Impacts of oak deforestation and rainfed cultivation on soil redistribution processes across hillslopes using ^{137}Cs techniques

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Abstract

Background: As one of the main components of land-use change, deforestation is considered the greatest threat to global environmental diversity with possible irreversible environmental consequences. Specifically, one example could be the impacts of land-use changes from oak forests into agricultural ecosystems, which may have detrimental impacts on soil mobilization across hillslopes. However, to date, scarce studies are assessing these impacts at different slope positions and soil depths, shedding light on key geomorphological processes.

Methods: In this research, the Caesium-137 (^{137}Cs) technique was applied to evaluate soil redistribution and soil erosion rates due to the effects of these above-mentioned land-use changes. To achieve this goal, we select a representative area in the Lordegan district, central Iran. ^{137}Cs depth distribution profiles were established in four different hillslope positions after converting natural oak forests to rainfed farming. In each hillslope, soil samples from three depths (0–10, 10–20, and 20–50 cm) and in four different slope positions (summit, shoulder, backslope, and footslope) were taken in three transects of about 20 m away from each other. The activity of ^{137}Cs was determined in all the soil samples (72 soil samples) by a gamma spectrometer. In addition, some physicochemical properties and the magnetic susceptibility (MS) of soil samples were measured.

Results: Erosion rates reached 51.1 t·ha^{-1}·yr^{-1} in rainfed farming, whereas in the natural forest, the erosion rate was 9.3 t·ha^{-1}·yr^{-1}. Magnetic susceptibility was considerably lower in the cultivated land ($\chi_{hf} = 43.5 \times 10^{-8}$ m^3·kg^{-1}) than in the natural forest ($\chi_{hf} = 55.1 \times 10^{-8}$ m^3·kg^{-1}). The lower soil erosion rate in the natural forest land indicated significantly higher MS in all landform positions except at the summit one, compared to that in the rainfed farming land. The shoulder and summit positions were the most erodible hillslope positions in the natural forest and rainfed farming, respectively.

Conclusions: We concluded that land-use change and hillslope positions played a key role in eroding the surface soils in this area. Moreover, land management can influence soil erosion intensity and may both mitigate and amplify soil loss.

Keywords: Land-use change, Soil redistribution, Topographical changes, Radionuclide, Rainfed farming, Deforestation

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Introduction

As one of the main components of land-use change, deforestation is considered the greatest threat to humankind because it can affect global environmental diversity (Akter et al. 2018; Al Sayah et al. 2019). To date, forests still cover about 30% of the world's surface area, but they disappear at an alarming rate (Curtis et al. 2018). Since humans started cutting down forests, recent studies estimated that 46% of trees had been felled (Ehrenberg 2015). Nowadays, there are 14.38 million hectares of forest in Iran, covering 7.8% of the country's total area, reaching the Zagros forests with 1.5 million hectares the 2% of Iran's forests (FRWO 2018). However, Zagros forests are suffering deforestation and burnt dramatically, and land-use changes to cultivated and urban areas are increasing (Mojiri et al. 2012; Kelishadi et al. 2014; Alidoust et al. 2018).

Such land-use change can influence multiple parameters that control the hydrological and geomorphological transport processes such as soil infiltration capacity, soil erodibility, surface roughness, and the local capacity to store water and sediment (Hill et al. 2008; Bajocco et al. 2012; Kavian et al. 2017; Taghizadeh-Mehrjardi et al. 2019). Land-use changes are a worldwide issue that commonly leads to land degradation, mainly modifying some soil quality parameters (Nabiollahi et al. 2020; Zeraatpisheh et al. 2020). Moreover, land-use change has a significant contribution to greenhouse gas emissions, and it was accounted for 12.5% of carbon emissions from 1990 to 2010 (Houghton et al. 2012) and one-third of total anthropogenic carbon discharges over the last 150 years (Quesada et al. 2018).

Soils, among other Earth's spheres, are highly affected, and increasing awareness by stakeholders, rural inhabitants, and policymakers is vital to reduce negative and irreversible impacts (Rodrigo-Comino et al. 2020a). In the context of global climate change and environmental degradation, protecting soils as a non-renewable resource must be a worldwide concern (Celik 2005; Lal 2015; Orgiazzi et al. 2018). Human activities have been the primary drivers of environmental change over recent years by transforming natural ecosystems into agricultural landscapes (Chauchard et al. 2007). Due to agricultural deforestation, the conversion of rangeland into croplands is a local and global environmental concern (Foley et al. 2005), resulting in altered soil properties and soil penetration rates and changed soil physical characteristics that ultimately increase soil erosion (Li et al. 2007; Nabiollahi et al. 2020; Zeraatpisheh et al. 2020).

Soil erosion research offers an opportunity to study the effect of land-use changes on degradation processes (Jordan et al. 2005; Szilassi et al. 2006; Ayoubi et al. 2018). Soil erosion is a major environmental issue after drastically land-use changes, especially after deforestation on hilly lands or abandonment. In qualitative terms, soil erosion is a multifactorial phenomenon driven by several key variables such as climate, soil properties, topography, and land management (Kosmas et al. 1995; Novara et al. 2015; Taghizadeh-Mehrjardi et al. 2019; Rodrigo-Comino et al. 2020b). The degree of human impact on each of these factors varies significantly depending on the major role of each one. Therefore, it is vital to use methods and perform studies able to detect and assess the intensity of each environmental factor.

One of the artificial radio-isotope used as a tracer to analyze soil redistribution trends and measure soil degradation rates is Caesium-137 (^{137}Cs). ^{137}Cs is a by-product of nuclear weapons tests that took place in the 1950s and 60s. This radio-isotope enters the earth's surface from the atmosphere through wet and dry deposition (mostly by wet deposition (i.e., precipitation)) (Elliott et al., 1990). The specific characteristic of ^{137}Cs that only adsorbed by soil particles, physically migrate with soil particles, and are rarely carried by rainwater or taken up by plants generated an appropriate potential for this radio-isotope to use soil loss process measurements (Hu and Zhang 2019). The successful use of ^{137}Cs to document rates of soil loss has now been for a wide variety of environments (Walling and Quine 1991; Ritchie and Ritchie 2007; Sac et al. 2008; Abbaszadeh Afshar et al. 2010; Ayoubi et al. 2012a; Nosrati et al. 2015; Meliho et al. 2019). However, the use of the ^{137}Cs to monitor soil erosion and investigate the effects of land-use changes on of ^{137}Cs is relatively mature (Hu and Zhang 2019).

Several decades of severe rainfed agriculture in the Zagros Mountains in Iran and afterward land abandonment have dramatically changed land-use and land cover (Naghipour et al. 2016; Saedi et al. 2016; Zebari et al. 2019). Over recent decades, the natural forest land conversion into agricultural lands has increased the surfaces prone to erosion. The difficulties that the land conversions have created are exclusively significant in mountainous areas and regions with unfavorable environmental conditions (MacDonald et al. 2000). In the Zagros Mountains, for example, where the natural forest lands have been gradually cleared and converted to rainfed agriculture (Ayoubi et al. 2012b). These disturbances result in losses of soil nutrients and diminished long-term fertility of the soil (Bakhshandeh et al. 2019; Ajami et al. 2020). It seems inappropriate land-use change; improper cultivation activities are significant factors in severe soil erosion in the Zagros forests for a long time. However, studies conducted assessing these issues are scarce to date. Therefore, the main goals of the current study are to (i) evaluate the influences of land-use change on soil physical, chemical, and magnetic attributes and (ii) determine the impacts of land-use

change on soil redistribution and erosion by using the ^{137}Cs technique at different hillslope positions. To achieve these goals, we selected a representative area located in the Lordegan district of Cheharmahal and Bakhtiari Province, western Iran. Therefore, the findings of this research could shed light on new advances related to the knowledge about soil erosion and the negative impacts of land-use changes, especially from oak forests to rainfed farming.

Materials and methods

Study site and sampling area

The studied area is located in the Lordegan region of Cheharmahal and Bakhtiari Province, west of Iran, at 51°48′ E longitudes and 31°37′ N latitudes (Fig. 1). The average annual precipitation and temperature of the region are 572 mm and 15.5 °C, respectively (Chaharmahal and Bakhtiari Meteorological Administration 2019). The study area has Xeric soil moisture and Thermic temperature regimes (Soil Survey Staff 2010). The

average elevation of the studied area is 1700 m a.s.l. The vegetation of the area is generally oak forests (*Quercus brantii* and *Quercus infectoria*), and species such as *Astragalus* sp. and *Mucronata* sp. covered the region.

Two paired-hillslopes were selected with similar elevation and slope gradients but with different land-uses, a natural oak forest and rainfed farming. In each land-use type, soil cores were collected from a plot with dimensions of 20 m × 20 m. The soil was sampled at different depths (0–10, 10–20, and 20–50 cm) in four different topographical positions, including the summit, shoulder, backslope, and footslope in three transects 20 m away from each other in selected hillslopes. The reference soil samples were collected from an adjacent site (less than 1000 m away), the summit position of an oak forest land with relatively high soil development features and a stable state with minimum human disturbance in recent decades. Additionally, two reference soil profiles were also excavated, and soil samples were taken at several depths (0–10, 10–20, 20–30, and 30–50 cm). Then, at
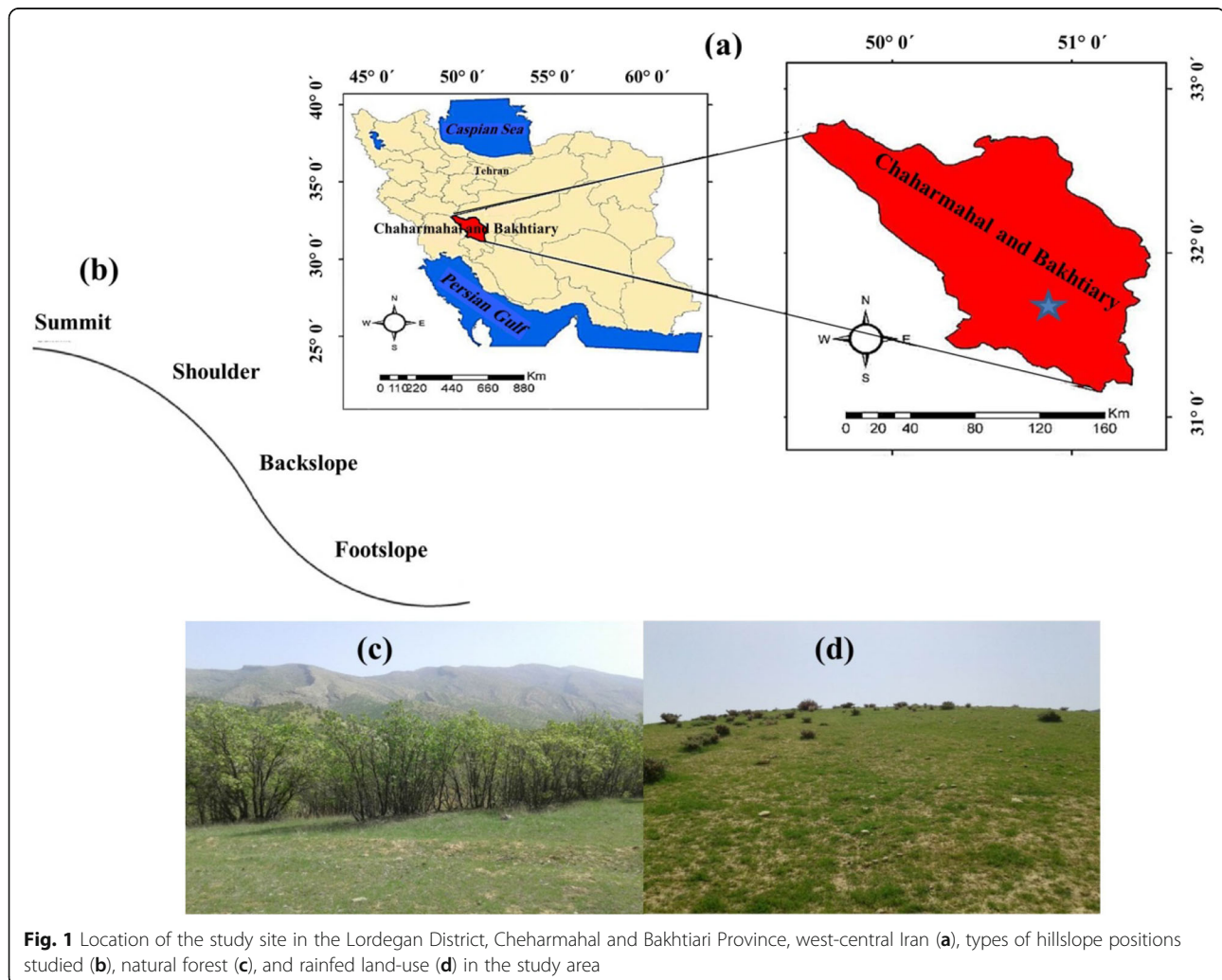

Fig. 1 Location of the study site in the Lordegan District, Cheharmahal and Bakhtiari Province, west-central Iran (**a**), types of hillslope positions studied (**b**), natural forest (**c**), and rainfed land-use (**d**) in the study area

the reference location, the vertical distribution of ^{137}Cs was determined.

Laboratory analysis and ^{137}Cs measurements

Before the laboratory analysis, the air-dried soil samples were crushed, homogenized, and passed through a 2-mm sieve. From June to July 2018, a total of 72 soil samples (two land-use types × three replicates per sample plots × three soil depth classes × four hillslope positions) were collected within the studied area. In 2018, at the Isfahan University of Iran, soil samples (500 g) were placed in Marinelli beakers and sealed for ^{137}Cs analysis. The ^{137}Cs activity (Bq·kg^{-1}) was measured from the net area under the full-energy peak at 662 keV (ISO 11929-1, 2000) using gamma spectroscopy with a high-resolution germanium detector. The reference material No. IAEA-375 obtained from Analytical Quality Control Services, International Atomic Energy Agency, was used for quality control. The count time was approximately 80,000 s, and the counting error was kept at < 10% and at the 95% confidence level. The ^{137}Cs activities (Bq·kg^{-1}) were converted to area activities (Bq·m^{-2}) (Walling et al. 2002).

The core method (Blake and Hartge 1986) and wet combustion method (Nelson and Sommers 1996) were used to determine soil bulk density and soil organic matter (SOM) concentration, respectively. The Kjeldahl digestion method was used to determine the total nitrogen (TN) (Bremmer and Mulvaney 1982). Electrical conductivity (EC) was determined in the extract using a conductivity meter (Rhoades 1982). Extractable potassium (K_{ava}) was measured using 1 mol·L^{-1} ammonium acetate as the extractant (Richards 1954). The pipette method (Gee and Bauder 1986) was applied to measure soil particle size distributions. Bernard's calcimeter method was used to measure calcium carbonate equivalent (CCE) content (Black et al. 1965). By using a Bartington MS2 dual-frequency sensor at low frequency (χ_{lf}) (0.47 kHz), high frequency (χ_{hf}) (4.7 kHz), dependent frequency (χ_{fd}), and the magnetic susceptibility (MS) were measured in a four-dram clear plastic vial (2.3 cm diameter) using approximately 10 g of soil.

Soil redistribution calculation

Several different techniques have been applied to convert ^{137}Cs measurements to quantitative estimates of soil erosion and deposition rates (Walling and He 1999; Walling and He 2000). By using the Simplified Mass Balance Model (SMBM), we decide to use the conversion of ^{137}Cs areal activities into soil redistribution rates (t·ha^{-1}·yr^{-1}) (Walling and He 1999; Walling et al. 2002; Zhang et al. 2008).

Statistical analyses

Descriptive and correlations among the variables were determined. The mean values of the ^{137}Cs, soil physicochemical properties, magnetic measures of two land-uses, and four hillslope positions were calculated. All statistical analyses, including the LSD test (test of significance of differences among the mean values) and correlation analyses, were performed using SPSS 17.0 (IBM, USA) software. Dexter et al. (2008) proposed several equations (Eqs. 1–4) to calculate complexed and non-complexed organic carbon (OC) and clay. Then, the additional amount of complexed OC, which could be stored in the soil, was estimated using Eq. 5:

$$CC = (nOC) \text{ if } (nOC < clay), \text{ else } CC = clay \qquad (1)$$

$$NCC = (clay - CC) \text{ if } (clay - CC) > 0, \text{ else } NCC = 0 \qquad (2)$$

$$COC = OC \text{ if } OC < (clay/n), \text{ else } COC = (clay/n) \qquad (3)$$

$$NCOC = OC - COC \text{ if } (OC - COC) > 0, \text{ else } NCOC = 0 \qquad (4)$$

$$PAOC = (CMAX - COC) \text{ if } (CMAX - COC) > 0, \text{ else } PAOC = 0 \qquad (5)$$

where CC and NCC are complexed and non-complexed clays (g·kg^{-1}), COC and NCOC represent complexed and non-complexed organic carbons (g·kg^{-1}), respectively, and n means the ratio of clay to OC, where clay is assumed to be saturated with OC, which is considered equal to 10 (Dexter et al. 2008). Therefore, saturation line was defined by COC = Clay/n (i.e., $n = 10$). PAOC (g·kg^{-1}) is the potential additional complexed OC which indicates the potential capacity for sequestering carbon, and CMAX (g·kg^{-1}) is the maximum possible amount of complexed OC according to clay/n ($n = 10$) (Dexter et al. 2008).

Results and discussion

Specific results per land-use and hillslope position

Table 1 presents the descriptive statistics of ^{137}Cs measurements, physicochemical parameters, and soil magnetic parameters in the studied two land-uses. In the natural forest and the rainfed farming, the coefficient of variation (CV) of the ^{137}Cs contents was 35.7% and 30.8%, respectively. Abbaszadeh et al. (2010) and Ayoubi et al. (2012a) reported a CV value of 50.0% and 103.9% for the ^{137}Cs inventory under rainfed farming and the hilly regions in western Iran, respectively. Consistent with Wilding (1985) for CV classification, ^{137}Cs, TN, and clay in the natural oak forest and SOM, P_{ava}, and clay in the rainfed farming land-uses were classified as

Table 1 Descriptive statistics for ^{137}Cs, soil physicochemical properties, and magnetic parameters in the different land-uses (N = 72)

Land-use	Variables	Unit	Mean	Min	Max	SD	CV	Skewness	Kurtosis
Oak forest	^{137}CS	Bq·m^{-2}	516.5	140.8	1399.2	310.6	35.7	1.2	1.7
	SOM	%	1.7	0.6	3.2	0.6	32.1	0.7	0.6
	CCE	%	37.9	11	68.5	12.3	22.8	0.2	0.05
	TN	%	0.1	0.2	0.6	0.1	131.9	4	16.8
	P_{ava}	mg·kg^{-1}	63.1	39	124	20	32	1	1
	K_{ava}	mg·kg^{-1}	230.3	101.6	381	74.5	23	0.1	−0.7
	EC	dS·m^{-1}	169	136	255.5	25.4	13.3	1.4	2.5
	pH	–	7.65	7.3	7.9	0.1	1.2	−0.7	−0.7
	Clay	%	20.8	0.8	41.6	13.38	53.9	−0.04	−1.7
	Silt	%	66.8	50.3	90.9	13.8	20.7	0.46	−1.3
	Sand	%	12.4	5.9	33.3	5.9	35	1.5	3.1
	BD	g·cm^{-3}	1.2	1.1	1.3	0.1	5.8	0.3	0.3
	χ_{lf}	10^{-8} m^3·kg^{-1}	58.2	28.2	101.7	18.2	17.2	0.6	−0.3
	χ_{hf}	10^{-8} m^3·kg^{-1}	55.1	26.6	94.7	16.7	16.9	0.5	−0.3
	χ_{fd}	%	5.2	3.3	7.7	1.3	10.5	0.6	−0.9
Rainfed farming	^{137}CS	Bq·m^{-2}	285.6	102.8	929.1	206.7	30.8	1.3	2.3
	SOM	%	1.1	0.4	2.5	0.4	37.7	1.2	1.5
	CCE	%	41.59	23.5	72.5	8.8	20.5	1.1	3.2
	TN	%	0.05	0.02	0.05	0.01	33.2	0.5	0.5
	P_{ava}	mg·kg^{-1}	71.8	32.6	248.3	42.9	59.6	2.8	8.6
	K_{ava}	mg·kg^{-1}	192.9	114.2	312.3	51.1	24.8	0.6	−0.1
	EC	dS·m^{-1}	157.4	126.9	207.8	21.2	12.7	0.6	−0.2
	pH	–	7.87	7.6	7.9	0.07	0.9	0.8	1.3
	Clay	%	21.8	5.6	56.8	14.9	58.5	0.7	−0.2
	Silt	%	67.4	34.7	87.4	14.7	21.8	−0.5	−0.2
	Sand	%	10.1	5.2	20.4	4.3	33.2	1.3	0.7
	BD	g·cm^{-3}	1.2	1.1	1.3	0.1	4.2	0.9	1.3
	χ_{lf}	10^{-8} m^3·kg^{-1}	47.8	32.1	66.2	7.3	15.9	0.8	0.5
	χ_{hf}	10^{-8} m^3·kg^{-1}	43.5	30.2	61.8	6.7	15.3	0.8	0.5
	χ_{fd}	%	4.9	3.1	6.7	0.9	18.9	0.04	−0.6

Min Minimum, *Max* Maximum, *CV* Coefficient of variation, *SOM* Soil organic matter, *CCE* Calcium carbonate, *TN* Total nitrogen, *P_{ava}* available phosphorus, *K_{ava}* available potassium, *EC* Electrical conductivity, *pH* Soil acidity, *BD* bulk density, *χ_{lf}* MS at low frequency, *χ_{hf}* MS at high frequency, *χ_{fd}* dependent frequency MS

highly variable (CV > 0.35). Whereas SOM, CCE, P_{ava}, K_{ava}, slit, sand, χ_{lf}, and χ_{hf} in the forest land-use, and ^{137}Cs, CCE, TN, K_{ava}, slit, sand, χ_{lf}, χ_{hf} and χ_{fd} in the rainfed farming land-uses were classified as moderately variable (0.15 < CV < 0.35). Other parameters were classified as a low variable in the two land-uses. These findings indicate substantial heterogeneity in the soil properties distribution caused by soil erosion and deposition along with the hillslope positions and different land-uses.

The mean inventories of ^{137}Cs achieved in the oak forest soils varied from 140.8 to 1399.2 Bq·m^{-2}. On the other hand, in the rainfed farming soil, the results ranged from 102.8 to 929.1 Bq·m^{-2} (Table 1). We

observed that the spatial distribution of ^{137}Cs showed higher variability in the oak forest soils (higher CV), possibly due to susceptibility to being eroded by the rainfall and vegetation cover degree, which use to be more elevated in forestry areas than in the cultivated ones with bare soils. The distribution of ^{137}Cs was significantly correlated with plant harvest, vegetation type, residual cover, soil properties, and microtopography (Table 1, Fig. 3). In Fig. 3, the main reason for the irregular distribution of ^{137}Cs in rainfed farming land-use can be related to soil management applied to agricultural fields, which leave the soils bare and applied intense tillage practices (Abbaszadeh et al. 2010). Therefore, since there are no differences between precipitation and elevation in

Ayoubi *et al. Forest Ecosystems*   (2021) 8:32

Page 6 of 14

the studied sites, it can be concluded that the main reason for ^{137}Cs variation and its redistribution could be the agricultural practices when the rainfed farming soils are compared to the oak forest soils.

In rainfed farming, the lowest and highest CV values for the soil chemical properties were attributed to pH (0.07%) and P_{ava} (59.6%), respectively. On the other hand, in the natural forest, the lowest and highest CV values for the soil chemical properties were ascribed to pH (0.1%) and TN (131.9%), respectively. In general, the high variance for the chosen soil properties in the hilly area of the studied site suggested a possible redistribution of the soil during the long-term cultivation of the rainfed land and natural soil detachment and deposition at different locations of the hillslope (Jones et al. 2008). This agrees with other agricultural lands such as steep vineyards where tillage and the use of herbicides leaving the soil bare can change soil erosion rates and, subsequently, soil properties among hillslope positions (Rodrigo-Comino et al. 2016; Rodrigo-Comino et al. 2017). However, when the inclination factor is reduced to the minimum, other authors used rainfall simulators also in vineyards, which could not confirm this premise: differences among hillslope positions (Rodrigo-Comino et al. 2018; Cerdà et al. 2020).

Relationships between ^{137}Cs, MS, and soil properties

The relationships between selected soil properties and ^{137}Cs inventory in different land-uses are shown in Table 2. The ^{137}Cs inventory showed consistent significant correlation coefficients with K_{ava}, CCE, χ_{lf}, χ_{hf}, and clay in oak forest soils and significant correlation

Table 2 Correlation coefficients among ^{137}Cs inventory and selected soil properties in the study area

Variable	Oak forest	Rainfed farming
	Cs-137	Cs-137
SOM	0.301	0.020
K_{ava}	0.687[b]	−0.130
EC	0.135	0.122
pH	0.279	−0.082
CCE	0.572[b]	0.382[a]
TN	0.083	−0.207
BD	0.239	−0.329
P_{ava}	−0.055	0.345[a]
χ_{lf}	0.780[b]	−0.325
χ_{hf}	0.776[b]	0.334[a]
Sand	0.275	−0.345[a]
Clay	−0.399[a]	0.374[a]

SOM Soil organic matter, *CCE* Calcium carbonate, *TN* Total nitrogen, P_{ava} available phosphorus, K_{ava} available potassium, *EC* Electrical conductivity, *pH* Soil acidity, *BD* bulk density, χ_{lf} MS at low frequency, χ_{hf} MS at high frequency
[a] and [b] stand for significance at probability levels of 0.05 and 0.01, respectively

coefficients with P_{ava}, CCE, χ_{hf}, sand, and clay in rainfed farming soils. Moreover, in the oak forest, significant positive correlation coefficients between ^{137}Cs and K_{ava} ($r = 0.69$, $p < 0.01$), ^{137}Cs and CCE ($r = 0.57$, $p < 0.01$), and ^{137}Cs and χ_{lf} ($r = 0.78$, $p < 0.01$), and ^{137}Cs and χ_{hf} ($r = 0.78$, $p < 0.01$) were observed (Table 2). The negative significant correlation coefficient between ^{137}Cs and clay content ($r = - 0.40$, $p < 0.05$) was achieved (Table 2) for the oak forest. The ^{137}Cs inventory showed consistent significant correlation coefficients with CCE ($r = 0.38$, $p < 0.05$), P_{ava} ($r = 0.35$, $p < 0.05$), χ_{hf} ($r = 0.33$, $p < 0.05$), clay ($r = 0.37$, $p < 0.05$) and sand ($r = - 0.35$, $p < 0.05$), in rainfed farming land-uses. The highest correlation coefficient for ^{137}Cs was observed with χ_{lf} and χ_{hf} in oak forest land-uses. These ^{137}Cs correlations with soil physico-chemical properties indicated that soil erosion and deposition processes could partially regulate the ^{137}Cs variability within the study sites for the selected soil properties (de Neergaard et al. 2008; Olson et al. 2013). In other words, certain soil properties such as soil nutrients, SOM, and magnetic minerals, and ^{137}Cs inventory were related to detachment and accumulation of fine particles are regulated simultaneously along the hillslope (Fu et al. 2009; Wakiyama et al. 2010; Li et al. 2017). This outcome revealed that the effects of natural factors on soil erosion rates and other factors, such as the role of land-use types and human activity, could affect the local soil erosion.

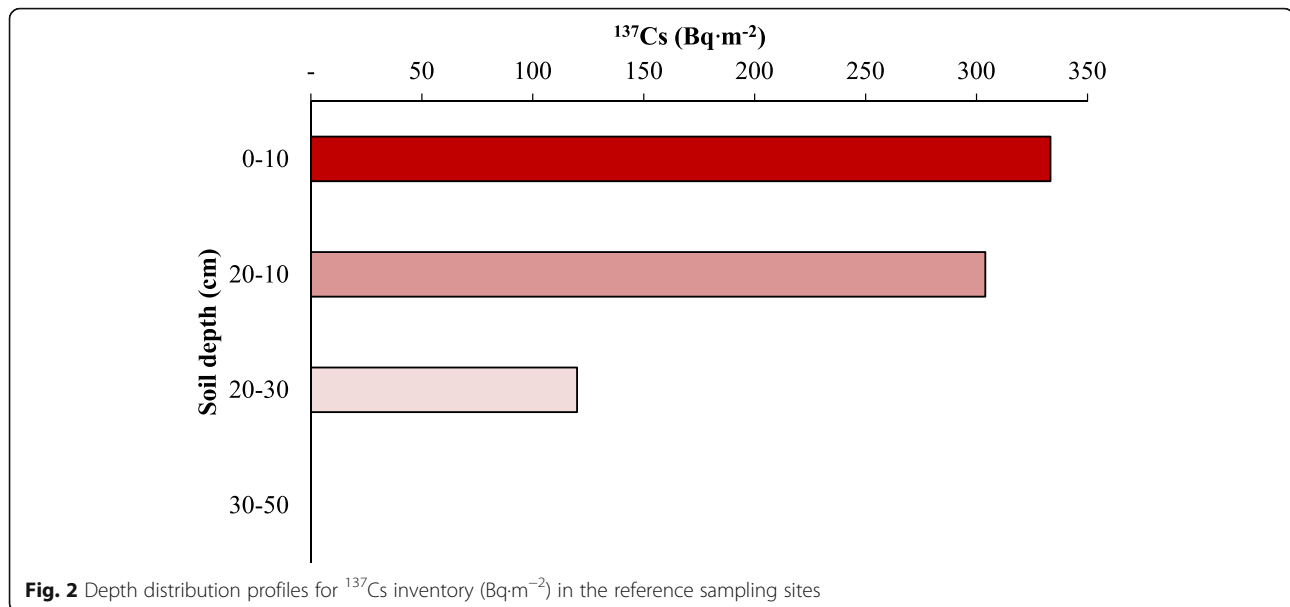### ^{137}Cs inventory and soil redistribution assessment

The characteristic of reference sampling locations, including ^{137}Cs depth profiles and their inventories, are given in Fig. 2. In the topsoil layer (0–10 cm), a significant volume of activity of ^{137}Cs was concentrated and decreased with depth. The mean value of ^{137}Cs inventory obtained from the two reference sites was 978 Bq·m$^{- 2}$, which is consistent with another study from western Iran with 2120 Bq·m$^{- 2}$ (Abbaszadeh Afshar et al. 2010), 2067 Bq·m$^{- 2}$ (Rahimi et al. 2013), and 878 Bq·m$^{- 2}$ (Bazshoshtari et al. 2016) inventory of soils.

The vertical distribution of ^{137}Cs values in the rainfed farming and natural forest sites for four different hillslopes positions was showed in Fig. 3. A significant amount of ^{137}Cs activity was concentrated in the topsoil layer (0–10 cm) in oak forest land-use (Fig. 3), and the profile on the summit and shoulder positions showed a near-exponential decline in ^{137}Cs activity with a depth that indicated undisturbed soils in nature forest land-use (Fig. 3a and b). Several studies also reported a high concentration of ^{137}Cs activity in the upper soil layers than the lower ones (Abbaszadeh Afshar et al. 2010; Ayoubi et al. 2012a; Rahimi Ashjerdi et al. 2013; Bazshoushtari et al. 2016).

Fig. 2 Depth distribution profiles for ^{137}Cs inventory (Bq·m^{-2}) in the reference sampling sites

As demonstrated in Fig. 3, the ^{137}Cs values in the natural forest soils are significantly different between 0 and 10, 10–20, and 20–50 cm depths, but in the rainfed farming are significantly different between 0 and 10 and 10–20 cm depths in the summit positions (Fig. 3a and e). The natural forest soils showed considerably greater values of the ^{137}Cs than rainfed farming soils at three depths in summit position (Fig. 3a and e). The distribution of ^{137}Cs activity through the surface horizons was influenced by both plowing and soil erosion. There was a significant difference in ^{137}Cs activity distribution following the land-use change to rainfed farming in the upper 20 cm of the soil with subsoil in shoulder positions (Fig. 3f). The ^{137}Cs activity was showed a significant difference ($p < 0.05$) between 20 and 50 and 10–20 cm depths in backslope and footslope positions in both land-uses (Fig. 3c and g). These findings indicate that the conversion of the natural forest land into rainfed farming significantly reduced ^{137}Cs values in each hillslope position.

The soil erosion estimation rate by SMBM was (9.3 t·ha^{-1}·yr^{-1}) for the natural forest, while the higher soil loss (51.1 t·ha^{-1}·yr^{-1}) was calculated in rainfed farming. The sloping rainfed farming erosion rate is more than double that of the natural forest, suggesting that significant soil loss occurred during the agriculture practices after forest conversion (Fig. 4). By using SMBM in the Ardal district, west of Iran, Abbaszadeh et al. (2010) showed that soil erosion rates varied between 4.8 to 183.9 t·ha^{-1}·yr^{-1} in rainfed farming.

The soil erosion and deposition rates were presented in Fig. 4 in oak forest and rainfed farming sites for four different hillslope positions. The highest soil erosion rate with a mean value of 162.3 t·ha^{-1}·yr^{-1} occurred in the summit component of rainfed farming land-use. Previous studies showed that inclination is one of the most influential factors that could enhance soil loss in the highest hillslope position (i.e., summit position) (Bradford and Foster, 1966; Aksoy and Kavvas 2005; Assouline et al. 2006). The soil deposition occurred mainly in the back- and foot-slope positions in the natural forest area with mean values of 148.3 and 376 t·ha^{-1}·yr^{-1}, respectively. This shows that eroded material from summit and shoulder positions are mobilized in the two lowest hillslope positions. In the rainfed farming areas, the highest soil erosion occurred on summit and shoulder positions with mean values of 162.3 and 99.3 t·ha^{-1}·yr^{-1}, respectively. Unlike the oak forest areas, soil erosion occurred on the backslope of the rainfed farming areas. In rainfed farming, the highest soil deposition rate occurred in the footslope position with a mean value of 140.95 t·ha^{-1}·yr^{-1}. The sediments carried from the upslope parts deposited in the lower position (e.g., footslope position) (Fig. 4). Several studies obtained similar results (Sac et al. 2008; Abbaszadeh et al. 2010; Ayoubi et al. 2012b) confirmed the deposition rate in the downslopes (i.e., back- and foot-slope) was the highest.

The soil erosion rate in rainfed soils was greater than that of natural forest soils (Fig. 4). On the summit position, for instance, the soil erosion rate in all three rainfed farming land-use samples was 162.3 t·ha^{-1}·yr^{-1}, but in the oak forest was only 7.2 t·ha^{-1}·yr^{-1}. The soil erosion rate on the shoulder position of rainfed farming land-use (99.3 t·ha^{-1}·yr^{-1}) was much higher than natural forest land-use (32.4 t·ha^{-1}·yr^{-1}) (Fig. 4). The soil losses in the summit and shoulder positions obtained by the SMBM showed significant differences ($p < 0.05$) for the oak forest and the rainfed farming. Also, there was a
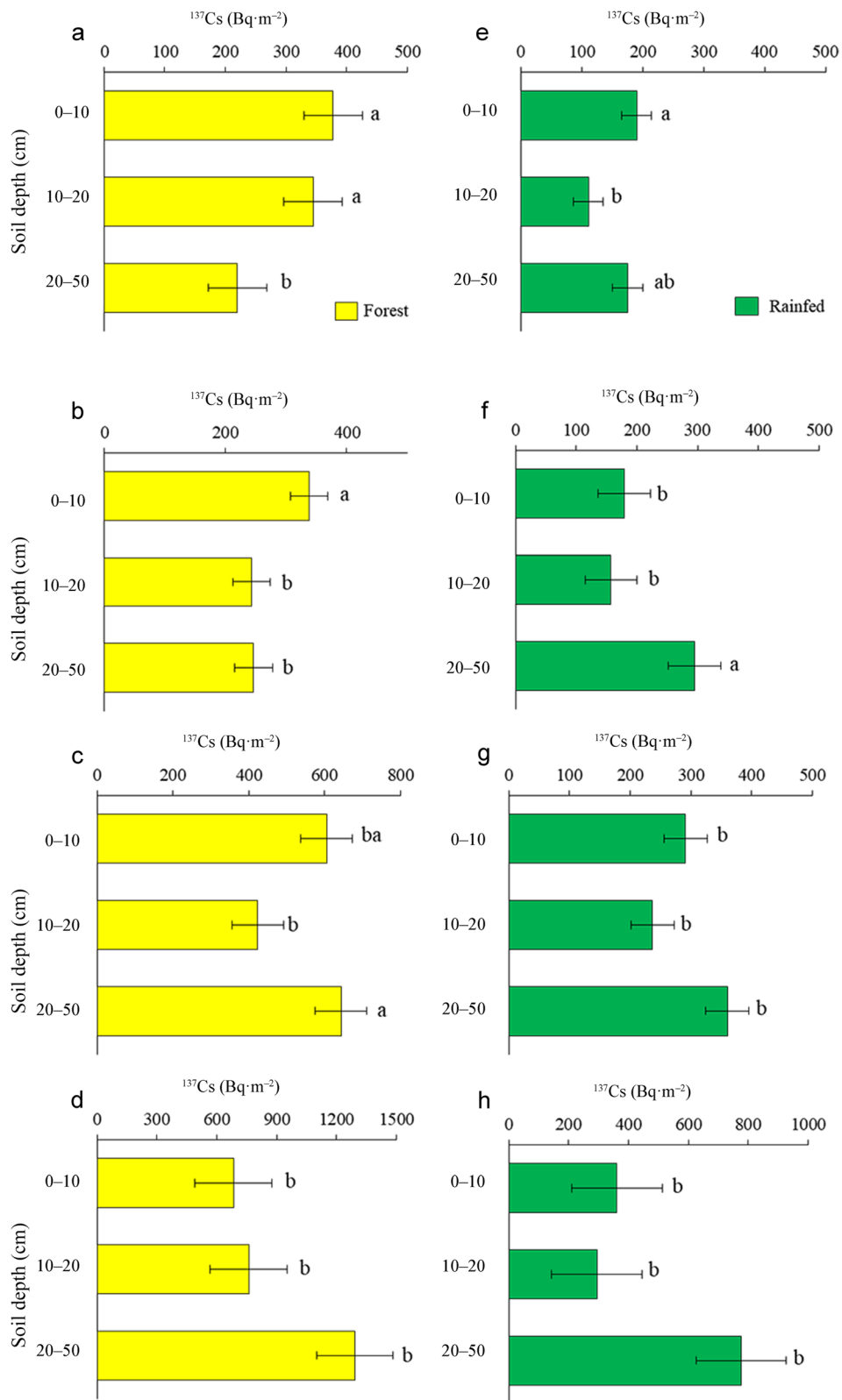
Fig. 3 Depth distribution profiles for ^{137}Cs inventory (Bq·m^{-2}) in forest land-use (**a**), summit (**b**), shoulder (**c**), backslope (**d**) footslope and rainfed land-use (**e**), summit (**f**),shoulder (**g**), backslope (**h**) footslope. Different letters on the bars show the statistical difference at $p < 0.05$
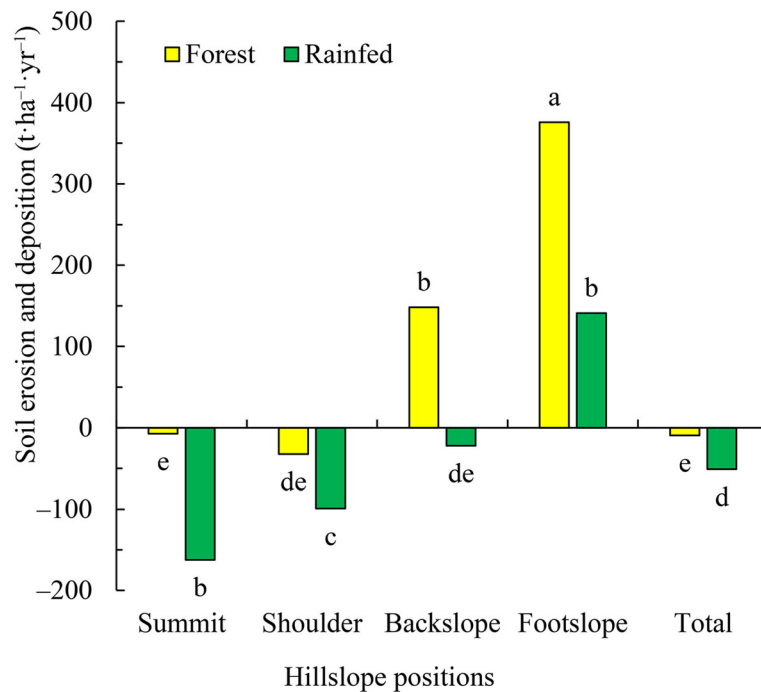
Ayoubi *et al. Forest Ecosystems*   (2021) 8:32

Page 9 of 14

Fig. 4 The soil erosion rates and deposition in natural forest and rainfed farming per hillslope positions (summit, shoulder, backslope, and footslope). Different letters on the bars show the statistical difference at $p < 0.05$
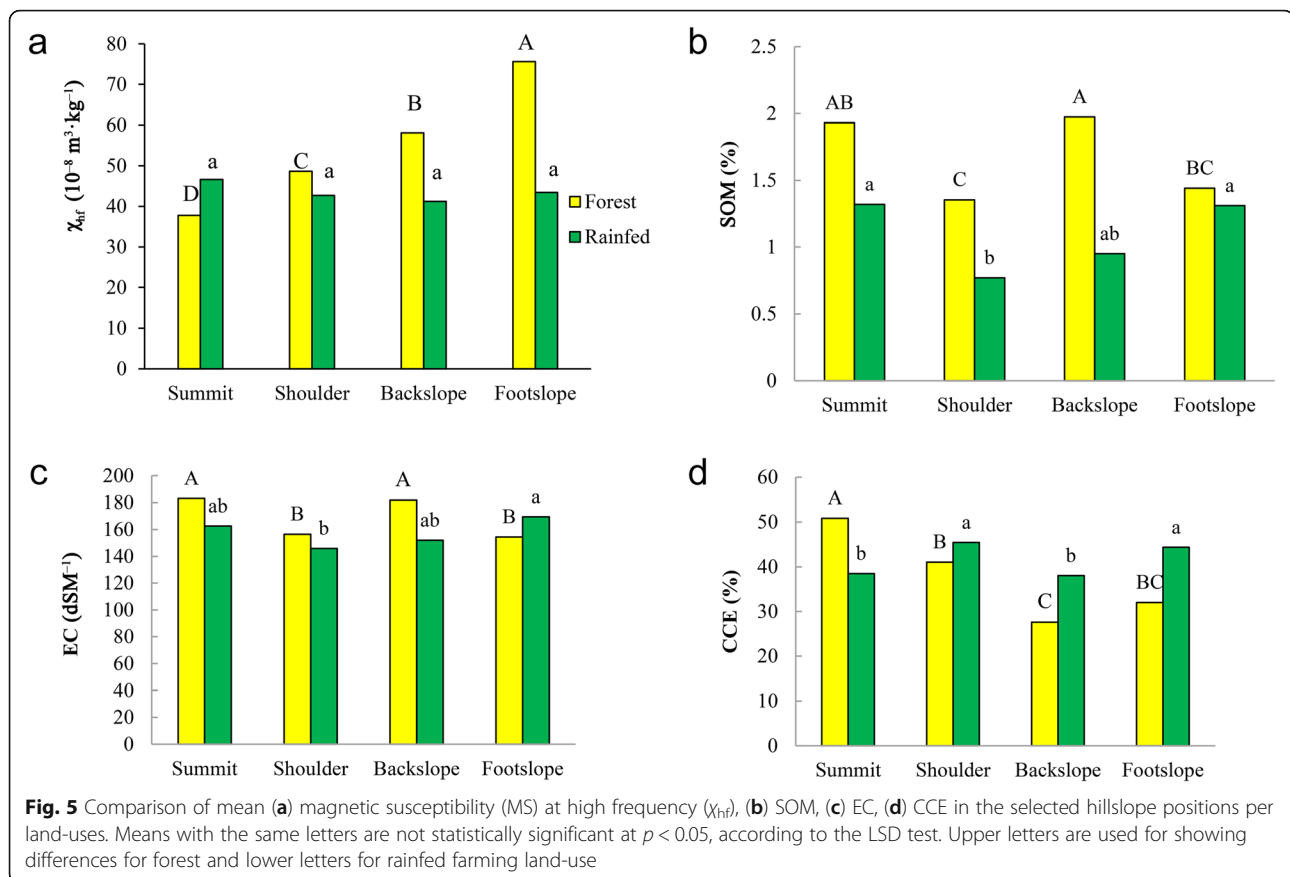
significant difference ($p < 0.05$) between the two land-uses for the backslope and footslope positions according to soil deposition (Fig. 4). Higher soil redistribution on different hillslope positions of rainfed farming lands compared with forest land-use confirmed changing land-use (e.g., human activity), which remarkably enhances soil erosion in the study area. Moreover, the tillage practices and loss of vegetation cover in the steep slopes of the cultivated areas were considered as the major factors affecting soil properties in the studied area. Therefore, removing vegetation cover or tillage practices could increase the probability of large erosion events. Sheet and rill erosion are the dominant erosion processes within the rainfed cultivation catchment. These findings are in line with the findings of Mokhtari Karchegani et al. (2011) and Ayoubi et al. (2012a). Although rainfed farming vegetation could help to sustain the soil, but the vegetation cover would be less dense and stable than after deforestation. Additionally, the tree roots improved soil water retention and reduced the direct effect of rainfall splash (Wittenberg et al. 2020).

Soil property variations in slope positions and land-uses
In the oak forest soil, the mean MS at high frequency (χ_{hf}) was significantly ($p < 0.05$) higher than in the rainfed agricultural soil (Fig. 5a). The undisturbed soil with a lower soil loss in the summit and shoulder positions of hillslope (Fig. 4) indicated higher χ_{hf} rather than

in the disturbed soils (Fig. 5). On the other hand, due to soil deposition in the backslope and footslope positions, χ_{hf} showed higher value than other positions. Furthermore, in the downslope positions, especially in the natural forest land, the pedogenic process was more intense because of the water received from the upslope in the form of surface and sub-surface flows, which can cause the leaching of carbonates and enhanced χ_{hf} (Singer et al. 1996; Ayoubi et al. 2012a; Rahimi et al. 2013). There was no significant difference in χ_{hf} in rainfed farming soils, which could be related to soil tillage disturbance (Fig. 5a). These findings agree with Liu et al. (2018), who stated a significant positive correlation between soil erosion and magnetic properties. The location of the hillslope position influences the variability of soil attributes, especially magnetic properties. There is evidence within the hillslope for soil movement as soil erosion occurs in the shoulder and backslope and soil deposition in downslope positions.

SOM in the natural oak forest soil was significantly ($p < 0.05$) higher than in the rainfed farming soil. The lowest SOM was observed in both land-uses in the shoulder position, which was associated with the highest slope and soil loss rate. In addition, SOM was significantly ($p < 0.05$) in both land-uses in different hillslope positions (Fig. 5b). On the other hand, Ayoubi et al. (2012a) and Nosrati et al. (2015) obtained the low SOM in shoulder positions of hillslope in the Chelgerd Nachi

Fig. 5 Comparison of mean (**a**) magnetic susceptibility (MS) at high frequency (χ_{hf}), (**b**) SOM, (**c**) EC, (**d**) CCE in the selected hillslope positions per land-uses. Means with the same letters are not statistically significant at $p < 0.05$, according to the LSD test. Upper letters are used for showing differences for forest and lower letters for rainfed farming land-use

District in the west of Iran. This may be contributed by higher soil temperature because of low vegetation cover, less shading, and subsequent susceptibility of soils to erosion (Pathak et al. 2005; Sugasti and Pinzón 2020).

The lowest EC has been observed in the shoulder and footslope positions in rainfed and oak forest land-uses. There was a significant difference ($p < 0.05$) between the shoulder and footslope positions in rainfed farming land-use for EC. There was a significant difference in EC in natural forest soils between the summit, backslope, and shoulder, footslope positions. The findings indicated that hillslope components and land-uses independently affect soil properties and change their values in different hillslope components and land-uses (Fig. 5c).

Calcium carbonate equivalent (CCE) in the rainfed farming soil in all of the hillslope positions except in the summit was significantly ($p < 0.05$) higher than in the natural forest soil. There were significant differences ($p < 0.05$) between summit and backslope with shoulder and footslope positions in CCE in rainfed farming soils, which could be related to the soil's heterogeneity due to plowing and different stability of hillslope positions (Khormali et al. 2006). In natural forest soils, there were significant differences ($p < 0.05$) in CCE contents in different hillslope positions. The highest and lowest CCE

values were observed in the summit and backslope positions in oak forest land-use (Fig. 5d). Moreover, in rainfed farming, the low and high CCE values in the summit and footslope positions could be due to soil erosion in the upper hillslope position (i.e., summit) and deposition in the lower hillslope position (i.e., footslope) (Fig. 5d). A previous study showed that CCE variations could be used to indicate soil loss and landscape stability (Khormali et al. 2006). A variety of complex processes accounting for the CCE dynamics in the soil (Khormali et al. 2006; Khormali et al. 2009).

Potential carbon sequestration in soil

To estimate the additional amount of carbon, which could be sequestered as complexed OC in each land-use, complexed and non-complexed carbon and clay were calculated using Eqs. 1–4. Afterward, the potential additional complexed OC was calculated. The mean clay content varied between 1 to $57 \, g \cdot 100 \, g^{-1}$ at a depth of 0–30 cm, and no significant differences were observed between the land-uses. By using n = clay/(SOC concentration) = 10, the average complexed clay (CC) in the oak forest and rainfed farmlands was found to be 20.8 and $21.8 \, g \cdot 100 \, g^{-1}$, respectively. As shown in Fig. 6, the saturation line is the boundary for controlling non-

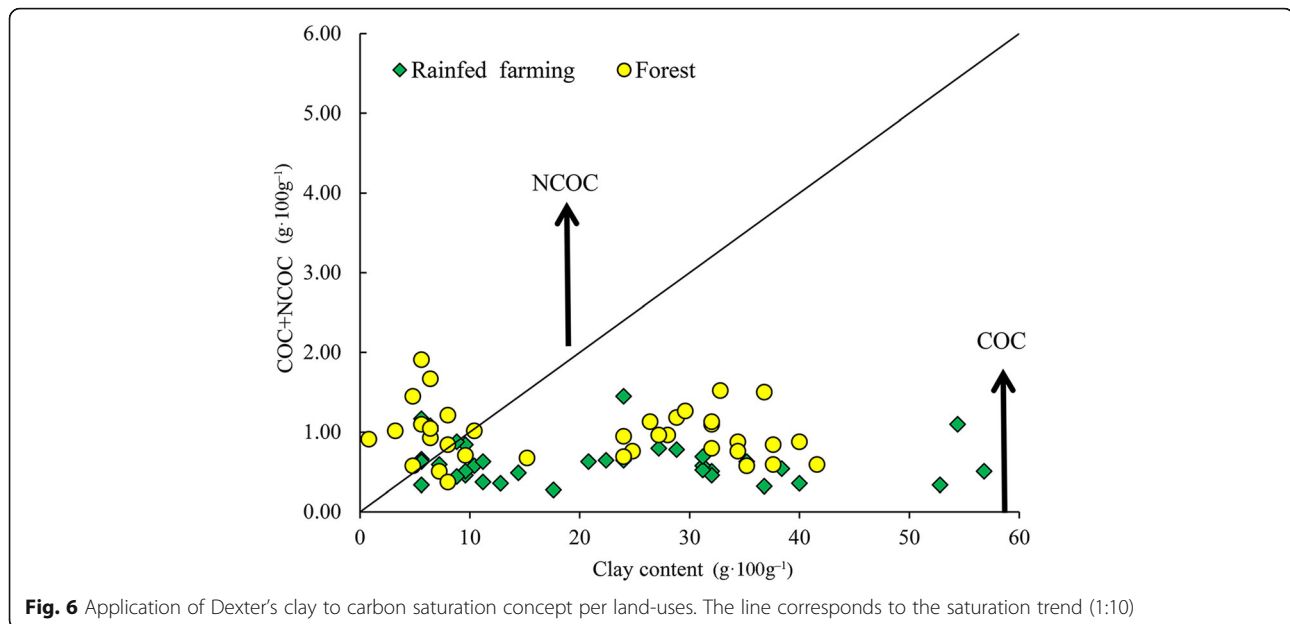Ayoubi *et al. Forest Ecosystems*   (2021) 8:32

Page 11 of 14

Fig. 6 Application of Dexter's clay to carbon saturation concept per land-uses. The line corresponds to the saturation trend (1:10)

complexed organic carbon (NCOC) and non-complexed clay (NCC). More the soils were located under the saturation line (Fig. 6), the amount of complexed clay (CC) corresponded to the complexed organic carbon (COC) (whole amount of SOC concentration), and the non-complexed organic carbon (NCOC) was equal to 0. The texture of the oak forest soil is closer to the saturation line. In the natural forest, soil behavior is affected by non-complexed carbon. However, in rainfed farming, due to the heavy texture of the soil, the composition of the soil is affected by non-complexed clay. This indicates that the textures of the two land-uses are not the same. Alidoust et al. (2018) assess and compare improvements and capacity of SOC sequestration under various land-uses in western central Iran. The findings revealed that all soils analyzed consisted of non-complexed clay, showing a significant carbon sequestration capacity. Moreover, the findings have shown that the SOC controlling variables differed considerably between land-uses and soil depths. Reduction of inputs biomass, acceleration of soil erosion, and the increase of SOM turnover rate are the key factors for the SOC concentration reduction due to the conversion of forest to agricultural lands (Albaladejo et al. 2013). Some studies have also shown that the depletion of SOC land-use conversion to agricultural lands in the semi-arid areas could be higher than in humid areas (Martinez-Mena et al. 2008).

Conclusions

Soil redistribution rate demonstrates remarkably higher erosion in rainfed farming than natural forest (oak forest) soils. The results of using ^{137}Cs radionuclide measurements indicated severe erosion in the summit

($162.3\ \text{t·ha}^{-1}\text{·yr}^{-1}$) and shoulder ($99.3\ \text{t·ha}^{-1}\text{·yr}^{-1}$) hillslope positions of rainfed farming soil after changes from oak forests. This confirms that land-use changes from the undisturbed ecosystem (i.e., natural forest) to disturbed ecosystems (i.e., dryland farming) significantly increase soil erosion. The shoulder and summit positions were the most erodible hillslope positions in the natural forest and rainfed farming, respectively. These results highlight the critical role of hillslope position and land-use changes in eroding the surface soils in hilly natural and anthropogenic areas. In addition, the results illustrated that land management has a powerful influence on soil erosion intensity and may both mitigate and amplify soil loss. Our findings present evidence that the combined influence of soil redistribution and land-use change applies a significant control over the spatial distribution of soil properties. Therefore, the data obtained achieves a better understanding of the effect of land-use change and land management in the Zagros region.

Authors' contributions

SA: Conceptualization, Methodology, Software, Validation, Writing - original draft, Writing - review & editing, Visualization, Supervision; NS: Methodology, Software, Validation, Writing - original draft, Writing - review & editing, Visualization; FAA: Writing - original draft and Writing - review & editing; MRA: Methodology and Writing - review & editing; MZ: Writing - original draft, Writing - review & editing, Supervision, and Visualization; JR: Writing - review & editing. The authors read and approved the final manuscript.

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Competing interests

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