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Soil health (physical, chemical and biological) status under short rotation tree plantations on riverain soils

Sanjeev Kumar Chauhan, Shawinder Singh, Sandeep Sharma, Bharat Bhushan Vashist, Rajni Sharma and Harmeet Singh Saralch

Abstract
Soil health under four multipurpose tree plantation (*Acacia catechu, Dalbergia sissoo, Melia azedarach* and *Terminalia arjuna*) after ten years of growth was assessed on riverain soils. Data revealed higher nutritional level under canopy of *Terminalia arjuna* than other three tree species. However, soil health in terms of physical and chemical parameters showed improvement under all the tree species than the control (tree-less area). An enhanced enzymatic activity besides microbial biomass carbon was observed underneath soil of different species than tree-less area, which shows ameliorative potential of soil through plantations on degraded soils.

Keywords: Plantation, soil amelioration, nutrients, microbial biomass carbon, water holding

Introduction

Agriculture in irrigated agro-ecosystem faces a very complex set of social and biophysical issues associated with the economic, social and environmental sustainability. Land degradation in the Indo-Gangatic plains occurred mainly due to human interference of the ecosystem not only to meet their actual demands but their greediness to harvest more crop yield by pumping out more underground irrigation water and making use of more inorganic fertilizers/agro-chemicals. The existing community/private land system has been excessively exploited for survival and realization of short-term objective without taking care of soil health for the posterity. The major cropland areas are depleted of nutrients very fast than the natural processes and degrading the soils. In farmers' fields breakdown of nutrient cycling and the loss of soil fertility and structure has resulted in the loss of biodiversity, the breakdown of ecosystem functions and the loss of crop yield. In traditional agriculture, trees used to be the integral component of the cropped area but the due to commercialization of agriculture, trees were first to be axed to realize more crop yield.

Tree species differ in their nutrient use efficiency for biomass production and recycling. Trees are known to maintain soil organic matter and nutrient cycling through the addition of litter, root residues into the soil, enzymatic reactions and ameliorating physical structure of the soil. Tree plantations, especially in the tropics, play an important role in carbon sequestration through the accumulation of carbon in the wood and increase in soil carbon storage. The availability of more wood biomass from plantations will facilitate in the exploitation of the potentials of using biofuels instead of fossil fuel in future and issue is gaining importance and a number of biomass based power plants have been commissioned to make use of agricultural residue judiciously, adding to income and generating carbon neutral power. Plantations also play an important role in meeting the biomass needs of local communities and industries thus helping in conserving the natural forest carbon pools, besides uplifting socio-economic status of adopters and sustainable environment for all.

In recent past emphasis has been placed on the physical and chemical changes being realised in cultivated lands but soil biological life has least been recognised. It can be assumed that the soil fertility is primarily associated with soil microbial activity and soil biological parameters. Soil microbial biomass comprise about 1-5 per cent of organic carbon in soil. It acts as a source and sinks for the plant nutrients playing a crucial role in nutrient cycling and soil organic matter dynamics. It is the prime agent involved in plant residue decomposition, nutrient conservation and cycling processes in the soil [40, 43]. The microbial biomass has therefore been used as an index of soil fertility, which depends on nutrient fluxes [18]. The soil should be monitored regularly for nutrient deficiencies and/or other problems. There are different strategies i.e., inorganic fertilizers, organic soil management, biological amelioration, etc. to look after these problems but integration of trees on degraded lands not only ameliorates soil in terms of physical, chemical and biological processes but supports economically. This paper deal with amelioration of degraded riverain soil through plantations.

Material and Methods

The study was carried out to record the soil health under four fast growing tree species after ten years of plantation on the bank of Satluj river at University Seed Farm, Ladhowal, Ludhiana. The site is situated at an elevation of 223m above mean sea level and lies at 30° 58" latitude and 75° 45" longitude, which represents the central agro-climatic zone of the Punjab with mean monthly temperature ranging from 12.9°C (January) to 32.2°C (June). The area receives an average rainfall of 732mm per annum and eighty per cent is received during July to September. Four short rotation tree species (*Acacia catechu, Melia azedarach, Dalbergia sissoo* and *Terminalia arjuna*) were used for the study to compare the soil health in comparison to open condition. The growth/annual increment of tree species is presented in Table 1, whereas, the biomass partitioning is depicted in Fig.1 for reference.

The soil samples from surface (0-15 cm) and subsurface (15-30 cm) layer were collected with the help of post-hole auger at five sites in each plot of different tree species and adjoining non-planted sites. The soil samples from different sites under each species were mixed together and a composite sample from each plot was prepared. Thus for each treatment, three samples were prepared and analyzed for various parameters including samples from control plot.

Table 1: Growth performance of different tree species (ten years)

Species	DBH (cm)	Height (m)	Canopy spread (m^2)	Root spread (m^2)	Root depth (m)
Acacia catechu	20.59 (2.06)	10.37 (1.04)	56.53	34.77	3.8
Dalbergia sissoo	20.70 (2.07)	9.2 (0.92)	54.09	24.91	3.0
Melia azedarach	17.52 (1.75)	9.3 (0.93)	95.2	18.48	4.1
Terminalia arjuna	28.56 (2.86)	11.37 (1.14)	80.68	26.4	3.5
CD (p=0.05)	3.71 (0.37)	1.64 (0.16)	12.65	1.88	1.64

*Mean annual increment (DBH and Height) in parentheses

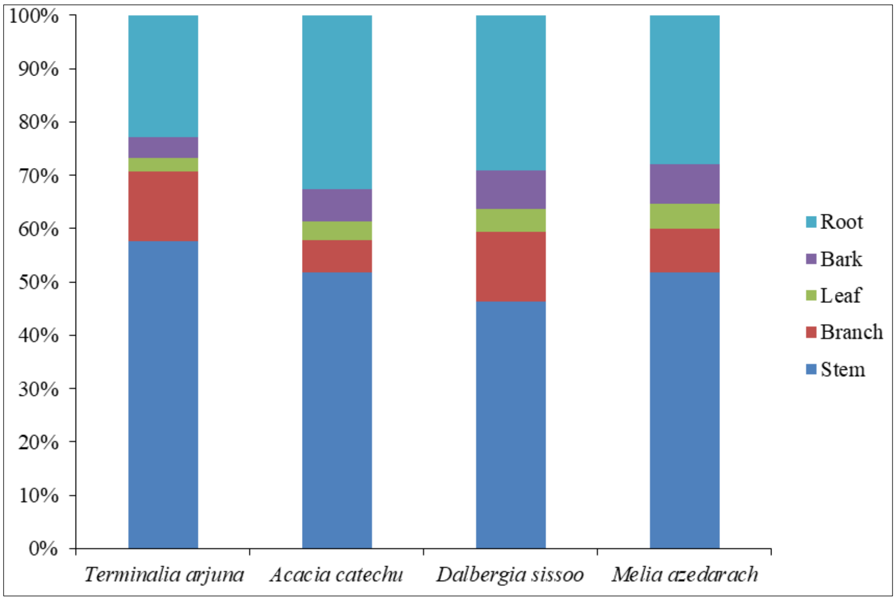


Fig 1: Biomass proportion (dry weight basis) in four tree species

Physical Properties

pH and electrical conductivity (dS m^{-1}): Equilibrium pH of 1:2 soil water suspension and saturated extract was determined with Elicho L1-10 and the electrical conductivity of 1:2 soil water supernatant (kept overnight) was estimated using solubridge.

Bulk density (Mg m^{-3}): For the determination of bulk density, fresh weight of each sample collected by soil core sampler was taken from five different depths (0-15, 15-30, 30-60 and 60-90). The undisturbed soil cores were taken out at all the depths with the help of cylindrical iron ring and dried in an oven at 105°C for 24 hours or till the weight of the soil become constant. The ratio of dry soil mass of core and internal volume of the cylindrical ring (equivalent to bulk soil volume) is expressed as bulk density of soil in Mg m^{-3} [6].

$$\text{Bulk density (Bd)} = Ms / Vt$$

Where,

Ms = mass of dry soil (Mg)

Vt = total volume of soils (m^3).

Water retention characteristics: The water retention characteristic was determined by Pressure Plate Assembly. The readings were observed at 0.3,0.5, 1.5, 3, 5, 10 and 15 bar [8].

Chemical Properties

Organic carbon (%) and SOC (Mg ha^{-1}): Total organic carbon was estimated by Walkley and Black (1934) [34] rapid titration method. For this purpose, 2g soil sample was treated with 10 ml of 1N $K_2Cr_2O_7$, 20 ml of concentrated H_2SO_4 and 5g of sodium fluoride and 100 ml of distilled water. To this, 10 drops of diphenylamine indicator were added and it was treated with N_2 ferrous ammonium sulphate till the colour of the solution changed from violet to bright green. The organic carbon was calculated from the amount of ferrous ammonium sulphate consumed in the titration.

The organic carbon concentration in the soil was converted to total SOC pool as per Kukal *et al.* (2009) [25] and described below:

Total SOC pool = (OC/100) × (Bd × 1500)
Where, total SOC pool is weight of soil organic carbon (Mg ha^{-1})
OC - soil organic carbon (%)
Bd - soil bulk density of respective layer (Mg m^{-3})
1500 is the volume (m^3) of 1 hectare furrow slice (15cm)

Available N (kg ha^{-1}): Available N was estimated by alkaline-permanganate method given by Subbiah and Asija (1965) [45]. 5g soil was treated with an excess of alkaline $KMno_4$ and the ammonia, thus evolved is absorbed in a standard acid. The excess of the acid was titrated with a standard alkali using methyl red as indicator and from the volume of H_2SO_4 used for absorption of ammonia, the amount of nitrogen in the given soil sample was calculated.

Available P (kg ha^{-1}): The available phosphorous was determined by extracting the soil samples with 0.03 NH_4F + 0.025N HCL [7] and measuring the P content in the extract by calorimetric method using a spectrophotometer at 760 nm wavelength using ascorbic acid method.

Available K (kg ha^{-1}): Available potassium content was estimated by extraction with neutral normal ammonium acetate and determined on flame photometer [29].

Biological Properties

Dehydrogenase activity of soils (g TPF g^{-1} soil hr^{-1}): Weighed exact 10 g of soil mixed with $CaCO_3$ in each of three vials (20 ml). Add 0.5 ml of TTC solution to two vials and third tube as control. Incubated for 24 hours at 37ºC, after incubation added 5ml of methanol to each vial and shaked properly. The pink colour developed and measured at a wavelength of 485 nm on spectrophotometer or colorimeter using methanol as blank [22].

Microbial biomass carbon: Microbial biomass C was measured by the chloroform fumigation extraction method [51]. Two portion of moist soil (20 g oven dry soil) were weighed, the first one (non- fumigated) was immediately extracted with 80 ml of 0.5 M K_2SO_4 for 30 minutes by oscillating shaking and filtered (Whatman no. 42); the second one was fumigated for 24 h with ethanol free $CHCL_3$ and then extracted. Extractable organic carbon in soil extracts was analyzed by dichromate digestion.

The data generated was analyzed using analysis of variance (ANOVA) and the results compared at 95% of significance on the basis of least square difference (LSD 0.05) values as described by Gomez and Gomez (1984) [16].

Results and Discussion

Influences on Soil Health by Tree Plantations

Soil is largest reservoir for all essential nutrients. With increasing emphasis on fast growing trees in short rotation forestry, nutritional requirement of the trees has to be considered for optimum forest productivity, particularly when such trees are planted on degraded lands of low fertility status. Short rotation trees could affect the soil quality by causing changes in physical, chemical and biological properties including soil biodiversity. Tree species differ in their nutrient use efficiencies for biomass production. The removal of nutrients can be altered by varying plantation and harvest design [54]. Data presented in Table 2 depict the important soil physical and chemical parameters in two different soil depths i.e., soil pH, electrical conductivity, organic carbon, available nitrogen, phosphorus and potassium. Bulk density, soil water retention and biological properties such as dehydrogenase enzymatic activity and microbial biomass carbon under plantations of different fast growing tree species have been prescribed in Fig 2, 5 and table 3, respectively. The chemical and biological characteristics of the soil improved below the tree canopy, may be due to return of nutrient rich leaf litter to the soil surface and its subsequent release in soil on decomposition.

Soil pH and Electric conductivity: The data presented in Table 2 clearly show that there was no significant impact of afforestation on pH value of the soil but some reduction was observed in all plantation sites except site having plantation of *Acacia catechu*. Significant variation in the EC of the soil existed and it ranged between 0.36 dS m^{-1} and 0.53 dS m^{-1} in the top 15 cm of the soil profile (Table 2). While in the subsurface soil profile between 15 cm to 30 cm, the values of EC ranged from 0.28 dS m^{-1} to 0.41 dS m^{-1}. The EC values decreased with increase in the soil depth, which is possibly due to the slow mobility of salts of various ions towards lower horizons. The variation in high litter fall addition leads to higher values of electric conductivity under the tree plantations. The differences in the soil ameliorative efficiency of different tree species may be due to the differences in absorption and translocation of sodium salts.

Bulk density: It is evident from the data presented in Fig.4 that there was no significant difference in bulk density of soil at different depths. Bulk density ranged from 1.09 to 1.53 Mg m^{-3} under plantations. Maximum value was noticed in 0-15 cm soil depth. Surface layer had comparatively higher values of bulk density than deeper layers. The lesser value of bulk density in deeper layer may be due to the less sand particle or more clay particles and lesser disturbance by heavy machinery. In present study, no inter-cultivation was followed so there was less use of heavy machinery. A study conducted by Koul and Panwar (2012) [23] in which they observed a decrease in bulk density with increase in tree component is correlated to more organic matter, which leads to better soil structure and hence more porosity. The bulk density has been observed to be inversely related to tillage intensity by Halvorson *et al* (2002) [19] and also by Baruah and Barthakur (1997) [3]. Similar observations were reported by Lal (1989) [27] and Sen (2014) [35]. An increase in bulk density with depth has also been observed by different workers under different soil types. Stockfish *et al* (1999) [44] observed that bulk density increased with depth due to compaction. The increase is largely because of decreasing organic matter content and reduced aggregation with depth. The reduction in bulk density may be ascribed to increased soil porosity and better aggregation by decomposition of crop residue in the soil [4]. Shirani *et al* (2002) [38] also reported a significant decrease in surface layer bulk density of the manured fields. Slight reduction in bulk density was observed in plantation area than open area, which finds the support of Seobi *et al*. (2005) [36]. Changes in bulk density could be attributed to improvement in soil properties caused by the permanent vegetation. Roots, bio-pores, organic matter, fauna, and other related biological processes, as well as management contributed to improvement in soil physical properties [49].

Available soil N: Higher available soil N was noticed in soil profile from 0-15 cm depth, i.e., 124.9 - 166.8 kg ha^{-1}. The maximum value of available soil N was found under *Terminalia arjuna* (166.8 kg ha^{-1}), which was significantly higher than the other three species including tree less area. This was followed by *Melia azedarach* (156.9 kg ha^{-1}), *Dalbergia sissoo* (148.1 kg ha^{-1}) and *Acacia catechu* (145.7 kg ha^{-1}). The nitrogen accumulation was 25% more under *Terminalia arjuna* plantation as compared to the site without tree species. The soil N content decreased as we move to the lower horizons of the soil. *Acacia catechu* and *Dalbergia sissoo* are both nitrogen fixing tree species and the activity of root symbionts such as nitrogen – fixing nodule could increase soil N level and as the suitable carbon substrate provide an energy source for bacterial mineralization and thereby enhance the availability of other soil nutrients as well [11]. Good amount of litter fall addition in the soil lead to higher accumulation of soil N. These are in accordance with the findings of Yadava (2001) [55], who reported that the available soil nitrogen has been higher under the plantation throughout the soil depth, with the maximum in top 15 cm of the soil profile. Mohsin and Ram (2002) [31] also reported higher levels of the available soil nitrogen, phosphorus and potassium (kg ha^{-1}) under the tree plantations at various depths of the soil. They also found that the nutrient contents were higher in the top 0-15 cm of the soil profile and decreased with the increase in depth of the soil, which may be due to the surface layer enrichment through nutrient cycling. Similarly, Swamy *et al* (2003) [46] also reported that total N accumulation in six year old stand of *Gmelina arborea* ranged from 212.9 to 279.5 kg ha^{-1}. In another similar study conducted by Singh *et al* (2009) [41] at highly degraded site, the nitrogen accumulation due to plantation of multipurpose tree species (MPT) increased and was found 250.88 kg ha^{-1}. Singh *et al* (2012) [42] also reported improvement in physico-chemical properties under *Terminalia arjuna* than open condition.

Available P: There were significant differences in available soil phosphorous content, which ranged between 17.3 to 31 kg ha^{-1} at 0-15 cm depth, and 11.6 to 25.7 kg ha^{-1} at 15-30 cm depth. The maximum content of available P was recorded under *Terminalia arjuna* (31 kg ha^{-1}), which is significantly higher than other species. All the other three tree species of *Acacia catechu, Dalbergia sissoo* and *Melia azedarach* had phosphorus content of 26.6, 24.4 and 28.3 kg ha^{-1}, respectively (statistically at par with each other). Swamy *et al* (2006) [47] also noticed that the concentration of soil chemical parameters was higher in 0-20 cm soil depth and decreased with increase in soil depth. Similar findings have been reported by Mohsin and Ram (2002) [31], Yadava (2001) [55], Singh and Sharma (2007) [39]. Sharma *et al* (1994) [37] have also reported higher concentration of nitrogen and phosphorus in N_2 fixing *Alnus* species as compared to non-N_2 fixing mixed tree species. Yadav *et al* (2008) [56] ascribed the increase in N & P to microbial immobilization and decrease to the mineralization of nutrients from the decomposing litter.

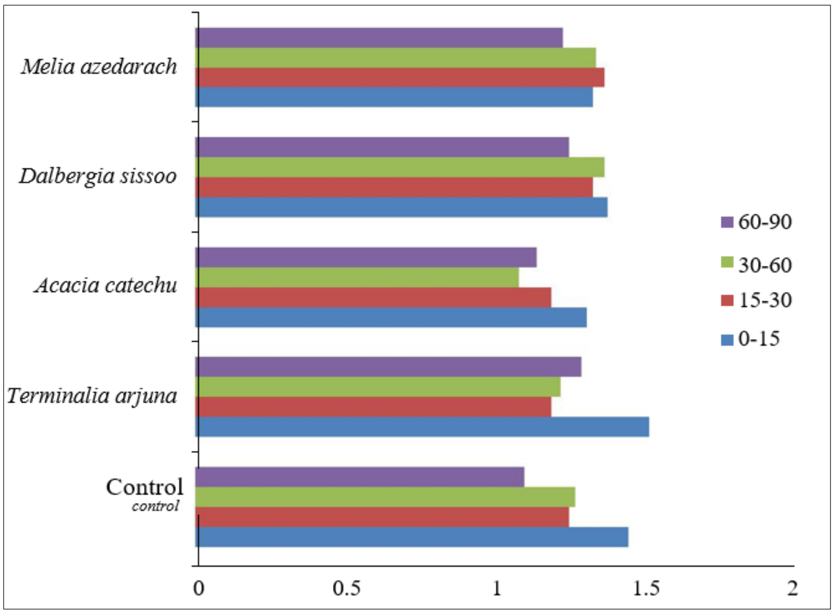


Fig 2: Bulk density of soil profile under different species

Available K: Significant differences in available potassium content of the soil were recorded under different tree species (Table 2). The potassium content at the surface layer i.e., at 0-15 cm ranged between 156.7 to 232.3 kg ha^{-1} under plantations of four different species but much more than under control (97 kg ha^{-1}). The available K content under trees was significantly higher than control by 58 %. The higher potassium content under plantations may be due to the litterfall and presence of good amount of grasses on site.

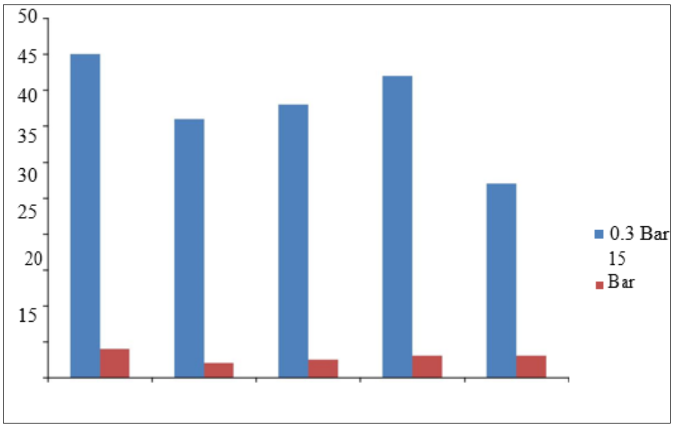
These results are in agreement with the findings of Swamy *et al* (2006) [47], and also with the studies conducted by Singh and Sharma (2007) [39]. They noticed that higher organic carbon (OC) and available nitrogen, phosphorus and potassium content were observed in the soil under plantations than from a site without trees. Higher build-up of available nutrients (N, P and K) on surface layers under tree species is attributed to accumulation and decomposition of litterfall on the soil surface as well as its incorporation in the soil surface layers. It leads to mineralization of organic N and P from the litter and its release into the soil. Higher availability of K at surface layers under trees is attributed to liberation of K by decomposition process of litterfall as well as solubilization of insoluble forms of K present in soil due to organic decomposition products. The differences in available nutrient content under different species might be due to variation in nutrient concentration of litter, total litter production and varying rates of mineralization in these species. Yadav *et al* (2008) [56], Das and Chaturvedi (2008) [11] also recorded improvement in soil chemical properties under different tree species. Inter-species variations in litter fall have also been observed by Garg (1997) [14]; George and Kumar (1998) [15] presumably due to release of nutrient by leaf litter in soil and variation under different species for quantity/quality of litter produced by the respective species. Kumar *et al* (1993) [26] favoured the improvement of physico-chemical characteristics of soil under tree canopy.

Table 2: Chemical properties of soil (0-15 cm)

Species	EC	pH	OC (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Control	0.39(0.33)	8.54(8.65)	0.23(0.22)	124.9(132.4)	17.3(11.6)	97.0(71.3)
Terminalia arjuna	0.53(0.41)	8.42(8.56)	0.64(0.48)	166.8(158.9)	31.0(25.7)	232.3(196.7)
Acacia catechu	0.42(0.37)	8.55(8.62)	0.46(0.46)	145.7(148.7)	26.6(22.4)	164.7(133.3)
Dalbergia sissoo	0.39(0.28)	8.52(8.70)	0.42(0.39)	148.1(138.1)	24.4(19.1)	156.7(123.7)
Melia azedarach	0.36(0.34)	8.51(8.62)	0.38(0.32)	156.9(150.1)	28.3(23.2)	171.0(140.0)
CD (p=0.05)	0.01(0.01)	NS(NS)	0.08(0.06)	6.9(2.7)	5.1(3.3)	16.2(9.2)

Soil chemical properties (15-30 cm) in parentheses

Water retention characteristics: Water retention characteristics of soil differed significantly under different species (Fig. 3). At 0.3 bar, soil water retention ranged between 27 to 45%, whereas, at 15 bar or wilting point, it ranged between 2.5 to 4.00%. The result of study showed the capacity of soil to retain water was more at 0.3 bar and low at 15 bar. All the species behave better than site without trees. Similar results were reported by Sen (2014) [35] in ten fast growing tree species after eight years of growth. Water retention properties of soil can be correlated with the soil organic carbon, this property can be enhanced with increase in the organic matter of the soil. Organic matter addition takes place continuously with gradual addition of leaf litter. Ramesh *et al* (2013) [34] also recorded higher moisture content under trees because of improvement in soil physical characters.



Terminalia, Acacia, Dalbergia, Melia, Control, Arjuna, catechu, sissoo azadirach

Fig 3: Water retention characteristics of soil under different tree species

Soil Biological Properties

Addition of organic matter makes significant changes in the degraded soils with respect to physico-chemical and biological properties. The problem is most actively managed through afforestation. Information on the dynamics of soil organic matter and nutrient cycling, which are closely related to the microbial driven process of nutrient immobilization and minerlization in agro-ecosystems is limited [13, 17]. Now a days studies are increasingly focusing on the dynamics of soil microbes, which due to their ability to serve both source and sink of plant nutrients and as a driving force of nutrient availability play a key role in the process [28, 10]. Soil microbial diversity and activities are intricately tied to the overall soil health and long term soil productivity. Enzyme assays provide quantitative information on functional diversity of microbial activity, soil chemical processes, mineralization rates, and organic matter accumulation. Some enzymes are routinely produced by microbial cells while others are formed in the presence of an appropriate substrate [21]. Soil enzyme activities are very sensitive to both natural and anthropogenic disturbances, and show a quick response to the induced changes [12]. The presence of a large and diverse soil microbial community is crucial to the productivity of any agroecosystem. Enzymatic activities can be considered effective indicators of soil quality changes resulting from environmental stress or management practices. Previous research suggests that relationships between organic matter, microbial activity, and microbial biomass are good indicators of soil maturity [1, 20].

Dehydrogenase activity: The dehydrogenase activity in soil under 0-15 cm varied significantly in two succeeding depths (Table 3). The dehydrogenase activity was maximum under *Terminalia arjuna* (176.3 µg TPF g^{-1} soil hr^{-1}) followed by *Melia azedarach* (124.3 µg TPF g^{-1} soil hr^{-1}). Whereas, lower activities was found under both the leguminous species with minimum activity under *Dalbergia sissoo* (109.3 µg TPF g^{-1} soil hr^{-1}). The less decomposed organic matter is main source of energy for enzymatic activity. The plantation of *Terminalia arjuna* had abundant of leaf litter, which provided food and medium of energy to micro–organisms, hence had good enzyme activity than other species. Vegetative cover provides favorable conditions for a balanced soil functional diversity reflected by higher enzyme activities compared with soils without trees. Increased enzyme activities in these studies are attributed to increased organic matter and litter quality and quantity as well as improved soil physical parameters. Increased enzyme activity is proportionally linked to microbial function leading to improved nutrient cycling and availability, which favors root growth, promotes beneficial plant–microbial interactions, and eventually increases the total soil carbon pool [50]. Veres *et al* (2013) [52] conducted a similar study to observe the effect of leaf litter on enzymatic activity and they found that with decrease in litter production, soil dehydrogenase activity also decreased. Decomposition of litterfall and decay of roots under the canopy of tree are important for supplying energy for microbial populations, thus resulting in increase in microbial biomass carbon.

Microbial biomass carbon (MBC): Microbial biomass carbon is not accorded much importance in accounting carbon in the ecosystem, though it contributes a large proportion. Maximum microbial biomass carbon was found under *Terminalia arjuna*, while other three species exhibited statistically at par values to each other. MBC was observed more than 200 per cent higher in *Terminalia arjuna* plantation than control (Table 3). Bardhan *et al* (2013) [2] noticed that the soil microbial diversity is intricately tied to the overall soil health and long term soil productivity. Very few studies have investigated soil microbial biomass and enzymatic activities under plantations [24, 32, 33]. Soil enzymes and microflora regulate ecosystem functioning and play a key role in nutrient cycling. In few studies of semi-arid region where monoculture as well as mixed forests were developed, both have reclaimed the soil to a considerable level [5, 30, 48]. Ramesh *et al* (2013) [34] recorded 34% soil microbial biomass carbon under multipurpose trees than control. Yadav *et al* (2011) [57] recorded soil microbial biomass carbon of 262-320 µg g^{-1} under agroforestry plantation than corresponding carbon of 186 µg g^{-1} under a no tree control and attributed to varying degree of organic matter input through litterfall and fine roots.

Table 3: Biological properties (0-15 cm) of soil

Species	Dehydrogenase (µg TPF/g soil/hr)	Microbial biomass carbon(µg/gm)	
Control	45.0(25.7)	180	(164)
Terminalia arjuna	176.3(154.3)	729	(462)
Acacia catechu	113.0 (77.7)	315	(224)
Dalbergia sissoo	109.3 (67.7)	369	(206)
Melia azedarach	124.3 (47.0)	477	(297)
CD (p=0.05)	15.6(10.9)	178.17	(100.22)

Biological properties (15-30 cm) in parentheses

Measured physical, chemical and biological properties in the present study showed a significant effect on the soil quality indicators in less than 10 years. However, the response varied with vegetation type. The loss of nutrient in the rich surface layer cannot be compensated by additional inputs. Soil improvement technologies including integration of trees can ameliorate the degraded land including riverain soils.

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