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Impact of post-mining subsidence on nitrogen transformation in southern tropical dry deciduous forest, India

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ABSTRACT

The goal of our research was to assess the impact of post-mining land subsidence, caused due to underground coal mining operations, on fine root biomass and root tips count; plant available nutrient status, microbial biomass N (MBN) and N-mineralization rates of a Southern tropical dry deciduous forest of Singareni Coalfields of India. The changes were quantified in all the three (rainy, winter and summer) seasons, in slope and depression microsites of the subsided land and an adjacent undamaged forest microsite. Physico-chemical characteristics were found to be altered after subsidence, showing a positive impact of subsidence on soil moisture, bulk density, water holding capacity, organic carbon content, total N and total P. The increase in all the parameters was found in depression microsites, while in slope microsites, the values were lower. Fine root biomass and root tips count increased in the subsided depression microsites, as demonstrated by increases of 62% and 45%, respectively. Soil nitrate-N and phosphate-P concentrations were also found to be higher in depression microsite, showing an increase of 35.68% and 24.74%, respectively. Depression microsite has also shown the higher MBN value with an increase over control. Net nitrification, net N-mineralization and MBN were increased in depression microsite by 29.77%, 25.72% and 34%, respectively. There was a positive relation of microbial N with organic C, fine root biomass and root tips.

1. Introduction

India has the world's third-largest hard coal reserves, after the United States and China with an output of 328 million tonnes in 2001–2002. Public sector coal companies contribute 95% of India's coal production, of which Coal India Limited accounts for 80% and Singareni Collieries Company Limited for 10%. Other companies like TISCO & captive mining firms make up the balance (http://www.iea.org/textbase/nppdf/free/2000/coalinindia2002.pdf, accessed 30/8/2008).

As a consequence of increased demand for coal, more and more coal is being mined and processed. The underground coal mining has caused a large amount of land subsidence leading to farmland losses and undulation of land surface. Subsidence can be defined as movement of the ground surfaces as a result of readjustments of the overburden due to collapse or failure of underground mine workings. It is an abrupt depression of local ground surface, which occurs due to sudden collapses of the overburden into an underground void. Subsidence can occur due to pillar, roof, or floor failure, particularly in older mines (Bauer et al., 1995).

Subsidence effects on agriculture land have been documented in Illinois (Darmody et al., 1989), United Kingdom (Selman, 1986), China (Hu and Gu, 1995), South Africa (ven der Merwe, 1992), and Australia (Holla and Bailey, 1990). These effects include soil erosion, disruption of surface and subsurface drainage, wet or ponded areas, and reduction of crop yields. Large cracks that develop at the soil surface after subsidence can pose a hazard and may alter soil hydrology. Landscapes with erosive soils on long slopes may be subject to increased erosion potential because of slope increase or displacement of erosion control structures (Darmody file http://www.mcrcc.osmre.gov/PDF/Forums/Prime%20Farmland%201998/4d.pdf, accessed 30/08/2008). The disturbances due to subsidence can also alter N availability. For example, the intact tropical forests have higher rates of N mineralization and nitrification than agricultural sites (Piccolo et al., 1994; Reiners et al., 1994; Neill et al., 1995, 1997), suggesting that N availability is greater (Nadelhoffer et al., 1983) where there is less human disturbance.

Roots are the largest fraction of the biological material in most arable soils. They comprise a substantial portion of forest ecosystems, generally accounting for 15–25% of total biomass. Roots can return nutrients to the soil in several ways: death and decay, exudation and leaching, and, indirectly, when consumed by grazers (Harris and McGinty, http://cwt33.ecology.uga.edu/publications/902.pdf, accessed 30/08/2008).

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The most dynamic component of root biomass is the fine roots. The distinction between fine and coarse roots is usually based on an arbitrarily chosen diameter ranging from 1.0 to 10 mm. These roots are distributed in upper soil layers, generally, 90% are in the top 30 cm and 70% in the top 15 cm of soil. Fine roots function primarily as resource-capture organs and their responses comprise a major component of whole plant response to changes in soil resource availability (Robinson, 1991; Aerts and Chapin, 2000). The growth, death and decomposition of fine roots are major processes in nutrient dynamics of forest ecosystems (Edwards and Harris, 1977; Roy and Singh, 1995), and the dominant form of available N (NO_3^- or NH_4^+) influences the root dynamics in forest ecosystems (Aber et al., 1985).

Microbial biomass is considered a labile reservoir of plant-available nutrients (Brookes, 2001) and is an important live, dynamic component of soil organic C. It can serve as an estimate of microbial N immobilization, as the soil microorganisms mediate many of the major processes involved in soil nitrogen cycling. Soil microbial biomass constitutes a transformation matrix for all the natural organic materials in the soil and is responsible for the associated mineralization of important nutrients that regulate plant productivity (Jenkinson and Ladd, 1981; Cleveland et al., 2004). Because microorganisms affect soil fertility and hence the functioning of ecosystems, measurement of the dynamics of nutrients held in the soil microbial biomass has attracted considerable attention in recent years (Roy and Singh, 2003). Microbial activity is fundamental in the processes that make energy and nutrients available for recycling in the ecosystem (Schoenholtz et al., 2000).

There is no information available for changes in soil nitrogen transformation rates, soil microbial biomass and fine roots biomass due to mine subsidence from the Indian dry tropical forest ecosystem. According to Ministry of Environment and Forest, Govt. of India guidelines issued on 27th March 2000, all the underground coal mining industry situated below forest land will have to quantify the impact of subsidence due to mining under the forest land with respect to changes in soil nitrogen transformation and microbial biomass and forest cover.

Therefore, the present study was aimed towards the assessment of the impact of underground mining subsidence on the land soil characteristics with particular reference to nitrogen transformation, microbial biomass N (MBN), fine root biomass and root tips counts. We hypothesize that the land subsidence after coal extraction has profound effects on soil microbial biomass and nitrogen transformation rates in dry tropical soils due to damage of plant root biomass and depression of land surface.

2. Materials and methods

2.1. Location

The study sites (5B incline Mine spread over an area of 2.85 km^2) are located in Singareni Coalfields of Singareni Collieries Company Ltd. (SCCL), Kothagudem (Andhra Pradesh, India) at 17°30′N latitude and 80°40′E longitude. The topography is almost undulating plain terrain to gently sloping towards the river Godavari in the southeast with the average elevation varying from 119 to 157 m above mean sea level. There is no effective drainage developed in this area due to sandy soil cover and number of faults and fractures.

2.2. Climate

The climate is seasonally tropical and divisible into 3 distinct seasons, namely, rainy (mid June to October), winter (November to February) and hot summer (March to mid June). According to the mean monthly rainfall data (1996–2006) of Kothagudem, the annual rainfall of the area is 1084 mm, being maximum in July (300.31 mm) and minimum in January (7.82 mm). The study site receives about 86.8% of rainfall during S–W monsoon and 7.4% during N–E monsoon season. The mean air temperature varies from as low as 11.42 °C in December to as high as 46.6 °C during May. The predominant wind direction is southeast to west. The relative humidity of the area fluctuates from 49% during February to 73.21% during April (CIMFR, 2007).

2.3. Land use pattern

Within 10 km radius from the edge of mine site 23,004 ha area is covered by Ramavaram Reserve forest. An area of 2781 ha is barren and uncultivated land, while 2377 ha area is fallow land and 1757 ha of land is put to non-agricultural uses. The net area sown is 14,005 ha and 535 ha during Kharif (July to October) and Rabi (November to February) seasons, respectively.

2.4. Forest

Vegetation of this region has been classified as Southern Tropical Dry Deciduous Forest (Champion and Seth, 1968). The total forest area is spread over an area of 748,882 ha, constituting nearly 46.72% of the total geographical area. The density of forest ranges from 45–65 stems 100 m^2. The forest is dominated by *Tectona grandis.* The other co-dominant species are *Holarrhena antidysentrica*, *Hardwikia binata*, *Chloroxylon swietenia*, *Anogiessus latifolia*, *Morinda tomentosa*, *Diospyros melanoxylon*, *Terminalia tomentosa*, *Strychnos-nux-vomica*, *Acacia catechu*, *Boswellia serrata*, *Emblica officinalis*, *Xylia xylocarpa* etc. The ground flora is dominated with *Andrographis paniculata*, *Gymnema sylvestris*, *Abrus precatorius*, *Aristolochia indica*, *Desmodium trifolium*, *Gloriosa superba*, *Hemidesmus indicus*, etc. (ICFRE, 2004).

2.5. Geology and soil

The coal of Godavari Valley Coalfield belongs to Lower and Upper Gondwana. Lower Gondwana consists of the Talchir, Barakar, and Kamthi series and the Upper Gondwana are classified into Maleri, Kota and Chikiala formations. The average thickness of Barakar formation is about 100–200 m. It is divided into an upper coal-bearing member of about 50–100 m thick and lower non-coalliferous one of a less thickness. The coal mining area is blanketed by soil on the surface. Coal seams, shales, clays and felspathic, medium to coarse grained and brown gray sandstones are the main litho-units. The average thickness of soil in the area is about 1.5 m. Alluvium soil layer is of recent origin, underlain by Kamthis, Barakars and Talchirs boulder bed (CIMFR, 2007). The texture of the soil is mostly sandy loam. The pH of the soil extract varies from 6.0 to 7.9. In terms of soil pH the soil characteristics vary from 'slightly acidic' to 'moderately alkaline' in nature.

2.6. Subsidence investigation

Geo-mining details of the subsided study areas (panel) are given in Table 1. A panel is an area demarcated for the excavation of coal. The surface subsidence investigation was conducted over the selected panels MK-4 A-19, 5B N-18 and MK4 Y-12. The topography of all the panels before and after subsidence was undulating. The vertical ground movement was monitored by self-aligning level with precision leveling staves. A total of 6 sets of observation were taken during 2004–2005 with respect to vertical and horizontal movement of the ground surface by theodolite equipment. The least count of the instrument was 0.05 mm. The recorded subsidence ranged from 315 to 992.4 mm with compressive strain of 4.5–16.41 mm/m and tensile strain of 3.5–14.06 mm/m (Table 1). The safer limit of tensile strain of surface topography is 3 mm/m (Anon, 1991). The extraction period of coal was from August 2001 to June 2002. There was a trough subsidence after depillaring, so the ground surface indicated saucer shaped depression sites with undulations (Fig. 1). Maximum slopes in these panels after subsidence were 12.48–56.76 mm/m. Formation of cracks occurred in tensile strain zone at the edge of panel. The angle of break varied from about 5–10° from the vertical (Fig. 1). All the trees lying at the edge of the subsided sites were lying down with broken roots.

2.7. Field sampling

One plot, 100 × 100 m in size, in undamaged forest (undisturbed microsite) and one plot, 10 × 10 m in size, each, in the adjacent slope and depressed microsites of the subsided panel area, were selected for the study on each of the three sites to understand the impact of mine subsidence on the surface land. Five soil samples were collected at random locations from upper 0–10 cm from each of the undisturbed microsite and adjacent slope and depression microsites in the months of August for rainy season and December for winter season and May for summer season during 2004–2005. The soil was uniform between 0–10 cm depth and there was no distinct 'O' horizon. The samples of the respective microsites were composited to get one representative sample from each plot. The mean values of each site were used for comparison in the study. The soil sample in its field moist