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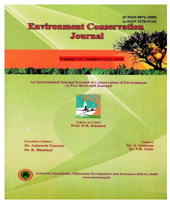

Characterization of soils under different periods of eucalyptus cultivation and restoration in Malur and Hoskotetaluks of Karnataka, India

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ABSTRACT

Considerable area under eucalyptus plantation in the form of farm forestry exists in Malur and Hoskotetaluks of Karnataka, India. But in the recent years, Government of Karnataka has checked the spread of eucalyptus and farmers are gradually converting their eucalyptus plantations into agricultural lands. This study was aimed to evaluate soils of eucalyptus during growing and after restoration and its adjacent croplands having no history of eucalyptus cultivation in Taluks of Malur and Hosakote, Karnataka for physico-chemical properties and evaluated during the year 2019-2020 at College of Horticulture, Kolar. The results revealed that soils under 12, 24 and 48 years of eucalyptus cultivation when compared to soils after two, six and ten years of restoration and adjacent soils, showed significantly high bulk density (1.28 to 1.51 Mg/m^3) and low water holding capacity (30.30 to 45.61%). These soils were more acidic in reaction (pH: 6.21 to 6.65) and contained significantly lower amounts of total soluble salts (EC: 0.04 to 0.07 dS/m), organic carbon (OC: 0.24 to 0.59%), available N, P_2O_5 and K_2O (163.07 to 235.42, 26.03 to 47.23 and 112.89 to 168.55 Kg/ha, respectively), exchangeable Ca and Mg (1.70 to 2.75 and 0.80 to 1.32 cmol (p$^+$)/Kg, respectively) and available S (5.60 to 7.09 ppm) but contained significantly high amounts of available Fe, Mn, Zn and Cu (13.52 to 29.74, 14.06 to 20.14, 1.44 to 2.06 and 1.16 to 1.74 ppm, respectively). Further, bulk density, acidity and available micronutrient cations of soils tends to increase with prolonging the cultivation period of eucalyptus while, reverse trend was observed with respect to water holding capacity, organic carbon and available macronutrients contents. On the other hand, restored plots showed significantly decreased acidity, bulk density and available micronutrient cations and increased water holding capacity and macronutrients contents with increasing the restoration period.

Introduction

Eucalyptus trees are the most dominated species of the natural forests growing in a range of diverse climates and in all types of soils. Eucalyptus is indigenous to Australia with genus covering more than 700 species belonging to the family Myrtaceae and subfamily Myrotideae and its life span is about more than 250 years. Eucalyptus is commonly known by different names such as 'nilgiri tree', 'iron bark', 'string bark', 'mountain ash' and 'gum tree'. In Karnataka, it is commonly called as 'Mysore gum' because it exudes copious sap from any cut in the bark (Coppen and Hone,

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1992).Eucalyptus was introduced in many countries owing to its fast growth and raises its demand for paper and plywood (Cossalter and Pye-Smith, 2003). It was introduced to India as an ornamental tree in the late 18th century by the ruler of Mysore 'Tippu Sultan' in Karnataka. He planted about sixteen species of eucalyptus on Nandi hills of Karnataka during the period 1782-1802 (Shyam Sunder, 1979). Subsequent to the planting at Nandi hills, the next significant introduction of eucalyptus was in the Nilgiri hills, Tamil Nadu, in 1843 and large-scale plantation of eucalyptus in Mysore district was raised from seeds collected from plants grown in the Chikkaballapur range near the Nandi hills. Eucalyptus was promoted as a profitable, no maintenance and low investment crop in cultivated land. Karajagi *et al.* (2009) have documented an area of 2.1 lakh hectares of eucalyptus in Karnataka. But in the recent years, Government of Karnataka has checked the spread of eucalyptus and its latest notification in January 2011, its cultivation was banned in Western Ghats of the state due to reported loss of soil fertility.Eucalyptus tree has special characters like fast growth, inability to fix atmospheric nitrogen in soil, resistance mechanism to severe periodic moisture stress and low soil fertility due to xeromorphic leaves (structural modifications that enable the reduction of water loss) and have specialized nutrient supplying symbiotic fungi, ectomychorrhizae that can greatly increases the rate of nutrient uptake. Being fast growing, eucalyptus also use more amounts of nutrients and water from the soil in comparison to slow-growing species. Some studies have reported that monoculture of eucalyptus plantation may affect soil fertility but ultimate impacts of eucalyptus plantation on agriculture land remains fiercely debated. Therefore, physicochemical properties of soils under different coppiced eucalyptus plantations and converted agricultural lands were evaluated. This would give a clear status of eucalyptus with respect to fertility and sustenance of soils for its continuous cultivation, diversification or possible restoration requirements.

Material and Methods

Site description

Malur taluk was situated between 13.28^0 N latitude and 77.60^0 E longitudes with an altitude of 900 m above mean sea level (MSL). The average rainfall of this region is 751 mm and the mean maximum and minimum temperatures recorded were 34 and 15ºC, respectively. While, Hoskote taluk was situated between 13.17^0 N latitude and 78.20^0 E longitudes with an altitude of 849 m above mean sea level. The average rainfall of this region is 724 mm with a large spatial and temporal variability and the mean maximum and minimum temperatures recorded were 31.6 and 19.9ºC, respectively.

Collection of surface soil samples

Considerable area under eucalyptus plantation in the form of farm forestry exists in Malur and Hoskote taluks of Karnataka. Twelve eucalyptus plantations were selected on the basis of number of coppiced or age from each taluk apportioned four each into two (12 years), four (24 years) and eight (48 years) coppiced plantations. Besides, twelve agricultural lands converted from eucalyptus plantation from each taluk were selected apportioned four each into two, six and ten years of restoration. In addition to this, four adjacent croplands from each taluk having no history of eucalyptus cultivation were selected. Thus, a total of 28 surface soil samples (0-15 cm) from each taluk were collected and processed for analysis as described by Jackson (1973).

Analysis

The collected soil samples were analyzed for various physical properties *viz.*, soil texture, bulk density and maximum water holding capacity and chemical properties *viz.*, pH, EC, organic carbon and available primary, secondary and micronutrient cations status. The soil textural class was identified using USDA equilateral textural triangle after per cent sand, silt and clay particles were determined by Bouyoucos hydrometer method as described by Bouyoucos (1962). The bulk density (BD) and maximum water holding capacity (MWHC) of soil were determined by using Keen's cup as outlined by Piper (2019). Soil pH was estimated in 1 : 2.5 soil - water suspension using calibrated pH meter, while the electrical conductivity (EC) of the supernatant was measured by using conductivity meter (Jackson, 1973). Organic carbon was determined by following wet-oxidation method (Walkley and Black, 1934). Available nitrogen was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956). Available phosphorus content of soil was extracted with either

Bray's extractant-I or Olsen's extractant depending on pH of the soil and determined by spectrophotometric method (Jackson, 1973). Available potassium was determined flame photometrically using neutral normal ammonium acetate extractant as described by Jackson (1973). Exchangeable calcium and magnesium contents of soil were extracted with neutral normal ammonium acetate extractant and estimated by complexometric titration method as outlined by Hesse (1971). Available sulphur was extracted with 0.15 per cent $CaCl_2$ solution and estimated by turbidometric method as explained by Jackson (1973). The available micronutrient cations *viz.,* iron, manganese, zinc and copper were simultaneously extracted with DTPA extractant as explained by Lindsay and Norvell (1978) and were estimated using Atomic Absorption Spectrophotometer (AAS) with suitable hallow cathode lamp and measuring conditions. The data obtained during the course of study were analyzed using standard statistical procedure and independent T-test was performed for all data to assess the differences. The statistical significance was determined at $p<0.05$ (Panse and Sukhatme, 1989).

Results and Discussion

Physical properties

The soils of all sites under different cultivation periods of eucalyptus plantation and restoration were sandy clay loam in texture at Malur taluk and sandy loam at Hoskote taluk (Table 1). However, soils under cropland plots were sandy loam at Malur taluk and loamy sand at Hoskote taluk. Soil texture mainly depends on primary soil fractions present in site. The proportion of primary soil particles such as sand, silt and clay particles in a given soil (soil texture) cannot be easily altered and hence, it is considered as a basic property of a site. However, significantly lowest clay content was noticed in soils of cropland plots at both Malur and Hoskote taluks (16.84 and 12.16%, respectively). This might be due to intensive cultivation of cropland soils coupled with less quantity of organic manure application that might have resulted in destruction of soil structure followed by eluviation of clay particles from surface to lower layer of soil during heavy rain. On the other hand, clay content of soil under eucalyptus plantation and restoration was relatively high compared to cropland soils at both the taluks studied. This might be attributed to accumulation of leaf litter under eucalyptus plantation and restored lands coupled with less cultivation that might have protected the surface soil. These observations are in accordance with the observations made by Balamurugan *et al*. (2000). Alem *et al*. (2010) observed the significantly higher percentage of clay in soils collected from *Eucalyptus grandis* plantation than that of the adjacent native sub-mountain rain forest in Ethiopia.The bulk density of soil differed significantly due to prolonging the cultivation period of eucalyptus plantation and restoration (Table 1). The examination of data revealed that the soils under fourty eight years old eucalyptus plantation had significantly highest bulk density of 1.51 and 1.38 Mg/m^3 at Malur and Hoskote taluks, respectively. On the other hand, cropland plots had significantly lowest bulk density of 1.28 and 1.26 Mg/m^3 at Malur and Hoskote taluks, respectively. In general, the bulk density of soils under different cultivation periods of eucalyptus plantation ranged from 1.29 to 1.51 Mg/m^3 at Malur taluk and 1.28 to 1.38 Mg/m^3 at Hoskote taluk and was found to increase with prolonging the cultivation period of eucalyptus plantation at both the taluks studied. On the other hand, bulk density of soils under different periods of restoration ranged from 1.28 to 1.37 Mg/m^3 at Malur taluk and 1.27 to 1.30 Mg/m^3 at Hoskote taluk and was found to decrease with prolonging the period of restoration at both the taluks studied. Bulk density of soil might be affected by soil texture, soil structure, soil porosity, soil compaction, soil organic matter content, soil depth, tillage operation and nature of crop grown. In general, fine textured soils usually have lower bulk density than coarse textured soils. Even though soils of eucalyptus and restored plots at both the taluks contained relatively more amount of clay particles as compared to cropland plots still showed higher bulk density values. This might be due to the fact that sparse undergrowth vegetation in eucalyptus plantation due to its allelopathic effects and very high water utilization rate by eucalyptus tree with respect to its unit biomass production that leads to drying up of water from the site of eucalyptus plantation and forms high soil compaction on top soil.

Table 1: Physical properties of surface soils under different periods of eucalyptus cultivation and restoration

Description	Age (Years)	Particle size distribution (%)			Textural class	BD (Mg/m^3)	MWHC (%)
		Sand	Silt	Clay			
Malur taluk							
Eucalyptus plots	12	76.16	3.80	20.04	Sandy clay loam	1.29	40.45
	24	62.56	7.28	30.16	Sandy clay loam	1.38	31.67
	48	71.20	4.96	23.84	Sandy clay loam	1.51	30.30
Restored plots	2	62.88	4.00	33.12	Sandy clay loam	1.37	31.06
	6	65.68	12.00	22.32	Sandy clay loam	1.35	33.04
	10	75.04	4.00	20.96	Sandy clay loam	1.28	42.89
Cropland	-	78.69	4.47	16.84	Sandy loam	1.28	41.75
S.Em±		**3.20**	**1.29**	**2.58**		**0.03**	**2.74**
C.D. @ 5%		**9.98**	**NS**	**8.03**		**0.09**	**8.55**
Hoskote taluk							
Eucalyptus plots	12	79.84	3.28	16.88	Sandy loam	1.28	45.61
	24	78.32	3.04	18.64	Sandy loam	1.36	35.39
	48	81.84	1.28	16.88	Sandy loam	1.38	34.59
Restored plots	2	79.28	4.56	16.16	Sandy loam	1.30	36.74
	6	78.48	4.00	17.52	Sandy loam	1.29	40.64
	10	76.84	5.00	18.16	Sandy loam	1.27	45.54
Cropland	-	81.84	6.00	12.16	Loamy sand	1.26	52.13
S.Em±		**1.39**	**0.92**	**1.19**		**0.01**	**2.09**
C.D. @ 5%		**4.3**	**NS**	**3.71**		**0.05**	**6.53**

The compactness of soil might have increased the soil bulk density (Aweto and Moleele, 2005). The increased bulk density of soil in eucalyptus and restored plots may also due to reduced soil infiltration, increased runoff of the surface soil and correspondingly reduced soil moisture content (FAO, 2011).Maximum water holding capacity of soil had significantly influenced by different periods of eucalyptus cultivation and restoration (Table 1). Soils after ten years of restoration showed significantly maximum water holding capacity of 42.89 per cent at Malur taluk, while soils of croplands showed maximum water holding capacity of 52.13 per cent at Hoskote taluk. However, soils of cropland and soils after twelve years of eucalyptus cultivation were on par with each other with respect to maximum water holding capacity of soil. On the other hand, soils under prolonged fourty eight years of eucalyptus cultivation showed significantly lowest water holding capacity at both Malur (30.30%) and Hoskote (34.59%) taluks. In general, maximum water holding capacity of soils under different cultivation periods of eucalyptus cultivation ranged from 30.30 to 40.45 per cent at Malur taluk and 34.59 to 45.61 per cent at Hoskote taluk and was found to decrease with prolonging the cultivation period of eucalyptus plantation at both the taluks studied. On the other hand, it ranged from 31.06 to 42.89 per cent at Malur taluk and 36.74 to 45.65 per cent at Hoskote taluk under different periods of restoration and was found to increase with increasing the restoration period at both the taluks studied. The decrease in water holding capacity of soil with prolonging the cultivation period of eucalyptus plantation might be attributed to the fact that eucalyptus is a fast growing tree absorb more water according to its unit biomass production and has ability to control its stomatal opening and closing according to water availability without reducing in the biomass production (Dinesh Kumar, 1984). Gurumurthi and Rawat (2000) reported that eucalyptus tree has inherent capacity of luxury consumption of water when it is abundantly available and transpiration of water in eucalyptus tree is dependent on availability of soil moisture near the tree. Further, sparse undergrowth vegetation in eucalyptus plantation due to its allelopathic effect can leads to higher rate of soil evaporation which further contributes to reduction of soil moisture content in the eucalyptus plantation than those of cropland and restored lands.

Chemical properties

The chemical properties *viz.*, pH, EC and organic carbon content of soil were significantly influenced by different periods of eucalyptus cultivation and restoration (Table 2). Soils under fourty eight years old eucalyptus plantation had significantly lowest pH of 6.21 at Malur taluk and 6.28 at Hoskote taluk. On the other hand, soils after two years of restoration had significantly highest pH of 7.50 at Malur taluk and 7.10 at Hoskote taluk. In general, pH of soils under different cultivation periods of eucalyptus plantation ranged from 6.21 to 6.65 at Malur taluk and 6.28 to 6.46 at Hoskote taluk and was found to decrease with prolonging the cultivation period of eucalyptus plantation at both the taluks studied. On the other hand, pH of soils under different restoration periods ranged from 7.21 to 7.50 at Malur taluk and 6.50 to 7.10 at Hoskote taluk and was found to decrease with prolonging the period of restoration at both the taluks studied. The soil pH values under different periods of eucalyptus cultivation at both Malur and Hoskote taluks were acidic to neutral in reaction because of the fact that eucalyptus tree immobilizes the exchangeable bases present in soil and leads to lower bases in soil that correspondingly reduces soil pH under eucalyptus plantation. Sanchez and Uehara (1980) observed the lower values of soil pH under eucalyptus plantation compared to native plantation.

With regard to total soluble salts content or electrical conductivity (EC) of surface soil, the soils under fourty eight years old eucalyptus plantation had significantly lowest EC of 0.04 dS/mat Malur and 0.05 dS/mat Hoskote taluk. On the other hand, soils after two years of restoration had significantly highest EC of 0.66 and 0.19 dS/mat Malur and Hoskote taluks, respectively. In general, the EC of soils under different cultivation periods of eucalyptus plantation ranged from 0.04 to 0.06 dS/mat Malur taluk and 0.05 to 0.07 dS/mat Hoskote taluk and was found to slightly decrease with prolonging the cultivation period of eucalyptus at both the taluks studied. On the other hand, EC of soils under different restoration periods ranged from 0.50 to 0.66 dS/mat Malur taluk and 0.14 to 0.19 dS/mat Hoskote taluk and was found to decrease with prolonging the period of restoration at both the taluks studied. However, soils under croplands and different periods of restoration were found to be on par with each other with respect to EC at both Malur and Hoskote taluks. The reduction of soil EC under eucalyptus tree plantation might be attributed to accumulation and subsequent decomposition of organic matter that releases organic acids (Gupta and Sharma, 2009; Ruhela *et al.,* 2022) and ameliorate salinity and sodicity of soil by decreasing soil EC and pH (Nasim *et al.,* 2007).

With respect to organic carbon status, soils of fourty eight years old eucalyptus plantation had significantly lowest organic carboncontent of 0.24 and 0.45 per cent at Malur and Hoskote taluks, respectively. On the other hand, soils after ten years of restoration at Malur taluk and soils of croplands at Hoskote taluk had significantly highest soil organic carbon content (0.58 and 0.70%, respectively).

In general, organic carbon content of soils under different cultivation periods of eucalyptus plantation ranged from 0.24 to 0.53 per cent at Malur taluk and 0.45 to 0.59 per cent at Hoskote taluk and was found to decrease with prolonging the cultivation period of eucalyptus plantation at both the taluks studied. On the other hand, organic carbon content of soils under different restoration periods ranged from 0.32 to 0.58 per cent at Malur taluk and 0.52 to 0.62 per cent at Hoskote taluk but no definite trend was observed. The decreased organic carbon content of soil with prolonging the cultivation period of eucalyptus plantation might be attributed to less accumulation of organic matter or slower rate of organic matter decomposition due to sparse undergrowth cover in eucalyptus plantation as a result of its allelopathic effect (Aweto and Moleele, 2005).

Available primary nutrients

The available N, P_2O_5 and K_2O status of soil differed significantly due to different cultivation periods of eucalyptus plantation and restoration at both Malur and Hoskote taluks (Table 2).

Table 2: Chemical properties of surface soils under different periods of eucalyptuscultivation and restoration

Description	Age (Years)	pH (1:2.5)	EC (dS/m)	OC (%)	Avail. N	Avail. P2O5	Avail. K2O
					(Kg/ha)		
Malur taluk							
Eucalyptus plots	12	6.65	0.06	0.53	197.57	47.23	168.55
	24	6.32	0.05	0.32	169.34	32.71	137.62
	48	6.21	0.04	0.24	163.07	28.26	112.89
Restored plots	2	7.50	0.66	0.32	177.12	57.27	185.98
	6	7.29	0.56	0.43	212.80	61.73	209.98
	10	7.21	0.50	0.58	219.26	78.10	235.35
Cropland plots	-	6.86	0.60	0.55	259.24	117.02	313.01
S.Em±		**0.19**	**0.09**	**0.05**	**15.66**	**7.37**	**20.70**
C.D. @ 5%		**0.62**	**0.28**	**0.16**	**48.80**	**22.98**	**64.58**
Hoskote taluk							
Eucalyptus plots	12	6.46	0.07	0.59	235.42	31.98	142.46
	24	6.30	0.06	0.51	192.34	28.63	126.51
	48	6.28	0.05	0.45	188.16	26.03	115.18
Restored plots	2	7.10	0.19	0.62	250.88	46.52	175.12
	6	6.63	0.17	0.54	244.61	53.49	188.16
	10	6.50	0.14	0.52	238.33	62.48	199.80
Cropland plots	-	6.49	0.16	0.70	282.24	89.99	288.49
S.Em±		**0.19**	**0.02**	**0.02**	**15.38**	**6.26**	**15.11**
C.D. @ 5%		**0.62**	**0.08**	**0.08**	**47.90**	**19.52**	**47.07**

The soils of forty eight years old eucalyptus plantation had significantly lowest available N, P_2O_5 and K_2O contents of 163.07, 28.26 and 112.89 Kg/ha, respectively at Malur taluk and 188.16, 26.03 and 115.18 Kg/ha, respectivelyat Hoskote taluk. On the other hand, soils of cropland plots had significantly highest available N, P_2O_5 and K_2O contents of 259.24, 117.02 and 313.01 Kg/ha, respectivelyat Malur taluk and 282.24, 89.99 and 288.49 Kg/ha, respectivelyat Hoskote taluk while, soils under different periods of restoration were intermediate in available N, P_2O_5 and K_2O contents. In general, the available N, P_2O_5 and K_2O contents of surface soils under different cultivation periods of eucalyptus plantation ranged from 163.07 to 197.57, 28.26 to 47.23 and 112.89 to 168.55 Kg/ha, respectively at Malur taluk and 188.16 to 235.42, 26.03 to 31.98 and 115.18 to 142.46 Kg/ha, respectively at Hoskote taluk and was found to decrease with prolonging the cultivation period of eucalyptus plantation at both the taluks studied. On the other hand, the available N, P_2O_5 and K_2O contents of surface soils under different periods of restoration ranged from 177.12 to 219.26, 57.27 to 78.10and 185.98 to 235.35 Kg/ha, respectively at Malur taluk and 238.33 to 250.88, 46.52 to 62.48 and 175.12 to 199.80 Kg/ha, respectively at Hoskote taluk and was found to increase with prolonging the restoration period at both the taluks studied. The relatively low available N, P_2O_5 and K_2O status of soil under eucalyptus plantation compared to restored and cropland plots might be due to rapid growth of eucalyptus that utilizes a large amount of available soil nutrients than any other crops and nutrients return of litter failed to make up for the deficiency of nutrients in time (Bauhus and Barthel, 1995; Turner and Lambert, 2008; Bhardwaj *et al.,* 2020). Further, increased harvest of eucalyptus trees decreased the available primary nutrients contents in soils due to the fact that repeated harvest of eucalyptus trees removes the primary nutrients from the soil. Zerfu Hailu (2002) reported that potential macronutrients removed from the upper layers of soil through harvesting of wood biomass from eucalyptus tree can exceeds the removal of nutrients through harvesting in agricultural crops. Tererai *et al.* (2015) observed the decreased available nitrogen content in the eucalyptus plantation area compared to the land not covered with eucalyptus plantation. Aweto and Moleele (2005) observed the lower amount of available phosphorus under 8 – 10 harvest (>50 - 60 years) of eucalyptus plantation that might be attributed to long term immobilization and P fixation in soils under eucalyptus plantation as a result of decreased soil pH. On the other hand, soils under restoration showed improved available N, P_2O_5 and K_2O contents at both Malur and Hoskote taluks that might be attributed to translocation of macronutrients from deeper horizons to the surface layer of soils (Tchienkoua and Zech, 2004) and regular application of manures and fertilizers to restored plots and croplands (Yitaferu *et al.,* 2013).

Available secondary nutrients

The exchangeable Ca and Mg as well as available S contents of soil differed significantly due to different periods of eucalyptus cultivation and restoration (Table 3). Soils under forty eight years of eucalyptus plantation had significantly lowest exchangeable Ca and Mg contents of 1.75 and 1.05cmol (p^+)/Kg, respectivelyat Malur taluk and 1.70 and 0.80cmol (p^+)/Kg, respectivelyat Hoskote taluk. On the other hand, soils of croplands had significantly highest exchangeable Ca and Mg contents of 3.85 and 1.95 cmol (p^+)/Kg, respectivelyat Malur taluk and 3.85 and 1.95 cmol (p^+)/Kg, respectivelyat Hoskote taluk while, soils under different periods of restoration were intermediate in exchangeable Ca and Mg contents. In general, the exchangeable Ca and Mg contents of soils under different cultivation periods of eucalyptus plantation ranged from 1.75 to 2.75 and 1.05 to 1.32 cmol (p^+)/Kg, respectively at Malur taluk and 1.70 to 2.65 and 0.80 to 1.25 cmol (p^+)/Kg, respectivelyat Hoskote taluk and were found to decrease with prolonging the cultivation period of eucalyptus plantation at both the taluks studied. On the other hand, exchangeable Ca and Mg contents of soils under different restoration periods ranged from 2.07 to 3.50 and 1.19 to 2.00 cmol (p^+)/Kg, respectively at Malur taluk and 2.00 to 3.17 and 1.08 to 1.70 cmol (p^+)/Kgat Hoskote taluk and were found to increase with prolonging the period of restoration at both the taluks studied. With respect to available sulphur content,soils under twelve years old eucalyptus plantation had significantly lowest available sulphur content of 5.60 and 5.94 ppm at Malur and Hoskote taluks, respectively. On the other hand, soils of cropland plots had significantly highest available sulphur content of 14.79 and 12.35 ppm at Malur and Hoskote taluks, respectively while, soils under different periods of restoration were intermediate in available sulphur status. In general, the available sulphur content of soils under different cultivation periods of eucalyptus plantation ranged from 5.60 to 6.97 ppm at Malur taluk and 5.94 to 7.09 ppm at Hoskote taluk and was found to increase with prolonging the cultivation period of eucalyptus plantation at both the taluks studied. On the other hand, available sulphur content of soils under different periods of restoration ranged from 7.76 to 12.08 ppm at Malur taluk and 8.92 to 10.82 ppm at Hoskote taluk and was found to increase with prolonging the period of restoration at both the taluks studied. The relatively low exchangeable Ca and Mg contents observed of surface soil under eucalyptus plantation probably due to increase in H^+ ions that lead to reduction in cation retention capacity. Aweto and Moleele (2005) reported that eucalyptus trees immobilize soil nutrients faster than that of soil nutrient recycle back to the topsoil and soil pH was significantly lower in eucalyptus tree plantations in 0 – 20 cm soil layers. Another possible reason for decreased available nutrients in soils under eucalyptus plantation might be due to greater demand of eucalyptus trees for available nutrients at the later stage of growth besides, decomposition and conversion rate of organic matter after 15 to 20 years plantation cannot meet the demand of eucalyptus trees growth (Zhu *et al.,* 2019).

Available micronutrient cations

The DTPA extractable micronutrients status of soil differed significantly due to different periods of eucalyptus cultivation and restoration (Table 3). Soils under forty eight years old eucalyptus plantation had significantly highest DTPA extractable Fe, Mn, Zn and Cu contents of 26.54, 20.14, 2.06 and 1.74 ppm, respectively at Malur taluk and 29.74, 18.28, 1.96 and 1.56 ppm, respectively at Hoskote taluk. On the other hand, cropland soils had significantly lowest DTPA

Table 3: Secondary and micronutrients content of surface soils under different periods ofeucalyptus cultivation and restoration

Description	Age (Years)	Exch. Ca	Exch. Mg	Avail. S (ppm)	DTPA extractable micronutrient cations (ppm)			
		[cmol (p+)/Kg]			Fe	Mn	Zn	Cu
Malur taluk								
Eucalyptus plots	12	2.75	1.32	5.60	15.16	16.72	1.60	1.34
	24	2.20	1.09	5.75	19.20	17.98	1.74	1.42
	48	1.75	1.05	6.97	26.54	20.14	2.06	1.74
Restored plots	2	2.07	1.19	7.76	13.32	15.54	1.20	0.88
	6	3.16	1.54	11.99	12.22	14.22	0.96	0.78
	10	3.50	2.00	12.08	9.92	12.90	0.76	0.64
Cropland plots (Control)	-	3.85	1.95	14.79	6.93	10.76	0.62	0.46
S.Em±		**0.17**	**0.11**	**0.56**	**0.29**	**0.65**	**0.18**	**0.13**
C.D. @ 5%		**0.52**	**0.35**	**1.75**	**0.90**	**2.04**	**0.58**	**0.42**
Hoskote taluk								
Eucalyptus plots	12	2.65	1.25	5.94	13.52	14.06	1.44	1.16
	24	2.01	0.97	6.25	27.34	15.90	1.63	1.32
	48	1.70	0.80	7.09	29.74	18.28	1.96	1.56
Restored plots	2	2.00	1.08	8.92	14.32	13.04	1.39	0.94
	6	2.80	1.35	9.29	12.22	12.60	1.26	0.86
	10	3.17	1.70	10.82	9.30	9.60	1.15	0.76
Cropland plots (Control)	-	3.85	1.95	12.35	4.55	6.74	0.86	0.50
S.Em±		**0.06**	**0.04**	**0.66**	**0.27**	**0.73**	**0.17**	**0.13**
C.D. @ 5%		**0.19**	**0.13**	**2.07**	**0.86**	**2.29**	**0.53**	**0.42**

extractable Fe, Mn, Zn and Cu contents of 6.93, 10.76, 0.62 and 0.46 ppm, respectively at Malur taluk and 4.55, 6.74, 0.86 and 0.50 ppm, respectively at Hoskote taluk while, soils under different periods of restoration were intermediate in available micronutrient cations status. In general, DTPA extractable Fe, Mn, Zn and Cu contents of surface soils under different cultivation periods of eucalyptus plantation ranged from 15.16 to 26.54, 16.72 to 20.14, 1.60 to 2.06 and 1.34 to 1.74 ppm, respectively at Malur taluk and 13.52 to 29.74, 14.06 to 18.28, 1.44 to 1.96 and 1.16 to 1.56 ppm, respectively at Hoskote taluk and were found to increase with prolonging the cultivation period of eucalyptus plantation at both the taluks studied. On the other hand, DTPA extractable Fe, Mn, Zn and Cu contents of soils under different restoration periods ranged from 9.92 to 13.32, 12.90 to 15.54, 0.76 to 1.20 and 0.64 to 0.88 ppm, respectively at Malur taluk and 9.30 to 14.32, 9.60 to 13.04, 1.15 1.39 and 0.76 to 0.94 ppm, respectively at Hoskote taluk and were found to decrease with prolonging the period of restoration at both the taluks studied. The increased availability of micronutrient cations in soils of eucalyptus plantation might be attributed to reduction in soil pH under eucalyptus plantation that leads to the increased availability of micronutrient cations compared to restored and cropland plots. Horneck *et al*. (2011) reported that availability of Fe, Mn, Zn and Cu increases as soil pH decreases and *vice-versa* and found higher in eucalyptus plantation.

Conclusion

The results obtained from the study, it can be inferred that eucalyptus tree affected the physical properties of soil by increasing bulk density and decreasing water holding capacity of soil and removed more macronutrients from the soil during its biomass production and enhanced the availability of micronutrient cations by reducing soil pH. On the other hand, restoration of eucalyptus plantation with agricultural crops have improved the physical properties of soil by decreasing bulk density and increasing water holding capacity of soil and enhanced the availability of macronutrients and reduced the toxicity of micronutrient cations by increasing the soil pH to near neutrality.

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Conflict of interest

The authors declare that they have no conflict of interest.

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