Agriculture, Ecosystems and Environment 134 (2009) 178–189

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Role of deforestation and hillslope position on soil quality attributes of loess-derived soils in Golestan province, Iran

F. Khormali [a,*], M. Ajami [a], S. Ayoubi [b], Ch. Srinivasarao [c], S.P. Wani [c]

[a] Dept. of Soil Science, College of Agriculture, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran
[b] Dept. of Soil Science, College of Agriculture, Isfahan University of Technology, 84156-83111 Isfahan, Iran
[c] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India

ARTICLE INFO

Article history:
Received 15 November 2008
Received in revised form 2 June 2009
Accepted 30 June 2009
Available online 31 July 2009

Keywords:
Soil quality
Deforestation
Hillslope position
Soil degradation
Organic matter loss
Loess

ABSTRACT

Conversion of natural land resources into croplands, which is triggered by the rapid population growth, causes serious soil degradation. A loess hillslope located in eastern Golestan province of Iran was selected to study the role of deforestation and slope position on soil quality attributes. Surface (0–30 cm) and subsurface (30–60 cm) soil samples were taken from five slope positions (summit, SU, shoulder, SH, backslope, BS, footslope, FS and toeslope, TS) of forest (FO) and adjacent deforested cultivated land (DEF) in a factorial trial with completely randomized design. Ten pedons were also investigated and undisturbed soil samples were taken from different horizons for micromorphological studies. The texture of the original loess is silt loam. The soil textural class varies from silty clay loam in FO to silt loam in DEF, mainly due to the loss of finer particles as a result of soil erosion followed by deforestation and long-term cultivation. Mean weight diameter (MWD) of aggregates decreased following deforestation (0.88 mm compared to 1.49 mm in FO), as a result of considerable losses of organic carbon (OC) and breakdown of aggregates. Bulk density (BD) increased and soil infiltration rate decreased by about 50% in DEF. Reduction of annual organic matter input to soil as a result of deforestation and also rapid oxidation of organic matter in DEF were responsible for a significant decrease (>70%) in OC and total nitrogen (TN). Soil microbial respiration (SMR) also decreased significantly, following deforestation. Carbon, and N contents and population of fungi were significantly higher in all hillslope positions of the FO than the DEF. Changes in soil quality attributes were not significant in different slope positions of FO, which might be related to the stability of forest landscape. Effect of different slope positions on soil quality attributes was more pronounced in the DEF. The SH and BS were found as the most susceptible positions to erosion in DEF. Soils of the FO were mainly classified as Alfisols and Mollisols with evidences for clay illuviation compared to the weakly developed Inceptisols formed in the DEF. Micromorphological investigations revealed that the FO soils had strong granular and crumb microstructure with a high porosity indicating the presence of high amount of organic matter. The high microbial and faunal activity was confirmed through the presence of excremental pedofeatures in the topsoil of the FO. Lower organic matter and consequently microbial activity in the topsoil of the DEF have resulted in the massive microstructure with little porosity.

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) define soil quality as the capacity of a soil to function within the ecosystem boundaries and to interact positively with surrounding ecosystems. Conversion of forest and grasslands into agricultural land is one of the main concerns worldwide in the context of environmental degradation and global climate change (Wali et al., 1999). Conversion of natural land resources to crop production as the largest source of anthropogenic carbon emissions after fossil fuel burning, has resulted in the release of about 200 Pg C over the past 250 years, globally (Scholes and Noble, 2001; Fitzsimmons et al., 2004).

It is also very well known that cultivation of the natural land resources brings about the loss of OM and this directly affects the soil chemical, physical, and biological properties resulting in loss of

Abbreviations: FO, forest; DEF, deforested land; SU, summit; SH, shoulder; BS, backslope; FS, footslope; TS, toeslope; MWD, mean weight diameter; BD, bulk density; *F*, soil porosity; OM, soil organic matter; OC, soil organic carbon; TN, total nitrogen; CEC, cation exchange capacity; CCE, calcium carbonate equivalent; EC, electrical conductivity; K_{ava}, available potassium; SMR, soil microbial respiration; BioC, biomass carbon; BioN, biomass nitrogen; *K*-factor, erodibility factor; WSA, water stable aggregates.

* Corresponding author. Tel.: +98 171 4426523; fax: +98 171 4420981.
E-mail address: khormali@yahoo.com (F. Khormali).

0167-8809/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2009.06.017

crop production capacity (Stevenson and Cole, 1999). Vagen et al. (2006) report the lowest OC and TN contents in areas that have been under cultivation for more than 50 years.

Wang et al. (2001) relates a considerable decrease in OC contents in the loess plateau of China to soil erosion followed by land use change. Lemenih et al. (2005) demonstrate that soil C and total N contents in the 0–10 cm soil layer declined significantly in 53 years under cultivation compared to the natural forest. The OM loss within the last 80 years, on average is about 30% in Canadian Prairies (Anderson, 1995; Landi et al., 2003).

The reduction in OM following deforestation influences the SMR as an important soil biological quality indicator. Enhanced microbial activities in soils under natural forest are related to greater levels of available organic C (Nael et al., 2004).

Land use change has a great influence on many soil quality attributes mostly through its effect on soil organic matter. Structural stability of soils is affected by land use, which in turn is positively associated with total organic C content (Caravaca et al., 2004). Six et al. (2000) report that cultivation has reduced soil C content and changed the distribution and stability of soil aggregates. The MWD of soil aggregates is significantly greater in the forest and pasture than in the cultivated soils. Cultivation has caused significant decreases in MWD for the 0–10 cm layer (about 61 and 64%) and the 10–20 cm layer (52 and 62%), respectively for the forest and pasture soils. Similarly, cultivation has resulted in, on an average, a 34% decrease in WSA (water stable aggregation) (Celik, 2005).

Puget and Lal (2005) report a lower bulk density in forest compared to cultivated plots and the pasture at 0–30 cm depth. The average BD under rainforest is significantly less than the deforested areas (Rasiah et al., 2004). Reduction in porosity, the size and changes in shape and continuity could have serious impact on hydraulic properties such as, infiltration and percolation of water and thus can lead to soil degradation and other adverse effects on environmental quality (Zhang et al., 2004).

Macroaggregation is a soil quality indicator that is positively related to the physical protection of organic matter, improved water infiltration, and reduced soil erosion (Rhoton et al., 2002). Breakdown of aggregates due to cultivation results in the release of labile OM accompanied by increased availability for microbial decomposition (Shepherd et al., 2001; Kavdir et al., 2004).

Forest provides a good protection against surface runoff and soil erosion. Agriculture has caused a 7-fold increase in surface runoff and 21-fold increase in soil erosion (McDonald et al., 2002). Soils become more susceptible to erosion as aggregates are disrupted (Six et al., 2000). USLE *K*-factor in cultivated soils, as an indicator of soil erodibility, is 2.4 times higher than that of the forest soil (Boix-Fayos et al., 2001). Removal of permanent vegetation, loss of OM, and decreases in WSA and MWD in the process of the conversion of the forest and pasture areas into cultivated land have contributed to the increase in soil erodibility.

Soil quality attributes are strongly related to slope position. There is evidence for soil movement within small watersheds as soil erosion occurring in the BS and SH and soil deposition in the FS and TS positions (Moorman et al., 2004). OC and TN are lower for the BS and SH and greater for the FS, TS and SU elements. Soil pH is significantly lower for the SU position relative to other landform elements. Long-term average corn yield is lowest in the BS position and highest in the FS and TS positions (Cambardella et al., 2004). This is in line with the findings of Khormali et al. (2007) for tea production area in northern Iran.

Loess soils are among the most fertile in the world. They often contain little clay, which leads to loss of organic matter under cultivation; the resulting structural instability of the surface soil causes problems of crusting, poor germination of crops and erosion (Catt, 2001). Golestan province of Iran is one of the most important agricultural areas well known for its loess deposits and loess-derived fertile soils.

Land use change and deforestation on loess hillslopes (even up to 45%) are considered as the main causes of the dramatic floodings (e.g. August 2001 and 2002) resulted in loss of the lives of many people (Hadiani, 2007). Mosaedi and Gharib (2008) report that in spite of spring floods, summer one has the lowest average time of duration, peak and falling and the highest amount of peak discharge, because of precipitation characteristics in this season. Summer is the time when the surface of the deforested soils is bare and runoff occurs as a result of surface sealing by the first rain drops.

The main objective of the present study is to determine the effects of deforestation and slope position on soil quality attributes incorporated with soil profile studies and micromorphological analyses. The results are expected to provide information on the most susceptible slope positions regarding the loss of soil quality and be useful for the development of future practical management strategies.

2. Materials and methods

2.1. Description of the study area

Two adjacent sites were selected, consisting of a natural forest and deforested cultivated land on a loess hillslope located in Agh-Su watershed, Kalaleh area of Golestan (55°27′–55°42′E, 37°22′–37°29′N) Northeast of Iran (Fig. 1), with an average annual temperature of 16 °C and 650 mm of precipitation. The parent material is composed mainly of loess. The main plant species are *Carpinus* sp. in forest and *Triticum aestivum* in adjacent cultivated land. Based on the present reports, forest degradation and cultivation on the sloping areas have started almost 50 years ago (Forest, Rangeland and Watershed Management Organization, 1999).

2.2. Sampling and field work

Ten representative soil profiles were prepared and described on each slope positions of the two land uses (SU, SH, BS, FS, TS). Three extra samples were also randomly taken on each slope position of both land uses from two depths, 0–30 and 30–60 cm. Samples were air-dried and passed through a 2 mm sieve for chemical and physical analyses. Thirty fresh samples were also taken for soil respiration analysis from 0 to 30 cm layer of both land uses. Another set of undisturbed samples for bulk density determination were taken from two depths, 0–30 and 30–60 cm. Infiltration measurements were done on FS in two selected land uses, using double rings (Bouwer, 1986). Air-dried, undisturbed and oriented clods were taken for micromorphological studies.

2.3. Laboratory analyses

The soil samples were oven-dried at 105 °C for 24 h and weighed to estimate BD using paraffin method (Blake and Hartge, 1986). Particle size distribution and soil texture were 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. Approximately 50 g of soil sieved through 4.6 mm was put on the first sieve of the set and gently moistened to avoid a sudden rupture of aggregates. The set was sieved in distilled water at 30 oscillations per minute for 10 min, and the resistant aggregate on each sieve were dried at 105 °C for 24 h, weighted and corrected for sand fraction to obtain the proportion of the true aggregates. The mass of <0.1 mm fraction was obtained by difference. The method

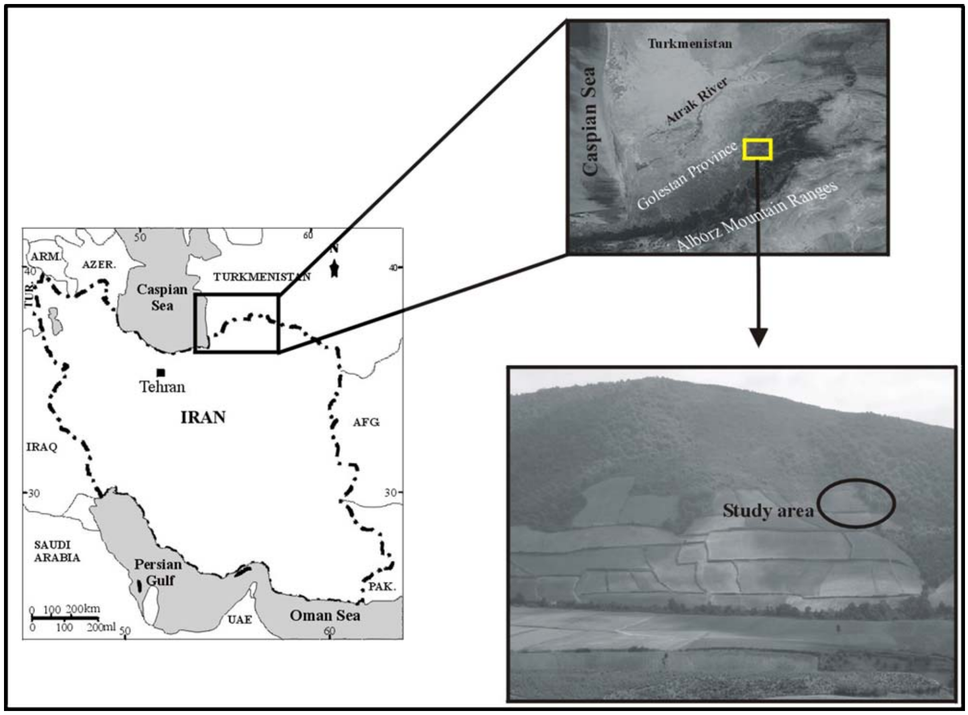

Fig. 1. Location map and the site of the sampled area showing deforestation on the loess hillslopes.

of Kemper and Rosenau (1986) was used to determine MWD using the following equation (Eq. (1)):

$$MWD = \sum_{i=1}^{n} X_i W_i \quad (1)$$

where MWD is the mean weight diameter of water stable aggregates, X_i is the mean diameter of each size fraction (mm), and W_i is the proportion of the total sample mass in the corresponding size fraction after deducing the stone mass as indicated above.

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). CEC was determined using sodium acetate (NaOAc) at a pH 8.2 (Chapman, 1965). TN was determined by Kjeldahl method (Bremner, 1996). The soil available K was determined using the methods outlined by Knudsen et al. (1996).

SMR was measured by the closed bottle method of Stotzky (1965). Biomass C was estimated by multiplying the ninhydrin N with the factor given by Amato and Ladd (1988). Biomass N was estimated by chloroform fumigation and incubation method (CFIM) (Anderson and Domsoh, 1978). Microorganisms were enumerated using dilution and plate method on specified media plates and inoculated plates were incubated at specified temperature and duration. After the incubation period, the colony forming units were counted and were expressed as CFU g^{-1} of the soil. USLE K factor was calculated according to Wischmeier and Smith (1978).

2.4. Micromorphological studies

Thin sections of about 80 and 40 cm^2 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 bio-related pedofeatures.

2.5. Statistical analysis

For statistical analysis of the data, a factorial experiment (Factor 1: land use in two levels, Factor 2: slope position in 5 levels, Factor 3: soil depth in two levels, with three replications) based on the completely randomized blocks was performed. Statistical analyses of the studied soil properties were carried out on the samples prepared from two depths (0–30 cm and 30–60 cm) except for the soil microbial respiration analyses which were limited to the surface soils.

Descriptive statistical analyses including mean, standard deviation, and coefficient of variation (CV) measures and one-way analysis of variance (ANOVA) and mean comparison using Duncan's test were conducted using SAS software (SAS institute, 2000).

3. Results and discussions

The FO soils were mainly classified as Mollisols (Argixerolls; SU, FS, TS) and Alfisols (Typic Haploxeralfs, SH, BS), and those of DEF were mainly Inceptisols (SH, BS, FS) and Mollisols (SU, TS) (Table 1). Most of the FO soils showed mollic and argillic horizons. Formation of argillic horizons indicates the higher stability of the FO hillslopes. In contrast, soils of the DEF were less-developed with only occurrence of the calcic horizon. Absence of mollic epipedon in the SH, BS and FS positions, presence of the near surface calcic horizon and absence of argillic horizon could be an indication of the severe erosion occurred after deforestation.

Table 2 presents the coefficient of variation (CV) for the selected studied soil properties. The coefficient of variation for the factors studied is low (<35%) indicating the homogeneity of the samples of each site and accuracy of the statistical experiment (Ogunkunle and Eghaghara, 2007). For the FO, CV is lower than DEF, which is mainly due to the lower soil erosion and human disturbance.

Table 1
Classification of the studied soils formed on two land uses and different slope positions.

Slope position	Land use			
	FO		DEF	
	Soil taxonomy[a]	WRB[a]	Soil taxonomy	WRB
SU	Calcic Argixerolls	Luvi-Calcic Chernozems (siltic)	Typic Calcixerolls	Calcic Kastanozems (siltic)
SH	Typic Haploxeralfs	Haplic Luvisols (siltic)	Typic Haploxerepts	Haplic Cambisols (siltic)
BS	Typic Haploxeralfs	Haplic Luvisols (siltic)	Typic Calcixerepts	Haplic Calcisols (siltic)
FS	Calcic Argixerolls	Luvi-Calcic Chernozems (siltic)	Typic Calcixerepts	Haplic Calcisols (siltic)
TS	Typic Argixerolls	Calcic Kastanozems (siltic)	Aquic Calcixerolls	Stagnic Kastanozems (siltic)

[a] Soil Survey Staff (2006) and World Reference Base for Soil Resources (2006).

Table 2
Coefficient of variation for the selected soil quality indicators in FO and DEF for two studied depths.

Land use	Coefficient of variation % (CV)										
Depth (cm)	OC	CEC	CCE	Clay	Silt	TN	K_{ava}	BD	F	MWD	SMR
FO 0–30	27.3	19.3	41.7	25.4	12.5	3.5	9.7	4.3	4.8	10.5	14.7
DEF 0–30	71.0	29.8	5.2	14.1	5.3	7.0	9.6	8.7	12.4	10.7	34.3
FO 30–60	11.3	13.9	46.3	27.3	10.4	10.8	8.1	6.4	9.0	–	–
DEF 30–60	32.2	21.7	26.9	25.5	9.0	29.0	5.2	6.1	9.5	–	–

Non-uniform management and the subsequent erosion along the hillslope of DEF are responsible factors for increased variations of the studied soil properties. The variations in the 30–60 cm depths of both land uses however, are not significant indicating to the lower human disturbance and soil erosion. CV for clay and calcium carbonate is higher in FO which can be explained by the decalcification and clay illuviation processes occurred in this land use resulting in a considerable increase in clay and carbonate in the lower horizons.

3.1. Physical soil quality indicators

3.1.1. Particle size distribution

Table 3 presents comparison of the mean values for the soil properties studied. There is a significant difference on the soil texture following 50 years of cultivation from silty clay loam in FO to silt loam in DEF in the upper 60 cm of the soil. Comparing to the parent loess deposits, the silt content of the both land uses is lower with the lower values for the FO. The surface soil clay content was 32% in FO and 22% in DEF ($P \leq 0.05$) (Table 3, Fig. 2a and b). The silt content of surface soil increased from 58 to 69% ($P \leq 0.05$) in DEF (Table 3, Fig. 2c and d).

Hajabbasi et al. (1997) reported lower clay content in cultivated areas than the adjacent forest in the upper 30 cm layer, due to loss of organic matter and the subsequent disintegration of the aggregates and loss of the finer particles in the DEF. The highest variation was observed in the surface layers of SH and BS. Soil texture was determined as silty clay loam and silt loam in 0–30 cm and 30–60 cm of FO, respectively. In contrast it was silt loam in both depths of the DEF which could be mainly due to the loss of preferential clay sized particles from the topsoil by erosion.

Removal of the topsoil and the subsequent outcropping of the lower horizons are confirmed by having the similar soil texture in the topsoil of DEF with the subsoil of FO. In the upper 0–30 cm of the BS, clay content decreased from 39.3% in FO to 19.7% in DEF (Fig. 2a, Table 4) while silt content increased from 53.2% in FO to 71.2% in DEF (Fig. 2c, Table 4). High slope gradient and the unstable soil structure in these slope positions are main responsible factors for the soil erosion and the loss of upper horizons following deforestation. In contrast, soils of FO are in more stable conditions as evidenced by the formation of argillic horizons. The higher clay content of the depth of FO could therefore be partly described by the illuviation of clay in the Bt horizons as also discussed in the micromorphology section (3.4).

In contrast to the other slope positions, TS position showed a heavier texture with significantly higher clay content in the surface of DEF (Fig. 2a, Table 4). This is attributed to deposition of the clay sized particle received from the upper positions. Wilding et al. (1982) state that soils of TS have finer texture than the other positions. Analyses of the soils in different hillslope positions of FO revealed that the surface and subsurface soils all showed a silty clay loam textural class. The higher clay content of the subsurface horizons of SU and FS of FO could be explained by the clay illuviation and formation of the Bt horizon (Table 4). The highest clay content in the 30–60 cm of DEF was observed in the TS position. SH position had the lowest clay content in the 30–60 cm soil (Fig. 2b). The sand content of the surface soil was not significantly affected by deforestation (Tables 3 and 4).

3.1.2. Soil aggregate stability

Deforestation resulted in a significant decrease in aggregate stability of the 0–30 cm soils ($P \leq 0.05$). MWD decreased from 1.49 mm in FO to 0.88 mm in DEF with significantly higher values in all slope positions of FO (Tables 3 and 4, Fig. 2e). This is in line 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 (Nardi et al., 1996; Shepherd et al., 2001).

Severe loss of OM, increased silt content, decreased microbial activity and use of heavy machinery were the main responsible factors for the decreased MWD following deforestation. There are no significant differences observed in MWD of different slope positions of FO (Fig. 2e). This could mainly be due to the insignificant change in OM and microbial activity of different slope positions of FO which consequently show the stable conditions of FO hillslope. The lowest MWD (0.72 mm) was found in the TS position of DEF due to the intensive tillage and agricultural activity (Fig. 2e).

3.1.3. Soil bulk density (BD) and soil porosity (F)

Bulk density and soil porosity showed significant differences in two selected land uses. BD increased significantly in the DEF ($P \leq 0.05$) compared to the FO (1.40 g/cm^3 in FO and 1.54 g/cm^3 in DEF) (Table 3, Fig. 2f). The soil porosity followed the reverse trend (47.6% in FO to 42.3% in DEF) in the surface soil (Fig. 2g). The results

Table 3
Comparison of the mean values of the studied soil properties in two studied land uses and depths.

Depth cm	Land use	Clay (%)	Silt (%)	Sand (%)	BD (g/cm^3)	*F* (%)	pH	SP (%)	OC (%)	TN (%)	CEC (cmol kg^{-1})	CCE (%)	K_{ava} (mg kg^{-1})	MWD (mm)	SMR (mg CO_2/g day)	BioC (mg kg^{-1})	BioN (mg kg^{-1})	Fungi (CFU g^{-1})	OC stock (ton ha^{-1})
0–30	FO	31.8 a	60.0 b	8.2 a	1.40 b	47.6 a	7.1	60.6 a	3.5 a	0.29 a	32.1 a	5.3 b	67.9 a	1.49 a	0.19 a	395.3 a	30.9 a	1114.0 a	147 a
	DEF	21.5 b	68.6 a	9.9 a	1.54 a	42.3 b	7.4	47.1 b	1.0 b	0.08 b	25.0 b	20.9 a	56.1 b	0.88 b	0.10 b	220.2 b	14.8 b	102.4 b	42 b
30–60	FO	32.4 a	57.6 b	10.7 b	1.59 a	40.2 a	7.3	52.1 a	0.9 a	0.07 a	30.6 a	10.7 b	59.3 a	–	–	–	–	–	37.8 a
	DEF	21.5 b	66.1 a	12.4 a	1.54 a	41.9 a	7.6	46.8 b	0.4 b	0.03 b	21.9 b	24.6 a	52.5 b	–	–	–	–	–	16.8 b
Original loess		15	75.8	9.2	1.52	42.6	7.7	41	0.3	–	18.0	24.0	–	–	–	–	–	–	–

Numbers with the similar letters are not significantly ($P < 0.05$) different in two land uses in each depths.

Table 4
Comparison of the mean values of the studied soil properties in different slope positions and depths of two studied land uses.

Depth (cm)	Position	Land use	Clay (%)	Silt (%)	Sand (%)	BD (g/cm^3)	*F* (%)	pH	SP (%)	OC (%)	TN (%)	CEC (cmol kg^{-1})	CCE (%)	K_{ava} (mg kg^{-1})	MWD (mm)	SMR (mg CO_2/g day)	BioC (mg kg^{-1})	BioN (mg kg^{-1})	Fungi (CFU g^{-1})
0–30	SU	FO	31.1 a	57.3 b	11.4 a	1.40 b	48.0 a	6.7 b	53.4 a	3.4 a	0.28 a	36.9 a	6.4 b	65.7 a	1.72 a	0.21 a	465.0 a	37.1 a	2849 a
		DEF	20.9 b	68.6 a	10.4 a	1.69 a	44.0 b	7.5 a	48.0 b	1.8 b	0.15 b	33.0 b	27.6 a	54.0 b	0.87 b	0.15 b	162.3 b	12.4 b	117.5 b
	SH	FO	33.8 a	56.1 b	10.0 a	1.39 b	47.7 a	7.3 a	67.0 a	4.2 a	0.36 a	29.4 a	8.2 b	28.2 a	1.48 a	0.21 a	462.4 a	27.8 a	1171.5 a
		DEF	21.8 b	68.0 a	10.2 a	1.47 a	44.7 b	7.4 a	46.3 b	0.7 b	0.06 b	18.5 b	28.2 a	61.6 b	0.91 b	0.06 b	236.5 b	13.8 b	24.1 b
	BS	FO	39.3 a	53.2 b	6.0 a	1.40 b	47.7 a	7.3 a	60.8 a	3.2 a	0.27 a	29.4 a	2.6 b	74.6 a	1.74 a	0.17 a	382.8 a	28.1 a	298.5 a
		DEF	19.7 b	71.2 a	8.9 a	1.60 a	40.0 b	7.4 a	44.3 b	0.5 b	0.04 b	18.1 b	27.8 a	49.5 b	0.97 b	0.11 b	330.0 b	19.8 b	98.5 b
	FS	FO	32.4 a	55.8 b	11.7 a	1.38 b	48.0 a	7.0 b	67.0 a	3.8 a	0.33 a	36.5 a	4.0 b	65.1 a	1.76 a	0.15 a	385.7 a	34.9 a	2825.4 a
		DEF	19.4 b	69.7 a	10.8 a	1.48 a	44.5 b	7.5 a	46.8 b	0.5 b	0.04 b	25.3 b	16.1 a	55.5 b	0.92 b	0.11 b	256.3 b	16.4 b	127.8 b
	TS	FO	19.6 b	65.7 a	14.7 a	1.42 b	46.7 a	7.2 a	54.7 a	2.8 a	0.26 a	28.3 a	5.5 a	60.2 a	1.52 a	0.21 a	389.1 a	26.6 a	269.8 a
		DEF	25.9 a	64.5 a	9.5 b	1.64 a	38.5 b	7.3 a	50.2 a	1.1 b	0.09 b	30.0 a	4.6 a	60.2 a	0.72 b	0.07 b	115.8 b	11.8 b	144.1 b
30–60	SU	FO	38.8 a	51.7 b	9.4 b	1.53 b	42.6 a	6.9 b	58.4 a	0.7 a	0.06 a	37.1 a	9.0 b	56.6 a					
		DEF	20.3 b	59.4 a	20.2 a	1.60 a	40.0 a	7.6 a	48.6 b	0.4 b	0.03 b	19.6 b	34.1 a	50.8 b					
	SH	FO	25.2 a	66.4 b	8.3 a	1.55 b	41.6 a	7.6 a	47.7 a	1.0 a	0.08 a	26.2 a	15.5 b	64.1 a					
		DEF	14.9 b	74.2 a	10.7 a	1.42 a	46.6 a	7.6 a	42.9 b	0.2 b	0.02 b	19.3 b	25.3 a	50.6 b					
	BS	FO	28.2 a	65.3 a	6.4 a	1.43 a	46.3 a	7.4 a	51.4 a	1.4 a	0.12 a	30.4 a	17.0 b	60.6 a					
		DEF	22.7 b	67.3 a	10.0 a	1.49 a	44.3 a	7.7 a	45.0 b	0.4 b	0.03 b	19.0 b	27.3 a	52.6 b					
	FS	FO	35.8 a	56.2 b	7.9 a	1.68 a	37.0 a	7.5 a	48.7 a	1.0 a	0.08 a	31.0 a	5.0 b	53.0 a					
		DEF	19.4 b	68.5 a	12.0 a	1.66 a	37.6 a	7.6 a	45.5 a	0.3 b	0.03 b	20.7 b	19.1 a	52.1 a					
	TS	FO	30.3 a	60.6 a	9.1 a	1.60 a	39.6 a	7.0 b	55.3 a	0.4 a	0.03 a	28.4 a	7.3 b	62.1 a					
		DEF	30.2 a	60.3 a	9.3 a	1.56 a	41.0 a	7.6 a	52.2 a	0.5 a	0.04 a	30.8 a	17.0 a	56.1 b					

Numbers with the similar letters are not significantly ($P < 0.05$) different in two land uses in each depths.

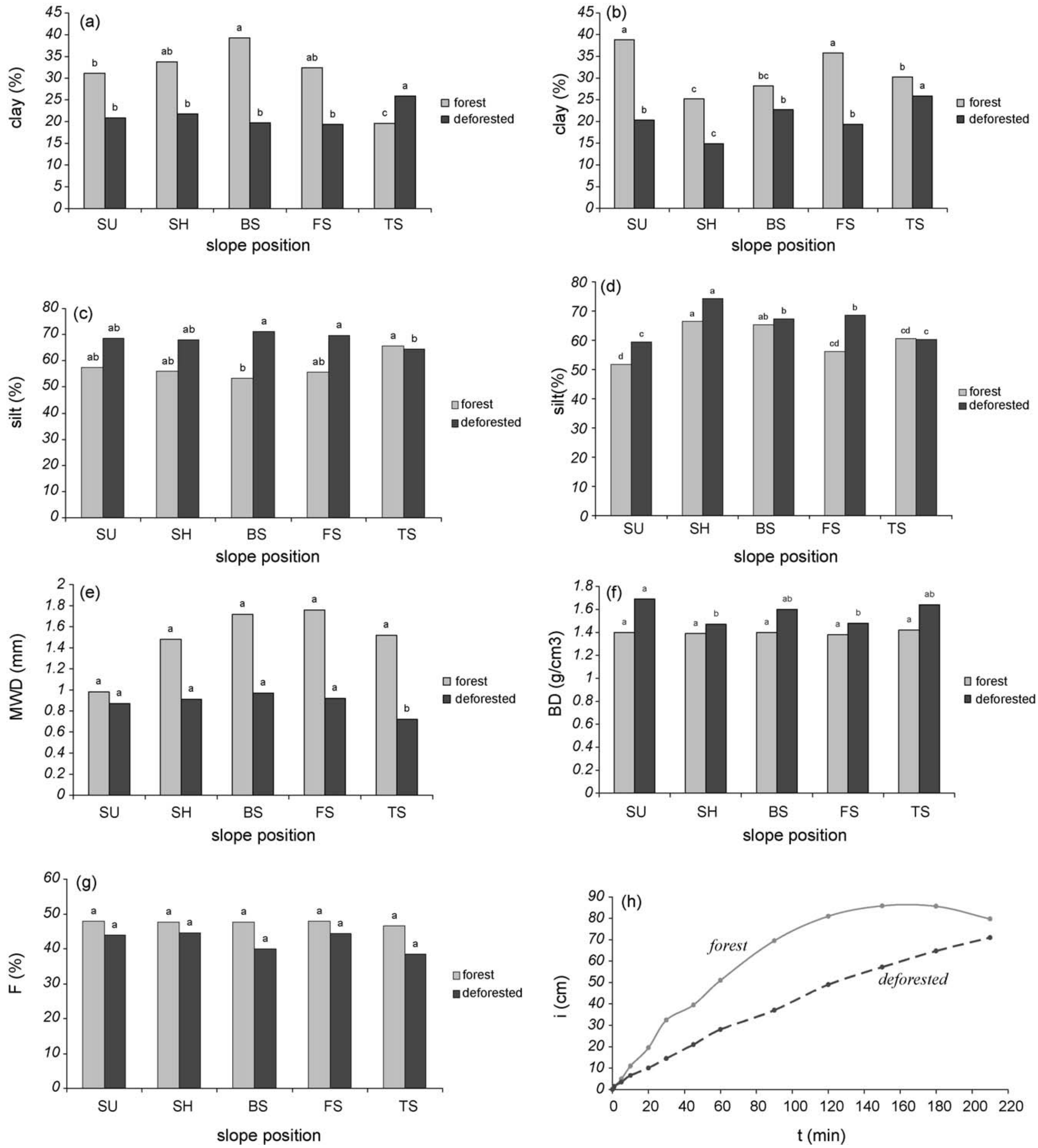

Fig. 2. Clay and silt content in 0–30 cm (a and c) and 30–60 cm (b and d) depths of two land uses on different slope positions; MWD (e), BD (f), F (g) in the topsoil of FO and DEF and infiltration rate (h) (columns with similar letters in each land use are not statistically significant).

are in line with the findings of Reiners et al. (1994), McDonald et al. (2002), and Lemenih et al. (2005). Increased BD and decreased total porosity are related with the loss of OM and soil compaction due to tillage practices in the DEF (Dang et al., 2002). According to Shepherd et al. (2001) reduced porosity is due to disintegration of soil aggregates with tillage practices. Islam and Weil (2000) relate the reduction in porosity following deforestation to the remaining higher sand content in DEF and the weak soil structure.

BD was not affected significantly by slope positions in FO, which can be related to its high OM in all slope positions (Fig. 2f, Table 4). There was a significant difference between the adjacent slope positions in two land uses (Table 4). The highest BD was found in the SU and TS positions of DEF mainly caused by the intensive tillage practices.

3.1.4. Soil infiltration rate

The soil infiltration rate was higher in FO than that of the DEF mainly due to the loss of OM, and consequently the lower aggregate stability, higher BD and soil compaction (Fig. 2h). Because of the stable soil structure, soil hydraulic conductivity of the FO is higher (Kiani et al., 2004). Many scientists such as Sparling et al. (1994) believe that deforestation and cultivation decrease the soil infiltration through decreasing porosity and soil water holding capacity. The soil compaction severely affects the soil infiltration and produces high surface runoff and increases the susceptibility of the soil to erosion (USDA-NRCS, 1998).

3.2. Chemical soil quality indicators

3.2.1. Soil organic carbon (OC) and total nitrogen (TN)

Organic carbon variability is considered as one of the most important soil quality parameters to evaluate the effects of management practices (Pathak et al., 2004). A significant decrease (>70%) has occurred in both OC and TN following deforestation ($P \leq 0.05$) on almost all slope positions. Both depths showed reduction in OC and TN in the DEF with the higher reduction in the surface layers (Tables 3 and 4, Fig. 3). The average OC of the 60 cm depth reduced from 2.4% in the FO to 0.7% in the DEF. The results are in accordance with the findings of Saviozzi et al. (2001) and Puget and Lal (2005). Nardi et al. (1996) believe that the rupture of the larger aggregates to the smaller ones following deforestation aggravates the loss of OM. Carter et al. (1998) report the increased soil temperature due to the less shading, low vegetation cover, and tillage practices and subsequent susceptibility of soils to erosion in the DEF.

Hebert et al. (1991) also believe that the coarser texture increases the OM decomposition risk. Although the OC and TN of the studied soils were lower in all the slope positions of the DEF compared to the FO, they did not show any significant difference in

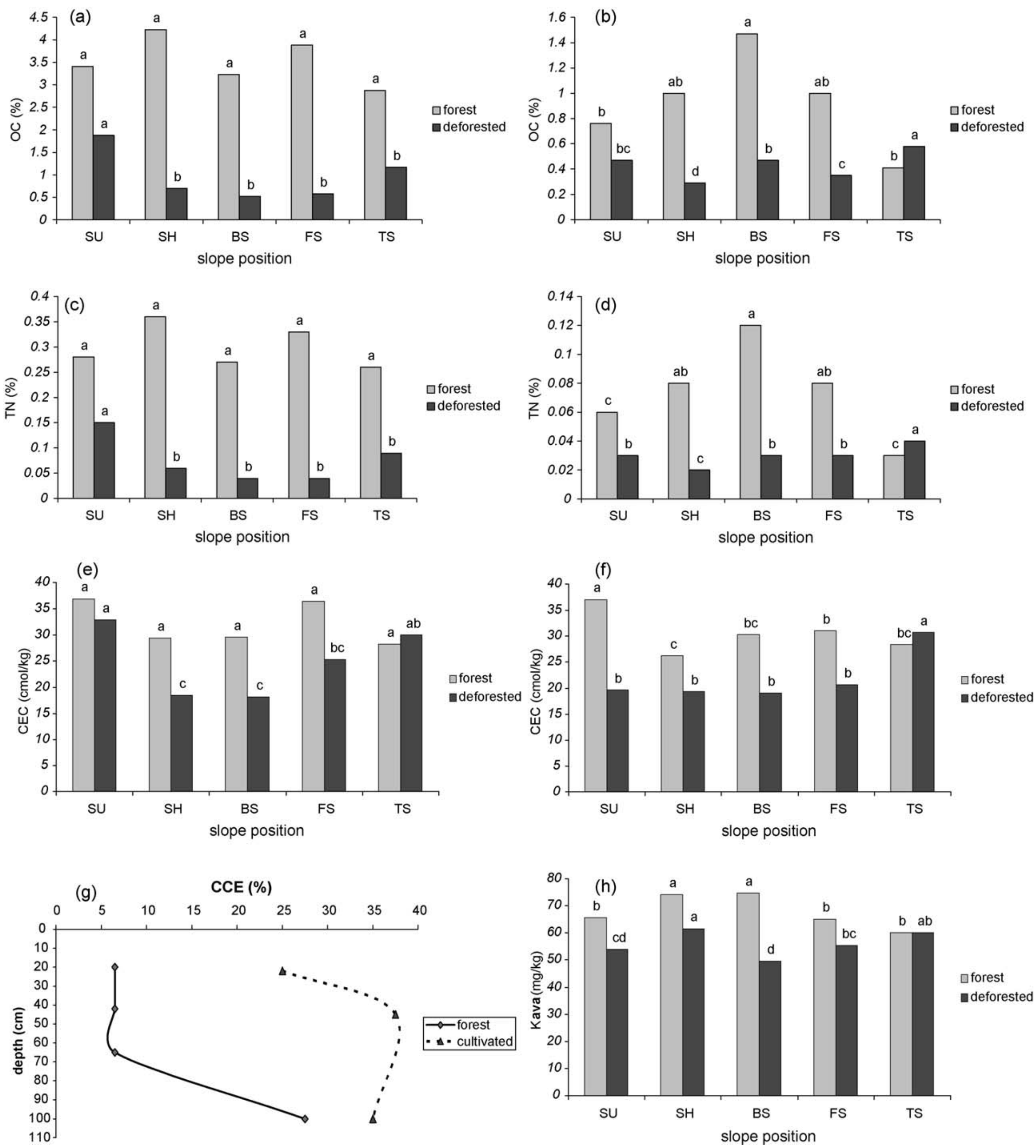

Fig. 3. OC, TN and CEC in the 0–30 cm (a, c, e) and 30–60 cm (b, d, f) depths of two land uses on different slope positions; CCE depth variations in the summit positions of FO and DEF (g); K_{ava} (h) in the topsoil of FO and DEF (columns with similar letters in each land use are not statistically significant).

the SU positions of the FO and DEF. This is mainly due to the application of manure as fertilizers for high nutrient demanding crops such as cotton, tomato and watermelon (Fig. 3). OC and TN did not vary significantly in different slope positions of the FO, in the surface layer (Fig. 3).

3.2.2. Cation exchange capacity (CEC)

The CEC of the soils decreased significantly ($P \leq 0.05$) in all the depths and slope positions of DEF compared to FO (Tables 3 and 4). Decrease in CEC reflects the textural and OM changes in DEF and these are in line with the findings of Vagen et al. (2006). In the SH position, CEC reduced significantly (28 cmol kg^{-1} in FO and 18 cmol kg^{-1} in DEF) in the DEF up to 60 cm depth. This reduction is more significant in the surface soil layer (Fig. 3e and f). The differences in CEC of the slope positions of FO were insignificant in the surface layer (Fig. 3). In the surface layer of DEF, the highest CEC was related to the SU position (33.0 cmol kg^{-1}) which could be explained by its higher OM and clay content (Fig. 3).

3.2.3. Calcium carbonate equivalent (CCE)

Loess material contain high amount of lime. Land use change has resulted in the significant change in CCE. FO had the lower CCE in all the slope positions of both depths compared to the DEF (Tables 3 and 4). The CCE content in the upper 60 cm soil is significantly lower in FO (7.6% in FO to 22.4% in DEF) ($P \leq 0.05$). Fig. 3g shows variations of the CCE with depth in the summit positions of FO and DEF.

Loess parent material contains about 20–30% of CCE in the region. The similarity in the CCE content of the DEF to the loess parent material and subsurface layer of the FO could be an indication of the loss of topsoil in DEF and subsequent outcropping of the CCE rich material. Khormali et al. (2006) introduced the variety of complex processes accounting for the CCE dynamics in the soil. CCE variations can be used as an indicator for soil loss and landscape stability. CCE in the FO is significantly lower than DEF in almost all the slope positions, indicating the stability of FO landscape to allow the downward movement and subsequent accumulation as secondary carbonates.

3.2.4. Available soil potassium (K_{ava})

The K_{ava} showed a significant decrease in the DEF ($P \leq 0.05$) compared to that of FO (Table 3). It varied from 64.2 mg kg^{-1} in the FO to 54.6 mg kg^{-1} in the DEF. The results are in line with the findings of Dang et al. (2002) and Vagen et al. (2006). Coarser soil texture, lower CEC, lack of permanent vegetative cover and water erosion are the main possible reasons for the loss of K_{ava} in the DEF. It is worth mentioning that the farmers are not using K fertilizers. In the SU position the K_{ava} decreased significantly from 61.8 to 52.6 mg kg^{-1} following deforestation in the upper 60 cm soil ($P \leq 0.05$).

Intensive cultivation and application of urea which is an acidifying fertilizer might be also an important reason for the lower K_{ava} in DEF (Baker et al., 1997). Lower soil clay content is also important as the main pool for the soil K. In the FS and TS positions however, there was not a significant difference in K_{ava} in two land uses. The clay transport from upper slope positions and subsequent deposition and accumulation in the TS position are mainly responsible for the improved K_{ava} conditions in the 60 cm soil of the DEF (Fig. 3h).

3.3. Biological soil quality indicators

The biological soil quality attributes are relatively responding rapidly to management compared to other variables and therefore they can play a considerable role in monitoring the effects of cultivation after deforestation and clear cutting on soil quality (Powlson et al., 1987).

3.3.1. Soil microbial respiration (SMR)

The SMR is an important soil quality indicator decreased from 0.19 mg CO_2/g day in the surface layers of the FO to 0.10 in DEF ($P \leq 0.05$) (Table 3). Deforestation and cultivation could be responsible for the significant decrease in the SMR in all the slope positions (Fig. 4a). In the SH position with high OM loss SMR decreased from 0.21 mg CO_2/g day to 0.06 following deforestation. According to Islam and Weil (2000) the higher SMR of FO is mainly explained by its high OC levels. Kiani et al. (2004) believe that the addition of fresh plant residues and organic matter in the FO is important for the increase in SMR compared to other land uses. Slope stability and nonsignificant OM variation in the different

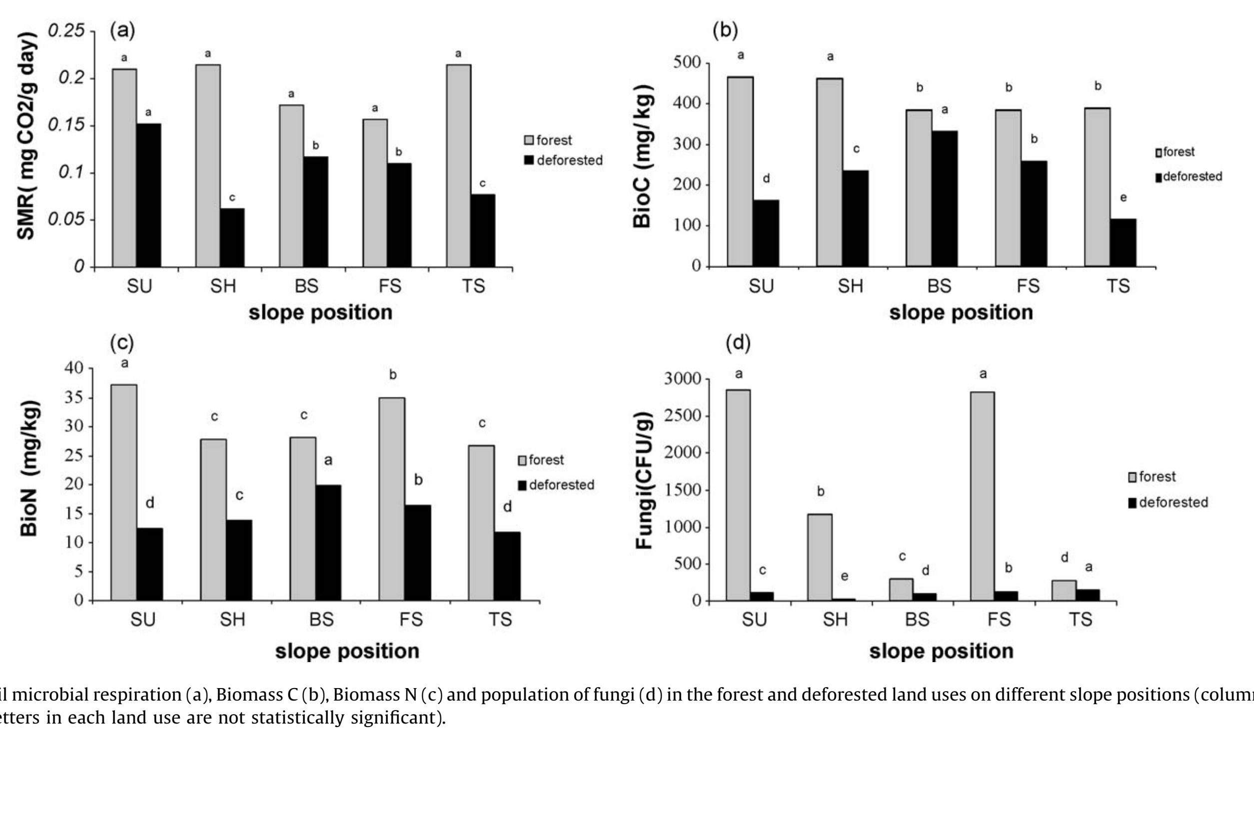

Fig. 4. Soil microbial respiration (a), Biomass C (b), Biomass N (c) and population of fungi (d) in the forest and deforested land uses on different slope positions (columns with similar letters in each land use are not statistically significant).

slope positions of FO could explain the lack of significant variation in the SMR on slope positions of FO (Tables 3 and 4).

3.3.2. Biomass C (BioC), biomass N (BioN) and population of fungi

Soil microbial biomass (generally measured as undifferentiated whole) is defined as the living part of the soil organic matter excluding plant roots and soil animals larger than $5 \times 10^3\ \mu m^3$ (Jenkinson, 1988). Microorganisms act as nutrient flow regulators (source and sink) through the process of retention (immobilization) and release (mineralization) of nutrients (Wani and Rego, 1999).

Fig. 4 shows the variation of some of the biological indicators of the soil quality studied. BioC, BioN values and population of fungi are significantly higher in all the slope positions of the forest compared to the cultivated land use. Table 3 shows the average values for the different parameters studied in the surface horizons of the forest and cultivated areas. Organic carbon and N pools have been significantly depleted by deforestation largely due to sheet and rill erosion occurred especially in the SH and BS positions.

Tillage practices and inappropriate management have aggravated the loss of organic matter and caused the subsequent decrease in microbial population and lower respiration. Tillage is mainly responsible for mining of lime from calcic horizons. This has affected the population of fungi by the increase in soil pH as a result of clear cutting (Tables 3 and 4, Fig. 4).

3.4. Micromorphological soil quality indicators

Soil micromorphology can be used to interpret the processes occurring in soils exposed to deforestation. Soil animals influence many soil processes, in particular aggregation and the organization of void space. Excrement pedofeatures constitute most of the microaggregates in organic horizons of the soil and they can

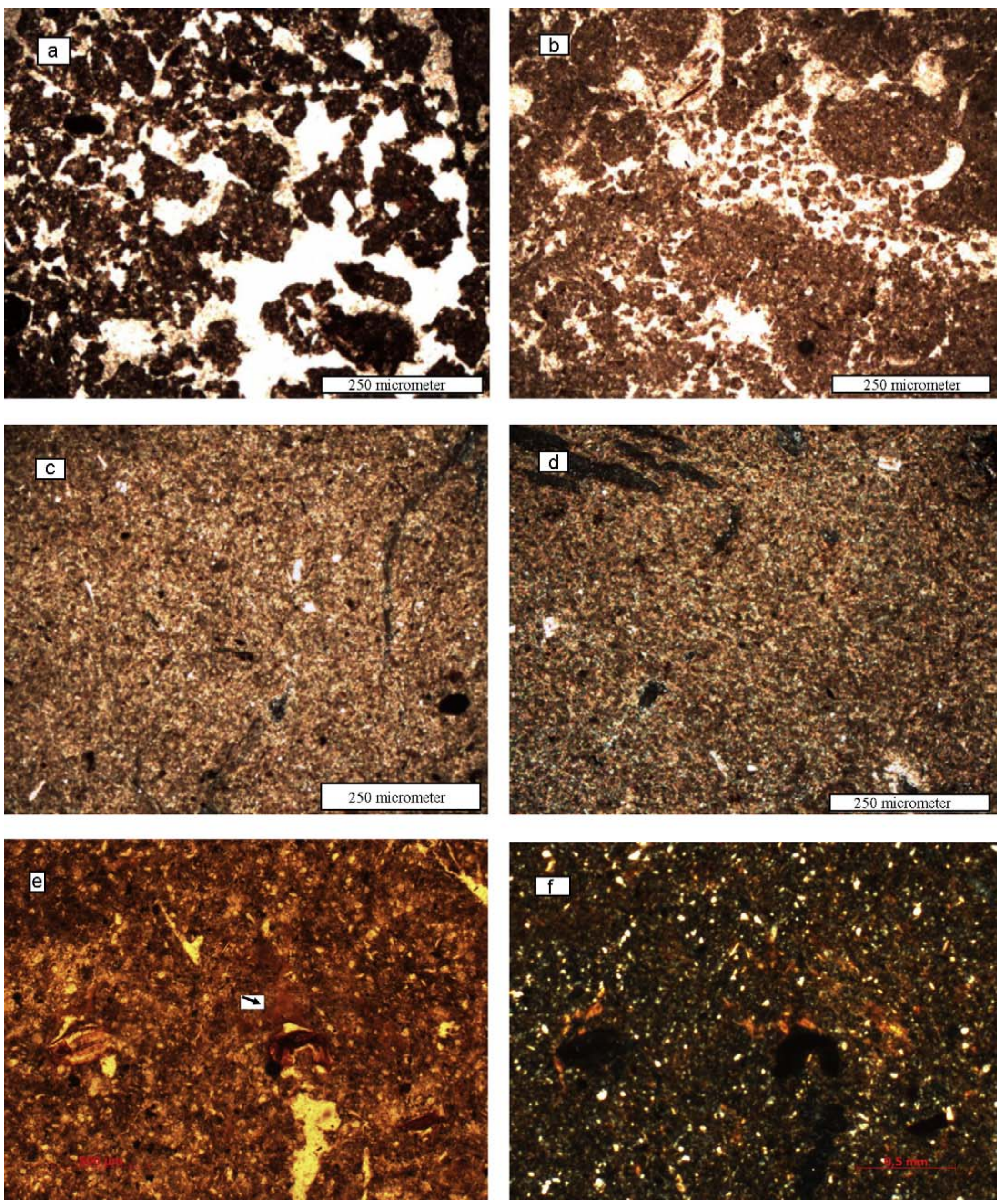

Fig. 5. (a) Crumb microstructure in the topsoil of summit position of FO (Plain Polarized Light, PPL); (b) excremental pedofeatures (passage features, biologic activity) in the topsoil of shoulder position of FO (PPL); (c and d) massive microstructure and little porosity in the topsoil of shoulder position of DEF (c: PPL, and d: cross-polarized light, XPL); (e and f) clay pedofeatures in the Bt horizon of the FO soils (e: PPL and f: XPL).

accumulate to such an extent that they may dominate a horizon (Davidson et al., 2002).

Soil micromorphology provides a method of studying the interactions between animals and soil, with emphasis on features indicative of faunal activity, such as excremental pedofeatures and void space, which persist even after the organisms were no longer present. Microstructure, porosity (shape, size, and distribution pattern), and biological activity are the properties important as soil quality indicators.

Khormali and Nabiallahi (2009) investigated the land use effects on the degradation of Mollisols, in western Iran. The results revealed that unlike rangelands, cultivated soils lacked enough OC to meet the requirements of Mollisols and had only ochric epipedons. Micromorphological investigations reveal that the rangeland soils have strong granular and crumb microstructure. Fig. 5 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. 5a).

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. 5b). 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. 5c and d, the microstructure of the topsoil of the DEF is mainly massive or very weakly developed with very low porosity. Cultivation practices have resulted in soil loss and compaction, deteriorating soil quality in terms of the microbial activity, porosity, and microstructure.

In the natural forest land use, formation of argillic horizon with speckled b-fabric strongly supports the presence of highly stable landscape which provides enough time for leaching of carbonates from the topsoil and cause the downward movement of clay particles. The former Bt horizon was eroded following 50 years of cultivation. The b-fabric of the surface and subsurface soils of the DEF is crystallitic (Fig. 5e and f). Absence of carbonate depletion and clay illuviation pedofeatures indicate the unstable conditions occurred following soil erosion in the DEF. Intense erosion of the surface horizons of cultivated land has resulted in the outcropping of the subsurface carbonate rich horizons preventing soil development and clay translocation.

Presence of clay coatings in most of the FO soils reflects a more stable geomorphic surface required for the processes of decalcification and subsequent clay translocation (Khormali et al., 2003) (Fig. 5e, and f). The higher clay content of the subsurface horizons of the FO could be explained by the clay illuviation process.

3.5. Soil erodibility

In the universal soil loss equation (USLE) and the revised universal version (RUSLE), soil erodibility is represented by an erodibility factor (*K*-factor). The *K*-factor was defined as the mean rate of soil loss per unit rainfall erosivity index from unit runoff plots (USLE, Wischmeier and Smith, 1978). Results found by Zhang et al. (2004) indicate that the *K*-factor for USLE/RULSE is more appropriate for agricultural soils on the loess plateau than the erodibility index developed locally. As shown in Fig. 6, *K*-factor in the FO is lower than DEF. This factor is lowest in the summit positions. Moreover, the *K*-factor values were not significantly different on slope positions of FO.

In the DEF, however, it showed significant variations with the highest *K*-factor value found in the SH, FS, and BS positions. In the TS positions of both land uses with hydromorphic conditions and lower organic matter, the differences in *K*-factor were not significant. The erodibility of a certain soil is closely related to its particle size distribution, permeability, organic matter content,

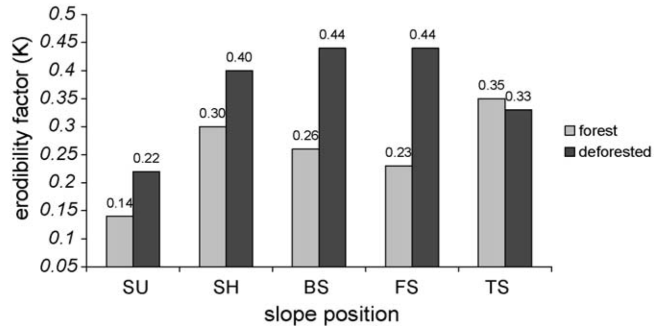

Fig. 6. Variation of erodibility factor (*K*-factor) in different slope positions of FO and DEF.

and structure. For loess-derived soils, the difference in soil erodibility is mainly a result of the variations in particle size distribution among which silt and clay contents are the most important factors. The lowest *K*-factor values in the summit positions of the FO, therefore, could be mainly due to the higher clay and organic matter and lower silt content.

4. Conclusion

The study showed that deforestation and cultivation on the loess hillslopes have resulted in a significant deterioration of soil quality as described by different physical, chemical, biological, and micromorphological indicators. According to Table 3, the average OC stock of the 0–60 cm depth of the FO and DEF are, 184.8 and 58.8 ton ha^{-1}, respectively. In other words the OC loss of the DEF is almost 3 times of the FO. Taking into account the role of slope positions, BS and SH are responsible for almost two-third of the OC loss in the DEF. OC of the soil, has a great influence on other soil quality indicators.

Considering the difficulty in persuading the farmers in restoration of the forest or other plantations, and the highly risk of the SH and BS positions, controlling these two important slope positions by plantations such as olive (Ayoubi and Khormali, 2008) and or other sustainable practices, e.g. fallow and rotations would help reduce soil loss and preventing the flood hazards. Knowledge of soil micromorphology can be a valuable tool to monitor some important soil quality changes and its use is, therefore, suggested in the soil quality investigations.

Acknowledgments

The authors would like to thank Prof. Sahrawat for his valuable comments, and Mr. Jangawat and Mrs. Vineela from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for their help in the biological analyses of the samples. The help of Dr. E. Dordipour from Gorgan University of Agricultural Sciences and Natural resources in statistical analyses is also appreciated.

References

Adesodun, J.K., Davidson, D.A., Hopkins, D.W., 2005. Micromorphological evidence for faunal activity following application of sewage and biocide. Appl. Soil Ecol. 29, 39–45.
Amato, M., Ladd, J.N., 1988. Assay for microbial biomass based on ninhydrin reactive nitrogen in extracts of fumigated soil. Soil Biol. Biochem. 20 (1), 107–114.
Anderson, D.W., 1995. Decomposition of organic matter and carbon emission from soils. In: Lal, R., John Kimble, Elissa Levine, B.A., Stewart, (Eds.), Soils and Global Change. Advances in Soil Science. CRC Press, USA, pp. 165–175.
Anderson, J.P.E., Domsoh, K.H., 1978. Mineralization of bacteria and fungi in chloroform-fumigated soils. Soil Biol. Biochem. 10, 207–213.
Angers, D.A., Mehuys, G.R., 1993. Aggregate stability to water. In: Carter, M.R. (Ed.), Soil Sampling and Methods of Analysis. Lewis Pub., Boca Raton, pp. 651–657.

Ayoubi, S., Khormali, F., 2008. Use of factor analysis to evaluate soil quality relation to land use change in Azadshar district, north of Iran. In: 18–23 May 2008, 15th International of Congress of ISCO, Budapest, Hungary.

Baker, M.R., Nys, C., Picard, J.F., 1997. The effect of liming and gypsum applications on a sessile oak (*Quercus petraea*) stand at Larcroix-Scaille (*French ardennes*) I. Site characteristics, soil chemistry and aerial biomass. Plant Soil. 150, 99–108.

Blake, G.R., Hartge, K.H., 1986. Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1, Physical and Mineralogical Methods, 2nd ed., Agronomy 9, 363–382.

Boix-Fayos, C., Calvo-Cases, A., Imeson, A.C., Soriano-Soto, M.D., 2001. Influence of soil properties on the aggregation of some Mediterranean soils and the use of aggregate size and stability as land degradation indicators. Catena 44, 47–67.

Bouwer, H., 1986. Intake rate: cylinder infiltrometer. In: Klute, A. (Ed.), Methods of Soil Analysis. Part I: Physical Analysis. SSSA, Madison, WI, pp. 825–844.

Bremner, J.M., 1996. Nitrogene-total. In: Bigham, et al. (Eds.), Methods of Soil Analyses, Part III, Chemical Methods. SSSA, Madison, WI, pp. 1085–1184.

Cambardella, C.A., Moorman, T.B., Andrews, S.S., Karlen, D.L., 2004. Watershed-scale assessment of soil quality in the loess hills of southwest Iowa. Soil Till. Res. 78, 237–247.

Caravaca, F., Lax, A., Albaladejo, J., 2004. Aggregate stability and carbon characteristics of particle-size fractions in cultivated and forested soils of semiarid Spain. Soil Till. Res. 78, 83–90.

Carter, M.R., Gregorich, E.G., Angers, D.A., Donald, R.G., Bolinder, M.A., 1998. Organic C and N storage and organic C fractions in adjacent cultivated and forested soils of eastern Canada. Soil Till. Res. 47, 253–261.

Catt, J.A., 2001. The agricultural importance of loess. Earth-Sci. Rev. 213–229.

Celik, I., 2005. Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. Soil Till. Res. 83, 270–277.

Chapman, H.D., 1965. Cation exchange capacity. In: Black, C.A. (Ed.), Methods of Soil Analysis, Part 2. American Society of Agronomy, Madison, WI, USA.

Dang, V.M., Anderson, D.W., Farrell, R.E., 2002. Indicators for assessing soil quality after long-term tea cultivation in Northern Mountainous Vietnam. In: Proceedings of the 17th WCSS. Thailand pp. 14–21.

Davidson, A., Bruneau, P.M.C., Grieve, I.C., Young, I.M., 2002. Impacts of fauna on an upland grassland soil as determined by micromorphological analysis. Appl. Soil Ecol. 20, 133–143.

Evrendilek, F., Celik, I., Kilic, S., 2004. Changes in soil organic carbon and other physical soil properties along adjacent Mediterranean forest, grassland, and cropland ecosystems in Turkey. J. Arid Environ. 59, 743–752.

Fitzsimmons, M.J., Pennock, D.J., Thorpe, J., 2004. Effects of deforestation on ecosystem carbon densities in central Saskatchewan, Canada. Forest Ecol. Manage. 188, 349–361.

Forest, Rangeland and Watershed Management Organization, 1999. Detailed survey on the management of renewable resources. Gorgan, Iran, p. 143.

Gee, G.W., Bauder, J.W., 1986. Particle-size analysis. In: Klute, A. (Ed.), Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods, 2nd ed., Agronomy 9, 383–411.

Hadiani, M.O., 2007. Role of land use change on the local floods volume (a case study in Madar Su watershed, Golestan Province, Iran). Environmentology 33 (42), 9–16 (in Farsi).

Hajabbasi, M.A., Jalalian, A., Karimzadeh, H.R., 1997. Deforestation effects on soil physical and chemical properties, Lordegan, Iran. Plant Soil. 190, 301–308.

Hebert, K., Karam, A., Parent, L.E., 1991. Mineralization of nitrogen and carbon in soils amended with composted manure. Biol. Agric. Hortic. 7, 336–361.

Islam, K.R., Weil, R.R., 2000. Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. Agric. Ecosyst. Environ. 79, 9–16.

Jenkinson, D.S., 1988. Determination of microbial biomass carbon and nitrogen in soil. In: Wilsom, J.R. (Ed.), Advances in Nitrogen Cycling in Agricultural Ecosystems. CAB International, Wallingford, Oxon, UK, pp. 368–386.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.T., Harris, R.F., Schuman, G.E., 1997. Soil quality: a concept definition and framework for evaluation. Soil Sci. Soc. Am. J. 90, 644–650.

Kavdir, Y., Ozcan, H., Ekinci, H., Yigini, Y., 2004. The influence of clay content, organic carbon and land use types on soil aggregate stability and tensile strength. Turk. J. Agric. 28, 155–162.

Kemper, W.D., Rosenau, R.C., 1986. Aggregate stability and size distribution. In: Klute, A. (Ed.), Methods of Soil Analysis. Part I: Physical Analysis. SSSA, Madison, WI, pp. 425–442.

Khormali, F., Abtahi, A., Stoops, G., 2006. Micromorphology of calcitic features in highly calcareous soils of Fars Province, Southern Iran. Geoderma 132, 31–46.

Khormali, F., Abtahi, A., Mahmoodi, Sh., Stoops, G., 2003. Argillic horizon development in calcareous soils of arid and semiarid regions of southern Iran. Catena 53, 273–301.

Khormali, F., Nabiallahi, K., 2009. Degradation of Mollisols in western Iran as affected by land use change. J. Agric. Sci. Technol. 11, 363–374.

Khormali, F., Ayoubi, S.H., Kananro Foomani, F., Fatemi, A., Hemmati, Kh., 2007. Tea yield and soil properties as affected by slope position and aspect in Lahijan area, Iran. Int. J. Plant Product. 1 (1), 99–111.

Kiani, F., Jalalian, A., Pashaee, A., Khademi, H., 2004. Effect of deforestation on selected soil quality attributes in loess-derived landforms of Golestan province, northern Iran. In: Proceedings of the 4th International Iran Russia Conference. pp. 546–550.

Knudsen, D., Peterson, G.A., Partt, P.E., 1996. Lithium, sodium and potassium. In: Page, A.L., et al. (Eds.), Methods of Soil Analysis, Part 2. American Society of Agronomy, Madison, WI, pp. 403–429.

Landi, A., Anderson, D.W., Mermut, A.R., 2003. Organic carbon storage and stable isotope composition of soils along a grassland to forest environmental gradient in Saskatchewan. Can. J. Soil Sci. 83 (4), 405–414.

Larson, W.E., Pierce, F.J., 1991. Conservation and enhancement of soil quality. In: Dumanski, J. (Ed.), Evaluation for Sustainable Land Management in the Developing World. Proceedings of the International Workshop, Chiang Rai, Thailand, 15–21 September 1991. Technical papers, vol. 2. Int. Board for Soil Res. and management Bangkok, Thailand, pp. 175–203.

Lemenih, M., Karltun, E., Olsson, M., 2005. Assessing soil chemical and physical property responses to deforestation and subsequent cultivation in smallholders farming system in Ethiopia. Agric. Ecosyst. Environ. 105, 373–386.

McDonald, M.A., Healey, J.R., Stevens, P.A., 2002. The effects of secondary forest clearance and subsequent land-use on erosion losses and soil properties in the Blue Mountains of Jamaica. Agric. Ecosyst. Environ. 92, 1–19.

McLean, E.O., 1982. Soil pH and lime requirement. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2nd ed., Agronomy 9, 199–224.

Moorman, T.B., Cambardella, C.A., James, D.E., Karlen, D.L., Kramer, L.A., 2004. Quantification of tillage and landscape effects on soil carbon in small Iowa watersheds. Soil Till. Res. 78, 225–236.

Mosaedi, A., Gharib, M., 2008. Investigation of flood characteristics in Gharahchy basin of Ramian (Golestan, Iran). J. Agric. Sci. Nat. Resour. 14 (6) (in Farsi, with English abstract).

Murphy, C.P., 1986. Thin Section Prepration of Soils and Sediments. A&B Academic Publ., Berkhamsted.

Nael, M., Khademi, H., Hajabbasi, M.A., 2004. Response of soil quality indicators and their spatial variability to land degradation in central Iran. Appl. Soil Ecol. 27, 221–232.

Nardi, S., Cocheri, G., Dell'Agnola, G., 1996. Biological activity of humus. In: Piccolo, A. (Ed.), Humic Substances in Terrestrial Ecosystems. Elsevier, Amsterdam, pp. 361–406.

Nelson, D.W., Sommers, L.E., 1982. Total carbon, organic carbon, and organic matter. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2nd ed., Agronomy 9, 539–579.

Ogunkunle, A.O., Eghaghara, O.O., 2007. Influence of land use on soil properties in a forest region of Southern Nigeria. Soil Use Manage. 8 (3), 121–124.

Pathak, P., Sahrawat, K.L., Rego, T.J., Wani, S.P., 2004. Measurable biophysical indicators for impact assessment: changes in soil quality. In: Shiferaw, B., Freeman, H.A., Swinton, S.M. (Eds.), Natural Resource Management in Agriculture. Methods for Assessing Economic and Environmental Impacts. ICRISAT, Patancheru, India.

Powlson, D.S., Brookes, P.C., Christensen, B.T., 1987. Measurement of microbial biomass provides an early indication of changes in total soil organic matter due to the straw incorporation. Soil Biol. Biochem. 19, 159–164.

Puget, P., Lal, R., 2005. Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. Soil Till. Res. 80, 201–213.

Rasiah, V., Florentine, S.K., Williams, B.L., Westbrooke, M.E., 2004. The impact of deforestation and pasture abandonment on soil properties in the wet tropics of Australia. Geoderma 120, 35–45.

Reiners, W.A., Bouwman, A.F., Parson, W.F.J., Keller, M., 1994. Tropical rainforest conservation to pasture: changes in vegetation and soil properties. Appl. Ecol. 4, 363–377.

Rhoades, J.D. 1982. Soluble salts. In: Page, A.L. (Ed.), Methods of Soil Analysis, Part II, 2nd ed., ASA, Monograph No. 9, Madison, WI, pp. 167–179.

Rhoton, F.E., Shipitalo, M.J., Linbo, D.L., 2002. Runoff and soil loss from midwestern and southeastern US silt loam soils as affected by tillage practice and soil organic matter content. Soil Till. Res. 66, 1–11.

SAS Institute, 2000. SAS Online Doc. Version 8. SAS Inst., Cary, NC. Availabe at: <http://v8doc.sas.com/sashtml/> (accesses 02.04.08; verified 23.02.04).

Saviozzi, A., Levi-Minzi, R., Cardelli, R., Riffaldi, R., 2001. A comparison of soil quality in adjacent cultivated, forest and native grassland soils. Plant Soil. 233, 251–259.

Scholes, R.J., Noble, I.R., 2001. Storing carbon on land. Science 294, 1012–1013.

Shepherd, T.G., Saggar Newman, R.H., Ross, C.W., Dando, J.L., 2001. Tillage induced changes in soil structure and soil organic matter fractions. Aust. J. Soil Res. 39, 465–489.

Six, J., Paustian, K., Elliott, E.T., Combrink, C., 2000. Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon. Soil Sci. Soc. Am. J. 64, 681–689.

Soil Survey Staff, 2006. Keys to Soil Taxonomy, 10th ed. U.S. Department of Agriculture.

Sparling, G.P., Hart, P.B.S., August, J.A., Leslie, D.M., 1994. A comparison of soil and microbial carbon, nitrogen and phosphorus contents, and macroaggregate stability of a soil under native forest and after clearance for pastures and plantation forest. Biol. Fertil. Soil 17, 91–100.

Stevenson, F.J., Cole, M.A., 1999. Cycles of Soil, 2nd ed. Wiley, NY, USA.

Stoops, G., 2003. Guidelines for Analysis and Description of Soil and Regolith Thin Sections. SSSA Inc., Madison, WI.

Stotzky, G. 1965. Microbial respiration. In: Black, C.A. (Ed.), Methods of Soil Analysis, Part 2. ASA: 1550-1572. Inc., Madison, WI.

USDA-NRCS, 1998. Soil Quality Information Sheet. Soil Quality Indicators.

Vagen, T.G., Andrianorofanomezana, M.A.A., Andrianorofanomezana, S., 2006. Deforestation and cultivation effects on characteristics of Oxisols in the highlands of Madagascar. Geoderma 131, 190–200.

Wali, M.K., Evrendilek, F., West, T., Watts, S., Pant, D., Gibbs, H., McClead, B., 1999. Assessing terrestrial ecosystem sustainability usefulness of regional carbon and nitrogen models. Nat. Resour. 35, 20–33.
Wang, J., Fu, B.J., Qiu, Y., Chen, L.D., 2001. Soil nutrients in relation to land use and landscape position in the semi-arid small catchments on the Loess Plateau in China. J. Arid Environ. 48, 537–550.
Wani, S.P., Rego, T.J., 15–26 November, 1999. Biological and chemical properties of soil. In: Wani, S.P., Piara Singh, Pathak, P. (Eds.), Methods and Management of Data for Watershed Research, Technical Manual for the Training Workshop. ICRISAT Center, Patancheru, India.
Wilding, N.E., Smeck, A., Hall, G.F., 1982. Pedogenesis and Soil Taxonomy. II. The Soil Orders. Developments in Soil Science 11b. Elsevier Publ., 410 pp.
Wischmeier, W.H., Smith, D.D., 1978. Predicting of rainfall erosion losses: a guide to conservation planning. In: Agriculture Handbook 537, US Department of Agriculture, Washington, DC, 58 pp.
World Reference Base for Soil Resources (WRB), 2006. Food and Agriculture Organization of the United Nations, Rome.
Zhang, K., Li, S., Peng, W., Yu, B., 2004. Erodibility of Agricultural soils on the Loess Plateau of China. Soil Till. Res. 76, 157–165.