Redevelopment of Soil Carbon Pools and Biological Properties on Restored Mine Spoils Under Plantation

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Mining causes soil disturbance and creates a huge load of overburden that disturbs the ecosystem and poses environmental problems. Restoration of overburden dumps by planting trees is an economical process of soil conservation that stabilizes the soil. The study was made on an overburden chronosequence of the largest coal mining project of Asia to unravel the relationship of carbon pools and biological properties on soil redevelopment. Organic carbon status of soils under various years of restoration increased substantially from 0.1 g kg^{-1} in fresh dump to 37.8 g kg^{-1} under 25 years of restoration, which was complimented by concomitant increase in microbial biomass carbon during the period from nil to 316.8 μg g^{-1} and was also strongly correlated to it (r=0.97*). The rate of carbon mineralization also closely followed microbial biomass carbon and increased from 84 in fresh dumps to 396 mg 396 CO_2 C kg $soil^{-1}$ day^{-1} after 25 years of restoration and was strongly related to organic carbon (r=0.99*) and microbial biomass (r=0.99*) of soil. The dehydrogenase enzyme activity also increased from 7.28 to 15.9 μg TPF g^{-1} soil day^{-1} during the restoration period. The proportion of soil carbon in microbial biomass was small (0.84 to 1%) and the labile fraction decreased while the resistant fraction increased (from 0 to 41%) over the years of restoration suggesting the carbon was being stabilized into stable pools.

Key words: Mine spoil, reclamation, biological properties, carbon pools.

Surface mining is the most common technique used for mining of coal and other minerals when they occur close to the surface. In the process, the surface is completely stripped of vegetation, and the earth and rock (overburden) overlaying the coal layer is removed from large continuous areas to provide access to the coal bed or mineral of interest. Surface mining, therefore, causes soil disturbance and degradation on a large land area, and generates a large volume of heterogeneous mass, consisting of freshly blasted overburden materials called "mine spoils," a term given to any unwanted earth material that is left unmanaged. These mine spoils are devoid of organic carbon, soil structure and plant nutrients and pose a problem to biological reclamation. It is essential to increase the soil organic carbon pools to a critical level to set the restoration process in motion. Maintaining soil organic matter above a threshold is critical to sustaining soil quality because of the improvement in soil structure, controlling erosion, increasing soil water holding capacity, increasing nutrient reserves in soil, enhancing soil biotic activity and strengthening the nutrient recycling.

Soil organic carbon (SOC) is a useful indicator of soil quality and represents an important global carbon pool. Soils hold one of the largest terrestrial reservoirs of organic carbon (OC), and while most of this pool cycles on very

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slow time scales (centuries to millennia), climate change and landscape disturbance can affect the proportion of soil organic carbon (SOC) with the potential for more rapid exchange with the atmosphere (Houghton et al., 2001; Trumbore, 2009). Since post-mining soils are depleted of carbon, they serve as a perfect model for long-term study of carbon dynamics.

Several studies reported that microbial population, diversity and microbial biomass carbon increase over time in the restored mine degraded land and can be used as a criteria for the assessment of reclamation successes. Soil enzymes are involved in the decomposition of organic matter, nutrient cycling, availability of plant nutrients, soil structuring, organic matter storage, biological control and suppression of plant pathogens, and in many other chemical transformations in the soil (Pancholy and Rice, 1973). The activity and diversity of soil organisms are directly affected by the reduction of soil organic matter content, and indirectly by the reduction in plant diversity and productivity and has been used as an index of the success of restoration. The objective of this investigation was thus to study the effect of plantation on mine spoil biological properties and carbon pools in four chronosequences of coal overburden sites in a dry tropical area.

MATERIALS AND METHODS

The study was conducted in the Gevra open cast coal mining project operated by South Eastern Coalfields Ltd., situated in Korba district of Chhattisgarh. Opened in 1981, the Gevra opencast project covers an area of about 19.03 sq.km and has been described as the largest open cast mine in Asia and is the second largest in the world (figure.1). On the average, the project produced 0.66 million m^3 of overburden per 1 million tonnes of coal each year. The Gevra opencast project lies between 22° 18'00" and 82° 39'30" N latitude and is at an elevation ranging from 288 m to 328 m above mean sea level. The climate of the area is dry to moist tropical. The temperature rises to 48°C in May and drops to 7°C in December. The average rainfall is 1265 mm. Large areas of the mining project were used for dumping of overburden. To stabilize the dumps, different species of plants have been planted. Samples were collected from different overburden dumping areas of the Gevra mining project that were under various stages of restoration (<1, 7, 10, 25 years) under neem plantation. In addition, one reference under natural forest was used in the study. To collect a soil sample, surface litter was gently scrapped off and soil samples were collected from 0-5 cm. Three replicated samples from each site were taken to represent a stage of soil restoration. The soil samples were mixed thoroughly and about 0.5 kg of composite sample was taken for analysis. Soil samples were air dried, ground to pass a 2 mm sieve and then analysed for selected biological properties by standard methods.

Microbial biomass carbon was determined by the chloroform fumigation extraction method of Vance *et al.* (1987), dehydrogenase enzyme activity was determined by triphenyl tetrazolium chloride (TTC) method and mineralizable carbon was estimated by soil incubation under aerobic condition and measuring the amount of carbon di oxide evolved in a given period of time (Page *et. al.,* 1982). Walkley and Black organic carbon content (WBC) in the soil was determined by oxidizing (1 g) soil with chromic acid (Potassium dichromate + H_2SO_4) and back titrating the unconsumed potassium dichromate against ferrous ammonium sulphate (Walkley and Black, 1934). The oxidizable soil organic carbon (SOC) content was fractionated into different pools by the modified Walkley-Black method as described by Chan *et al.* (2001) using 12, 18 and 24 **N** H_2SO_4, respectively. Hence, it involves mixing of 1**N** dichromate solution with H_2SO_4 in different proportions. Oxidizable SOC was, thus, divided into three different pools(very labile,less labile and resistant) according to their decreasing order of stability (Chan *et al.,* 2001). Soil organic C oxidized by 12.0 **N** H_2SO_4 was termed very labile pool, the difference in SOC oxidizable by 18.0 **N** H_2SO_4 and that by 12.0 **N** H_2SO_4 was less labile pool, the difference in SOC oxidizable by 24.0 **N** H_2SO_4 and that by 18.0 **N** H_2SO_4 was resistant pool. Data obtained were subjected to one way analysis of variance using SPSS 15.0 and mean separated using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

The soils under forest, which were used as reference, were acidic in reaction, bright yellow in colour and had a sandy clay loam texture. The bulk density was low and water holding capacity was moderate. Soils of the region under study have been reported to be predominantly acidic in reaction (Bhausaheb, 2014) and have developed on acidic parent material due to presence of iron and humus. This soil is composed of many minerals due to its formation from erupted lava and is rich in iron, magnesia, lime and alumina. Fresh overburden dumps were acidic in reaction but the pH increased with increasing years of restoration under tree plantation and after 25 years under tree plantation reached a neutral value (Table 1). The colour of fresh overburden was grey, indicating the influence of leaching of organic matter/clay/iron oxide with percolating water. Overburden soils are usually subsurface soils which are subjected to leaching process. The soil colour changed to grey yellowish brown in soils under 25 years of reclamation, revealing the fact that restoration by planting trees had a favourable effect in improving the colour of mine soil.

The results of present study reveal that clay content increased from 21 to 31% and sand content decreased from 68 to 58% under 25 years of reclamation (Table 1). Maharana and Patel (2013) has reported variation in soil texture with progressive increase in the clay content with increase in age of overburden. Gradual establishment of the vegetation cover on the overburden can be one of the reasons for the increase in the clay formation (Jha and Singh, 1993). Root of the vegetation component, specifically root exudates, in the form of organic acids, promotes disintegration of coarse particles to finer clay particles (Dutta and Agarwal, 2002). Besides, the absence of vegetation cover makes clay more prone to losses (Parr and Papendick, 1997). On the other hand, vegetation cover development on degraded barren land has been reported to check the loss of clay particles, and promote its conservation (Khoshoo, 1987). Progressive increase in clay content in mine spoil indicated

Table 1. Selected properties of coal mine overburden dump in a restoration chronosequence.

Restoration period (years)	Soil Color	Sand/Silt/ Clay(%) Texture	Water holding capacity (%)	Bulk density ($Mg\ m^{-3}$)	pH
<1	5YR7/2Grey	68/11/21 Sandy Clay loam	36.48[a]	1.57[c]	5.7[b]
7	10YR 4/3Dull yellowish brown	61/1/38 Sandy Clay loam	41.78[c]	1.44[bc]	6.6[c]
10	10YR 5/3Dull yellowish brown	64/6/30 Sandy Clay loam	41.28[c]	1.44[bc]	6.7[c]
25	10YR 4/2Greyish yellow brown	58/11/31 Sandy Clay loam	44.59[b]	1.40[abc]	6.9[d]
Reference Forest	10YR 6/6Bright yellow	48/20/32 Sandy Clay loam	48[d]	1.10[a]	5.6[ab]

Table 2. Carbon fractions and biological properties of a coal mine overburden dump in a restoration chronosequence

Restoration period (Years)	Microbial biomass carbon(μg g-1)	Mineralized carbon (mg CO_2C kg soil $^{-1}$ day $^{-1}$)	Organic carbon (g kg^{-1})	Carbon pool (% organic carbon)			Dehydrogenase enzyme activity (μg g^{-1} day^{-1})
				Very labile	Less labile	Resistant	
<1	0[a]	84[a]	0.1[a]	100[e]	0[a]	0[a]	7.28[a]
7	168.9[b]	228[b]	16.3[c]	62.58[c]	30.06[e]	7.36[b]	11.8[b]
10	211.2[c]	276[c]	20.9[d]	54.07[b]	32.05[d]	13.87[c]	19.6[c]
25	316.8[d]	396[d]	37.8[e]	38.89[a]	20.10[c]	41.00[d]	15.90[d]
Reference Forest	633.4[e]	N.A.	3.5[b]	68.57[d]	2.86[b]	28.57[e]	16.95[e]

N.A. Not assayed

progressive development of soil structural stability, aggregation, and development of resistance to erosion, with the increase in age of mine overburden (Nath, 2004).

The water holding capacity (Table 1) of the mine spoils also increased with increasing years under restoration. Several researchers also reported low water holding capacity of mine soil (Nath *et al*., 2004; Juwarkar *et al*., 2004) which increased progressively with increased time of restoration. Maharana and Patel (2013) reported progressive increase in water holding capacity with the increase in age of overburden soil, which indicates the development of soil structural stability and aggregation. The bulk density (Table 1) of fresh overburden was high (1.57 Mg m^{-3}) which decreased to 1.40 Mg m^{-3} with increase in the age of reclamation under trees. Maiti (2007) analysed the bulk density for different types of minesoil and found that it was significantly higher for minesoil than cultivated land (1.35-1.48Mg m^{-3}) or grasslands(1.20-1.28Mg m^{-3})or forest (1.13-1.20 Mg m^{-3}).

The organic carbon status (Table 2) of the fresh dump was very low (0.1 g kg^{-1}) and increased gradually over the years of restoration to 37.8 g kg^{-1}. Several studies have shown that tree plantations on overburden dumps improve soil conditions by increasing the mass and concentrations of organic matter and available nutrients and by decreasing the soil bulk density (Parrotta, 1992). An increasing trend of organic carbon has also been noticed with increasing clay content. According to Marshman and Marshall, (1981), clay acts as an absorption sink for organic material. Increase in organic fraction, with increase in clay, can also be due to the fact that organic complexes being absorbed onto the clay surface, are being physically protected against decomposition (Dixon, 1989), which lead to an accumulation of soil organic carbon level with respect to age of mine overburden. Organic carbon, in association with the primary soil particles, is reported to promote macro aggregation (Gupta and Germinda, 1988).

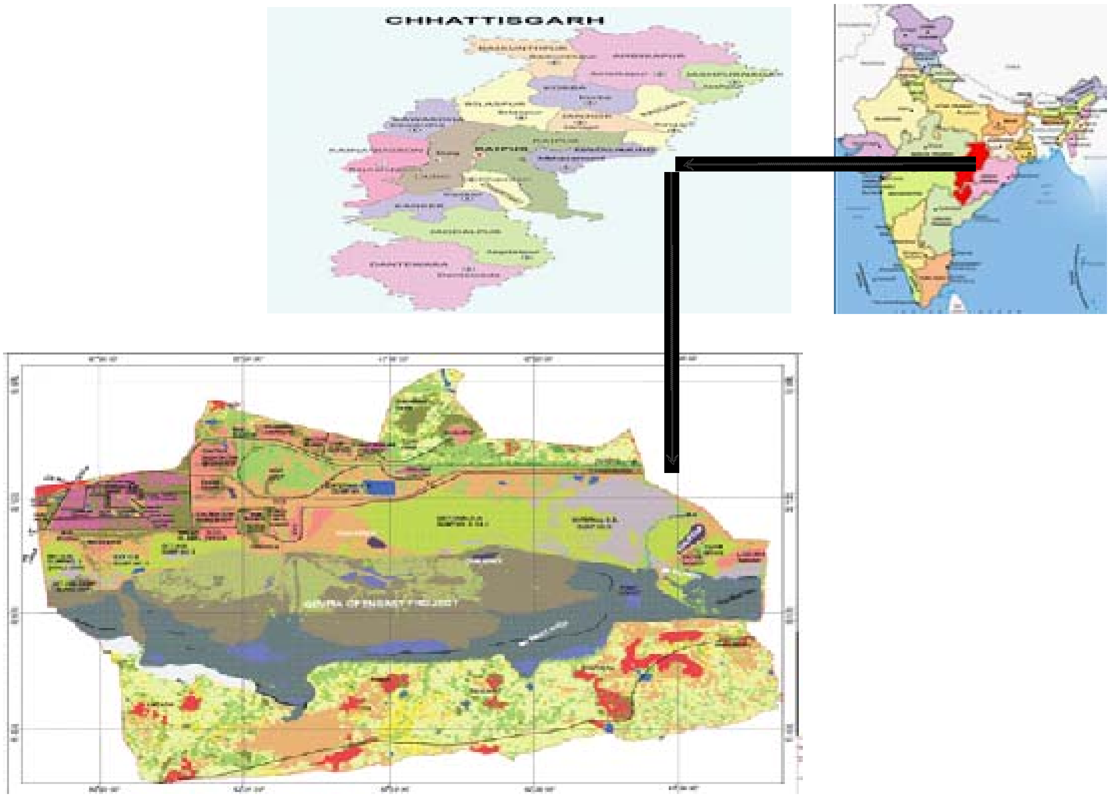

Fig. 1. Map of the Sampling Site (Gevra Open Cast Project, Korba, Chhattisgarh)

The microbial biomass carbon was below detection limit in the fresh dump, but increased continuously over the period of restoration to 316.8 µg g^{-1} indicating recovery of soil microbial communities with time under tree plantation. The reduction in microbial nutrients of the mine spoils is due to the lack of functional top soil layer, fewer levels of nutrients and lack of active microbial system. Dutta and Agrawal, (2001) reported that plantation age had a significant effect on soil microbial biomass. It has been reported that the microbial biomass can provide one of the most satisfactory estimates of the restoration of soil microbial populations (Ross *et al*., 1990). A continuous increase in microbial biomass with age in our study indicates continuous soil redevelopment on mine spoils. Bentham *et al.* (1992) observed that during recovery of soil 5 years after lignite mining, microbial biomass increased more rapidly than soil organic matter suggesting that recovery of carbon and nitrogen are much more slower than microbial biomass, and hence microbial biomass can act as an indicator of the progress of soil genesis in mine spoils. Determining recovery time of microbial biomass in reclaimed systems is therefore important because microbial associations with organic matter and nutrient cycling are critical for ecosystem function and availability of essential plant nutrients, particularly nitrogen and phosphorous (Clayton *et al*., 2009).

The microbial biomass in the forest soils were however much higher than that of dumps under restoration by trees. Higher MBC in forest soils was probably due to non disturbance of soil and high litterfall. Root biomass and above ground plant biomass are considered to be the main source of soil organic matter (Schnurer *et al.*, 1985). Litterfall also acts as a critical regulating component to enrich the microbial biomass on mine spoil soil (Dutta, 1999) and several fold higher concentration of microbial biomass has been reported for forest soils (Dutta and Agarwal, 2002). The microbial biomass carbon was strongly correlated (r=0.97*) to soil organic carbon. The proportion of soil carbon in microbial biomass however was found to be between 1.0 % (7 years old plantation) to 0.84 % (25 years old plantation).

The rate of carbon mineralized closely followed microbial biomass carbon and increased from a low level (84 mg CO_2C kg soil $^{-1}$day $^{-1}$) in the more recently reclaimed sites to a higher level (396 mg CO_2C kg soil $^{-1}$day $^{-1}$) in the older sites (Table 2). A general trend of increasing carbon mineralization rate indicates availability of greater amount of nutrients with time. Carbon mineralization was strongly correlated to organic carbon content (r=0.99*) and microbial biomass carbon (r=0.99*). The dehydrogenase enzyme activity of the recent overburden dump was found to be 7.28 µg TPF g^{-1} soil day^{-1}, which was found to increase with increasing years of restoration to 15.90 µg TPF g^{-1} soil day^{-1} after 25 years of restoration under trees (Table 2) but was the highest in forest soils (16.95 µg TPF g^{-1} soil day^{-1}). The dehydrogenase activity (DHA) has been proposed as a measure of overall microbial activity and has been used as an index of the soil microbial biomass (Mukhopadhyay and Maiti, 2010). The great increase in DHA after 25 years of restoration as compared to recent dumps reveal the fact that restoration by planting trees had a favourable effect in increasing the microbial population of mine spoils.

The carbon pools were further fractionated to labile and resistant pools (Table 2) using 12, 18 and 24 **N** sulphuric acid. It was found that the very labile pool of soil organic carbon decreased, whereas the resistant pool increased with increasing age of reclamation. Chaudhury *et al.*, (2015) studied labile and resistant organic carbon fractions of mine spoils and reported that the labile soil organic fraction decreased from 38 to 11% with increasing years of reclamation between 1 and 22 years. Higher proportion of labile SOC fraction in younger mine soils were in agreement with the findings of Chaudhuri *et al.*, (2012) and probably resulted from input of fresh plant litter comprising of more labile organic matter. However the resistant fraction increased during this period and had lower E4/E6 ratios suggesting that with increasing time along the chronosequence, the SOC molecules became more enriched with condensed aromatic species having larger molecular sizes and significantly higher degrees of humification.

Summary

The organic carbon status of the fresh dump was very low and increased gradually over the years of restoration. The microbial biomass carbon was below detection limit in the fresh dump, but increased continuously over the period of restoration indicating recovery of soil microbial communities with time under tree plantation. The rate of carbon mineralized closely followed microbial biomass carbon and increased from a low level in the more recently reclaimed sites to a higher level in the older sites. The dehydrogenase enzyme activity of the recent overburden dump was found to be very less, which was found to increase with increasing years of restoration under trees but was the highest in forest soils. It was found that the very labile pool of soil organic carbon decreased with time with increase in the age of reclamation, whereas the resistant pool increased with increasing age of reclamation.

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