

Influence of Man-Made Plantation on Soil Properties Under Hot and Humid Climate

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ABSTRACT

Restoring soil quality on degraded lands is crucial for achieving UN Sustainable Development Goal 15.3, which emphasizes land degradation neutrality. This study evaluates the impact of various vegetation restoration projects on soil properties in the Bilaspur district of Chhattisgarh, Central India, where Acacia nilotica, Eucalyptus hybrid, Tectona grandis, and Mixed Forest plantations were established in 1993. Over 30 years, these plantations have influenced soil characteristics such as pH, electrical conductivity (EC), soil organic carbon (SOC), nitrogen, phosphorus, potassium, and various micronutrients. Soil pH ranged from 5.53 to 7.44, with Tectona grandis showing the highest pH and Eucalyptus the lowest. EC values were highest under Tectona grandis (0.43 dSm^{-1}) and lowest in Eucalyptus (0.13 dSm^{-1}). SOC percentages varied, with Acacia nilotica having the highest at 0.57%, while Eucalyptus had the lowest at 0.14%. Nitrogen content was highest in the Mixed Forest ($226.89 \text{ kg ha}^{-1}$) and lowest in Eucalyptus ($147.89 \text{ kg ha}^{-1}$). Phosphorus availability was greatest in the Mixed Forest (20 kg ha^{-1}), and potassium levels were highest in Acacia nilotica ($416.11 \text{ kg ha}^{-1}$). Iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), and boron (B) concentrations also differed among the plantations, with Mixed Forest generally showing higher levels of Mn and Zn. Sulfur content varied minimally across plantations. These findings demonstrate that the type of vegetation significantly affects soil properties, with Mixed Forest generally showing better soil quality indicators. This suggests that the choice of vegetation in restoration projects can have substantial impacts on soil health and fertility, influencing both ecosystem functioning and carbon sequestration potential.

Keywords: Soil Quality, Vegetation Restoration, Land Degradation Neutrality, Mixed Forest Plantations, Soil Nutrients.

Mathematics Subject Classification: 62P12, 62G07

Journal of Economic Literature (JEL) Classification : Q23

1. INTRODUCTION

Soil quality restoration of the degraded lands is a global concern as mentioned in the goal 15.3 of the UN Sustainable Development Goals (SDGs). This has been the basis of several afforestation and restoration projects in the world. Soil property is often considered as one of the key indicators used to

measure the restoration pattern of degraded lands (Ma *et al.*, 2022). The organic carbon present in the soil is the main component of stored soil carbon which maintains ecosystem functioning. Vegetation restoration in the degraded lands induces the ability to sequester more carbon by the land use, and thus offsetting anthropogenic carbon emissions (Bastin *et al.*, 2019; Wang and Huang, 2020). Developmental stages of plantations profoundly affect the forest carbon pools by changing the soil structure and environmental factors (Ma *et al.*, 2022).

Degraded lands are characterized with poor soil fertility level and are mostly devoid of efficient soil microorganisms responsible for nutrient mineralization. These soils lack soil organic matter becoming a threat to carbon sequestration potential of soils. The absence of vegetation in these soils often lowers the organic matter availability which subsequently leads to poor soil quality and structure. The establishment of vegetations in the degraded lands determines the rate of organic matter accumulation in the soil (Wehr *et al.*, 2019; Putten *et al.*, 2013). The changes in the soil nutrients during the restoration process is an important entity to quantify. Owing to the differences in type of plantations and secondary forest developed on the degraded sites, the soil quality is likely to be different due to distinct mineralization rates, microbial activity and soil aggregate fractions (Manpoong *et al.*, 2020, Dou *et al.*, 2020; Zhang *et al.*, 2019, Manpoong and Tripathi, 2019). Soil organic carbon is an important component which regulates the soil fertility (Pandher *et al.*, 2020). Several studies have reported a reduction in SOC concentration when forest is converted to other land uses (Ahirwal *et al.*, 2017; Iqbal and Tiwari, 2016; Manpoong *et al.*, 2021).

Acacia nilotica, *Eucalyptus* hybrid, *Tectona grandis* plantations along with Mixed Forest were developed as a vegetation restoration in the degraded lands of Bilaspur district, Chhattisgarh, Central India during the year 1993. The purpose of this study was to investigate the changes in the soil nutrients under *Acacia nilotica*, *Eucalyptus* hybrid, *Tectona grandis* plantations and Mixed Forest after 30 years of vegetation establishment.

2. GENERATION OF THE DATA

Materials and methods

Study area

The study area was located in Bilaspur district, Chhattisgarh, Central India. The geographical coordinates of the study area lie in 82.1409° E longitude and 22.0797°N latitude. The soil is calcareous lithosols (limestone soil) according to the FAO/UNESCO classification system or entisols in the U.S. Soil Taxonomy. In order to see the impact of vegetation restoration on soil quality four different types of vegetation namely, *Acacia nilotica*, *Eucalyptus* hybrid, *Tectona grandis* plantations along with Mixed Forest were selected as sampling sites.



Fig. 1. Plantation types in study area (A) *Acacia nilotica* (B) *Eucalyptus* hybrid (C) *Tectona grandis* (D) Mixed Forest

Soil sampling and laboratory analysis

Soil sampling was performed during November 2022. Five sampling sites were established in each of the sites. The sampling sites were randomly distributed, and soil samples were collected to a depth of 30 cm. Soils were sampled using a hand-held auger (4 cm in diameter), and 10 soil samples were obtained at each site. Accordingly, 50 soil samples were obtained from each vegetation type. Three replicate samples were collected for analysing various soil properties. All the collected soil samples were air dried in the laboratory, gravel and roots in the soil were removed. The air-dried soil samples were sieved using 2 mm mesh sieve.

Soil pH was measured in a soil-water suspension (1:2.5 soil-water ratios) with pH analyser. The gravimetric method was followed to determine soil moisture content. Soil organic carbon (SOC) and total nitrogen (TN) was determined by dry combustion in a CHNS/O Elemental Analyzer.

2 Statistical analyses

Analysis of variance was performed to test the significance of the differences in the soil properties at an alpha level of 0.05 ($\alpha = 0.05$) among *Acacia nilotica*, *Eucalyptus* hybrid, *Tectona grandis* plantations and Mixed Forest. All statistical analyses were performed with the Statistical Program for Social Sciences (SPSS 24 version).

3. DISCUSSION AND CONCLUSION

The soil properties of selected land use sites of *Acacia nilotica*, *Eucalyptus* hybrid, *Tectona grandis* and mixed forest is presented in table 1. The pH of all the soil samples from various plantations showed neutral to slightly acidic ranging from 5.53 to 7.44. The pH of soil under *Tectona grandis* was found significantly higher (7.44) and was followed by *Acacia nilotica* (6.99) and mixed forest (5.99). The minimum pH was recorded in *Eucalyptus* (5.53). The pH of the soil under various plantations is

probably due to significant input of organic matter to the surface soil beneath the trees and the organic acid released during the decomposition of the litter. The similar trends of results in variation of pH under different trees has been reported by Singh et al. (2018) and reported that highest pH was found in *Tectona grandis* compared to other systems.

The soil electrical conductivity (EC) is associated with soil parameters such as cation exchange capacity, drainage requirements, organic matter content and soil salinity. The EC was higher in soil under the teak plantation (0.43 dSm^{-1}) which is 69.76 %, 41.86 %, and 18.60 % more than Eucalyptus, mixed forest and *Acacia nilotica* soil, respectively. The minimum EC of soil was found in eucalyptus soil (0.13 dSm^{-1}).

Table 1: Macro nutrients and micro nutrient distribution pattern in different plantation

	pH	EC (DSM)	OC (%)	N (kg/ha.)	P (kg/ha.)	K (kg/ha.)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	S (ppm)	B (ppm)
<i>Acacia nilotica</i>	6.99	0.35	0.57	194.22	15.97	416.11	3.98	6.22	1.54	28.63	12.16	1.33
<i>Eucalyptus</i>	5.53	0.13	0.14	147.89	19.34	366.33	8.82	3.44	20.05	15.49	10.84	2.44
<i>Tectona grandis</i>	7.44	0.43	0.37	187.33	15.22	413.22	3.90	5.00	1.44	27.78	11.24	1.23
<i>Mixed forest</i>	5.99	0.25	0.43	226.89	20.00	212.33	11.25	3.23	35.88	18.70	11.24	2.89

Soil organic carbon plays a significant role in the enhancement soil physical, chemical and biological properties of soil. Our results revealed that *Acacia nilotica* site has got maximum soil organic carbon percent (0.57 %) followed by mixed forest site (0.43%) and *Tectona grandis* (0.37). The site with eucalyptus tree has got the minimum soil organic carbon percent (0.14). The main source of organic carbon in soil is fallen leaves, barks, and small branches of trees. The similar trend of results was reported by Salim et al. (2018) and Adekunle et al. (2011) that the soil under the teak plantation has the maximum SOC than other tree species plantations.

Land use systems have a significant impact on the overall nitrogen concentration of the soil which is a key element for plant growth. The result shows that the variation in nitrogen content from different plantation ranges from $226.89 \text{ kg ha}^{-1}$ to $147.89 \text{ kg ha}^{-1}$. The maximum nitrogen content was obtained under the mixed forest ($226.89 \text{ kg ha}^{-1}$) which is 34.81 % more than lowest nitrogen content, which is obtained in the eucalyptus plantation ($147.89 \text{ kg ha}^{-1}$). The nitrogen content in *Acacia nilotica* and *Tectona grandis* plantation was recorded 194.22 and 187.33 kg ha^{-1} respectively, which is 14.39 % and 17.43 % less than the mixed forest. Increased N mineralization may be because of higher organic input from root deposition and leaf litter fall of mixed plantation. Singh et al. (2018) also reported that nitrogen content in soil varied with different tree plantation. Nazir and Netajini (2014) also reported that total nitrogen increased as organic matter increased.

In terrestrial ecosystems, the most prominent physicochemical factors limiting plant development is that of available P in the soil. P is essential for plant survival, specifically for the storage and replication of plant genetic material, as well as energy-related processes known as photo-phosphorylation (Elser and Bennett, 2011). The data presented in Table 1 reveals that the available phosphorus was higher in the mixed forest (20 kg ha⁻¹) among all the plantations. The order of phosphorus availability of soil in selected tree system was mixed forest>*Eucalyptus*>*Acacia nilotica* and minimum was recorded in soil under the *Tectona grandis* plantation which is 23.90 % less than mixed forest. The availability of phosphorus in mixed forest was high may be due to is addition of more organic matter in the form of litter fall and root biomass of various tree species.

The highest potassium was recorded in *Acacia nilotica* (416.11 kg ha⁻¹) followed by *Tectona grandis* (413.22 kg ha⁻¹), *Eucalyptus* (366.33 kg ha⁻¹) while the lowest in mixed forest (212.33 kg ha⁻¹), which is 48.97 % less than that in *Acacia nilotica* plantation. Salim et al. (2018) also found similar trend of result that maximum potassium content was found in mixed plantation site and lowest was recorded in acacia system. Ravula et al. (2022) concluded that along with the age gradient, there has also been an increase in the amounts of accessible potassium, phosphorus, and nitrogen in eucalyptus plantation of various age group.

In the mixed forest and *Tectona grandis*, the Fe content in soil of selected tree systems ranged from 11.25 to 3.90 ppm respectively, which differed by 65.33 % from the highest and the lowest levels. The Fe level on soil under *Eucalyptus* and *Acacia nilotica* was 8.82 ppm, 3.98 ppm respectively which had 21.6% and 64.22 % less than Fe content in mixed forest. Similar trends of results agreed with Mandal et al. (2018) revealed that the maximum concentration of Fe was higher in horticulture (fruit tree) system (12.38 mg kg ha⁻¹), which was 30 and 83 percent lower than cropland and uncultivated land.

The Cu concentration of soil varies from 3.23 ppm to 6.22 ppm under soil obtained from various tree systems. A comparison made regarding the trends of Cu concentrations under various tree systems illustrated *Acacia nilotica* > *Tectona grandis* > *eucalyptus*; the lowest recorded Cu concentration in mixed forest was 86.91 % lower than that in *Acacia nilotica*. All the four tree species differed significantly from each other regarding the availability of Cu in the surface soil. Similar trends of results were reported by Dhaliwal et al. (2019).

A number of variables, including organic matter, pH, CaCO₃, and redox conditions, affect the availability of manganese (Mn) in soils. The data presented in table 1 indicated that the maximum Mn content was found in soil collected from mixed forest (35.88 ppm) followed by eucalyptus 20.05 ppm, *Acacia nilotica* (1.54 ppm) and minimum was found in (1.44 ppm). However, *Acacia nilotica* and *Tectona grandis* displayed statistical similar Mn content in soil. The higher Mn content in mixed forest soil was 44.11 % higher than soil sample collected from eucalyptus tree system.

The Zn content among all soil samples of different tree systems showed that the least Zn content was found in eucalyptus (15.49 ppm), which was 45.89 % less than the highest recorded Zn content. The maximum content of Zn was recorded in the *Acacia nilotica* system (28.63 ppm), followed by *Tectona*

grandis (27.78 ppm), and that in mixed forest was 18.70 ppm. On the other hand, the highest Boron content recorded was 2.89 ppm in mixed forest and a minimum of 1.23 ppm in *Tectona grandis*, while in eucalyptus and *Acacia nilotica* it was 2.44 ppm and 1.33 ppm respectively. The results recorded agree with the findings of Dhaliwal et al. (2019); Mandal et al. (2018).

Nitrogen metabolism is linked to sulphur, which is also required for the synthesis of proteins, vitamins, and essential amino acids (Pandey et al. 2023). The sulphur content in various soil samples ranges from 12.16 ppm to 10.84 ppm which is found in *Acacia nilotica* and Eucalyptus respectively. *Tectona grandis* and mixed forest showed similar concentration of sulphur recorded at 11.24 ppm. The difference between the highest and the lowest sulphur content was 10.85 percent. Data recorded revealed that mixed forest generally have displayed better soil properties parameters over others. Therefore choice of species for the restoration projects should be based on soil quality indicators under different tree species.

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