ACCUMULATION OF ORGANIC CARBON IN RECLAIMED COAL MINE SOILS OF WYOMING[1]

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Abstract. The potential to sequester carbon and increase organic nutrient storage in disturbed soils, such as those reclaimed after surface coal mining, appears to be significant. Quantification of organic carbon accumulation is complicated, however, by the presence of coal and coal dust in these soils. Our preliminary data on organic matter content of reclaimed soils at surface coal mines in Wyoming suggest they are sequestering carbon at a rapid rate. Data from a surface mine reclamation site near Hanna, WY indicate that surface (0-15 cm) soil organic carbon content has increased from a low of 10.9 g C kg^{-1} soil in 1983 to 18.6 g C kg^{-1} soil in 1998 and to 20.5 g C kg^{-1} soil in 2002. Undisturbed soil directly adjacent to the reclaimed site has a mean organic carbon content of 15.1 g kg^{-1} soil. At a mine near Glenrock, WY, soil organic carbon at a site reclaimed in 1979 increased from an estimated low of 5.8 g C kg^{-1} soil to a current level of 18.4 g C kg^{-1} soil. Organic carbon content of undisturbed soils adjacent to the reclaimed area range from 9.9 to 15.7 g C kg^{-1} soil. In contrast to the elevated organic carbon content, amounts of microbial biomass in reclaimed soils at both mines are lower than in nearby undisturbed soils (ca. 60% or less). We have collected similar data from a number of other surface coal mines in Wyoming. We hypothesize that decomposition rates are slow in reclaimed mine soils due to low microbial activity relative to that in undisturbed soils.

Additional Keywords: carbon sequestration, reclaimed mine soil, soil organic matter, surface coal mine, soil microbial biomass

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Introduction

One of the most consistent and problematic impacts of disturbance associated with surface coal mining on affected soils is loss of soil organic matter (SOM) including organic carbon (OC) (Severson and Gough, 1983; Harris et al., 1993). SOM is lost as a result of initial stripping of the soil from the site to be mined, and further losses occur during storage in stockpiles as well as at the time it is replaced during site reclamation. This problem has serious implications because of the role of SOM in fertility, water holding capacity and overall quality of soil used for site reclamation.

A number of experts on soil carbon (C) have hypothesized that there is a large potential to sequester OC in disturbed and degraded soils (Lal, 1995; Cole et al., 1996; Lal et al., 1999). Because these soils commonly have lost a large part of their SOM content as a result of disturbance or during the degradation process, there is the potential to replace this material through proper management. Land revegetation and soil remediation practices set soil restorative processes in motion including the accumulation of various fractions of soil organic carbon (SOC). Reestablishment of a plant community initiates primary productivity resulting in inputs of plant root and shoot biomass as well as biomass of soil microorganisms and fauna supported by plant activity.

Since hundreds of millions of hectares of degraded and disturbed soils exist worldwide, land remediation, in theory at least, represents an important opportunity to sequester significant amounts of C in soils and restore productivity to human-impacted ecosystems. At this time, however, minimal empirical data exist on actual rates and endpoints of C accumulation through land remediation (Lal et al., 1999). The objective of this paper is to present some preliminary observations on accumulation of OC in reclaimed soils on three surface mine sites in Wyoming.

Methods

Soils from three surface coal mines in the state of Wyoming were examined in this study; the former Rosebud Coal Mine site currently on Cyprus-Shoshone Mine Property just north of Hanna, the Dave Johnson Mine north of Glenrock, and the North Antelope-Rochelle Complex Mine in the Powder River Basin. All mines are located within a semiarid region and have native vegetation classified by Kuchler (1964) as *Agropyron-Stipa-Artemisia* shrubsteppe. Soils on all three mines are dominated by Aridisols.

Soil samples were first obtained from the Rosebud Mine in the fall of 1983 from a newly established research site in which stockpiled (14 years) topsoil had just been respread, mulched and seeded. Seven randomly located soil samples (0 – 15 cm depth) were obtained from the research site as well as from a nearby-undisturbed area. Soil samples were collected again in an identical manner from both the reclaimed and undisturbed sites in summer of 1997 and 2002. Soil samples were placed on ice in a cooler and transported back to the laboratory within 8 hours of collection. Within 48 hrs of collection, samples were aired dried at room temperature and placed in plastic bags and stored at 3 degrees centigrade.

Collection of soil from the North Antelope Mine was conducted during the summer of 2000. Two reclaimed and 2 undisturbed sites were sampled. Soil samples (0-2.5 cm, 2.5-15 cm, 15-30 cm) were obtained at 10 m intervals along a transect through areas of interest. Samples were placed on ice in a cooler and transported back to the laboratory within 48 hours. Samples were air dried and stored at room temperature.

At the Dave Johnson Mine, soil samples (0 – 30 cm depth) were collected in the summer of 2001 from a number of reclaimed sites varying in age since reclamation was initiated (2 to 32 years) as well as a number of nearby undisturbed sites for comparison. For each site sampled 2 randomly located 100 m transects were designated and 4 samples were collected from each at 25 m intervals. Topsoil used in reclamation of these sites was stockpiled for different lengths of time. Soil samples were placed on ice in a cooler and transported back to the laboratory within 12 hours of collection. Samples were air dried and stored in the same manner as the samples from the Rosebud Mine.

OC content of soil from the Rosebud and Dave Johnson Mine were determined using the Walkley-Black method (Walkley, 1947; Greweling and Peech, 1960). Analyses of OC in soil from the North Antelope-Rochelle Complex was accomplished by using a Carlo-Erba C and N analyzer.

Microbial biomass in soil was quantified using the chloroform fumigation extraction method as described by Horwath and Paul (1994). Sieved (2 mm) rewetted (50% water holding capacity, reinsulated for 10 days) soil samples were extracted with 0.5 M K_2SO_4 (Tate et al., 1988; Horwath and Paul, 1994). Soluble OC in the fumigated and non-fumigated extracts were measured using a Techmar-Dohrman Total Carbon Analyzer (Rosemont Analytical Services, Santa Clara, CA).

Bulk density measurements were not made on most of the soils discussed in this paper because the objectives of the studies for which these soils were examined for did not require this data. During analysis of soils data for our other studies we observe the trend of increasing organic carbon content with age of reclamation and decided to report these observations in these proceedings. All of our future studies of carbon accumulation in soil will include soil bulk density data.

Results

Mean OC concentration in newly respread-stockpiled topsoil on the research site at the Rosebud Mine when determined in 1983 was 10.9 g C kg^{-1} soil (Fig. 1). At this time, mean OC concentration in undisturbed soil adjacent to the site was 15.0 g C kg^{-1} soil. Bulk densities of the disturbed and undisturbed soils in 1983 were 1.45 g cm^{-3} and 1.2 g cm^{-3}, respectively. Fourteen years later, in 1997, OC content of reclaimed and undisturbed soil were determined to be 18.6 and 14.9 g C kg^{-1} soil, respectively. Finally, when soils were sampled and analyzed again in 2002, OC content of reclaimed soil had risen to 20.5 g C kg^{-1} soil while that of the undisturbed soil remained at about 15.0 g C kg^{-1} soil (Fig. 1).

Data from two reclaimed areas at the North Antelope Mine show that mean OC concentration in disturbed soil at two depths (0-2.5 cm and 2.5-15.0 cm) is greater than that of nearby undisturbed soil (Fig. 2). At one of these sites (reclaimed 15 years earlier), SOC concentration in the 0 –2.5 cm depth is 245% that of undisturbed soil; at the other site (reclaimed three years earlier), SOC content was 170% that of native soil. For the 2.5 – 15 cm depth, differences in OC content between reclaimed and native soils were much smaller (8.5 g C kg^{-1} soil vs. 7.3 g C kg^{-1} soil and 9.9 g C kg^{-1} soil vs. 7.3 g C kg^{-1} soil).

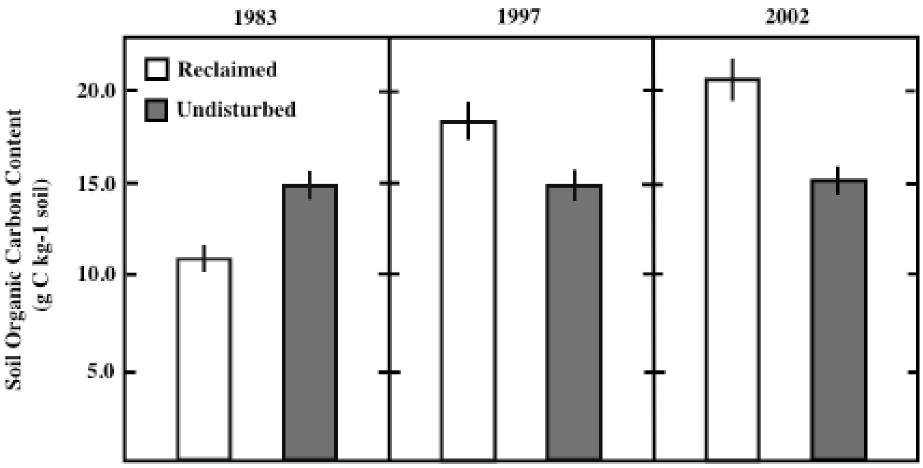

Figure 1. Organic carbon content of reclaimed and undisturbed soil at the Rosebud mine. Vertical bars at the top of columns indicate ±1 standard error.

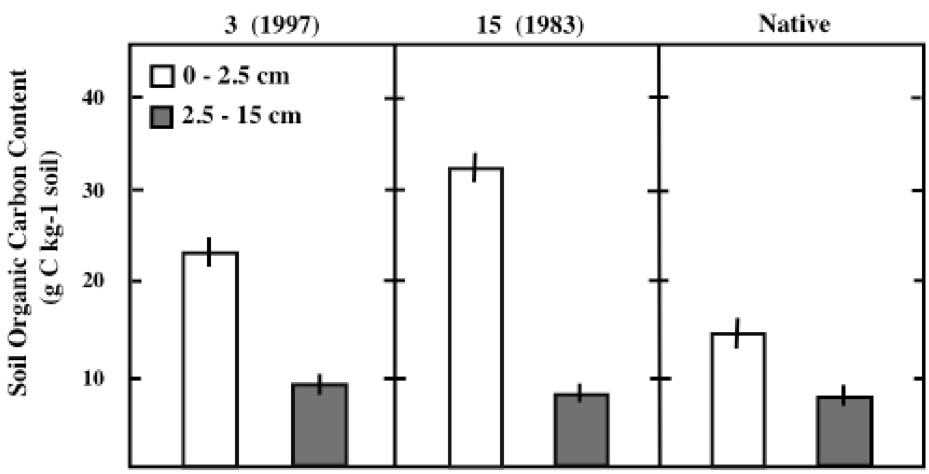

Figure 2. Organic carbon content of reclaimed and undisturbed soil at the North Antelope Mine. Vertical Bars at top of columns indicate ± 1 standard error.

Data on SOC concentration from a chronosequence of reclaimed sites at the Dave Johnson Mine demonstrates that soil of older reclamation sites (> 15 yr old) has more OC than younger reclamation sites and the oldest reclaimed sites (>20 yr old) contain more than adjacent undisturbed sites (Fig. 3). Specifically, all sites reclaimed before 1989 had greater SOC concentration than sites reclaimed in 1989 or later. Additionally, for the 3 sites reclaimed prior to 1989, SOC content increased with age and the two oldest reclaimed soils had higher mean SOC contents than did undisturbed soil (Fig. 3). Microbial biomass carbon data from the same soils, however, show a very different pattern (Fig. 3). Generally, there is a strong positive correlation between the amount of OC in soil and microbial biomass carbon content because SOM is a principal energy source for soil microorganisms.

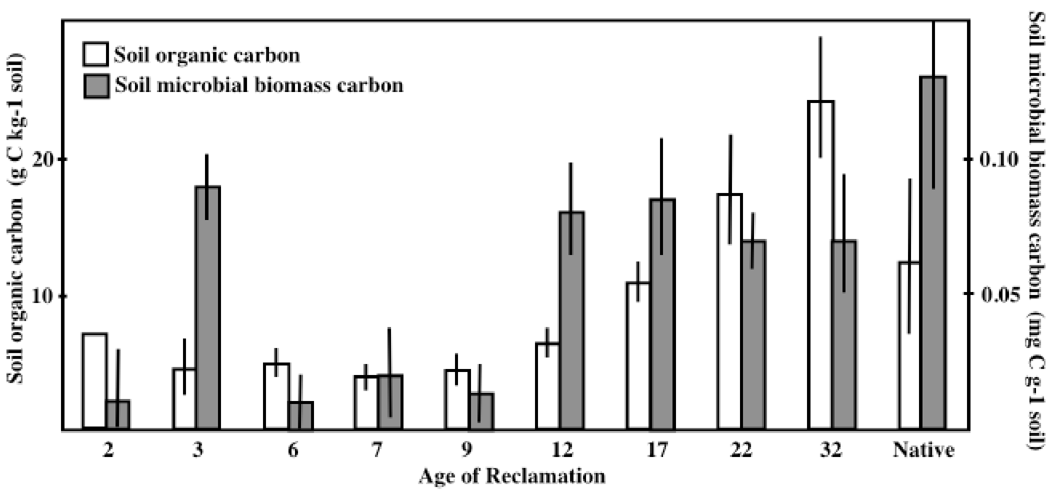

Figure 3. Soil organic carbon and soil microbial biomass carbon from reclaimed and undisturbed sites at the Dave Johnson Mine.

Examination of data in Figure 3 shows that this relationship does not hold up for the reclaimed soils examined at the Dave Johnson Mine. For example, the two oldest reclaimed sites with greatest SOC concentration have lower mean microbial biomass carbon contents than three sites with less SOC. Also, undisturbed soil has a mean soil microbial biomass carbon content 120% greater than soil on the site reclaimed in 1969 but contains only 51% as much OC. Of all reclaimed sites examined, only one had a soil microbial biomass content greater than 50% of the native value, regardless of age of reclamation or SOC concentration.

Discussion

Monitoring of soil organic carbon concentration in reclaimed and undisturbed soil at a research site established in 1983 on the Cyprus-Shoshone Mine near Hanna, Wyoming provide the best data on accumulation of carbon in a reclaimed surface mine soil we have so far collected (Fig. 1). Because we have been analyzing soil on this site since reclamation was initiated, we have direct observations of the 170% increase in organic carbon content of reclaimed soil over the past 19 years. Additionally, since this research site was far from any open mine pits or haul roads and the mine ceased production in 1990, it is unlikely that there has been any significant input of coal or coal dust into the soil. Rate of accumulation of OC over the 19-year period has been 0.50 g C kg^{-1} soil yr^{-1}. Over the last four years, however, from 1998 to 2002 the rate has been to 0.47 g C kg^{-1} soil yr^{-1}.

Results from the North Antelope Mine showing greater concentrations of OC in reclaimed soils than in native soil suggest C is accumulating in these soils also. It is possible that the surface soil (0 – 2.5 cm depth) could be contaminated with coal dust blowing around the mine, but the 2.5 – 15 cm depth would not be exposed to contamination unless it occurred during topsoil storage in stockpiles. To increase SOC concentration in the 0 - 2.5 cm depth of soil from 13.7 g C kg^{-1} soil to 33.6 g C kg^{-1} soil, as was observed at the 15-year-old reclamation site, an input of 597 g coal dust carbon per square meter of soil would be necessary. Assuming the bituminous coal of this region is approximately 80% carbon, it would require deposition of 746 g (1.6 lb) of coal dust per square meter of soil surface to account for the observed difference in soil organic carbon concentration between reclaimed and native soils. On a larger scale, the amount of coal dust deposition needed to account for the observed increase in soil organic carbon over a 10-hectare (25 acre) reclamation site would be 74,600 kg (82 tons, or 3.28 tons per acre). It seems unlikely that this much coal dust is blowing around the mine site and being deposited on the soil surface. This amount of coal dust on the soil surface would also be quite obvious and we have not noticed this during our fieldwork on this mine. Although it is highly likely that coal dust blowing around this mine represents an input of OC to soil on reclamation sites, it is unlikely that coal dust accounts for majority of the observed increase in OC content of reclaimed soil on this mine.

Data from the chronosequence of sites at the Dave Johnson Mine showing a general trend of increasing SOC concentration with age of reclamation indicates OC is accumulating in reclaimed soil at this mine. Results from this mine also suggests accumulation of OC in soil may take a few years to begin after reclamation is initiated. All sites sampled having been reclaimed for less than 10 years had SOC concentrations less than that of undisturbed sites. All reclamation sites greater than 10 years old had SOC concentrations similar to or greater than undisturbed sites and concentration increased with age.

It is important to note that there is no obvious relationship at Dave Johnson Mine reclaimed sites between SOC concentration and soil microbial biomass carbon content as would be expected in undisturbed soil and has been reported in the literature (Paul & Clark, 1996; Stevenson and Cole, 1999). A different relationship between the soil microbial biomass and SOC in reclaimed and undisturbed soils suggests that factors controlling microbial decomposition of organic matter in reclaimed soils are different than in undisturbed soils. Because the microbial biomass assay was conducted on soil samples uniformly wetted to 50% soil water holding capacity at a room temperature, we know soil moisture and temperature are not the cause. Also, plant community productivity on reclaimed sites is known to be at least equal to that of native plant communities, so plant litter inputs are not the explanation for low soil microbial biomass. We hypothesize the reason for a lack of recovery of the soil microbial biomass is related to the soil structural changes resulting from disturbance associated with surface coal mining. Initial removal of topsoil from a site, placement in stockpiles and subsequent replacement, cultivation and revegetation management practices are known to result important physical changes to affected soils (Severson and Gough, 1983; Harris et al., 1989), including increased bulk density. Further, we believe loss of soil macroaggregate structure by this disturbance may represent an important change in soil environmental conditions, which adversely affects soil biota. This, in turn, leads to a reduction in decomposition rates and the observed accumulation of OC in soil. The larger question resulting from these observations and hypotheses is whether or not carbon cycling and other nutrient cycles are sustainable in the long term.

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