CARBON INVENTORY OF REFORESTED MINED LAND IN THE EASTERN UNITED STATES: PRELIMINARY RESULTS

J. A. Burger* and J. A. Rodrigue
Department of Forestry (0324)
228 Cheatham Hall
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061 USA
Phone 540-231-7680; Fax 540-231-3330; E-mail jaburger@vt.edu

ABSTRACT

The reforestation of mined land has the potential to sequester large amounts of atmospheric carbon on sites where carbon-based fuels were extracted. The extent to which reforested mined land captures atmospheric carbon compared to natural undisturbed land is still largely unknown. We compared the amount of carbon sequestered on 14 reforested mined sites to 8 natural sites in the midwestern and eastern coalfields. After 20 to 55 yr, total site carbon levels on mined study sites averaged 217 Mg ha^{-1}, while total carbon amounts on natural sites averaged 285 Mg ha^{-1}. The amounts of carbon captured within the plant biomass and litter layer were the same on mined and natural sites. However, the soil carbon content of mined sites averaged 39% lower than natural soils. The amount of carbon captured across mined sites was largely a function of forest stand age and forest and site productivity. This 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 levels.

INTRODUCTION

Under the 1992 Framework Convention on Climate Change, 153 nations agreed to mitigate global climate change by controlling greenhouse gases. The governments and industries of these nations would reduce greenhouse gasses by sequestering atmospheric carbon or by reducing CO_2 emissions (Wright et al., 2000). Carbon accreditation of forest development projects is one approach to sequestering atmospheric carbon under the climate change agreement. Forests provide a low-cost method of carbon accreditation compatible with other environmental, economic, and social development projects (Wright et al., 2000). Forest development projects use trees to sequester carbon for long-term storage. As young forests develop, atmospheric carbon is locked into wood during growth and stored in litter layers. Carbon is also incorporated into the soil via root turnover, litter decomposition, and turnover of meso- and microfauna. The carbon sequestration potential of a forest depends on stand growth rates, the site's biological carrying capacity, stand age, and product utilization. Furthermore, carbon sequestration and storage may be increased if forests are harvested and trees are converted into wood products (Skog and Nicholson, 1998).

The eastern deciduous hardwood forest of the midwestern and eastern regions of the United States stores large amounts of carbon in forest biomass and forest soils. Anderson (1991) estimated average worldwide carbon levels for temperate deciduous forests at 175 Mg ha^{-1}, with 90 Mg ha^{-1} in the plant biomass and 85 Mg ha^{-1} in the soil and litter layer. The average carbon content of forests in the eastern half of the U.S. was 179 Mg ha^{-1}, including 81 in the forest biomass, 9 Mg ha^{-1} in the litter layer, and 89 Mg ha^{-1} in the soil (derived from Turner et al., 1995). However, a comprehensive study of forest carbon pools of a northern hardwood forest at Hubbard Brook in New Hampshire found 134 Mg ha^{-1} of C in tree biomass, 30 Mg ha^{-1} in the forest floor, and 130 Mg ha^{-1} in the soil, for a total of 294 Mg ha^{-1} (Johnson et al., 1995). These studies provide baseline examples of carbon content in temperate deciduous forests, and they show that carbon content can be highly variable and forest-specific.

Within the eastern and central hardwood regions, thousands of acres have been surface-mined for coal. Coal mining and the use of the mined coal for power generation are major sources of CO_2 emissions. In addition to coal combustion, surface mining for coal contributes further to CO_2 emissions because it totally removes the forest vegetation. Some forest biomass is harvested, but most is typically bulldozed in piles and burned.

A compelling argument can be made for restoring forestlands mined for coal back to carbon-rich forests that existed prior to mining. The new forest will absorb some of the CO_2 emitted from the coal for which the original forest was sacrificed. Maximizing the productivity of the restored forest is also compelling. Productive forests will enhance the site's ability to recapture the carbon contained in the original forest and some of the carbon contained in the coal that was mined beneath it.

The carbon sequestration potential of forested mined land is not well understood. It must be characterized in order to make comparisons with other carbon sequestration projects, and to better understand differences in carbon capture levels under varying forest and mined land conditions. Therefore, we characterized fourteen 20- to 55-year-old mined sites throughout the midwestern and eastern coal regions to accomplish the following objectives: (1) quantify the carbon sequestered under varying mined site and forest stand conditions, and (2) compare the carbon sequestered on these sites to adjacent natural forested sites.

METHODS

Site Selection and Layout

Fourteen pre-SMCRA forest sites across seven states, each with an average size of 2.5 ha of contiguous forest cover, were located on mined lands in the midwestern and eastern coal fields of the U.S. (Figure 1). The study sites were chosen to represent a cross-section of stand age and site conditions. The 14 sites ranged from 20 to 55 years old. The canopy layer species ranged from pure hardwood and conifer stands to mixed stands (Table 1). All sites were planted with trees produced in local nurseries. Natural soils included Inceptisols, Ultisols, and Alfisols. Mined sites were classified as Udorthents.

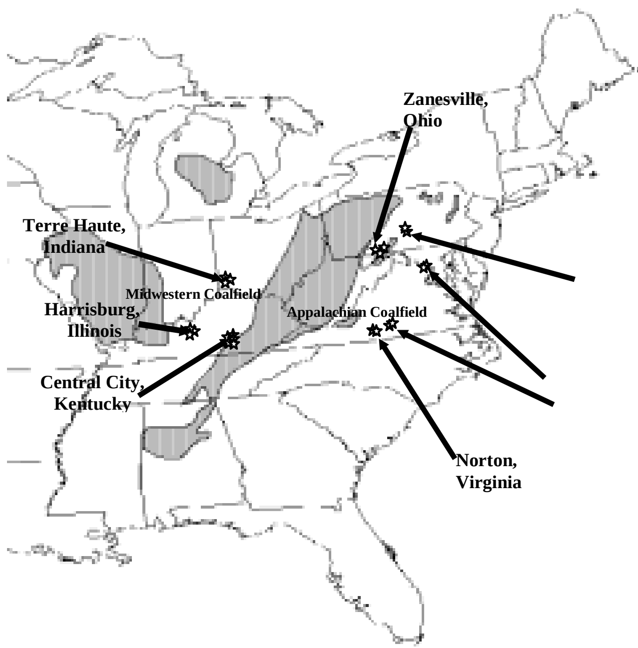

Figure 1. General location of study sites in the Midwestern and Appalachian coalfields.

Within each similar geographic region (e.g., southern Illinois), reference native forest sites were located and measured. These non-mined sites represented land conditions similar to those present on mined sites before they were disturbed. The undisturbed reference sites were located within 2 km of the selected mined sites. All sites were mature, well-stocked, native forest stands, but all had been harvested to varying degrees at some point in their history. From this point forward the native, non-mined control sites will be referred to as natural stands.

A 20 x 20-m grid was superimposed across the site after the boundaries were established. A 20-m buffer strip was maintained on all edges of each forest site (Figure 2). Grid lines were placed perpendicular to the banks of open-pit mined sites where more than one spoil bank existed to ensure that the site's microtopography was taken into account. All subsequent sampling was based from intersections of the grid. Field data collection took place between May and August 1999, with the exception of two sites, which were measured in August 1998.

Table 1. Description of study sites, including dominant canopy species and stand age at time of measurement.

State	Site	History	Canopy Type	Stand Age
Illinois	***IL-C***	***Natural***	***Scarlet oak/red maple***	***43†***
	IL-1	Mined	White oak/tulip poplar	54
	IL-2	Mined	Cottonwood	43
Indiana	***IN-C***	***Natural***	***Oak/tulip poplar***	***40†***
	IN-1	Mined	Pitch pine	55
	IN-2	Mined	Pitch pine/hardwoods	50
Kentucky	***KY-C***	***Natural***	***Oak/tulip poplar***	***52†***
	KY-1	Mined	Mixed hardwoods	35
	KY-2	Mined	Mixed hardwoods	35
	KY-3	Mined	White pine/loblolly pine	40
	KY-4	Mined	Loblolly pine	33
Ohio	***OH-C***	***Natural***	***Oak/tulip poplar***	***59†***
	OH-1	Mined	Mixed hardwoods	50
	OH-2	Mined	Mixed hardwoods	50
West Virginia	***WV-C1***	***Natural***	***Oak/tulip poplar***	***62†***
	WV-1	Mined	White pine	38
	WV-C2	***Natural***	***Oak/tulip poplar***	***60†***
	WV-2	Mined	White pine	28
Pennsylvania	***PA-C***	***Natural***	***Oak/tulip poplar/cherry***	***62†***
	PA-1	Mined	White pine/Scots pine	40
Virginia	***VA-C***	***Natural***	***Oak/tulip poplar***	***72†***
	VA-1	Mined	White pine	20

† Represent average age of trees measured on non-mined reference sites.

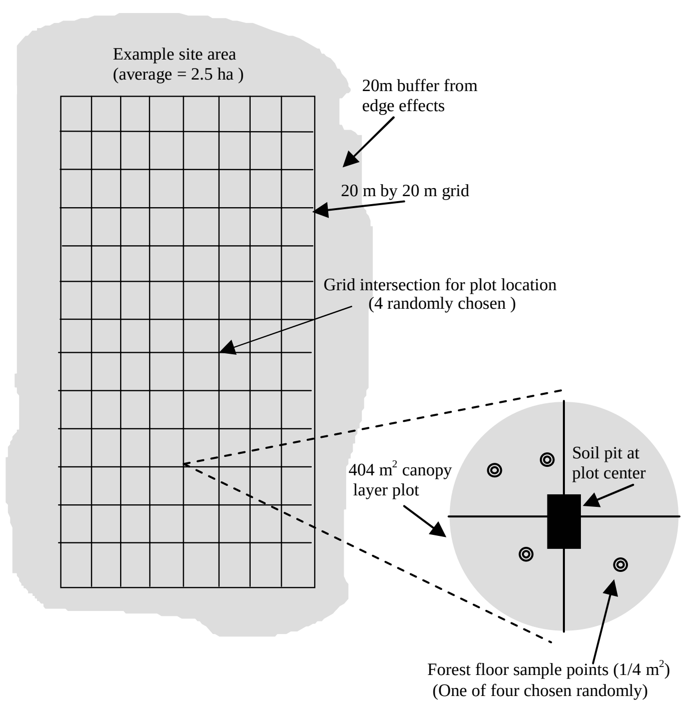

Figure 2. Typical site layout and plot diagram used at each study site.

Site Carbon Capture Calculations

Carbon captured in the above-ground biomass was estimated on each site by randomly choosing measurement points at four of the 20 x 20-m grid intersections (Fig. 2). Trees in the main canopy greater than 13.0 cm in diameter were tallied within a 404 m^2 circular plot. A merchantable stem height to a 10-cm top was measured on trees between 13 and 25 cm in diameter. Trees with diameters greater than 25 cm were measured to a 20-cm top. Merchantable stemwood volumes for all trees measured on a site were generated from species-specific volume equations and tables (Clark and Saucier, 1990; Clark and Souter, 1996; Clark et al., 1986a; Clark et al., 1986b; Tritton and Hornbeck, 1982; Clark et al., 1980). Merchantable stem volumes were converted to total forest volume (m^3 ha^{-1}) using ratios reported for softwoods and hardwoods in U.S. forest regions (Birdsey, 1992). Total forest volume includes merchantable stems, tops, branches, rotten trees, small trees (< 5.0 in dbh), snags, stumps, roots and bark. Total forest volumes were 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 aboveground 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 (Fig. 2) 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 m^2 random samples at each measurement plot and bulked to form a 1 m^2 sample. Bulked 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 t-tests termed “different” in this paper have a significance level of $\alpha \leq 0.1$.

RESULTS AND DISCUSSION

Total Carbon

Total carbon sequestered on natural reference sites ranged from 220 to 365 Mg ha^{-1}, with an average of 285 Mg ha^{-1} (Table 2). Total carbon sequestered on mined sites ranged from 107 to 322 Mg ha^{-1}. The average across all mined sites was 217 Mg ha^{-1}. Most of the carbon present on both the natural reference sites and mined sites was associated with the above- and below-ground tree biomass (Table 2). This component contained 71% of the sequestered carbon on natural sites. On mined sites, tree biomass made up 75% of the total. Natural forest litter layers contained 4% of the total carbon, and mined site litter layers contained 6%. The soils of natural and mined sites contained 25% and 20% of the sequestered carbon, respectively.

In all cases, the carbon distribution among tree, litter, and soil components was more variable on mined sites (Table 2). 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 65% and 77% of the total. On mined sites the range was 44% to 84%. Litter layer carbon varied between 2% and 5% on natural sites, and between 2% and 15% on mined sites. Soil carbon on natural sites varied between 19% and 30% of the total; on mined sites the range was 12% to 41%.

Table 2. Carbon sequestered by ecosystem component on mined and non-mined sites in the midwestern and eastern coalfields.

Site	Tree Carbon	Litter Layer Carbon	Soil Carbon	Total Carbon Sequestered
	----------------------------------	Mg ha^{-1}	----------------------------------	
Natural Sites:				
IL-C	250 (68) †	7 (2)	108 (30)	365
IN-C	227 (74)	5 (2)	74 (24)	306
KY-C	142 (65)	11 (5)	66 (30)	220
OH-C	158 (72)	9 (4)	53 (24)	220
PA-C	174 (73)	13 (5)	49 (21)	237
VA-C	270 (77)	15 (4)	66 (19)	352
WV-C1	206 (71)	10 (3)	73 (25)	289
WV-C2	198 (69)	8 (3)	81 (28)	287
Average	**203 (71)**	**10 (4)**	**71‡ (25)**	**285‡**
Mined Sites:				
IL-1	265 (83)	7 (2)	48 (15)	320
IL-2	272 (84)	8 (2)	42 (13)	322
IN-1	143 (73)	21 (11)	32 (16)	195
IN-2	103 (59)	13 (7)	58 (33)	174
KY-1	126 (66)	8 (4)	57 (30)	191
KY-2	164 (77)	4 (2)	44 (21)	212
KY-3	186 (75)	7 (3)	55 (22)	249
KY-4	190 (76)	23 (9)	39 (16)	251
OH-1	192 (73)	4 (2)	67 (25)	263
OH-2	221 (83)	5 (2)	39 (15)	265
WV-1	87 (72)	18 (15)	16 (13)	121
WV-2	161 (70)	20 (9)	48 (21)	229
PA-1	106 (75)	19 (13)	17 (12)	142
VA-1	47 (44)	16 (15)	44 (41)	107
Average	**162 (75)**	**12 (6)**	**43‡ (20)**	**217‡**

† Numbers in parentheses indicate carbon distribution as a percent of the site total.
‡ Natural and mined averages are statistically different at $\alpha \leq 0.10$.

Tree Carbon

Carbon present within the developing tree biomass (merchantable volume, tops, branches, rotten trees, small trees < 5.0 in dbh, snags, stumps, roots and bark) on natural sites ranged from 142 to 250 Mg ha^{-1} (Table 2). Mined-site tree carbon ranged from 47 to 272 Mg ha^{-1}. 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.

Tree carbon averaged 203 Mg ha^{-1} for our natural sites and 162 Mg ha^{-1} for mined sites. Carbon associated with tree biomass of hardwood forests in Indiana were measured by Kaczmarek et al. (1995). Carbon pools ranged from 61 to 117 Mg ha^{-1}. Our estimates for both natural and mined hardwood sites in Indiana, Illinois, and western Kentucky were higher than these estimates (188 Mg ha^{-1}). However, our estimation procedures, as outlined by Birdsey (1992), include carbon estimates for large woody debris and complete root systems. 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 186 and 190 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 100 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, 1992).

Mined site carbon content associated with the tree community had returned to average natural site levels (Table 2). The average age of the natural sites was approximately 60 years. Many mined sites, especially those whose stand age approached 60 (IL-1, OH-1, OH-2), had levels within the range of the natural sites. Mined sites planted to pine (KY-3, KY-4, WV-2) and fast-growing hardwoods (IL-2) rapidly sequestered carbon in rapidly growing wood (Figure 3). Overall, these mined sites were new forest communities that 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, were planted on an ideal spacing, and 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.

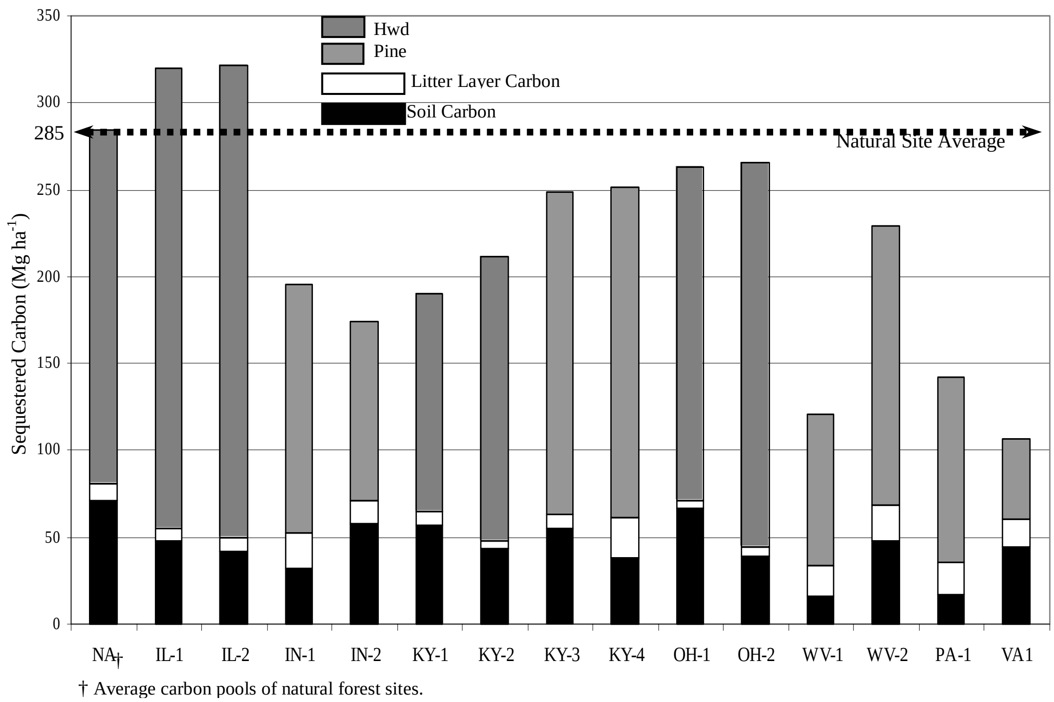

Figure 3. Total carbon sequestered on mined study sites separated into forest system components.

Litter Layer Carbon

Natural-site litter layer carbon pools ranged from 5 to 15 Mg ha^{-1} (Table 2). Litter layer carbon pools on mined sites ranged from 4 to 23 Mg ha^{-1}. Litter layer carbon estimates also 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 12 Mg ha^{-1}. 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}.

The carbon content of litter layers under our natural hardwood sites averaged 10 Mg ha^{-1}, compared to 6 Mg ha^{-1}for litter under hardwoods on mined sites. Carbon content of litter layers under pine canopies were significantly greater, averaging 17 Mg ha^{-1}. Litter decomposition rates differ with litter type, a result of variation of litter quality, litter chemical composition, availability of nutrients from other site resources, and climatic factors (Vogt et al., 1986).

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. If conditions for litter layer redevelopment are similar for mined sites, then the majority of sites in this study should have approached, or will be approaching, equilibrium.

Soil Carbon

Natural site soil carbon ranged from 49 to 108 Mg ha^{-1} (Table 2). The amount of carbon in the mine soils ranged from 16 to 67 Mg ha^{-1}. 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 43 Mg ha^{-1} (Table 2).

Soil carbon levels of mined study sites were 39% lower than natural site estimates; however, the mined site average 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 Lai (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}.

For both the natural and mined sites, the carbon associated with the plant community and the litter layers make up similar percentages of the total system carbon. However, there was an important difference in soil carbon content between mined and natural soils. Soil carbon made up 25% of the total on natural sites and only 20% on the mined sites. After mining, the mined study sites were left devoid of soil organic matter and carbon. Soil carbon levels of even the most productive and oldest mined sites had not reached the average soil carbon level of measured natural sites (Table 2, Fig. 3).

As with natural forest communities, carbon sequestration on reforested mined sites is a function of age. This relationship is shown in Figure 4, in which total carbon of mined sites was plotted as a function of increasing forest age. Projection of the regression line shows that the average mined site carbon content will approach the natural stand average near age 70. This is roughly the average rotation length for commercially-valuable Appalachian hardwoods. Therefore, by age 70, under average site conditions, mined land returned to forests will have the commercial value of a mature forest and carbon content approaching pre-mining carbon levels.

As time goes on, we expect further incorporation of organic matter into the soil of these mined sites. Evidence from the literature suggests that current organic carbon determination techniques, including the Walkley-Black method, invariably include some amounts of geogenic carbon in the estimate (Thurman and Sencindiver, 1986; Indorante et al., 1981; Pedersen 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.

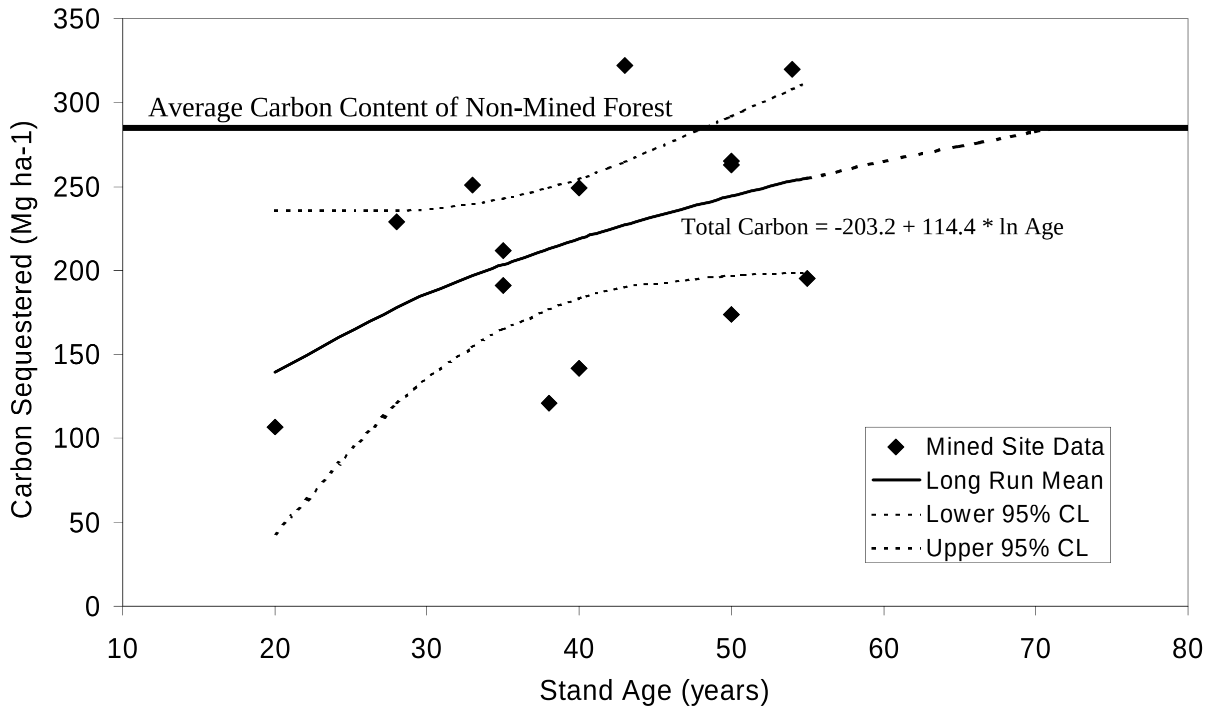

Figure 4. Total carbon accumulation of mined sites and predicted return to average non-mined levels.

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 contributes to 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 at a level of productivity equal to or greater than that present before mining.

This study showed that restored forest ecosystems have the potential to build carbon pools that will eventually approximate natural forest levels. This is especially the case for carbon levels in trees and litter layers. Average carbon pools of these two components were similar to natural sites in this study after 55 years. However, the variation of the carbon pools was greater within the trees and litter layer on mined sites, representing the greater variability of forest and site conditions on mined sites. Mined soil organic carbon levels were lower than average natural sites due to the pre-law mining process, which removes original topsoil and buries it at the bottom of the previous cut. 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. A projection of carbon sequestration rates established by this study indicated that mined sites would achieve pre-mining carbon levels after 60 to 65 years.

ACKNOWLEDGMENTS

We would like to thank the Powell River Project and the U.S. Department of Energy (DE-PS26-02NT41422) for financial support of this study. Special thanks go to those people involved in the location of study sites, including C. Ashby, A. Boyer, F. Brenner, D. Burger, B. Gray, R. Gullic, T. Probert, J. Skousen, J. Vimmerstdedt, and D. Williamson, and to our colleagues at Virginia Tech: K. Hollandsworth, R. Oderwald, S. Zedaker, and C. Zipper for their technical assistance.

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.

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.

Clark, A, III., D. R. Phillips, and D. J. Frederick. 1986a. Weight, volume, and physical properties of major hardwood species in the piedmont. USDA For. Serv. Southeast. For. Exp. Sta. Res. Pap. SE-255. 80pp.

Clark, A, III., D. R. Phillips, and J. C. Schroeder. 1980. Predicted weights and volumes of northern red oak trees in western North Carolina. USDA For. Serv. Southeast. For. Exp. Sta. Res. Pap. SE-209. 22pp.

Clark, A, III., and J. R. Saucier. 1990. Tables for estimating total-tree weights, and volumes of planted and natural southern pines in the Southeast. Georgia For. Res. Pap. No. 79. Georgia For. Comm. 23pp.

Clark, A, III., J. R. Saucier, and W. H. McNab. 1986b. Total-tree weight, stem weight and volume tables for hardwood species in the Southeast. Georgia For. Res. Pap. No. 60. Georgia For. Comm. 45pp.

Clark, A, III., and R. A. Souter. 1996. Stem cubic-foot volume tables for tree species in the Appalachian area. USDA For. Serv. South. Res. Stat. Res. Pap. SE-292. 127pp.

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.

Heath, L. S., and R. A. Birdsey. 1993. Carbon sequestration on non-industrial private forestlands in the US. p. 326-333. *In* Symp. on Non-Industrial Private Forests: Learning from the Past, Prospects for the Future. Washington, DC, Feb. 18-20, 1996.

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.

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.

McNab, W. H., and A. Clark III. 1982. Total tree and major component green weights of white pine and hemlock in north Georgia. Georgia For. Res. Pap. No. 31. Georgia For. Comm. 15pp.

Murray, B. C., S. P. Prisley, R. A. Birdsey, and N. Sampson. 2000. Carbon sinks in the Kyoto Protocol, potential relevance for United States forests. *J. For.* 98:6-11.

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., and J. A. Burger. 2001. Forest and site productivity on pre-SMCRA mined land. p. 121-132. *In* R. I. Barnhisel (ed.). Proc., 2001 Ann. Mtg., Amer. Soc. for Surface Mining and Reclam. Amer. Soc. for Surface Mining and Reclam., Lexington, KY.

Skog, K. E, and G. A. Nicholson. 1998. Carbon cycling through wood products: the role of wood and paper products in carbon sequestration. *For. Prod. J.* 48:75-83.

Thurman, N. C., and J. Sencindiver. 1986. Properties, classification, and interpretations of minesoils at two sites in West Virginia. *Soil Sci. Soc. Am. J.* 50:181-185.

Turner, D. P., G. J. Koerper, M. E. Harmon, and J. J. Lee. 1995. A carbon budget for forests of the conterminous United States. *Ecol. Appl.* 5:421-436.

Torbert, J. L., S.S. Schoenholtz, J. A. Burger, and R. E. Kreh. 2000. Growth of three pine species after eleven years on reclaimed minesoils in Virginia. *N. J. Appl. For*. 17:1-5.

Tritton, L. M., and J. W. Hornbeck. 1982. Biomass equations for major tree species of the Northeast. USDA For. Serv. Northeast. For. Exp. Sta. Gen. Tech.l Rep. NE-69. 46pp.

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. 489-501. *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.

Vogt, K. A., C. C. Grier, and D. J. Vogt. 1986. Production, turnover, and nutrient dynamics of above- and belowground detritus of worlds forests. p. 303-375. *In* Advances in Ecological Research, V. 15. Academic Press, London.

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.

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.