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# Soil development in 2–21 years old coalmine reclaimed spoil with trees: A case study from Sonepur-Bazari opencast project, Raniganj Coalfield, India

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ABSTRACT

Soil development is an integral process of mining spoil restoration, which is critical for vegetation establishment and may help to predict reclamation success. In this study, changes in soil properties, microbial activities and biomass, and plant community structure, were examined at different rehabilitated phases in chronosequence reclaimed coal mine spoils ecosystems, and discussed potential functional relationships. These reclaimed coal mine spoils were studied by taking manmade and naturally developed chronosequence sites covering successional ages in the ranges of 2 year, 5 year, 9 year, 15 year and 21 years with three depth profiles in the Raniganj Coalfield of India, and compared with natural forest close to the study area. Over time, significant changes in soil variables with respect to soil organic carbon ($C_{org}$) and nitrogen ($N_{org}$), texture qualities, moisture contents, exchangeable cations ($Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$ and CECe), base saturation, soil microbial indices (enzymatic activities, microbial respiration quotient and microbial biomass carbon) were observed. In addition, increase in species richness and colonization of native species also observed with rehabilitated ages at chronosequence sites. Study indicates that changes in soil variables were related with succession, whereas functional/structural changes in vegetation were related to accumulation of organic matter, soil texture and enhanced microbial properties. The results indicate that age of restoration was the main driving force in terms of soil and vegetation compositional changes during ecorestoration. The study concludes that soil forming process is priming materials for vegetation development and these floristic changes mainly driven by abiotic and biotic component of the soil ecosystem.



## 1. Introduction

Mining activities have made a significant contribution to India's economic developments. At the same time, they are also brought significant impairment to the environments in terms of land degradation (Maiti, 2013). In general, opencast mining degrades 2–10 times more lands than underground mining (Li, 2006). Open-cast mining is a major environmental disturbance which often leaves a landscape with no vegetation, changes in topography, alters soil and subsurface geological structures and very poor soil-forming materials for subsequent ecosystem development (Herath et al., 2009; Keskin and Makineci, 2009).

In such degraded ecosystems, the concept of ecological restoration should be the restoration of a healthy, long-term, self-sustaining ecosystem (Hobbs and Norton, 1996), with effective vegetation cover (Dazy et al., 2008) and a fully-functioning soil ecosystem (Moreno-de las Heras, 2009; Dölle and Schmidt, 2009), including appropriate soil biota and microbial processes (Helingerová et al., 2010; Lange et al., 2015). Ideally, a self-sustaining restored ecosystem should have at least a resemblance of the original soil dynamics (Walker and del Moral, 2009). Therefore, knowledge of how the soil develops during restoration is of particular importance to guide future ecological restoration (Dutta and Agrawal, 2003; Abreu et al., 2009; Courtney et al., 2009).

During mining reclamation or restoration process, the initial restoration treatment provides a starting soil material, although the physico-chemical properties of these new soils usually delay plant growth (Fu et al., 2010; Alday et al., 2011b). Successful forest reclamation approaches is a function of many factors, but one of the most important issues for the restoration of functional

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ecosystems in post-mining lands is soil formation, because most sites have unfavourable soil physical and chemical properties (Wong and Ho, 2003; Bai et al., 1999b). These soil properties, identified as indicators of soil quality, include soil organic matter, total organic nitrogen, total organic carbon, nutrient availability, pH, and electrical conductivity, etc. (Masto et al., 2015). During succession, changes in vegetation composition and structure occur, which can ameliorate soil qualities condition and assist further vegetation development (Isermann, 2005). Vegetation development enhances the accumulation of carbon and nutrients in the soil (Marrs and Bradshaw, 1993; De Kovel et al., 2000; Walker and del Moral, 2009) and these processes improve the soil conditions for subsequent species colonization and ecosystem development (Fu et al., 2010; Frouz et al., 2008). Therefore, in order to envisage a change in soil ecosystem development, knowledge of the likely changes (rates of change) in organic matter content and the proportion of nutrients in the soil during chronosequence of restoration stages are needed (Sourkova et al., 2005).

Changes in soil properties and vegetation development during succession has been studied in various types of landscapes including china clay wastes (Marrs et al., 1980a,b; Roberts et al., 1980), abandoned fields (Knops and Tilman, 2000), inland drift sand dumps (De Kovel et al., 2000), urban sites (Schadek et al., 2009), glaciers (Hodkinson et al., 2003) and forests (Matlack, 2009). However, there have been few attempts to study the changes in soil properties and vegetation succession in restoration projects with emphasis on soil developments of coal mined degraded sites in the dry tropical environment of Indian climates (Maiti, 2013).

In this paper, we study the distinguishing changes in soil properties and vegetation succession (composition and structure) in chronosequence sites after simulated and natural restoration was implemented on an opencast coal mine spoils in eastern part of Raniganj Coalfield, India. Chronosequence site studies often offer valuable insights into soil, nutrient and vegetation changes during succession (Dölle and Schmidt, 2009). The main aims of this studies were to explore the interactions of changes in soil physico-chemical properties with vegetation succession (composition and structure), and discuss potential functional relationships. Specifically, we aimed to: (i) describe the changes in soil physico-chemical properties intermittently soil developments in different chronosequence sites after post-restoration succession, (ii) identifying the main processes and patterns, and determine the relationship between soil properties and the vegetation structure variables (richness, diversity and cover), and (iii) assess what determines the early floristic compositional dynamics (changes in soil properties, aspect, time-effect). This study would lead to improving methods for ecological restoration, increasing their effectiveness, and help to gain a more predictive understanding of mine restoration dynamics.

## 2. Materials and methods

### 2.1. Study sites

This study was carried out on reclaimed coal mine spoils in one of the largest surface opencast mining areas (Sonepur-Bazari) in the Eastern Coalfield Limited (Fig. 1) Raniganj, India. The study area is located between latitudes 23°40′00″N and 23°43′06″N & Longitude 87°11′14″E and 87°17′42″E. It has an average elevation of 91 m (298 feet). This is an ecologically fragile area with sub humid and tropical climatic environment which has three seasons viz. summer, rainy and winter in succession. The average annual rainfall is 1206 mm, with 65% falling from June to September (Supplementary Fig. 1a). The average annual temperature is 25.4 °C. The maximum temperature often goes over 35 °C in summer (May–June) and minimum temperature goes down below 10 °C (Supplementary Fig. 1b). The average relative humidity is highest in the month of July (85.2%) while December records the lowest relative humidity of 61.2%.

Sonepur-Bazari block has a total quarriable area of 920 ha with a maximum projected quarrying depth of 270 m. Surface opencast mining activities in this area have resulted into extensive land scarification and development of the anthropogenic landforms which include mine pits, quarries and spoil dumps (Supplementary Fig. 2). The mine spoil in this study area is composed of weathered products of sandstones, shales, and conglomerates of the Barakar Formation (Supplementary Fig. 3). The sandstones, the majority of the spoil, being feldspathic in nature, are easily prone to weathering and erosion and, thus, are responsible for considerable spread of the spoil material over the surrounding unmined land, and has eventually made the face of the overburden (OB) dump gently (5–150) during the period of abandonment. The shales are carbonaceous and, these together with the low-grade waste coal associated with the area, have imparted a black look to the spoil (De and Mitra, 2002).

After mining stopped, the open pit was filled with coal mine wastes from adjacent mines and the surface was covered with 15–30 cm of topsoil fine-textured materials on sediments from deeper parts of the nearest open-cast pits. This mixture had a sandy loam texture, the pH was moderately alkaline (pH-7–8, w/v), organic matter content below 0.5% and there was a very sparse seed bank (González-Alday et al., 2008, 2009).

From 1990 to 2011, the coal mine spoil dumps were reclaimed planting mixed tree species and were evenly distributed comprising of mainly *Acacia auriculiformis, A. nilotica, Albizzia lebbeck, Alstonia scholaris, Butea monosperma, Cassia siamea, Dalbergia sissoo*, and *Tectona grandis*. The youngest age of the reclaimed site is 2 year old having mostly sparse ligno-herbaceous mixed type vegetation, the middle aged (9–15 years) of mine spoils are characterized by sparse herbaceous and shrubs mixed type turning into young forest and the 21 years old spoil dump are characterized by mixed forest. There are six different tree species which were found dominating in nature and characterized by fast growing, hardy tree species, and also importantly for mine spoils as nitrogen fixer species. During survey along with the afforested species, few incidental tree species like *Prosopis juliflora, Azadirachta indica, Ficus retusa, Ficus relegiosa, Zizyphus jujuba, Trema orientalis* and *Heloptelia integrifolia*, were also observed. Moreover, favourable microclimate and soil conditions created by planted tree species have helped these trees to inhabit the mine spoil dumps. The details lists of composition and structure of the vegetation are given in Supplementary Table 1.

### 2.2. Vegetational sampling

To measures the aspect of major factors affecting the soil developments and vegetation succession on different chronosequence of reclaimed mine spoils, we have sampled and study the composition and structure from 2 years to 21 years old sites. Floristic composition was examined using frame quadrat method. Within each phase of the five quarries, four 10 m × 10 m plots were randomly placed in at least 10 m away from each plot. All woody plant species including woody climbers, shrubs, and trees were recorded and counted within each plot. Four 1 m × 1 m quadrates in each site were randomly set, and all herb species were recorded and counted. The coverage of woody species (trees and shrubs) and understory vegetation (grasses and herbs) within the plot was estimated separately. Plant species were identified following the nomenclature of the Botanical Survey of India (India) check list and ICUN list (Anon., 2002).

The reference site was a natural forest, which is mixed dry deciduous type, dominated by *Shorea robusta* (Sal tree), along with *Terminalia tomentosa, Butea monosperma, Dalbergia sisoo, Madhuca indica, Terminalia arjuna, Pongamia pinnata*, and *Azadirachta*