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Research Article

The long-term effect of land-use change from forest to cropland in different slope aspects on soil chemical and physiological properties

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ABSTRACT- Land-use change from forest to arable lands may have a major significance on soil processes, properties, and functioning. This research investigated the influence of long-term land-use change from untouched forests to arable lands under northern and southern slope aspects on soil physical and chemical properties. Six regions of the Zagros area in the west of Iran, where the increasing trend of forest to agricultural land conversion has occurred during the last decades, were selected for this study. Composite soil samples were collected from the 0-20 cm depth in both the northern and southern slopes of native forests and their related cultivated areas. The highest dispersible clay and soil bulk density and the lowest aggregate stability were observed in cultivated areas. Soil organic carbon and total N declined in response to the land-use change from forest to cultivated areas in all study areas. The highest amounts of soil organic carbon, total N, C/N ratio, and available P were observed in northern slopes compared with southern slopes in some studied regions. In general, the conversion of natural forests to agricultural cropping systems resulted in soil quality declining. However, the deterioration intensity in the northern and southern slope aspects was similar approximately.

INTRODUCTION

Soils are the largest supply of terrestrial carbon. Conserving and enhancing soil organic matter through soil management helps to decrease climate change and increase soil and water quality, and handle food security (Drake et al., 2018; Scharlemann et al., 2014). Forest conversion to cropland has severely changed soil dynamics and the interaction of soil nutrients, and vegetation worldwide (Murty et al., 2002) by affecting critical aspects of ecosystem structures, functions, and services (Adeel, 2008). Land-use change is usually attended by changes in abiotic and biotic factors and soil organic matter rate, and thereafter changes in fertility and quality of soil (Beheshti et al., 2012; Coser et al., 2018; Golchin & Asgari, 2008; Hernández et al., 2016; Paz-Kagan et al., 2014; Solomon et al., 2000; Zinn et al., 2018).

Land use change plays a significant role in global carbon storage in soils (Foley et al., 2005; Guidi et al., 2014; Houghton, 2003; Poeplau & Don, 2013; Zinn et al., 2018). The loss of the carbon sequestering process of soils after the land-use change is a considerable problem because sequestered carbon in soils is the more giant terrestrial carbon pool. This pool is in the exchange with the biological carbon cycle and atmospheric CO_2 (Lal, 2004; Swift, 2001). The soil properties, fertility, bulk density, nutrient availability, water penetration, holding capacity, etc. affected soil organic carbon losses (Bastida et al., 2008; Guillaume et al., 2016; Lal, 2006, Lal, 2010; Wynants et al., 2018; Zare et al., 2017).

Land slope aspect can play an essential role in soil properties controlling, mainly through its influence on soil temperature and moisture (Begum et al., 2013; Jakšić et al., 2021; Måren et al., 2015). Soil microbial diversity and vegetation cover can be significantly influenced by land slope aspects (Huang et al., 2015; Navas et al., 2008). Consequently, land-use change impacts on soil properties may depend on the land slope aspect. Studying the relationship between the soil's physical and chemical properties and different slope aspects in land-use change research can provide helpful information for soil quality monitoring and vegetation restoration attempts in the future (Liu et al., 2018; Tamene et al., 2020).

A previous study revealed that the slope aspect impacted the nitrogen forms and the ratio of each form of nitrogen. In that study, the highest basal respiration, the microbial quotient, and the relative abundance of anaerobe were measured on the shady/half-shady slopes. Also, a lot of Gram-negative bacteria and aerobic bacteria were the most significant on the shady slope (Huang et al., 2015).

A large ratio of the earth's terrestrial has converted from a natural to a human-dominated environment in the last decades (DeFries et al., 2004; Foley et al., 2005; Paz-Kagan et al., 2014). In Iran, land-use changes over the last decades have resulted in a significant deterioration of soil quality and, consequently declines in soil fertility and crop production, environmental threats, and severe flooding throughout the country (Beheshti et al., 2012; Emadi et al., 2009; Golchin & Asgari, 2008; Khormali et al., 2009; Zare et al., 2017). Though there are many studies on land-use changes' impacts on soil properties around the world, little attention has been paid to this matter in Iran (Beheshti et al., 2012), in particular in the Zagros area.

In the recent 40 years, a considerable part of the Zagros natural forests has been converted to croplands. To evaluate the adopted management practices, it is necessary to study the influence of cultivation following native forest conversion on soil properties in the Zagros area. Considering the profound effects of land slope aspects on soil properties and probably soil response to the land-use change, this factor was also considered. The aim of the current study was to investigate soil physical and chemical properties changes resulting from several decades of conventional tillage systems following natural forest conversion to agricultural lands, under different northern and southern land slope aspects, in the Zagros area.

MATERIALS AND METHODS

Regions Description

Zagros is a broad region consisting of different areas with various climatic, ecological, and management conditions. To conduct this study, six regions located in the Zagros area, Kermanshah Province, were chosen (Fig. 1). The climate of these areas is semi-humid or humid, according to the Emberger classification (Table 1). The ranges of annual temperature and rainfall mean among areas are 12-15 °C and 500-850 mm, respectively (Table 1).

The major land use of the study areas is natural forests and cultivated lands. All studied soils were classified as Inceptisols. In each area, for each slope aspect (north or south), the paired sampling points were untouched forests and cultivated fields with similar slope gradients and parent materials (Fig. 2).

Soil Sampling and Analysis

Soil samples were taken from the untouched forest and cultivated areas, including different slope aspects of north or south, with three replication. Three subareas, each >2.0 ha (as pseudo-replications) were selected for sampling within each area. The land-use history and land slope of the subareas were similar.

In each replicated subarea, the composite soil samples were collected in September - October 2020 from 0-20 cm surface layer of forests and the corresponding farming sites (four composite soil samples including forest-north, forest-south, cultivated-north, and cultivated-south per subarea) in both north and south slopes (Fig. 2). Ten soil samples were taken and appropriately mixed to make a composite sample. Visible roots and rock fragments were removed from samples of soil at the sampling time. Bulk density was determined in undisturbed soil samples collected from 0-20 cm using cylindrical samplers (Blake & Hartge, 1986). Soil samples were air-dried and then passed through sieves for analysis

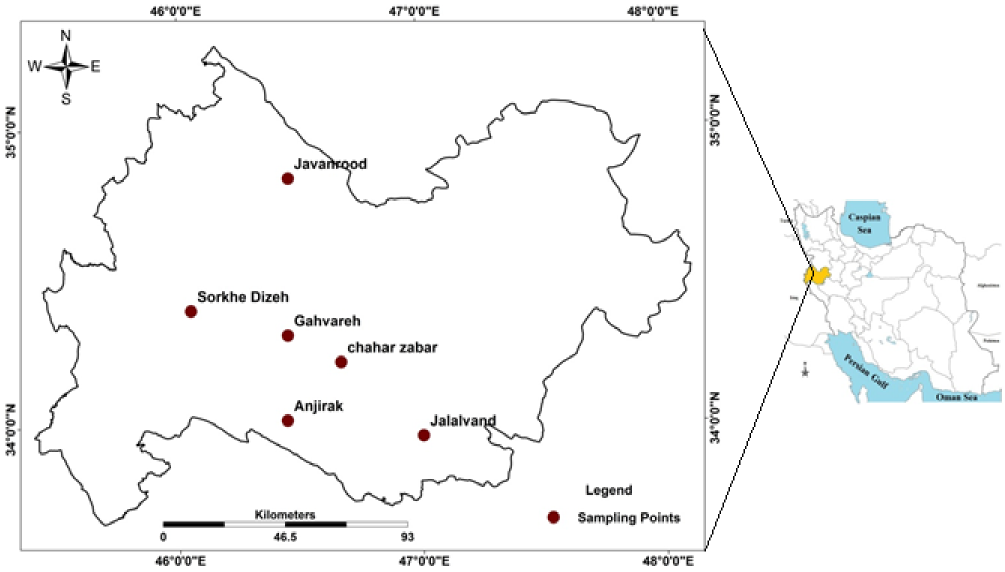

Fig. 1. Locations of the six study regions in Kermanshah Province, western Iran

Table 1. Description, agro-ecological characteristics, and site history of the natural forest and cultivated sites in the six study regions of the Zagros area

Region names	Chahar Zabar	Anjirak	Gahvareh	Sorkhe Dizeh	Jalalvand	Javanrood
Latitude	34°13′	34°01′	34°18′	34°23′	34°50′	33°57′
Longitude	46°40′	46°26′	46°27′	46°03′	46°27′	47°00′
Altitude (m)	1640	1660	1530	1210	1440	1520
Mean temperature (°C)	15	12	12	15	12	14
Annual rainfall (mm)	500	600	850	500	850	500
Climate (Emberger)	cold semi-humid	cold humid	cold humid	cold semi-humid	cold humid	cold semi-humid
Slope gradient (%)	15-18	9-14	9-14	9-14	30-35	15-18
Dominant forest plant coverage	*Quercus brantii*	*Quercus brantii* *Crataegus pontica* *Daphne mucrona*	*Quercus brantii* *Quercus infectoria* *Crataegus pontica*	*Quercus brantii* *Cerasus microcarpa*	*Quercus brantii* *Quercus infectoria* *Cerasus microcarpa*	*Quercus brantii* *Quercus infectoria* *Cerasus microcarpa*
Tillage systems	conventional tillage using moldboard plowing	conventional tillage using moldboard plowing	conventional tillage using moldboard plowing	conventional tillage using moldboard plowing	conventional tillage using moldboard plowing	conventional tillage using moldboard plowing
Cropping systems	wheat-barley	wheat-barley	wheat-barley	wheat-barley	wheat-barley	wheat-barley
Cultivation period	>50 years	>40 years	>40 years	>40 years	>40years	>40 years
Soil texture	silty clay and silty clay loam	silty clay loam	clay loam - loam	silt loam - loam	loam	silt loam

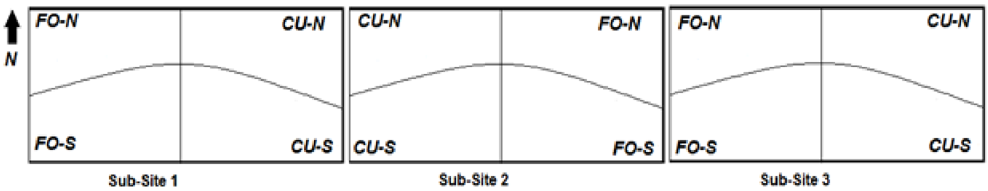

Fig. 2. A schematic design for three sub-sites (pseudo-replications) in each study region

Soil chemical and physical properties including pH in 1:5 soil: water suspension (McLean, 1983), electrical conductivity (EC) in saturated paste (Bottomley et al., 2020), soil organic carbon (Nelson & Sommers, 1983), cation exchange capacity (CEC. Rhoades, 1983), total nitrogen (Bottomley et al., 2020), available P (Olsen, 1954), available K (Knudsen et al., 1983), DTPA extractable Fe, Zn, Mn, and Cu (Lindsay & Norvell, 1978) and calcium carbonate content using the titration method (Nelson, 1983) were determined in soil particle fraction <2 mm.

Soil organic carbon and total nitrogen were determined in a subsample passed through a 0.5 mm mesh (Carter & Gregorich, 2007; Rayment & Lyons, 2010). Particle size distribution analysis was carried out by the hydrometer method (Gee & Or, 2002). The mechanically dispersible clay content was determined in three replications based on the method described by Rengasamy et al. (1984). Modification of the wet-sieving method (Kemper & Rosenau, 1986) was used to measure aggregate stability. In brief, three replications of 8 mm aggregates (50 g) were placed on a set of 6 sieves (i.e., 6.0, 4.0, 2.0, 1.0, 0.5, and 0.25 mm diameter). The set oscillated in distilled water for 15 min, and the resistant aggregates on each sieve were dried at 105 ºC for 24 h, weighted, and corrected for the sand fraction to obtain the proportion of the true aggregates. The results were expressed as a mean weight diameter (MWD). The soil carbon and nitrogen stocks in 0-20 cm layer of soil were determined considering the equivalent soil mass using equations (1) and (2).

Carbon stock (Mg.ha^{-1}) = organic carbon (g.kg^{-1}) × soil bulk density (Mg.m^{-3}) × soil depth (m) × 10 Eq. (1)

N stock (Mg.ha^{-1}) = total N (g.kg^{-1}) × soil bulk density (Mg.m^{-3}) × soil depth (m) × 10 Eq. (2)

Statistical Analyses

The hierarchical design was used to analyze the obtained data. Before statistical analyses, box plots were drawn to detect the outliers in the data. Obtained data were tested for normality with the Shapiro -Wilk test and were assessed for homogeneity of variances with Levene’s test. Two-way ANOVA was performed separately for each area to identify the differences between land-use systems (forest and cultivated areas) and slope aspects (north and south) and their interactions. For those properties that were found significantly different via ANOVA, post hoc mean comparisons were made with Tukey's honestly significant difference at $P < 0.05$. Pearson correlation coefficients were calculated to examine the relations among the variables. All of the above statistical analyses were performed using SAS (version 9.4, SAS Institute Inc., Cary, NC) software.

RESULTS

Impacts of Land-Use Change on Soil Physical Properties

Soil physical properties demonstrated considerable modifications following land-use conversion in the studied areas (Table 2). Soil particle size distribution occurred to be almost similar for both land-use, probably indicating the similarity of soil conditions before the conversion. However, the effect of the slope aspect on particle size distribution was not alike in different areas. Clay percent was significantly higher in the south aspect than in the north aspect in most of the studied regions (Table 2).

The cultivated areas had greater dispersible clay than forest areas in both slope aspects (1.7 to 2.2-fold more on north slopes and 1.4 to 2.3-fold more on south slopes). Also, there were no significant differences between the two slope aspects at each land use (Table 2). Soil bulk density in cultivated areas was significantly ($P<0.05$) higher than forest areas in both slope aspects (12 to 21% more on north slopes and 8 to 20% more on south slopes), while it was unchanged by slope aspect (Table 2).

Land-use changes from forest to arable land resulted in a significant decrease in aggregate soil stability. Forest areas had 1.1 to 2.2-fold and 1.2 to 2.6-fold higher MWD values than cultivated areas on the north and south slopes, respectively (Table 2). Soil bulk density correlated negatively ($P<0.01$) with aggregate stability (r ranging from -0.85 to -0.96) in all regions except for Sorkhe Dizeh. Also, a highly significant and positive correlation ($r \geq 0.82$, $P<0.01$) was between aggregate stability and soil organic carbon content in all studied regions except for the Sorkhe Dizeh area.

Impacts of Land-use Change on Soil Chemical Properties

Land-use changes had a significant impact on most of the soil chemical properties of the studied regions (Table 3). Soil pH values were observed to be higher (3 to 27%, $P<0.05$) in cultivated soils than in forest soils in the studied areas, except for Gahvareh and Chahar Zabar (Table 3). Soil pH was not affected by the slope aspect in the studied areas (Table 3).

Soil EC values were significantly ($P<0.05$) influenced by land-use changes in Chahar Zabar, Gahvareh, and Sorkhe Dizeh regions and by slope aspects in Anjirak, Gahvareh, and Javanrood areas. However, the effects of land-use changes and slope aspects were not similar in those regions. Land-use change from natural forest to agriculture led to soil EC increase in Chahar Zabar but decreased in Gahvareh and Sorkhe Dizeh regions (Table 3).

The amounts of calcium carbonate in cultivated soils were lower than in forest soils ($P<0.05$) in Chahar Zabar and Javanrood in both the north and south aspects. The effect of the slope aspect on this variable was generally insignificant except for the Chahar Zabar forest area (Table 3).

Soil CEC in forest areas, depending on the region and the slope aspect, was 13 to 57% higher than in cultivated areas (Table 3). Soil CEC was decreased following land-use changes in the studied areas, resulting from soil organic carbon decrease, as confirmed by the significant correlation between CEC and soil organic carbon (r ranging from 0.79 to 0.88, $P< 0.01$). Forest soils of Chahar Zabar and Sorkhe Dizeh had higher amounts of CEC on the north than south slope. This higher CEC is probably due to more soil organic carbon and soil organic matter on the north slope. Correlation coefficients between CEC and soil organic carbon were 0.88 and 0.79 at $P<0.01$ for Chahar Zabar and Sorkhe Dizeh, respectively.

Land-use changes significantly affected the soil organic carbon and total N contents in both slope aspects. Higher levels of organic carbon (1.2 to 2.5-fold on the north slope, and 1.2 to 2.2-fold on the south slope) and total N (1.3 to 3-fold on the north slope, and 1.4 to 2.7-fold on the south slope) was measured at forest areas in comparison with cultivated areas (Table 4).

The C/N ratios in both slope aspects were significantly higher in cultivated than forest areas (9 to 29% in north slopes and 13 to 22% in south slopes), with no significant difference between slope aspects, except for Chahar Zabar cultivated land (Table 4). The total C and N stocks decreased significantly in response to the land-use change from forest to cultivated areas (Table 4).

The higher concentration of available P was soil observed in forest soils in both slope aspects (1.4 to 2.4-fold on the north slope, and 1.3 to 2.2-fold on the south slope), with no significant differences between the slope aspects, except for Gahvareh forest area (Table 5). Also, forest soils showed higher available K contents than cultivated soils in both slope aspects (7 to 129 % on the north slope, and 13 to 100% on the south slope). In Javanrood and Jalalvand forest areas, soils on the south slope contained more available K than on the north slope (Table 5).

The concentrations of DTPA- extractable Fe, Zn, and Mn showed a declining trend from forest to cultivated soils, with no significant effect on the slope aspect. In contrast, soil DTPA- extractable Cu was not significantly affected by the cultivation or slope aspect (Table 5). The amounts of available P, available K, and DTPA- extractable Fe, Zn, and Mn in forest soils were higher than in cultivated soils (Table 5).

Table 2. Main physical properties (mean ± SE, n=3) in the surface soil of natural forest sites compared to adjacent cultivated sites in six regions of the Zagros area

Region names	Land use	Slope aspect	Sand (%)	Silt (%)	Clay (%)	Bulk density (Mg.m-3)	Dispersible clay (%)	MWD (mm)
Chahar Zabar	forest	N	17 ± 0.67 (a)	43 ± 0.33 (a)	40 ± 0.60 (b)	1.19 ± 0.02 (b)	16.2 ± 1.6 (b)	2.86 ± 0.14 (a)
		S	15 ± 0.33 (ab)	42 ± 0.80 (a)	42 ± 0.68 (a)	1.15 ± 0.02 (b)	19.1 ± 1.2 (b)	2.91 ± 0.09 (a)
	cultivated	N	17 ± 0.58 (a)	43 ± 0.90 (a)	40 ± 0.67 (b)	1.34 ± 0.02 (a)	30.9 ± 2.2 (a)	2.08 ± 0.09 (b)
		S	14 ± 0.58 (b)	44 ± 0.58 (a)	42 ± 1.00 (a)	1.35 ± 0.03 (a)	26.9 ± 2.6 (a)	2.05 ± 0.11 (b)
Anjirak	forest	N	17 ± 1.00 (c)	49 ± 0.60 (b)	34 ± 0.60 (a)	1.16 ± 0.02 (b)	15.9 ± 1.0 (b)	3.18 ± 0.16 (a)
		S	18 ± 0.59 (ab)	52 ± 0.58 (a)	30 ± 0.60 (b)	1.16 ± 0.02 (b)	13.4 ± 1.0 (b)	2.94 ± 0.12 (a)
	cultivated	N	17 ± 1.16 (b)	50 ± 1.20 (b)	33 ± 0.33 (a)	1.30 ± 0.02 (a)	25.8 ± 3.0 (a)	1.75 ± 0.17 (b)
		S	19 ± 0.33 (a)	52 ± 0.33 (a)	29 ± 0.56 (b)	1.30 ± 0.03 (a)	26.1 ± 1.7 (a)	1.67 ± 0.08 (b)
Gahvareh	forest	N	30 ± 1.20 (a)	43 ± 0.90 (a)	27 ± 0.34 (b)	1.12 ± 0.02 (b)	9.0 ± 1.2 (b)	1.81 ± 0.09 (a)
		S	30 ± 0.88 (a)	39 ± 0.58 (b)	31 ± 0.67 (a)	1.15 ± 0.02 (b)	10.7 ± 0.9 (b)	1.88 ± 0.12 (a)
	cultivated	N	31 ± 0.58 (a)	42 ± 0.88 (a)	27 ± 0.67 (b)	1.35 ± 0.03 (a)	20.2 ± 1.5 (a)	0.96 ± 0.05 (b)
		S	30 ± 0.33 (a)	39 ± 0.33 (b)	31 ± 0.08 (a)	1.35 ± 0.04 (a)	22.2 ± 2.3 (a)	0.98 ± 0.11 (b)
Sorkhe Dizeh	forest	N	24 ± 0.67 (a)	50 ± 1.16 (ab)	26 ± 0.67 (b)	1.22 ± 0.03 (b)	12.6 ± 0.5 (b)	2.16 ± 0.14 (ab)
		S	23 ± 0.88 (a)	48 ± 0.58 (b)	29 ± 0.33 (a)	1.23 ± 0.02 (b)	14.0 ± 1.0 (b)	2.29 ± 0.05 (a)
	cultivated	N	24 ± 1.10 (a)	51 ± 0.34 (a)	25 ± 0.88 (b)	1.37 ± 0.02 (a)	22.8 ± 2.8 (a)	1.90 ± 0.10 (b)
		S	23 ±0.59 (a)	48 ± 0.68 (b)	29 ± 0.40 (a)	1.37 ± 0.03 (a)	22.2 ± 2.2 (a)	1.90 ± 0.08 (b)
Javanrood	forest	N	29 ± 0.67 (b)	48 ± 0.33 (a)	23 ± 0.60 (b)	1.09 ± 0.01 (b)	5.5 ± 0.5 (b)	3.95 ± 0.09 (a)
		S	31 ± 0.34 (a)	44 ± 0.33 (b)	25 ± 0.58 (a)	1.13 ± 0.01 (b)	6.2 ± 0.6 (b)	3.96 ± 0.08 (a)
	cultivated	N	31 ± 0.33 (a)	48 ± 0.60 (a)	21 ± 0.34 (c)	1.25 ± 0.04 (a)	12.3 ± 1.0 (a)	1.86 ± 0.20 (b)
		S	31 ± 0.33 (a)	43 ± 0.80 (b)	25 ± 0.67 (a)	1.22 ± 0.02 (a)	14.3 ± 1.1 (a)	1.96 ± 0.14 (b)
Jalalvand	forest	N	28 ± 0.88 (a)	58 ± 0.60 (b)	14 ± 0.70 (b)	1.28 ± 0.02 (b)	20.3 ± 1.5 (b)	2.46 ± 0.19 (a)
		S	22 ± 0.60 (b)	61 ± 0.34 (a)	17 ± 0.40 (a)	1.25 ± 0.04 (b)	20.0 ± 2.0 (b)	2.39 ± 0.17 (a)
	cultivated	N	29 ± 1.20 (a)	57 ± 0.88 (b)	14 ± 0.40 (b)	1.46 ± 0.03 (a)	33.7 ± 1.9 (a)	1.12 ± 0.14 (b)
		S	21 ± 0.60 (b)	61 ± 0.40 (a)	18 ± 0.90 (a)	1.51 ± 0.02 (a)	36.2 ± 3.8 (a)	0.91 ± 0.09 (b)

Within a column, for each region, mean values with different small letters are significantly different between land uses and slope aspects at $P < 0.05$ (Tukeys test at α= 0.05)
N=North, S=South

Table 3. Main chemical properties (mean ± SE, n=3) in the surface soil of natural forest sites compared to adjacent cultivated sites in six studied regions of the Zagros area

Region names	Land use	Slope aspect	pH	EC (dS.m^{-1})	Calcium carbonate (g.kg^{-1})	CEC (cmol^{c}.kg^{-1})
Chahar Zabar	forest	N	7.73 ± 0.03 (a)	0.32 ± 0.03 (c)	22.5 ± 0.9 (a)	29.4 ± 0.5 (a)
		S	7.67 ± 0.03 (a)	0.37 ± 0.03 (bc)	17.7 ± 0.7 (b)	27.9 ± 0.8 (b)
	cultivated	N	7.63 ± 0.09 (a)	0.51 ± 0.02 (a)	14.0 ± 0.8 (c)	25.0 ± 0.9 (c)
		S	7.70 ± 0.01 (a)	0.45 ± 0.05 (ab)	12.3 ± 0.6 (c)	22.6 ± 0.4 (c)
Anjirak	forest	N	7.50 ± 0.01 (c)	0.38 ± 0.01 (b)	11.8 ± 1.4 (a)	34.3 ± 0.5 (a)
		S	7.57 ± 0.03 (bc)	0.49 ± 0.05 (a)	11.0 ± 0.5 (a)	32.4 ± 0.4 (a)
	cultivated	N	7.67 ± 0.03 (ab)	0.42 ± 0.02 (ab)	12.3 ± 0.8 (a)	29.1 ± 0.9 (b)
		S	7.70 ± 0.06 (a)	0.44 ± 0.04 (ab)	12.5 ± 1.0 (a)	28.6 ± 0.6 (b)
Gahvareh	forest	N	7.97 ± 0.03 (a)	0.53 ± 0.01 (a)	25.2 ± 1.3 (a)	32.3 ± 1.4 (a)
		S	7.93 ± 0.03 (a)	0.52 ± 0.03 (a)	25.8 ± 1.2 (a)	31.2 ± 1.1 (a)
	cultivated	N	7.90 ± 0.06 (a)	0.45 ± 0.04 (a)	23.2 ± 1.3 (a)	24.2 ± 1.1 (b)
		S	7.80 ± 0.10 (a)	0.34 ± 0.04 (b)	24.7 ± 2.4 (a)	27.3 ± 1.0 (b)
Sorkhe Dizeh	forest	N	7.57 ± 0.07 (c)	0.49 ± 0.02 (a)	6.3 ± 0.4 (a)	29.4 ± 0.6 (a)
		S	7.60 ± 0.06 (bc)	0.45 ± 0.09 (ab)	7.3 ± 1.0 (a)	25.7 ± 1.6 (b)
	cultivated	N	7.77 ± 0.03 (a)	0.32 ± 0.03 (bc)	6.7 ± 1.9 (a)	18.7 ± 0.8 (c)
		S	7.73 ± 0.03 (ab)	0.29 ± 0.03 (c)	7.2 ± 0.6 (a)	18.5 ± 0.7 (c)
Javanrood	forest	N	7.47 ± 0.03 (b)	0.27 ± 0.01 (c)	17.3 ± 0.9 (a)	29.4 ± 2.2 (a)
		S	7.43 ± 0.03 (b)	0.44 ± 0.01 (a)	16.8 ± 1.3 (a)	28.2 ± 0.7 (a)
	cultivated	N	7.73 ± 0.03 (a)	0.32 ± 0.02 (b)	10.3 ± 1.8 (b)	22.8 ± 1.1 (b)
		S	7.70 ± 0.01 (a)	0.31 ± 0.01 (bc)	12.2 ± 0.6 (b)	21.0 ± 1.0 (b)
Jalalvand	forest	N	7.80 ± 0.01 (b)	0.39 ± 0.02 (a)	28.5 ± 0.8 (a)	25.7 ± 0.9 (a)
		S	7.87 ± 0.03 (b)	0.44 ± 0.06 (a)	26.0 ± 1.8 (a)	23.6 ± 0.4 (a)
	cultivated	N	8.03 ± 0.03 (a)	0.47 ± 0.03 (a)	28.2 ± 0.6 (a)	19.3 ± 0.5 (b)
		S	8.00 ± 0.01 (a)	0.38 ± 0.02 (a)	26.5 ± 1.2 (a)	20.0 ± 0.8 (b)

Within a column, for each region, mean values with different small letters are significantly different between land uses and slope aspects at $P < 0.05$ (Tukey's test at α= 0.05)
N=North, S=South

Table 4. Soil organic carbon and total nitrogen, their ratio and stocks carbon and nitrogen (mean ± SE, n=3) in the surface soil of natural forest sites compared to adjacent cultivated sites in six studied regions of the Zagros area

Region names	Land use	Slope aspect	SOC (g.kg^{-1})	TN (g.kg^{-1})	C/N	C Stock (Mg C.ha^{-1})	N Stock (Mg N.ha^{-1})
Chahar Zabar	forest	N	26.0 ± 1.5 (a)	2.63 ± 0.20 (a)	9.9 ± 0.3 (c)	61.8± 3.5 (a)	6.3± 0.5 (a)
		S	24.8 ± 1.3 (a)	2.43 ± 0.18 (a)	10.2 ± 0.2 (c)	57.0± 2.3 (a)	5.6± 0.4 (a)
	cultivated	N	16.1 ± 1.1 (b)	1.27 ± 0.09 (b)	12.7 ± 0.2 (a)	43.2± 3.5 (b)	3.4± 0.3 (b)
		S	16.2 ± 1.7 (b)	1.37 ± 0.15 (b)	11.8 ± 0.3 (b)	43.5± 3.6 (b)	3.7± 0.3 (b)
Anjirak	forest	N	30.7 ± 1.1 (a)	2.83 ± 0.07 (a)	10.8 ± 0.2 (b)	71.4± 3.5 (a)	6.6± 0.2 (a)
		S	31.0 ± 0.9 (a)	3.00 ± 0.17 (a)	10.3 ± 0.3 (b)	71.8± 1.4 (a)	7.0± 0.4 (a)
	cultivated	N	14.6 ± 1.7 (b)	1.23 ± 0.15 (b)	11.8 ± 0.2 (a)	38.1± 5.0 (b)	3.2± 0.4 (b)
		S	14.9 ± 1.4 (b)	1.27 ± 0.09 (b)	11.7 ± 0.3 (a)	38.8± 3.9 (b)	3.3± 0.3 (b)
Gahvareh	forest	N	35.9 ± 1.4 (a)	3.67 ± 0.20 (a)	9.8 ± 0.2 (b)	80.4± 2.2 (a)	8.2± 0.4 (a)
		S	30.6 ± 0.7 (b)	3.03 ± 0.03 (b)	10.1 ± 0.2 (b)	70.3± 1.3 (b)	7.0± 0.1 (b)
	cultivated	N	15.5 ± 1.4 (c)	1.20 ± 0.06 (c)	12.9 ± 0.6 (a)	41.8± 3.7 (c)	3.2± 0.1 (c)
		S	13.9 ± 1.2 (c)	1.13 ± 0.09 (c)	12.3 ± 0.4 (a)	37.8± 3.8 (c)	3.1± 0.3 (c)
Sorkhe Dizeh	forest	N	28.8 ± 0.8 (a)	2.97 ± 0.09 (a)	9.8 ± 0.6 (ab)	70.3± 4.0 (a)	7.2± 0.1 (a)
		S	28.4 ± 1.6 (a)	3.00 ± 0.15 (a)	9.5 ± 0.5 (b)	69.6± 2.7 (a)	7.4± 0.3 (a)
	cultivated	N	24.3 ± 1.9 (ab)	2.23 ± 0.15 (b)	10.9 ± 0.4 (ab)	66.4± 4.5 (a)	6.1± 0.3 (b)
		S	22.8 ± 1.5 (b)	2.07 ± 0.12 (b)	11.0 ± 0.3 (a)	62.3± 2.8 (a)	5.6± 0.2 (b)
Javanrood	forest	N	47.4 ± 0.6 (a)	4.57 ± 0.15 (a)	10.4 ± 0.2 (b)	103.0± 0.9 (a)	9.9± 0.3 (a)
		S	41.9 ± 1.2 (b)	4.13 ± 0.09 (b)	10.1 ± 0.4 (b)	94.3± 2.1 (b)	9.3± 0.1 (a)
	cultivated	N	19.1± 1.3 (c)	1.67 ± 0.09 (c)	11.4 ± 0.2 (a)	47.8± 3.3 (c)	4.2± 0.2 (b)
		S	20.2 ± 0.8 (c)	1.67 ± 0.03 (c)	12.1 ± 0.3 (a)	49.3± 2.9 (c)	4.1± 0.1 (b)
Jalalvand	forest	N	18.3 ± 0.7 (a)	1.83 ± 0.09 (a)	10.0 ± 0.2 (b)	46.9± 2.0 (a)	4.7± 0.3 (a)
		S	16.7 ± 0.6 (a)	1.67 ± 0.07 (a)	10.0 ± 0.2 (b)	41.8± 0.8 (b)	4.2± 0.2 (a)
	cultivated	N	10.4 ± 0.6 (b)	0.84 ± 0.03 (b)	12.3 ± 0.3 (a)	30.2± 1.2 (c)	2.4± 0.1 (b)
		S	9.2 ± 0.6 (b)	0.76 ± 0.04 (b)	12.1 ± 0.4 (a)	27.7± 1.5 (c)	2.3± 0.1 (b)

Within a column, for each region, mean values with different small letters are significantly different between land uses and slope aspects at $P < 0.05$ (Tukey's test at α= 0.05)
N=North, S=South
SOC= Soil organic carbon, TN= Total nitrogen

Table 5. Selected macro and micronutrients (mean ± SE, n=3) in the surface soil of natural forest sites compared to adjacent cultivated sites in six studied regions of the Zagros area

Region names	Land use	Slope aspect	available P ($mg.kg^{-1}$)	available K ($mg.kg^{-1}$)	Fe ($mg.kg^{-1}$)	Zn ($mg.kg^{-1}$)	Mn ($mg.kg^{-1}$)
Chahar Zabar	forest	N	30.8 ± 1.4 (a)	553 ± 41(ab)	12.0 ± 0.4 (a)	1.0 ± 0.04 (a)	13.4 ± 1.3 (a)
		S	28.6 ± 1.0 (a)	610 ± 26 (a)	11.5 ± 0.4 (a)	0.9 ± 0.14 (ab)	13.3 ± 0.8 (a)
	cultivated	N	19.7 ± 1.7 (b)	483 ± 20 (b)	7.9 ± 0.4 (b)	0.7 ± 0.07 (bc)	12.6 ± 0.9 (a)
		S	17.5 ± 0.8 (b)	537 ± 37 (ab)	7.8 ± 0.7 (b)	0.6 ± 0.06 (c)	12.1 ± 0.7 (a)
Anjirak	forest	N	25.6 ± 1.0 (a)	663 ± 38 (a)	12.7 ± 0.6 (a)	0.9 ± 0.04 (a)	16.3 ± 0.8 (a)
		S	23.9 ± 1.4 (a)	737 ± 46 (a)	12.7 ± 1.1 (a)	0.9 ± 0.13 (a)	14.8 ± 1.6 (a)
	cultivated	N	16.5 ± 1.7 (b)	467 ± 21 (b)	11.4 ± 0.3 (a)	0.6 ± 0.04 (a)	12.5 ± 1.0 (ab)
		S	16.7 ± 2.1 (b)	483 ± 27 (b)	11.2 ± 0.6 (a)	0.7 ± 0.09 (a)	11.9 ± 0.9 (b)
Gahvareh	forest	N	33.8 ± 2.1 (a)	543 ± 18 (a)	9.8 ± 0.4 (a)	0.9 ± 0.08 (a)	9.7 ± 0.8 (ab)
		S	28.4 ± 1.3 (b)	560 ± 26 (a)	9.7 ± 0.5 (a)	0.8 ± 0.11 (a)	10.0 ± 1.1 (a)
	cultivated	N	14.1 ± 1.2 (c)	303 ± 44 (b)	8.1 ± 0.3 (b)	0.5 ± 0.06 (b)	7.5 ± 0.4 (bc)
		S	12.8 ± 0.7 (c)	280 ± 41 (b)	8.6 ± 0.6 (ab)	0.5 ± 0.09 (b)	7.1 ± 0.5 (c)
Sorkhe Dizeh	forest	N	26.5 ± 1.4 (a)	787 ± 48 (a)	9.0 ± 0.2 (a)	0.8 ± 0.08 (a)	14.3 ± 1.1 (a)
		S	27.6 ± 1.5 (a)	723 ± 34 (a)	8.9 ± 0.3 (a)	0.8 ± 0.09 (a)	13.7 ± 0.1 (a)
	cultivated	N	18.7 ± 1.1 (b)	343 ± 31 (b)	7.5 ± 0.2 (b)	0.6 ± 0.06 (ab)	10.0 ± 0.4 (b)
		S	18.1 ± 0.8 (b)	370 ± 26 (b)	7.0 ± 0.4 (b)	0.5 ± 0.07 (b)	8.6 ± 0.4 (b)
Javanrood	forest	N	33.5 ± 1.6 (a)	470 ± 17 (b)	15.5 ± 0.3 (a)	1.3 ± 0.07 (a)	17.3 ± 0.6 (a)
		S	29.8 ± 2.1 (a)	573 ± 18 (a)	16.2 ± 0.2 (a)	1.2 ± 0.12 (a)	16.9 ± 0.3 (a)
	cultivated	N	16.5 ± 1.0 (b)	437 ± 26 (bc)	11.5 ± 0.5 (b)	1.0 ± 0.06 (b)	11.9 ± 0.7 (b)
		S	18.3 ± 0.4 (b)	373 ± 23 (c)	10.8 ± 0.5 (b)	1.0 ± 0.07 (b)	13.2 ± 0.7 (b)
Jalalvand	forest	N	20.4 ± 0.7 (a)	570 ± 20 (b)	7.1 ± 0.4 (a)	0.5 ± 0.04 (a)	8.4 ± 1.1 (a)
		S	20.1 ± 1.2 (a)	693 ± 35 (a)	6.3 ± 0.2 (ab)	0.5 ± 0.07 (a)	7.6 ± 0.8 (ab)
	cultivated	N	12.8 ± 1.1 (b)	337 ± 21 (c)	5.3 ± 0.2 (bc)	0.4 ± 0.05 (a)	5.4 ± 0.7 (bc)
		S	15.1 ± 1.1 (b)	427 ± 35 (c)	5.0 ± 0.4 (c)	0.4 ± 0.04 (a)	4.7 ± 0.6 (c)

Within a column, for each region, mean values with different small letters are significantly different between land uses and slope aspects at $P < 0.05$ (Tukey's test at $\alpha = 0.05$).
N=North, S=South

DISCUSSION

Soil Physical Properties

In this study, it was shown that particle size distribution was alike for both land-use, which indicated similar conditions before the conversion. The higher dispersible clay in cultivated soils is probably due to tillage and management practices, soil nature, and vegetation. Golchin and Asgari (2008) reported the tilled soils presented 41 to 89% more dispersible clay than the uncultivated soils (forest and grassland). It seems that declining soil organic matter content in cultivated soils increases clay dispersibility in these regions (R ranging from -0.60 to -0.94, *P*<0.01). It has been reported that physically breaking the aggregates decrease soil organic matter percentage with the degradation of soil carbon to CO_2 (Balesdent et al., 2000; Plante & McGill, 2002; Šimanský et al., 2013; Wong et al., 2010).

Dispersible clay was also significantly and negatively correlated with MWD at all studied regions (R ranging from -0.84 to -0.93, *P*<0.01) except for the Sorkhe Dizeh area. The lower aggregate stability (12 to 62%) in cultivated soils relative to forest soils may result from soil macro-aggregate disruption by tillage and plowing. Beheshti et al. (2012); Golchin and Asgari (2008); Islam and Weil (2000); Khormali et al. (2009); Zhu et al. (2018); Liu et al. (2019) reported similar results on aggregate stability changes following land-use conversion. It has been reported that the aggregate stability decreased by 11-81% in cultivated soils compared with natural forests in the north of Iran (Beheshti et al., 2012). It is believed that soil structure declines following natural soil conversion due to soil organic carbon decrease and aggregates breakdown (Beheshti et al., 2012; Emadi et al., 2009; Khormali et al., 2009). Previous studies have indicated that soil organic matter and aggregate stability are interrelated variables (Beheshti et al., 2012; Golchin & Asgari, 2008).

The aforementioned findings confirm that a decrease in soil organic matter following natural to cultivated soil conversion would result in the aggregate stability declining, consequently, clay dispersion increasing. Mills and Fey (2004) indicated that a decrease in soil organic carbon is accompanied by an increase in clay dispersibility and a reduction in aggregate stability.

Dispersible clay did not correlate with MWD in the Sorkhe Dizeh area. The lower aggregate stability could not adequately explain the high proportion of dispersible clay (83% on average for both slope aspects in Sorkhe Dizeh). In Addition to soil organic carbon decrease, other factors may have led to the enhancement of dispersible clay in cultivated fields (Guo et al., 2020; Zhu et al., 2021).

High organic matter in the surface horizons of the soils leads to low bulk density. Organic matter causes the aggregation of particles, resistance to deformation, and increases the degree of elasticity under compression (Soane, 1990). Soil structure and texture are affected by tillage and management practices. Therefore, it can change bulk density, especially in soils with low organic matter components (Ayoubi et al., 2020; Bulmer, 1998; Duan et al., 2021).

Soil Chemical Properties

Soil pH was higher (3 to 27%, *P*<0.05) in cultivated soils, but it was not affected by the slope aspect in the studied areas. Because of the long-term application of inorganic fertilizers (in particular urea) to agricultural soils, soil pH in cultivated is higher than in forest soils in the studied areas. Urea application may increase soil pH through its hydrolysis and ammonium ion production. However, the ammonium may convert to nitrate by nitrification or be taken up by crops. It will raise soil pH if it remains in the soil (Beheshti et al., 2012). Furthermore, soil organic carbon losses following the land-use change from forest to agricultural lands can play an essential role in pH increase (Biro et al., 2013). Previous studies have reported that soil pH increases when natural soils are converted to cropland (Biro et al., 2013; Celik, 2005; Khormali et al., 2009).

Following a long summer in the absence of precipitation and under the conditions of considerable evaporation, untouched soils are expected to have higher amounts of soluble salts and EC than cultivated soils. The natural porosity system in untouched soils helps groundwater rise in the evaporation process (Xin et al., 2017). But, this trend was not observed in the Chahar Zabar area.

More significant EC in the south slope than the north slope aspect of Anjirak and Javanrood forest soils could be related to a higher evaporation rate on the south slope. In the northern hemisphere, south slopes receive more radiation and energy from the sun generally, and consequently, their evaporation rate could be higher than on north slopes in natural conditions. Conversely, in the cultivated soils of Gahvareh, the north slope showed a higher EC amount than the south slope. This finding may be due to soil disturbance (by plowing or livestock grazing) and fertilizer application which both can alter the natural status.

The reduced calcium carbonate contents in the cultivated soils of Chahar Zabar and Javanrood could have resulted from plant root system changes from deep (forest species) to surface (crops) patterns. Also, more intensive agricultural practices in these areas are associated with more CO_2 production and probably the downward movement of bicarbonate and its accumulation in the lower layers as secondary carbonates. A significant negative correlation was observed between carbonate contents and pH value (r=-0.83; *P*<0.01) only at the Javanrood area, probably suggesting that at Javanrood cultivated soils, the repeated applications of urea were responsible for pH increase as discussed by Taalab et al. (2019) and Valencia-Galindo et al. (2021). Soil CEC was decreased following land-use changes at the studied areas. Similar results have been reported in previous investigations (Beheshti et al., 2012; Khormali et al., 2006; Khormali et al., 2009).

The differences in soil organic carbon and total N between the two slope aspects were significant only in Gahvareh and Javanrood forest areas, where soils on the north slope contained more soil organic carbon and total N than those on the south slope. Bayat et al. (2017) reported a lower level of organic matter in soils on the southern than northern slope.

Previous studies have concluded that natural soil conversion to cultivated lands led to soil organic carbon and total nitrogen contents decrease (Biro et al., 2013; Don et al., 2011; Martens et al., 2004; Pabst et al., 2013). According to Magdoff and Weil (2004), soil organic matter is affected by tillage and planting crops, managing crop residue, crop rotations, and practicing soil conservation. Pabst et al. (2013) reported that investigated semi-natural ecosystems of their study had, on average 4-fold higher soil organic carbon in the 0-10 cm soil layer than their respective agroecosystems. Important factors such as fewer returns of organic residues to soil and lower physical protection of soil organic carbon due to degradation of aggregate by tillage practices lead to a decrease in soil organic carbon in cultivated areas (Islam & Weil, 2000; Martens et al., 2004). It has been reported that organic matter inputs to croplands probably possess a higher quality and consequently higher decomposition rate because of lower contents of lignin and other plant secondary compounds in comparison with residues of woody plant species (Solomon et al. 2000; and Martens et al. 2004). Beheshti et al. (2012) showed that native soil carbon and nitrogen stocks losses, due to tillage practices and cultivation that have been 36 to 66% and 29 to 64% (depending on the study area), respectively.

The enhancement of the carbon oxidation process and fresh organic matter mineralization, and the application of nitrogen fertilizers usually result in a C/N ratio decrease following forest conversion to croplands (Shang et al., 2015). This result may be due to the sampling time (September to October) that was simultaneous with the end of the growing season and high amounts of crop residues return to the cultivated soils of the studied areas. A significant difference between slope aspects in Chahar Zabar cultivated land was observed due to the higher soil moisture on the north slope and probably higher yield, higher crop residues, and consequently higher C/N ratio. The maximum losses of about 54% for carbon stock and about 61% for nitrogen stock in cultivated soils relative to the forest soils occurred in Javanrood and Gahvareh regions, respectively, on the north slope. This may be attributed to different conditions of the studied regions, including annual rainfall, initial soil status (organic matter content), the time passed after the land-use change and the kind of cropping and tillage systems.

The higher amounts of available P, available K, and DTPA- extractable Fe, Zn, and Mn in forest soils relative to the cultivated soils could be resulted from nutrient uptake by crops without their replacement by adequate fertilizers' application in the long term. Farmers usually do not apply sufficient amounts of fertilizers (in particular P, K, and micro-nutrients) in these dryland farming converted fields. Significant differences between the slope aspects were observed in Gahvareh forest soil, with more available P in the north than on the south slope, similar to the soil organic carbon pattern in this area. There was a close positive correlation between available P and soil organic carbon (r= 0.95, $P < 0.01$) in Gahvareh.

In Javanrood and Jalalvand areas, forest soils contained a higher amount of available K on the south slope than on the north slope, probably due to the greater rate of clay minerals weathering on the south slope. The soil temperature is usually higher on the south slope, and weathering can release more available K in the soil. On the other hand, plant uptake on the north slope is high, because soil moisture is more. As a result, the concentration of K on the north slope is low. Unlike P, which usually enters the soil via organic matter, K is most usually exists in the soil in inorganic materials, and K released in the soil through mineral weathering of parent material (Nair,, 2002).

CONCLUSIONS

The findings of the current study showed that, in both slope aspects (north and south), soil organic carbon and total N stocks decline, following the land-use change from forests to a farming system. Soil depletion of organic carbon resulting from the land-use change had a significant impact on the other soil properties, mainly negatively, in terms of soil quality. The adverse effects of the land-use change were observed in particular in Gahvareh and Javanrood areas with more annual rainfall. The land slope aspect resulted in higher soil organic carbon, total N, CEC, C/N ratio, and available P, and lower available K on northern than southern slopes, in some studied areas. In general, it seems that in the studied regions, conversion from forests to agricultural lands and farming operations can reduce soil quality. However, the north and south slope aspects were almost similar in terms of degradation severity.

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مقاله علمی- پژوهشی

تأثیر طولانی‌مدت تغییر کاربری اراضی از جنگل به زمین زراعی در جهت‌های مختلف شیب بر ویژگی‌های شیمیایی و فیزیولوژیکی خاک

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واژه‌های کلیدی:

جنگل
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زمین زراعی
سیستم‌های خاک‌ورزی
کیفیت خاک

چکیده – تغییر کاربری زمین از جنگل به زمین‌های زراعی ممکن است بر فرآیندها، خواص و عملکرد خاک تأثیر بسزایی داشته باشد. این تحقیق به‌منظور بررسی تأثیر تغییر کاربری طولانی‌مدت از جنگل‌های بکر به زمین‌های زراعی در شیب‌های شمالی و جنوبی بر ویژگی‌های فیزیکی و شیمیایی خاک انجام شد. شش منطقه از ناحیه زاگرس در غرب ایران که روند رشد جنگل به اراضی کشاورزی در دهه‌های اخیر در آن‌ها رخ داده است، برای این مطالعه انتخاب شدند. نمونه‌های مرکب خاک از عمق صفر تا ۲۰ سانتی‌متری در دامنه‌های شمالی و جنوبی جنگل‌های بومی و مناطق زیر کشت مرتبط با آن‌ها جمع‌آوری شدند. بیشترین مقدار رس قابل انتشار و چگالی ظاهری خاک و کمترین پایداری خاکدانه در زمین‌های کشاورزی مشاهده شد. کربن آلی خاک، نیتروژن کل و ذخایر کربن و نیتروژن کل در پاسخ به تغییر کاربری زمین از جنگل به زمین کشاورزی در تمام مناطق مورد مطالعه کاهش یافت. مقادیر بالاتر کربن آلی خاک، نیتروژن کل، نسبتC/N و فسفر قابل دسترس در دامنه‌های شمالی در مقایسه با دامنه‌های جنوبی در برخی از مناطق مورد مطالعه مشاهده شد. به‌طورکلی، تبدیل جنگل‌های طبیعی به سیستم‌های کشت کشاورزی منجر به کاهش کیفیت خاک شد. با این حال، شدت زوال در جهت های شیب شمالی و جنوبی تقریباً مشابه بود.