Ecological Engineering 90 (2016) 482–490

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Soil carbon development in rejuvenated Indian coal mine spoil

Nimisha Tripathi[a,*], Raj S. Singh[a], Colin D. Hills[b]

[a] Central Institute of Mining and Fuel Research, Barwa Road, Dhanbad 826015, Jharkhand, India
[b] University of Greenwich, Chatham Maritime, ME4 4TB, UK

ARTICLE INFO

Article history:
Received 6 August 2015
Received in revised form 31 October 2015
Accepted 26 January 2016
Available online 27 February 2016

Keywords:
Mine spoil
Disposal
Land degradation
Re-vegetation
Age gradient
Root proliferation
Carbon development and accretion
Microbial biomass C
Carbon budget

ABSTRACT

The impact of mine spoil on the landscape is significant, as excavated rock-debris is commonly disposed in heaps that blanket the original land surface. Spoil heaps destroy the original soil habitat releasing soil-bound carbon, which is difficult to re-estate when mining operations cease and restoration begins. The present work follows the development of vegetative cover on a coalmine spoil tip in India over a period of 19 years following restoration. The potential of re-vegetated the mine spoil to imbibe carbon is examined through the development of above- and below-ground biomass development. It was observed that the soil organic carbon and microbial biomass carbon (MBC) significantly increased with re-vegetation age, with above ground biomass increasing by 23 times, and belowground biomass increased by 26 times during the period of study. Soil organic carbon and MBC increased by 4× and 6.6× times, respectively. The average calculated annual carbon budget was 8.40 T/ha/year, of which 2.14 T/ha was allocated to above ground biomass, 0.31 T/ha to belowground biomass, 2.88 T/ha to litter mass and 1.35 T/ha was sequestered into the soil. This work has shown that the development of biomass following the restoration of mine spoil was significant and that considerable quantities of carbon were stored in above and below ground plant matter, and in the soil itself. It is concluded that appropriate restoration strategies can be used to rapidly establish a viable, healthy and sustainable ecosystem that imbibes carbon into former mine-impacted land.

1. Introduction

Effective global carbon management strategies are required to mitigate the effects of the emission of carbon to the atmosphere (405 ± 30 Pg carbon (C) over the past 200 years), and which arise from the burning of fossil fuels (75%) and changes in land use (25%) (IPCC, 2001). During the past 2 centuries these emissions have resulted in atmospheric CO_2 concentrations rising from 280 to 400 ppm. An increase in global temperatures of 1.8–3.6% is predicted over the 21st Century (Macdonald et al., 2011), despite 60% of anthropogenic emissions being removed from the atmosphere by ocean and terrestrial ecosystems (Canadell et al., 2007).

India is a major coal producer, with total coal production (from Coal India Limited) being 431 MT for the year 2010–2011. The amount of spoil generated by coal mining is significant, being typically >2 to 3 times that of the coal produced itself. Opencast coal mining operations produced 252 MT of spoil alone during that year (Singh, 2011). Mining spoil is typically dumped in heaps, which significantly degrade land quality and disrupts/destroys existing ecosystems. Mining operations result in drastic landscape perturbations that cause major ecosystem damage, and irreparable impacts to former soil quality/nutrient cycling capability (Anderson et al., 2004; Shrestha and Lal, 2006).

The natural recovery of these disturbed habitats (i.e. colonization of the mine spoil) by plant and animal species extends over long timescales (of decades/centuries), can be shortened if the restoration of soil fertility and biological diversity can be managed. However, reclamation can return mined land to a useful (but not necessarily its original) state (Barnhisel and Hower, 1997; Bradshaw, 1997). As reclaimed mine soils are man-made or anthropic soils (Lal, 2004), the introduction of a sustainable vegetative cover is the key to the reconstruction of an ecosystem, as the development of soil 'quality' depends on an improvement of a soils physical, chemical and biological characteristics (Bradshaw, 1997).

Carbon dioxide is removed from the atmosphere by aboveground plant biomass, belowground root biomass and soil organisms, and in stable forms of soil organic (SOC) and inorganic (SIC) carbon, resulting in organic matter comprising 1–8% (w/w) of most soils. Because of this, the soils of the world store about 1600 Pg of carbon (Dakora and Phillips, 2000). The FAO (2001), estimates that 125GT of carbon are exchanged annually between vegetation,

* Corresponding author.
E-mail addresses: nymphaea7@gmail.com, rajcimfr@gmail.com (N. Tripathi).

http://dx.doi.org/10.1016/j.ecoleng.2016.01.019
0925-8574/

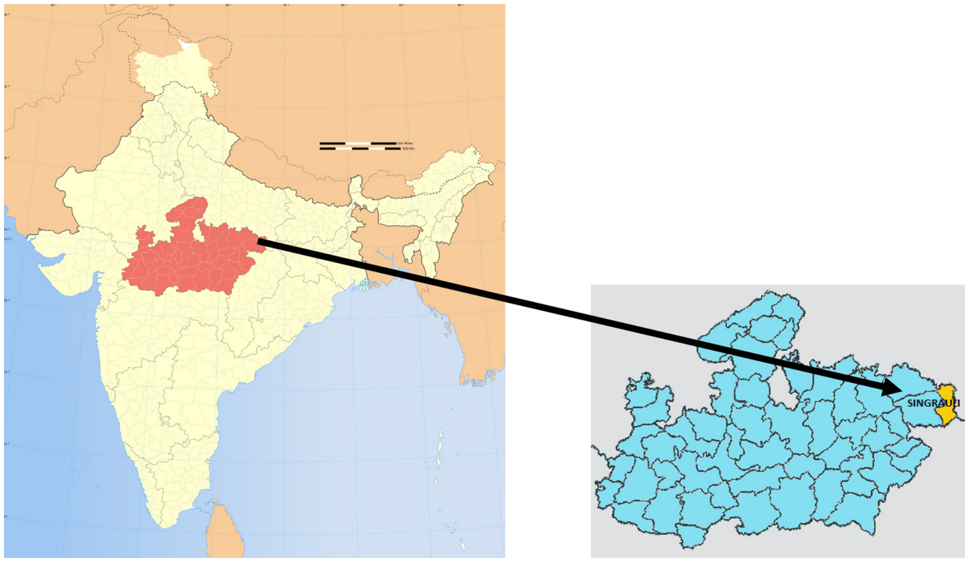

Fig. 1. Location map of study site.

soils and the atmosphere, with terrestrial sequestration accounting for two-fifths of the total exchange.

Therefore, if the re-vegetation of mine-spoil can be managed in shorter (than natural) timescales, increased biomass volumes will enhance the storage of carbon.

The focus of the present work is a long-term study of re-vegetated mine spoil which extended over 19 years following restoration by planting. The monitoring of key soil characteristics and biomass during this time provides important data that demonstrates the wider value of managed restoration of mine spoil through the increase in the amount of carbon stored in plant and mineral–carbon complexes.

2. Study sites

The present study was performed (during 2009–2011) on re-vegetated mine spoil, between 2, 4, 10, 14, 16 and 19 years of age at Northern Coalfields Limited (NCL), Singrauli, India. The project site was located in Moher basin of Singrauli (between latitudes 24°08′45″ to 24°11′25″; longitudes 82°38′21″ to 82°40′45″) on the eastern border of Madhya Pradesh and Uttar Pradesh (Fig. 1). The area is undulating landscape with an elevation of 375 m to 500 m above MSL.

The area has an annual temperature ranging from 6.4 to 28 °C and an annual rainfall average of 1069 mm, of which about 90% occurs during the late June to September monsoon. The predominant geology is alternating sandstone and shale, with white and grey clays with ferruginous bands, carbonaceous shale and coal seams, providing for one of India's largest coalmines, in terms of total excavations (Singh, 2010).

The NCL excavated about 770 MT of coal using shovel and dumper and about 22 MT of overburden between 1964 and 1965 with an average stripping ratio of 2.89 m^3/T. During 2005–2006 coal production increased to 133.86 MT, and to >250 MT by 2011–2012, with an average stripping ratio of 3.64 m^3/T.

Before mining the study site was gently to moderately sloping land, but the establishment of spoil heaps significantly changed relief by 20–30 m. The dumps were 5 years of age in 1997 when their sides (with slopes of <35°) were planted with: grass species (*Stylohemata* spp., Dinanath grass, Sawai grass) and tree species (*Eucalyptus*, *Dalbergia sissoo*, *Pongamia pinnata*, *Prosopis juliflora*, Silver oak, *Terminalia chebula*, *Terminalia bellerica*, *Schizygium jambolana*, *Azadirachta indica*, *Emblica officinalis*, *Cassia samea*, *Leucena leucocephala*, *Acacia catechu*, *Shorea robusta*, Bamboo, *Pithecolobium dulce*, *Madhuca indica*, *Ficus religiosa*, *Ficus bengalensis*, *Bauhinia variegata*, *Delonix regia*, *Cassia fistula*, *Gmelina arborea*, *Peltopherum enormii*).

3. Materials and methods

3.1. Physical and chemical characteristics

Mine spoil samples from the re-vegetated tips were collected (using a randomized block design) at different times and were characterized for, for example, pH, Moisture, bulk density, water holding capacity, total nitrogen, total phosphorus and organic carbon.

Five soil samples were collected at each of the three replicate plots at three depths (upper 0–10, 10–20 and 20–30 cm). Large pieces of plant material were removed by hand and the samples were composited to get one sample per plot. Each sample was sub-divided into two, with one (in its field-moist condition) used for determining moisture, available N, available P, and microbial biomass C, and the other (air-dried) used for physical/chemical analysis.

Soil pH (soil: water ratio = 1:2) was estimated by ORION ion analyzer. Bulk density and water holding capacity were determined following Piper (1994). Organic C of soil was determined following Walkley Black's method and total N by modified Kjeldahl method (Jackson, 1958). Soil organic matter (SOM) was calculated by multiplying the percent organic C by a factor of 1.72 following the standard practice that organic matter is composed of 58% carbon (Brady, 1985). For the determination of total P, the perchloric acid digestion method was followed (Mehta et al., 1954).

3.2. Microbial biomass C

Microbial biomass C in soil sample was determined using the $CHCl_3$ fumigation-incubation method of Jenkinson and Powlson (1976), except that liquid $CHCl_3$ was used instead of vapour and CO_2-C evolved from fumigated soil during 10–20 days was taken as control (Srivastava and Singh, 1988). Microbial C was calculated as: Microbial C = Fc/0.45.