Communications in Soil Science and Plant Analysis
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lcss20

Soil Fertility Index, Soil Evaluation Factor, and Microbial Indices under Different Land Uses in Acidic Soil of Humid Subtropical India

Pankaj Panwar [a], Sharmistha Pal [a], S. K. Reza [b] & Biplab Sharma [c]
[a] Central Soil and Water Conservation Research and Training Institute, Research Centre, Madhya Marg, Chandigarh, India
[b] National Bureau of Soil Survey and Land Use Planning, Jorhat, Assam, India
[c] Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal, India

Available online: 23 Nov 2011

Communications in Soil Science and Plant Analysis, 42:2724–2737, 2011

ISSN: 0010-3624 print / 1532-2416 online
DOI: 10.1080/00103624.2011.622820

Soil Fertility Index, Soil Evaluation Factor, and Microbial Indices under Different Land Uses in Acidic Soil of Humid Subtropical India

PANKAJ PANWAR,[1] SHARMISTHA PAL,[1] S. K. REZA,[2] AND BIPLAB SHARMA[3]

[1]Central Soil and Water Conservation Research and Training Institute, Research Centre, Madhya Marg, Chandigarh, India
[2]National Bureau of Soil Survey and Land Use Planning, Jorhat, Assam, India
[3]Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal, India

A study was conducted to examine the impact of land use on soil fertility in an Entisol in the Jalpaiguri District of humid subtropical India. The natural forest served as a control against which changes in soil properties were compared. Soil samples were collected from four different depths (0–25, 25–50, 50–75, and 75–100 cm) of soil from four land uses (viz. forest, home garden, arecanut plantation, and agriculture) and examined for pH, organic carbon (OC), electrical conductivity (EC), cation exchange capacity, available nitrogen (N), phosphorus (P), exchangeable calcium (Ca), magnesium (Mg), potassium (K), aluminum (Al), microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and dehydrogenase activity (DHA). Soil pH (5.7), OC (2.29%), N (386 kg ha^{-1}), and P (22.54 kg ha^{-1}) were greatest in forest soil, followed by soil from arecanut plantation, agriculture, and home garden. The greatest Ca (0.892 cmol kg^{-1}), Mg (0.527 cmol kg^{-1}), and Al (1.86 cmol kg^{-1}) were found in the arecanut plantation, whereas K (0.211 cmol kg^{-1}) was greatest in forest. The greatest content of diethylenetriaminepentaacetic acid–extractable copper, zinc, manganese, and iron (2.25, 1.66, 4.86, and 7.65 ppm, respectively) were found in forest. MBC (558 mg kg^{-1}), MBN (26.67 mg kg^{-1}), and DHA (33.03 μg TPF 24 h^{-1} g^{-1}) was greatest in forest soil. Soil fertility index varied from 13.13 in arecanut plantation to 18.49 in forest. The soil evaluation factor ranged from 5.32 in agriculture to 6.56 in forest. Pearson's correlation matrix revealed strongly significant positive correlation of soil fertility index and soil evaluation factor with soil properties.

Keywords Available nutrients, exchangeable cations, land use, microbial activity, soil evaluation factor, soil fertility index

Introduction

With the rapid increase of population and limited land resources, many countries throughout the world are facing acute scarcity of lands for food production, which causes people to convert forestland into agricultural, horticultural, and many other kinds of land. Such activities have led to the depletion of existing forests throughout the world and in Asian countries in particular. In the 19th century, large-scale deforestation of tropical moist

Received 8 July 2010; accepted 2 February 2011.
Address correspondence to S. K. Reza, National Bureau of Soil Survey and Land Use Planning, Jamuguri Road, Jorhat, Assam 785 004, India. E-mail: nbsslup09@gmail.com

deciduous forest took place in the foothill plains (*Terai* zone) of West Bengal to create commercial plantation of *Tectona grandis*. The plantations were created through the method of Taungya, wherein the Forest Department allows migrant labors to cultivate land in between the rows of trees and in return they protect the trees. The destruction of the natural forest and pasture ecosystems and its conversion to cropland can reduce precipitation or increase temperature, reduce soil productivity because of increased erosion, cause decline in fertility, change in soil flora or fauna, and reduce soil organic matter, which plays a crucial role in sustaining soil quality, crop production, and environmental quality (Doran and Parkin 1994; Spaccini et al. 2001; Kara and Bolat 2007).

The land-use systems play a tremendous role in influencing nutrient availability and cycling and may also influence secondary succession and biomass production (Lu, Moran, and Mausel 2002). In a soil–plant system, plant nutrients are in a state of continuous dynamic transfer. Plants take up nutrients from the soil and use them for metabolic activities. In turn, these nutrients are returned back to the soil either naturally as litter falls in unmanaged systems, deliberately as pruning in agroforestry systems, or through root senescence in both managed and unmanaged systems. These plant parts are decomposed by microbial activities, thereby releasing nutrients into the soil that become available for plant uptake once again (Nair, Kang, and Kass 1999). Natural forest ecosystems of the tropics are self-sustaining, efficient, and "closed" nutrient cycling systems with relatively little loss or gain of the actively cycling nutrients and with high rates of nutrient turnover within the system. In contrast, most of the agricultural systems are "open" or "leaky" systems with comparatively high nutrient losses. Nutrient cycling in agroforestry systems falls between these extremes (Nair 1993; Nair, Kang, and Kass 1995).

Soil quality can be monitored by a set of measurable attributes termed *indicators*. These indicators can be broadly grouped as physical, chemical, and biological indicators, and one can assess overall soil quality by measuring changes in these indicators (Larson and Pierce 1991; Doran and Parkin 1994; Dalal and Moloney 2000; Ditzler and Tugel 2002; Sahrawat and Narteh 2002) and transforming them into a single value known as the *soil quality/fertility index*. It is imperative to compare the changes in soil properties due to changes in land cover to understand the influence of changes in soil and water quality, biodiversity, and global climatic systems on natural resources and ecological processes (Houghton 1994; Chen et al. 2001; Chaudhury et al. 2005; Abbasi, Zafar, and Sultan 2010).

The study attempted to quantify the changes in the properties of soil under home garden, areca nut plantation, and agriculture land uses by comparing them with the properties of soils under natural forest. The natural forests served as a control against which the changes in soil properties resulting from the removal of natural forest and cultivation of soil under other land uses were compared, using the soil profile data. Keeping these facts in mind, the present study was undertaken to (1) compare the influences of four most common land uses on selected soil physicochemical, chemical, and biological properties in the *Terai* zone and (2) establish the interrelationships between soil fertility indices and soil properties.

Materials and Methods

Soil Sampling, Processing, and Analysis of Soil Properties

The study fields were located in Madarihat, Jalpaiguri District, West Bengal State, India. The experiment site is situated at 26° 19′ 86″ N latitude and 89° 23′ 53″ E longitude at an elevation of 43 m above mean sea level. The region receives on an average 3300 mm rainfall. In addition to paddy cultivation, plantations of arecanut (*Areca catechu*) and teak (*Tectona grandis*), and home gardens are the dominant land-use systems of the region. The cultivation is basically rainfed. According to the USDA Soil Taxonomy, the soils in the study region are classified as Entisols. Existing land-use systems were used for the study. These systems included (1) plantation of *Tectona grandis* (forest), (2) home gardens (mixture of arecanut, banana, citrus, vegetables, and flowers in four to five vertical strata), (3) plantation of arecanut (*Areca catechu*), and (4) agriculture (monocroping of rice and maize). Because the systems had trees as one of the components, soil sampling was done up to a depth of 100 cm taking four soil layers (0–25 cm, 25–50 cm, 50–75 cm, and 75–100 cm) in three replications. Soil samples were collected following standard procedure. Soil samples were air dried and ground to pass through a 2-mm sieve. A combined glass–calomel electrode was used to determine the pH of aqueous suspensions (1:2.5 soil/solution ratio). Electrical conductivity (dS m^{-1}) was measured in the supernatant liquid of soil/water suspension (1:2) with conductivity bridge (Richards 1954). Soil organic carbon (OC) was determined using the wet digestion method of Walkley and Black (1934). Available nitrogen (N) was measured by the alkaline permanganate method as described by Subbiah and Asija (1956). Available phosphorus (P) was determined by the Bray II method (Bray and Kurtz 1945). Cation exchange capacity (CEC) of soil was determined as per the procedure outlined by Jackson (1974). Exchangeable cations [calcium (Ca), potassium (K), and magnesium (Mg)] were extracted with 1 M ammonium acetate (NH_4OAc) (pH 7.0). Potassium content was determined by flame photometry (Rich 1965), while Ca and Mg were determined by ethylenediaminetetraacetic acid (EDTA) titration. Exchangeable Al was extracted with 1 N potassium chloride (KCl) solution and titrated with 0.1 N sodium hydroxide (NaOH) solution. Available micronutrient content [copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn)] were determined by diethylenetriaminepentaacetic acid (DTPA) extraction (Lindsay and Norvell 1978), followed by atomic absorption spectrophotometry.

Soil Biological Properties

Microbial biomass carbon (MBC) determinations were made by using chloroform fumigation technique as described by Jenkinson and Powlson (1976) and Jenkinson and Ladd (1981). Microbial biomass nitrogen (MBN) determination was made by using the standard method (Brookes et al. 1985). The dehydrogenase activity (DHA) was measured using triphenyl tetrazolium chloride (Tabatabai 1982), which was reduced to triphenyl formazan.

Computation of Indices

Values of soil fertility index (SFI) (Moran et al. 2000) and soil evaluation factor (SEF) (Lu, Moran, and Mausel 2002) were calculated to quantify soil fertility. The following equations were used to calculate the values (Lu, Moran, and Mausel 2002):

$$\begin{aligned} \text{SFI} = {} & \text{pH} + \text{organic matter } (\%, \text{dry soil basis}) + \text{available P } (\text{mg kg}^{-1}, \text{ dry soil}) \\ & + \text{exch. K } (\text{ceq kg}^{-1}, \text{ dry soil}) + \text{exch. Ca } (\text{ceq kg}^{-1}, \text{ dry soil}) \\ & + \text{exch. Mg } (\text{ceq kg}^{-1}, \text{ dry soil}) - \text{exch. Al } (\text{ceq kg}^{-1}, \text{ dry soil}) \end{aligned}$$

$$\begin{aligned} \text{SEF} = {} & [\text{exch. K } (\text{ceq kg}^{-1}, \text{dry soil}) + \text{exch. Ca } (\text{ceq kg}^{-1}, \text{ dry soil}) \\ & + \text{exch. Mg } (\text{ceq kg}^{-1}, \text{ dry soil}) - \log(1 + \text{exch. Al } (\text{ceq kg}^{-1}, \text{dry soil}))] \\ & \times \text{organic matter } (\%, \text{dry soil}) + 5 \end{aligned}$$

Statistical Analysis

Data obtained in the experiment were subjected to analysis of variance (ANOVA) appropriate to the experimental design. For statistical analysis of data, Microsoft Excel (Microsoft Corporation, Seattle, Wash.) and MSTATC (MSTATC, East Lansing, Mich.) packages were used. The relationship between soil properties and soil fertility indices were determined by Pearson's correlation matrix using SPSS Windows version 14.0 (SPSS Inc., Chicago, Ill.).

Results and Discussion

Effects of Land-Use Systems on Soil Physiochemical Properties at Different Depths

Data presented in Table 1 showed significant influence of land-use systems on soil pH; however, variation in soil profile with respect to depth was nonsignificant. Soil pH varied from 5.7 in forest to 5.2 in agriculture system. Interestingly, the forest land-use system showed greater pH than the arable land, which could be attributed to the release of bases

Table 1
Effect of land-use systems on physicochemical properties of soil

	Soil layer (cm)			
System	0–25	25–50	50–75	75–100
pH				
Forest	5.7	5.7	5.6	5.7
Home garden	5.4	5.5	5.4	5.5
Areca nut Plantation	5.6	5.5	5.6	5.5
Agriculture	5.2	5.3	5.3	5.2
$LSD_{0.05}$	L = 0.01	D = NS	L × D = NS	
Organic carbon (%)				
Forest	2.29	1.81	1.16	1.08
Home garden	1.71	1.48	1.40	1.07
Areca nut Plantation	2.07	1.96	1.33	1.07
Agriculture	1.60	1.04	1.16	1.07
$LSD_{0.05}$	L = 0.004	D = 0.004	L × D = 0.008	
Electrical conductivity (dS m^{-1})				
Forest	0.26	0.23	0.21	0.20
Home garden	0.26	0.23	0.19	0.21
Areca nut Plantation	0.24	0.22	0.21	0.18
Agriculture	0.20	0.21	0.22	0.23
$LSD_{0.05}$	L = NS	D = NS	L × D = NS	
Cation exchange capacity (c mol kg^{-1})				
Forest	10.50	11.20	10.80	11.40
Home garden	10.24	8.80	10.41	9.68
Areca nut Plantation	11.17	9.50	10.92	11.33
Agriculture	10.23	10.30	11.39	9.06
$LSD_{0.05}$	L = NS	D = NS	L × D = NS	

Notes. L, land-use system; D, soil layer; NS, nonsignificant; LSD, least significant difference at the 5% probability level.

and their deposition over a long period of tree growth. Earlier results also revealed that trees have the capacity to moderate the effects of leaching by contributing bases to the soil. The greater pH level in some of the tree-based land-use systems could also be due to humic matter released as a result of tree root exudates that complex the aluminum (Al^{+3}) and consequently result in greater soil pH, especially in acidic soils as reported by Young (1997). The EC did not vary significantly under different land uses at varying soil depths, although the greater values of EC under tree-based land-use system as compared to arable land has been reported earlier by Sharma and Gupta (1989) and Chakraborthy and Chakraborthy (1989).

The OC content was greater in forest (2.29%) followed by arecanut plantation (2.07%). The least value for OC (1.07%) was in found in deeper soil layers for all the land uses. As a general trend, the OC decreased with increase in the depth of soil layer. The enrichment of OC content under tree-based systems could be due to litter fall and root biomass accumulation. The surface soil layer tended to be richer in OC than subsoil layers in all land uses. This may be attributed to the contribution made by litter fall (Russel 1986; Madhumitha, Singh, and Khan 1997). Naitham and Bhattacharyya (2004) had also reported that soils under horticulture and forest systems showed greater amounts of soil OC than agriculture lands.

Effects of Land Use and Soil Depth on Available Nitrogen and Phosphorus in Soil

Available N and P contents were significantly influenced by land use and soil depths (Table 2). Nitrogen was greatest (386 kg ha^{-1}) in forest and least (248 kg ha^{-1}) in the agricultural system. Nitrogen content tended to decrease with increasing soil depth, and N buildup in different tree-based land use over agricultural land is attributed to more accumulation of biomass through litter fall and root biomass (Juo and Lal 1977; Srinivasan and Caulfield 1989). The greatest P content was 22.54 kg ha^{-1} in the surface layer of forest

Table 2
Effect of land-use systems on available nutrients in soil profile

	Soil layer (cm)			
System	0–25	25–50	50–75	75–100
Available nitrogen (kg ha^{-1})				
Forest	378	386	357	329
Home garden	294	292	280	265
Areca nut Plantation	327	326	321	327
Agriculture	286	248	250	271
$LSD_{0.05}$	L = 14.20	D = 6.55	L × D = 13.10	
Available phosphorus (kg ha^{-1})				
Forest	22.54	17.90	11.91	15.23
Home garden	14.21	14.09	13.21	13.10
Areca nut Plantation	17.50	17.50	12.41	15.12
Agriculture	16.05	15.22	14.20	17.13
$LSD_{0.05}$	L = 0.12	D = 0.12	L × D = 0.24	

Notes. L, land-use system; D, soil layer; NS, nonsignificant; LSD, least significant difference at the 5% probability level.

system, and the least was 13.10 kg ha^{-1} in home gardens at a depth of 75–100. On average, forest had the greatest P content and agriculture the least. In tree-based land-use system, the greater P content could be due to recycling of P through mining by the tree species and subsequently recycling by way of surface litter fall. Kumar and Chaudhuri (1997) had also reported greater P in tree-based land-use systems.

Effects of Land Use and Soil Depth on Exchangeable Nutrient Cations

Exchangeable nutrient cations (Ca, Mg, K, and Al) were significantly influenced by land use (Table 3). The content of Ca was greatest (0.892 cmol kg^{-1}) in plantations in the

Table 3
Effect of land-use systems on exchangeable nutrients in soil profile

	Soil layer (cm)			
System	0–25	25–50	50–75	75–100
Exchangeable Ca (c mol kg^{-1})				
Forest	0.699	0.655	0.710	0.717
Home garden	0.784	0.752	0.787	0.803
Areca nut Plantation	0.803	0.623	0.892	0.699
Agriculture	0.729	0.701	0.703	0.621
$LSD_{0.05}$	L = 0.002	D = 0.005	L × D = 0.01	
Exchangeable Mg (c mol kg^{-1})				
Forest	0.219	0.235	0.224	0.221
Home garden	0.218	0.217	0.225	0.228
Areca nut Plantation	0.249	0.355	0.527	0.335
Agriculture	0.351	0.351	0.242	0.236
$LSD_{0.05}$	L = 0.001	D = 0.002	L × D = 0.004	
Exchangeable K (c mol kg^{-1})				
Forest	0.211	0.130	0.131	0.144
Home garden	0.142	0.144	0.133	0.132
Areca nut Plantation	0.190	0.183	0.162	0.153
Agriculture	0.125	0.101	0.081	0.075
$LSD_{0.05}$	L = 0.015	D = 0.041	L × D = 0.080	
Exchangeable Al (c mol kg^{-1})				
Forest	1.20	1.55	1.32	1.48
Home garden	1.50	1.12	1.14	1.28
Areca nut Plantation	1.62	1.30	1.86	1.53
Agriculture	1.45	1.21	1.08	1.49
$LSD_{0.05}$	L = 0.03	D = 0.01	L × D = 0.02	

Notes. L, land-use system; D, soil layer; NS, nonsignificant; LSD, least significant difference at the 5% probability level.

50- to 75-cm soil layer and least (0.621 cmol kg^{-1}) in agriculture in the 75- to 100-cm soil layer. The Mg content was greatest (0.527 cmol kg^{-1}) in plantation at the 50- to 75-cm soil layer and least (0.217 cmol kg^{-1}) in home gardens at the 25- to 50-cm soil layer. The exchangeable K varied from 0.075 cmol kg^{-1} in agriculture at the 75- to 100-cm soil layer to 0.211 cmol kg^{-1} in surface soil of forests. Aluminum content varied from 1.08 cmol kg^{-1} to 1.86 cmol kg^{-1} in agriculture and plantations at the 50- to 75-cm soil layer, respectively. No consistent trend of increase or decrease in nutrient content with soil depth was recorded for all the exchangeable cations studied. Similar results had been reported for Ca, Mg, and Na by Sharma et al. (2009).

Effects of Land Use and Soil Depth on Available Micronutrients

The effects of land use on micronutrients such as Cu, Zn, Mn, and Fe were studied in four different soil layers (Figure 1). There was a significant effect of different land use and soil layer on micronutrient content. The content of Cu was greatest (2.25 ppm) in forest and least (0.52 ppm) in agriculture. Zinc content varied from 1.66 ppm in the surface soil layer of forest and to 0.50 ppm in the 75- to 100-cm soil layer in agriculture. Manganese content was greatest in (4.86 ppm) in the 50- to 75-cm soil depth of forest and least (1.03 ppm) in the 25- to 50-cm soil depth of home gardens. Available Fe varied from 7.65 ppm in the surface soil of forest to 4.78 ppm in the surface soil of arecanut plantation. Except for Fe, all the rest of the micronutrients did not show any consistent trend both for land use or soil layer. The inconsistency of micronutrients, particularly Cu and Zn, with respect to soil depth had also been reported by Sharma et al. (2009).

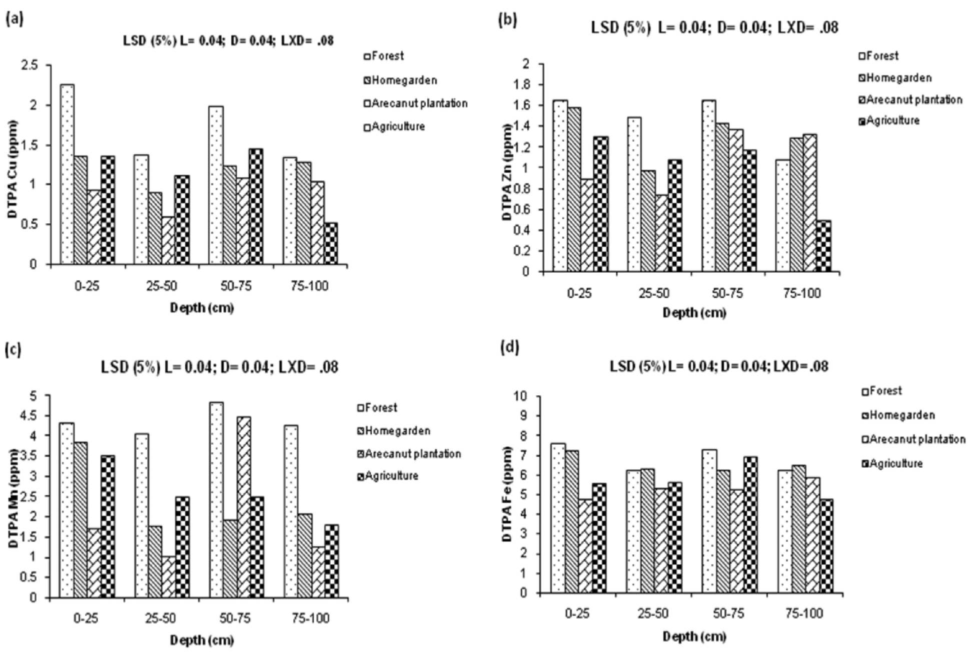

Figure 1. Effect of different land-use systems on DTPA-extractable micronutrients in soil profile: (a) Cu, (b) Zn, (c) Mn, and (Fe).

Effects of Land Use and Soil Depth on Soil Biological Properties

Soil biological properties MBC, MBN, and DHA were greatest under surface soil of forest (558 mg kg^{-1}, 26.67 mg kg^{-1}, and 33.03 μg TPF 24 h^{-1} g^{-1}dry soil, respectively) and least in the 75- to 100-cm layer under agriculture (150 mg kg^{-1} and 13.53 μg TPF 24 h^{-1} g^{-1}dry soil, respectively). However, MBN was least (11.13 mg kg^{-1}) in the 25- to 50-cm soil layer of agricultural land-use system (Table 4).

The values of MBC obtained in the study (150–558 mg kg^{-1}) are well within the reported range (61–1900 mg kg^{-1}) (Vance, Brookes, and Jenkinson 1987; Srivastava and Singh 1988). There is strong relationship between soil organic-matter content and enzyme activities (Gracia, Hernandez, and Costa 1994). Addition of organic matter and better nutrient cycling in forest might have increased the biological activity of the soil (Min et al. 2003). While working on improvement of soil fertility of moderately alkaline soils in Karnal, India, Kaur, Gupta, and Singh (2000) reported that MBC, which was low in rice–berseem crop, increased in soils under tree plantation and soil C increased by

Table 4
Effect of land-use systems on soil biological properties

	Soil layer (cm)			
System	0–25	25–50	50–75	75–100
Microbial biomass carbon (mg kg^{-1})				
Forest	558	536	471	312
Home garden	360	318	315	306
Areca nut Plantation	482	414	440	321
Agriculture	251	235.3	219	150
$LSD_{0.05}$	L = 19.51	D = 11.90	L × D = 18.21	
Microbial biomass nitrogen (mg kg^{-1})				
Forest	26.67	21.42	21.37	18.56
Home garden	16.17	14.53	15.25	17.13
Areca nut Plantation	21.32	18.31	17.14	15.73
Agriculture	12.73	11.13	12.77	15.67
$LSD_{0.05}$	L = 3.98	D = 2.55	L × D = NS	
Dehydrogenase activity (μg TPF 24 h^{-1} g^{-1}dry soil)				
Forest	33.03	31.7	28.23	30.07
Home garden	22.93	18.08	17.92	19.09
Areca nut Plantation	27.39	27.58	21.71	21.47
Agriculture	20.31	17.98	15.48	13.53
$LSD_{0.05}$	L = 7.92	D = 6.15	L × D = NS	

Notes. L, land-use system; D, soil layer; NS, nonsignificant; LSD, least significant difference at the 5% probability level.

11–52% because of integration of trees and crops. The decrease in microbial activity due to land-use changes have also been reported (Maggs and Hewett 1990; Sahani and Behera 2001).

Soil Fertility Index and Soil Evaluation Factor under Different Land-Use Systems at Varying Depths

Soil fertility index and SEF for different land uses and soil depths were calculated to find out the overall effect of land-use systems on soil quality. The SFI with respect to soil depth and land use is given in Figures 2a and 2b, respectively. There was a sharp decrease in fertility index in forest land use and arecanut plantation from surface layer to deepest layer as compared to agricultural land use. The greater fertility in surface soil in forest and arecanut is attributed to the greatest accumulation of organic matter from litter fall. By averaging the soil layer of each land use (Figure 2b), it is clear that the forest maintains greater fertility, followed by arecanut plantation and home gardens. Fertility is least in agricultural land use. SEF was also calculated for all the land uses and soil layers. It was found that SEF was greater (6.56) for forest, followed by arecanut plantation (6.43) and home garden (6.15), and least for agriculture (5.78) (Figure 2c). While calculating SEF for soil depth, it was found that the values for SEF decreased in all the land uses with the increase in the soil depth. By averaging the soil layer of each land use (Figure 2d), it is clear that forest land use had the greatest SEF (6.06), followed by arecanut plantation (6.14) and home garden (5.96), and least for agriculture (5.54). Studies on the effect of trees on soil fertility improvement such as with *Faidherbia albida* in West Africa (Felker 1978) and *Prosopis cineraria* in Rajasthan, India (Singh and Lal 1969) have revealed that the

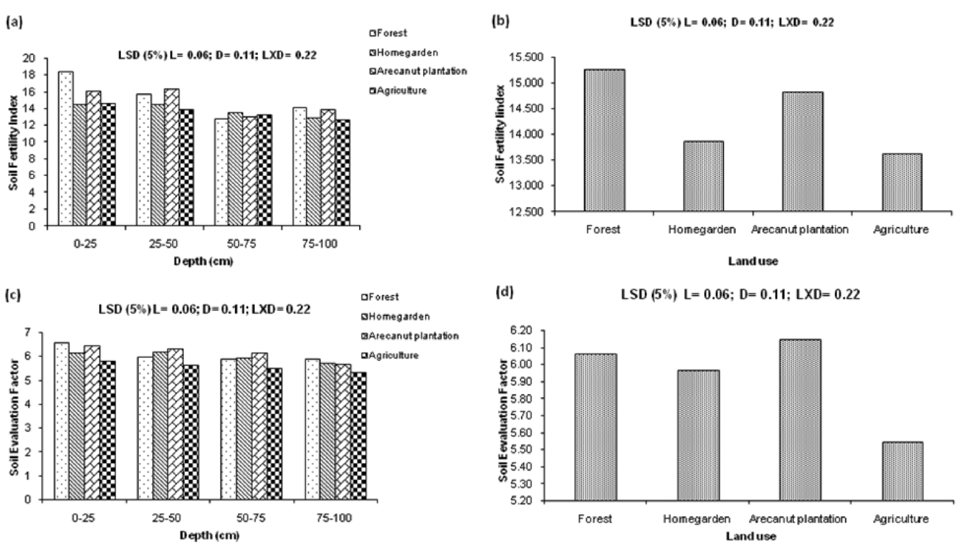

Figure 2. Effect of different land-use systems and depths on (a) soil fertility index with depths, (b) soil fertility with land use, (c) soil evaluation factor with depths, and (d) soil evaluation factor with land use.

Table 5
Pearson correlation coefficients between soil properties and soil fertility indices

	SFI	SEF	pH	OC	EC	CEC	Ca	Mg	K	Al	N	P	MBC	MBN	DHA
SFI	1.000														
SEF	0.753**	1.000													
pH	NS	NS	1.000												
OC	0.900**	0.834**	NS	1.000											
EC	0.540*	0.496*	NS	NS	1.000										
CEC	0.494*	0.635**	−0.673**	NS	NS	1.000									
Ca	NS	NS	NS	NS	NS	NS	1.000								
Mg	NS	NS	NS	NS	NS	NS	NS	1.000							
K	0.774**	0.890**	NS	0.765**	NS	0.720**	NS	NS	1.000						
Al	NS	NS	NS	NS	NS	NS	NS	0.517*	NS	1.000					
N	0.582**	0.613**	NS	0.551**	NS	0.900**	NS	NS	0.649**	NS	1.000				
P	0.847**	NS	NS	0.698**	0.523**	NS	−0.500*	NS	NS	NS	NS	1.000			
MBC	0.640**	0.807**	NS	0.695**	NS	0.860**	NS	NS	0.778**	NS	0.878**	NS	1.000		
MBN	0.616**	0.638**	NS	0.611**	NS	0.829**	NS	NS	NS	NS	0.863**	0.540**	0.855**	1.000	
DHA	0.692**	0.681**	NS	0.605**	NS	0.891**	NS	NS	0.687**	NS	0.901**	0.487*	0.857**	0.842**	1.000

**Significant at the 0.01 level.
*Significant at the 0.05 level.

accumulation of mineral nutrients is the result of a long-term process of capture of nutrient-rich litter. Increased soil fertility under mature scattered trees has also been reported by other researchers (Puri and Kumar 1995; Pandey, Singh, and Sharma 2000). Better soil fertility under forest may also be attributed to the fact that trees are generally much less degrading to the soil then many commercial agricultural crops. Studies conducted by the FAO have convincingly demonstrated that the amount of N removed by cereal crops was two and half times more than the amount removed by eucalyptus plantations. In the case of P, it was 15 times more (FAO 2000). Further, Nair (1984) established that agroforestry, agrihorticultural, and agripastoral systems have the potential to reduce erosion and runoff, maintain soil organic matter, improve soil physical properties, augment N fixation, and promote efficient nutrient cycling.

Correlation between Soil Properties and Soil Fertility Indices

Pearson's correlation matrix (Table 5) revealed strong significant positive correlations of SFI and SEF with OC, CEC, N, P, K, MBC, MBN, and DHA. Soil fertility parameters such as available K, P, and N and biological parameters such as MBC, MBN, and DHA showed strong positive relationships with OC. With increase in CEC of the soil, microbial activity increased significantly, as evidenced from very high positive values of correlation coefficients.

Conclusions

It is evident from the study that forest-based land use helped in increasing the OC content, exchangeable cations, available nutrients, micronutrients, and microbial activities over the arable land. Further, it was also found that forests have better soil quality than other tree-based land-use systems. We infer from the study that to maintain the soil fertility of the land on a sustainable basis, tree-based land-use systems should be advocated. The trees should be deep rooted as they are capable of utilizing nutrients beyond the root zone of agriculture crops and also help in nutrient cycling. However, density of trees and other vegetation should not be great, as in the case of home gardens, as greater density will exhaust the soil, as most of the components are of commercial use. A balanced tree–crop combination is ideal for both production and maintenance of soil health. Highly significant correlations of SFI and SEF with soil chemical and biological properties indicate that these two indices can successfully be used as indicators of soil quality.

References

Abbasi, M. K., M. Zafar, and T. Sultan. 2010. Changes in soil properties and microbial indices across various management sites in the mountain environments of Azad Jammu and Kashmir. *Communications in Soil Science and Plant Analysis* 41:768–782.

Bray, H. R., and L. T. Kurtz. 1945. Determination of total organic and available forms of phosphorus in soil. *Soil Science* 59:39–45.

Brookes, P. C., J. F. Kragt, D. S. Powlson, and D. S. Jenkinson. 1985. Chloroform fumigation and release of soil nitrogen: The effect of fumigation time and temperature. *Soil Biology and Biochemistry* 17:831–835.

Chakraborthy, R. N., and Chakraborthy, D. 1989. Changes in soil properties under *Acacia auriculiformis* plantation in Tripura. *Indian Forester* 115:272–273.

Chaudhury, J., U. K. Mandal, K. L. Sharma, H. Ghosh, and B. Mandal. 2005. Assessing soil quality under long-term rice-based cropping system. *Communications in Soil Science and Plant Analysis* 36:1141–1161.

Chen, L. D., J. Wang, B. J. Fu, and Y. Qiu. 2001. Land-use change in a small catchment of northern Loess Plateau, China. *Agriculture Ecosystem and Environment* 86:163–172.

Dalal, R. C., and D. Moloney. 2000. Sustainability indicators of soil health and biodiversity. In *Management for sustainable ecosystems*, ed. P. Hale, A. Petrie, D. Moloney, and P. Sattler, 101–108. Brisbane: Centre for Conservation Biology, University of Queensland.

Ditzler, C. A., and A. J. Tugel. 2002. Soil quality field tools: Experiences of USDA-NRCS Soil Quality Institute. *Agronomy Journal* 94:33–38.

Doran, J. W., and T. B. Parkin. 1994. Defining and assessing soil quality. In *Defining soil quality for a sustainable environment*, ed. J. W. Doran, D. C. Coleman, D. F. Bezdicek, and B. A. Stewart, 3–21. Madison, Wisc.: SSSA.

FAO. 2000. *The global outlook for future wood supply from forest plantations* (Working Paper GFPOS/WP/03). Rome, Italy: FAO.

Felker, P. 1978. *State of the art:* Acacia albida *as a complementary permanent intercrop with annual crops*. Riverside, Calif.: University of California.

Gracia, C., T. Hernandez, and F. Costa. 1994. Microbial activity in soils under Mediterranean environmental conditions. *Soil Biology and Biochemistry* 26:1185–1191.

Houghton, R. A. 1994. The worldwide extent of land-use change. *Bioscience* 44:305–313.

Jackson, M. L. 1974. *Soil chemical analysis*. Englewood Cliffs, N.J.: Prentice Hall.

Jenkinson, D. S., and J. N. Ladd. 1981. Microbial biomass in soil: measurement and turnover. In *Soil biochemistry*, ed. E. A. Paul and J. N. Ladd, 415–457. New York: Marcel Dekker.

Jenkinson, D. S., and D. S. Powlson. 1976. The effects of biocidal treatments on metabolism in soil, V: A method for measuring soil biomass. *Soil Biology and Biochemistry* 8:209–213.

Juo, A. S. R., and R. Lal. 1977. The effects of fallow land continuous cultivation on the chemical and physical properties of Alfisols in western Nigeria. *Plant and Soil* 47:517–589.

Kara, O., and I. Bolat. 2007. Impact of alkaline dust pollution on soil microbial biomass carbon. *Turkish Journal of Agriculture and Forestry* 31:181–187.

Kaur, B., S. R. Gupta, and G. Singh. 2000. Soil carbon, microbial activity, and nitrogen availability in agroforestry systems on moderately alkaline soils in northern India. *Applied Soil Ecology* 15:283–294.

Kumar, K., and M. R. Chaudhuri. 1997. Phosphorus fractions as affected by different land uses in acid hill soils of Monupur. *Journal of the Indian Society of Soil Science* 45:574–577.

Larson, W. E., and F. J. Pierce. 1991. Conservation and enhancement of soil quality. In *Proceedings of the International Workshop on Evaluation for Sustainable Land Management in the Developing World*, 175–203. Bangkok, Thailand: International Board for Soil Research and Management.

Lindsay, W. L., and W. A. Norvell. 1978. Development of a DTPA test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal* 42:421–428.

Lu, D., E. Moran, and P. Mausel. 2002. Linking Amazonian secondary succession forest growth to soil properties. *Land Degradation and Development* 13:331–343.

Madhumitha, D., B. P. Singh, and S. K. Khan. 1997. Effect of major land uses on soil characteristics of Alfisols in Meghalaya. *Journal of the Indian Society of Soil Science* 45:547–553.

Maggs, J., and B. Hewett. 1990. Soil and litter respiration in rainforest of contrasting nutrients status and physiognomic structure near Lake Eacham, northeast Queensland. *Australian Journal of Ecology* 15:320–336.

Min, D. H., K. R. Islam, L. R. Vough, and R. R. Weil. 2003. Dairy manure effects on soil quality properties and carbon sequestration in alfalfa–orchardgrass systems. *Communications in Soil Science and Plant Analysis* 34:781–799.

Moran, E. F., E. S. Brondizion, J. M. Tucker, M. C. Da Silva-Forsberg, S. McCracken, and I. Falesi. 2000. Effects of soil fertility and land use on forest succession in Amazônia. *Forest Ecology and Management* 139:93–108.

Nair, P. K. R. 1984. *Role of trees in soil productivity and conservation: Soil productivity aspects of agro-forestry*. Nairobi: International Council for Research in Agro-forestry.

Nair, P. K. R. 1993. *An introduction to agroforestry*. Dordrecht, the Netherlands: Kluwer.

Nair, P. K. R., R. J. Buresh, D. N. Mugendi, and C. R. Latt. 1999. Nutrient cycling in tropical agroforestry systems: Myths and science. In *Agroforestry in sustainable agricultural systems*, 1–31. Boca Raton, Fl.: CRC Press.

Nair, P. K. R., B. T. Kang, and D. B. L. Kass. 1995. Nutrient cycling and soil erosion control in agroforestry system. In *Agriculture and environment: Bridging food production in developing countries* (ASA Special Publication No. 60), ch. 7. Madison, Wisc.: American Society of Agronomy.

Naitham, R., and T. Bhattacharyya. 2004. Quasi-equilibrium of organic carbon in shrink–swell soils of the subhumid tropics in India under forest, horticultural, and agricultural systems. *Australian Journal of Soil Research* 42:181–188.

Pandey, C. B., A. K. Singh, and D. K. Sharma. 2000. Soil properties under *Acacia nilotica* trees in a traditional agroforestry system in central India. *Agroforestry Systems* 49:53–61.

Puri, S., and A. Kumar. 1995. Establishment of *Prosopis cineraria* (L.) Druce in the hot desert of India. *New Forests* 9:21–33.

Rich, C. I. 1965. Elemental analysis by flame photometry. In *Methods of soil analysis, part 2: Chemical and microbiological properties*, ed. C. A. Black, 849–864. Madison, Wisc.: American Society of Agronomy.

Richards, L. A. 1954. *Diagnosis and improvement of saline and alkali soils* (USDA Agriculture Handbook No. 60). Washington, D.C.: U.S. Government Printing Office.

Russel, J. S. 1986. The human impact. In *Australian soils*, ed. J. S. Russell and R. F. Isbell, 374–396. Lucia, Australia: University of Queensland Press.

Sahani, U., and N. Behera. 2001. Impact of deforestation on soil physicochemical characteristics, microbial biomass, and microbial activity of tropical soil. *Land Degradation and Development* 12:93–105.

Sahrawat, K. L., and L. T. Narteh. 2002. A fertility index for submerged rice soils. *Communications in Soil Science and Plant Analysis* 33:229–236.

Sharma, B. D., and I. C. Gupta. 1989. Effect of tree cover on soil fertility in western Rajasthan. *Indian Forester* 115:57–68.

Sharma, K. L., K. Ramachandra Raju, S. K. Das, B. R. C. Prasad Rao, B. S. Kulkarni, K. Srinivas, J. Kusuma Grace, M. Madhavi, and P. N. Gajbhiye. 2009. Soil fertility and quality assessment under tree-, crop-, and pasture-based land-use systems in a rainfed environment. *Communications in Soil Science and Plant Analysis* 40:1436–1461.

Singh, K. S., and P. Lal. 1969. Effect of *Prosopis spicigera* (or *cineraria*) and *Acacia arabica* trees on soil fertility and profile characteristics. *Annals of Arid Zone* 8:33–36.

Spaccini, R., A. Zena, C. A. Igwe, J. S. C. Mbagwu, and A. Piccolo. 2001. Carbohydrates in water-stable aggregates and particle size fractions of forested and cultivated soils in two contrasting tropical ecosystems. *Biogeochemistry* 53:1–22.

Srinivasan, U. M., and I. Caulfield. 1989. Agroforestry land management system in developing countries: An overview. *Indian Forester* 115:57–68.

Srivastava, S. C., and J. S. Singh. 1988. Carbon and phosphorus in the soil biomass of some tropical soils of India. *Soil Biology and Biochemistry* 19:743–747.

Subbiah, B. V., and G. L. Asija. 1956. A rapid procedure for assessment of available nitrogen in soils. *Current Science* 31:196–260.

Tabatabai, M. A. 1982. Soil enzymes. In *Methods of soil analysis, part 2: Chemical and microbiological properties*, 2nd ed., ed. A. L. Page, R. H. Miller, and D. R. Keeney, 937–940. Madison, Wisc.: American Society of Agronomy.

Vance, E. D., P. C. Brookes, and D. S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry* 19:703–707.

Walkley, A., and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37:29–38.

Young, A. 1997. *Agroforestry for soil management*, 2nd ed. Wallingford, UK: CAB International.