Journal of the Indian Society of Soil Science, Vol. 66, No. 3, pp 249-257 (2018)
DOI: 10.5958/0974-0228.2018.00031.2

Effect of Land Uses on Soil Physical Qualities in Mountainous Ecosystem of Western Ghats, India

M. Sonaimuthu, K. Sivakumar, K. Rajan[1]*, M. Tilak, R. Jude Sudhagar, P. Raja[1] and D. Dinesh[2]

Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam, Tamil Nadu

The present study attempts to relate the soil physical quality with five different land uses (Shola forest, *Eucalyptus* plantation, wattle plantation, grass land and scrub land) of a forest area (Udhagai range), which comes under Nilgiri south forest division, Nilgiri District, Tamil Nadu State. The objective of the study was to investigate the effects of different land uses on soil physical quality. The soil samples were collected from different land uses at 0-15 cm (surface) and 15-30 cm (sub-surface) depth and were analyzed for soil physical properties with standard procedures. The results showed that soil texture is clay in all the land uses except in grassland which is clay loam. The higher sand (41.8%) and silt (25.4%) contents were recorded in the surface layer of grassland, and the lower values were recorded under wattle plantation. The clay content was higher in Shola forest (68.6%) and lower in grassland. The higher bulk density was recorded in scrub land (1.62 Mg m^{-3}) and the least in grass land (1.35 Mg m^{-3}); the particle density was higher in Shola forest (2.60 Mg m^{-3}) and lower under grassland (2.36 Mg m^{-3}). The soil samples of different land uses recorded wide variation in porosity, the highest being recorded in the Shola forest (57.1%) and lowest (45.8%) in wattle plantation. Shola forest recorded the highest available soil moisture (13.7%, w/w basis), and the lowest was with *Eucalyptus* plantation (9.3%). Shola forest and wattle plantations have soils with superior physical quality. Soils under *Eucalyptus* plantation and scrub lands recorded with poor physical quality which are prone to soil erosion and may deteriorate further. It is suggested that growing cover crops will minimize soil erosion and improve soil physical quality. Implementing soil and water conservation measures such as stone walls and continuous trenches will reduce soil losses and improve water availability and biomasses.

Key words: Land use, soil physical qualities, soil quality index, Western Ghats

Land use and land cover managements have tremendous impact on soil quality. An undisturbed forest ecosystem maintains a quality soil *vis-à-vis* other ecosystems into poor quality soils. Land uses without conservation measures may aggravate soil erosion process and leads to land degradation. The lands which are used for quite a long period with different management practices may develop a good or poor quality soils. Forests land use in general have a greater influence on soil conditions than most other ecosystems, due to a well-developed O (organic) horizon, moderating soil temperature, and humidity at the soil surface, input of litter with high lignin content (Binkley and Giardina 1998). The sodicity of the lands irrigated with poor quality water has led to heavy clay dispersion which has resulted in the erosion of the land (Rajan *et al.* 2016). The effect of land use on soil properties will provide an opportunity to evaluate sustainability of land use systems. Soil, is also the foundation of infinite life and is the most vital and expensive natural resource, and not renewable in short-time (Sannappa and Manjunath 2013). Assessment of soil quality in a geographical area under varied land uses in different time period is essential to know its status. Vulnerable soils in any land uses are needed to be identified and land uses which maintained better soil quality can be recommended. Hilly ecosystems are highly delicate and its natural resources are more susceptible for the natural processes such as rain, wind, *etc.* High

*Corresponding author (Email: krajanars@gmail.com)
Present address
[1]ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Udhagamandalam, Tamil Nadu
[2]ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Vasad, Gujarat

intensive rainfall in hilly region is alarming for the soil resources which causes soil erosion if the land uses are improper. Nilgiri region of Western Ghats is a high rainfall hilly zone which has forest and grassland ecosystems under major area. Soil physical properties are playing critical role in hydrology of the region. Water movement in the soil is governed by its physical properties and further supported by vegetations on the land surfaces. Therefore, soil physical quality was assessed in Udhagai south forest range (The Nilgiris) under different forest land use system.

Materials and Methods

Site characteristics

The study was conducted in Udhagai forest range, an administrative region with resource-managed forests, Nilgiri south forest division, Nilgiri district of Tamil Nadu during August 2015 to July 2016. Udhagai range consisted of 3,577 ha with the major land uses of Shola forest, *Eucalyptus* plantations, wattle plantations, temperate grassland and scrubs lands. Geographically, the study area lies between 11°22′47″ N latitude and 76°40′1″ E longitude at an altitude ranging from 2000 to 2350 m above mean sea level (MSL) and considered to be mountainous ecosystem. The climate of the study area is temperate. The average rainfall of the study is 1310 mm with 157 rainy days. The soils of the study area are lateritic and are derived from Charnockite or gneisses which also known as Nilgiri gneiss. The soils are strongly acidic with pH values ranging from 3.8 - 5.5 and deficient in plant nutrients. Representative area for five land uses under Udhagai South range were selected and five representative sites were demarcated in each land uses for soil sample collection. Geo-coordinates were demarcated using geographical positioning system (GPS) and slopes were measured using Abney's level at all the sites of sampling. The physiography and the dominant species available in each plantation are furnished in the table 1.

Soil sampling and analysis

The soil samples were collected from each land uses by adopting V-shaped sampling method at the depths of 0-15 cm (surface) and 15-30 cm (sub-surface) for analyzing soil physical qualities. Core samples were collected from the field at two depths to estimate soil bulk density (Gupta and Dakshinamoorthy 1981). The soil samples collected were air-dried, mixed well, passed through 2-mm sieve and stored for the analyses. The soil texture was determined by the International Pipette method (Piper 1966). Particle density and total porosity was measured in Cylinder method (Gupta and Dakshinamoorthy 1981). Available soil moisture (field capacity moisture (0.33 bar) – permanent wilting point moisture (15.0 bar)) was determined using pressure plate apparatus (Jackson 1973). The data obtained were analyzed using XLSTAT 2016 for Duncan Multiple Range Test (DMRT) and descriptive statistics (Chauhan *et al.* 2014).

Table 1. Physiography and dominant plant species available in different land uses

Land uses	Physiography	Dominant spp.
Shola forest	Located between 11°23′58″ N latitude and 76°40′14″ E longitude and at an altitude range is 2202 m above MSL. The slope of the sampling site ranged from 15 to 20%.	*Syzygium cumunii, Syzygium montana, Michelia champaca, Eleocarpus oblangus, Rhododendron nilagaricum, Litsia wightiana, Mappia foetida*, etc.
Eucalyptus plantation	Located at 11°01′12.3″ N latitude and 76°15′36.3″ E longitude and at an altitude is 2310 m above MSL. The slope of the sampling site ranged from 20 to 25%.	*Eucalyptus globulus* (Blue gum)
Wattle plantation	Located at 11°23′51.8″ N latitude and 76°39′33.4″ E longitude and at an altitude of 2313 m above MSL. The slope of the sampling site ranged from 20 to 25%.	Wattle or black wattle (*Acacia mearnsii*) family Fabaceae
Grass land	Located at 11°24′20.6″ N latitude and 76°40′20.6″ E longitude and at an altitude range is 2257 m above MSL. The slope of the sampling site ranged from 30 to 35%.	Ikuye grass (*Pennisetum clandestinum*) (Poaceae), sedges (Cyperaceae) and rushes of Juncaceae families
Scrub land	Located at 11°26′50.3″ N latitude and 76°40′16″ E longitude at an altitude of 2257 m above MSL. The slope ranges from 10-15%.	Thorny shrubs species called Gorse (*Ulex europaeus) which* belongs to Fabaceae family

Table 2. Soil quality index for lateritic soils of Western Ghats

Parameter	Weights	Class I	Class II	Class III	Class IV
Bulk density (Mg m^{-3})	20	1.0-1.3	1.3-1.4	1.4-1.5	>1.5
Texture	30	Loam	Clay loam, silty loam, silty clay, silty clay loam, sandy clay	Silt, sandy clay loam	Sandy loam, loamy sand, sand, clay
Porosity (%)	30	>50	50-45	40-45	<40
Available soil moisture (%)	20	>20.0	15.0-20.0	10.0-15.0	<10.0
	100	4	3	2	1

Assessment of soil physical quality

Soil physical quality evaluation was done by the methods described by Larson and Pierce (1994) and Singh (2007). In this study, four soil quality indicators namely soil texture, bulk density, porosity and available soil moisture were used. These factors have therefore been adopted to reflect the soil physical quality in relation to soil and water conservation. The methodology for evaluation of soil quality is described below:

Weights of the indicators: The contribution of each indicator towards soil quality is usually different and can be indicated by a weighing coefficient. There are many ways to assign the weights for each indicator. In this study, the weight for each indicator (Table 2) was assigned on the basis of existing soil conditions, cultivation practices, slope and vegetation cover with reference to soil and water conservation in the hilly area. The sum of all weights is normalized to 100%.

Subdivision of the indicators and their marks

Each of the indicators was divided into four classes (I, II, III, IV). Class I is the optimum property for water transmission and retention, plant growth and no limitation for soil and water conservation, Class II is with slight limitations, Class III is with more serious limitations than class II, and Class IV, with severe limitations for soil and water conservation. Marks of 4, 3, 2 and 1 were given to class I, II, III and IV, respectively. The range for each class is shown in table 2.

Quantitative evaluation of changes in soil quality:

By introducing the concept (Karlen and Stott 1994) of relative soil quality index (RSQI), the four indicators were combined into an RSQI. The maximum cumulative soil quality index value is considered to arrive RSQI for other soils. The equation for calculating RSQI value is given below:

$$RSQI = (SQI/SQIm) \times 100 \quad \ldots(1)$$

where, SQI = soil quality index; SQIm = maximum value of SQI.

The maximum value of SQI for soil is 400 and the minimum value 100 (Wang and Gong 1998).

SQI is calculated from the equation:

$$SQI = \Sigma Wi\ Ii \quad \ldots(2)$$

where, Wi = weights of the indicators; Ii = the marks of the indicators classes

The SQI of every indicator was calculated separately by multiplying weight of indicators and marks allotted to each class (Table 2). For example, if the bulk density is 1.4 Mg m^{-3}; it belongs to class III.

As the weight for bulk density is 20, and the marks for class III is 2, then the

SQI (slope) = 20 × 2 = 40

In this way, SQI for every indicator was calculated. If all the quality indicators of an optimum soil falls in Class I would score 400 marks. Summing up of all four indicators produced the SQI value for soils under study. An optimum soil in any region will have a normalized RSQI of 100, but real soils will have lower values which directly indicate their distance from the optimal soil. According to the RSQI values, soils were classified into 5 classes from best to worst, represented as follows by I (Best), II (Very good), III (Good), IV (Average) and V (Poor), respectively (Table 3).

Quantification of physical quality of soil with bulk density, texture, porosity and available soil moisture has been attempted. These are relevance with soil physical qualities to land degradation by soil erosion. Water transmission characteristics in soil

Table 3. Classes of relative soil quality

Classes	Value ranges	Grade
I	90-100	Best
II	80-90	Very good
III	70-80	Good
IV	60-70	Average
V	<60	Poor

profile are determined by soil physical properties which are under tremendous change by various land uses. Conservation measures are implemented based on hydro-physical properties such as infiltration, and hydraulic conductivity. These hydro-physical properties are governed by soil physical properties especially texture, bulk density, porosity and water retention.

Bulk density: The optimum range of bulk density in the region falls between 1.0 to 1.3 Mg m^{-3}. The soil organic carbon is very high in the Western Ghats hilly area hence the bulk density is low. Wherever the organic carbon content reduces by erosion loss the compactness is increasing and the bulk density is increasing.

Texture: Soil texture varies from sand to clay depending upon its formation. However, texture is modified by degradation processes especially water and wind erosions. Soils in the hilly areas are more vulnerable to erosion and tend to change the classes. An optimum class of loam provided favourable soil quality compared to other classes. Soil quality decreases when sand and clay contents increase. High sand content increases water movement and reduces water and nutrient holding capacities whereas high clay content reduces water movement and induces runoff.

Porosity: Porosity in the soil should be optimum and it is influenced by texture, organic matter and management practices. Erosive rainfall distracts the soil aggregates and disperses the soil particles which will modify the pore spaces. Frequent rainfall with high soil moisture dislocates the clay particles and changes the porosity. Low porosity decreases infiltration and increases the runoff and the high porosity increases the infiltration and reduces the runoff. Hence, the porosity plays a major role in soil erosion processes which has been considered for the framing of soil quality index.

Available soil moisture: It is a moisture holding capacity that explains water intake by any soil. It reflects the soil qualities indirectly. Soil with optimum water transmission characteristics holds more water and delays the runoff generation. A soil quality index was framed with the four physical qualities.

Results and Discussion

Five land uses under Udhagai forest range have recorded varied levels of impacts on soil physical quality and soil productivity. The variations of soil physical qualities under a forest range with similar climatic condition are mainly due to its land use and land cover condition.

Soil texture

Across the land use systems, there were significant variations in soil texture. The textural analysis showed that all the soils were clay textured except the soils collected from grassland which comes under clay loam. Sand content of surface soil differed significantly among different land use systems. In surface soil at 0-15 cm depth, the highest quantity of sand content was recorded in the grass land (41.8%) and the remaining land uses has not shown any difference among themselves (Table 4). In sub-surface soil of 15-30 cm depth, the sand content followed the

Table 4. Effect of different land uses on particle size (sand, silt, clay %) distribution of soils

Land	Sand (%)		Mean	Silt (%)		Mean	Clay (%)		Mean	Soil texture
use	0-15 cm	15-30 cm		0-15 cm	15-30 cm		0-15 cm	15-30 cm		
SF	19.6^{b}	15.1^{b}	17.5	11.4^{b}	11.1^{b}	11.3	65.8^{a}	71.3^{a}	68.6	Clay
	(18.1 – 22.2)	(13.6–16.1)		(10.9-11.9)	(10.7-11.5)		(64.2-67.7)	(65.8-72.0)		
EP	20.2^{b}	14.5^{b}	17.4	11.3^{b}	11.1^{b}	11.2	66.1^{a}	69.8^{a}	67.4	Clay
	(19.5-21.3)	(12.2-19.4)		(10.7-11.4)	(10.9-11.6)		(64.6-68.2)	(66.8-73.0)		
WP	20.3^{b}	12.9^{b}	16.6	10.5^{b}	9.9^{b}	10.2	64.6^{a}	72.1^{a}	67.1	Clay
	(19.3-21.0)	(11.5-14.6)		(10.0-11.0)	(9.7-10.1)		(62.0-66.3)	(68.9-75.4)		
GL	41.8^{a}	41.8^{a}	41.8	25.4^{a}	23.9^{a}	24.7	33.1^{b}	33.9^{b}	32.4	Clay loam
	(33.5-45.6)	(28.7-48.6)		(18.4-50.1)	(16.6-45.4)		(19.1-38.5)	(20.3-38.0)		
SL	19.0^{b}	13.0^{b}	16.0	11.9^{b}	10.3^{b}	11.1	67.3^{a}	68.8^{a}	66.8	Clay
	(18.2-19.8	(11.8-14.6)		(11.6-12.4)	(9.6-10.7)		(66.5-67.9)	(69.7-75.4)		
Mean	24.2	19.5		14.1	13.3		59.4	63.2		
SD	9.2	9.2		8.1	7.3		13.8	16.5		
CV%	38.0	47.2		57.4	54.9		23.3	26.1		

SF – Shola forest; EP – *Eucalyptus* plantation; WP – Wattle plantation; GL – Grass land; SL – Scrub land
Means with the same letter are not significantly different at $P \leq 0.05$ according to DMRT.
The value in parentheses is range.

similar trend of surface soil. The highest sand content was observed in grassland and lowest in wattle plantation. In all the land uses, the sand content decreased with depth *i.e.* from surface to sub-surface layer. Similar findings were witnessed by Rehman *et al.* (2017). The silt content in 0-15 cm depth ranged from 10.5 to 25.4% in different land uses which is differing significantly with highest in grassland and lowest in wattle plantation. At 15-30 cm depth, the silt content varied from 9.9 to 23.9%. The silt content was recorded to be higher in grassland and lower in wattle plantation. Except the grassland, the silt content was on par among the other land uses. There was a significant variation in the clay content of the surface soil of all the land uses which varied from 33.1 to 67.3%. The highest clay content was recorded with scrub land which is on par with Shola forest, *Eucalyptus* plantation and Wattle plantation. Similar trend was observed in sub-soil as well. Clay content of all the land uses except grassland is on par with each other. The clay content at sub-surface soil was significantly varying from 33.9 to 72.1% with highest in wattle plantation and lowest in grassland. Except grassland, the clay content in other land uses were on par. Clay content is found more in sub-surface soil than surface soil and the reverse condition was observed with sand. The study area is slopy in nature and also high rainfall zone hence the detached finer particles such as clay and silt are carried away by the runoff water leaving heavy sand particle. Clay translocation is distinct in the soils of study area due to illuviation process hence the clay accumulation in sub-surface is heavy and it affected the other physical qualities of the soil. Gebeyaw (2015) reported that the clay content was higher in the sub-surface layer than in the surface layer of forest soils. The grasslands are being grazed by the domestic and wild animal in the study area has reduced the land cover. Exposed land area are victim for natural process such as rainfall and erosion and that might have carried away the finer particles of clay and left the sand and silt content in the surface and sub-surface soils in higher quality.

The soil texture was significantly affected by land use and soil depth interactions. The sand and silt fractions were observed to be higher (41.8 and 25.4%) in surface soils of grassland while the highest clay content (72.1%) was recorded in the sub-surface soil of wattle plantation which might be due to the high leaching of clay particles down the profile in wattle plantation. In all the land uses, the clay content increased with soil depth while sand and silt contents decreased with increasing soil depths. These findings are in line with that of Eyayu *et al.* (2009). They reported that the overall mean values of sand and silt contents were higher in surface than in sub-surface and the clay content was lower in the surface layer than in the subsurface layer.

Bulk density

The bulk density in different land uses at surface soil (0-15 cm) was significantly differing and it ranged from 1.24 to 1.58 Mg m^{-3} (Table 5). The highest bulk density was recorded in scrub land (1.58 Mg m^{-3}) and it was significant in other land uses. The second higher bulk density was observed with *Eucalyptus* plantation. The third higher bulk density (1.39 Mg m^{-3}) was observed with wattle plantation. The bulk density was observed to be lower in grassland (1.34 Mg m^{-3}). The bulk density of Shola forest and wattle plantation is on par with each other. In case of sub-surface soil of 15-30 cm depth, the bulk density of different land uses are differing significantly and it ranged from 1.46 to 1.66 Mg m^{-3}. The highest bulk density was observed with scrub land. It was followed by the bulk density values from *Eucalyptus* plantation (1.61 Mg m^{-3}) and grassland (1.55 Mg m^{-3}). The bulk density was observed to be lower in wattle plantation (1.46 Mg m^{-3}). This is in close agreement with the result of Zerfu Hailu (2002) who has reported that the mean values of bulk densities were between 1.2 to 1.5 Mg m^{-3} in *Eucalyptus camaldulensis* plantations. It was observed in this study that soil bulk density increased with increasing soil depth. High bulk density was observed in the scrub land, which is very low in organic matter when compared to other land use systems. Okonkwo (2010) has also reported that high bulk density in the continuous cropping land over the other land use systems is attributed to the low level of organic matter and tillage.

Fikadu *et al.* (2013) reported that the soil bulk density was lower in the surface soils of all the land use types indicating the tendency of bulk density to increase with depth due to less disturbance of sub-surface compacted soil and the corresponding decrease in soil organic matter content (Rajan *et al.,* 2014). In the present study, the bulk density was distinctly less in the surface soil samples of 0-15 cm in all the land uses. The soil bulk density was low in the grassland (1.34 Mg m^{-3}) at the depth of 0-15 cm. The decrease in the soil bulk density in the grassland might be due to high organic residues of grass roots.

Particle density

The particle density was varying from 1.98 to 2.56 Mg m^{-3} at surface soils. The Shola forest recorded

Table 5. Effect of different land uses on physical qualities of soils

Land use	Soil bulk density (BD) ($Mg\ m^{-3}$)		Mean	Particle density (PD) ($Mg\ m^{-3}$)		Mean	Total porosity (TP) (%)		Mean	Available soil moisture (ASM) (%)		Mean
	0-15 cm	15-30 cm		0-15 cm	15-30 cm		0-15 cm	15-30 cm		0-15 cm	15-30 cm	
SF	1.24^d (1.14-1.58)	1.48^b (1.39-1.59)	1.36	2.56^a (1.60-3.45)	2.60^a (2.00-2.90)	2.18	58.7^a (52.3-63.8)	55.3^a (48.8-62.5)	57.06	12.1^a (5.7-19.1)	15.1^a (12.6-18.1)	13.68
EP	1.47^b (1.21-1.28)	1.61^b (1.29-1.64)	1.54	1.98^a (1.40-2.90)	2.38^a (1.50-3.30)	2.58	49.1^a (31.6-66.7)	44.3^a (26.8-60.1)	46.71	8.5^d (3.8-14.1)	10.0^b (5.4-13.9)	9.29
WP	1.39^c (1.41-1.52)	1.46^c (1.29-1.72)	1.43	2.02^a (1.20-2.70)	2.36^a (1.80-3.30)	2.19	53.5^a (38.9-68.4)	45.8^a (33.4-62.3)	49.34	11.7^b (8.8-15.8)	13.9^c (12.8-15.6)	12.87
GL	1.34^c (1.16-1.54)	1.55^c (1.56-1.68)	1.45	2.25^a (1.40-2.90)	2.56^a (1.80-3.30)	2.41	52.8^a (44.4-58.8)	50.8^a (40.50-66.7)	49.18	9.0^c (4.3-14.3)	14.3^c (12.3-18.8)	11.73
SL	1.58^a (1.44-1.72)	1.66^a (1.62-1.68)	1.62	2.42^a (2.00-2.90)	2.58^a (1.65-3.25)	2.50	50.9^a (31.5-60.5)	47.3^a (37.5-57.6)	49.12	11.1^b (6.9-14.4)	13.1^d (10.3-17.1)	12.17
Mean	1.40	1.55		2.25	2.50		52.6	48.2		10.5	13.3	
SD	0.15	0.11		0.62	0.52		11.9	10.3		3.16	4.12	
CV%	10.71	7.10		27.5	20.8		22.2	21.3		29.9	30.8	

Means with the same letter are not significantly different at $P \leq 0.05$ according to DMRT.
SF – Shola forest; EP – *Eucalyptus* plantation; WP – Wattle plantation; GL – Grass land; SL – Scrub land
The value in parentheses is range.

the highest particle density (2.56 $Mg\ m^{-3}$) followed by scrub land, grassland and wattle forest. The *Eucalyptus* forest recorded the lowest particle density (1.98 $Mg\ m^{-3}$) in surface soils. Dense and stabilized vegetations in Shola forest do not support high erosion and permeability compared to *Eucalyptus* plantations. Under protected environment the clay dispersion and translocation is meager. Hence, high clay content in unit volume in Shola forest might be the reason for high particle density compared to *Eucalyptus* forest where the erosion is more and coarse sand particles are also more in the soil for higher particle density. This is in confirmation with the findings of Thomas and Sankar (2001). They have also witnessed highest particle density values in the Shola forest compared to grassland. The particle density was varying from 2.38 to 2.60 $Mg\ m^{-3}$ in the sub-surface soils. The highest particle density (2.60 $Mg\ m^{-3}$) was recorded in Shola forest followed by scrub land (2.58 $Mg\ m^{-3}$), grassland (2.56 $Mg\ m^{-3}$) and *Eucalyptus* plantation (2.38 $Mg\ m^{-3}$). The lowest particle density was recorded with wattle plantation (2.36 $Mg\ m^{-3}$). However, the particle density was not significant among the land uses in sub-surface soils. Particle density was found to be higher in the sub-surface soil compared to the surface soil in all the land uses which may be due to more clay accumulation in sub-surface soil.

Total porosity

The soil total porosity ranged from 49.1 to 58.7% in different land uses in surface soils. The highest total porosity was recorded in Shola forest (58.7%) followed by wattle plantation (53.5%), grassland (52.8%), and scrub land (50.9%). The lowest total pore spaces was recorded with *Eucalyptus* plantations (49.1%) (Table 5). This coincides with the findings of Ramachandran (2006) who reported high porosity in Shola forest. The increase in the total porosity observed in the Shola forest might be due to the high organic matter content. Similar results were also reported by Habtamu *et al.* (2014) that the highest porosity was observed on the forest land and lowest on the grazing land which might be due to high organic matter in forest land and higher compaction with bulk density in grazing land. Total porosity in sub-surface soil layer was varying from 45.8 to 55.3%. The highest total porosity was recorded in Shola forest followed by grassland, *Eucalytpus* plantation and scrub land. Similar observations on the influence of organic matter on the improvement of total porosity were reported by Anikwe *et al.* (2003). Organic matter influences soil physical properties by encouraging granulation, assisting aggregate (structure) stability, helping aggregation of soil particles, improving aeration and water holding capacities and reducing plasticity and cohesion. The lowest porosity was recorded in wattle plantation. There is a reduction in porosity in sub-soil of all the land uses which might be due to more compaction in the sub-soil compared to surface soil.

Available soil moisture

Soil water retention plays an important role in hydrology. Water holding capacity of soil varies depending upon soil quality and soil management. Various land use systems developed difference in soil qualities and one such a quality is soil water retention and available soil moisture. Among five land uses studied the available soil moisture ranged from 8.5 to 12.1% in the surface soils (Table 5). The available soil moisture among land uses differs significantly. The highest available soil moisture (12.1%) was recorded in Shola forest followed by wattle plantation, scrub land and grassland. The lowest available soil moisture (8.5%) was recorded with Eucalyptus plantation. The available soil moisture was observed to be 15.1, 13.9 and 10% (w/w basis) in Shola forest, Wattle plantation and *Eucalyptus* plantation respectively at 15-30 cm depth and it was statistically significant (5% level) compared to all the other samples. The highest available soil moisture of Shola forest may be attributed to the high clay content and organic carbon of the soils as observed by Rajan *et al*. (2014). It finds the support of Roy and Landey (1962) who has reported that the relatively higher moisture content could be attributed to the high clay content of the soils. This has been strengthened by Brady and Weil (2002) that fine textured soils hold more moisture than coarse-textured soils. In the study area the available soil moisture was distinctly less in the surface soil layer in all the land uses when compared to the sub-surface layer. This may be attributed to the fact that the surface soil with well developed stable macro aggregates permits easy infiltration and the deeper soil have more effective volume per unit area for greater moisture storage (Ravikumar and Somashekar 2014).

Soil physical quality assessment

The highest cumulative value of soil quality was observed with Shola forest of Western Ghats. It is an undisturbed natural forest brought under reserve forest category (Table 6). Since this forest develops in the depressions of hill slopes along the water courses, hence, water availability is not a limitation. Being a temperate evergreen forest, litter accumulation and organic addition is very high which has contributed for highest soil physical quality. Second highest value was observed with temperate grassland, where the grass vegetations are permanent. The organic matters are added continuously in the soil from its root and leaf biomasses. High root biomass in the grassland adds high amount of organic carbon in the soil. Flesh growth of grasses which covers the land is a form of conservation measure for soil and water. Hence, the soil physical quality is maintained as that of Shola forest.

The soil physical quality of wattle plantation falls in middle category. Dense foliage of wattle plantations with considerable quantity of litter accumulation might have protected the soil from erosion. The wattle trees are legumes which fix nitrogen from the atmosphere by the roots and addition of nutrients through litter fall might be the reason for maintaining medium level of soil physical quality. The scrub land was found with ground cover vegetations with weed plants. The land lies as such for long time without any protection from rain water erosion which might be the reason for poor soil physical quality. The lowest soil physical quality was recorded with *Eucalyptus* plantations (Table 6). The land under this plantation was observed with gravels on the surface with poor conservation measures. Wide

Table 6. Ranking of soils under different land uses in mountainous ecosystem of Western Ghats

Parameter	Shola forest	*Eucalyptus* plantation	Wattle plantation	Temperate grassland	Scrub land
BD (Mg m^{-3})	60	20	40	40	20
Texture	30	30	30	60	30
Porosity (%)	120	90	90	90	90
Available soil moisture (%)	40	20	40	40	40
Cumulative value for 400	250	160	200	230	180
RSQI	-	64	80	92	72
Ranking		IV	II	I	III

spacing with trees felling might have enhanced soil erosion and compaction and it might have resulted in poor soil physical quality. The relative soil quality index (RSQI) was worked out for different land uses to prioritize them to adopt conservation measures. The highest cumulative value arrived through soil quality index (SQI) was Shola forest with the SQI of 250. Keeping the Shola forest as reference, the RSQI was calculated for other land uses. Grassland scored the SQI value of 92 which ranked first place to maintain the "best" followed by wattle plantation as "very good" and scrubland as "good" soil physical quality under mountainous ecosystem of Western Ghats. Among all the vegetations or land uses, *Eucalyptus* plantation falls under "average" quality which needs immediate attention for conservation measures to protect the land from further degradation. Contour stone wall and continuous contour trenches inside the *Eucalyptus* plantation will conserve soil from erosion and water in the field itself. The velocity of the runoff is reduced by the stone wall and trenches hence the carrying capacity of the runoff is reduced. Therefore, the soil being carried away by the runoff is deposited in the field itself. Since the velocity and speed of the runoff is reduced, it provides sufficient time for water to infiltrate into soil.

Conclusions

Soil physical quality was assessed in North forest division of Nilgiri district of Tamil Nadu. There were five land uses namely shola forest, *Eucalyptus* plantation, wattle plantation, grass land and scrub land in the study area. Soil samples were collected from two depths (0-15 and 15-30 cm) and soil physical qualities were assessed. The land uses were ranked based on the soil quality index framed by using different classes and weights for soil physical qualities. The result of the above study states that Shola forest and wattle plantations have soils with superior physical qualities followed by grassland soils mainly due to highest degree of land cover. *Eucalyptus* plantation and scrub lands have soils with poor physical qualities which are prone to soil erosion and land degradation. Land cover is relatively less in *Eucalyptus* plantation compared to Shola forest and wattle plantation and poor in scrub land which have reflected on the soil physical quality. It is suggested that growing cover crops will minimize the soil erosion and improve the soil physical qualities. Implementing soil and water conservation measures such as stone walls and trenches will reduce soil losses and improve water availability and biomass especially in *Eucalyptus* plantation and scrub lands.

Acknowledgement

The authors wish to acknowledge the Department of Forest, Government of Tamil Nadu for granting permission to conduct the research in the Udhagai range forest areas of Nilgiri South Division, Nilgiris, Tamil Nadu.

References

Anikwe, M.A.N., Obi, M.E. and Agbim, N.N. (2003) Effect of crop and soil management practices on soil compatibility in maize and groundnut plots in a Paleustult in southeastern Nigeria. *Plant and Soil* **253**, 457-465.

Binkley, D. and Giardina C. (1998) Why do species affect soils. The warp and woof of tree-soil interaction. *Biogeochemistry* **42**, 89–106.

Brady, N.C. and Weil, R.R. (2002) *The Nature and Properties of Soils*.13th Ed. Prentice- Hall Inc., New Jersey, USA..

Chauhan, R.P., Pande, K.R. and Thakur, S. (2014) Soil properties affected by land use systems in western Chitwan, Nepal. *International Journal of Applied Science and Biotechology* **2**, 265-269.

Eyayu, M., Gebrekidan, H. Mamo, T. and Assen, M. (2009) Effects of land use change on selected soil properties in the Tera Gedam Catchment and adjacent agro-ecosystems, north-west Ethiopia. *Ethiopian Journal of Natural Resources* **11**, 35-62.

Fikadu, G., Abdu, A., Mulugeta, L. and Aramde, F. (2013) Effects of different land uses on soil physical and chemical properties in Wondo Genet Area Ethiopia. *New York Science Journal* **5**, 110-118.

Gebeyaw T.Y. (2015) Assessment of soil fertility variation in different land uses and management practices in Maybar Watershed, South Wollo Zone, North Ethiopia. *International Journal of Environmental Bioremediation and Biodegradation* **3**, 15-22.

Gupta, R.P. and Dakshinamoorthy, C. (1981) Procedures for physical analysis of soil and collection of agrometerological data. Division of Agricultural Physics, IARI, New Delhi .

Habtamu, A., Heluf, G., Bobe B. and Enyew A. (2014) Fertility status of soils under different land uses at Wujiraba Watershed, North-Western Highlands of Ethiopia. *Agriculture Forestry and Fishery* **3**, 410-419.

Jackson, M.L. (1973) *Soil Chemical Analysis*. Prentice Hall of India (Pvt) Ltd., New Delhi.

Karlen, D.L. and Stott (1994) A framework for evaluating physical and chemical indicators of soil quality. In

Defining Soil Quality for a Sustainable Environment (J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart, Eds.). SSSA Special Publication. No. 35, Soil Science Society of America, American Society of Agronomy*,* Madison, WI, pp. 53-72.

Larson, W.E. and Pierce, F.J. (1994) *The Dynamics of Soil Quality as a Measure of Sustainable Management, In Defining Soil Quality for a Sustainable Environment*. SSSA Special Publication 35, Soil Science Society of America and American Society of Agronomy, pp. 37-51.

Okonkwo, C.I. (2010) Effect of burning and cultivation on soil properties and microbial population of four different land use systems in Abakaliki. *Research Journal of Agriculture and Biological Sciences* **6**, 1007-1014.

Piper, C.S. (1966) *Soil and Plant Analysis*, Hans Published, Bombay.

Rajan, K., Natarajan, A., Anil Kumar, K.S., Gowda, R.C. and Abdul Haris, A. (2014) Assessment of some soil physical indicators in severely eroded lands of southern Karnataka**.** *Indian Journal of Soil Conservation* **42**, 154-163.

Rajan, K., Natarajan, A., Kasthuri Thilagam, V., Anil Kumar, K.S., Dinesh, D., Alam, N.M., Khola, O.P.S. and Gowda, R.C. (2016) Clay dispersion induced by changes in some soil properties in undulating salt affected landscapes of southern Karnataka, India. *Current Science* **110**, 874-883.

Ramachandran, A. (2006) Carbon sequestration potential and biodiversity conservation for better management of forests in Kolli hill, Eastern Ghats of Tamil Nadu – A geospatial approach. *Ph.D. Thesis,* Bharathidasan University, Tiruchirapalli, India.

Ravikumar, P. and Somashekar R.K. (2014) Spatial distribution of macronutrients in soils of Markandeya river basin, Belgam, Karnataka, India. *Proceedings of the International Academy of Ecology and Environmental Sciences* **4**, 81-94.

Rehman, N.Z., Ram,D.,Wani, J.A. and Masrat Maqbool (2017) Characterization, classification and evaluation of cultivated soils under different toposequences in Pulwama district of Kashmir valley. *Journal of the Indian Society of Soil Science* **65**, 239-247.

Roy, B.B. and Landey, R.I. (1962) Studies on red and lateritic soils of Mond watershed area of Raigarh district. *Indian Journal of Agricultural Sciences* **32**, 294-302.

Sannappa, B. and Manjunath, K.G. (2013) Fertility status of soils in the selected regions of the Western Ghats of Karnataka, India. *Scholar Academy Journal of Biosciences* **1**, 200-208.

Singh, A.K. (2007) Evaluation of soil quality under integrated nutrient management. *Journal of the Indian Society of Soil Science* **55**, 58-61.

Thomas, P. and Sankar, S. (2001) Role of Shola forests in maintaining water courses in the high ranges of the Western Ghats of Kerala. *KFRI Research Report* No. **205**.

Wang, X. and Gong Z. (1998) Assessment and analysis of soil quality changes after eleven years of reclamation in subtropical China. *Geoderma* **81**, 339-355.

Zerfu Hailu (2002) Ecological impact evaluation of *Eucalyptus* plantation in comparison with agricultural and grazing land use types in the high lands of Ethiopia, *Ph.D Thesis,* University of Agricultural Science, Vienna.

Received 13 March 2018; Accepted 17 July 2018