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Effect of Land Use on the Carbon Stock and Soil Quality Attributes in Loess Derived Soils in Agh-Su Watershed, Golestan Province, Iran

F. Khormali*[1], S. Shamsi[1]
[1]Gorgan University of Agricultural Sciences and Natural Resources

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Abstract

Monitoring the effect of land use on soil quality attributes within an ecosystem can provide a useful way to control land degradation and achievement of sustainable management. In order to study the effects of different land uses on carbon stock and soil quality attributes, a loess hillslope was selected in eastern Golestan Province, Agh-Su area. Six pedons in four land uses including pasture; Oak natural forest; Cypress plantation forest and a cultivated land, were studied. Important physical, chemical and biological soil quality attributes such as bulk density (Bd), mean weight diameter (MWD), cation exchange capacity (CEC), available P, Biomass carbon (BioC) and Soil Microbial respiration (SMR) were studied. The results revealed that cultivation has led to the deterioration of soil quality attributes. Organic matter, CEC and MWD were significantly lower in the cultivated land. MWD varied between the highest 2.36 mm in the Oak natural forest and the lowest 0.54 mm in cultivated land. Soil organic carbon stock in the forest and pasture area was considerably higher than that of the cultivated land. Soils classified as Calcic Argixerolls and Typic Calcixerepts were formed under the Oak natural forest and the cultivated land respectively. Soils of the pasture and the Cypress forest were classified as Typic Calcixerolls. Micro-morphological studies revealed that size and frequency of microcrystalline calcite nodules and coatings increase from cultivated land to pasture. Cytomorphic and acicular calcite were observed mainly in the Oak natural forest and a denser vegetative growth, but rarely in cultivated areas.

Keywords: Carbon stock; Soil quality; Land use; Loess

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*Corresponding author; khormali@yahoo.com

1. Introduction

Soil quality is a concept that integrates soil biological, chemical and physical factors into a framework for soil resource evaluation (Karlen *et al.*, 1997). Larson and Pierce (1991) defined soil quality as the capacity of a soil to function within the ecosystem boundaries and to interact positively with surrounding ecosystems. Destruction of vegetative covers and conversion to agriculture deteriorates the natural ecosystem and diminish soil quality (Islam and Weil, 2000). Soil organic matter (SOM) directly affects soil chemical, physical and biological properties, and plays an important role in enhancing crop production (Stevenson and Cole, 1999).

Tesfahunegn (2013) studied the effect of different vegetation cover on soil quality attributes and found that the final principal component chosen indicators that mainly influence soil quality variability were organic carbon, total nitrogen, cation exchange capacity, total phosphorus, silt, bulk density, and iron. The amount of carbon in any soil is a function of the soil forming factors including: climate, relief, organisms, parent material, and time. Over the centuries, humans, usually included as part of the "organisms" factor, have profoundly influenced the dynamics and sequestration of carbon in soils by their land use and management practices. Their practices include deforestation and cultivation. In general, human activities have decreased the amount of carbon held in the affected soils. Effective carbon management can help not only in building of the SOC stock, but will also help reduce the soil inorganic matter (SIC) stock to the benefit of growing plants in terms of better physical and chemical environment of soil (Bhattacharyya *et al.* 2000). Structural stability of soils was clearly affected by land use, which in turn was positively associated with total organic C concentration (Caravaca *et al.*, 2004). Six *et al.*, (2000) reported that cultivation reduced soil C content and changed the distribution and stability of soil aggregates. The MWD of soil aggregates was significantly greater in the forest and pasture soils than in the cultivated soils.

Moges *et al.*, (2013) compared soil quality within culturally protected forest areas and adjacent grassland, grazing land, and farmland in Abo-Wonsho, Southern Ethiopia. And concluded that soil quality can be protected and maintained by improving existing land use practices within both agricultural and modern forest management areas.

Biological parameters are relatively dynamic and sensitive to change, so they can be used as indicators of soil quality at an early stage (Pathak *et al.,* 2004). Soil respiration, rate of nutrient mineralization, and microbial biomass are some biological soil quality indicators. Recently Paz-Kagan *et al.*, (2014) developed a spectral soil quality index for characterizing soil function inn areas of changed land use. The results revealed that classification of soils into spectral definitions provided a basis for a spatially explicit and quantitative approach for developing spectral soil quality index (SSQI). The SSQI can be used to assess hot spots of change in areas of land-use change and to identify soil degradation.

The type of pedogenic calcium carbonate is controlled mainly by the parent material, climate, and vegetation (Wright. 1987). Water availability together with vegetation, creating higher soil respiration and providing extra acidity, control the dissolution/precipitation of calcium carbonate in soils (Treadwell-Steitz and McFadden, 2000). Impregnative micritic calcite noudules represent the most common type of pedogenic calcite. Formation and morphology of these noudules are determined by many factors including processes of dissolution recrystallisation, salt concentration, hydromorphism (Sehgal and Stoops, 1972), soil texture (Wieder and Yaalon, 1982), stability of the soil (absence of vertic features, erosion), and conditions favoring rapid carbonate precipitation, such as frequent desiccation, CO2 loss from the soil solution, or both (Sobecki and Wilding, 1983). Due to the importance of the land use change on loess deposits with regard to the soil degradation, the main objective of this study was to monitor the effect of land use change on major soil properties on loess hillslopes.

2. Material and methods

Description of the study area

The study area is Age-Su watershed, located in eastern Province of Golestan, Northern Iran, with average annual temperature of 15.9 ºC and 635 mm of precipitation. The soil moisture and temperature regimes of the study region are xeric and thermic, respectively. Six soil profiles in four land uses including Quercuse natural forest; Cupressus artificial forest; pasture and cultivated land were dug and studied. The parent material is composed of loess and the soils of the study area were classified as Alfisols, Mollisols, and Inceptisols according to Keys to Soil Taxonomy (Soil Survey Staff, 2014). Samples from different horizons were collected for physicochemical and microscopic analyses. Six surface soil samples were collected around each soil pit for statistical analyses.

Soil sampling and analyses: The different horizons were sampled and the physico-chemical analyses were carried out in the laboratory. The soil samples were oven-dried at 105°C for 24h and weighed to estimate bulk density (Blake and Hartage, 1986) using paraffin method. Particle size distribution and soil texture was determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986). The wet sieving method of Angers and Mehuys (1993) was used with a set of sieves of 2.0, 1.0, 0.5, 0.25 and 0.1 mm in diameter. The method of Kemper and Rosenau (1986) was used to determine MWD.

The soil pH was measured in saturated paste using pH electrode (Mclean, 1982) and EC was measured in the extract using conductivity meter (Rhoades, 1982). OC was determined using a wet combustion method (Nelson and Sommers, 1982). Equivalent calcium carbonate was determined by titration with acid. CEC was determined using sodium acetate (NaOAc) at a pH 8.2 (Chapman, 1965). SMR was measured by the closed bottle method of Stotzky (1965). The size of TC stock is calculated following standard methods described by Batajes (1996) and Bhattacharyya *et al.* (2000). The first step (step 1) involves calculation of OC by multiplying OC content (g/g), bulk density (BD) in Mg/m3 and thickness of horizon (m) for individual soil profile with different thickness. In the second step (step 2) the total OC content determined by this process is multiplied by the area (ha) (Velayutham *et al.* 1999; 2000). For the SIC, the calculation was made using 12% C values in $CaCO_3$ using steps 1 and 2.

Micromorphological analyses: Thin sections of about 80 and 40cm2 were prepared using standard techniques described by Murphy (1986) from different soil horizons. Micromorphological descriptions were made according to Stoops (2003). A Zeiss polarizing microscope was used to study thin sections under both plain and cross-polarized lights. The main features studied were those important for soil quality interpretations such as microstructure, voids, and biorelated pedofeatures.

3.Results

Chemical soil quality indicators

Cation exchange capacity (CEC)

The cation exchange capacity (CEC) of the soil is determined by the amount of clay and/or humus that is present. The soil CEC decreased in the soil from 58.6 cmol kg-1 in Quercuse natural forest to 31cmol kg-1 in the cultivated land (Fig. 1). The results are in accordance with the findings of Vagen *et al.*, (2006). The reduction of CEC in cultivated land is largely due to the loss of SOM and the clay content. This reduction is higher for the surface soil layer.

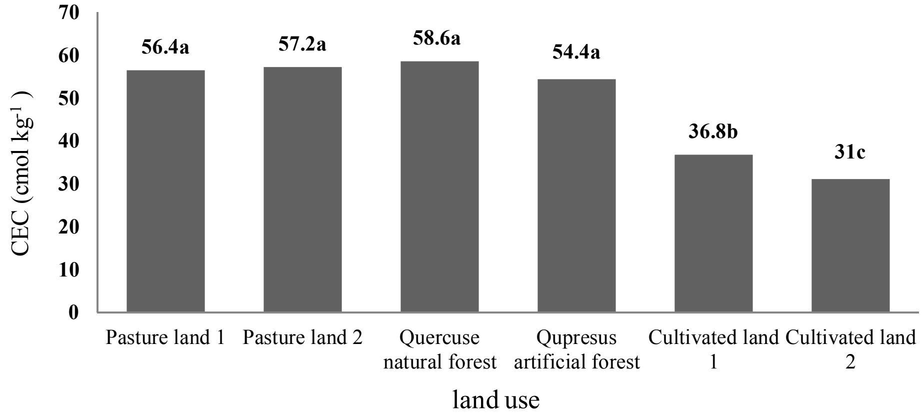

Figure 1. Effect of different vegetation covers on CEC.

Soil pH: Soil pH was significantly lower in the surface layers of the forest compared to the cultivated soils. The average pH in the surface soil increased from 6.3 in Queues natural forest to 7.65 in the cultivated land (Table 1, Figure 2). Leaching of basic cations in the forest, and CO^2 release by microbial respiration, are the main reasons for the lower soil pH of forest (NRCS, 1999).

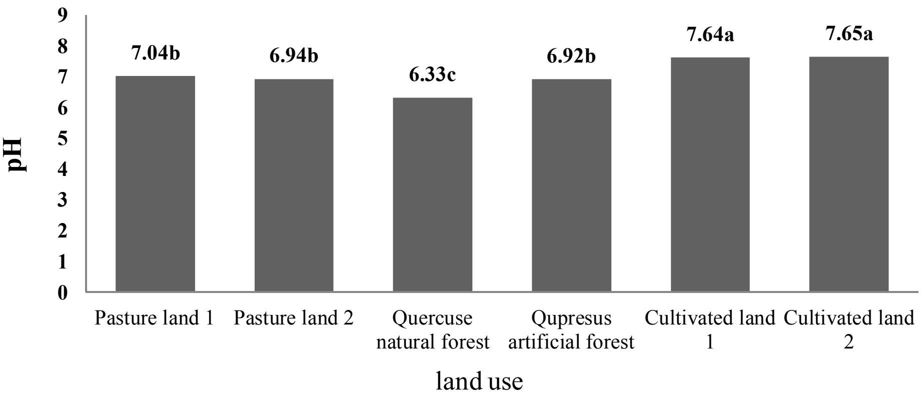

Figure 2. The effects of different land vegetation covers on pH.

Physical soil quality indicators

Soil aggregate stability: Mean weight diameter (MWD) of the soils showed that tillage practices resulted in the significant decrease in aggregate stability. Results showed that MWD was significantly different in the studied land uses and varied between 2.36 mm in Quercuse natural forest and 0.54 mm in cultivated land use 1 (Table 1, Fig.3). This is in accordance with the findings of Hajabbasi *et al.*, (1997), Caravaca et al (2004), Evrendilek *et al.*, (2004) and Celik (2005). Tillage practices disintegrate the larger aggregates and result in higher loss of organic matter (Shepherd *et al.*, 2001). Severe losses of SOM, increased silt content, and decreased microbial activity. Heavy machinery were the main responsible factors for the decreased MWD following tillage practices.

Soil bulk density: Soil bulk density (BD) showed significant differences in the studied land uses. BD increased significantly 1.24 g cm-3 in the Cupressus artificial forest to 1.54 g cm-3 cultivated land use in the in the surface soil (Table 1, Figure 4). The increase BD was related with the loss of SOM and soil compaction in the cultivated land and soil compaction due to tillage practices (Dang *et al.*, 2002).

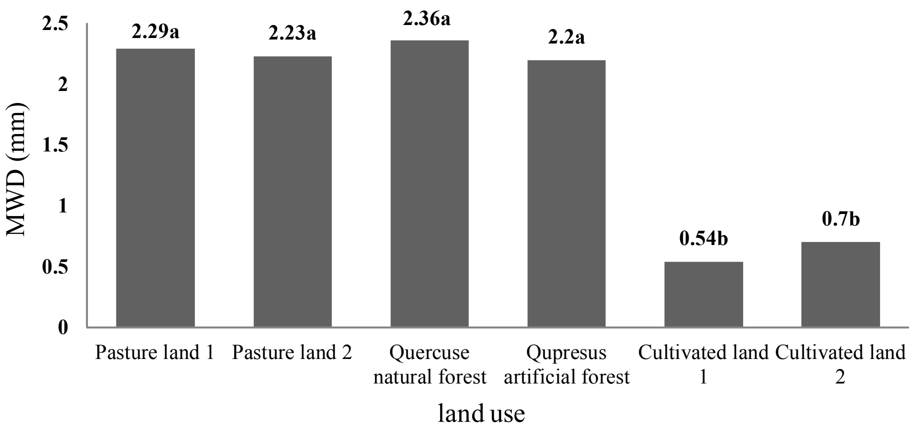

Figure 3. The effects of different land vegetation covers on MWD.

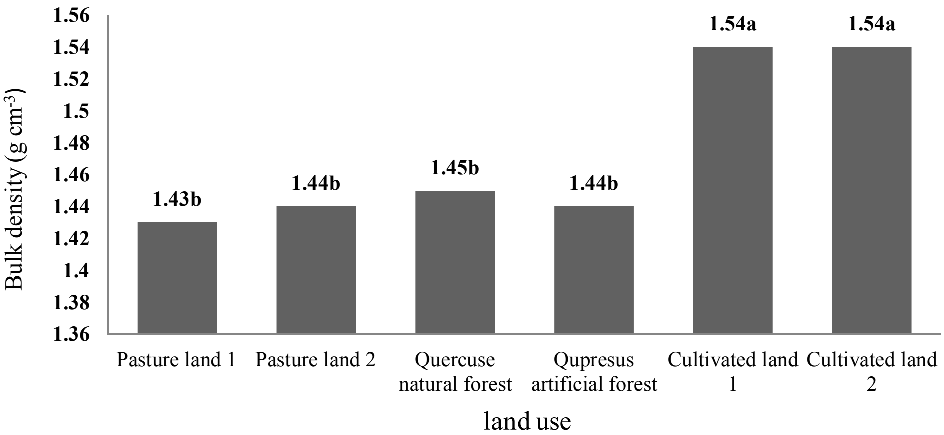

Figure 4. Effect of different vegetation covers on bulk density

Biological soil quality indicators

Soil Microbial Respiration (SMR): Soil respiration is a process involving uptake of O_2 and release of CO_2 by living metabolizing entities in the soil (Anderson, 1982). This important soil quality indicator decreased from 0.26 mg CO2/g day in the surface layers of Pasture land 2 to 0.10 in the cultivated land (Table 1, Figure 5). Loss of organic matter in the cultivated area as a result of tillage practices and inappropriate management have caused lower respiration.

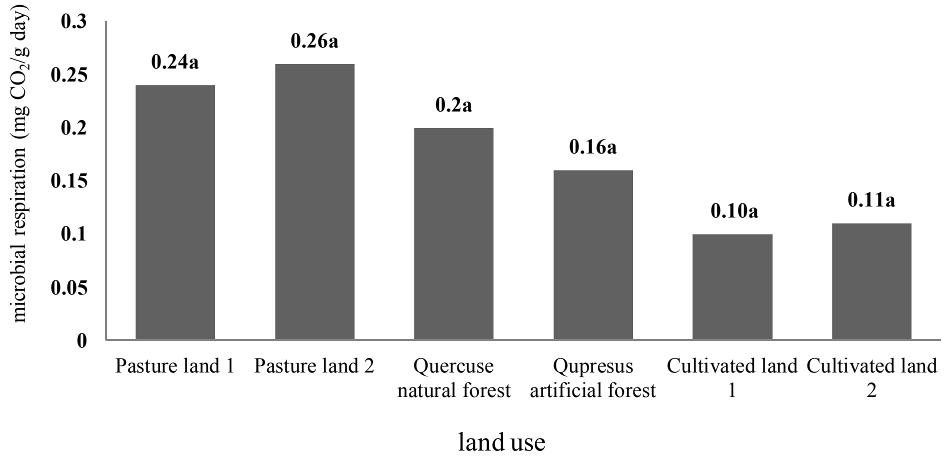

Figure 5. Effects of different vegetation covers on soil microbial respiration

Biological soil quality indicators

Soil Microbial Respiration (SMR): Soil respiration is a process involving uptake of O2 and release of CO2 by living metabolizing entities in the soil (Anderson, 1982). This important soil quality indicator decreased from 0.26 mg CO2/g day in the surface layers of Pasture land 2 to 0.10 in the cultivated land (Table 1, Fig. 5). Loss of organic matter in the cultivated area as a result of tillage practices and inappropriate management have caused lower respiration.

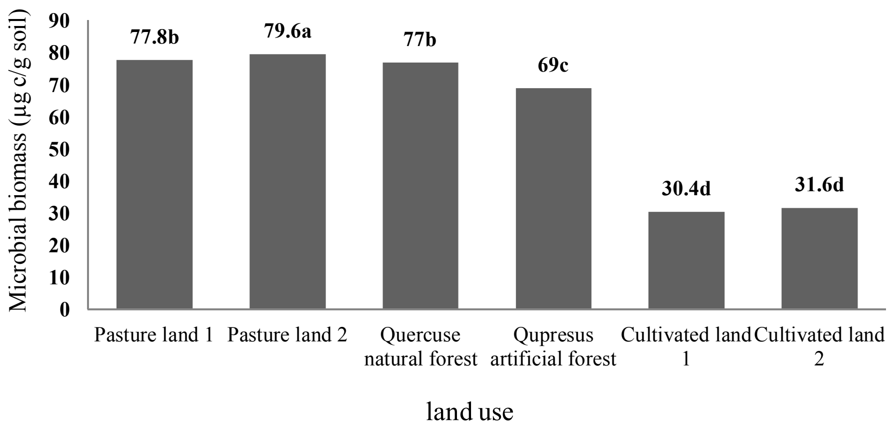

Figure 6. Effects of different vegetation covers on biomass carbon

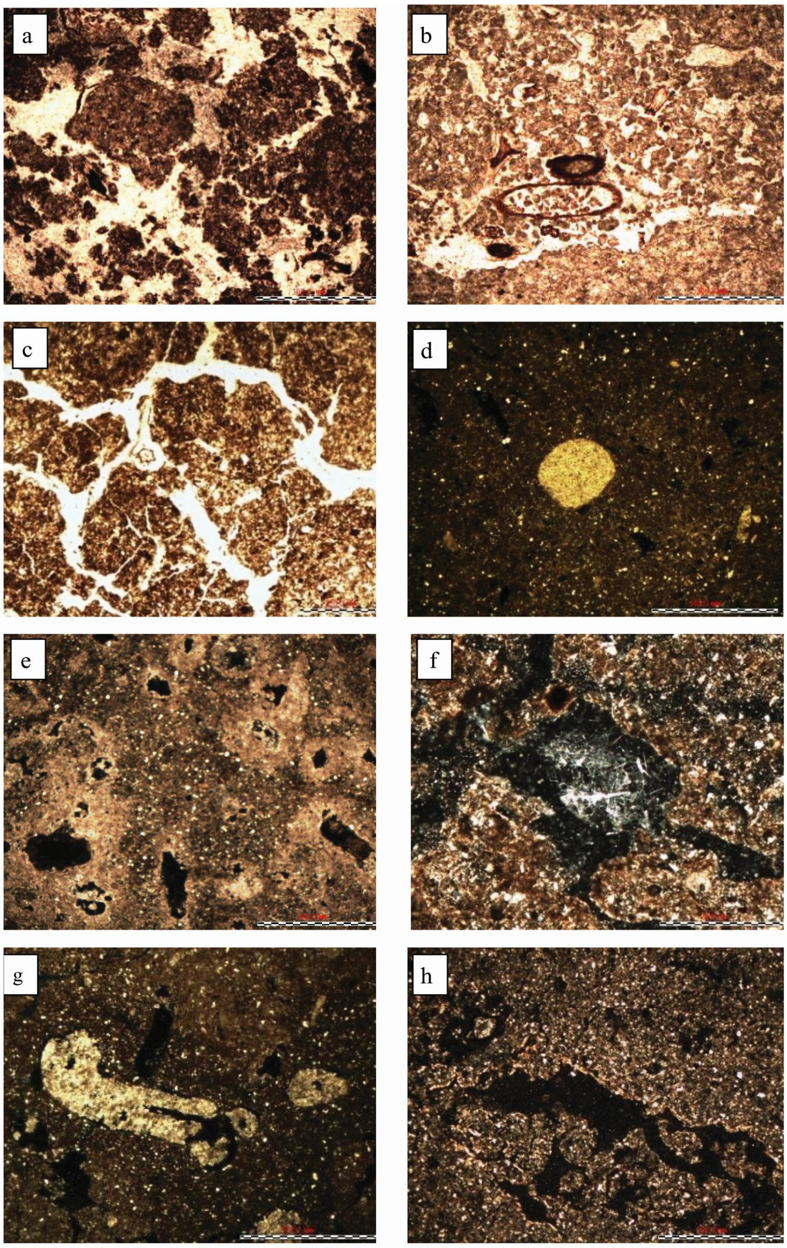

Figure 7. (a) Crumb microstructure in the topsoil of FO; (b) excremental pedofeature in the topsoil of FO; (c) microstructure and little porosity in the topsoil of DEF; (d and e) calcite nodules in the Bk horizon of FO; (f and g) Needle- shaped calcite and Cytomorphic in the Bk horizon of FO (h) clay pedofeature in the Bt horizon of the FO soils

Table 1. Mean values of some soil physico-chemical and biological properties in different land uses

Land use	pH	EC dSm^{-1}	Sp %	Lime %	C %	Si %	S %	BD gcm^{-3}	MWD mm	Microbial respiration (mg CO_2/g day)	OC %	Biomas carbon (µg c/g soil)	P ppm	CEC (Cmol kg^{-1})
Pasture land 1	7.04b	1.13b	62.92b	6.6b	36.4a	53.4f	10.2b	1.43b	2.29a	0.24a	2.72a	77.8b	10.10f	56.4a
Pasture land 2	6.94b	0.84c	65.38a	5.2bc	36.4a	54.4e	9.2bc	1.44b	2.23a	0.26a	2.92a	79.6a	11.1e	57.2a
Quercuse natural forest	6.33c	1.4a	56.66a	4.8c	35.4b	56.4d	8.2c	1.45b	2.36a	0.20a	2.84a	77b	12.12c	58.6a
Qupresus artificial forest	6.92b	1.2b	62.2b	6.6b	32.4c	57.4c	10.2b	1.44b	2.2a	0.16a	2.54a	69c	11.96d	54.4a
Cultivated land 1	7.64a	0.48d	43.12c	26.2a	24.4d	63.4b	12.2a	1.54a	0.54c	0.10a	0.75b	30.4d	15.48a	36.8b
Cultivated land 2	7.65a	0.58d	43.32c	25.2a	23.4e	64.4a	12.2a	1.54a	0.70c	0.11a	0.62b	31.6d	15.02b	31c

Table 2. soil physicochemical properties in different land uses

Land use	Horizon	depth	pH	EC dSm^{-1}	Sp %	Lime %	C %	Si %	S %	BD gcm^{-3}	MWD mm	Microbial respiration (mg CO_2/g day)	OC %	Biomas carbon (µg c/g soil)	P ppm	CEC (Cmol kg^{-1})
Fine-silty, mixed, superactive, thermic, Typic Calcixerolls																
Pasture land 1	A	0-20	7.11	1.2	62.2	8.5	36	53	11	1.44	2	0.26	2.2	78	10	56
	Bk1	20-55	7.23	0.9	46.9	29.5	37	50	13	1.45	1.65	0.11	0.9	38	2	34
	Bk2	55-95	7.71	0.3	43.2	28.5	27	54	19	1.45	1.5	0.09	0.68	20	2.5	29
	Ck	95-130	7.79	0.2	40.9	26	26	62	12	1.46	0.27	0.02	0.1	8	5.5	28
Fine-silty, mixed, superactive, thermic, Typic Haploxerolls																
Pasture land 2	A	0-20	6.9	0.8	65.3	5	36	54	10	1.44	2	0.27	3	80	11	58
	Bk	20-32	7.16	0.6	64.1	14	37	51	12	1.46	1.3	0.1	2	45	2.5	34
	Cr	>32	7.7	0.5	56	10	25	60	15	1.47	0.4	0.05	0.1	10	6.5	29
Fine, mixed, superactive, thermic, Calcic Argixerolls																
Quercuse natural forest	A	0-23	6.30	1.5	65	5	35	56	9	1.5	2.4	0.2	2.24	75	12	59
	Bt	23-60	5.9	0.6	69	6	41	50	9	1.54	1.58	0.15	0.87	50	10	52
	Bk	60-90	7.44	0.5	50	26	28	57	15	1.56	1.04	0.09	0.77	15	1.5	39
	BCK	90-115	7.79	0.3	43.4	17	22	64	14	1.63	0.55	0.06	0.48	7	6	36
Fine-loamy, mixed, superactive, thermic, Typic Calcixerolls																
Qupresus artificial forest	A	0-18	6.85	1.2	62.3	7.5	32	57	11	1.46	2.24	0.17	2.73	70	12	54
	Bk1	18-63	7.79	0.50	48.2	20.5	33	54	13	1.39	1.2	0.14	0.87	30	2.5	34
	Bk2	63-110	7.82	0.3	44	20	27	58	15	1.49	0.23	0.09	0.48	8	6	31
Fine-silty, mixed, superactive, Typic Calcixerepts																
Cultivated land 1	A	0-15	7.72	0.5	42.1	25	24	63	13	1.53	0.5	0.1	0.87	30	15.4	38
	Bk	15-70	7.73	0.4	44.7	32.5	23	60	17	1.69	0.4	0.07	0.39	8	2.5	33
	Ck	70-130	7.88	0.3	41	30	20	64	16	1.77	0.23	0.003	0.10	0.75	8.25	31
Fine-loamy, mixed, superactive, Typic Calcixerepts																
Cultivated land 1	A	0-32	7.6	0.6	43	24	23	64	13	1.51	0.56	0.1	0.58	31	15	34
	Bk	32-73	7.8	0.4	45	38	22	61	17	1.59	0.53	0.05	0.39	8	2.1	32
	Ck	>73	7.89	0.3	42	32	19	65	16	1.7	0.49	0.001	0.2	0.2	8	26

Soil organic carbon stock

The SOC content sharply declines when put to cultivation and reduction of SOC level is significant even within 15 to 25 years of cultivation (Naitam and Bhattacharyya., 2003). Potentially large carbon stocks can be stored in soils as organic matter (Wilson, 2002) but this is affected greatly by land use. For example, land clearing and cultivation lead to significant soil organic carbon stock losses due to increased organic matter mineralization (Lal, 1997). Results of present study showed that SOC stocks was different in the studied landuses and varied between 0.199Gg in Quercuse natural forest and 0.058 in cultivated land use (Table 2).

Soil inorganic carbon stock

The atmospheric CO_2 along with The CO_2 formed by respiration of the roots and soil animals forms H_2CO_3 in an aqueous solution in soil:

CO_2 (g)+ H_2O (liquid) = H_2CO_3 (liquid)

The generally higher level of soluble and exchangeable Ca_2+ ions react with H_2CO_3 to form soluble $Ca(HCO_3)_2$ in the soil environment.

$Ca_2+ + H_2CO_3 = Ca(HCO_3)_2$

Calcium bicarbonate moves down the soil profile in moist bioclimate and depending on the quantity of rainfall $Ca(HCO_3)_2$ gets concentrated deep down in the soils. With the onset of dry climate, the pedoenvironment also gets dry. The dry pedoenvironment initiates the formation of calcium carbonate as powdery lime which gets accumulated over time and increase in size to form lime concretions. The amount of such concretions increase with depth. The genesis and characteristics of these concretions called pedogenic carbonate have been detailed elsewhere (Pal *et al.* 2000). This is the reason why $CaCO_3$ becomes common in soils of arid to sub-humid bioclimatic in the cultivated land.

Total stock carbon

Carbon stock in soil depends largely on the areal extent of the soils besides other factors such as carbon content, the depth and the BD of soils. The TC stock depends on the SOC and SIC stocks; with low SOC stock and high SIC stock, the TC stock may be very high. The TC stocks of study area are shown in Table 1. The corresponding Table for TC increase from 0.345 Gg in pasture 2 to 0.89 Gg in the cultivated land 2.

Table 3. SOC, SIC and TC stock in different land uses

Carbon stock	Pasture 1	Pasture 2	Quercuse natural forest	Qupresus artificial forest	Cultivate d land 1	Cultivate d land 2
SOC(Gg)	0.154^b	0.134^c	0.199^a	0.149^{bc}	0.058^e	0.086^d
SIC(Gg)	0.6^c	0.211^f	0.289^e	0.434^d	0.838^a	0.696^b
ΣSOC+SIC(TC)(Gg)	0.753^b	0.345^e	0.488^d	0.583^c	0.896^a	0.782^a

Gigagram (10^9gr)

Table. 4. Micromorphological properties in different land uses

horizon	Depth (cm)	Void	Microstructure	Grounmass: c/f ratio	b-fabric	Micromass, color & limpidity	Pedo features
				pasture			
A	0-20	Channel(30-40%)	granular(90%)	2/8, Single-spaced Porphyric	Calcitic Crystallitic	Speckled, dark brown	
Bk	20-55	Channel(30-40%)	Granular(many), well separated angular blocky(few)	2/8, Single-spaced Porphyric	Calcitic Crystallitic	Speckled, brown	Typic Calcite nodule(10%)
Ck	95-130	Channel(many)	Subangular blocky	Single-spaced Porphyric	Calcitic Crystallitic	Speckled, yellowish brown	Calcite coating , Cytomorphic calcite
				Quercuse natural forest			
A	0-23	Channel and chamber (20-30%)	Crumb(many), well separated Subangular blocky(few)	2/8, Single-spaced Porphyric	Speckled(70%), undifferentiated (30%)	Speckled, dark brown	Excrements of the soil fauna
Bt	23-60	Channel and chamber (20-30%)	well separated angular blocky	2/8, double-spaced Porphyric	Speckled, striated	Speckled, brown	Clay coatings(5%)
Bk	60-90	Channel(many)	moderately separated subangular blocky	Single-spaced Porphyric	Calcitic Crystallitic (70%), Speckled(30%)	Speckled, yellowish brown	Calcite coating (needle), Calcite nodule (geodic), Cytomorphic, Excrements of the soil fauna
BCk	90-115	Channel(many)	weakly separated Subangular blocky	2/8, Single-spaced Porphyric	Calcitic Crystallitic (90%), Speckled(10%)	Speckled yellowish brown,	Cytomorphic, Calcite nodule (typic), Calcite coating
				Cupressus artificial forest			
A	0-18	Channel(15-20%)	Granular (90%)	3/7, Single-spaced Porphyric	Speckled(60%), Undifferentiated (40%)	Speckled, Very dark brown	Excrements of the soil fauna
Bk1	18-63	Channel(many)	moderately separated angular blocky	3/7, Single-spaced Porphyric	Calcitic Crystallitic (70%), Speckled(30%)	Speckled, Grayish brown	Calcite nodule(10%), Calcite coating
2Bk	63-110	Channel(many)	weakly separated angular blocky	3/7, Single-spaced Porphyric	Calcitic Crystallitic (90%), Speckled(10%)	Speckled, light brown	Calcite nodule ,Cytomorphic calcite
				cultivated land			
Ap	0-15	Channel (10%)	Subangular blocky, massive	4/6, Porphyric	Calcitiv Crystallitic	Speckled, light brown	Typic Calcite nodule(<5%)
Bk	15-73	Channel(many) and chamber(few)	moderately separated subangular blocky	Porphyric	Calcitic Crystallitic	Speckled, yellowish brown	
Ck	>73	Channel(few) and plane(few)	Massive(90%)	3/7, Porphyric	Calcitic Crystallitic	Speckled, light brown	Calcite coating

Soil Micromorphology: Soil micromorphology can be used to interpret the processes occurring in soils exposed to land use change. Fig. 7 shows the thin section of the soil samples studied from topsoil of the FO and DEF. Topsoil of the FO is mainly consisted of crumb microstructure with a high porosity which is the indications of the presence of high OC and faunal activity (Fig. 7a). The high faunal activity could be deduced from the presence of high amount of excremental pedofeatures or passage features as discussed by Adesodun *et al.* (2005) (Fig. 7b). In contrast, the topsoil of the DEF lacks sufficient organic matter and consequently microbial activity for the improvement of soil microstructure and porosity. As seen in Fig. 7c and d, the microstructure of the topsoil of the DEF is mainly massive or very weakly developed with very low porosity (Fig. 7c). Cultivation practices have resulted in soil loss and compaction, deteriorating soil quality in terms of the microbial activity, porosity, and microstructure. Size and frequency of microcrystalline calcite as nodules or coatings along channels increase from cultivated land to pasture. A higher frequency of calcite nodules is observed in Quercuse natural forest (fig. 7d and e). Calcite coating are frequent along channels in forest. Cytomorphic and Needle- shaped calcite are the dominant features in the Quercuse natural forest, rather than calcite nodules, pointing to different processes of accumulation, rather steered by biological factors than pure phisico-chemical ones.

Cytomorphic and needle-like calcite formed in areas with relatively higher rainfall, higher soil temperature and denser vegetative growth, corroborating their biologic origin. The lower content of nodules in the cultivated area can be explained by a lower precipitation slowing down the process of dissolution recrystallisation and therefore limiting the formation of nodules. Clay illuviation and formation of argillic horizon in the forest land use has occurred by the dissolution and downward migration of carbonates and the subsequent clay dispersion and movement witch is also in accordance with the finding of Khormali *et al.*, (2003).

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