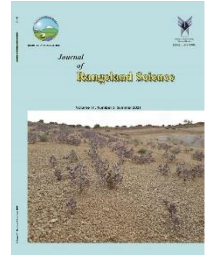

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Soil Organic Carbon Stock Changes in Response to Land-use Changes in Iran

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Abstract. Land-use and land-use change can directly affect soil organic carbon. Improper land management can lead to carbon loss from the soil, which can greatly intensify global warming. Despite the abundance of evidence on Soil Organic Carbon (SOC) in Iran, no paper has so far compiled the data for this region. Therefore, data were collected from 120 papers and 393 data points regarding land use and SOC changes. Stepwise regression analysis was used to analyze the relationship between SOC with annual precipitation, average annual temperature, latitude and average depth of sampling. Pearson correlation coefficients were calculated between SOC and other factors. Based on the results, primary forests and reforested areas had significantly higher SOC stocks at the depth of 20cm with average values of 70.03 (±4.45) Mg C ha^{-1} and 84.38 (±9.01) Mg C ha^{-1}, respectively while there were no significant differences among other land use categories. The findings of this study showed no changes in SOC stocks among land-use change categories and average annual rates of SOC changes. However, among farmlands, evidence was obtained for a significant SOC reduction in cases with a historic forest land-use (-15.2%) compared with those with historic grassland use. Results indicated that farmlands and primary forests had the highest level of SOC input from litter and fine roots, respectively. By evaluating the impact of different factors on SOC using a stepwise regression analysis, it was demonstrated that 31% of the variations in soil carbon storage at different land-use types can be explained by precipitation, temperature, latitude, and sampling depth. Using the obtained equation, SOC variation in Iran was simulated and mapped showing that except for a narrow strip in northern Iran, the rest of the country suffers from low SOC levels. Totally, protecting forests against land conversion is recommended as the top priority for land managers in Iran.

Key words: Carbon, Land-use, Meta-analysis, Land-cover, SOC loss

Introduction

Terrestrial ecosystems are major pools for the global carbon cycle. Plant biomass is the main conduit for transferring atmospheric CO_2 into the soil (IPCC, 2006). Most of the plant biomass turns into dead organic matter which then constitutes soil organic carbon. The continual addition of decaying residues to the soil surface contributes to the biological activity and the carbon cycling process in the soil (Tisdall and Oades, 1982; Cates *et al.*, 2019). Any factor that can affect litter input and organic matter loss can alter soil carbon storage (Davidson and Janssens, 2006). Although plants and soil uptake carbon, soil retains carbon for a much longer time which makes it the most important carbon pool in terrestrial ecosystems (Watson *et al.*, 2000; Yang *et al.*, 2007; He *et al.*, 2016). Soil organic matter contains three times as much carbon as either the atmosphere or terrestrial vegetation (Schmidt *et al.*, 2011). Global carbon storage in the top one meter of the soil is as high as 1502 Pg., with a carbon flux of 68±4 Pg C yr^{-1} (Raich and Schlesinger, 1992; Jobbágy and Jackson, 2000). The release of carbon stored in vegetation and soil into the atmosphere will have a serious impact on the global climate (Heimann and Reichstein, 2008; Chen *et al.*, 2020).

The interaction of atmospheric composition, climate, and land-cover influences soil carbon storage (Jobbágy and Jackson, 2000). Humans by deliberately affecting land cover and ecosystem processes have significantly facilitated the release of greenhouse gasses from the soil and vegetation into the atmosphere (IPCC, 2006; Barančíková *et al.*, 2016; Mendelsohn and Sohngen, 2019). Land management directly affects the amount of soil organic matter and the balance of primary productivity and decomposition (Burke *et al.*, 1989; Lal, 2020). Intensive use of earth resources which is exemplified by land conversion, deforestation, biomass burning, drainage of wetlands and intensive soil cultivation has reduced soil capacity to store carbon (Lal, 2004).

By land conversion, the amount of organic matter input and output in different ecosystems has changed in favour of releasing significant amounts of CO_2 into the atmosphere (Dai and Huang, 2006; Kallenbach and Grandy, 2012; Kallenbach and Stuart Grandy, 2015). Soil organic carbon loss has contributed 78 ± 12 Pg C to the atmosphere. There is evidence of the loss of one-half to two-thirds of SOC in some cultivated lands, which accumulates to 30-40 Mg C ha^{-1} (Lal, 2004). Land use changes in the US released 27 ± 6 Pg of carbon into the atmosphere before 1945 (Houghton *et al.*, 1999). In Europe, maintaining current land use system will decrease carbon sequestration by 4% in 2030, relative to 2000 (Schulp *et al.*, 2008). Because of the importance of land management to soil carbon dynamics, there is a growing number of attempts to model SOC changes in response to this factor (Burke *et al.*, 1989, Pulleman *et al.*, 2000; Chen *et al.*, 2010; Molina *et al.*, 2017). But our knowledge of the impact of land-conversion on soil carbon dynamics is still limited (Falkowski *et al.*, 2000; Conant *et al.*, 2001), and there is a major debate on the direction and magnitude of changes in soil C stock with land use changes (Falkowski *et al.*, 2000; Sainepo *et al.*, 2018).

One of the regions lacking data on the impact of land conversion on SOC is the West Asia-North Africa (WANA) region with an area of 1.7 billion ha and a population of 600 million (Lal, 2004). Iran as one of the largest countries of WANA has experienced major land-use changes during the past decades. Iran has four important ecological zones namely Hircanian (extended from northwest to north east), Zagros (extended from northwest to south east), Khalij-o-Omani (along the coasts of the Persian Gulf and Oman Sea) and Iran-o-Touranian (Mainly the Central Plateau of Iran) zones. Zagros and Alborz mountain ranges by encapsulating the central part of Iran prevent the moisture from reaching the inner plateau. The mountain ranges are covered with forests, named after the mountain ranges as Alborz and Zagros forests. The central part of Iran is mainly a high plateau with minor elevations, including deserts and steppe rangelands. Another major ecological zone known as the Khalij-o-Omanian Zone extends from south west along the coasts of the Persian Gulf and Oman Sea, to the south east of the country. As far as precipitation is concerned, the Hircanian Zone enjoys abundant precipitation during summer and mild temperature throughout the year. Zagros forests with a semi-arid climate and by having comparatively less precipitation are covered with a less dense forest, mainly Oak trees. Precipitation in this area is concentrated in winter and early spring in the form of snowfalls. The central plateau receives the least amount of precipitation which normally does not exceed 100 mm. The khalij-o-Omani region also receives most of its precipitation during winter and partly during summer as heavy rain showers. High temperatures and relative humidity have resulted in the development of especial Savana-like vegetation with Acacia, Prosopia, Ziziphus, Avicennia, and Rhizophora *spp.* as its major tree species. To obtain more information on major ecological zones of Iran, readers are referred to Heshmati (2012).

According to the Statistics Centre of Iran (www.amar.org.ir, 2018), 16.4 million ha of Iran is agricultural fields and orchards, of which 46.2% is irrigated for farming and the remaining area is used for rain-fed agriculture. Desert ecosystems and forest cover comprise 20% (32576492 ha) and 8.8% (14319062.66 ha) of Iran's area, respectively (Watershed, Forest and Rangeland Organization of Iran (WFR, 2018) (Based on the latest assessment of the WFR, 86 million ha of the country is devoted to rangelands, of which 45.4 million ha (52%) is degraded rangelands). Over the past few decades because of a multitude of factors such as improper policy making and lack of law enforcement, a considerable area has been converted from its original state into often unsustainable land uses. Major land-use change types include conversion of rangelands and forests into orchards and then private properties; clear-cutting forests for transient agriculture; burning and ploughing rangelands for rain-fed agriculture; abandoning rain-fed and irrigated croplands due to the loss of fertility, erosion, encroachment of sand dunes and salinization. During the past 16 years, more than 16 thousand hectares of agricultural fields in Iran has been converted into residential areas and private villas (according to the Iranian Land Affair Organization). According to the Iranian Department of Environment between 2003 and 2012, one million hectares of Iran's forests were converted into residential areas, transient agricultural fields, roads, industrial facilities, mines, and private properties. It has also been estimated that the area of Zagros Forests of Iran has been diminished by 96 thousand hectares during the past decade, mainly for the purpose of rain-fed agriculture. At the same time, the rangeland area has been diminished from 86 million ha in 2003 to 84 million ha in 2012 (www.amar.org.ir - Statistical Reports for Year 2018).

Despite the land conversion in Iran, the overall impact of this issue has not been quantified. Land-use conversion by changing SOC not only affects soil fertility, but could also affect global warming. Therefore, this study is aimed at collecting all the available data regarding the impact of land use changes on SOC in Iran from the literature, and quantitatively analysing carbon stock changes. The results of this study will help understanding the dynamics of SOC changes in response to land management in Iran and can be used as a guide for further large-scale modeling of SOC in WANA.

Materials and Methods

Data collection

In this study, we compiled data from 120 papers from peer-reviewed journals, in both English and Persian languages. It was attempted for the data list to be as inclusive as possible up to 2018. The location of the study sites is illustrated in Fig. 1. We were unable to locate the related studies for the central plateau of Iran and the south-eastern part of the country. The English papers were acquired from the Google Scholar, and the Persian articles were collected from the Scientific Information Database (SID). Only those papers were included in our database that had robust and rigorous methodology and sound experimental design. Those papers reporting extremely high or low values in terms of SOC and bulk density were discarded before data analysis. Those papers with SOC reported in concentration (percentages) and without bulk density were also discarded since the SOC concentration values were not readily convertible into SOC stocks. In some cases, we also evaluated the SOC values reported in the paper with those reported for relatively close locations to verify if the reported values fell into a reasonable range. Those studies performed with insufficient number of samples or lacking replications were also not considered. It was also tried to check the validity of the average annual temperature and precipitation values by comparing them with the average values of the nearest weather station.

The following categories were found in the reviewed papers: natural grasslands, replanted grasslands, primary forests, afforestation, reforestation, enclosure grasslands, farmlands, and abandoned lands. Natural grasslands included scrublands, pastures and deserts that are used for livestock or wild animal grazing. Replanted grasslands were those replanted with grasses and shrubs for rangeland improvement for grazing, soil conservation or water harvesting. Primary forests were large areas dominated by natural tree cover. Afforested areas were those without previous forest cover on which a new forest cover was established. Reforestation referred to re-establishing forest cover on a part of land with forest cover history. Enclosure of grassland meant to fence or guard parts of a rangeland or pasture to confine animals grazing. Farmlands as the name implies were those areas mainly used for farming but we also included orchards under this category meaning those farmlands planted with trees and mainly managed for fruit production. Abandoned lands or derelict farmlands were those lands no longer farmed because of infertile soils.

The SOC values were either provided in the articles or calculated based on SOC concentration, soil bulk density and soil depth (eq. 1 and eq. 2). In cases where raw data were provided either in the form of Tables or Graphs, graphical data were extracted in GetData Graph Digitizer 2.26. The SOC values provided in the reviewed papers ranged from 0.45 Mg C ha^{-1} (depth=40 cm) to 368 Mg C ha^{-1} (depth=40cm) and we used Eq. 2 to convert all values into an equivalent depth of 20 cm. We collected the data regarding the authors, location (longitude and latitude), climate (precipitation and temperature), current land use, land-conversions (if any), age of land use conversion, soil bulk density, soil organic carbon input (through litter and root mass), soil organic carbon change, total depth of measurement, annual SOC changes and land management type. Data on temperature and precipitation were either directly available in the reviewed papers or obtained from the nearest stations at www.irimo.ir. We tabulated all 343 measurements of SOC from 138 sites as provided in Fig. 1. The occurrence of each land-use among all papers is provided in Table 2.

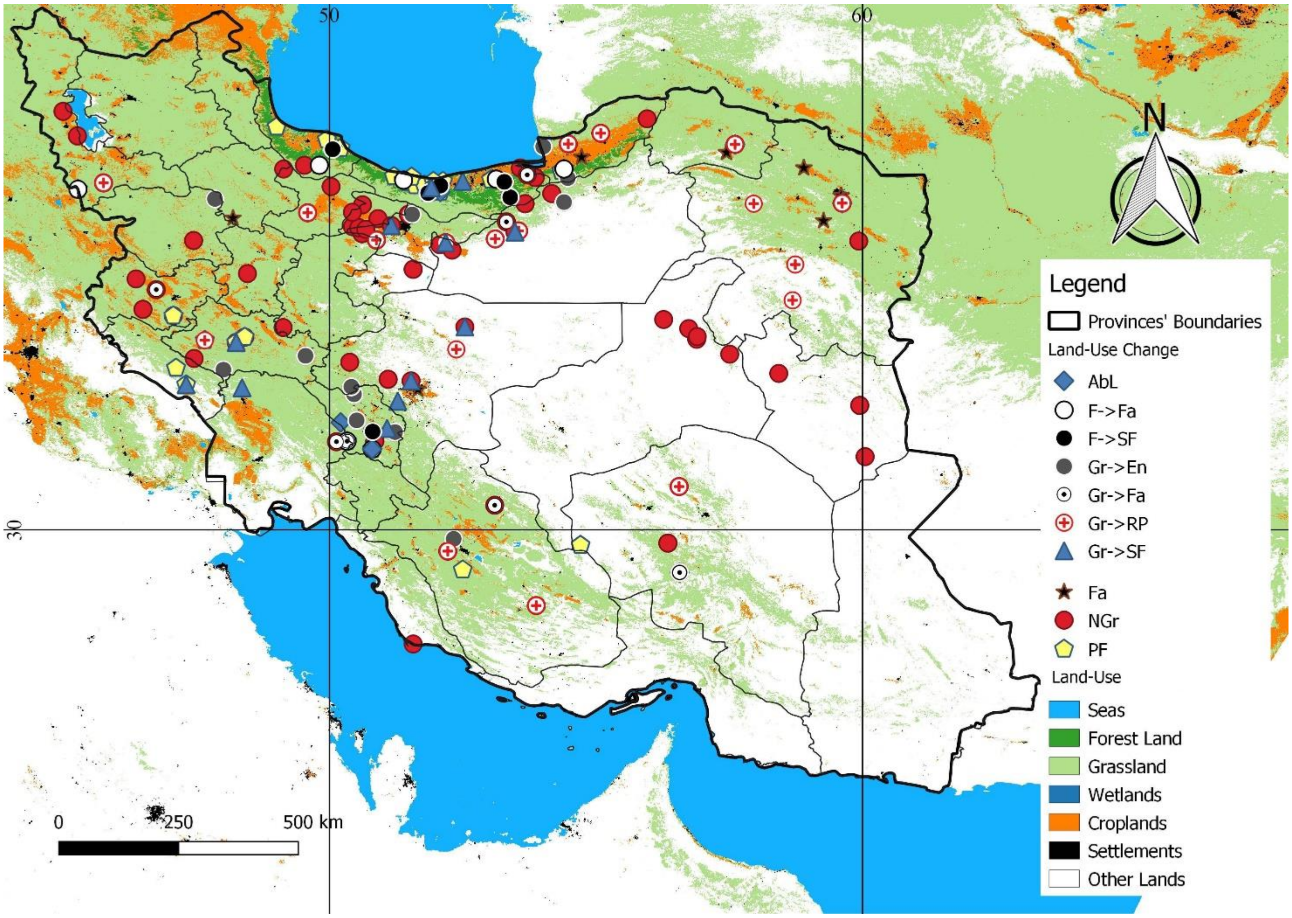

Fig. 1. Distribution of study sites relative to Iran's boundary. Land cover map was acquired from the MODIS Land Cover Type product (Short Name: MCD12Q1) available at http://reverb.echo.nasa.gov. Abbreviated words in the legend are: RP: Replanted Grassland, PF: Primary Forest, NGr: Natural Grassland, Fa: Farmland, En: Enclosure Grassland, SF: Secondary Forest (Afforestation), AbL: Abandoned Land

Table 1. Summary of variables of the data points included in our analysis

Variable	N	N*	Mean	Minimum	Median	Maximum
Average annual temperature (ºC)	379	14	15.4	9.0	15.3	28.0
Average annual precipitation (mm)	393	0	507.7	3.4	375.0	1345.3
Maximum Sampling Depth (cm)	355	38	39.6	10.0	30.0	120.0
Bulk Density (g cm^{-3})	230	163	1.44	0.64	1.44	2.20
Age (yr)	139	254	17.2	1.0	20.0	45.0
Soil carbon input (litter) (t ha^{-1})	89	304	1.7	0.0	0.4	11.3
Soil carbon input (root) (t ha^{-1})	89	304	2.1	0.0	0.4	66.0
Soil organic carbon at 20cm (t ha^{-1})	344	49	43.4	0.2	34.3	223.5
Soil organic carbon change (t ha^{-1} yr^{-1})	113	280	0.8	-6.7	0.2	30.5

N (number of non-missing cases); N* (number of missing cases)

For converting soil organic matter (in cases with non-missing values) into SOC, we used the following formula (Schulte, 1995) (Eq. 1):

$$SOC = SOM \times 0.58 \qquad (1)$$

Where SOC indicates soil organic carbon and SOM is the soil organic matter. To convert SOC values into organic carbon storage per hectare, we adopted the following formula (Deng *et al.*, 2016) (Eq. 2):

$$C_s = \frac{SOC \times BD \times D}{10} \qquad (2)$$

Where Cs is soil organic carbon content ($Mg\ ha^{-1}$); SOC is organic carbon concentration ($g\ kg^{-1}$); BD is soil bulk density ($g\ cm^{-3}$); and D is soil sampling depth (cm).

Comparisons between land uses and management practices need to be conducted on an equivalent mass basis particularly when shallow depths are compared. However, only nearly half of the reviewed manuscripts reported BD values. Interpolating the missing values was also not possible as the relationship between SOC concentrations and BD was not significant (R^2 =0.11 and p>0.05). On the other hand, as reported by (Laganiere *et al.*, 2010; Deng *et al.*, 2014a), not considering a common SOC mass for comparisons only results in a slight bias in the estimation of SOC changes. Therefore, we did not consider equivalent masses in this study for SOC comparisons.

To compare the changes in SOC in different land-uses, we adopted the depth function as in Jobbágy and Jackson (2000) and Deng *et al.* (2016) (Eq. 3):

$$X_{20} = \frac{1-0.9786^{20}}{1-0.9786^{d0}} \times X_{d0} \quad (3)$$

Where X_{20} is the SOC storage at the depth of 20cm; and Xd0 is the total SOC provided in each study.

To measure carbon stock changes in different land conversion cases, carbon stock of different land uses were compared with a control plot as (Eq. 4):

$$\Delta_{SOC}(\%) = \frac{SOC_{LUC}-SOC_{Control}}{SOC_{Control}} \times 100 \quad (4)$$

Where $\Delta_{SOC}(\%)$ indicated the changes in SOC stock in percentage, SOC_{LUC} is the SOC stock in the new land-use system and $SOC_{Control}$ is the SOC stock of the control plot.

Annual rate of SOC stock change in those papers providing the age of land-use conversion was calculated as (Eq. 5):

$$\Delta_{SOC} = \frac{SOC_L-SOC_C}{\Delta t} \quad (5)$$

Where Δ_{SOC} is the annual change in SOC storage ($Mg\ ha^{-1}\ yr^{-1}$); SOC_L is SOC stock at current land-use system ($Mg\ ha^{-1}$); SOC_C is the SOC values in the original land use ($Mg\ ha^{-1}$); and, Δt is the number of years since land-use conversion occurred (yr).

Statistical Analysis

In order to evaluate the impact of land use changes on SOC, ANOVA with the general linear model (GLM) was used. The test was calculated based on the 95% confidence level. Multiple comparisons were done using Tukey's HSD method. We used the stepwise regression analysis to analyze the relationship between SOC with annual precipitation, average annual temperature, latitude and average depth of sampling. Pearson correlation coefficients were calculated between SOC and other considered factors (Schober *et al.*, 2018). Data handling and analysis were carried out in R, Minitab 18, and Microsoft Excel Spreadsheets.

Results

Summary of the variables

Table 1 provides the summary of variables from different studies. The study sites were distributed between 27-38 N and 45-61E (Fig. 1). In total, there were 393 studied land-uses from 120 papers (Appendix A). Out of this number, 21 (17%) cases took place on a single land-use while 99 cases (82.5%) considered more than one land-use type. Resampling of the same field occurred in none of the articles in the subsequent years. In the cases considering the effect of land-use on SOC, the area(s) of interest was compared with an adjacent site, resembling the condition of the land prior to the conversion. The lowest average soil bulk density occurred in primary forests (1.36 $g\ cm^{-3}$), and the maximum in afforested lands (1.53 $g\ cm^{-3}$). As in forests, there were two cases, including organic layer (O) in their measurements of SOC which were discarded from the analysis.

Soil sampling was conducted at only one depth in 73 cases. In 150 cases, the history of land conversion was also provided. The information regarding the type of management applied on each land (the amount and type of fertilizers, irrigation (volume and timing), harvest, type of grazing animals, management schedule, etc.) was seldom available and was not considered as an independent variable in the analysis. In Table 2, the summary of the different types of land-uses (management systems) along with the corresponding number of papers are provided. Natural grassland and primary forest categories had the highest occurrence rate in our database (≈54%). Afforestation and replanted grasslands were the most frequent land-use change categories, with the minimum cases reported for abandoned lands (10 cases or 2.5%).

Table 2. Number of studies, data points and the relative percentages of different land management types

Land-use	*NO of Occurrence*	*Data points*	*Rel. Percentage*
Abandoned Land	9	10	2.54
Afforestation	16	46	11.70
Enclosure Grassland	11	13	3.31
Farmland	28	64	16.28
Natural Grassland	73	135	34.35
Primary Forest	35	76	19.34
Reforestation	7	21	5.34
Replanted Grassland	17	28	7.12
Total	196	393	100

Impact of land management on carbon stocks

The total amount of SOC for different land-uses is provided in Fig. 2. Total SOC at the 20cm depth ranges from 17.49 Mg C ha^{-1} to more than 84 Mg C ha^{-1}. Based on the result, primary forests and reforested areas had significantly higher SOC stocks at the depth of 20cm ($p<0.05$), respectively containing 70.03 (±4.45) Mg C ha^{-1} and 84.38 (±9.01) Mg C ha^{-1} carbon. The lowest level of SOC occurred in replanted grasslands by 17.49 (±1.62) Mg C ha^{-1}, but no significant differences were found between replanted grasslands and enclosure grasslands, farmlands, natural grasslands, and abandoned lands ($p<0.05$).

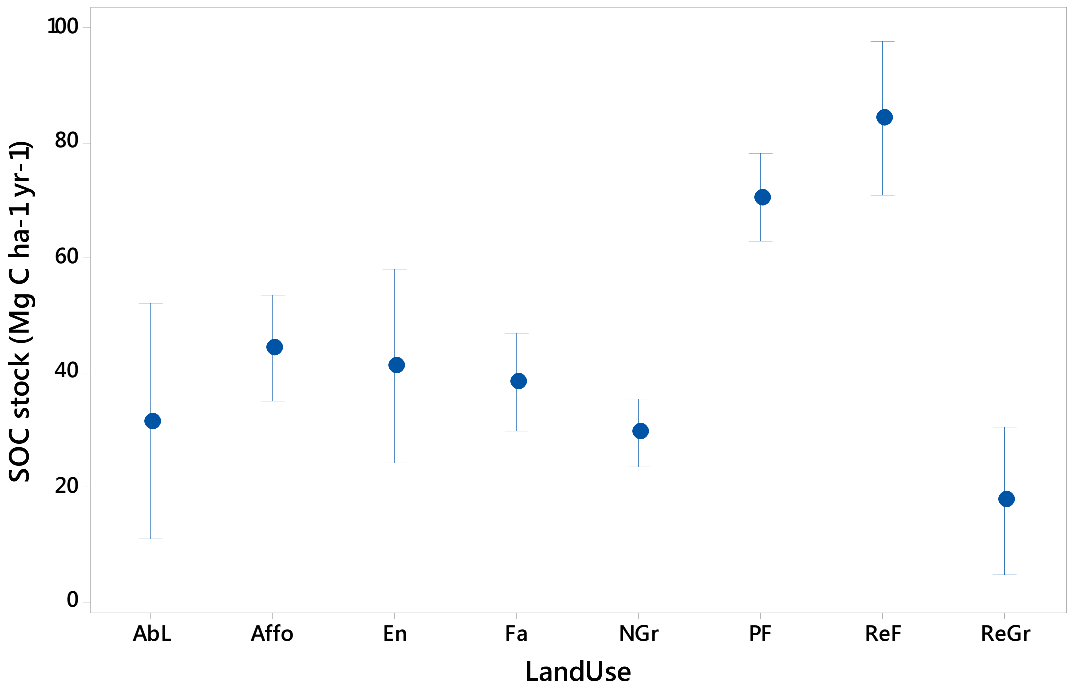

Fig. 2. Average SOC values in different land management systems (land-uses) studied in Iran. Abbreviated words in the graph are: RGr: Replanted Grassland, ReF: Reforestation, PF: Primary Forest, Gr: Grassland, Fa: Farmland, En: Enclosure Grassland, Affo: Afforestation, AbL: Abandoned Land

The SOC differences for all land-use changes are provided in Fig. 3a. There were no significant differences between land-use change categories (p>0.01). However, we further analysed SOC stock changes among farmlands with forest and grassland origins. Our results indicated that farmlands with forest origin have significantly lower carbon stocks compared with their previous land use (-15.2% SOC loss) while those with grassland origin showed no significant changes. The annual changes (accumulation or loss) of SOC in different land-uses are illustrated in Fig. 3b. We again found no significant differences among land-use categories in terms of average annual SOC loss or gain.

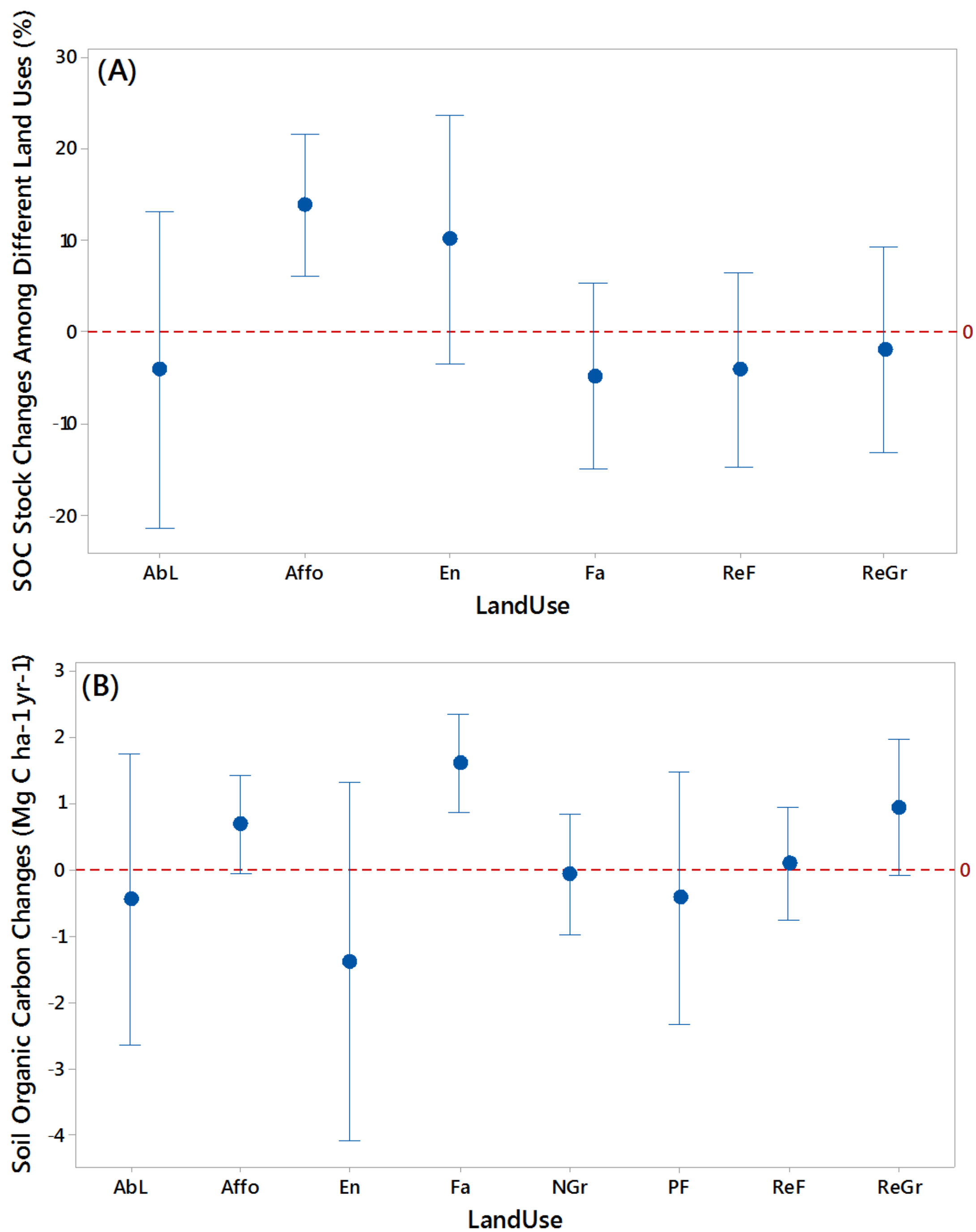

Fig. 3. Average SOC changes in different land conversion categories studied in Iran (A): SOC differences compared with the historic land-use types in percentage; (B): annual SOC gain/loss in different land use categories; Abbreviations used in the graphs are: RGr: replanted grassland, ReF: reforestation, F: primary forest, NGr: natural grassland, Fa: farmland, En: enclosure grassland, Affo: afforestation, AbL: abandoned land, T: total.

Soil carbon input values from litter and fine roots are provided in Table 3. Accordingly, farmlands had significantly higher litter inputs basically because of the application of manure. We did not find any significant differences among other land use categories. As for the SOC input from fine roots, primary forests had significantly higher values while we did not find any significant differences among other land use categories.

Table 3. Summary statistics of the variables of different land-use types

Abbr	land-use type	Number	Precipitation (mm)	Temperature (°C)	Depth (cm)	Soil bulk density (g.cm^{-3})	SOC20 (Mg C h^{-1})	Litter (Mg C h^{-1} y^{-1})	Root (Mg C ha-1 yr-1)	Annual Change (Mg C ha-1 yr-1)
AbL	Abandoned Land	10	531.9	14.3	47.13	1.40 (±0.15)	28.2 (±29)	0.05 (±0.00) ab	0.19 (*) ab	-0.45 (±0.93)
Affo	Afforestation	46	499.4	15.8	30.43	1.58 (±0.24)	42.3 (±34)	3.20 (±0.62) ab	2.01 (±1.75) ab	0.67 (±1.00)
En	Enclosure Grassland	13	360.4	13.6	32.31	1.41 (±0.29)	41.0 (±25)	3.12 (±5.4) ab	1.28 (±0.90) ab	-1.39 (±3.34)
Fa	Farmland	53	430.6	14.8	39.98	1.41 (±0.28)	37.5 (±32)	3.91 (±2.6) a	0.35 (±0.01) b	1.59 (±2.9)
NGr	Grassland	121	332.6	14.8	43.47	1.48 (±0.31)	27.6 (±27)	0.86 (±1.53) b	1.05 (±1.80) ab	-0.08 (±1.9)
PF	Primary Forest	67	916.5	16.4	35.34	1.36 (±0.33)	68.9 (±36)	1.41 (±1.44) ab	2.42 (±2.10) a	-0.42 (±0.6)
ReF	Reforestation	21	827.1	14.7	37.62	1.44 (±0.43)	84.3 (±41)	3.76 (±1.08) ab	*	0.08 (±1.13)
ReGr	Replanted Grassland	24	251.9	17.4	52.5	1.48 (±0.28)	16.7 (±7)	0.11 (±0.11) b	1.34 (1.56) ab	0.92 (±1.68)

SOC equivalent at the depth of 20cm; * indicates no observation.

Effect of different factors on SOC

In order to ascertain which factors affect SOC variations among different land use categories, a forward stepwise regression analysis was performed. According to Table 5, temperature had a significant effect on SOC in primary forests, abandoned lands, reforested lands, and replanted grasslands. Average annual precipitation significantly affected SOC in afforested areas, farmlands, natural grasslands and reforested areas. The total sampling depth had a significant effect on SOC in primary forests, afforested areas, enclosure grasslands, farmlands, natural grasslands and replanted grasslands. Finally, the geographic distribution of different land management systems at different latitudes had a significant effect on SOC in primary forests, abandoned lands, enclosure grasslands, and reforested areas. In total, average annual precipitation, average annual temperature and total depth of sampling affected SOC. In Fig. 4, actual SOC values are plotted against the simulated SOC values based on the formulas provided in Table 4.

Table 4. Results of the forward stepwise regression analysis for the effect of factors on total SOC level at 95% confidence level

Land-use Category	Equations	R^2	Sig.	df
Primary Forest	SOC= -376 - 5.40 T - 0.1026 P + 17.49 L + 0.927 D	39.03	0.000	61
Abandoned Lands	SOC= -733 + 16.37 T + 16.33 L	65.70	0.040	8
Afforestation	SOC= -64.5 + 0.1186 P + 2.279 D	62.25	0.000	43
Enclosure Grassland	SOC= -321.0 + 8.69 L + 2.809 D	78.99	0.000	12
Farmland	SOC= -38.4 + 0.1227 P + 0.945 D	42.06	0.000	42
Natural Grassland	SOC= -14.7 + 0.1134 P + 0.480 D	27.05	0.000	112
Reforestation	SOC= -1992 + 52.3 T - 0.330 P + 44.9 L	58.20	0.002	20
Replanted Grassland	SOC= -48.7 + 2.020 T + 0.1129 P + 0.331 D	56.41	0.001	22
Overall	SOC= -37.7 + 1.99 T + 0.07201 P + 0.899 D	30.97	0.000	208

SOC is the average soil organic carbon; T is temperature (℃); L is latitudes in decimal degrees; P is precipitation (mm); D is the average depth of sampling

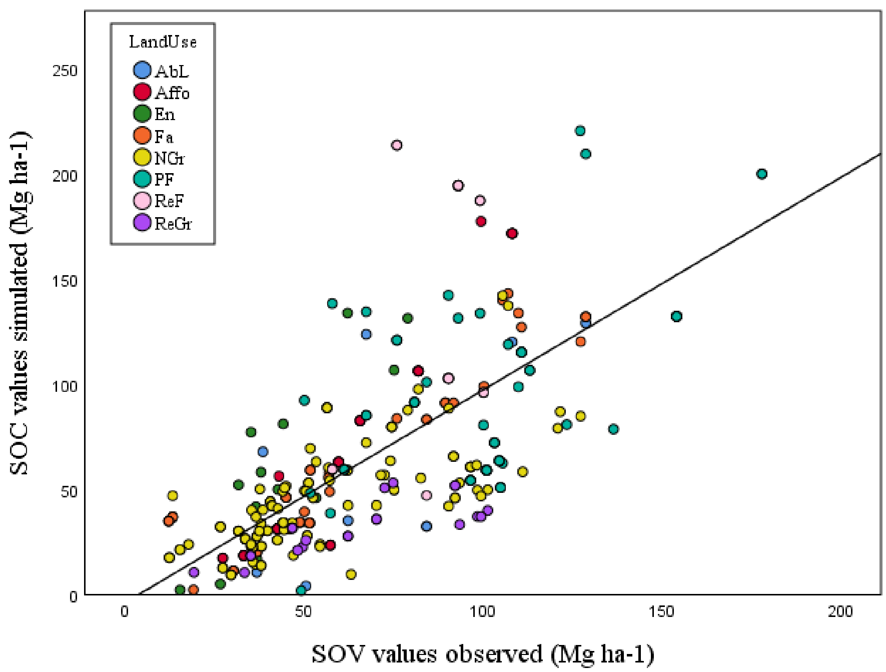

Fig. 4. Simulated vs. observed SOC values at different land use classes, along with the fitted regression line. RGr: Replanted Grassland, ReF: reforestation, PF: Primary Forest, NGr: Natural Grassland, Fa: Farmland, En: Enclosure Grassland, Affo: Afforestation, AbL: Abandoned Land, T: total changes

Using the relationship between SOC, precipitation, temperature and depth, we simulated the SOC variations in Iran as illustrated in Fig. 5. The simulation is carried out at the depth of 20 cm. Data for temperature and precipitation were downloaded from WorldClim dataset available at https://www.worldclim.org/bioclim. According to this map, except for a narrow strip to the north and along the west, the rest of the country has relatively low soil organic carbon stocks. Therefore, it is desirable to develop a systematic and comprehensive approach to protect the country's lands in order to ensure the quantitative and qualitative protection of soil conditions until we can effectively take steps to deal with air pollution and climate change crisis.

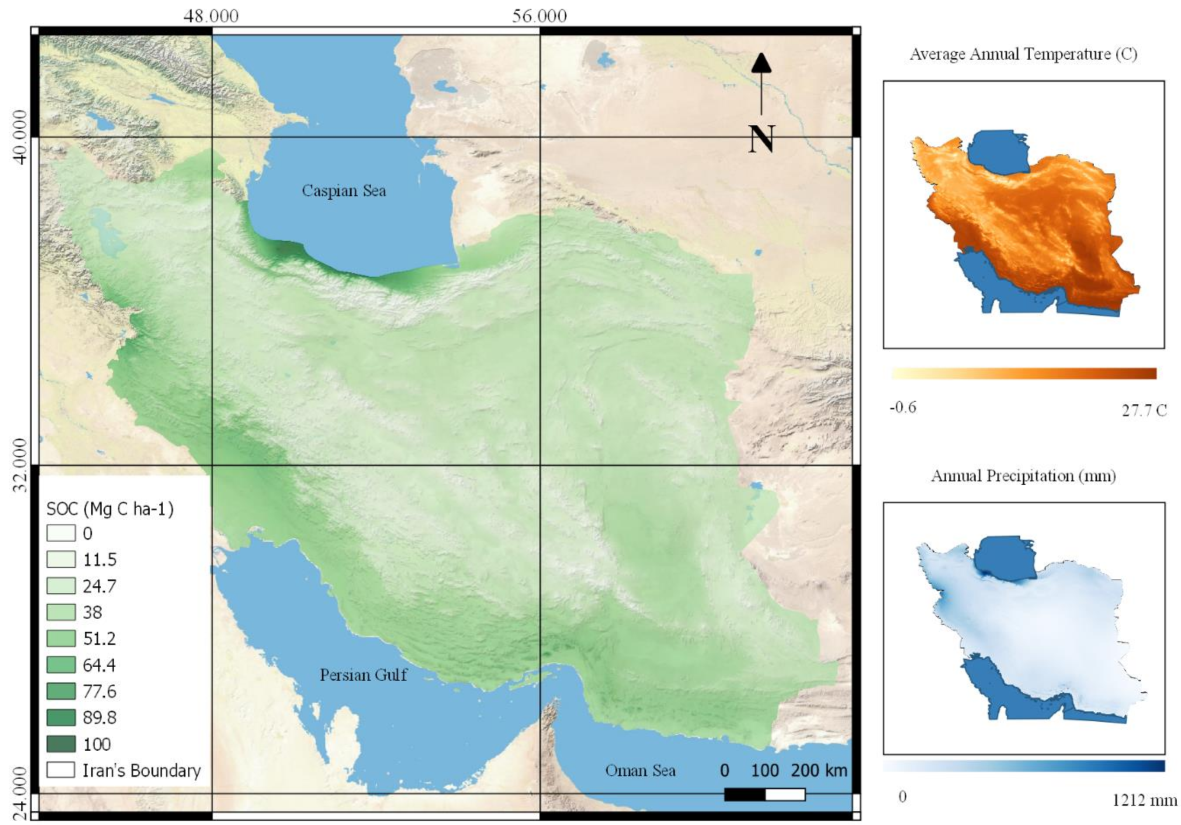

Fig. 5. SOC variations in Iran simulated at the depth of 20 cm

Discussion

SOC changes in different land-uses

This study is an attempt to quantify the impact of land-use change on soil organic carbon stocks. Our results indicated that except for natural forests and reforested areas, there is no significant differences between average SOC stocks of other land-uses categories. The positive impact of reforestation on SOC is also reported in several papers (Kallenbach and Stuart Grandy, 2015; Nobakht *et al.*, 2011; Jahed *et al.*, 2017). The highest SOC value at the depth of 20cm was found by Falahatkar *et al.* (2013) at Deilaman site in a primary forest area in the northern part of Iran. Similarly, the highest SOC value in the reforested areas was 149 Mg C ha^{-1} at Chamestan northern Iran in the work of Jahed *et al.* (2017). Natural forests studied were a combination of cases from both northern and western forests. Lower precipitation and higher temperature of western forests have resulted in a comparatively less dense vegetation cover and hence lower SOC contents. Mixing these two groups of forests resulted in lowering SOC stocks of the natural forest category. However, most of the reforestation cases were located at the northern part of Iran with naturally higher SOC values. For this reason, reforested areas had higher SOC values than natural forests. As for the SOC stock changes, we found no significant evidence on SOC reduction or accumulation among the land-use change categories. Likewise, average annual rate of SOC gain/loss did not show significant differences among different categories. However, by further analysing the data for farmlands (from forest and grassland origins) we found a significant SOC reduction in cases with a historic forest land-use (-15.2%). Same results were found by

Kallenbach and Stuart Grandy (2015). The authors by reviewing 74 papers on the impact of land-use change on SOC found SOC reductions by the conversion of pastures into plantation (-10%), native forest to plantation (-13%), native forest to croplands (-42%), and pasture to croplands (-59%). Our results also indicated that farmlands have significantly higher soil carbon inputs from litter because of the application of chemical fertilizers, plant residue retention and manure application. Gholami *et al.* (2013) also argue that the impact of cropland on carbon gain and loss depends heavily on the type of management applied. Tillage, fertilizer application, choice of crop, cropping management, residue retention, irrigation, mixing grazing with cropping systems, and agroforestry systems can affect SOC (IPCC, 2006). Murty *et al.* (2002), Oğuz *et al.* (2015) and Kallenbach and Stuart Grandy (2015) found that conversion of forest lands into croplands could result in SOC loss. Obtained results indicated that primary forests had significantly higher SOC input from fine roots as 2.42 (±2.10) Mg C ha^{-1} yr^{-1} which is evidently because of its comparatively denser vegetation cover.

Factors affecting SOC

Soil organic carbon is influenced by many factors such as land-management, climate, soil properties, vegetation and land-use history (Wiesmeier *et al.*, 2019; Cui *et al.*, 2005; Deng *et al.*, 2016; Yang *et al.*, 2014). In our dataset, SOC was measured at different depths. We found that sampling depth can significantly affect SOC in different land-uses. Ogle *et al.* (2005) found that sampling depth can explain 15% of SOC variations (7% and 8.5% for values reported as carbon concentration and content) in improved and unimproved grasslands. Conant *et al.* (2001), and Marinho *et al.* (2017) also believe that sampling depth can affect SOC measurement in different land-uses. Many land uses such as forests accumulate a large proportion of their carbon content at the soil surface (IPCC, 2006). In some cases in our dataset, soil samples were taken from two to three depths and homogenized, which could negatively affect the accuracy of measurements. Jobbágy and Jackson (2000) showed that vertical distribution of root tissues and the type of vegetation cover heavily affect carbon distribution in soil profile. Therefore, it appears that for achieving a higher accuracy, SOC in different land-uses should be compared at the same depth to be able to remove the confounding effect of sampling depth on carbon measurement. We followed the procedure proposed by Jobbágy and Jackson (2000) and Deng *et al.* (2016) to convert SOC values to their equivalents at 20cm of soil profile. However, based on the IPCC guidelines for national greenhouse gas inventories, the depth of 30 cm is proposed for comparing SOC in different land-uses (IPCC, 2006). Apparently, each land-use has its own characteristics and behaviour regarding carbon distribution with depth, and there's a need to set different sampling depths for different land-uses. However, there is no accepted reference depths for SOC measurements or we could not find it by the time of writing this manuscript. One of the main factors that is affected by land-use change is soil bulk density. Soil bulk density *per se* influences soil SOC (Shiferaw *et al.*, 2019; Murty *et al.*, 2002; Celik, 2005; Song and Woodcock, 2003). Bulk density differences could not explain the variations in measured SOC values in our study. Contrary to the results of (Zaher *et al.*, 2020; Deng *et al.*, 2016; Laganiere *et al.*, 2010; Carter, 1990), we found no differences between SOC values of different land-use age groups (0-10, 10-20, and 20<). Solar radiation, temperature, and available water affect photo-synthesis, plant respiration and decomposition, thus climate change can lead to changes in net primary production and hence C dynamics in soils (Deng *et al.*, 2014b). Previous land-use, current management system, soil properties and climate variability are four major causes of SOC variations among different areas (IPCC, 2006). We investigated the SOC impact of latitude, precipitation and temperature. Griggs and Noguer (2002) found that 1℃ increase in temperature as the result of climate change could amount to 10% and 3% increase in soil carbon loss in the regions with an annual mean temperature of 5 ℃ and 30 ℃ respectively. Therefore, the author believes that global warming and increase in temperature could result in a considerable reduction of SOC. Similar to our finding Murty *et al.* (2002) showed that land-use change, climatic factors and clay type could explain 55% of SOC changes between different areas. Kirschbaum (1995) found that precipitation, temperature, and elevation can explain 41.5-56.2% of variations in SOC. Therefore, we believe that SOC can be better estimated by combining land-use, soil properties and climate, which is also reported by (Chen *et al.*, 2010).

Conclusion

This study gathered all the information from authentic sources on how land use and land use changes in Iran have affected soil organic carbon stock. As our results indicated, land use change, except for reforestation, has not significantly deteriorated or improved soil organic carbon stock. However, by further analysis croplands, we found that forest conversion to farmlands (compared with grassland conversion into croplands) has led to a significant SOC loss. Converting forests into transient croplands in most cases leads to considerable SOC loss, even though farmers by applying fertilizers and manure are trying to compensate for the loss of SOC and soil fertility. We found that farmlands and natural forests had higher litter and root material inputs, respectively. It was also attempted to analyse which factors can affect SOC. Results suggested that precipitation, temperature and sampling depth can significantly alter SOC. Based on the developed regression equation, we simulated SOC distribution at the depth of 20cm in Iran. Accordingly, except for a narrow strip to the north of country, a considerable proportion of Iran suffers from low SOC levels. Even though increasing SOC in arid areas is an extremely difficult task because of physical limitations, however, maintaining current SOC levels should become a priority for land managers to prevent soil fertility loss and mitigate global warming. We believe that protecting forests and inhibiting forest clear-cutting for croplands should be the first priority in order to prevent soil organic loss in Iran.

Conflict of interest

The authors declare they have no actual or potential competing financial interests.

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Appendix A

References included in the database for meta-analysis

NO	Author	Land use	Lat.	Long.	Site in ran	T(°C)	P(mm)
1	(Abdi &Gaikani, 2015)	Natural Grassland	35.63	50.68	Mighan	13.8	280
2	(Abdi *et al.*, 2008)	Natural Grassland	33.79	49.13	Shazand	14.8	478
3	(Abdi *et al.*, 2009)	Natural Grassland	33.14	50.38	Khansar	13.23	400
4	(Afshar *et al.*, 2010)	Abandoned Land	32.01	50.21	Ardal	15	600
5	(Ahmadi Beni *et al.*, 2015)	Farmland, Natural Grassland	37.7	55.96	Kechik	16.7	482
6	(Ahmadi *et al.*, 2014)	Natural Grassland	32.82	51.1	Aran Bidgol	19.1	129
7	(Ajami *et al.*, 2016)	Abandoned Land, Farmland, Primary Forest	36.76	54.4	Toshan	16	620
8	(Alizadeh *et al.*, 2009)	Natural Grassland	35.26	50.53	Robat karim	16.6	206.4
9	(Alizadeh *et al.*, 2011)	Natural Grassland	35.43	50.88	Saveh	16.6	206.4
10	(Amiri, 2017)	Natural Grassland	27.86	51.57	Gotag	28	3.4
11	(Ariapour *et al.*, 2013)	Natural Grassland	34.13	46.5	Siahkhoor	11.3	621.8
12	(Asadian *et al.*, 2014)	Farmland, Reforestation, Primary Forest	36.23	53.39	Sari	15.9	765.12
13	(Atashnama *et al.* 2017)	Primary Forest	37.15	50.21	Shalman	17.5	1180
14	(Ayoubi *et al.*, 2012)	Abandoned Land, Farmland, Primary Forest	31.51	50.8	Lordegan	15	600
15	(Azadi *et al.*, 2014)	Afforestation, Natural Grassland, Primary Forest	33.51	48.25	Makhmal Kouh	12.7	509
16	(Badehyan *et al.*, 2014)	Reforestation, Primary Forest	36.45	52.08	Chamestan	14	830
17	(Baghdar, 2014)	Natural Grassland	37.38	45.27	Tez Kharab	12.6	229
18	(Bagheri *et al.*, 2016)	Abandoned Land, Enclosure Grassland, Farmland, Natural Grassland	29.2	56.57	Baft	15	247
19	(Bahrami *et al.*, 2013)	Natural Grassland	37.84	45	Khanghah sorkh	11.6	393
20	(Bakhshipour *et al.*, 2013)	Primary Forest, Reforestation	37.13	50.06	Lahijan	17.35	1228
21	(Borj *et al.*, 2014)	Afforestation, Natural Grassland	33.8	52.54	Isfahan	15	114.5
22	(Broum&*et al.*, 2014)	Farmland	36.57	53.13	Samaskandeh	17	672
23	(Falahatkar *et al.*, 2013)	Farmland, Natural Grassland, Primary Forest	36.83	49.81	Deilaman	12.2	1173
24	(Forouzeh *et al.*, 2008)	Replanted Grassland, Natural Grassland	28.58	53.88	Garbiegan, Fasa	20.6	259
25	(Geraei *et al.*, 2016)	Farmland, Natural Grassland, Primary Forest	31.66	50.33	Akaat Basin	13.6	680
26	(Ghanbarian *et al.*, 2015)	Replanted Grassland, Natural Grassland	29.6	52.22	Fars	17.6	420
27	(GharmakherA *et al.*, 2015)	Enclosure Grassland, Natural Grassland	37.18	54.01	Gomishan	16.6	343
28	(Ghasemi Aghbash &Maleki, 2015)	Primary Forest	33.03	47.12	Dehloran	26.27	274.59
29	(Gholami *et al.*, 2013)	Farmland	36.78	58.9	Chenaran	15.2	212.6
30	(Gholami *et al.*, 2014)	Replanted Grassland, Natural Grassland	35.94	49.59	Nodahak	14.1	250
31	(Gudarzi *et al.*, 2015)	Natural Grassland	35.83	50.91	Karaj	10.4	222
32	(Habibian &Salehpour, 2016)	Enclosure Grassland, Natural Grassland	29.83	52.33	Shiraz	18.2	315.7
33	(Haghdoost *et al.*, 2012)	Reforestation, Primary Forest	36.31	51.85	Chamestan	15.8	840
34	(Hasan Nejad *et al.*, 2014)	Natural Grassland	36.6	53.86	Behshahr	17	409
35	(Heidari Safari Kouchi *et al.*, 2016)	Afforestation	31.9	51.08	Chaharmahal	11	443
36	(Heidari *et al.*, 2017)	Farmland, Natural Grassland	31.65	50.13	Rakaat	14.6	536

NO	Author	Land use	Lat.	Long.	Site in ran	T(°C)	P(mm)
37	(Helmi Siasi Farimani *et al.*, 2014)	Farmland	36.98	54.73	Agh ghala		275
38	(Hemmat *et al.*, 2010)	Farmland	32.63	51.66	Research Farm (IUT)	14.5	140
39	(Heshmati *et al.*, 2012)	Farmland, Natural Grassland, Primary Forest	34.01	47.07	Merek	17.7	481
40	(Jafari fotami &Niknahad, 2014)	Natural Grassland	36.78	53.58	Miankale	18.6	535.5
41	(Jafari *et al.*, 2013)	Replanted Grassland, Natural Grassland	*	*	Ahovan, Ivanaki, Sorkh	*	*
42	(Jafari *et al.*, 2016)	Natural Grassland	35.55	50.61	Shahriar	13.5	243
43	(Jafari *et al.*, 2017)	Farmland, Natural Grassland	36.65	53.71	Avard	11.4	459
44	(Jafarian *et al.*, 2012)	Natural Grassland	36.11	53.67	Sari, Kiasar	12.5	375
45	(Jamshidnia *et al.*, 2014)	Afforestation	32.66	48.36	Rimaleh	17.3	500
46	(Joneidi *et al.*, 2015a)	Enclosure Grassland, Natural Grassland	36.2	47.85	Bijar	11.7	439.9
47	(Joneidi *et al.*, 2015b)	Replanted Grassland, Afforestation, Natural Grassland	35.38	52.18	Ivanaki	19.4	120
48	(Karami *et al.*, 2015)	Afforestation, Natural Grassland	36.41	51.91	Chamestan	15.3	864.3
49	(Karami *et al.*, 2015a)	Replanted Grassland	36.11	57.96	Sabzevar	17.6	181
50	(Karimi *et al.*, 2015b)	Farmland, Natural Grassland	30.46	53.1	Safashahr	11.8	191
51	(Kashi *et al.*, 2016)	Farmland, Natural Grassland	35.77	53.32	Shahmirzad	9.5	287
52	(Kashki *et al.*, 2015)	Natural Grassland	35.41	59.93	Zharf	14.5	270
53	(Khoram Del *et al.*, 2016)	Farmland	35.79	59.27	Khorasan Prov.	14.5	260
54	(Khosravi *et al.*, 2015)	Natural Grassland	29.75	56.35	Baghbazm	16	202
55	(Kolahchi *et al.*, 2008)	Natural Grassland	34.8	48.46	Heidareh	11.1	277
56	(Kooch &Bayranvand, 2017)	Primary Forest	36.62	51.21	Kelarabad	15.9	1300
57	(Kooch &Moghimian, 2015)	Farmland, Natural Grassland, Primary Forest	36.55	51.39	Noshahr	15.9	1300
58	(Kooch &Parsapour, 2017)	Primary Forest	36.51	51.47	Neyrang	16.2	1345.3
59	(Lashaniz&*et al.*, 2013)	Replanted Grassland, Natural Grassland	*	*	Kouhdasht, Rimaleh, Roumeshgan	*	*
60	(Mohseni Fashami *et al.*, 2009)	Enclosure Grassland, Natural Grassland	35.91	51.55	Fasham	11	692.5
61	(Mahdavi &Esmaili, 2015)	Replanted Grassland, Natural Grassland	30.81	56.56	Zarand	25	239
62	(Mahdavi *et al.*, 2017)	Natural Grassland	34.88	51.57	Varamin	20.2	128
63	(Mahdavi *et al.*, 2009)	Replanted Grassland	33.38	52.38	Ardestan	18.2	111
64	(Mahdavi *et al.*, 2015)	Natural Grassland	34.7	46.37	Kermanshah	13.3	437
65	(Mahdizadeh *et al.*, 2017)	Replanted Grassland	*	*	Gonabad, Mahvalat	*	*
66	(Mahmoudi *et al.*, 2012)	Natural Grassland	32.33	59.95	Hosein Abad	16	165
67	(Mahmoudi *et al.* 2013)	Abandoned Land, Replanted Grassland, Natural Grassland	37.22	57.61	Meidan	11.8	358.7
68	(Mahmoudi *et al.*2007)	Primary Forest	36.45	51.61	Golband	10.4	753.5
69	(Mirzaei *et al.*, 2013)	Afforestation, Primary Forest	32.72	47.31	Dehloran	25.8	358
70	(Moradi Shahgharyeh &Tahmasebi, 2015)	Enclosure Grassland, Natural Grassland	*	*	Tang Sayyad, a semi-steppe grassland	*	*
71	(Moradi *et al.*, 2015)	Farmland	36.26	59.6	Mashhad	15.1	286

NO	Author	Land use	Lat.	Long.	Site in ran	T(°C)	P(mm)
72	(Moshki *et al.*, 2017)	Afforestation, Natural Grassland	35.58	53.48	Semnan	18.3	139.9
73	(Moslehi *et al.*, 2017)	Primary Forest	36.72	54.35	Shast kalate		649
74	(Naghdi *et al.*, 2014)	Primary Forest	37.55	49.01	Khoje dare	16.5	1065.93
75	(Naghipour *et al.*, 2012)	Enclosure Grassland, Natural Grassland, Farmland, Replanted Grassland	33.26	49.55	Sisab	11.6	270
76	(Naghabipour Borj *et al.*, 2014)	Afforestation, Natural Grassland	32.79	51.53	Isfahan	15	114.5
77	(Narimani *et al.*, 2015)	Afforestation	32.41	51.28	Isfahan	15.8	120
78	(Nobakht *et al.*, 2011)	Afforestation	36.53	52.5	Dehmian	11.9	858
79	(Noormohammadi &Esmailzadeh, 2015)	Primary Forest	36.46	51.78	Galandrood Basin	15.4	1300
80	(Nourbakhsh *et al.*, 2016)	Farmland	36.26	59.6	Mashhad	15.1	286
81	(Olfati *et al.*, 2013)	Primary Forest	29.71	54.71	Yazd	13.3	285.2
82	(Panahian *et al.*, 2013)	Natural Grassland	35.24	52.3	Ivanaki	19.4	120
83	(Panahian *et al.*, 2016)	Natural Grassland	35.34	52.07	Ivanaki	19.4	120
84	(Parsamanesh *et al.*, 2014)	Farmland, Natural Grassland	34.5	46.75	Bilehvar	15.3	370
85	(Parvizi *et al.*, 2016)	Replanted Grassland	28.58	53.88	Garbiegan Fasa	20.6	259
86	(Pato *et al.*, 2016)	Farmland, Primary Forest	36.38	45.28	Sardasht	17.1	965.1
87	(Pilevar *et al.*, 2017)	Afforestation, Natural Grassland	33.51	48.25	Makhmal Kouh	12.7	509
88	(Puladi *et al.*, 2013)	Primary Forest	37.31	49.95	Safrabasteh	11.6	1200
89	(Rafiei Jahed *et al.*, 2017)	Reforestation, Primary Forest	36.31	51.85	Chamestan	15.8	818
90	(Raheb *et al.*, 2017)	Natural Grassland	*	*	Three different climatic regions of Iran	*	*
91	(Ranjbari Karimian *et al.*, 2013)	Natural Grassland	35.66	50.55	Akhtarabad	13.76	236.76
92	(Riahi Samani &Raiesi, 2014)	Enclosure Grassland, Natural Grassland	*	*	Boroujen, Sheida, Sabzkouh	*	*
93	(Rizvandi *et al.*, 2017)	Primary Forest	36.61	51.54	Noshahr	15.9	1300
94	(Rosta *et al.*, 2013)	Primary Forest	29.25	52.5	Firouzabad	16.7	559
95	(Rouhi Moghadam, 2014)	Abandoned Land, Afforestation	36.41	51.91	Chamestan	15.8	840
96	(Saeidifar *et al.*, 2016)	Farmland	37.07	57.45	Agh ghala	18.3	360
97	(Saremi *et al.*, 2015)	Natural Grassland	35.91	51.48	Tehran	15.2	696.2
98	(Shahraki *et al.*, 2016)	Abandoned Land, Farmland, Reforestation, Primary Forest	31.84	50.81	Ardal	15	530
99	(Shahrokh *et al.*, 2016)	Natural Grassland	36.5	45.76	Azarbijan Gharbi	11.5	450.9
100	(Shahrokh *et al.*, 2017)	Replanted Grassland, Natural Grassland	36.5	45.76	Mahabad, Khalifan	14.2	350.9
101	(Sheidaei Karkaj *et al.*, 2015)	Enclosure Grassland, Natural Grassland	36.59	54.47	Charbagh	16.6	305
102	(Sheidaye Karkaj *et al.*, 2013)	Replanted Grassland, Natural Grassland	37.43	55.09	Chaparghoime	18.1	250
103	(Soleimani *et al.*, 2017)	Reforestation, Primary Forest	36.52	53.28	Darabkola	12.5	733
104	(Souri *et al.*, 2016)	Enclosure Grassland, Natural Grassland	33	48.01	Zagheh	13.7	364
105	(Naseri *et al.*, 2016)	Abandoned Land, Replanted Grassland, Natural Grassland	36.12	59.62	Kardeh	9	353
106	(Nosrati. 2011)	Natural Grassland, Farmland	36.09	50.62	Savojbolagh. Zidasht basin	14	460
107	(Nasri *et al.*, 2016)	Natural Grassland	35.63	50.68	Melard	15	171.69

NO	Author	Land use	Lat.	Long.	Site in ran	T(°C)	P(mm)
108	(Tabalvandi *et al.*, 2010)	Abandoned Land, Primary Forest	36.33	52.08	Nomeh	16.1	640
109	(Tamartash *et al.* 2012)	Natural Grassland	36.3	54.17	Sem	14.4	140
110	(Tavakoli, 2016)	Natural Grassland	*	*	Deyhuk,Se Farsakh, Khur, Dehshur, Halvan, Joriz, Jams	*	*
111	(Vanaee *et al.*, 2017)	Natural Grassland	35.42	47.45	Dehgolan	10.9	440
112	(Vahdi &Bijani Nejad, 2015)	Farmland, Primary Forest	36.53	52.13	Nour	16.4	1097
113	(Vahdi *et al.*, 2015)	Primary Forest	36.53	51.95	Nour	18.1	1293.5
114	(Vahedi, 2017)	Primary Forest	36.56	53.03	Nour	16.1	1293
115	(Varamesh *et al.*, 2011)	Afforestation, Natural Grassland	35.7	51.16	Chitgar forest park	18.4	232
116	(Varamesh *et al.*, 2014)	Afforestation, Natural Grassland	35.7	51.16	Chitgar forest park	18.4	232
117	(Vazirian *et al.*, 2015)	Replanted Grassland, Natural Grassland	37.23	54.48	Incheborun	17.9	304
118	(Yousefian *et al.*, 2011)	Enclosure Grassland, Natural Grassland	36.14	54.4	Shahtappeh	15.4	213
119	(Z&*et al.*, 2016)	Primary Forest	*	*	Rimele, Kouhdasht	*	*
120	(Zarin Kafsh *et al.*, 2015)	Farmland, Natural Grassland	*	*	Garmab, Kashkevar, Gharpuz Abad	*	*

Cells filled with an asterisk symbol indicate that the corresponding paper has more than one study site

References

Barančíková, G., Makovníková, J. and Halas, J., 2016. Effect of land use change on soil organic carbon. Agriculture (Pol'nohospodárstvo), 62(1), pp.10-18.

Burke, I.C., Yonker, C.M., Parton, W.J., Cole, C.V., Flach, K. and Schimel, D.S., 1989. Texture, climate, and cultivation effects on soil organic matter content in US grassland soils. Soil science society of America journal, 53(3), pp.800-805.

Carter, M.R., 1990. Relative measures of soil bulk density to characterize compaction in tillage studies on fine sandy loams. Canadian Journal of Soil Science, 70(3), pp.425-433.

Cates, A.M., Ruark, M.D., Grandy, A.S. and Jackson, R.D., 2019. Small soil C cycle responses to three years of cover crops in maize cropping systems. Agriculture, Ecosystems & Environment, 286, p.106649.

Celik, I., 2005. Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. Soil and Tillage research, 83(2), pp.270-277.

Chen, J., Elsgaard, L., van Groenigen, K.J., Olesen, J.E., Liang, Z., Jiang, Y., Lærke, P.E., Zhang, Y., Luo, Y., Hungate, B.A. and Sinsabaugh, R.L., 2020. Soil carbon loss with warming: New evidence from carbon‐degrading enzymes. Global change biology, 26(4), pp.1944-1952.

Chen, S., Huang, Y., Zou, J., Shen, Q., Hu, Z., Qin, Y., Chen, H. and Pan, G., 2010. Modeling interannual variability of global soil respiration from climate and soil properties. Agricultural and Forest Meteorology, 150(4), pp.590-605.

Conant, R.T., Paustian, K. and Elliott, E.T., 2001. Grassland management and conversion into grassland: effects on soil carbon. Ecological applications, 11(2), pp.343-355.

Cui, X., Wang, Y., Niu, H., Wu, J., Wang, S., Schnug, E., Rogasik, J., Fleckenstein, J. and Tang, Y., 2005. Effect of long-term grazing on soil organic carbon content in semiarid steppes in Inner Mongolia. Ecological Research, 20(5), pp.519-527.

Dai, W. and Huang, Y., 2006. Relation of soil organic matter concentration to climate and altitude in zonal soils of China. Catena, 65(1), pp.87-94.

Davidson, E.A. and Janssens, I.A., 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature, 440(7081), pp.165-173.

Deng, L., Shangguan, Z.P. and Sweeney, S., 2014a."Grain for Green"driven land use change and carbon sequestration on the Loess Plateau, China. Scientific Reports, 4(1), pp.1-8.

Deng, L., Wang, K.B. and Shangguan, Z.P., 2014b. Long-term natural succession improves nitrogen storage capacity of soil on the Loess Plateau, China. Soil Research, 52(3), pp.262-270..

Deng, L., Zhu, G.Y., Tang, Z.S. and Shangguan, Z.P., 2016. Global patterns of the effects of land-use changes on soil carbon stocks. Global Ecology and Conservation, 5, pp.127-138.

Falahatkar, S., Hosseini, S.M., Ayoubi, S. and Salman, M.A., 2013. The impact of primary terrain attributes and land cover/use on soil organic carbon density in a region of Northern Iran.

Falkowski, P., Scholes, R.J., Boyle, E.E.A., Canadell, J., Canfield, D., Elser, J., Gruber, N., Hibbard, K., Högberg, P., Linder, S. and Mackenzie, F.T., 2000. The global carbon cycle: a test of our knowledge of earth as a system. science, 290(5490), pp.291-296.

Gholami, A., Asgari, H.R. and Zeinali, E., 2013. Effects of short-term soil management practices on soil carbon and nitrogen sequestration and some physical and chemical characteristics as well as soil aggregate stability in Khorasan Razavi Province, Iran. International Journal of Agriculture and Crop Sciences (IJACS), 5(21), pp.2622-2629.

Griggs, D.J. and Noguer, M., 2002. Climate change 2001: the scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change. Weather, 57(8), pp.267-269.

He, Y., Trumbore, S.E., Torn, M.S., Harden, J.W., Vaughn, L.J., Allison, S.D. and Randerson, J.T., 2016. Radiocarbon constraints imply reduced carbon uptake by soils during the 21st century. Science, 353(6306), pp.1419-1424.

Heimann, M. and Reichstein, M., 2008. Terrestrial ecosystem carbon dynamics and climate feedbacks. Nature, 451(7176), pp.289-292.

Heshmati, G.A., 2012. Vegetation characteristics of four ecological zones of Iran. International Journal of plant production, 1(2), pp.215-224.

Houghton, R.A., Hackler, J.L. and Lawrence, K.T., 1999. The US carbon budget: contributions from land-use change. Science, 285(5427), pp.574-578.

IPCC., 2006. 2006 IPCC guidelines for national greenhouse gas inventories. Solid Waste Disposal, 5(2).

Jobbágy, E.G. and Jackson, R.B., 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological applications, 10(2), pp.423-436.

Kallenbach, C. & Grandy, S., 2012. Litter decomposition dynamics following land-use change are driven by land-use legacies.

Kallenbach, C.M. and Stuart Grandy, A., 2015. Land‐use legacies regulate decomposition dynamics following bioenergy crop conversion. Gcb Bioenergy, 7(6), pp.1232-1244.

Kirschbaum, M.U., 1995. The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage. Soil Biology and biochemistry, 27(6), pp.753-760.

Laganiere, J., Angers, D.A. and Pare, D., 2010. Carbon accumulation in agricultural soils after afforestation: a meta-analysis. Global change biology, 16(1), pp.439-453.

Lal, R., 2004, July. The potential of carbon sequestration in soils of south Asia. In Conserving Soil and Water for Society: Sharing Solutions, 13th International Soil Conservation Organisation Conference, Brisbane, paper (No. 134, pp. 1-6).

Lal, R., 2020. Soil organic matter content and crop yield. Journal of Soil and Water Conservation, 75(2), pp.27A-32A.

Marinho, M.A., Pereira, M.W., Vázquez, E.V., Lado, M. and González, A.P., 2017. Depth distribution of soil organic carbon in an Oxisol under different land uses: stratification indices and multifractal analysis. Geoderma, 287, pp.126-134.

Mendelsohn, R. and Sohngen, B., 2019. The Net Carbon Emissions from Historic Land Use and Land Use Change. Journal of Forest Economics, 34(3-4), pp.263-283.

Molina, L.G., Moreno Pérez, E.D.C. and Pérez, A.B., 2017. Simulation of soil organic carbon changes in Vertisols under conservation tillage using the RothC model. Scientia Agricola, 74(3), pp.235-241.

Murty, D., Kirschbaum, M.U., Mcmurtrie, R.E. and Mcgilvray, H., 2002. Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. Global Change Biology, 8(2), pp.105-123.

Nobakht, A., Pourmajidian, M. and Hojjati, S.M., 2011. A comparison of soil carbon sequestration in hardwood and softwood monocultures (case study: Dehmian Forest Management Plan, Mazindaran). Iranian Journal of forest, 3(1), pp.13-23.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J., 2000. Land use, land-use change and forestry: a special report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Ogle, S.M., Breidt, F.J. and Paustian, K., 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry, 72(1), pp.87-121.

Oğuz, İ., Koçyİğİt, R. and Erşahİn, S., 2015. The effect of range management on soil carbon content in degraded soil. Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Dergisi, 32(3), pp.133-137.

Pulleman, M.M., Bouma, J., Van Essen, E.A. and Meijles, E.W., 2000. Soil organic matter content as a function of different land use history. Soil Science Society of America Journal, 64(2), pp.689-693.

Jahed, R.R., Fakhari, M.A., Eslamdoust, J., Fashat, M., Kooch, Y. and Hosseni, S.M., 2017. Restoration of degraded forest using native and exotic species: investigation on soil productivity and stand quality (case study: Chamestan, Mazandaran province). Iranian Journal of Forest and Poplar Research, 25(3).

Raich, J.W. and Schlesinger, W.H., 1992. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. Tellus B, 44(2), pp.81-99.

Sainepo, B., Gachene, C. and Karuma, A., 2018. Effects of Land Use and Land Cover changes on Soil Organic Carbon and Total Nitrogen Stocks in the Olesharo Catchment, Narok County, Kenya. Journal of Rangeland Science, 8(3), pp.296-308.

Schmidt, M.W., Torn, M.S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I.A., Kleber, M., Kögel-Knabner, I., Lehmann, J., Manning, D.A. and Nannipieri, P., 2011. Persistence of soil organic matter as an ecosystem property. Nature, 478(7367), pp.49-56.

Schober, P., Boer, C. and Schwarte, L.A., 2018. Correlation coefficients: appropriate use and interpretation. Anesthesia & Analgesia, 126(5), pp.1763-1768.

Schulp, C.J., Nabuurs, G.J. and Verburg, P.H., 2008. Future carbon sequestration in Europe—effects of land use change. Agriculture, Ecosystems & Environment, 127(3-4), pp.251-264.

Schulte, E.E. and Hoskins, B., 1995. Recommended soil organic matter tests. Recommended Soil Testing Procedures for the North Eastern USA. Northeastern Regional Publication, 493, pp.52-60.

Shiferaw, A., Yimer, F. and Tuffa, S., 2019. Changes in Soil Organic Carbon Stock Under Different Land Use Types in Semiarid Borana Rangelands: Implications for CO2 Emission Mitigation in the Rangelands. J Agri Sci Food Res, 9(254), p.2.

Song, C. and Woodcock, C.E., 2003. A regional forest ecosystem carbon budget model: impacts of forest age structure and landuse history. Ecological Modelling, 164(1), pp.33-47.

Tisdall, J.M. and Oades, J., 1982. Organic matter and water-stable aggregates in soils. Journal of soil science, 33(2), pp.141-163.

Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Lützow, M., Marin-Spiotta, E., van Wesemael, B., Rabot, E., Ließ, M., Garcia-Franco, N. and Wollschläger, U., 2019. Soil organic carbon storage as a key function of soils-a review of drivers and indicators at various scales. Geoderma, 333, pp.149-162.

Yang, R., Su, Y., Wang, M., Wang, T., Yang, X., Fan,

G. and Wu, T., 2014. Spatial pattern of soil organic carbon in desert grasslands of the diluvial-alluvial plains of northern Qilian Mountains. Journal of Arid Land, 6(2), pp.136-144.

Yang, Y., Mohammat, A., Feng, J., Zhou, R. and Fang, J., 2007. Storage, patterns and environmental controls of soil organic carbon in China. Biogeochemistry, 84(2), pp.131-141.

Zaher, H., Sabir, M., Benjelloun, H. and Paul-Igor, H., 2020. Effect of forest land use change on carbohydrates, physical soil quality and carbon stocks in Moroccan cedar area. Journal of environmental management, 254, p.109544.

تغییرات کربن آلی خاک در واکنش به تغییرات کاربری اراضی در ایران

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چکیده. کاربری اراضی و تغییرات آن به صورت مستقیم بر کربن آلی خاک اثر می‌گذارد. مدیریت نامناسب اراضی می‌تواند به هدررفت کربن خاک منجر شده و اثر تشدید کننده‌ای بر گرمایش جهانی داشته باشد. با وجود مدارک فراوان از وضعیت کربن آلی خاک در ایران، هنوز منبعی کامل که به جمع بندی این مدارک پرداخته باشد موجود نیست. بنابراین، داده‌ها از ۱۲۰ مقاله و ۳۹۳ نقطه، در مورد کاربری اراضی و تغییرات کربن آلی خاک گردآوری شد. آنالیز رگرسیون گام به گام جهت تجزیه و تحلیل رابطه کربن آلی خاک با بارش سالانه، میانگین دمای سالانه، عرض جغرافیایی و میانگین عمق نمونه برداری استفاده شد. ضریب همبستگی پیرسون بین کربن الی خاک و سایر عوامل محاسبه شد. بر اساس نتایج، اراضی جنگلی و اراضی جنگلی احیا شده به صورت معنی‌داری کربن بیشتری در عمق ۲۰ سانتی‌متری خود داشتند که بالغ بر ۷۰/۰۳ و ۸۴/۳۸ تن کربن بر هکتار بود در حالی که سایر کاربری‌های مورد بررسی تغییر معنی‌داری در خصوص حجم توده کربن و نرخ سالانه تغییرات کربن نشان ندادند. اما در میان اراضی کشاورزی، کاهش معنی‌داری در اراضی با سابقه جنگلی (۱۵/۲- درصد) در مقابل اراضی با سابقه مرتعی دیده شد. نتایج نشان داد که اراضی کشاورزی و جنگلی بالاترین ورودی کربن از لاشبرگ و ریشه را دارند. با ارزیابی اثرات عوامل مختلف بر کربن با استفاده از رگرسیون پیش رونده مشخص شد که ۳۱ درصد از واریانس توده کربن خاک را می‌توان با عوامل بارش، دما، عرض جغرافیایی و عمق نمونه‌برداری توجیه کرد. با استفاده از معادله به دست آمده، تغییرات کربن آلی خاک در ایران شبیه‌سازی شد که نشان می‌دهد به جز نوار باریکی در شمال کشور، سایر مناطق ایران از مقادیر پایین کربن آلی خاک رنج می‌برند.

کلمات کلیدی: کربن، کاربری اراضی، متاآنالیز، پوشش اراضی، هدررفت کربن آلی خاک