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Minesoil Reclamation Due to Tree Plantation: A Chronosequence Study

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Abstract: A chronosequence study has been conducted at different aged reclaimed coalmine overburden dumps to assess the changes in mine soil properties due to tree plantation. The improvement in mine soils characteristic in chronosequence sites were compared with fresh mine soils and adjacent natural forest soil. Coarse fraction, moisture content, organic matter and base saturation can be used as indicator parameters to assess the status of reclaimed mine soil. Coarse fraction is found to influence the entire biological reclamation process by influencing moisture retention capacity, bulk density and porosity. Soil moisture content increases with the age of reclaimed mine soils due to accumulation of litter, growth of herbaceous vegetation, increase in organic matter and improvements in texture. Nutrient content was found significantly higher in 17-year old dumps compared to other sites. Increased organic matter is associated with increase in nitrogen and phosphorus which results in overall increase in microbial activity of soil. Significant increase in exchangeable cations was found with the increase in age of dumps due to increase in clay content and base saturation. Progressive build up of adequate nutrient pool in 17 years mine soil may be sufficient for ecosystem maintenance. Chronosequence study of reclaimed coalmine overburden dumps concludes that tree plantation improves productivity of mine soil.

Key words: *Coal mine soil · Reclamation · Chronosequence · Base saturation · Coarse fraction · Organic matter*

INTRODUCTION

Forestry reclamation approach (FRA) is a common practice for reclamation of coal mine degraded lands in India. About 85% of coal is produced by opencast mining which causes severe land degradation. These lands are characterized by higher stone content, lack of moisture and soil forming materials, higher compaction, lower nutrient content, and impoverished microbial activity which limits initiation of nutrient cycling [1, 2]. Mine degraded lands are reclaimed by the principle of *phytostabilisation*. The normal practice is to choose drought resistant, fast growing trees, which can grow in harsh environmental conditions. Under FRA practice, the overburden dumps are leveled by dozer and plantation pit is dugged manually before the onset of monsoon. Only topsoil is added in the pits without any pH correction or amendments. The growth of tree species accelerate soil-forming processes, buildup organic matter, develop microbial communities and initiate nutrient cycling [3, 4]. The constraints related to plant establishment, physico-chemical properties of mine soils and choice of appropriate plant species are major issues for the revegetation of mine soils.

Different tree species have different ameliorative affect on soil physico-chemical properties [5-9]. Menyailo *et al.* [10] found that tree species improve soil properties such as texture, pH, organic carbon, NPK and Cation Exchange Capacity (CEC). Yao *et al.* [11] studied the improvement of physical and chemical properties of 15-year old reclaimed coal mine soils in Inner Mongolia, China and findings indicate that plant types affect soil forming process especially in the upper layer (0–20 cm) due to increase in organic matter and soil organic carbon. Rodrigue and Burger [12] studied the effects of surface mining on forest land productivity in the eastern coalfields of the USA and identified 5 soil properties (i.e. soil profile base saturation, total coarse fragments, total available water, total porosity, and electrical conductivity) that influence 52% of the variation in tree growth.

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Chronosequence (25+ year, 10 year and 5 year) analysis by Boerner *et al*. [13] in coal mine site in USA indicates that N, P and organic carbon content increase with time but they did not exhibit any clear and temporal trend. Another chronosequence study was carried out by Šourková *et al*. [14] in 5 reclaimed sites ranging from 8-40 year old in the lignite mine spoil (Germany and Czech Republic) and concluded that vegetation type and litter quality have higher importance for development of soil microbial activity than the substrate quality.

The objective of the present study was to compare the improvement in physico-chemical activities with time by considering different aged tree strands growing in the reclaimed overburden dumps. The studied properties included coarse fraction, soil texture, bulk density, pH, soluble salts, organic matter, available NPK content, cation exchange capacity and base saturation. These chosen parameters are commonly used in soil quality assessment and may be useful in estimation of reclamation success [7, 12, 15]. Improvement in soil properties in course of time due to establishment of plantations was also compared with natural forest soil.

MATERIALS AND METHODS

Study Area: This study was conducted in the different aged reclaimed coal mine overburden dumps of North Karanpura Area, Central Coalfield Limited (CCL) in Ranchi district, Jharkhand, India. The coalfield is basin shaped, having an area of 60 sq km. There are six production projects in this area, out of which Rohini, Karkatta and K.D. Heslong Projects has been considered for the present study. The study area falls between latitudes 23°39'53'' and 23°42'30''N and longitudes 84°59'15" and 85°0'3"E. The general topography of this area is characterized by flat terrain with gentle undulation having maximum elevation of 467 m above mean sea level. The annual rainfall is around 1100mm to 1600mm and maximum monthly rainfall recorded is 545mm, 89% precipitation occur during rainy season only (July-October). The climate is tropical with severe summer (March – May) and temperature goes as high as 45°C and minimum 20°C. The minimum winter (November – February) temperature recorded is 1°C.

To assess the changes in mine soil properties due to tree plantation the present chronosequence study has been conducted at different aged reclaimed coalmine overburden dumps according to their availability as follows:

- 17-year old reclaimed dump
- 7-year old reclaimed dump
- 5-year old reclaimed dump
- 2-year old reclaimed dump

An adjoining natural Sal (*Shorea robusta*) forest (undisturbed by mining) was taken as control site for comparing the soil development process in all age series of reclamation.

Vegetation Characteristics: The plantations have been raised on overburden dumps because natural colonization is very slow. Six month old nursery raised seedlings of different tree species were used for plantation by the Mander Social Forestry Division, Ranchi in previously dug pits (40 cm^3) at a spacing of 2 m x 2 m at the onset of monsoon. During pit plantation only topsoil was added without any amendments; however watering was done manually in the summer months for the first year only. Approximately 20 different tree species were planted during biological reclamation, among them *Cassia siamea, Dalbergia. sissoo, Acacia catechu, A. auriculiformis, A. mangium, Gmelina arborea, Leucaena leucocephala, Terminalia arjuna, Dendrocalamus strictus* were most popular. The ground vegetation consists of natural growths of *Lantana camara, Leonotis nepetifolia, Eupatorium odoratum, Hyptis suavelons*, *Pennisetum pedicellatum, Saccharum spontaneum* and *Zizyphus jujuba.*

The natural forest is mixed dry deciduous type, dominated by *Shorea robusta* (sal tree), along with *Terminalia tomentosa, T. arjuna, Butea monosperma, Dalbergia sisoo, Madhuca indica, Pongamia pinnata* and *Azadirachta indica.* Ground vegetation consists of sapling of *S. robusta,* common shrubs (*Lantana camara, Eupatorium odoratum, Leonotis neptifolia)* and herbaceous species (*Xanthium strumarium, Saccharum spontaneum, Tridex procumbence* and *Evolvulus* sp).

Vegetation Analysis: Six quadrates of 10 m×10 m area were demarcated in each of the different aged reclaimed overburden dumps and average number of trees of a particular species, in each quadrate was recorded. The relative density (RD) of each tree species was calculated using the following formula:

$$\text{Relative density (\%)} = \frac{\text{no. of individuals of a particular species}}{\text{no. of individuals of all species}} \times 100$$

Table 1: Vegetation analysis in the different aged reclaimed overburden dumps

Age of Reclaimed dump	Dominant tree species	DBH (cm) (average±SD)	Height (m) (average±SD)	Canopy cover (%) (average)	Relative Density (%) (average)
17-year	*Cassia siamea*	19.76±2.35	7.1±0.61	120	95
7-year	*Dalbergia sissoo*	9.09±2.19	5.12±0.75	95	52
	C. siamea	8.97±2.12	4.2±0.68	88	16
	Acacia auriculiformis	5.41±0.64	5.1±0.82	65	10
	A. mangium	6.47±1.29	4.1±0.51	90	10
5-year	*D. sissoo*	7.81±1.51	4.91±0.71	85	39
	A. catechu	4.97±1.75	3.09±0.80	68	33
2-year	*D. sissoo*	3.82±1.18	3.76±0.67	48	47
	C. siamea	2.15±0.12	2.15±0.37	46	17

The tree species growing in the different aged reclaimed overburden dumps along with vegetation characteristics are represented in Table 1. The 17 years old dump was reclaimed by *C. siamea* plantation and *D. sissoo* was found dominant (38-52%) in the other dumps. The girth of each tree species was measured at the height of 1.37 m above the ground level (i.e., diameter at the breast height, DBH). All trees in the 100 m^2 plot were recorded and their canopy covers measured by the line intercept method [5]. Canopy cover for each species was recorded in cm/1000 cm and summed to determine total canopy cover. Next, these totals were converted to percent by dividing by 10. A value of 0% indicates no canopy cover, 100% reflects complete canopy cover, and values >100% signifies an overlapping canopy.

Soil Sampling: Sampling sites were selected after a geo-botanical survey of the dumps. Soil samples were collected from (a) different aged reclaimed coalmine overburden dumps (b) an adjoining natural forest (control site) for comparing the soil development process in all age series of reclamation (c) fresh overburden: six composite samples were prepared and each composite sample was made up of 5 sub-samples collected from different dumpers carrying overburden material. Soil samples (0-10 cm depth) from within a quadrate were thoroughly mixed to yield one composite sample per quadrate. After collection, the samples were air dried at room temperature (30–35°C) and lightly crushed with a mortar and pestle and passed through a 200-micron mesh.

Physico-Chemical Analysis of Soil: Samples were analyzed for coarse fraction (>2 mm size, w/w) by sieving method [16], particle-size analysis by the International pipette method [16], bulk density with the metal core sampler method [17], porosity was determined from bulk density measurements with an assumed particle density of 2.65 Mg m^{-3} [18].

The pH and electrical conductivity (EC) was determined in soil/water (1:2.5; w/v) suspension with a pH meter and a conductivity meter, respectively. The paste pH (1:1, w/v) and paste electrical conductivity (1:1, w/v) were also measured [19]. Organic matter was determined by loss on ignition (LOI). Samples were heated in crucibles for 24 h in a muffle furnace at 425°C and organic matter was estimated from net weight loss [20]. Available nitrogen was determined by the alkaline potassium permanganate method [21], available phosphorus by Bray's method [22], exchangeable Na, K, Ca were extracted by neutral 1(N) ammonium acetate solution (soil-to-extractant ratio of 1:10) and determined by Flame photometer [23]. The Cation Exchange Capacity (CEC) was determined by extraction with 1N sodium acetate, followed by washing with 95% ethanol and leached with 1N ammonium acetate solution and measured by Flame photometer [23]. Base saturation was calculated as the proportion of the CEC occupied by base cations [24].

Statistical Analysis: One-way ANOVA (analysis of variance) was carried out to compare the means of nutritional characteristics of different aged reclaimed overburden dumps. Where significant F value was obtained, differences between individual means were tested using DMRT (Duncan's Multiple Range Test) at 0.05 significance level. The data were analysed using SPSS window version 10.0 (SPSS Inc., Chicago, USA) packages.

RESULTS AND DISCUSSIONS

Physical Characteristics: Soil physical properties varied considerably between different aged reclaimed dumps. Coarse fraction (>2mm size) is an important parameter that affects the soil productivity of the coal mined land because excessive amount of coarse fragments limit the fine earth volume available for root proliferation,

Table 2: Physical characterization of soils of different aged reclaimed overburden dumps, natural Sal forest and fresh overburden dumps (values are mean, standard deviations are reported in italic, n=6)

Age of reclaimed overburden dumps	Coarse soil fraction (>2mm)%	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk Density (g/cm3)	Porosity (%)	Soil moisture (%)
17-year	42.06 b	67.12c	18.43a	14.45a	Sandy loam	1.39ab	47.40ab	5.79a
	17.38	4.27	1.46	1.23		0.13	4.72	0.78
7-year	46.70 b	73.70c	14.18b	12.12b	Loamy sand	1.55a	41.42 b	4.45b
	11.4	4.92	1.34	1.43		0.11	4.15	1.4
5-year	39.36 b	75.68b	13.65b	10.67b	Loamy sand	1.51a	43.11b	4.96ab
	11.03	4.19	1.65	1.25		0.18	6.77	0.66
2-year	45.35b	83.33a	9.63c	7.10c	Loamy sand	1.56a	40.25b	2.04d
	11.61	4.92	1.49	1.15		0.22	5.32	1.62
Natural Sal Forest	12.87c	74.23bc	20.34a	5.43c	Loamy sand	1.24b	53.38a	3.86c
	2.35	2.68	1.25	0.83		0.04	0.98	0.98
Fresh OB dumps	62.17a	88.58a	8.15c	3.53d	-	-	-	-
	8.54	6.19	1.39	0.74				

water-holding capacity, and long-term nutrient availability. The characteristics of mine soils under different aged plantations were compared with fresh mine soil and natural forest soil adjacent to the study area (Table 2). Highest coarse fraction was found in fresh mine soil (62.2%) and lowest in natural forest (12.9%), while in different aged reclaimed dumps coarse fraction was found between 39% to 47%. No significant difference was observed between age of reclaimed dumps and coarse fraction due to greater site variability and heterogeneous nature of mine soil. The coarse fraction was reported between 14 to 83% in Appalachain coalfields of USA [12]. The present analysis indicates a gradual increase of soil fraction as age of plantation increases. Thurman and Sencindiver [25] also concluded that mine soils developing on lands mined for coal often have greater rock fragment content than the surrounding native soils. The present analysis indicates a gradual increase of soil fraction as age of plantation increases. However the trend of increase was not found consistent because overburden materials were not same at different depths of opencast mines. Moreover, the amount of rock present on mined sites, even after a period of 20 to 55 yr, depends on rock hardness, blasting techniques, and spoil handling [26].Other researchers have noted similar ranges in rock content on mined sites and their impact on plant growth [27,28]. Several researchers reported a reduction of coarse fractions with time in surface horizons where weathering processes are rapid [5, 26, 29]. Coarse fraction content more than 50% is rated as poor quality of mine soils, which retards plant growth [30].

Particle size distribution is a major factor in governing successful revegetation on reclaimed land as it influences water holding capacity, bulk density, soil moisture availability and nutrient contents as well as availability [31]. Mine soils texture vary from dump to dump depending upon the overburden materials excavated from different depth of opencast mines and also upon the parent material from which the soil is developing [32]. The percentage of sand was found higher in fresh mine soil (88.6%) compared to other reclaimed dumps (67% – 83%); while silt and clay percentages were found higher in reclaimed dumps than fresh mine soil. Highest silt content was found in native forest soil. The texture of mine soils gets drastically disturbed due to irregular pilling of overburden materials. The variations in sand percentage between different aged reclaimed dumps were found statistically significant. Similarly, silt and clay percentages showed significant variations among the reclaimed dumps. Significant variations in silt and clay suggest that plantations are capable of changing the soil texture after their establishment and growth in due course.

Different letters in the same column indicate significant differences between different sites (Duncan's multiple range tests, $p<0.05$).

Numerous investigators have reported bulk density values of mine soils to be higher than contiguous native soils [6, 25]. The bulk density was found between 1.24 to 1.56 g $cm^{-3,}$ which was again not with the age of dumps. In the oldest dumps (17-year) the average bulk density was found 1.39 g cm^{-3} which is higher than natural forest (1.24 g cm^{-3}). The variations within the same aged plots were found statistically significant due to heterogeneous nature of mine soils [4]. The bulk density differences were attributed to mining equipment and organic inputs on older sites. In a study comparing mine soils of different ages, bulk density of the old mine soil (~50 years) was equal to or less than the native soil [6]. New mine soils had a slightly higher bulk density than the native soils due to the differences in mining method rather than pedogenic processes.

Profile porosity was considered the fourth most influential variable on mine soil quality and higher porosity resulted in higher site productivity [5]. Porosity of forest soils generally range from 30 to 65% [33]. In the present study, porosity ranged from 40 to 47% across all mined sites. Porosity of mine soils reported in other studies ranged from 27 to 83% [27, 12, 28]. In mine soil, voids are characterised by macrospores and formed bridge [34]. These voids form because overlapping rock fragments do not allow all spaces to be filled with fine-earth material during the backfilling process.

Soil moisture content among different aged reclaimed dumps was found between 4.5 – 5.8%, close to the native forest soil (3.86%) but higher than that 2-year old dump (Table 2). The lack of moisture retention of about 25% was also reported for most of the coal mine spoil in Pennsylvania [2]. The field moisture content in a dump is a fluctuating parameter that is dependent on time of sampling, height of dump, age of reclaimed mine soils stone content, amount of organic carbon, texture and thickness of litter layers on the dump surfaces. From samplings during winter, the average field moisture content was found to be approximately 5%, while in peak summer moisture content was as low as 2–3% [35]. Low moisture content in the overburden dumps is due to lack of organic matter and the higher stone content, combined with a sandy soil texture. Lack of significant change in physical properties with age probably demonstrates that mining and grading techniques were more important to physical properties at this young stage of mine soils development than mine soils genesis processes [6, 25].

Nutritional Characteristics: Mine soil pH (reaction) is a property inherited directly from overburden parent materials, and can vary widely depending on the amount of acid-producing or acid-neutralizing material present in the parent overburden material. In the present study, soil pH showed significant variations among the different aged reclaimed dumps ($p<0.05$). The pH was found acidic in all samples and no significant trend was found with the increasing age of reclaimed dumps (Figure 1(a)). The pH (1:1) values were found between 4.91 to 5.80, which in lower than natural forest (5.90) and showed significant variations among the different aged reclaimed dumps ($P<0.05$). The study indicates that soil pH of this regions were slightly acidic which favours the growth of natural sal forest and leguminous trees. The gradual increase in pH from 5.52 (fresh overburden) to 5.80 was due to plantations and inputs of organic matter that modifies the pH of the soil. Since the plant species are dicotyledenous, they may release more base cations like Ca^{2+} into the soil (highest Ca^{2+} was found in 17 and 7 year old dumps), thus increase the pH of the soil more than the fresh mine soils. Richart *et al.* [36] also observed that the change in pH of opencast spoil was directly related to the tree growth.

Soluble salts are an influential variable in the survival and growth of tree seedlings, and site productivity decreases with an increase in soluble salt concentration [12, 27, 28]. The EC values were relatively low in the mine soils, varying from 0.115 to 0.187 dS m^{-1} and reduced significantly in natural forest; however significantly high value was found in fresh overburden materials (Figure 1(b)). The variation of EC values are attributed by leaching, composition of parent materials and plants uptake. Soluble salt concentrations of >1–3 dS m^{-1} were found to be unfavourable for plant growth and tree survival [37].

Soil organic matter, N and P have been reported as growth limiting on mined sites, but usually within the first 10-year after disturbance [27]. Increased organic matter is associated with enhanced organic carbon, which results in overall increase in microbial activity of soil [2]. The organic matter was found maximum in the 17-year old reclaimed dumps (4.25%) and lowest in 2-year old dump (0.31%), while in native forest value was 0.64%. This higher organic matter in the oldest reclaimed overburden dump is due to the accumulation of leaf litter and its decomposition to form humus. Soil organic matter improves soil structure, fertility and water storage capacity; therefore its content is widely accepted as indicator of soil quality and functioning part of the ecosystem. Available N and P also followed the same trend as organic matter (Figure 1). Significant increase in concentration of available N was found with the increasing age of plantation (135.7 mg/kg), which is significantly higher than native forest (48.5 mg/kg). In the younger reclaimed dumps, available N stock was found between 26 to 51 mg/kg, indicating N is limiting initially after reclamation when very little organic matter was present. Nitrogen accumulation is controlled by organic carbon input and N fixation, and phosphorus content is determined by the organic matter, pH of the soil substrate and weathering process [27]. Available P varied along the chronosequence and there were significant differences among sites, with the greatest levels of P in the 17-year old reclaimed dump. Available P levels were found to decrease in the recently reclaimed dumps, however no

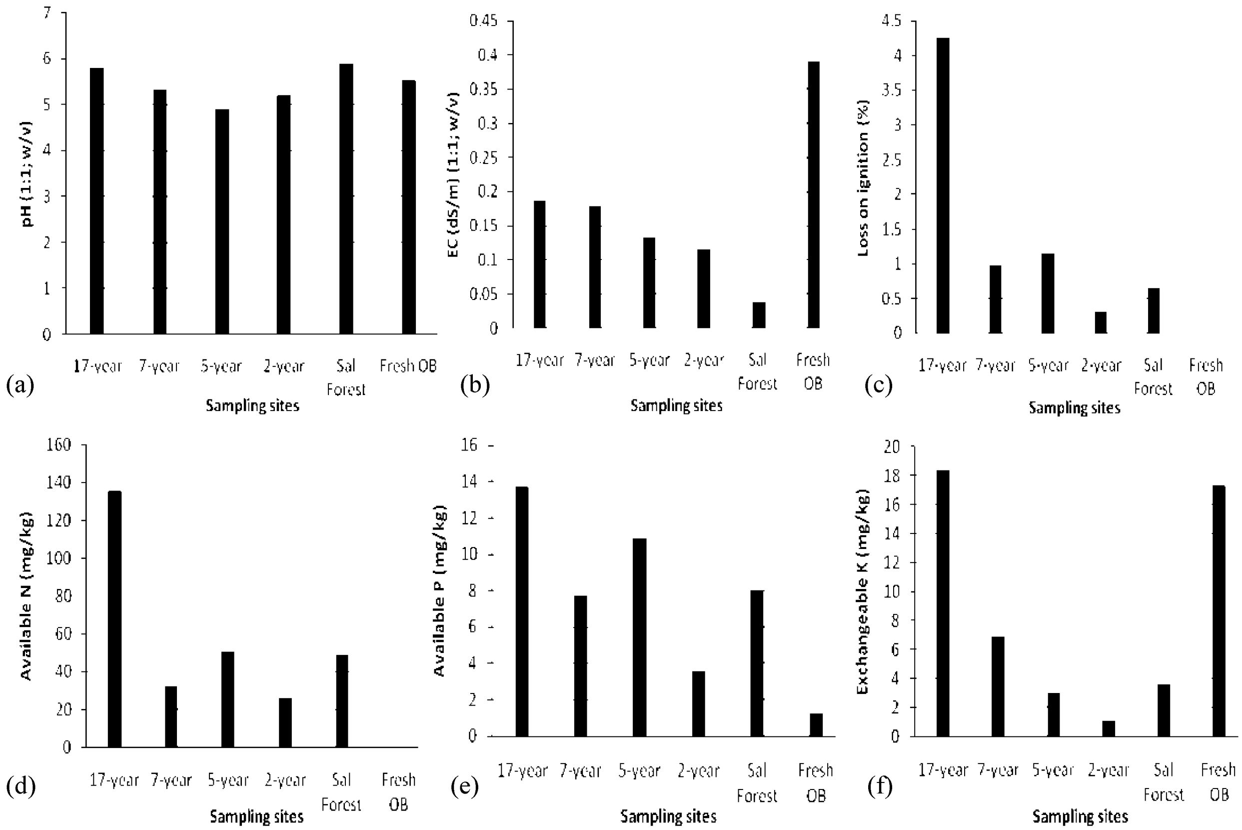

Fig. 1: Chemical characterization of soils of different aged reclaimed dumps, natural Sal forest and fresh overburden dumps (values are mean, n=6)

Table 3: Exchangeable cations, cation exchange capacity and base saturation in different aged reclaimed dumps (values are mean, standard errors are reported in italic; n=6)

		Exchangeable cations [cmol (+)/100g soil]					
Age of reclaimed dumps	pH (1:2.5; w/v)	Ca	Mg	K	Na	CEC[cmol (+)/100g soil]	Base saturation (%)
17-year	6.01 a	4.23 a	1.63 a	0.52 a	0.21a	21.20a	31.04b
	0.13	*1.12*	*0.023*	*0.092*	*0.006*	*1.82*	*0.58*
7-year	5.55 b	2.30b	0.92 b	0.22b	0.18a	12.2b	29.61b
	0.15	*0.21*	*0.018*	*0.029*	*0.028*	*0.82*	*0.42*
5-year	5.05 c	0.61c	0.24d	0.08b	0.18a	10.56b	10.55c
	0.07	*0.09*	*0.017*	*0.012*	*0.002*	*0.96*	*0.56*
2-year	5.29 bc	0.43c	0.22 d	0.03b	0.18a	6.57cd	13.16c
	0.09	*0.07*	*0.024*	*0.011*	*0.002*	*0.61*	*0.53*
Natural Sal Forest	6.07 a	0.52c	0.26d	0.09b	0.18a	9.43bc	11.23c
	0.25	*0.10*	*0.011*	*0.006*	*0.009*	*0.68*	*0.43*
Fresh overburden	5.66 ab	1.60bc	0.64c	0.46a	0.22a	3.53d	82.56a
	0.10	*0.39*	*0.028*	*0.21*	*0.005*	*0.40*	*1.14*

clear trend with time was observed, but available P showed similar trend with organic matter and N, that is 17-year old reclaimed dump > 5-year old > 7-year old > natural forest > 2-year old > fresh overburden materials. Therefore, integrating organic matter accumulation with N and P contents is important for soil formation and ecosystem restoration. Development of vegetation cover enhanced the natural soil cycle and thus showed higher values of available P compared to fresh mine spoil [28].

CEC is used as a measure of fertility and nutrient retention capacity of soil. Significant increase in exchangeable cations was found with the increase in age of reclaimed dumps (Table 3). In natural forest and 2-year old reclaimed dump concentration of cation nutrients was found low because of higher leaching caused by higher sand content, while in case of 17-year old dump, concentrations of cations were found higher due to low leaching and higher clay content. CEC is used as a measure of fertility and nutrient retention capacity of soil. CEC was found to vary significantly among the reclaimed sites and highest was observed in 17-year old reclaimed dumps (Table 3).

Different letters in the same column indicate significant differences between different sites (Duncan's multiple range tests, $p<0.05$).

Base saturation (BS) is an important mine soil chemical property that is positively correlated with forest productivity. In fresh overburden materials base saturation is high (82.6%) due to higher concentration of bases in the parent materials but once exposed to natural weathering process, they leach slowly. In initial stage of reclamation due to low clay content and lower CEC, bases are continuously leached, which is evidenced in 2 and 5 year old reclaimed overburden dumps which have 10.6-13% base saturation. In course of time as dumps get stabilized, with the increase in clay content, base saturation also increases. Rodrigue and Burger [12] reported BS ranged from 13 to 100% in reclaimed mine soils located in midwestern and Appalachian coalfields, which is higher than that of the non-mined sites. Rodrigue and Burger [12] correlated BS with forest productivity as BS < 30% indicates lowest forest productivity, BS of 51% as average productivity and >70% BS as good productivity and could also be used for agronomic purposes. High BS levels (>50%) represent adequate base cation availability and a low amount of exchangeable acidity. Unlike typical forest soils, mine soils are commonly composed of freshly weathering material containing higher amounts of permanent charge than the pH-dependent charge associated with organic matter and highly weathered minerals. In mined site base saturation and cation nutrition are highly dependent on the parent material [38].

CONCLUSION

Chronosequence study of reclaimed coalmine overburden dumps concludes that tree plantation improves productivity of mine soil. The improvement of physico-chemical and microbial properties of reclaimed mine soils depend on the tree species composition, nature of overburden materials and climatic conditions of the area. Coarse fraction is found to influence the entire biological reclamation process by influencing moisture retention capacity, bulk density and porosity. Soil moisture content increases with the age of reclaimed mine soils due to accumulation of litter, growth of herbaceous vegetation, increase in organic matter and improvements in texture. Increased organic matter is associated with increase in nitrogen and phosphorus which results in overall increase in microbial activity of soil. Initially base saturation is higher due to presence of cations, gradually it reduces due to leaching and again it starts increasing, which is unique in mine soils development process. Progressive build up of adequate nutrient pool in 17 years old dumps may be sufficient for ecosystem maintenance in this region. Coarse fraction, moisture content, organic matter and base saturation can be used as indicator parameters to assess the status of reclaimed mine soil.

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