Mysore J. Agric. Sci., 57 (1) : 229-244 (2023)

Impact of Different Land - Use Systems on Soil Physico-chemical Properties

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Received : August 2022
Accepted : November 2022

ABSTRACT

Changes in land use and improper soil management have led to severe land degradation around the globe through the modification in soil physico-chemical and biological processes. The study aimed to assess the soil properties of different land use system types. In this regard soil samples (0-30 cm, 30-60 cm and 60-90 cm depth) were collected from different land uses; Natural forest, teak plantation, horticulture (mango and guava) land use system, agriculture (Finger millet cropping system), agri-horti land use system (custard and amla) and agroforestry (melia dubia). Soil collected from different land use systems was analyzed for both physical and chemical properties. The present investigation revealed that the soil texture was sandy clay loam. The mean bulk density of the soils ranged from 1.28 and 1.38 g cm^{-3} and the mean total porosity ranged from 35.54 - 42.71 per cent. The soil pH was acidic in agriculture (Finger millet cropping system-chemical fertilizer) land use and neutral in other land use systems and the mean electrical conductivity value ranged from 0.06-0.11 dSm^{-1}. The highest mean value (1.11%) of organic carbon was recorded in natural forest and the lowest mean value (0.25%) was recorded in agriculture (Finger millet cropping system-chemical fertilizer) land use. However, the mean values of available N ranged from 141.32 kg ha^{-1} to 260.02 kg ha^{-1}. Higher mean available P_2O_5 (88.76 kg ha^{-1}) and K_2O (207.59 kg ha^{-1}) were recorded in agriculture land use (Finger millet cropping system-integrated nutrient management). The concentration of secondary and micronutrients were higher in natural forest and tree plantations. The study revealed that conversion of natural forest to different land use systems had adverse effects on soil physical and chemical properties. Therefore, land use systems in the region must adopt a suitable management practice to enhance soil fertility and productivity.

Keywords : Soil properties, Soil depth, Natural forest, Teak plantation, Horticulture land use system, Agriculture, Agri-horti land use system and agroforestry

CHANGING land use from forest to croplands leads to a change in the chemical, physical and biological properties of the soil. Deforestation increases soil erosion which leads to floods, drought and natural ecosystem degradation. Land use change to cropland have changed significantly from the twentieth century, it is estimated that 25 per cent of the Earth's surface will be occupied by cropland, shifting cultivation and livestock production in the twenty first century. Globally the decreasing rate of forest was about 10 million hectares per year between 2015 and 2020 (UN FAO forestry data 2020). In the Indian context, about 275 million people, comprising nearly 27 per cent of the country's population, depend on forests for their subsistence or livelihoods (CSE 2020). The increasing demand for forest resources from global markets have contributed to the increased rates of conversion of forests to plantation crops.

Soil is an important component of terrestrial ecosystems, which directly or indirectly influences the life on earth. Soil health is one of the important deciding factors in the success of human civilization. In the recent past, with population explosion and urbanization, the forest land is permanently converted to various other land use systems *viz.,* agriculture, horticulture, plantations, agroforestry apart from various other uses. The intention of conversion of land is primarily to increase the production of food, fodder and wood to meet the increasing needs of burgeoning population. In the race to meet the production goals farming community has resorted to, inappropriate land use and soil management practices in terms of monoculture, intensive cropping patterns with heavy mechanization and injudicious usage of agri-chemicals (Chandel *et al*., 2018), rendering soil health and its sustainability completely out of context. In this context a study was conducted to know the Impact of different land - use systems on soil physico-chemical properties'

Material and Methods

Study Area

The study was conducted in different land use systems at University of Agricultural Sciences, GKVK, Bengaluru, Karnataka. It is located in the Northern part of Bengaluru between Latitude: 13º 05' North and Longitude: 77º 34' East and Altitude: 924 m (above mean sea level). GKVK has a tropical climate with distinct wet and dry seasons. The maximum and minimum temperature recorded was 29.6 and 18.2º C respectively. The annual rainfall for the period 1986 to 2021 ranged from 461 mm to 1115.8 mm, with a mean of 712 mm. The average relative humidity at 7:00 a.m. and 2:00 p.m. ranged from 89 - 47 per cent, respectively. The average wind speed recorded was 6.4 kmph. The annual mean sunshine was 6.7 hours.

The study area comprised of different predominant land use systems such as agriculture (Finger millet), horticulture (Mango and Guava), agri-horti system (Custard apple and Amla) and plantation (Teak and Melia dubia.) which have widely replaced the natural forest of GKVK. Hence to assess the impact of different land use systems on soil physico-chemical properties among different land uses. Different-land uses were identified such as;

1) Natural Forest: An undisturbed forest area and it was classified as dry deciduous forest. The forest area mainly comprised of *Acacia ferruginea, Ailanthus triphysa, Albizia amara, Albizia lebbeck, Albizia odoratissima, Azadirachta indica, Cassia siamea, Eucalyptus sp., Gliricidia sepium, Hardwickia binnata, Leucaena leucocephala, Pongamia pinnata, Santalum album, Swietenia macrophylla and Tamarindus indica* etc. 2) Teak plantations: The plantation was established in the year of 1986, with a spacing of 2 m x 2 m spacing. 3) Mango land use system: The mango plantation was established over an area of 10 hectares between 1974 - 77 with a spacing of 10 m x 10 m. 4) Guava land use system: The guava plantation was established in 1994 with a spacing of 6 m x 3 m. 5) Custard apple land use system: The custard apple saplings were planted during 2009 with a spacing of 5 m X 5m and finger millet, field bean, cowpea, niger, foxtail millet and fodder maize were grown continuously as inter crops from 2012. 6) Amla land use system: The amla saplings were planted during 2009 with a spacing of 6 m x 6 m and finger millet, field bean, cowpea, niger, foxtail millet and fodder maize were grown continuously as inter crops from 2012.) 7) Finger millet cropping system-chemical fertilizer: The finger millet crop is being continuously fertilized 50:50:25 N:P:K kg/ha/year since 1978.8) Finger millet cropping system-organic manure: The finger millet crop is being continuously manured with FYM 10 t/ha/year since 1978.9) Finger millet cropping system-integrated nutrient management: The finger millet crop is being continuously manured with FYM 10 t/ha/year and 50:50:25 N:P:K kg/ha/year since 1978 and 10) Melia dubia land use system: Melia dubia plantation was established during 2012 with a spacing of 8 m x 5 m spacing.

Soil Sampling and Analysis

In each land use system, five quadrats measuring 20 m x 20 m were randomly laid down in such a way that it represents the land use studied. Within each quadrat, soils were collected from ten points (5 in the corners and 5 in the center) at three depth classes *i.e.* 0-30, 30-60 and 60-90 cm. The five subsamples at each location and depth class were pooled to get one composite sample for each depth class per plot. The soils were mixed thoroughly and large plant debris, roots and stones were removed manually by hand. Equal number of soil samples from the same depths were collected from undisturbed plots separately for bulk density by using soil core of known volume. In the laboratory, the soil samples were homogenized, air-dried, grounded and passed through 2 mm sieve for further physical and chemical analysis.

Physico-Chemical Analysis of the Soils

Air-dried soil samples were used for analysis of texture, bulk density, pH, electrical conductivity (EC), organic C, available N, P_2O_5, K_2O, exchangeable cations *i.e.* Ca and Mg, available S and micronutrients. Soil texture was estimated using an International pipette method as described by Black (1965). Bulk density was determined by the core (Grossman and Reinsch 2002). Soil pH and electrical conductivity in soil samples were measured in 1:2 soil: water extract as outlined by Jackson (1973). Organic C was estimated by Walkley and Black (1934) rapid titration method. The alkaline potassium permanganate method was adopted to analyse the available nitrogen content in soils (Subbaiah and Asija, 1956). The available phosphorus in the soil samples was determined by Bray's No.1 reagent (0.03 NH_4F + 0.025 N HCl) (Jackson, 1973). The available sulphur was determined as described by Black (1965). Available potassium was extracted with 1 M ammonium acetate at pH 7 and measured using a flame photometer (Page *et al.*, 1982). Exchangeable calcium and magnesium were estimated by titrating suitable aliquot of ammonium acetate extract of soil against standard EDTA solution as described by Piper (1966) and The micro nutrients such as Zn, Cu, Mn and Fe were extracted by using DTPA (Diethylene tri amine penta acetic acid) and measured by using AAS (Lindsay and Norwell 1978).

Statistical Analyses

Analysis of variance (ANOVA) at 95 per cent confidence level was analyzed taking sampling sites as replicates (random effects) and land use types as treatments (fixed effects) using MS EXCEL and using SPSS for windows (IBM SPSS ver. 17.0).

Results and Discussion

Effect of different Land-use Systems on Physical Properties of Soil

Particle Size Distribution

The soils of different land use systems were sandy clay loam in texture. Among different land use systems, the highest mean value of sand content (67.49%) was recorded in finger millet cropping system-organic manure and the lowest mean value (54.67%) was recorded in amla land use system. The highest mean value of silt content (12.55%) was recorded in natural forest and the lowest mean value (5.91%) was recorded in finger millet cropping system-chemical fertilizer. The highest mean value of clay content (34.43%) was recorded in amla land use and the lowest mean value (23.94%) was recorded in finger millet cropping system-chemical fertilizer (Table 1). This could probably due to soils which were derived from coarse grained parent materials. The soils were dominant in sand content but the accumulation of clay and silt were observed in the subsurface layer with decrease in sand content. Similar results have been reported. According to the results of analysis of variance (ANOVA) revealed that there was a significant difference of the sand and clay particle under different land use systems at different soil depths. The highest (73.18%) and the lowest (47.26%) value of sand was recorded on the surface (0-30 cm) soil layer of finger millet cropping system-chemical fertilizer and subsurface layer (60-90 cm) of teak plantation, respectively (Table 1). Whereas the highest (39.38%) and lowest (19.76%) values of clay content were recorded in the subsurface (60-90 cm) soil layer of the amla land use system and surface layer of guava land use, respectively (Table 1).

Under different soil depth, the higher sand content was obtained at the surface (0-30 cm) soil layer, whereas the higher silt and clay content was recorded in the subsurface (60-90 cm) soil layer (Table 1).

TABLE 1

Physical properties of soils under different land use systems

Land use systems	Depth (cm)	Particle size (%)			Textural class	BD (g cm^{-3})	Total Porosity (%)	MWHC (%)
		Sand	Silt	Clay				
Natural Forest	0-30	62.02	9.27	28.71	SCL	1.21	45.98	41.15
	30-60	58.78	11.92	31.3	SCL	1.29	42.41	35.24
	60-90	52.89	16.45	30.66	SCL	1.35	39.73	32.67
	Range	52.89-62.02	9.27-16.45	28.71-31.30		1.21-1.35	39.73-45.98	32.67-41.15
	mean	57.9	12.55	30.22		1.28	42.71	36.35
Teak	0-30	68.12	7.23	24.65	SCL	1.28	41.53	37.32
	30-60	57.15	10.18	32.67	SCL	1.33	39.41	33.96
	60-90	47.26	15.43	37.31	SCL	1.41	38.56	30.87
	Range	47.26-68.12	7.23-15.43	24.65-37.31		1.28-1.41	38.56-41.53	30.87-37.32
	mean	57.51	10.95	31.54		1.34	39.83	34.05
Mango	0-30	70.21	7.23	23.56	SCL	1.3	41.74	36.01
	30-60	68.45	8.28	23.27	SCL	1.36	39.78	31.23
	60-90	59.76	9.73	30.51	SCL	1.4	37.17	21.56
	Range	59.76-70.21	7.23-9.73	23.27-30.51		1.30-1.40	37.17-41.74	21.56-36.01
	mean	66.14	8.41	25.78		1.35	39.56	29.6
Guava	0-30	71.41	8.83	19.76	SCL	1.31	43.19	33.05
	30-60	65.76	11.28	22.96	SCL	1.35	38.72	28.01
	60-90	54.68	13.53	31.79	SCL	1.41	32.35	22.34
	Range	54.68-71.41	8.83-13.53	19.76-31.79		1.31-1.41	32.35-43.19	22.34-33.05
	mean	63.95	11.21	24.84		1.35	38.08	27.8
Finger Millet-chemical fertilizer	0-30	73.18	5.87	21.22	SCL	1.32	43.1	30.15
	30-60	69.12	4.98	23.45	SCL	1.38	35.12	22.43
	60-90	57.87	6.87	27.16	SCL	1.43	28.42	19.56
	Range	57.87-73.18	4.98-6.87	21.22-27.16		1.32-1.43	28.42-43.10	19.56-30.15
	mean	66.72	5.91	23.94		1.38	35.54	24.04

Table 1 contd......

continued from Table 1

Land use systems	Depth (cm)	Particle size (%)			Textural class	BD (g cm^{-3})	Total Porosity (%)	MWHC (%)
		Sand	Silt	Clay				
Finger Millet-organic manure	0-30	72.13	6.15	21.79	SCL	1.27	44.98	38.56
	30-60	69.32	6.01	24.18	SCL	1.33	38.34	22.26
	60-90	61.01	9.12	29.34	SCL	1.38	33.92	19.34
	Range	61.01-72.13	6.01-9.12	21.79-29.34		1.27-1.38	33.92-44.98	19.34-38.56
	mean	67.49	7.09	25.1		1.33	39.08	26.72
Finger Millet-integrated nutrient management	0-30	72.2	5.69	20.96	SCL	1.28	43.05	31.78
	30-60	65.13	6.23	22.87	SCL	1.35	37.52	25.12
	60-90	57.27	10.12	28.65	SCL	1.4	30.65	19.89
	Range	57.27-72.20	5.69-10.12	20.96-28.65		1.28-1.40	30.65-43.05	19.89-31.78
	mean	64.87	7.35	24.16		1.34	37.07	25.59
Custard apple	0-30	60.37	13.31	26.32	SCL	1.32	41.25	33.34
	30-60	55.37	8.87	35.76	SCL	1.34	38.35	29.57
	60-90	48.85	12.89	38.26	SCL	1.4	36.83	28.21
	Range	48.85-60.37	8.87-13.31	26.32-38.26		1.32-1.40	36.83-41.25	28.21-33.34
	mean	54.86	11.69	33.45		1.35	38.81	30.37
Amla	0-30	61.46	12.11	27.22	SCL	1.33	41.87	32.14
	30-60	54.75	9.87	36.69	SCL	1.36	38.73	29.23
	60-90	47.79	13.78	39.38	SCL	1.41	34.21	26.76
	Range	47.79-61.46	9.87-13.78	27.22-39.38		1.33-1.41	34.21-41.48	26.76-32.14
	mean	54.67	11.92	34.43		1.36	38.27	29.38
Melia dubia	0-30	65.21	8.23	26.56	SCL	1.31	43.05	36.34
	30-60	59.45	11.28	29.27	SCL	1.34	41.91	30.56
	60-90	50.26	15.43	34.31	SCL	1.38	40.25	29.89
	Range	50.26-65.21	8.23-15.43	26.56-34.31		1.31-1.38	40.25-43.05	29.89-36.34
	mean	58.31	11.65	30.05		1.34	41.74	32.26
	CD (P=0.05)	1.61	1.74	0.67		0.165	0.23	0.28
	SEm±	0.43	0.51	0.18		0.0068	0.07	0.1
	CV (%)	57.6	38.16	28.21		0.48	18.13	23.38

Generally, the clay content was higher in the subsurface layer of different land use systems due to the translocation of finer particles from the surface horizons and subsequent illuviation in subsurface horizons. Similar observations were reported by Dasog and Patil (2011).

Bulk Density

The soil bulk density was significantly affected by land use and soil depth at $P \leq 0.01$ (Table 1). Considering the land use types, the highest mean value of bulk density (1.38 g cm^{-3}) was recorded in finger millet cropping system-chemical fertilizer and the lowest mean value (1.28 g cm^{-3}) of bulk density was recorded in natural forest (Table 1). Bulk density is an indicator of soil compaction and soil health. It affects infiltration, rooting, water holding capacity, soil porosity, plant nutrient availability and soil microorganism's activity all of which are key to soil processes and productivity. Bulk density is found to decrease under natural forest and trees due addition of organic matter (litterfall, fine root recycling, twigs *etc.*) at regular intervals. The addition of litter increased the organic matter in soil and inverse relationship of bulk density and per cent OC is established by several workers (Gupta and Sharma, 2008 and Oyedele *et al*., 2009)).

Total Porosity

The results of the analysis of variance (ANOVA) showed that the total porosity of soil was significantly affected by land use types and soil depth (Table 1). Considering the land use types with soil depth, the highest values of total porosity (45.98%) was recorded on the surface soil layer of natural forest while lowest values of total porosity (28.72%) was recorded in subsurface layer (60-90 cm) of the finger millet cropping system-chemical fertilizer (Table 1). The higher value of soil total porosity in natural forest was implied due to low bulk density of forest plantation. The mean total porosity of teak plantation, mango land use system, guava land use system, custard apple land use system, amla land use system, finger millet cropping system-organic manure and finger millet cropping system-integrated nutrient management were 39.83, 39.56, 38.08, 38.81, 38.27, 39.08 and 37.07 per cent respectively (Table 1). At different soil depths, the higher value of total porosity was recorded in the surface soil layer. The total porosity varies across the different land use types was implies to the bulk density values of that respective soil.

Maximum Water Holding Capacity

The soil moisture holding capacity is significantly influenced by varying land use systems (Table 1). Highest soil moisture content (36.35%) was recorded in natural forest followed by teak plantation (34.05%), agroforestry (32.26%), custard land use system (30.37%), mango (29.60%), amla land use system (29.38%) and least soil moisture was recorded in agriculture (finger millet cropping system-chemical fertilizer) (24.04%). Moisture holding capacity corroborates with other characteristics of land use systems. Soil bulk density was lowest in natural forest and tree plantations compared to agriculture and horticulture systems. Soil porosity and maximum water holding capacity were also recorded higher under natural forest and tree plantations. In tree plantations and natural forest higher amount of litter and organic matter were added, which has increased the soil organic carbon and thereby increased the soil moisture holding capacity of the soils, whereas in agriculture system there was no continuous addition of litter or organic matter. However, horticulture and agroforestry were also a tree based systems, but the tree spacing was larger in horticulture (10 m x 10 m) and agroforestry (8 m x 5 m) leading to less organic matter input and thereby less soil moisture holding capacity (Bhavya *et al*., 2018).

Chemical Properties of Soils under different Land use Systems

Soil pH

The soil pH was significantly influenced by different land use systems and soil depths (Table 2). The highest soil pH (6.80) was recorded in natural forest, which was followed by finger millet cropping system-organic manure and finger millet cropping system-integrated nutrient management having soil

TABLE 2

Chemical properties of soils under different land use systems

Land use systems	Depth (cm)	pH	EC (dSm^{-1})	OC (%)
Natural Forest	0-30	6.67	0.099	1.57
	30-60	6.78	0.115	0.98
	60-90	6.96	0.125	0.77
	Range	6.67-6.96	0.099-0.125	0.77-1.57
	mean	6.8	0.11	1.11
Teak	0-30	5.48	0.063	0.99
	30-60	5.66	0.079	0.86
	60-90	5.83	0.093	0.59
	Range	5.48-5.83	0.063-0.093	0.59-0.99
	mean	5.66	0.08	0.81
Mango	0-30	5.59	0.061	0.81
	30-60	5.72	0.069	0.62
	60-90	5.98	0.078	0.49
	Range	5.59-5.98	0.061-0.078	0.49-0.81
	mean	5.76	0.07	0.64
Guava	0-30	5.78	0.064	0.69
	30-60	5.93	0.078	0.47
	60-90	6.03	0.083	0.39
	Range	5.78-6.03	0.064-0.083	0.39-0.69
	mean	5.91	0.08	0.51
Finger Millet-chemical fertilizer	0-30	4.09	0.059	0.43
	30-60	4.21	0.065	0.21
	60-90	4.35	0.07	0.11
	Range	4.09-4.35	0.059-0.070	0.11-0.43
	mean	4.22	0.06	0.25
Finger Millet- organic manure	0-30	6.01	0.077	0.53
	30-60	6.17	0.087	0.41
	60-90	6.32	0.09	0.32
	Range	6.01-6.32	0.077-0.090	0.32-0.53
	mean	6.17	0.08	0.42
Finger Millet- integrated nutrient management	0-30	5.98	0.052	0.63
	30-60	6.12	0.074	0.5
	60-90	6.22	0.086	0.38
	Range	5.98-6.22	0.052-0.086	0.38-0.63
	mean	6.11	0.07	0.50

Table 2 contd......

Land use systems	Depth (cm)	pH	EC (dSm^{-1})	OC (%)
Custard	0-30	5.54	0.041	0.65
	30-60	5.78	0.058	0.53
	60-90	5.88	0.067	0.45
	Range	5.54-5.88	0.041-0.067	0.45-0.65
	mean	5.73	0.06	0.54
Amla	0-30	5.61	0.057	0.57
	30-60	5.72	0.068	0.41
	60-90	5.85	0.071	0.36
	Range	5.61-5.85	0.057-0.071	0.36-0.57
	mean	5.73	0.07	0.45
Melia dubia	0-30	4.78	0.069	0.86
	30-60	4.87	0.072	0.71
	60-90	5.05	0.081	0.58
	Range	4.78-5.05	0.069-0.081	0.58-0.71
	mean	4.9	0.07	0.72
	CD (P=0.05)	0.33	0.023	0.142
	SEm±	0.10	0.004	0.035
	CV (%)	1.84	0.01	0.12

pH of 6.17 and 6.11 respectively. The low pH was recorded in finger millet cropping system-chemical fertilizer (4.22). Soil pH or reaction indicates two important chemical properties (*i.e.* soil acidity and alkalinity) of soil, which are having profound influence on soil physical and biological properties and hence the plant nutrient availability. Soil pH regulates soil biogeochemical processes and has cascading effects on terrestrial ecosystem structure and functions.

The mean pH values of natural forest and tree based systems found to be neutral. This could be due to addition of litter in tree based land use systems. It can also be observed that, with the increase in the age of the tree based land use system, the soil pH is becoming more neutral. Verma *et al.* (2001) also found that soil pH increased under tree plantations. Whereas in melia dubia land use system recorded was slightly acidic, this might be due to the continuous addition of litter and subsequent release of organic acids, which tend to decrease the soil pH. These results are supported by Ananthkumar (2011). While in finger millet-chemical fertilizer, applied acid forming fertilizers (Ammonical fertilizers) release of H^+ ions after mineralization and lack of addition of organic manures to soil, hence crop takes up secondary and micronutrient from soil results in soil acidity (Gajanana *et al.*, 2005).

Considering the interaction of land use types with soil depth, soil pH increased consistently with increased in soil depth in all land use systems due to leaching of basic cations due to high rainfall. These results are supported by Rudramurthy *et al.* (2007).

Electrical Conductivity

The electrical conductivity (EC) values of soils were significantly affected by land use types and soil depths (Table 2). Highest EC was recorded in natural forest (0.11 dSm^{-1}), whereas lowest (0.06 dSm^{-1}) was recorded in custard land use systems and finger millet cropping system-chemical fertilizer. Soil EC under natural forest was higher compared to other land use systems. This could be due to enrichment of soil mineral by basic salts due to weathering and decomposition of litter. Verma *et al*. (2001) reported that soil EC increased in tree plantations. The lowest mean value of EC was found at 0 to 30 cm depths in different land use systems this might be mainly due to variation in soluble salts in soils and variation in the degree of leaching loss of salts from soils due to the intensity of rainfall and restricted drainage. These results are in line with the findings of Nagaraj *et al*. (2002).

Soil Organic Carbon

The analysis of variance revealed that the SOC (Soil Organic Carbon) content was significantly affected by land use types and soil depth (Table 2). Natural forest shows the highest mean value of organic carbon (1.11%). Similar result was observed by Govind *et al.* (2022). Followed by teak plantation (0.84%) and the lowest mean value observed in finger millet cropping system-chemical fertilizer (0.25%). In all the land use systems the organic carbon content decreases with increasing soil depth. The highest value of SOC content was (1.57%) recorded at the depth of 0-30 cm (surface) in natural forest land and the least value of SOC (0.11%) was recorded at depth of 60-90 cm (subsurface) in finger millet cropping system-chemical fertilizer (Table 2). However, the highest value of SOC on the surface layer of forest land use systems was attributed to the excessive amount of plant residues and biomass on surface land. The present research finding is in agreement with findings of Chibsa and Taa (2009), Iqbal *et al.* (2012) and Takele *et al.* (2014) in which they reported that the SOC decreases with increasing soil depth, with more accumulation on the upper surface soil layer. Singh and Sharma, 2012. Amanuel *et al.* (2018) also reported that overall mean soil organic carbon stock was higher under natural and mixed forest compared with other land use types and at all depths. The closer spacing of the plantation rendered thick and denser canopy and more is the litter biomass added. While the least mean soil organic carbon content was recorded in agriculture based land use systems compared to tree based land use because of continuous disturbance of soil through tillage activities and less input of litter and plant residues in the agriculture systems. These results are in line with the findings of Shivakumar *et al.* (2020).

Available Primary Nutrients in Soil under different Land Use Systems

The available nitrogen (N), phosphorous (P) and potassium (K) content of soils were significantly affected by land use types and soil depth (Tables 3). The highest mean value of available nitrogen (260.02 kg ha^{-1}) was recorded in finger millet cropping system-integrated nutrient management followed by mango (248.53 kg ha^{-1}), finger millet cropping system-organic manure (246.33 kg ha^{-1}), agroforestry (melia dubia) with 241.58 kg ha^{-1}, natural forest (227.12 kg ha^{-1}) and lowest mean (141.32 kg ha^{-1}) was noticed in amla land use system. Highest available nitrogen was recorded in agriculture system due to application of chemical nitrogenous fertilizers and organic source. The combined application of organic and inorganic fertilizer in soil has led to increase in organic matter content in the soil which has direct relation with the availability of nitrogen content in the soil and this result was found to be in accordance with Hemalatha and Chellamuthu (2013). Among tree-based land use system, the higher soil available nitrogen was recorded in mango land use system, this might be due to higher litter fall (6243.15 kg/ha/ year) and also due to higher nitrogen concentration (1.34%) in leaf litter. Similar results were reported by Sushanta kumar *et al.* (2018). The Available nitrogen in soil decreased significantly with increasing soil depth. This can be attributed to more turn-over of organic residues in the top layer compared to deeper layers. The available phosphorus and potassium in soil were significantly differed among different land use systems. The highest mean value (88.76 kg ha^{-1}) of available phosphorus was recorded in finger millet cropping system-integrated nutrient management followed by finger millet cropping system-organic manure (78.32 kg ha^{-1}), agroforestry (melia dubia) with 73.11 kg ha^{-1}, mango (55.12 kg ha^{-1}), natural forest (48.28 kg ha^{-1}) and least

TABLE 3

Available primary nutrient status of soil under different land use systems

Land use systems	Depth (cm)	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
Natural Forest	0-30	245.65	70.72	173.15
	30-60	225.67	46.07	155.25
	60-90	210.05	28.05	131.47
	Range	210.05-245.65	28.05-70.72	131.47-173.15
	mean	227.12	48.28	153.29
Teak	0-30	178.34	54.15	141.14
	30-60	157.34	43.55	122.28
	60-90	131.45	29.14	110.15
	Range	131.45-178.34	29.14-54.15	110.15-141.14
	mean	155.71	42.48	124.52
Mango	0-30	276.25	76.44	166.45
	30-60	265.56	55.17	148.35
	60-90	203.78	33.75	122.49
	Range	203.78-276.25	33.75-76.44	122.49-166.45
	mean	248.53	55.12	145.76
Guava	0-30	171.24	65.46	155.38
	30-60	155.47	55.43	135.26
	60-90	142.47	23.47	119.67
	Range	142.47-171.24	23.47-65.46	119.67-155.38
	mean	156.39	48.12	136.77
Finger Millet-chemical fertilizer	0-30	234.57	59.16	135.25
	30-60	228.24	47.45	129.13
	60-90	178.11	30.56	114.76
	Range	178.11-234.57	30.56-59.16	114.76-135.25
	mean	213.64	45.72	126.38
Finger Millet-organic manure	0-30	289.26	86.35	145.53
	30-60	251.89	78.48	131.27
	60-90	199.35	70.13	119.28
	Range	199.35-289.26	70.13-86.35	119.28-145.53
	mean	246.33	78.32	132.03
Finger Millet-integrated nutrient management	0-30	285.48	105.5	230.04
	30-60	268.35	92.65	201.36
	60-90	226.24	68.13	191.38
	Range	226.24-285.48	68.13-105.5	191.38-230.04
	mean	260.02	88.76	207.59

Table 3 contd......

Land use systems	Depth (cm)	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
Custard apple	0-30	187.65	55.35	155.24
	30-60	142.87	46.25	138.12
	60-90	101.45	40.67	126.39
	Range	101.45-187.65	40.67-55.35	126.39-155.24
	mean	143.99	47.42	139.92
Amla	0-30	177.24	60.57	219.37
	30-60	137.67	47.85	178.25
	60-90	109.05	31.05	145.16
	Range	109.05-177.24	31.05-60.57	145.16-219.37
	mean	141.32	46.49	180.92
Melia dubia	0-30	277.79	93.01	205.18
	30-60	237.49	74.54	186.35
	60-90	209.48	51.79	175.39
	Range	209.48-277.79	51.79-93.01	175.39-205.18
	Mean	241.58	73.11	188.97
	CD (P=0.05)	10.27	5.15	12.65
	SEm±	2.678	1.66	3.65
	CV (%)	142.77	121.32	148.26

available phosphorus (45.72 kg ha^{-1}) was recorded in finger millet cropping system-chemical fertilizer. The available phosphorous and potassium were higher in the surface soil layer than in the subsurface soil layer. Generally, variations in available phosphorous content in soils could be related to the intensity of soil weathering or soil disturbance under different land use systems. The buildup of available phosphorus in integrated treatments that is organic plus inorganic fertilizer treatment was mainly due to the increase in dissolution of native P compounds by the decomposition of FYM and the available P content in the soil and it was also contributed by the application of phosphorus through fertilizer and it was also due to increased phosphatase activity in the soil has led to increase in available phosphorus content in the soil. Similar results were reported by Hemalatha and Chellamuthu (2013).

The highest mean available potassium was recorded in finger millet cropping system-integrated nutrient management (207.59 kg ha^{-1}) followed by agroforestry (melia dubia) with 188.97 kg ha^{-1}, amla land use system with 180.92 kg ha^{-1}, natural forest (153.29 kg ha^{-1}) and mango (145.76 kg ha^{-1}). The trends noticed in these land use systems may be due to regular and continuous application of inorganic fertilizers. Among tree based land use systems, in melia dubia higher soil available potassium was recorded due higher litter fall (1750.37 kg/ha/year) and in and this result was found to be in accordance with Ishwarya laxmi *et al.* (2021). The available K in soil decreased significantly with increase in soil depth. A decreasing trend was observed with successive increase in soil depth as a consequence of higher litter fall and fine root turnover at surface layer. Similar decrease with soil depths has also been reported by Bhardwaj *et al.* (2001), Swamy *et al.* (2006) and Mishra and Swamy (2007).

Secondary Nutrients in Soil under different Land Use Systems

According to the analysis of variance results indicated that the exchangeable calcium (Ca),

TABLE 4

Secondary nutrient status of soil under different land use systems

Land use systems	Depth (cm)	Ca (cmol (p+) kg^{-1})	Mg (cmol (p+) kg^{-1})	S (cmol (p+) kg^{-1})
Natural Forest	0-30	6.65	1.89	6.15
	30-60	4.95	1.75	4.75
	60-90	3.46	0.58	4.12
	Range	3.46-6.65	0.58-1.89	4.12-6.15
	mean	5.02	1.4	5.01
Teak	0-30	5.87	0.61	5.87
	30-60	3.51	0.39	4.23
	60-90	2.42	0.31	3.36
	Range	2.42-5.87	0.31-0.61	3.36-5.87
	mean	3.93	0.44	4.49
Mango	0-30	6.55	1.41	6.55
	30-60	5.31	0.97	4.89
	60-90	2.78	0.29	4.34
	Range	2.78-6.55	0.29-1.41	4.34-6.55
	mean	4.88	0.89	5.26
Guava	0-30	6.47	0.49	4.23
	30-60	4.29	0.38	3.78
	60-90	2.88	0.21	3.54
	Range	2.88-6.47	0.21-0.49	3.54-4.23
	mean	4.54	0.36	3.85
Finger Millet-chemical fertilizer	0-30	1.46	0.48	2.24
	30-60	1.22	0.15	1.67
	60-90	1.08	0.09	0.47
	Range	1.08-1.46	0.09-0.48	0.47-2.24
	mean	1.25	0.24	1.46
Finger Millet-organic manure	0-30	2.68	0.57	4.43
	30-60	2.56	0.26	2.68
	60-90	2.23	0.11	1.16
	Range	2.23-2.68	0.11-0.57	1.16-4.43
	mean	2.49	0.31	2.75
Finger Millet- integrated nutrient management	0-30	3.41	0.54	4.68
	30-60	3.01	0.32	3.74
	60-90	2.78	0.17	1.39
	Range	2.78-3.41	0.17-0.54	1.39-4.68
	mean	3.06	0.34	3.27

Table 4 contd......

Land use systems	Depth (cm)	Ca (cmol (p+) kg^{-1})	Mg (cmol (p+) kg^{-1})	S (cmol (p+) kg^{-1})
Custard apple	0-30	4.15	1.25	6.12
	30-60	3.79	1.03	5.26
	60-90	2.54	0.89	1.33
	Range	2.54-4.15	0.89-1.25	1.33-6.12
	mean	3.49	1.05	4.23
Amla	0-30	4.19	0.68	5.95
	30-60	2.86	0.37	4.68
	60-90	2.45	0.01	1.06
	Range	2.45-4.19	0.01-0.68	1.06-5.95
	mean	3.16	0.35	3.89
Melia dubia	0-30	5.87	0.81	7.98
	30-60	4.53	0.59	5.62
	60-90	2.36	0.43	4.44
	Range	2.36-5.87	0.43-0.81	4.44-7.98
	mean	4.25	0.61	6.01
	CD (P=0.05)	0.812	0.094	0.921
	SEm±	0.173	0.031	0.258
	CV (%)	2.11	0.114	1.899

magnesium (Mg) and sulphur (S) of the study area was significantly affected by land use types and soil depth (Tables 4). The highest mean value (5.02 cmol (p+) kg^{-1}) of available calcium was recorded in natural forest soil followed by mango (4.88 cmol (p+) kg^{-1}), guava (4.54 cmol (p+) kg^{-1}), agroforestry (melia dubia) with 4.25 cmol (p+) kg^{-1} and lowest mean value (1.25 cmol (p+) kg^{-1}) was recorded in finger millet cropping system-chemical fertilizer. The highest mean value (1.40 cmol (p+) kg^{-1}) of available magnesium was recorded in natural forest soils followed by custard land use (1.05 cmol (p+) kg^{-1}), mango (0.89 cmol (p+) kg^{-1}), agroforestry (melia dubia) with 0.61 cmol (p+) kg^{-1}, teak plantation (0.44 cmol (p+) kg^{-1}) and lowest mean (0.31 cmol (p+) kg^{-1}) was noticed in finger millet cropping system-chemical fertilizer. Muche *et al*. (2015) found that, significantly higher exchangeable bases (Ca and Mg) were found in soil of the natural forest compared to the other land use types. This higher litter fall in natural forest (5182.79 kg/ha/year) and higher leaf litter calcium and magnesium concentration (2.67% and 0.44%) respectively, result in soil enriched with calcium and magnesium upon decomposition of litter. This variation in exchangeable bases (Ca and Mg) might be attributed to leaching losses, low content in the parent rock and the proportion of clay minerals as well as the conversion of forest land into the other land use types. Aweto and Dikinya (2003) reported that calcium and magnesium were higher in soil under the tree canopies and it was mainly due to the accumulation of litter.

The exchangeable calcium and magnesium recorded in soil were found to decrease with increasing soil depth. Maximum calcium (6.65 cmol (p+) kg^{-1}) and magnesium (1.89 cmol (p+) kg^{-1}) were recorded at depth of 0-30 cm and least calcium (1.08 cmol (p+) kg^{-1}) and magnesium (0.01 cmol (p+) kg^{-1}) were recorded at of 60-90 cm soil depth. The exchangeable calcium and magnesium decreased with increase in soil depth. This might be attributed to continuous addition of litter for several years and these soils remained undisturbed for many years.

The highest mean value (6.01 cmol (p+) kg^{-1}) of available sulphur was recorded in agroforestry (melia dubia) followed by mango (5.26 cmol (p+) kg^{-1}), natural forest soils (5.01 cmol (p+) kg^{-1}), teak plantation (4.41 cmol (p+) kg^{-1}) and lowest mean value was noticed in finger millet cropping system-chemical fertilizer (1.46 cmol (p+) kg^{-1}). The maximum available sulphur content of 7.98 cmol (p+) kg^{-1} was recorded in the surface soil layer of melia dubia and a minimum available sulphur content of 0.47 cmol (p+) kg^{-1} was recorded in the subsurface (60-90 cm) layer of finger millet cropping system). When compared to agriculture (finger millet) system, the available sulphur level in soils under agroforestry (melia dubia) was much higher followed by mango, natural forest (Table 4). The reason for this could be due to increasing soil organic carbon content which reduces sulphate ion leaching. Acid soils in Manipur have an inorganic sulphur level ranging from 10 to 70 ppm, according to Herojith Singh *et al*. (2007), with the higher available sulphur content ascribed to higher organic matter content.

Micronutrients in Soil under different Land Use Systems

The DTPA extractable iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) content of soils were significantly affected by land use types and soil depth (Tables 5). The highest mean value (18.88 mg kg^{-1}) of DTPA extractable iron (Fe) was recorded in natural forest soils followed by teak plantation (15.25 mg kg^{-1}), agroforestry (melia dubia) with 14.17 mg kg^{-1}, mango (14.07 mg kg^{-1}) and lowest mean value (8.19 mg kg^{-1}) was recorded in finger millet cropping system-chemical fertilizer. The highest mean value (32.74 mg kg^{-1}) of DTPA extractable manganese (Mn) was recorded in natural forest soils followed by teak plantation (25.79 mg kg^{-1}), mango (18.67 mg kg^{-1}), agroforestry (melia dubia) with 18.07 mg kg^{-1} and lowest mean value (7.78 mg kg^{-1}) was recorded in finger millet cropping system-chemical fertilizer. The highest mean value (1.53 mg kg^{-1}) of DTPA extractable zinc (Zn) was recorded in natural forest soil followed by teak plantation (1.31 mg kg^{-1}), agroforestry (melia dubia) with 1.22 mg kg^{-1}, mango (1.16 mg kg^{-1}) and lowest mean value (0.38 mg kg^{-1}) was recorded in finger millet cropping system-chemical fertilizer. The highest mean value (1.62 mg kg^{-1}) of DTPA extractable copper (Cu) was recorded in mango followed by natural forest soils (1.49 mg kg^{-1}), teak plantation (1.02 mg kg^{-1}), agroforestry (melia dubia) with 0.86 mg kg^{-1} and lowest mean value (0.41 mg kg^{-1}) was recorded in finger millet-chemical fertilizer.

Iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn) availability depends on soil pH, organic matter content, adsorptive surfaces, other physical, chemical and biological conditions in the soil rhizosphere (Kaur *et al*., 2020). The difference in various micronutrients status under different tree species could be attributed to variation in concentration and rate of decomposition of micronutrients in the litter as well as the quantity of litter added. The DTPA extractable iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) content in soil was decreased with increasing soil depth.

The results showed a distinct change in soil properties of the different land use systems. The study area has low bulk density, which is indicating the higher soil OM. The soil pH was acidic in agriculture (finger millet) land use and it is neutral in natural forest. The soil electrical conductivity was normal in all the land use systems. The higher SOC was recorded in natural forest and higher available N was recorded in the cultivated (finger millet). The higher SOC and available N were observed in the surface soil layers and they found decreasing with increasing soil depth. The available P_2O_5 and K_2O contents were higher in agriculture (finger millet) compared to other land use systems. Even higher concentration of secondary and micronutrients were recorded in natural forest, agroforestry, mango and teak plantation. These results demonstrate that conversion of natural forest into different land use systems adversely affect the soil properties, but land restoration in the region by promoting specific management practice like application of organic residue and sustainable land management practice in land use systems will improve and maintain soil physical and chemical properties.

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