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Soil physico-bio-chemical properties under different agroforestry systems in Terai region of the Garhwal Hiamalayas

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Abstract
An experiment was carried out to evaluate the effect of different agroforestry systems on soil physico-chemical and biological properties. The results revealed that different agroforestry tree species showed the positive impact on soil physic-chemical and biological properties in comparison to sole agriculture cropping system. At 0-15, 15-30 and 30-45 cm soil depth lowest soil bulk density (1.25, 127 and 128g/cm^3), particle density (2.62, 266 and 2.71 g/cm^3) and pH (6.50, 6.90 and 6.80) was recorded under *Populus deltoids, Anthocephalus cadamba* and *Madhuca indica* based agroforestry systems respectively. Soil organic carbon content was recorded highest (1.06, 0.90 and 0.84%) under *Quercus. leucotrichophora* at 0-15, 15-30 and 30-45 cm soil depth. Nitrogen, phosphorus and potassium content were also higher under *Q. leucotrichophora* based agroforestry system. In soil biological properties, the highest bacterial and fungal colony was also recorded under *Quercus. leucotrichophora* based agroforestry system. So, in this study, *Quercus. leucotrichophora* based agroforestry system found superior for the enhancement in soil fertility over the other tree based agroforestry systems as well as open cropping system.

Keywords: Soil, physico-bio-chemical properties, different agroforestry systems

Introduction

In an agroforestry system woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately combined with agricultural crops and/or animals in same land management unit, either in some form of spatial arrangement or temporal sequence. There are both ecological as well as economical interactions between the different components of agroforestry (Nair, 1993). The advantages of ecological interactions between trees and agricultural crops are *i.e.*, increase in soil fertility through nitrogen fixation, addition of organic matter production, recycling of nutrients (Young, 1986) [93], more biomass production per unit area, uptake of more water and nutrients (Huxley, 1983) and trees act as a protective barrier against soil erosion or as wind breaks (Wiersum, 1984) [89]. Apart from the effect of agroforestry in improving the soil physical properties through the improvement in the soil structure and porosity, it also influences the chemical properties of the soil. Trees add high amount of organic matter in the form of leaf litter, fine root biomass and pruning debris. They help in lowering down the pH and EC of soil through organic matter accumulation and addition of nitrogen, potassium and phosphorous. Soil microorganisms mineralize nutrients via organic matter decomposition. The living microbial cells comprises of 1% to 5% (w/w) of the total organic carbon, and 1% to 6% of the total organic nitrogen (Jankinson and Pawlson, 1976). Soil organic matter decomposition by various microorganisms takes place through various enzymes which catalyze innumerable reactions necessary for the life processes of microorganisms, decomposition of organic residues, nutrient cycling, organic matter formation and soil structure (Dick, 1992) [19]. Most of the soils are not so rich to supply all the nutrients for its optimum growth and development. Furthermore, it is difficult to sustain the yield of the crop and soil health for longer duration without integrated use of organics and inorganics. The removal of nitrogen, phosphorus and potassium by crops is much more than their replenishment through mineral fertilizers, thereby leading to nutrient mining but this problem can be overcome through the agroforestry. Because agroforestry improve the soil fertility status by the addition of continuous organic matter in the soil in the form of leaves, twig and branches etc. At present, the level of N, P and K removal in India is about 28 million tonnes against addition of only 18 million tonnes, thus resulting in a negative balance of about 10 million tonnes (Rao and Srivastava, 1998) [66]. The removal of nutrient from the soil can also be minimize by the agroforestry because the tree root works as a binding agent against the soil

Erosion and enhance the natural nutrient recycling into the soil. Thus, Present study was conducted for the assessment of soil health under different agroforestry tree species in Terai region of Udham Singh Nagar, Uttarakhand, at Agroforestry Research Centre, Pantnagar, and District U. S. Nagar.

Material and methods

Study site

The present investigation was carried out at Agroforestry Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar. The study site was located at 29^0 Latitude and 79^0.3' longitudes and at an altitude of 243.84 meters above the mean sea level in Terai region. The climate and weather of Pantnagar is humid sub-tropical with cold winters and hot dry summers. The maximum daily temperature in summer may reach up to 42^0C and minimum temperature in winter may fall up to 0.5^0C. Generally, south-west monsoon sets in the second or third week of June and continues up to the end of September. The mean annual rainfall is about 1450 mm, of which 80-90 per cent is received during the wet season (July to September). The soils of Terai region are developed from alluvial, medium to moderately coarse textures materials under predominant influence of tall vegetation and moderate to well drain conditions. The soils are weakly developed with mollic epipedons and horizons are classified as Mollisols (Despandey *et al*., 1971).

Experimental Details

The soil samples were collected from three depths 0-15cm, 15-30 cm and 30-45 from eight different agroforestry tree species and sole agriculture field (Open condition) as control during February to June 2018. The agroforestry systems were established in the year 2003-04. All the agroforestry tree species were regularly pruned up to five year to maintain as a single stem. First seven year wheat and soyabean crop were intercropped in all the agroforestry systems alternatively. Thereafter wheat-soyabean was replaced with turmeric and zinger due to drastic decrease in the yield of wheat and soyabean. In the present study we had selected eight agroforestry systems and one sole agriculture crop field. Each tree based agroforestry system and sole cropping system is considered as a treatment. Thus, there were nine treatments including control (Sole agriculture field). The details of the tree species are as following:

Table 1: Details of treatments

S. No.	Scientific name	Common name	Family	Spacing
1	*Eucalyptus spp.*	Eucalyptus	Myrtaceae	4×4
2	*Tectona grandis*	Teak	Verbanaceae	4×4
3	*Melia azedarach*	Baken	Melaceae	4×4
4	*Madhuca indica*	Mahua	Sapindaceae	4×4
5	*Anthocephalus cadamba*	Kadamba	Rubiaceae	4×4
6	*Shorea robusta*	Sal	Depterocarpaceae	4×4
7	*Populus deltoids*	Paplar	Salicaceae	4×4
8	*Quercus leucotrichophora*	Banj	Fagaceae	4×4
9	Sole Agriculture field (Control)	--	--	--

Soil analysis

Soil physic-chemical analysis

The soil analysis was done at the laboratory of Forest Soil and Land Reclamation Division of Forest Research Institute of Dehradun. Bulk density was determined by using the core sampler technique from a 10.3 cm diameter core sampler (Blake and Hartge, 1986) [9]. To measure the particle density a measuring cylinder of 100 ml capacity was taken and filled exactly half (50 ml) with water. Then, the 10 g of soil was put into the measuring cylinder and the rise in water level was observed after 30 minutes and continues till the level became constant. The particle density was calculated by using the following formula as PD= W/V; where PD is particle density in g/cm^3, W is the weight of dry soil and V is the volume of soil solution. Soil porosity was determined by the method described by (Danielson and Southerland, 1986) [16]. The pH of the soil was determined in 1:2 (soil: water) ratio after half an hour of equilibrium using glass electrode on a digital pH meter (Jackson, 1967) [36]. Electrical conductivity of the soil sample was measured in 1:2 (soil: water suspension) at 25^o C using conductivity meter (Bower and Wilcox, 1965) [10]. The organic carbon content in soil was determined by modified (Walkley and Black 1934) [87] method as described by (Jackson 1967) [36]. Available nitrogen in soil was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956) [78]. Available phosphorus was extracted by sodium bi-carbonate extractant (0.5 M $NaHCO_3$) adjusted to pH 8.5 as per the method of (Olsen *et al*., 1954) [59] and developing the blue colour acid as described by (Murphy and Riley 1962) [51]. Available Potassium in soil was determined by extraction with 1 N ammonium acetate (pH 7) and K concentration was determined by flame photometer (Perur *et al*., 1973) [65].

Soil biological analysis

Freshly collected soil samples were kept in refrigerator at temperature >4^0C till the analysis of some biological biological properties. The soil dilution and plate count techniques were adopted to enumerate micro flora of soil. 1g of soil was transferred to 10 ml of sterile water and serial dilutions were made. This stock solution was serially diluted to the concentrations up to 10^{-7} at which the desirable organisms showed optimum growth. This concentration was 10^{-3} to 10^{-5} for fungi, 10^{-5} to 10^{-7} for bacteria. 1 ml of the respective dilutions were spread evenly using a sterilized glass spreader on the plates. About 20-25 ml of the medium was poured in sterilized petri plates and allowed to solidify (Wollum, 1982) [90]. A nutrient medium were prepared separately according to the directions for respective micro-organisms, sterilized in autoclave at pressure 1.05 N cm^{-2} and temperature 120°C for 15 minutes and was cooled up to 40°C. Martin's Rose Bengal Agar, Plated Count Agar and Kenkenight and Munir's medium are used for the fungi and Bacteria respectively. After the corresponding incubation period, total numbers of colonies formed were noted. Bacteria colony counts were taken after two days incubation, fungi after five days. The colony forming unit (cfu) per gram of dry soil was calculated.

Results and discussion
Soil Physical Properties
Soil bulk density

The bulk density was increased with increasing soil depth both under different agroforestry tree species as well as in the sole agriculture cropping field. The soil bulk density for all the soil depths (0-15 cm 15-30 cm as well as 30-45 cm) was significantly higher (1.41, 1.43, 1.45) in sole agriculture field as compared to under different tree species (Table 2). Among all the tree species the maximum bulk density for all the soil depths was observed in the soil collected from *Melia azedarach* (1.37, 1.40 and 1.44) based agroforestry field while lowest in *Populus deltoids* (1.25, 1.27 and 1.28). The reduction in soil bulk density under trees is attributed to the addition of organic matter through litter fall, fine root recycling, twigs etc. The findings of the present study showed the inverse relation between soil bulk density and soil organic carbon content which has been also reported earlier (Gupta and Sharma, 2008). Similarly, the significant reduction in soil bulk density as compared to sole agricultural cropping has been reported as under the canopy of *Prosopis juliflora* (Nayak *et al*., 2009) [55].

Soil particle density

The soil particle density was increased successively with increasing soil depth from 0-15 cm to 30-45 cm under different agroforestry tree species as well as sole agriculture cropping field. The significant reduction in soil particle density was observed in the depth of 0-15 cm only. The maximum particle density in 0-15 cm depth was observed in sole agriculture cropping field (2.85 g/cm^3) while minimum under *Anthocephalus cadamba* (2.62). Similarly, the lower particle density was recorded under different agroforestry tree species as compared to the agriculture cropping field primarily due to the higher soil organic carbon content under tree species by addition of organic matter through leaf litter, twigs, pruning debris etc (Tandel *et al*., 2009) [81].

Table 2: Soil physical properties under various tree based agroforestry systems

Treatments	Bulk Density (g/cm^3)			Particle Density (g/cm^3)			Soil porosity (%)		
	Soil Depth			Soil Depth			Soil Depth		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
Eucalyptus spp.	1.31	1.33	2.65	2.75	2.78	2.787	55.20	53.50	53.20
Tectona grandis	1.30	1.35	2.73	2.77	2.78	2.78	54.46	54.03	53.06
Melia azedarach	1.37	1.40	2.74	2.78	2.82	2.82	55.10	52.83	52.10
Madhuca indica	1.36	1.40	2.74	2.76	2.8	2.8	55.80	53.83	52.43
Anthocephalus cadamba	1.28	1.30	2.62	2.667	2.713	2.713	56.46	55.40	53.43
Shorea robusta	1.27	1.33	2.69	2.72	2.76	2.76	54.90	53.70	52.83
Populus deltoids	1.25	1.27	2.66	2.693	2.76	2.76	55.23	54.50	52.20
Quercus leucotrichophora	1.27	1.32	2.72	2.75	2.797	2.797	57.60	56.86	54.60
Agriculturesole cropping	1.41	1.43	2.85	2.88	2.92	2.92	52.66	51.90	51.20
C.D.	0.062	0.062	0.099	NS	NS	N/A	2.26	1.673	NS
SEm±	0.021	0.02	0.033	0.044	0.046	0.046	0.747	0.553	0.654

Soil porosity

The soil porosity decreased with increasing soil depth from 0-15 to 30-45 cm. The soil porosity (% pore space) was significantly higher under the different agroforestry tree species as compared to the agriculture sole cropping field. Among the tree species, the highest soil porosity was observed under *Q. leucotrichophora* which was significantly higher over the other trees. The increase in soil porosity under tree species as compared to the agriculture might be due to the addition of organic matter through leaf litter and penetration of fine roots of trees in soil. Similar results were reported by (Tandel *et al*., 2009) [81] who concluded after their studies that the soil porosity and water holding capacity improved under trees as compared to the agriculture field.

Soil chemical properties
Soil pH

The soil pH was significantly higher in sole agriculture field as compared to under tree species. Soil pH increased with increasing soil depth from 0-15 cm, 15-30 cm and 30-45 cm. The trend was common among all the tree species as well as under the agriculture (Table 3). The highest pH for the surface soil depths (0-15 cm, 15-30 cm and 30-45 cm) was under agriculture (7.06, 7.5 and 7.9), which was significantly higher over the other soil samples collected from the tree based agroforestry system. Among all the tree species, the highest pH range was observed under *T. grandis* (6.9, 7.1 to 7.4) for soil depths 0-15 cm, 15-30 cm and 30-45 cm, which was significantly higher than the other species for all depths while, the lowest pH was recorded under *Madhuca indica*. Relatively lower pH was observed under 0-15 cm soil depth than other soil depths. This might be probably due to the leaching of salts down the soil profile and getting deposited into the deeper layers of soil. The significantly lower soil pH at 0-15 cm soil depth under different agroforestry trees than the agriculture might be due to substantial addition of organic matter to the surface soil under trees and the release of organic acid during decomposition of litter. This might also be due to the leaching of soluble salts from the surface to the deeper layers of soil. Similar results and trends of variation in soil pH under agroforestry systems in comparison to crop fields has been reported by (Prasadini and Sreemannarayana, 2007; Kumar *et al*., 2008 and Newaj *et al*., 2007) [69, 42, 15] also observed nominal changes in soil pH under white siris (*A. procera*) based agroforestry system after four years of experimentation as the pH value was lower compared to the initial value and it was also lower than the pH value of the Agriculture field.

Electrical Conductivity (EC)

The soil EC showed a decrease with successive soil depth. The soil EC was relatively higher under trees as compared to the agriculture field. However the difference in EC was significant for all the soil depths *i.e* for 0-15 cm 15-30 cm and 30-45 cm. Among the tree species, the maximum EC of soil was observed under *T. grandis* for all the soil depths (0.437, 0.36 and 0.32) which was significantly higher over other tree species and agriculture. The minimum EC value among all the treatments was found in *Eucalyptus spp.*, which was significantly lower over other treatments. Soil electrical conductivity (EC) is a measurement correlating with soil properties that influence crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, soil salinity and sub-soil characteristics. The EC was higher under *T. grandis* as compared to the agriculture field which could be due to enrichment of soil mineral basic salts through addition and decomposition of litter. Similar results and reasons have been reported by (Newaj *et al.*, 2007) [57] who also observed significantly higher values for soil EC under *A. procera* based agri-silvicultural system as compared to the agricultural field. Also contrary to this (Malik *et al.,* 1996) [47] observed reduction in soil EC values by 10% under tree canopy as compared to the Agriculture area which was also observed in the present study in case of the other four species except teak for the surface soil depths.

Soil Organic Carbon (**SOC**)

The soil organic carbon (SOC) content was significantly higher under the tree species as compared to the agriculture field. Also, the SOC decreased with successive soil depths from 0-15 cm, 15-30 cm and 30-45 cm under all the trees. Among all the trees SOC carbon was found under *Q. leucotrichophora* (1.07, 0.90 and 0.84%) which was significantly higher over the other tree species, while lowest in *Shorea robusta* (0.92, 0.75 and 0.69%) in all soil depths.

Table 3

Treatments	Soil pH			Electric Conductivity EC (dS m^{-1})			Soil Organic Carbon SOC		
	Soil Depth (g/cm^3)			Soil Depth (g/cm^3)			Soil Depth (%)		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
Eucalyptus spp.	6.70	7.03	7.20	0.26	0.21	0.20	0.93	0.77	0.71
Tectona grandis	6.90	7.13	7.40	0.43	0.36	0.32	1.03	0.90	0.82
Melia azedarach	6.86	7.13	7.30	0.35	0.30	0.27	0.97	0.83	0.78
Madhuca indica	6.50	6.90	6.80	0.29	0.24	0.21	0.92	0.79	0.67
Anthocephalus cadamba	6.86	7.00	7.00	0.36	0.34	0.29	0.96	0.80	0.74
Shorea robusta	6.80	6.93	7.23	0.33	0.26	0.23	0.92	0.75	0.67
Populus deltoids	6.60	6.73	7.00	0.33	0.28	0.24	1.02	0.85	0.73
Quercus leucotrichophora	6.70	6.93	7.06	0.35	0.31	0.27	1.07	0.90	0.84
Agriculture (Open)	7.06	7.56	7.90	0.25	0.21	0.19	0.75	0.63	0.60
C.D.	0.228	0.354	0.305	0.016	0.012	0.012	0.037	0.038	0.031
SEm±	0.075	0.117	0.101	0.005	0.004	0.004	0.012	0.013	0.01

The soil enrichment in SOC content under tree based systems might be because of several factors such as addition of litter, annual recycling of fine root biomass and root exudates and its reduced oxidation of organic matter under tree shades (Gill and Burman, 2002) [25]. The results obtained in the present study are in conformity with the findings reported by (Pingale, 2009 and Ghimire, 2010) [68]. There was a decrease in SOC content of soil with increasing soil depth and the highest SOC was observed 0-15 cm soil depth for all the treatments. This may be attributed mainly to the contributions made by litter fall at the surface layer. Similar variation of SOC with increasing soil depth has been observed by some investigators (Swamy and Puri, 2005; Chauhan *et al.*, 2010 and Ghimire, 2010) [80, 14, 23]. Higher SOC content are observed under tree + crop systems not only in surface but in all the soil depths as compared to the Agricultures and uncultivated lands. This can be attributed to the recycling of organic matter through roots in the layers they occur. When the decomposition of a root residue takes place, they supply nutrients to the soil through the process of mineralization and also contribute to the addition of carbon in the soil through the humification process. Several researchers have reported that root biomass addition in an agroforestry system is generally higher than agriculture or agriculture fields (Sharma *et al.*, 2009) [14]. Also, trees generally have lignified cells in its plant parts such as litter, small branches, bark, roots etc. which may lead to the biochemical stabilization of organic carbon in the soil and hence leads to the improvement in SOC content of soil under agroforestry as concluded by (Six *et al.,* 2002) [77]. Therefore, one of the reasons for lower concentrations of SOC under both the Agriculture field (without tree) is attributed to the lack of lignified cells in agricultural residues. Further, the large scale tillage and other Cultural operations could be a probable cause to reduce the SOC content of soil under Agriculture with full exposure to sunlight.

Available Nitrogen (N)

The available soil nitrogen (kg/ha) was significantly influenced by different tree species and soil depths (Table 4). The available soil nitrogen was significantly higher under tree species as compared to the Agriculture field. This showed that the availability of nitrogen in soil decreased with successive increase in soil depth from 0-15 cm, 15-30 cm and 30-45 cm under all the treatments. Highest N content in soil was recorded under *Q. leucotrichophora* which was significantly higher than other tree species while lowest under *Tectona grandis*. The available N content in soil increased in different tree species under agro-forestry over the Agriculture field which is attributed to the addition of organic matter in soil in the form of litter fall and fine root biomass. The release of nutrient into the soil through the process of mineralization of organic matter leads to an increase in the nutrient status of soil (Osman *et al*., 2001) [60]. (Chaudhry *et al*., 2007) [13] also reported similar results as obtained in the present study after his studies on poplar based agroforestry systems. The highest amount of available N was found in surface soil *i.e* 0-15 cm due to more turn-over of the organic residues on the surface layer of soil which decreased with depth of soil. The lower most layer (60-90 cm) had the lowest available N content in soil**.** (Bhardwaj *et al*., 2001) [7] also observed a decreasing trend in available N content in soil with an increase in soil depth under high density poplar plantation. Some other researchers also observed similar trends during their studies on soil properties under poplar based agroforestry systems (Ghimire, 2010 and Swami *et al.*, 2006).

Available Phosphorus (P) in soil under different tree species and agriculture

The available phosphorus content (kg/ha) in soil showed a decreasing trend with increase in successive soil depth for all the treatments. The available P in soil was significantly higher under different tree species over the agriculture. The maximum available P content for soil depth 0-15 cm, 15-30 cm and 30-45 cm was observed under *Q. leucotrichophora* (26.56 kg/ha, 21.54 kg/ha and 17.59 kg/ha) respectively which was relatively higher as compared to the other tree species and agriculture followed by *T. grandis* (26.41 kg/ha, 20.96 kg/ha and 16.67 kg/ha). The minimum available P was observed under Agriculture (Open) in all the depths (16.14kg/ha, 14.44 kg/ha and 12.10kg/ha) which was significantly lower as compared to the other treatments. The highest available P was observed in *Tectona grandis* for all the soil depths (26.41, 20.96 and 16.67 kg/ha) which was significantly higher than other tree species while lowest in agriculture sole cropping system (16.14, 14.44 and 12.10 kg/ha). This might be due to higher activity of acidic phosphatase enzyme at these soil depths under this species over the other treatments, as the organic anion exudation and acid phosphatase activity may lead to an increase in the mobilization of P in rhizosphere. The available P decreased with an increase in soil depth in the present investigation which is in conformity with the findings of (Swami *et al*., 2006; Majumdar *et al.*, 2004 and Ghimire, 2010) [46, 23] who also observed similar trends on studying the soil properties under poplar based agroforestry system.

Table 4

Treatments	N (Kg/h)			P (Kg/h)			K (Kg/h)		
	Soil Depth			Soil Depth			Soil Depth		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
Eucalyptus spp.	324.56	291.47	270.96	18.09	15.01	13.42	153.67	143.43	122.35
Tectona grandis	258.12	245.29	221.93	26.41	20.96	16.67	151.45	141.25	120.65
Melia azedarach	272.54	242.60	215.47	24.35	18.68	14.18	166.13	156.33	128.82
Madhuca indica	312.03	290.87	311.96	17.97	15.48	13.01	148.84	138.81	122.60
Anthocephalus cadamba	337.04	324.93	315.96	21.87	16.49	13.35	162.81	152.42	129.72
Shorea robusta	333.04	323.93	268.50	26.00	19.10	15.20	154.56	144.36	118.29
Populus deltoids	306.34	280.32	257.71	24.87	17.37	13.90	148.67	138.58	124.78
Quercus leucotrichophora	357.26	345.15	332.18	26.56	21.54	17.59	167.56	157.26	132.26
Agriculture (Open)	232.73	217.61	198.12	16.14	14.44	12.10	135.68	125.62	118.43
C.D.	17.54	8.67	13.27	1.129	0.88	0.65	7.65	5.88	6.15
SEm±	5.80	2.87	4.39	0.373	0.291	0.22	2.532	2.31	2.034

Available Potassium (K) in soilunder different tree species and agriculture

The available potassium (kg/ha) in soil decreased with increasing soil depth (Table 5) under all the tree species as well as agriculture. The available K content in soil was significantly higher under trees as compared to the agriculture sole cropping field. The depths (0-15 cm, 15-30 cm and 30-45 cm) available K was highest in *Q. leucotrichophora* (167.56, 167.56 and 132.26 kg/ha) respectively, which was significantly higher over the other tree species while, lowest sole agriculture crop field (135.68, 135.68 and 118.43 kg/ha). The surface soil (0-15 cm) had higher level of available K in soil in comparison to the sub-surface soil (15-30 and 30-45 cm) and decreased with successive increase in soil depth. This trend was found for all the tree species as well as agriculture. This was probably as a consequence of higher amount of organic matter at the surface layer due to higher litter fall and fine root turn over at the surface layer of soil than the sub-surface layer. Also, higher mobility of potassium at the surface layer could be another cause for higher K content in surface soil than sub-surface and deeper layers of soil. Similar decrease in soil available K content in soil with increase in soil depth have been observed by several investigators like (Bhardwaj *et al.,* 2001; Swamy *et al.,* 2006; Mishra and Swamy, 2007) [7, 51, 55, 21]. The available soil potassium was higher under alley cropping system as compared to the Agriculture field as a result of release of organic acids due to organic matter accumulation under agroforestry and ultimately resulting in higher mineralization of potassium has been reported by (Miah *et al.,*2001) [48]. Such findings have also been conferred by (Bajpai *et al.,* 2006) [4] who reported higher K content in soil as a result of higher organic matter. Availability of potassium is also increased under agroforestry as compared to treeless farming systems because of enhanced recycling of nutrients through bio-chemical process as reported by (Hasan and Ashraful Alam, 2006) [31].

Soil biological properties under different agroforestry species and agriculture

Among different tree species bacterial population was significantly highest (62.67 × 10^6 cfu g-1 soil) in surface and sub-surface soil (33.33 × 10^6 cfu g-1 soil) under *Q. leucotrichophora.* The minimum bacterial population was in both surface and sub-surface soil in Agriculture (35.00 × 10^6 cfu g-1 soil) and (13.00 × 10^6 cfu g-1 soil). The number of bacteria count in soil decreased with increasing soil depth under all the tree species as well as agriculture. All the tree species has significantly higher microbial population in the soil as compared to the agriculture field in surface as well as sub-surface soil horizon. Bacterial population in soil within range as reported by (Whitman *et al*., 1998) [88]. They had reported that bacterial population in different soils ranged between 4-106 to 2-109 g^{-1} dry soil.

Table 5: Soil bacteria (no of colony per g soil × 10^6 cfu) and soil fungi (no of colony per g soil × 10^4 cfu) under different tree species and agriculture field.

Treatments	Bacterial colony		Fungal Colony	
	Soil Depth		Soil Depth	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Eucalyptus spp.	53.00	17.67	82.33	25.00
Tectona grandis	56.67	25.67	100.00	34.33
Melia azedarach	46.00	19.00	61.33	19.00
Madhuca indica	55.33	19.67	57.33	28.67
Anthocephalus cadamba	62.00	29.67	120.33	39.67
Shorea robusta	58.33	26.33	72.33	22.33
Populus deltoids	50.33	26.00	88.00	19.33
Quercus leucotrichophora	62.67	33.33	123.67	58.67
Agriculture (Open)	35.00	13.00	45.67	12.33
C.D.	1.98	1.16	1.94	1.39
SEm±	0.66	0.38	0.64	0.46

Fungi in soil under different tree species and agriculture

The fungal population in soil ranged between 58.67 to 123.67 × 10^4 cfu. g^{-1} soil and 12.33 to 45.67 × 104 cfu g-1 soil at the surface (0-15 cm) and sub-surface (15-30 cm) soil, respectively. The fungal population, irrespective of agroforestry system and agriculture, decreased significantly with soil depth. All the tree species has significantly higher fungal population as compared to the agriculture. This may be due to the high availability of fresh litter or/and root exudates at the soil surface to select for microbial communities that are able to rapidly utilize these labile carbon substrates. The microbial community residing in the deeper soil horizons are more severely resource limited than their surface-dwelling counterparts. Similar result was shown by (Taylor *et al*., 2002) [82] who reported that the fungi were isolated from surface soils but were absent from the deep soil samples. Decrease in organic matter content in sub-soil sample caused the lower number of fungal population in sub-surface soil. The surface soil has the highest species richness whereas sub-surface soil of barren sand dunes shows lowest richness. The results obtained during this course work pertaining to soil microbial biomass carbon (MBC) got significant support from the findings of earlier workers (Kaur *et al.*, 2000) [39] who had also reported that the rate of mineralization of soil microbial biomass carbon increased appreciably under agroforestry systems. An increased proportion of microbial carbon in the total soil organic pool indicate higher nutrient availability to the plants in agroforestry systems as compared to sole cropping. Similarly (Yadav *et al*., 2011) [14] observed that soil microbial biomass carbon was higher ranging from 262-320 μg g^{-1} under agroforestry corresponding to lower soil microbial biomass C (186 μg g^{-1}) under treeless control. The probable reason being the different organic inputs from trees in the form of litter fall, recycling of fine root biomass and pruning debris contributed significantly towards organic matter pool under agroforestry enhancing the microbial population and mineralization rate of carbon. Other researchers (Campbell *et al.*, 1991; Munna *et al.*, 2007) [12, 50] observed similar trends of decrease in microbial biomass C in soil with increasing soil depths.

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