Original Research Article

Performance of tree species and their effects on soil properties in chromite mine spoil areas

Abstract

An experiment was carried out at Kakudia dump of Sukinda chromite mines, Tata Steel Limited, Kalarangiata, Jajpur, which is located near the trijunction of Cuttack, Dhenkanal and Keonjhar districts of Odisha, where 10 tree species from plantation were selected, their growth parameters were measured, volume and biomass was estimated and soil samples were analyzed for heavy metal contents which are collected from the root zone of tree species. Around 12 mines are operating in the area without proper environmental pollution controls, which cause major health hazards. According to estimates from an Indian health group, hexavalent chromium levels in drinking water are around 60% higher than the international norms, and chromite-related illnesses are thought to be the cause of 84.75 percent of fatalities in mining regions with no controls. There has been virtually no attempt to clean up the contamination. The experiment was based on three plantation blocks which consists of ten forest species such as *Melia azedarach* L., *Samanea saman* F. Muell., *Syzygium cumini* L., *Acacia mangium* Wild., *Alstonia scholaris* L., *Pongamia pinnata* L., *Casuarina equisetifolia* L., *Azadirachta indica* A. Juss., *Anacardium occidentale* L., *Neolamarckia cadamba* Roxb. and control with a mine barren spoil and natural forest. *Casuarina equisetifolia* recorded significantly highest height (10.43 m), DBH (13.99 cm), crown length (8.37 m), crown spread (4.2 m), volume (0.354 m^3) and biomass (115.74 kg $tree^{-1}$). *Acacia mangium* was the next best tree species followed by *Anacardium occidentale*, *Neolamarckia cadamba*, *Syzygium cumini*, *Pongamia pinnata*, *Samanea saman*, *Melia azedarach*, *Azadirachta indica* and *Alstonia scholaris.* Also, there is significant and positive correlation found among all the tree growth parameters. Among the growth parameters of trees, positive and significantly highest correlations was observed between tree DBH and tree biomass (r = 0.997761) followed by tree volume and tree biomass (r= 0.980047).

Keywords: Biomass, Total carbon sequestration, Chromite, Heavy metal, Soil properties, ` Tree species, Mine spoil area

Introduction

By mining minerals from the earth's surface, the rapidly expanding human population and rising need for energy resources have sped up the deterioration of natural environments. Mineral resources are viewed as a nation's industrial and economic foundation (Anwer *et al,* 2001). One of India's greatest employers, the mining industry employs more than one million people, or around 4% of the country's workforce, and provides roughly 4% of the country's GDP. Due to the fact that minerals make up a significant amount of the raw materials used in the country's industrial activity, the value of the minerals produced has a significant impact on the Indian economy (Upadhyay *et al*, 2016). India produces 89 minerals, including 4 that are used as fuels, 11 that are metallic, 52 that are non-metallic, and 22 that are minor. The fourth-largest coal deposits in the world, bauxite, titanium ore, chromite, natural gas, diamonds, petroleum, and limestone are all abundant in India (Tordoff *et al*. 2000; Krzaklewski and Pietrzykowski 2002). According to projections from the 2008 ministry of mines, India has increased its output to move up to the second spot among the world's chromite producers. India also comes in third in the production of coal and lignite, second in barytes, fourth in iron ore, fifth in bauxite and crude steel, seventh in manganese ore, and eighth in Aluminium (Bahrami *et al*, 2010). With 16.92% of the nation's total mineral reserves, Odisha is one of India's greatest mineral-bearing states. Chromites (98%), nickel (95.10%), graphite (76.67%), bauxite (49.74%), iron ore (33.91%), manganese (28.56%), and coal (27.59%) are among the precious minerals that the state is India's principal source of (Singh *et al*, 2002).

Mineral deposits are a resource that humanity can exploit to its advantage. The non-renewable resources that make up mineral deposits are exploited by man for his needs in material, life support, and energy. Although the nature and form of rock and mineral mining and quarrying have changed significantly through time in many ways and ways, these activities are as ancient as civilization itself (Hooper and Vitousek, 1998; Singh and Singh, 1999). The nomenclature of three eras—Stone Age, Bronze Age, and Iron Age—illustrates the dependency of prehistoric cultures on mined goods, as well as the escalating complexity of society's interaction with mining. The history of mining is, in some ways, the history of civilisation (Khoshoo, 1991). In the current world, mining is seen as one of the necessary evils since it produces the minerals needed to maintain quality of life. It has had a noticeable influence on the environment and the socioeconomic circumstances of the locals while also enhancing quality of life and fostering economic development (Vagholikar and Moghe, 2003).

The aim of reclamation is to return the minesoil to its natural form by restoring the nutritional qualities of soil through a variety of reclamation techniques. Continuous mining damages vegetation/soil systems and diminishes soil productivity and fertility (Upadhyay *et al*, 2016). These rebuilt minesoils go through a quick maturation phase with engineering, chemical, and biological methods and are used for the development of grasses, trees, and crops. The use of minesoils for crops and plants, to restore productivity and ecosystem sustainability, is a continuous challenge because to the vast variability and complexity of minesoils (Zhang, 2005).

Tree plantings are renowned for their capacity to improve microclimates and restore soil fertility (Singh *et al*, 2002). Each plant species, however, has unique growth traits that influence how effective they are at stabilizing and enhancing the soil. Numerous ways exist by which certain plant species might alter the dynamics of nutrients and ecological processes (Hooper and Vitousek, 1998; Singh and Singh, 1999). Because soil is one of the main factors influencing how plant develops, the study of soil properties has received particular attention in restoration research. Soil organic carbon (SOC), which is lost during mining and reclamation procedures, is lost in a number of ways. The majority of plants thrive in mine waste, however certain species exhibit atypical development due to nutritional deficiencies and the presence of heavy metals (Bradshaw and Chadwick, 1980; Deo, 2004). Most chromite mining wastes contain many metals, some of which may be present at dangerous proportions (Deo, 2011). The choice of suitable species for revegetation is crucial to the success of biological restoration. The selection of plants for replanting overburden dumps relies on a number of factors, including the temperature, the physical and chemical characteristics of the dump materials, the terrain, their viability, and the vegetation in the surrounding area (Singh and Jha, 1992).

Because degraded fields have adverse physical and chemical characteristics, it takes longer for plants to develop there (Tordoff *et al*. 2000; Krzaklewski and Pietrzykowski 2002). Biological reclamation may yield positive outcomes for overburden dump revegetation depending on the choice of suitable species and other factors including temperature, the physical and chemical characteristics of the dump materials, terrain, and nearby vegetation (Singh and Jha, 1992).

The soil surface is protected from erosion by vegetation coverings; thus, every effort should be made to support native species and hasten the genetic diversity recovery in habitat that has been restored (Deo, 2004). When it comes to ecological restoration, alien species have received a lot of attention in order to speed up reclamation in various mined and naturally damaged regions. Will these species restore ecological functions and produce the desirable natural ecosystem characteristics? However, community succession and need much focus to conduct ecological research (Zhang, 2005) as degradation of natural habitats by anthropogenic activities and faster rate of biodiversity loss witnessed now than ever. Restoration ecology is receiving increasing attention (Pensa *et al*, 2004). Around the world, mining may be responsible for 20% of all deforestation in developing nations (Bahrami *et al*, 2010). The mining waste is largely made up of refractory rock pieces that lack the nutrients and organic matter necessary to maintain a diverse range of biological organisms. Low organic matter concentrations and adverse pH are incompatible with both plant and microbial development (Agrawal *et al*., 1993; Burgharadt, 1993).

In Odisha about 98% countries chromite reserve is found in Sukinda block of Jajpur district. The overburdens generated during chromite extraction processes causes severe environmental hazards. So different tree species have been planted on the mine spoil areas by mining companies to restore the ecological habitat. Information regarding performance of different tree species on chromite mine spoil areas of Odisha is scanty and study on soil characteristics of chromite mine spoil areas is also rare. The current study offers a chance to comprehend the development characteristics of several tree species planted during the initial stages of mine spoil restoration and how these trees mitigate the negative effects of mining on the environment.

Materials and Methods

The experimental site is situated at the Kakudia dump of Sukinda chromite mines, Kalarangiata, Jajpur which is located near the trijunction of Cuttack, Dhenkanal and Keonjhar districts of Odisha. The Sukinda chromite mine is ultramafic. It lies on a westerly slopping vally between latitudes 21°00’00” to 21°03’00” N and longitudes of 85°44’00” to 85°48’00” E in the district of Jajpur. The study site is sloped; stripping dumps and dikes are manmade hills composed of overburden from open-cast mines. The mine spoils consisted of ultramafites which include serpentinite, talc-serpentine rock, talc-schist, silicified rock and quartzite. The valley is abundant in the deposits of chromite and has the largest open cast chromite ore mines in the world.

The experiment was laid out in a Randomized Block Design (RBD) with three replications. The experiment was based on three plantation blocks which consists of ten forest species such as *Melia azedarach* L., *Samanea saman* F. Muell., *Syzygium cumini* L., *Acacia mangium* Wild., *Alstonia scholaris* L., *Pongamia pinnata* L., *Casuarina equisetifolia* L., *Azadirachta indica* A. Juss., *Anacardium occidentale* L., *Neolamarckia cadamba* Roxb. and control with a mine barren spoil and natural forest (details in Table 1).

Table 1. Treatment details

Treatment	Common Name	Scientific Name	Family
T_1	Mahaneem	*Melia azedarach* L.	Meliaceae
T_2	Chakunda	*Samanea saman* F. Muell.	Fabaceae
T_3	Jamun	*Syzygium cumini* L.	Myrtaceae
T_4	Mangium	*Acacia mangium* Wild.	Fabaceae
T_5	Chhatian	*Alstonia scholaris* L.	Apocynaceae
T_6	Karanj	*Pongamia pinnata* L.	Fabaceae
T_7	Jhaun	*Casuarina equisetifolia* L.	Casuarinaceae
T_8	Neem	*Azadirachta indica* A. Juss.	Meliaceae
T_9	Kajubadam	*Anacardium occidentale* L.	Anacardiaceae
T_{10}	Kadamb	*Neolamarckia cadamba* Roxb.	Rubiaceae

Fig. 1. Sukinda chromite mine

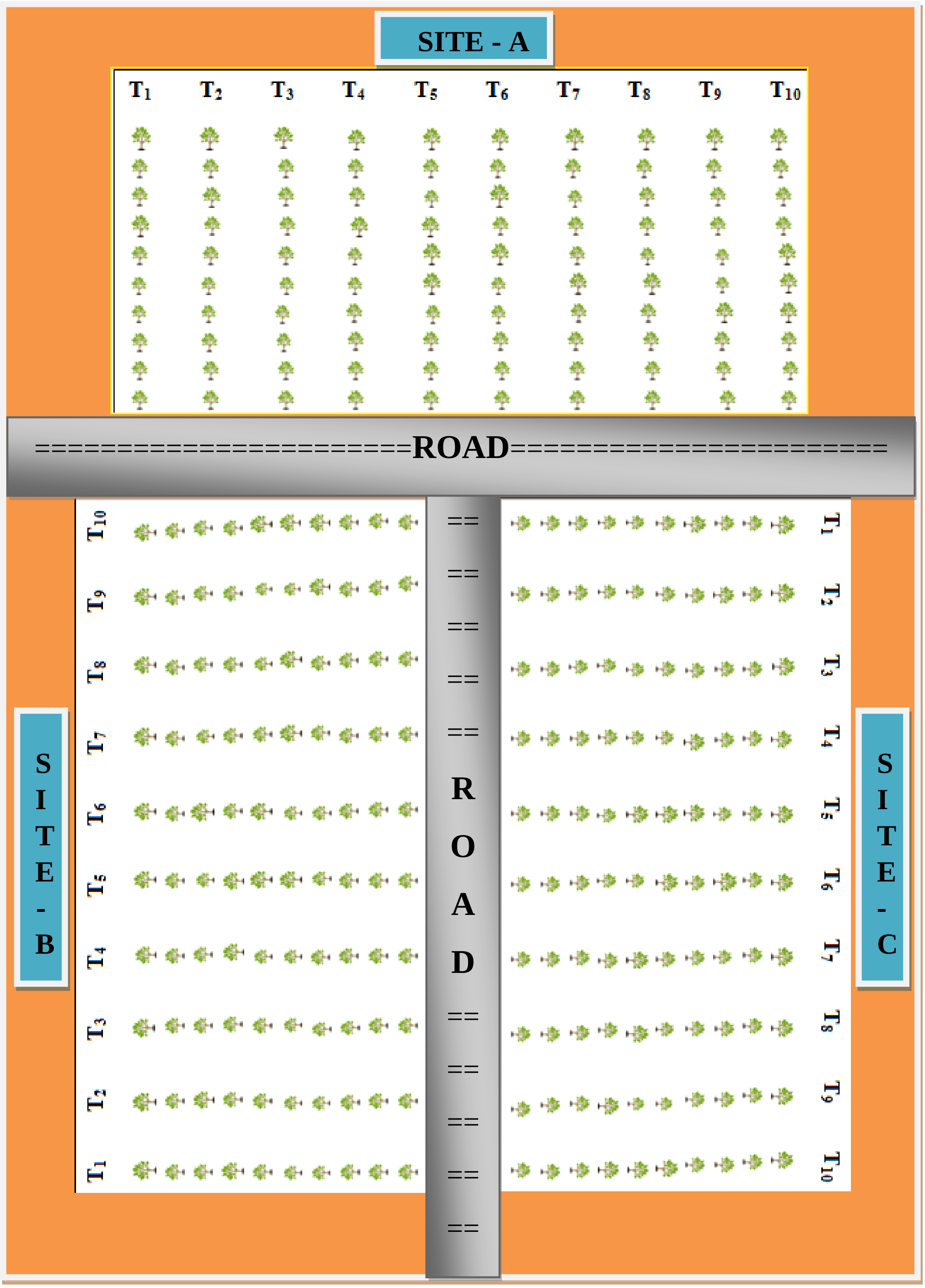

Fig. 2 Layout plan of the plantation site

The observations on tree growth were recorded as per standard procedures from 10 individual trees of same species from three plantation blocks and the average data was recorded. The height of tree species was measured vertically from ground level to tip of the leading shoot with the help of Ravi altimeter. Diameter at breast height (DBH) over bark of trees was measured at a height of 1.37 m with the help of calliper in two directions (major axis and minor axis) and the average was computed and expressed in centimetre (cm). The secondary branches were counted and average data recorded. Similarly, crown spread was measured along the widest diameter of crown. Crown length was measured as the vertical depth of the crown of a tree from the tip to the point halfway between the lowest green branches forming green crown all round and the lowest green branch on the bole.

The volume of trees was calculated by applying the following formula:

$$V = (0.00932054) + 1.68890 \times [(DBH^2) \times H]$$

[Source: United States Agency for International Development, 1998]

Where, V = Volume of tree in m^3

DBH = Diameter at breast height in m.

H = Tree height in m.

The biomass of standing tree was calculated by applying following formula:

Biomass of Tree (below ground) = $0.3789 \times (DBH)^{(1.7904)}$ (Mugasha *et al*., 2013)

Biomass of Tree (above ground) = $0.1245 \times (DBH)^{(2.4163)}$ (Hung *et al*., 2012)

Where DBH= Diameter at breast height in cm.

The total biomass of tree is calculated by adding the above-mentioned formulae.

Above and below ground biomass carbon sequestration in vegetation was determined by multiplying vegetation biomass with default value of 0.5 (IPCC, 1996). The carbon sequestration in the soil was computed for surface soil layer (0-60 cm) by using the formula given by the Nelson and Sommers (1996) as follows:

$$C\ (t\ ha^{-1}) = [\text{soil bulk density}\ (g\ cm^{-3}) \times 0.60\ cm \times SOC\ (\%)] \times 100$$

Total carbon sequestration ($t\ ha^{-1}$) was determined by adding carbon sequestered by tree with soil organic carbon.

For soil physico-chemical analysis, samples were collected from root zone of individual ten trees of ten species in three plantation sites at 50 cm distance from each tree at depth of 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm. Composite soil samples were made thoroughly mixing the collected soils of three locations from respective trees and depths.

Samples were cleaned, mixed, air dried at 20-25^{o}C and 20% to 60% relative humidity inside the laboratory under shade and finally soil analysis done.

Results and discussion

Growth performance of tree species

The growth performances of eight-year-old trees are presented in Table 2. Among trees *Casuarina equisetifolia* recorded significantly highest values of all growth parameters than other tree species. *Casuarina equisetifolia* recorded significantly highest height (10.43 m), Diameter at breast height (DBH) (13.99 cm), crown length (8.37 m), crown spread (4.2 m), volume (0.354 m^{3}) and biomass (115.738 kg tree^{-1}). *Acacia mangium* was the next best tree species which was found at par with all other tree species for tree height, DBH, number of branches and crown spread but for crown length it was at par with all species except *Melia azadarach* and *Pongamia pinnata*. For tree volume it was at par with all tree species except *Samanea saman, Syzygium cumini, Pongamia pinnata* and *Azadirachta indica*, for tree biomass it was at par with all species except *Alstonia scholaris*.

Growth performance of *Casuarina equisetifolia* was found to be better in comparison to other tree species. It shows significantly superior height, DBH, crown spread, crown length, volume and biomass over rest of the tree species. In our study, *Casuarina equisetifolia* tree on an average recorded 10.43 m height, 13.99 cm DBH, 20.27 numbers of branches, 8.37 m crown length, 4.20 m crown width and 0.35 m^{3} tree^{-1} volume, and 115.73 kg tree^{-1} biomass. This may be due to the character of *Casuarina equisetifolia* species resistant to the unfavourable soil characteristics inherent in mine debris, such as acidity, metal toxicity, and degrees of dryness. Additionally, nitrogen-fixing root nodules may grow as a result of symbiosis with the bacteria Frankia, which does nitrogen fixation. Proteoid roots are present in *Casuarina equisetifolia*, which also associates with vesicular arbuscular mycorrhizae (Upadhyay *et al.*, 2016).

The second-best tree species in terms of height, DBH, crown length, volume, and biomass were *Acacia mangium* (7.87 m), all of which were higher than those of any other tree species. One of the world's species of trees that grows the quickest and can thrive in any wasteland is the Acacia. This may be due to more natural colonisers as the tree became older. Similar results were reported by Dutta and Agarwal (2002), who discovered that among the other five alien tree species, Acacia was the dominant species in terms of growth performances. According to Banerjee *et al.* (2004), *Acacia mangium* outperformed all other species in terms of growth characteristics after eight years of planting, followed by *A. holoserecia, Dalbergia sissoo, Albizia procera, Pithecellobium dulce, Acacia auriculiformis, and Gmelina arborea.*

According to the aforementioned results, *Casuarina equisetifolia* must be regarded as the best and dominating tree species among the other species since it fared better in chromite mine debris. Similar findings were observed by Dutta and Agarwal (2002), who found *Casuarina equisetifolia* and *Acacia mangium* as the most suitable tree species in terms of modification of spoil characteristics during the revegetation process in Northern Coal Field Limited (NCL) mine dump area.

Table 2. Growth parameters, volume and biomass of eight-year-old tree species

Treatment	Tree height (m)	Tree DBH (cm)	No. of branches (nos.)	Crown length (m)	Crown spread (m)	Tree volume (m^3 $tree^{-1}$)	Tree biomass (kg $tree^{-1}$)
Melia azedarach	7.22	10.21	10.77	3.26	3.02	0.14	58.41
Samanea saman	6.78	10.27	9.13	3.89	2.72	0.13	59.15
Syzygium cumini	6.23	10.70	11.33	4.04	2.88	0.13	64.63
Acacia mangium	7.87	11.52	9.63	4.99	3.43	0.19	75.83
Alstonia scholaris	7.74	9.78	8.87	3.81	2.73	0.13	53.24
Pongamia pinnata	6.24	10.39	9.06	3.62	2.00	0.12	60.66
Casuarina equisetifolia	10.43	13.99	20.27	8.37	4.20	0.35	115.73
Azadirachta indica	6.39	10.09	12.57	4.82	3.07	0.12	56.941
Anacardium occidentale	7.76	11.33	11.53	4.52	3.36	0.18	73.15
Neolamarckia cadamba	6.82	11.26	12.33	4.38	3.18	0.16	72.17
CD (5%)	1.71	1.39	2.49	1.27	0.83	0.05	19.63

Table 3. Simple correlation analysis among different parameters of tree species

Parameters	Tree height	Tree DBH	No. of branches	Crown length	Crown spread	Tree volume	Tree biomass
Tree height	1	0.832627	0.738248	0.84273	0.810047	0.936863	0.853398
Tree DBH		1	0.860424	0.919429	0.818643	0.969051	0.997761
No. of branches			1	0.911579	0.798919	0.87376	0.879266
Crown length				1	0.824512	0.940625	0.935346
Crown spread					1	0.847545	0.817507
Tree volume						1	0.980047
Tree biomass							1

All the correlations are significant at the 0.05 level

It was revealed from Table 3 that, there is significant and positive correlation among all the tree growth parameters. Among the growth parameters of trees, positive and significantly highest correlation was observed between tree DBH and tree biomass i.e. (r = 0.997761) followed by tree volume and tree biomass i.e. (r= 0.980047). The minimum correlation (r= 0.738248) was observed between tree height and number of branches.

Carbon sequestration by tree species

Carbon is considered as 50% of biomass. So, assuming this, carbon content of all the studied trees of the plantation site was calculated. The soil organic carbon was also calculated and resulted data on hectare basis were presented in Table 4.

The carbon content of *Casuarina equisetifolia* (96.44 t ha^{-1}) was found to be the maximum and significantly superior over all the tree species. *Acacia mangium* (63.19 t ha^{-1}) was the next best for carbon content and found statistically at par with all other tree species except *Alstonia scholaris* (44.37 t ha^{-1}).

The soil organic carbon content of *Pongamia pinnata* (38.56 t ha^{-1}) was found to be the maximum over all the tree species. *Casuarina equisetifolia* (36.48 t ha^{-1}) was the next best for soil organic carbon followed by *Samanea saman* (36.07), *Acacia mangium* (35.57). The soil organic carbon content of *Syzygium cumini* (29.41 t ha^{-1}) was recorded the lowest among the tree species studied.

The total carbon sequestrated by *Casuarina equisetifolia* (132.92 t ha^{-1}) was found to be the maximum over all the tree species. *Acacia mangium* (98.76 t ha^{-1}) was the next best for carbon sequestration followed by *Anacardium occidentale*, *Neolamarckia cadamba*. *Alstonia scholaris* sequestrated lowest carbon among the tree species studied.

Table 4. Total carbon sequestration by tree species

Treatments	Total biomass (kg $tree^{-1}$)	Total biomass (t ha^{-1})	Carbon sequestrated by tree (t ha^{-1})	Soil organic cabon (SOC) (t ha^{-1})	Total carbon sequestration (t ha^{-1})
Melia azedarach	58.41	97.36	48.68	31.81	80.49
Samanea saman	59.15	98.58	49.29	36.07	85.36
Syzygium cumini	64.63	107.72	53.86	29.41	83.27
Acacia mangium	75.83	126.38	63.19	35.57	98.76
Alstonia scholaris	53.24	88.74	44.37	33.66	78.03
Pongamia pinnata	60.66	101.11	50.56	38.56	89.12
Casuarina equisetifolia	115.73	192.88	96.44	36.48	132.92
Azadirachta indica	56.94	94.91	47.46	32.26	79.72
Anacardium occidentale	73.15	121.92	60.96	34.88	95.84
Neolamarckia cadamba	72.17	120.26	60.13	34.23	94.36
CD (5%)	19.63	32.73	16.34	--	--

Conclusion

Among the tree species evaluated in cromite mine spoil areas *Casuarina equisetifolia* recorded the highest growth parameters, biomass and carbon sequestration followed by *Acacia mangium, Anacardium occidentale, Neolamarckia cadamba, Syzygium cumini, Pongamia pinnata*. Hence, in chromite mine spoil areas these tree species should be planted for reclamation as well as higher carbon sequestration.

References

Agrawal, M., Singh, J, Jha AK and Singh JS. 1993. Coal-based environmental problems in a low rainfall tropical region, *Landscape and Urban Planning*, **5**(2): 27-57.

Anwer M, Hussain I, McNeilly T and Putwain PD. 2001. Amelioration of NPK on metals polluted bare and vegetated sites of Trelogan mine, *Journal of Biological Science*, **1**: 280-283.

Bahrami A, Emadodin I, Atashi MR and Bork HR. 2010. Land-use change and soil degradation: A case study, North of Iran, *Agricultural Biology Journal of North America*, **1**: 600-605.

Banerjee SK, Mishra TK, Singh AK and Jain A. 2004. Impact of plantation on ecosystem development in disturbed coal mine overburden spoils, *Journal of Tropical Forest Science*, **16(**3): 294-307.

Bradshaw, A.D. and Chadwick, M.J. 1980. Underlying principles of restoration, *Canadian Journal of Fisheries and Aquatic Sciences*, **53**(1): 3-9.

Burgharadt W. 1993. Böden auf Altstandorten (Soils of contaminated land), 217-229. In Alfred-Wegener-Stiftung (ed.). Die benutzte Erde. Ernst, Berlin.

Deo B. 2004. Heavy metal accumulation by plant species from a coal mining area in Orissa, *Journal of Environmental Biology*, **25**(2): 163-166.

Deo B, Nahak G and Sahu RK. 2011. Studies on the uptake of heavy metals by selected plant species growing on coal mine spoils in sub-tropical regions of India, *Journal of American Science*, **7**(1): 26-34.

Dutta RK and Agrawal M. 2002. Effect of tree plantations on the soil characteristics and microbial activity of coal mine spoil land, *Tropical Ecology*, **43**(2): 315-324.

Hooper, D. U. and Vitousek. 1998. Effects of Plant composition and diversity on nutrient cycling. Ecological monograph. 68(1): 121-149.

Krzaklewski, W., Pietrzy kowski, M. 2002. Selectedphysico-chemical properties of Zinc and lead are tailings and their biological stabilization. Water Air Soil poll., 141: 125-142.

Pensa, M., Sellin, A., Luud, A., Valgma, I. 2004. Ananalysis of vegetation restoration on opencast oilshale mines in Estonia. Restoration Ecology 12(2):200-206.

Singh AN and Singh JS. 1999. Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region, *Forest Ecology and Management*, **119**: 195-207.

Singh AN, Raghubanshi AS and Singh JS. 2002. Plantation as a tool for mine spoil restoration, *Current Science***, 82**(12): 56-78.

Singh, J. S., Jha, A. K. (1992). Restoration ofdegraded land: an overview. In: J. S. Singh (ed.)Restoration of Degraded Land: Concepts and Strategies. Rastogi Publication, Meerut, India. pp.1-9.

Tordoff GM, Baker AJM and Willis AJ. 2000. Current approaches to the revegetation and reclamation of metalliferous mine wastes, *Chemosphere,* **41**(2): 219–228.

Upadhyay, N., Verma, S., Singh, A.P., Devi, S., Vishwakarma, K., Kumar, N., Pandey, A., Dubey, K., Mishra, R., Tripathi, D.K., Rani, R., Sharma, S., 2016. Soil Eco physiological and microbiological indices of soil health: a study of coal mining site in Sonbhadra, Uttar Pradesh. J. Soil Sci. Plant Nutr. 16 (3), 778–800.

Vagholikar, N. and Moghe, K. 2003. Undermining India: Impacts of Mining on Ecologically Sensitive Areas. Published by Kalpavriksh, Pune, India.

Zhang, J. T. 2005. Succession analysis of plant communities on abandoned cropland in the eastern lies plateau of chair. Journal of Arid Environment 63: 458-474.