INFLUENCE OF MINELAND RECLAMATION PRACTICES ON MICROBIAL COMMUNITY RECOVERY AND SOIL ORGANIC CARBON ACCUMULATION[1]

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Abstract: As the nation's leading producer of coal, Wyoming has thousands of hectares of soil that have been affected by surface mining. While the rate of coal production and soil disturbance has increased steadily for the past few years, our knowledge of the long-term sustainability and management of the reclaimed soil systems has remained limited. Preliminary data on soil organic matter content of reclaimed soils collected from a surface coal mine in Wyoming suggests carbon may be an accumulating at a rapid rate. Data collected at the same mine indicates that the productivity of the soil microbial community may take longer than 30 years to recover. An accumulation of soil organic matter and slow recovery of the microbial community may indicate an inhibited nutrient cycling in a reclaimed soil system. We hypothesize that an alteration of the soil structure, as a result of topsoil removal, long-term storage and replacement, may limit the ability of the soil biota to decompose plant litter and result in an accumulation soil organic matter. Reclamation management practices could potentially affect the rate and levels of recovery in these reclaimed soils. By using the most effective management practices, concentrations of soil organic carbon (SOC) and microbial biomass carbon (MBC) could be optimized. To test this hypothesis we are examining the relationship of MBC and SOC in reclaimed soils of different management practices and adjacent undisturbed soils on surface coal mines in the semiarid regions of Wyoming. Preliminary results of these analyses will be presented and discussed.

Additional Keywords: microbial biomass carbon, soil organic matter, management practices, semiarid mineland reclamation soils

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Introduction

As the nation's leading producer of coal, Wyoming has 41,876 hectares of land affected by surface mining (OSM, 2003a). In the year 2002 alone, 338 million metric tons of coal was mined in Wyoming (OSM, 2003b). At the beginning of the mining process soil is completely removed and stockpiled causing soil structure and soil microbial functions to be adversely affected. This disturbance can have a range of negative impacts on soil properties and microorganisms including organic matter and a potential for impaired nutrient cycling in reclaimed surface mine soils (Insam and Domsch, 1988; Bentham et al., 1992). Since plant productivity, wildlife habitat and general ecosystem function are dependent on the general fertility and quality of soils (Karlen et al., 1997; National Research Council, 1994), one of the most crucial challenges of mine land reclamation is to reestablish soils to a level of health similar to those originally present before mining (Munshower, 1994). To restore or reclaim disturbed ecosystems, functioning stable soils must be reestablished. Response of soil microorganisms to disturbance and their recovery during reclamation of surface mine sites is not well understood, yet extremely important to sustainable ecosystem function including sustainable cycling of nutrients.

Results from preliminary sampling of mineland reclamation soils in Wyoming indicate that at some reclamation sites the soil microbial biomass may take longer than 30 years to recover to levels found in undisturbed native soils (Anderson et al., 2002). Even though the plant community may recover in terms of biomass production and surface cover within 20 years or less, soil microbial biomass carbon (MBC) appears to be slower to recover and may be only approximately half of that found in adjacent undisturbed soils. At the same time, soil organic carbon (SOC) concentrations in these same reclaimed soils were found to be greater than that found in adjacent undisturbed soils.

Land management methods used in Wyoming such as grazing, and reclamation techniques including topsoil handling and mulching practices are commonly believed to have impacts on the success and quality of mineland reclamation as well as post mining rangeland conditions. Grazing is commonly believed to affect soil bulk density, shifts in plant species composition and the rate of incorporation of litter into the soil due to hoof action. The process of direct hauling topsoil is the immediate transporting of topsoil from an area being disturbed to an area where the reclamation is being initiated. This is believed to have advantages over stockpiling topsoil due to the adverse effects of storage. During storage, SOC in topsoil stockpiles tends to decrease or be diluted and microbial populations and mycorrhizae are adversely altered (Harris et al., 1993; Visser et al., 1984a; Visser et al., 1984b). Mulching techniques will affect soil surface temperature and moisture and may affect the amount of soil erosion that occurs during the early stages of reclamation, which may in turn affect SOC. Objectives of this study were to examine and compare amounts of SOC and MBC in reclaimed soils, subjected to different management practices, to assess the response of the microbial community and the accumulation of SOC. By compiling and analyzing data related to SOC and MBC (and in the future particulate organic matter (POM)) we expect to determine what fraction of soil organic matter (SOM) is accumulating in reclaimed soils and if soil microbial community size is influencing SOM accumulations. If any of the measured management practices prove to optimize C accumulation and show increased organic nutrient contents, these methods could be applied to sequester C and maximize soil fertility. Not only would this help to mitigate carbon dioxide in the atmosphere but also enhance overall soil quality and improve the suitability of the land for bond release.

Methods

Reclaimed soils were sampled to compare the influence of management practices on organic matter dynamics at three surface coal mines in Wyoming. Located throughout Wyoming, these mines are all semi-arid, sagebrush steppe communities with average annual precipitations ranging from 150-350 mm, most of this as snowfall. Elevations range from 1500-1800 m, average annual temperature is 9° C, and all have average growing seasons of approximately 165 days.

Management practices used at the mines include: grazing vs. non-grazed at the Dave Johnson Mine (Glenrock, WY), stock pile vs. direct haul topsoil handling at the Jim Bridger Mine (Point of Rocks, WY), and stubble vs. hay mulch at the Seminoe 1 Mine (Hanna, WY) (Table 1). Along with the management practice comparisons, adjacent native undisturbed sites were sampled to serve as baseline references. Reclamation sites at Jim Bridger and Seminole 1 were seeded with vegetation species compositions that were made up of 8-12 native species in an attempt to reestablish near native species compositions. Dave Johnston reclamation sites were

Table 1. Summary information of reclamation sites chosen from Dave Johnston, Jim Bridger and Seminole 1 mines used for comparisons.

Mine / Site	***Age***	***Topsoil depth** (cm)*	***Years grazed***	***Years stockpiled***
Dave Johnston / Grazed	26	30	20 (moderately)	Unknown
Dave Johnston / Ungrazed	26	30	0	Unknown
Jim Bridger / Direct Haul	19	46	0	0
Jim Bridger / Stockpile	19	46	0	12
Seminole 1 / Stubble	14	60	0	0
Seminole 1 / Hay	14	60	0	0

initiated in 1976 (pre-SMCRA) and crested wheatgrass was a major exotic addition to the native seed mix. All reclamation sites used generally had less shrub density and fewer species richness and less diversity than the native sites. Reclamation sites at Jim Bridger and Seminoe 1 tended to be dominated by 2-4 cool season grass species and visually appeared to have less bare ground when compared to native sites. Dave Johnston reclamation sites were dominated mainly by crested wheatgrass but also had significant amounts of cover from native cool season grass species and also had visually less bare ground than the adjacent native sites. Reclaimed and native sites have similar slope and were south facing. Three 100 m transects were randomly placed across the areas and four samples were taken along each of these transects in the summer of 2002. Soil samples were taken from depth increments of 0-5, 5-15 and 15-30 cm. In addition, at two points along the same transect bulk density was determined at the 0-5, 5-15 and 15-30 cm depth increments as determined by Blake and Hartge (1986). All soil samples were sieved to 2 mm, homogenized, air dried and stored at 4˚C.

Microbial biomass carbon in the soil samples was quantified by the chloroform fumigation extraction method (Horwath and Paul, 1994). Four 40 g soil sub-samples were rewetted to 50% water holding capacity as determined by the method of Forster (1995) and incubated for 10 days at 25˚C in a dark chamber (Franzluebbers et al., 2000). Four sub-samples were extracted with 200 ml of 0.5 M K_2SO_4 (potassium sulfate) and filtered through Whatman No. 42 filters. Soil solutions were analyzed for C in a Phoenix-8000 UV-persulfate total carbon analyzer (Techmar-Dohrman, Mason, Ohio).

Soil organic carbon was quantified by the difference of total carbon (TC) and inorganic carbon (IC). Total C was analyzed by an elemental analyzer (Fisons EA 1108) and IC was analyzed by means of a pressure calcimeter method (Sherrod et al., 2002). Standards used consisted of 0.25, 0.5, 1.0, 2.0, 4.0, 8.0, 12.0 and 25.0% $CaCO_3$, which encompassed concentrations found in our soil samples.

Each sample was also analyzed for pH (paste method; Thomas, 1996) and electrical conductivity (Rhoades, 1996) to compliment the SOC and MBC data.

Statistical analysis of ANOVA for comparisons was computed using SAS (1999), with an alpha of 0.05.

Results

Comparisons from sampling during 2002 of management practices pairs and native sites showed interesting results. Results of the comparison of the management practices at the Dave Johnston mine at the 0-5 cm depth show significant statistical differences ($P<0.05$) in SOC content between the grazed (Graz.) and ungrazed (Non) sites, while no significant difference occurred between management practices and the native levels (Fig. 1). Greatest concentrations of SOC occurred in the ungrazed mine site with the grazed site showing the least accumulation, but the range of both sites are similar to the native levels. No significant differences in MBC were detected between grazed, ungrazed and native sites at any depth at the Dave Johnston mine.

Results of the comparisons of topsoil handling at the Jim Bridger mine showed no significant statistical differences ($P>0.05$) in SOC content between the direct haul (Haul) and stockpiled (Piled) sites, but both topsoil handling management practices were significantly greater than the natives at all depths (Fig. 2). Greatest concentrations of SOC were found in the 0-5 cm depths with similar levels at both sites regardless of topsoil handling practice. At the 0-5 cm depth, MBC was significantly greater in both direct haul and stockpile sites than in undisturbed soils, while there were no significant differences at the 5-15 and 15-30 cm depth at the Jim Bridger mine.

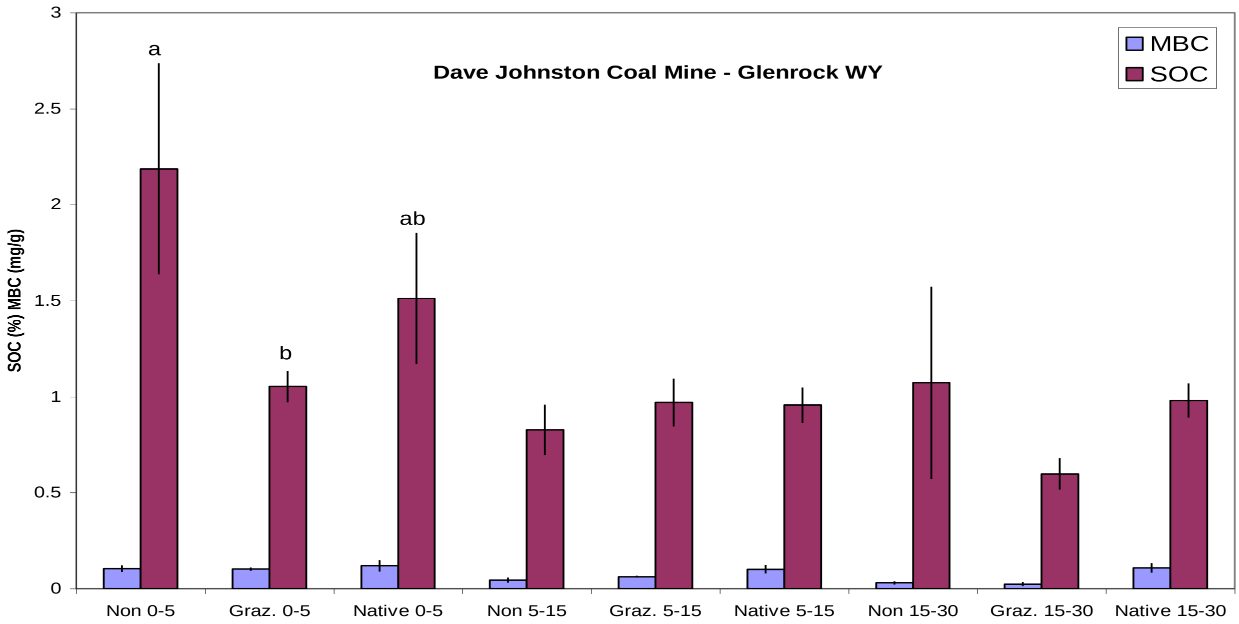

Figure 1 – Comparison of the MBC and SOC in the 26 year old grazed (Graz), ungrazed (Non) and the native undisturbed sites at Dave Johnston mine; variable means are shown. Comparisons are by depth (0-5, 5-15 and 15-30 cm), columns with different letters indicate statistically significance differences (P<0.05). Letters are omitted for columns without differences between any of the management practices at that depth.

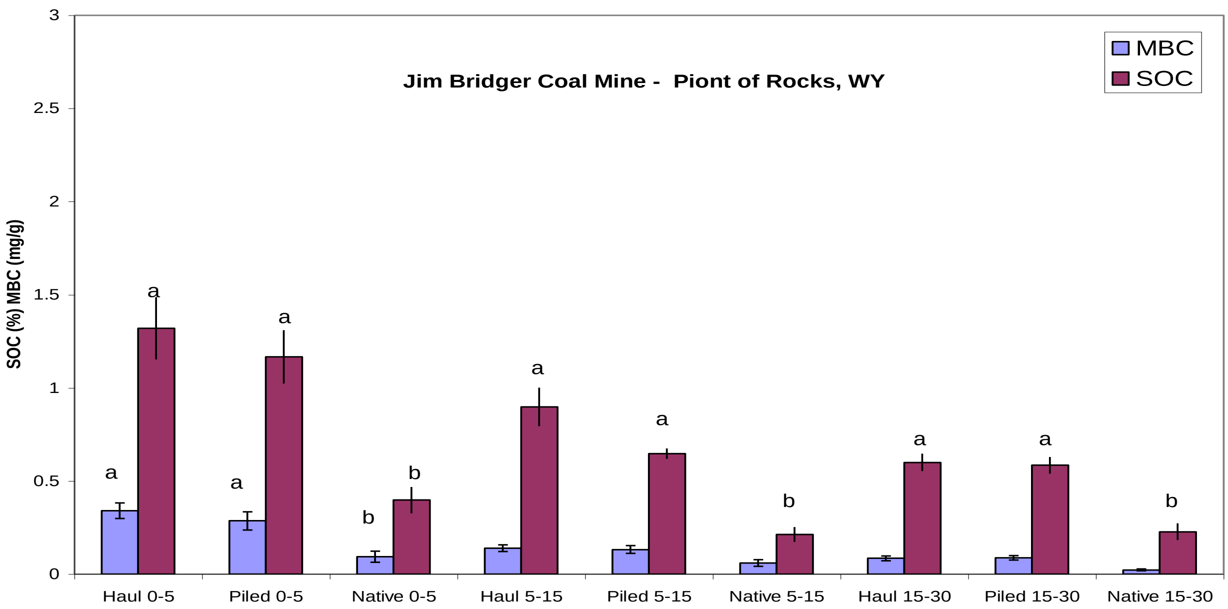

Figure 2 – Comparison of the MBC and SOC in the 19 year old Direct Haul (Haul), Stockpiled (Piled) and Native undisturbed sites at Jim Bridger mine; variable means are shown. Comparisons are by depth (0-5, 5-15 and 15-30 cm), columns with different letters indicate statistically significance differences (P<0.05). Letters are omitted for columns without differences between any of the management practices at that depth.

Comparisons of mulching methods at the Seminoe 1 mine at the 0-5 and 5-15 cm depths showed no significant differences in SOC concentration between the stubble (Stub) and hay mulching practices and native sites (Fig. 3). At the 15-30 cm depth, however, statistically greater amounts of SOC (P<0.05) were found in the Stubble (Stub) than in the hay mulching practice. No significant differences were found between stubble and hay practices against the native soils. Greatest concentrations of SOC occurred at the 15-30 cm depth stubble mulch site, with the hay mulched site having the lowest levels but the range of values from both mulching practices were similar to the native levels. No significant differences in MBC were found between mulching practices and native sites at any depth at the Seminoe 1 mine.

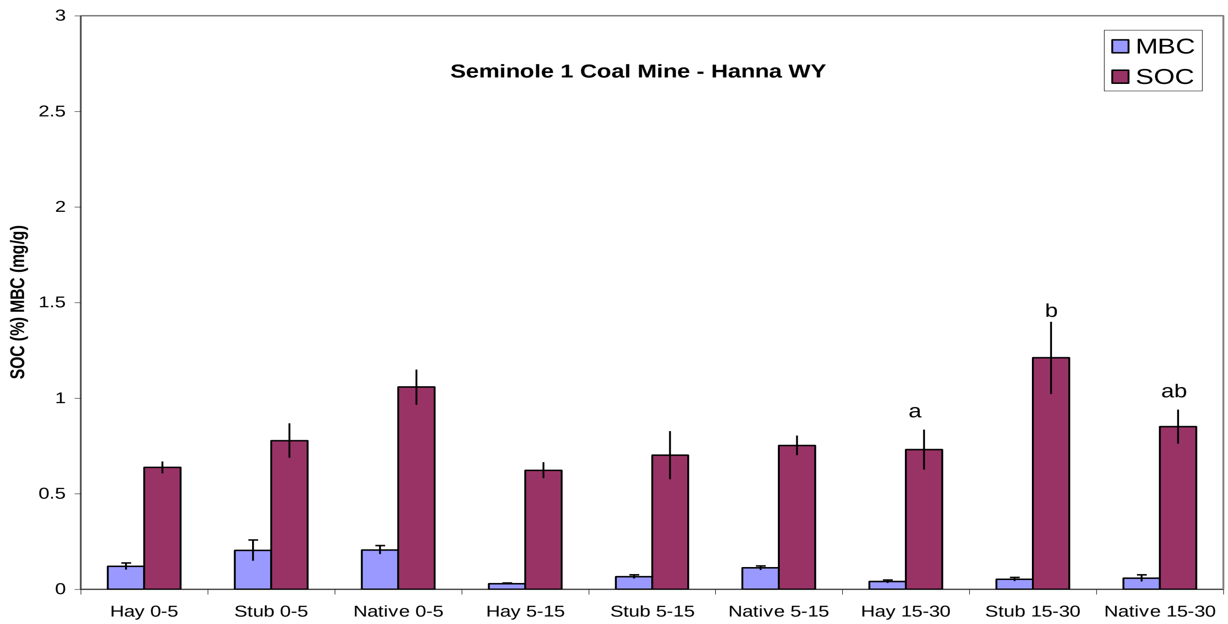

Figure 3 – Comparison of the MBC and SOC in the 14 year old Hay, Stubble (Stub) and Native undisturbed sites at Seminoe 1 mine; variable means are shown. Comparisons are by depth (0-5, 5-15 and 15-30 cm), columns with different letters indicate statistical significance (P<0.05). Letters are omitted for columns without differences between any of the management practices at that depth.

Discussion

Results from preliminary sampling, during 2001, of a chronosequence of reclamation soils at the Dave Johnston mine, sampled from 0-30 cm, indicated the soil microbial community had not yet recovered after 30 years to native undisturbed levels. In fact, soil microbial biomass carbon at these sites was found to be only approximately half of that found in adjacent undisturbed soils, although SOC concentrations were higher than those found in adjacent undisturbed soils (Fig. 4). This data indicates that soil microbial biomass was recovering slowly but not yet to native levels while SOC was accumulating to levels much greater than native sites. Soil microbial biomass carbon is expected to be positively related to SOC; so as SOC increases, an increase in MBC should result. This relationship was not observed in the chronosequence at the Dave Johnston mine.

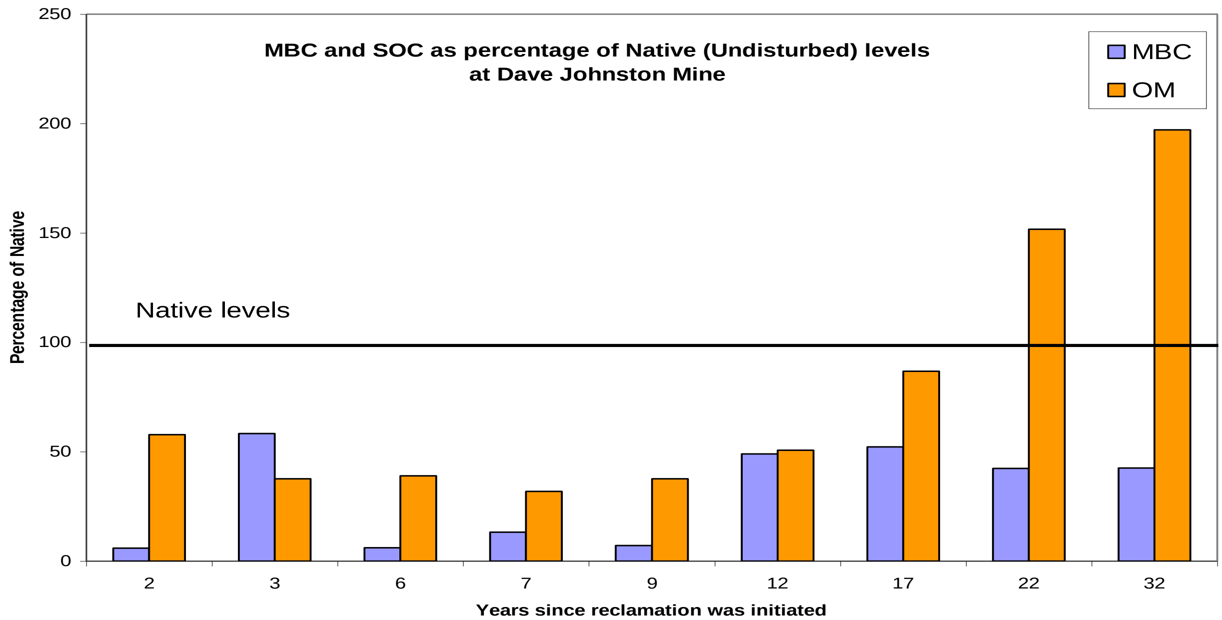

Figure 4 – Chronosequence of MBC and SOC shown as a percentage of the native value based on years since reclamation was initiated at the Dave Johnston mine.

Comparisons of management practices at the different mines showed mixed results with some practices resulting in significant accumulations of SOC while others did not. Significant differences were found at the 0-5 cm depth between the grazed and ungrazed sites at Dave Johnston but not at 5-15 or 15-30 cm; this is likely due to reduction of litter inputs from removal of aboveground biomass through grazing over a long period of time. No significant differences were observed between the direct haul and stockpiled sites at any depth at Jim Bridger mine. Levels of SOC and MBC, 19 years after reclamation, do not appear to be affected by topsoil handling methods at this mine. At Seminoe 1, the 15-30 cm depth was significantly less in the hay than in the stubble mulch practice, but not at the 0-5 or 5-15 cm depths. Differences may be due to stubble mulching allows organic matter inputs at depth by root inputs rather than just applying organic matter to the surface as with hay mulching. Although this is just one years input from stubble mulching over a 14 year period, it appears to make a significant effect considering a semiarid system with a possibly inhibited decomposition rate.

Comparisons of SOC concentrations in soils subjected to different management practices to native sites also showed mixed results. At the Dave Johnston mine, soils from the grazed and ungrazed practices, and also at the Seminoe 1 mine, soils from the stubble and hay mulching practices, showed no significant differences between management practices and the native levels at any depth. While significant differences occurred between topsoil handling practices and the native levels at every depth at the Jim Bridger mine.

Soil samples were taken from reclamation sites that were initiated 14, 19 and 26 years ago. If trends are proceeding according to the preliminary data shown in Figure 4, we do not expect to see an accumulation of SOC beyond native levels for approximately 17-22 years after reclamation, which is what was found in the 14 year old comparisons (stubble vs. hay, Seminoe 1). Yet, it appears that the accumulations are occurring in the 19 year old site (topsoil handling, Jim Bridger) but not in the 26 year old site (graze vs. ungrazed, Dave Johnston). At the Dave Johnston mine, grazed and ungrazed reclaimed sites, the reclamation was initiated before the Surface Mining Control and Reclamation Act of 1977 was in place. Although a uniform layer of 30 cm of topsoil was spread it is not known if substitute plant growth media (i.e. sand) was added to the 'topsoil'. An alternative explanation may be that a threshold has been reached and SOC levels have reached a maximum level after some age (20-30 years) and are declining back towards the native undisturbed level.

Comparisons between management practices with respect to MBC showed no significant differences at any depth. Comparisons of management practices to native soils showed no significant differences except at the Jim Bridger mine where the 0-5 cm depth was significantly greater for both topsoil handling practices against the native levels. Results of MBC from the management practice comparisons to natives showed unexpected results relative to what preliminary results indicated in Fig. 4. Recovery of the microbial community may be occurring sooner than the preliminary results indicated but the expected positive relationship between SOC and MBC was not observed.

Accumulations of SOC and the lack of recovery of the microbial community, as seen in Fig. 4, may represent a serious disconnect in the expected nutrient cycling of a reclaimed soil system during its early stages of recovery. We hypothesize that soil structure degradation caused from the disturbance, may be limiting the ability of the microbes to utilize new inputs of organic matter. With the abundance of SOC and the similarity of physio-chemical properties (pH and electrical conductivity, data not shown) to native soils, the microbial community should be responding with biomass production having a strong positive relationship with SOC concentrations. But this is not the case. Drastic disturbances, such as topsoil removal, storage and replacement, may be altering pore space and relatively homogenizing the soil. Homogenizing the topsoil changes the diversity in macropore spaces, such as destruction of macro aggregates and root channels, which limits available living and transport spaces for microbes and soil fauna (Whisenant, 1999). At the micropore level, changes in pore space that occur due to compaction limit access of larger predator microbes to smaller prey microbes, such as the relationship between nematodes and bacteria, which can influence the rates of decomposition and mineralization (Elliott et al., 1980). Development of a highly diverse pore space system which could support the equivalent microbial community present in the adjacent native undisturbed lands may take decades to develop with the aid of vegetation inputs, root channeling, soil macrofauna movements, aggregate formation and soil profile development, particularly in a semiarid system. Over the early stages of recovery (0-20+ years), an accumulation of organic matter is a positive outcome due to the significant amount of carbon being sequestered into the system and soil quality aspects of organic matter. But, a significant reduction in decomposition rates over the long term may represent a potential problem in the nutrient cycling.

Although this is only the first years' data and only one site replication of each management practice comparison has been completed, as far as management practices that optimize SOC accumulation, there is some supporting evidence that by not grazing a reclamation site some accumulation in the 0-5 cm depth may occur and that stubble mulching may cause an accumulation of SOC at the 15-30 cm depth within the first 14 years of reclamation in this region. None of the management practices comparisons have shown any significant advantage in microbial community recovery.

Future work will include the completion of the 2003 analysis of SOC, MBC and an analysis of POM to assess possible fractions of organic matter that may be accumulating over time. In addition, an analysis of organic carbon and organic nitrogen will be done to determine if differences in nutrient availability occur in the POM fractions between soils of different management practices and related native soils.

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