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Physico-Chemical Characterization and Mine Soil Genesis in Age Series Coal Mine Overburden Spoil in Chronosequence in a Dry Tropical Environment

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Abstract

A pre-requisite to any revegetation plan, as well as restoration of degraded land is the knowledge of physico-chemical characterization, which is crucial for prediction of ecological succession for mine overburden spoil, including soil texture, hydrological regimes, pH, organic carbon, nitrogen and extractable phosphorous. Effects of mining activities are markedly adverse, because many of the beneficial soil characteristics may require a long span of time to develop through pedogenic processes, in order to reach the native forest soil condition, which evaluates the degree of functional microbial processes for ecosystem recovery, and used as an index of the progress of soil genesis in mine overburden spoil. Mine spoil samples collected from six different age series overburdens showed progressive increase in clay (%) (r=0.982, $p<0.001$), water holding capacity and organic carbon, which indicates the development of soil structural stability, aggregation with the increase in age of overburden spoil. The pH of spoil samples was noted to be in acidic range (6.11-6.87). Approximately, 93.7% variability in clay (%) among different mine spoils can be explained due to the variation in organic carbon. The organic carbon, nitrogen and phosphorous content showed an improvement of 2 mg C/g spoil, 161 µg N/g spoil and 8 µg P/g spoil, respectively, over a period of 10 years. Thus, the net annual accumulation rate for carbon, nitrogen and phosphorous on hectare basis amounted to 255 kg C/ha/yr, 20 kg N/ha/yr and 1 kg P/ha/yr, respectively. Further, it was estimated that the mine overburden spoil to attain the soil features of nearby native forest soil at study site through the process of reclamation, shall take approximately 28 years.

Keywords: Mine overburden spoil; Reclamation; Land degradation; Physico-chemical characterization

Introduction

Soil is a dynamic system, in which continuous interaction between soil minerals, organic matter and microorganisms influences the physico-chemical and biological properties of terrestrial ecosystem. Anthropogenic activities such as mining activities, specifically open cast mining, have resulted in drastic alternations in their geochemical cycles and often lead to land degradation, with adverse changes in soil textural and structural attributes [1-6]. Pit scarred landscape with huge dumps of mine spoils, in the form of overburden, usually presents the common scenario in the opencast coal mine area. Mine spoil, which refers to a mixture of coal seam, parent rock and subsoil [7,8]. Being deficient in plant nutrients due to lack of biologically rich top soil, mine spoil represents a disequilibriated geomorphic system [9,10], and poses problem for the process of pedogenesis [11-13], revegetation [7,14,15] and restoration [4,16-18]. There have been reports about slow recovery process of mine spoil due to the constraints of microbial growth [19-21], and natural vegetational succession [7,17].

In view of the increasing mining activities, decreasing soil fertility and adverse effects on soil flora and fauna, it is of utmost concern to monitor the physico-chemical characteristics of coal mine overburden spoil in a chronosequence, which not only pave the way of greater understanding the direction of improving soil fertility and bioremediation, but also is pre-requisite for assessing the process of spoil reclamation, leading to the vegetational development/succession with respect to time. Since coal is one of the extensively mined and used for majority of purposes, coal mining based mine overburden and contaminants have become a major issue of environmental concern. Thus, an attempt was made in the present study to determine the spoil reclamation process, in terms of different soil textural (sand, slit and clay fraction), structural (bulk density) properties, hydrological regimes (water holding capacity, moisture content), and spoil chemical characteristics (pH, organic carbon, total nitrogen and $NaHCO_3$ extractable phosphorous) in six different coal mine overburden spoils (fresh to 10 yr) in chronosequence, located in the open cast coal mine area of Odisha, India.

Materials and Methods

Study site

The present study was carried out in the Basundhara (west) open cast colliery, Ib valley coalfields area of Mahanadi Coalfields Limited (MCL), Sundargarh, Odisha (Geographical location: 22°03'58"-20°04'11" north latitude and 83°42'46"-83°44'45" east longitude). Topologically, the area is hilly sloppy to plateau. The thickness of the native top soils in the study site varies from 0.15 m to 0.30 m (average: 0.22 m). Because of the mining activities and limited original soil materials, there is insufficient soil to allow successful revegetation. The area experiences a semi-arid climate with annual rain fall of 1514 mm yr^{-1}, annual average temperature of 26°C and relative humidity of 15%. Open cast mining activities lead to the formation of coal mine spoil overburdens, and were grouped according to the time elapsed (Fresh mine spoil: OB_0, 2 yr: OB_2, 4 yr: OB_4, 6 yr: OB_6, 8 yr: OB_8 and 10 yr: OB_{10} respectively), since abandonment. The moisture index (calculated from annual rainfall and potential evapo-transcription data) of the district is -20.7. Thus, tropical dry deciduous forest is considered to be the natural vegetation of the study site, and broadly the climate is dry, hot and arid,

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and shows the characteristics of seasonality with three distinct seasons, i.e. summer (March to mid-June), rainy (mid-June to mid of October) and winter (October to February).

Spoil sampling

Each age series mine overburden was divided into 5 blocks and from each block, five mine spoil samples were collected randomly from 0-15 cm soil depth, by digging pits (15×15×15) cm^3 size. Samples collected from each block were referred as 'sub-samples', and were thoroughly mixed to form one 'composite sample', obtained from each overburden site. Similar strategy has been followed for sampling from different age series of coal mine overburden, along with nearby native forest soil (NF) in three different seasons, i.e. summer (April), rainy (July) and winter (January). The composite samples were homogenized, sieved (0.2 mm) and stored at 4°C, until analyzed.

Spoil texture

Spoil texture analysis included the estimation of clay (<0.002 mm), silt (0.06 mm-0.002 mm) and sand (2 mm-0.06 mm) percentage. Spoil sample (50 g) was taken in a 500 ml heat resistant bottle, calibrated up to 250 ml. To this, 125 ml of water was added and the mixture was swirled to wet the spoil thoroughly. 20 ml of 30% hydrogen peroxide was added to it and the bottle was gently rotated. Few drops of amyl alcohol were added to the mixture and kept in a boiling water bath, till the reaction was complete. Then, 2 g of sodium hexametaphosphate was added, followed by water, to make it up to 250 ml, and was shaken for 28 hr in a mechanical shaker. Then, the contents were transferred to a 1 L sedimentation cylinder and the volume was made up to 1 L. A blank cylinder was maintained by dissolving 2 g of sodium hexametaphosphate in water and made up to the mark with water. Both experimental and blank samples were placed in a water bath to maintain a constant temperature (25 ± 2°C). After 30 min, the sample cylinder was mixed vigorously with a plunger. The Bouyoucos hydrometer readings were taken exactly at 40 sec and 5 hr for the samples, and at 5 hr for the blank. Temperature of the water bath was recorded. The percentage of sand, silt and clay were determined as per the following calculation.

40 sec (corr)=2 (40 sec reading-40 sec blank+T)

5 hr (corr)=2 (5 hr reading-5 hr blank+T)

Where, T=Temperature corrections:

For every degree centigrade above 20°C (d), T=0.3×d

For every degree centigrade below 20°C (d), T=-0.3×d

% sand=100-40 sec (corr)

% silt=40 sec (corr)-5 hr (corr)

% clay=5 hr (corr)

Bulk density

Bulk density of the mine spoil was calculated, following the method prescribed in TSBF Handbook [22]. A pit of 10 cm length×10 cm breadth×20 cm depth was dug, and the soil was excavated. The collected soil was dried in an oven at 105°C for 24 hr. Dry weight of the soil was determined. The pit was filled with known volume of dry sand. The bulk density (g/cm^3) was calculated as: [weight of excavated soil (in g)/volume of sand (cm^3)].

Water Holding Capacity (WHC)

WHC was determined, following the protocol proposed by Mishra [23]. Soil samples from the different age series mine spoil samples were collected, air dried and crushed to pass through 0.5 mm mesh sieve. A brass box with perforated bottom was taken, and a Whatman circular filter paper (No. 42) was placed on the perforated bottom. A split brass ring was used to press the filter paper to its position. The box along with the filter paper was weighed and recorded as W_1. The brass box was filled with soil, with constant tapping, to ensure uniform packing. The soil packed box was placed on a petridish and water was added to maintain the depth of 1 cm. From time to time, water was added to maintain the depth. The box was left in the position for 12 hr. After that, the box was removed, subjected to surface drying with blotting paper, and the weight of the box was recorded (W_2). The box was then placed in the oven at 105°C for 24 hr, and the dry weight was recorded as W_3. Water absorbed by the filter paper was determined by saturating five filter papers with water, and weighing after rolling with a glass rod. The average amount of water absorbed by one filter paper was determined as W_4. The WHC (%) of the soil was calculated as: $[(W_2-W_3-W_4)/(W_3-W_1)]\times100$.

Moisture content

About 10 g of coal mine overburden soil samples were taken (W_1). The samples were oven dried at 105°C for 24 hr or more, till a constant dry weight was obtained (W_2). The soil moisture (%) was calculated as: $[(W_1-W_2)/10]\times100$.

Soil pH

Air dried soil of 20 g was taken in a beaker, and to this 50 ml of water was added. The mixture was stirred for 10 min, and was allowed to stand for 30 min. The pH was measured by use of electronic digital pH meter (Make: Systronics, Model: MK VI).

Organic carbon

Soil organic carbon was estimated, following titration method of Walkley and Black by Mishra [23]. To 5 g of oven dried mine spoil, 10 ml of 1N $K_2Cr_2O_7$ and 20 ml of conc. H_2SO_4 were added in a 500 ml Erlenmeyer flask, thoroughly shaken for 5 min, and was allowed to stand for 30 min. The suspension was diluted with 200 ml of distilled water, followed by 1 ml of 85% H_3PO_4, and 1 ml of diphenylamine indicator. The mixture was titrated against 1N $(NH_4)_2Fe(SO_4)_2.6H_2O$, until the colour of the mixture flashed to green. Then, 0.5 ml of 1N $K_2Cr_2O_7$ was added, and the titration was completed by adding 1N $(NH_4)_2Fe(SO_4)_2.6H_2O$, till the last traces of blue color disappeared. Organic carbon (%) was calculated as: $[(V_1-V_2)/W]\times0.003\times100$; where V_1=volume of 1N $K_2Cr_2O_7$; V_2=volume of 1N $(NH_4)_2Fe(SO_4)_2.6H_2O$; W=wt of spoil sample.

Total nitrogen

Total soil nitrogen was determined by Kjeldahl method [24]. Spoil sample of 10 g was transferred to a 300 ml Kjeldahl flask and was moistened with 25 ml of distilled water; allowed to stand for 30 min. To it, 20 g of sodium sulfate and the catalyst mixture (20 g copper sulfate, 3 g of mercuric oxide, 1 g selenium powder) was added. To one part of this mixture, 20 parts of anhydrous sodium sulfate was added, and a pinch of granulated zinc was added to the suspension, followed by 35 ml of conc. H_2SO_4. The resulting mixture was subjected to low heat treatment for 30 min for digestion, till the digest become yellow and colorless. The digest was then cooled and 100 ml of water was added, and allowed to stand for 5 min. The supernatant was then transferred into a flask. 25 ml of 4% boric acid was pipetted into a 500 ml conical flask, and 5 drops of mixed indicator (0.5 g bromo-cresol green and 0.1 g methyl red dissolved in 100 ml of 95% ethyl alcohol) was added. The glass tube attached to the lower end of the condenser was dipped into the boric acid solution. The condenser was connected to the flask and 100 ml of 40% NaOH was added slowly through the separating funnel. By heating the mixture, 150 ml of distillate was collected in the conical flask and was titrated against N/14 H_2SO_4, till the faint pink coloration was reached. A blank was run instead of spoil. Total soil nitrogen (%) was calculated as: [(T-B)×N×14.007×100]/W; where T and B are the volume of titrant used against sample and blank; N=normality of titrant and W=weight of sample.

$NaHCO_3$ extractable phosphorous

The phosphorous content in mine spoil was estimated by using chlorostannous reduced molybdophosphoric blue colour method in HCl [25]. Molybdophosphoric acid, which is thought to be formed by the coordination of molybdate ions, with phosphorous, as the central coordinating atom. The oxygen of the molybdate radicals is being substituted by that of phosphate ions, and the formation of molybdophosphoric acid. Sieved and air dried spoil sample of 5 g was transferred to a 250 ml conical flask, and to it 50 ml of 0.03N NH_4F in 0.025N HCl was added and was shaken for 5 min, and filtered immediately. To 2.5 ml of the filtrate, 7.5 ml of ammonium molybdate was mixed thoroughly, followed by addition of freshly prepared 0.5 ml of SnCl solution, and allowed to stand for 4-20 min. The absorbance was measured at 660 nm, and extractable soil phosphorous content was expressed in µg/g spoil.

Statistical Analysis

All the composite samples collected from six different age series mine overburden and native forest were analyzed, with respect to different parameters in triplicates. Microsoft Excel 97 was used in the statistical processing of the data. Principal components analysis (PCA) was performed using Statistrix PC DOS Version-2.0 (NH Analytical software).

Results

Textural characteristics, bulk density, different hydrological regimes and pH of mine spoil samples (OB_0→OB_{10}) have been presented in table 1. The analysis indicated that the slit and clay (%) did exhibit an increasing trend from OB_0 to OB_{10}. However, the sand (%) showed a reverse trend. Analysis of variance (two way ANOVA) indicated that the textural variation in different age series mine overburden spoils was estimated to be significant (p<0.001). Further, the clay fraction of different spoil samples was marked to be statistically correlated with the age of spoils (r=0.982, (p<0.001), which indicated that 96.46% of the variability in clay (%) was accounted by the age of mine overburden spoil.

Bulk density was found to be maximum in OB_0 (1.752 g/cm^3), but it showed a declining trend with the increase in age of mine overburden (Table 1). In OB_{10}, bulk density was estimated to be minimum. However, water holding capacity showed the reverse trend, *i.e.* minimum in OB_0 (27.5 ± 1.121), and progressively increased with time (maximum in OB_{10}: 43.8%). The moisture content was found to be minimum in OB_0 (6.831 ± 0.103), and showed an increasing trend with the increase in age of mine spoil, i.e. maximum in OB_{10} (7.955 ± 0.087). Spoil pH of all the sites was in the acidic range (6.11-6.87). The pH of OB_0 was minimum (6.11) and maximum in OB_{10} (6.71). Study on soil pH indicated that with the increasing age of the overburden, soil pH progressed towards the neutral range (Table 1).

The clay (%) exhibited by the nearby native forest soil (12.1%) was more than two times greater than OB_0. The bulk density, water holding capacity and moisture content in NF was found to be 1.252 g/cm^3, 46.348% and 11.219%, respectively. The soil pH of NF was found to be closer to neutral range, as compared to OB_0 (Table 1).

It is evident from the data that the organic carbon, total nitrogen and extractable phosphorous content in OB_0 were beyond the detectable limit. In addition, extractable phosphorous, even in OB_2, was also not detected (Table 2). The organic carbon, total nitrogen and extractable phosphorous in spoil samples collected from different age series mine overburdens showed a range from 0.151-2.004 mg C/g spoil, 8.514-169.830 µg N/g spoil and 4.254-12.581 µg P/g spoil, respectively, with minimum in OB_2 and maximum in OB_{10}.

The analysis suggested that there was gradual increase in organic carbon, total nitrogen and extractable phosphorous, from OB_0 to OB_{10}. Further, the analysis of variance showed that there was significant variation in organic carbon (r=0.992; p<0.001), total nitrogen (r=0.979; p<0.001) and extractable phosphorous (r=0.980; p<0.001), in different mine spoil samples in chronosequence, with respect to the age of mine overburden. However, the organic carbon, total nitrogen and extractable phosphorous in NF was found to be 3.625 mg C/g soil, 2510 µg N/g soil and 275 µg P/g soil, respectively (Table 2).

Discussion

The soil samples collected from six different age series mine overburdens showed variation in soil texture, which may be due to the variation in clay (%). Clay (%) showed progressive increase with the 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 [7,26,27]. Root of the vegetational component, specifically root exudates in the form of organic acids, promotes disintegration of coarse particles to finer clay particles [26,27]. Besides, the absence of vegetational cover makes clay more prone to loss [28,29]. On the other hand, vegetational cover development on degraded barren land was reported to check the loss of clay particles, and promotes

Parameters	Coal mine spoil from different overburdens						NF
	OB_0	OB_2	OB_4	OB_6	OB_8	OB_{10}	
Sand (%)	86.8 ± 2.1	84.6 ± 1.5	81.4 ± 1.6	79.5 ± 1.1	77.8 ± 1.2	75.9 ± 1.8	74.1 ± 1.2
Silt (%)	7.8 ± 0.6	8.5 ± 0.6	9.9 ± 0.3	10.6 ± 0.8	11.5 ± 0.5	12.8 ± 1.2	14.2 ± 0.6
Clay (%)	5.4 ± 1.2	6.9 ± 0.7	8.7 ± 0.9	9.9 ± 0.6	10.7 ± 0.8	11.3 ± 1.3	12.1 ± 0.5
Bulk Density (g/cm^3)	1.752 ± 0.049	1.605 ± 0.021	1.364 ± 0.019	1.331 ± 0.028	1.294 ± 0.026	1.275 ± 0.014	1.252 ± 0.019
WHC (%)	27.5 ± 1.121	31.3 ± 1.005	36.1 ± 0.984	38.3 ± 0.833	41.2 ± 0.743	43.8 ± 1.413	46.348 ± 0.833
Moisture (%)	6.831 ± 0.103	7.138 ± 0.141	7.422 ± 0.097	7.541 ± 0.143	7.783 ± 0.121	7.955 ± 0.087	11.219 ± 0.132
Soil pH	6.11 ± 0.03	6.24 ± 0.04	6.38 ± 0.02	6.45 ± 0.05	6.62 ± 0.07	6.71 ± 0.06	6.87 ± 0.07

(Values are mean ± SD of three seasons, *i.e.* summer, rainy and winter).

Table 1: Textural composition, bulk density, water holding capacity, moisture content and pH of mine spoil samples collected from age series overburdens, as well as native forest soil.

Parameters	Season	Coal mine spoil from different overburdens						Native Forest soil (NF)
		OB_0	OB_2	OB_4	OB_6	OB_8	OB_{10}	
Organic C (mg C/g spoil)	Summer	ND*	0.130 ± 0.011	0.721 ± 0.018	0.896 ± 0.029	1.104 ± 0.026	1.692 ± 0.031	3.282 ± 0.024
	Rainy	ND*	0.175 ± 0.014	0.824 ± 0.014	1.177 ± 0.021	1.881 ± 0.033	2.212 ± 0.019	3.867 ± 0.021
	Winter	ND*	0.148 ± 0.023	0.792 ± 0.022	1.098 ± 0.031	1.614 ± 0.025	2.108 ± 0.024	3.726 ± 0.013
	Mean	ND*	0.151 ± 0.024	0.779 ± 0.048	1.057 ± 0.127	1.533 ± 0.242	2.004 ± 0.249	3.625 ± 0.25
Total N (µg N/g spoil)	Summer	ND*	8.121 ± 0.112	43.119 ± 0.326	68.151 ± 1.618	108.823 ± 1.612	159.104 ± 2.61	2354.09 ± 17.3
	Rainy	ND*	8.973 ± 0.331	48.268 ± 0.224	76.904 ± 1.712	117.197 ± 1.236	179.074 ± 2.1	2615.21 ± 19.4
	Winter	ND*	8.448 ± 0.214	46.112 ± 0.102	73.633 ± 1.512	114.645 ± 1.221	171.312 ± 2.35	2560.69 ± 21.51
	Mean	ND*	8.514 ± 0.425	45.833 ± 2.248	72.896 ± 4.078	113.555 ± 3.901	169.830 ± 8.95	2510 ± 28.43
Extractable P (µg P/g spoil)	Summer	ND*	ND*	2.728 ± 0.311	6.031 ± 0.212	10.170 ± 0.029	10.824 ± 0.118	263.34 ± 3.22
	Rainy	ND*	ND*	5.472 ± 0.451	9.711 ± 0.401	11.928 ± 0.113	14.022 ± 0.109	284.29 ± 4.65
	Winter	ND*	ND*	4.562 ± 0.239	8.447 ± 0.141	11.085 ± 0.042	12.897 ± 0.216	277.36 ± 3.4
	Mean	ND*	ND*	4.254 ± 1.246	8.063 ± 1.636	11.061 ± 0.764	12.581± 1.411	275 ± 9.97

* Not detectable. (Values are mean ± SD of three seasons, i.e. summer, rainy and winter).

Table 2: Soil organic C, total N and Extractable P content in mine spoil samples collected from different age series overburdens as well as native forest soil.

its conservation [7,30]. Clay being an important primary particle, contributes to the soil structural stability [31-33]. Progressive increase in clay particle in mine spoil indicated progressive development of soil structural stability, aggregation, and developed resistance to erosion, with the increase in age of mine overburden [7,17,29,34].

A positive relationship was observed between clay (%) and organic carbon (mg C/g soil) between different overburden sites (r=0.967, $p<0.001$). Increase in organic carbon was found to be correlated with the increase in clay fraction in ecologically disturbed lands [35,36]. According to Marshman and Marshall [37], clay acts as an absorption sink for organic material. Increase in organic fraction, with the 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 [38,39], 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 [16,40]. Beneficial influence of organic matter on soil aggregate formation, soil structural stability and nutrient retention capacity, has been extensively reviewed [41,42].

Further, the study revealed a declining trend of bulk density with age of mine overburden, which is analyzed to be negatively correlated (r=0.917, $p<0.001$). Importance of bulk density lies with the fact that it regulates space, air and water availability to soil organisms [43]. A decline in bulk density, with age of mine spoil, can be interpreted as a reduction in soil compactness, because of the development of soil micropore space [44,45]. According to Ohta and Effendi [45], it is the clay fraction, which has an ultimate bearing on the soil bulk density. An increased level of clay fraction contributes to the development of soil micropore space that reduces the soil bulk density. In the light of this concept, the gradual accumulation of clay fraction and organic matter input in OB_{10} because of the vegetation, led to the development of soil micropore space, that ultimately reduced the soil bulk density. A negative relation between bulk density and organic C (r=-0.903, $p<0.01$) of spoil samples collected from different age series of mine overburdens substantiated the concept [7,18,46,47]. Organic C in association with primary soil particle was reported to promote macro aggregation [40,45] and hence, soil bulk density declines.

WHC of the soil samples collected from different age series mine overburden exhibited an increasing trend, and was positively correlated with the age of overburden (r=0.991, $p<0.001$). Soil moisture showed progressive improvement with age of mine spoil, which is supported by the findings of Dutta and Agarwal [27]. This can be due to the positive influence of the canopy cover on the OB_{10} mine spoil, which prevented the loss of soil water through evaporation, by not allowing direct exposure of soil surface to the incoming radiation [5,48,49]. Several researchers also reported lower clay fraction, high soil bulk density, low water holding capacity and poor physical conditions of mine spoil [17,18, 26,27,50,51].

The mine spoils collected from OB_0 showed the maximum acidic value and exhibited gradual improvement with the age of spoils. Improving soil chemical condition by the reduction of soil acidity has been well explained [6,52]. Acidification in the mine spoil due to different mineral deposits in the mine spoil [6,17,27,52,53]. Improvement of pH value due to both passive and active reclamation, either by natural succession or by the plantation strategy on coal mine overburden spoil [7,27]. Promotion of organic matter decomposition on degraded soil also has been reported to lower soil acidity [47,53,54].

Organic C in spoil samples collected from different age series mine overburdens showed a considerable improvement, suggesting the restoration of coal mine spoils [7,42,55,56]. Establishment of vegetation and increase input of litter from the vegetation compartment, during the course of passive or active restoration, is supplemented by the improvement in soil organic carbon [57]. Along with the increase in organic C, total N and extractable P also did exhibit gradual improvement, and showed positive relationship with age of overburden. Thus, the study clearly revealed that with the passage of time, spoils on overburden showed the sign of restoration, accumulating carbon, nitrogen and phosphorous to support the vegetational and soil biodiversity. Comparative assessment of soil organic C, N and P levels between OB_0 and OB_{10} samples indicated an improvement of 2 mg C/g spoil, 161 µg N/g spoil and 8 µg P/g spoil, respectively over a period of 10 years. Thus, the net annual accumulation rate for C, N and P amounted to 200, 16.1 and 0.8 µg/g spoil, respectively. On hectare basis, these figures correspond to 255 kg C/ha/yr, 20 kg N/ha/yr and 1 kg P/ha/yr, respectively.

Several workers have been reported that the nutrient accumulation in the disturbed land is a time dependent process. While working on the impact of natural succession/restoration of degraded barren tropical soil, Sahani and Behera [47,54] reported a net annual carbon accumulation of 800-1000 kg C/ha. Hence, the present carbon accumulation data in the mine spoil is marked to be lower than that of Sahani and Behera [54] and Dutta and Agarwal [27]. This may be due to the hostile ambience of mine spoil, where natural successional process leading to the establishment of vegetation cover may be a much slower process. Visser et al. [21],Vimmerstedt et al. [31] and Jencks et al. [58], working on mine spoil reclamation in temperate climate reported a net nitrogen accumulation of 9.5 to 17 kg N/ha, and the figure of nitrogen accumulation estimated for the present study is 20 kg N/ha. Successional establishment of many leguminous herbaceous species on mine spoil in tropical environment can explain such higher N accumulation rate. Dancer et al. [59] have suggested that 700kg ha^{-1} of N accumulation in soil is critical for the establishment of a substantial self-sustaining ecosystem in disturbed lands. Roberts et al. [35] and Dancer et al. [59] have identified accumulation of nutrients as an important feature of ecosystem development in naturally colonized spoils. The increase in soil N can be attributed to the input from the growing plant species, i.e. *Cassia siamea* and *Acacia auriculaeformis* in mine spoil, in course of time, which are reported to have a good nitrogen fixing potential [60,61]. Besides, *A. auriculaeformis* is considered to be a tolerant species, which flourishes well in marginal acid soil with low nutrient [61]. Even after 10 years of restoration, the nitrogen level in mine spoil still observes to remain below the critical limit, which urges the management strategy for planned restoration of mine overburden spoil. With respect to soil phosphorous, the development of mycorrhiza and other phosphorous immobilizing microbial colonization in the coal mine overburden spoil, may be the reason for such accumulation.

Considering the tropical dry deciduous forest as natural vegetation of the study site, attempt was made to compare the spoil features of different mine spoils ($OB_0 \rightarrow OB_{10}$) in chronosequence, with that of NF soil using principle component analysis [62], in which the Z_1 and Z_2 components accounts for 99% cumulative variance (Figure 1).

Besides, the mining activities have resulted in the loss of forest cover in the mining area, as well as its peripheral zone, which was under the dense cover of tropical dry deciduous forest before mining operation. The study revealed that the different age series mine overburden spoils in chronosequence showed gradual improvement in different soil features over time, which indicates the pace and progress of reclamation. Considering the different soil parameters of NF as unit, proportionate level of these parameters for different mine overburden sites were calculated. Further attempt was made to calculate the time period required for reclamation of OB_0 to reach the nearby NF soil condition. Accordingly, a positive correlation was observed ($r=0.996$; $p<0.001$) between the mean soil feature value and age of mine overburden, which explained 99.69% of the variation in age, due to the change in mean soil features (Figure 2). Taking the value of the forest soil data (i.e. 1) as 'X', the equation was used to calculate the age of NF soil, i.e. 27.97 years.

Conclusion

Soil quality is intimately related to physico-chemical properties,

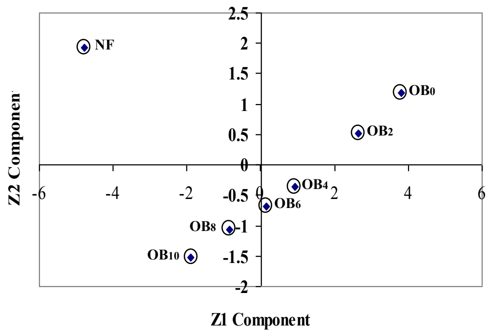

Figure 1: Segregation/discrimination analysis of different mine overburden spoil in chronosequence ($OB_0 \rightarrow OB_{10}$) and the native forest soil (NF).

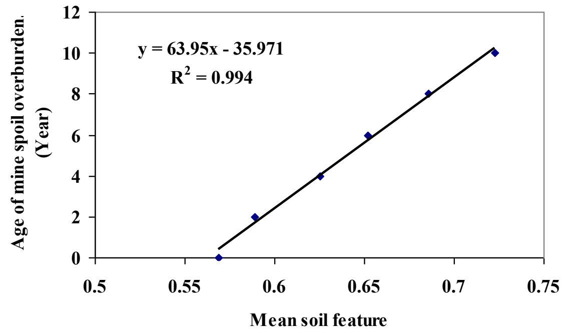

Figure 2: Relationship between mean soil features with age of the mine spoil overburdens.

and their evaluation will facilitate to characterize soil fertility and productivity. Soil physico-chemical indices appeared to be more informative, and could therefore be used to guide the selection of appropriate additional reclamation strategies. Soil physico-chemical characterization between different mine overburden spoils in chronosequence reflected changes in soil textural and structural attributes, organic carbon, total nitrogen and extractable phosphorus, which is due to the gradual establishment of vegetation in due course of time. Significant correlation between clay fraction and organic carbon indicated their potential utility, as rapid assessment tools for mine spoil reclamation. Besides, soil textural distribution is a major factor influencing water holding capacity, bulk density and soil moisture availability. Gradual increment in soil pH, from acid mine spoils to neutral range in chronosequence, also revealed the sign of restoration. Increases in the organic carbon, nitrogen and phosphorous content in chronosequence mine overburden spoil during the 10 yr period, clearly demonstrated their C sink potential. The lower level of organic carbon in mine overburden spoils, as compared to native forest soil, might be due to the disruption of ecosystem functioning, depletion of soil organic pool, and also due to the loss of litter layer during mining, which is an integral storage and exchange site for nutrients. The study suggested that the fresh mine spoil to attain the soil features of native forest soil through the process of reclamation shall take ~ 28 years, provided the spoil habitat is not subjected to any other interferences like erosion, vegetational degradation, etc.

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