhlenberg Counties, KY. Fifty-four, 15 x 15 meter plots were delineated on each site. Prior to planting, each site was ripped to a depth of approximately 2-meters using a dozer. Half of the area received an application of 40 tons per acre of a wood chip/manure compost mixture (Figures 11-12). The composted areas were subsequently ripped again to incorporate the material into the spoil. Two tree species; *Pinus taeda* (Loblolly Pine) and *Quercus rubra* (Northern Red Oak), were planted in the plots. Each plot received 100 seedlings spaced at *1.5*-meter centers. Each treatment will be examined in triplicate for each species. At 100 trees per plot x 3 plots per treatment x 8 treatments x 2 species, 4,800 seedlings were planted per site. Additional plots with no trees planted were established as controls and to evaluate potential for carbon sequestration on sites planted with grass species. Half of the seedlings from each plot were tagged and measured (height, diameter and leaf area) during this reporting period. These trees will be evaluated each year for growth and survival statistics. Soil samples were also collected from the sites during this reporting period and are currently being analyzed. Whole tree harvesting and tissue samples will be collected from non-tagged seedlings of each treatment in 2005.

Figure 11. Compost amended site, Knott Co. KY

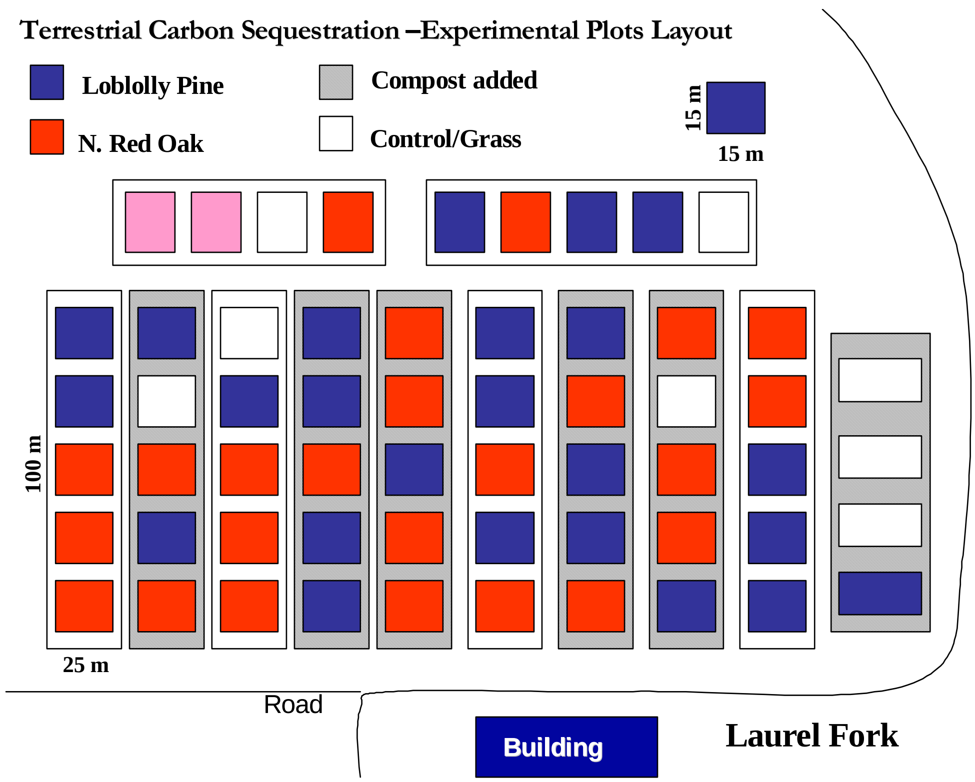

Figure 12. Example of plot layout on the Laurel fork site in Knott Co. KY.

Preliminary Findings

Prior to planting, twenty-five seedlings of each species were collected for an assessment of growth characteristics and mycorrhizal inoculation index. Average height was 39.7 and 18.4 cm for the N. Red Oak and Loblolly Pine, respectively. The oak exhibited an average diameter of 5.1 mm, while the pine had an average diameter of 3.4 mm. The inoculation index for both species was low as exhibited in Table 1. The mycorrhizal plots will receive additional inoculation in the field to further enhance these numbers. Non-mycorrhizal plots will receive continued application of fungicide to suppress natural inoculation. Treatment effects on seedling vigor were noticeable very soon after transplanting occurred (Figures 13 and 14), but an assessment of the extent of the amendment influence is not significant at this time (Table 2).

Table 1. Mycorrhizal inoculation index of seedlings prior to planting.

Species	Inoculation Index (%)†		
	Pt	***Sc***	***Tt***
N. Red Oak	18	3	0
Loblolly Pine	26	9	1

†Pt = Pisolithus tinctorius; Sc = Scleroderma cepa; Tt= Thelephora terrestris

Figure 13. One-year old N. Red Oak on non- amended site, Muhlenberg Co. KY

Figure 14. One-year old N. Red Oak on compost amended site, Muhlenberg Co. KY.

Table 2. Initial seedling height and diameters by treatment from a survey performed in August 2004.

Treatment*	Laurel Fork (EKY)				Nelson Creek (WKY)			
	Height (cm)		***Diameter (mm)***		***Height (cm)***		***Diameter (mm)***	
	AVG	*STD*	*AVG*	*STD*	*AVG*	*STD*	*AVG*	*STD*
LCFM	16.58	4.37	3.64	2.05	17.7	4.96	3.56	0.79
LCFN	17.58	3.86	3.44	0.71	19.09	4.51	3.30	0.83
LCM	20.12	17.42	3.62	0.79	18.61	5.14	3.90	1.13
LCN	17.33	3.65	3.70	0.67	18.69	4.27	3.68	0.71
LFM	18.17	4.33	3.31	0.66	19.25	4.34	3.36	0.78
LFN	18.08	4.62	3.34	0.74	20.32	4.00	3.02	0.96
LM	17.58	4.03	3.67	0.70	20.44	4.50	3.80	1.05
LN	18.26	3.87	3.50	0.76	19.28	3.96	3.72	0.75
NROCFM	38.85	12.09	4.92	1.24	37.6	13.19	6.02	1.81
NROCFN	35.03	9.50	4.71	1.09	40.81	13.50	5.73	1.93
NROCM	39.44	12.00	4.99	1.12	36.71	13.52	5.82	1.82
NROCN	37.97	12.48	4.80	1.17	37.71	11.34	5.81	1.69
NROFM	38.30	11.78	4.65	1.28	33.81	11.96	5.50	1.42
NROFN	41.29	12.63	5.27	1.14	40.52	12.25	6.46	1.94
NROM	42.82	11.76	5.06	1.24	36.52	13.67	5.44	1.72
NRON	37.67	11.40	4.82	1.06	35.36	10.99	5.96	1.84

*L = loblolly pine; NRO = northern red oak; C = compost; F = fertilizer;
M = mycorhizal; N = no mycorhizae

Whole-Tree Harvesting

A chronosequence approach was initiated to evaluate carbon accumulation (biomass and soil) as a function of time on the mined sites. Since the trees planted during this study are only 2 and 3 years of age, older stands within the same planting area that used the same reclamation practice were examined to provide information for older sites. This data will be used to project a trajectory that the planted areas may follow with respect to C and biomass accumulation in relation to growth. A whole-tree harvesting method was employed for this approach where trees were extracted from the sites and separated into the following components: foliage, stem, branches, and roots. Biomass estimates of the various components were obtained in the field and samples from each fraction were collected for chemical analyses. Four tree species (*Platanus occidentalis*: Sycamore, *Fraxinus Americana*: White Ash, *Quercus alba*: White Oak, and *Liriodendron tulipifera*: Yellow Poplar) representing 3 age classes (2, 3 and 7 years of age) on loose spoil material were examined. The trees were manually and randomly sampled by using a chain saw and shovels (Figure 15). The root collar diameter (RCD), crown height and width, and seedling height were measured prior to harvest. The trees were then subdivided into the 4 tree components and weighed using a portable analytical scale and a heavy-duty hanging scale. Subsamples of each tree component were taken to the laboratory where leaf area, dry weight, and physical and chemical analyses were, or will be, performed. All samples were washed and rinsed with deionized water, oven-dried, ground in a mill, and prepared for further analyses such as total C, total N, total organic C, pH, EC, nutrients, and trace elements. In addition, bulk and rhizosphere soils were collected for each age class and species sampled and will be analyzed for a similar suite of elements.

a. Two-year-old Sycamore b. Three-year-old Sycamore c. Seven-year-old Sycamore

Figure 15. Two (a), three (b), and seven-year-old (c) Sycamore were manually and randomly harvested by using a chain saw and shovels.

The above ground and below ground biomass weights were summed to produce the total tree biomass in dry weight units. Total tree biomass including foliage, stem, branch, and root was converted to kilograms of carbon with a tree survival data and biomass for each tree species. Soil samples were collected using soil core at a depth of 30 cm for each age class and species to measure soil carbon. Soil samples were air-dried, sieved at 2 mm, ground in a mill, and weighed to determine carbon content. Average of site bulk density, 1.6 g cm^{-3}, was used to correct for coarse fragment content. Ground soil and tree tissue samples were analyzed to determine the total carbon with a LECO carbon analyzer (CHN-2000 Elemental Analyzer, LECO Corporation, St. Joseph, MI). Total tree and soil carbon in kilogram per hectare were presented.

Preliminary Findings

Carbon captured in tree biomass, including biomass in the above ground and below ground components was measured by randomly choosing three replicates of each tree species at three age classes (Figure 16). The equations developed by Jenkins et al. (2003) were used to compute the root biomass estimates of 7 year trees because its complexity of harvesting. The carbon contents in trees vary with tree age and tree species. The average tree carbon of each tree was 8,571 kg ha^{-1}, 5, 590 kg ha^{-1}, 12,300 kg ha^{-1}, and 25,005 kg ha^{-1} for 7 years old White Ash, White Oak, Yellow Poplar, and Sycamore, respectively. The tree carbon content varied between 25 to 90 kg ha^{-1} for 2 years old trees, between 514 to 841 kg ha^{-1} for 3 years old trees, and between 5,590 to 25,005 kg ha^{-1} for 7 years old trees (Figure 16). The amount of carbon in the rhizosphere soils ranged from 4,958 to 15,127 kg ha^{-1} (2 years old), ranged from 16,203 to 21,744 kg ha^{-1} (3 years old), and ranged from 28,259 to 41,921 kg ha^{-1} (7 years old) (Figure 17). Johnson and Todd (1998) reported that forests regenerating following whole-tree harvesting in eastern Tennessee added 26,000 Mg C ha^{-1} to above ground biomass and 27,000 Mg C ha^{-1} to mineral soil reserves during 15 years. A century-old reference forest at the same site added 60 and 12 Mg C ha^{-1} to forest biomass and soil during the same period. Our mined site average soil carbon for 7 years old trees was comparable to that of Johnson and Todd (1998) sites and indicated that our reforestation of the mined sites has tremendous potential to sequester carbon. Carbon accumulation rate increased by 750 to 5,028 kg ha^{-1} yr^{-1}, 4,842 to 9,685 kg ha^{-1} yr^{-1}, 4,825 to 17,363 kg ha^{-1} yr^{-1}, and 2,744 to 9,888 kg ha^{-1} yr^{-1} for White Ash, White Oak, Yellow Poplar, and Sycamore, respectively (Figure 18).

This preliminary study showed that successful reclamation and reforestation of mined sites will largely restore the potential of forests and forest soil systems to sequester carbon at pre-mining level, and at some cases improve site quality by eliminating growth-limitation factors. A projection of carbon sequestration rates established by this study indicated that mined sites would achieve and exceed pre-mining carbon levels on sites.

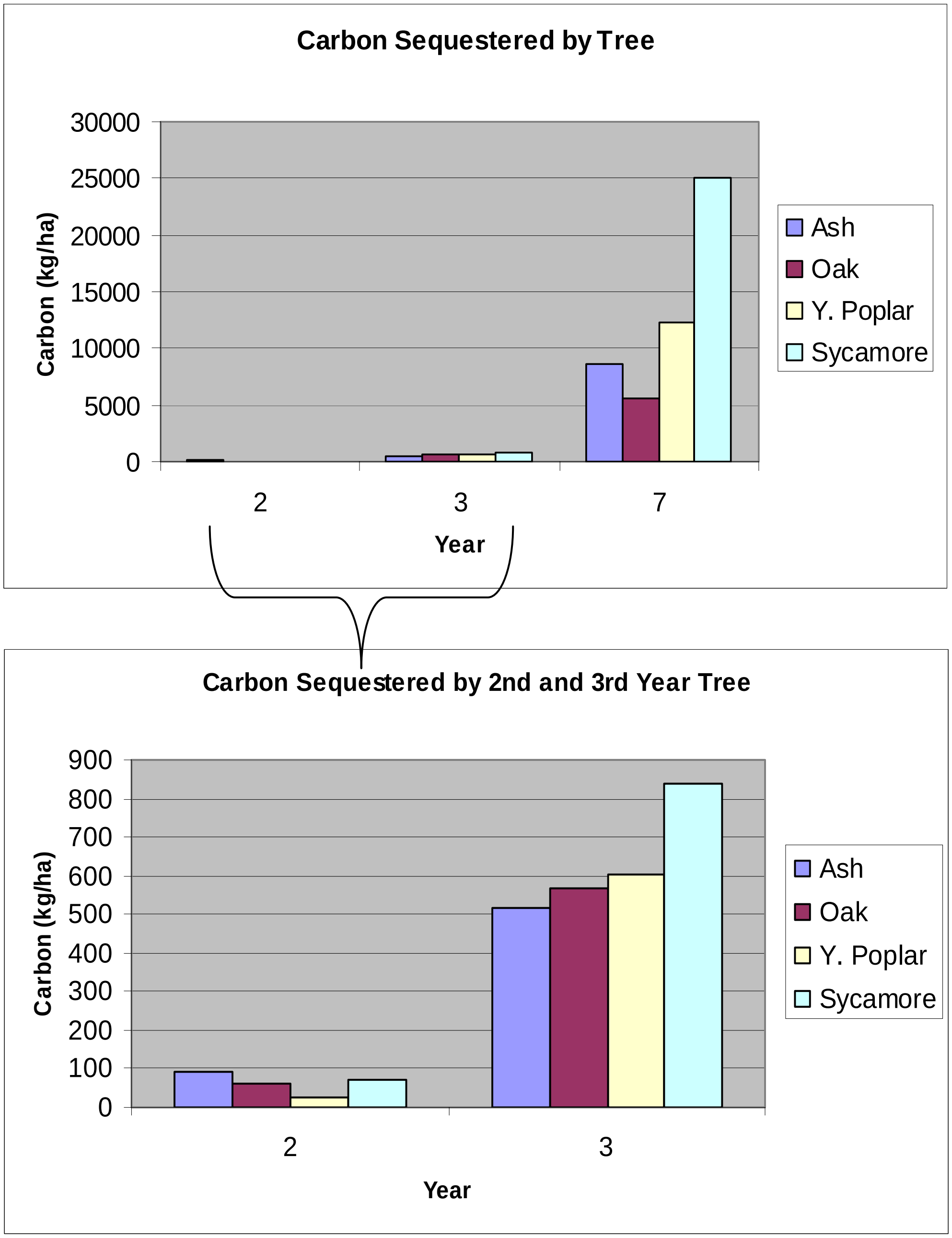

Figure 16. Carbon sequestered by four tree species, representing 3 age classes (2, 3, and 7 years) on a loose dump mined site in the Southern Appalachian Coalfield region.

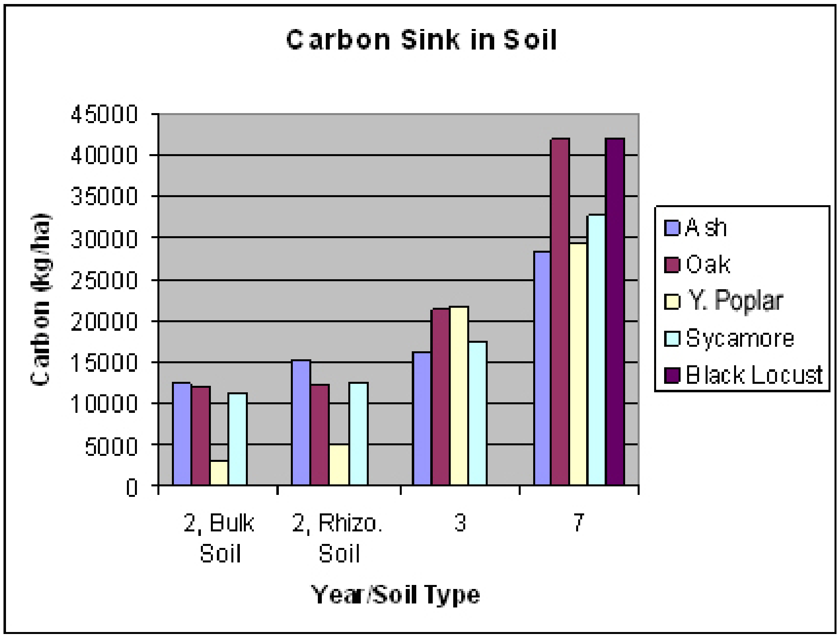

Figure 17. Soil carbon sequestered on mined study sites. Rhizosphere soils were presented for 3 and 7 years old trees.

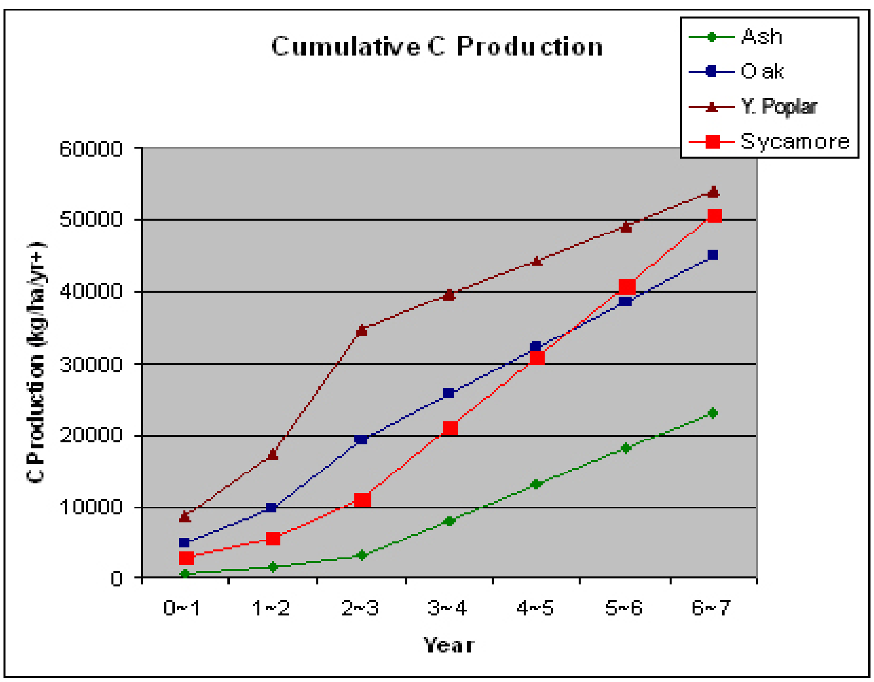

Figure 18. Cumulative carbon sequestered by tree and soil on study mined sites.

Decomposition and Soil CO_2Efflux

Efforts to examine decomposition and heterotrophic respiration on C cycling in the reforestation plots were enhanced during 2004. We examined six reforested mine sites along a chronosequence (age after reclamation between 1 and 8 years) and six adjacent non-mined forested sites along a chronosequence (between ages 3 and 20 years) for various ecosystem processes including soil CO_2 respiration, soil moisture and temperature, decomposition, aboveground primary productivity and biomass, belowground biomass, and litterfall. Litter bags (20 x 20 cm with 10 g of leaf material) were placed at random in selected plots within the reforestation area and on undisturbed forested sites. Each plot (12 total: 6 mined and 6 natural) received 24 bags, which were stapled to the surface soil using steel rods. Three bags from each site will be collected every three months, weighed and analyzed for C and N concentrations. In addition, permeable columns were inserted into the soil at each site (15 cm depth) in close proximity to the litter bags to evaluate carbon change over the same study period. The columns consisted of a homogenized spoil material with known C and N concentrations contained within a nylon bag. The spoil will be influenced by all climatic and biological activities subjected to original material located at the sites, and thus should be a good indicator of changes in soil carbon and nutrient levels. Columns will be removed at the same time and frequency as described for the litter bags. PVC collars have also been installed at these sites to evaluate soil CO_2 efflux using a LI-COR LI-8100 Automated Soil CO_2 Flux System. Carbon dioxide flux will be monitored monthly from the litter decomposition plots. Litter collectors were also placed in the field and are being collected monthly. Litter from the collectors is removed, dried, weighed, and separated to determine % species present and analyzed for total C and N.

Preliminary Findings

Sample collection and analysis will occur primarily in 2005/06, so results are not available at this time. Preliminary observations, however, suggest that aboveground biomass is greater on reforested mine sites than on regenerating forests of similar age, and differences in carbon allocation to roots between the two systems may exist. In addition, soil CO_2 measurements at the end of the 2004 growing season suggested that younger regenerating forests have different respiration rates compared to the young reforested mines (3.42 $\mu m/m^2/s$ and 6.49 $\mu m/m^2/s$, respectively), while the older regenerating forests have similar respiration rates compared to the older reforested mines (4.76 and 3.35, respectively). With this study, we expect to gain insight as to how nutrients cycle within the reforested surface mines, and address the potential for the areas to increase carbon storage.

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CONCLUSIONS

Conclusions are not available at this time as the study is scheduled to be monitored for another year.