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Original Article

Long-Term Temporal Variation of Land Use Transition on Soil Carbon Stocks in Mediterranean Karst Ecosystems

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ABSTRACT

Accelerating urbanization and unplanned excessive human pressure are increasing changes in major land use. These transitions cause long-term negative transformations in rural systems. This study was conducted to examine the changes in some soil properties and carbon stocks of lands that were converted from forest to cropland 30 years ago in ten different villages in the Karaisalı district of Adana, Türkiye. A total of 360 disturbed and undisturbed soil samples were taken from two depth levels (0–30 cm and 30–60 cm) from the soil pits in the adjacent forest and converted to cropland and agricultural areas. Soil organic carbon and bulk density analyses were performed on all soil samples. According to the data obtained from the topsoil (0–30 cm) 101.56 tC ha^{-1}, 69.06 tC ha^{-1}, and 66.25 tC ha^{-1} carbon were stored in the topsoil of the forest, and converted to cropland and agricultural area, respectively. There has been an average of 32% reduction in soil carbon stocks in converted cropland from degraded forest areas. Dramatic reduction in carbon stocks occurred in the topsoil (0–30 cm). Policymakers need to plan their land-use management policies to take into account the ecological consequences of the land-use transition.

Keywords: cropland, degradation, karst forest, land transition, land use type, soil carbon

Introduction

Land use changes have direct and indirect effects on the natural components of the environment such as soil, water, air, and biodiversity. Therefore, land use changes are considered one of the most important indicators of land degradation and global environmental changes (Babur et al., 2021a; Scherr, 1999). In the last two decades, research on determining reliable scenarios for the future and monitoring the change in global and local environmental land use has been very popular. In this direction, multidisciplinary and international research has been made and continues to be done on international platforms and at many different scales.

The 2030 Agenda for Sustainable Development has been adopted by the United Nations General Assembly to restore degraded soils, aiming to achieve land degradation (UNGA, 2015). Therefore, achieving sustainable soil management towards achieving the Sustainable Development Goals (SDGs) will depend on the sustainable use and conservation of natural resources, including limited and fragile soil resources, particularly on food, health, water, climate, and land management SDGs (Jónsson et al., 2016).

Soil organic carbon (SOC) stock, one of the world's most important natural resources is central to the composition of the soil, water, and air resources and supports critical soil-based ecosystem services (Adhikari & Hartemink, 2016; Babur et al., 2021b; Dindaroğlu et al., 2022; Smith et al., 2013). Establishing a reasonable SOC balance was one of the main agenda items at the COP21 Climate Summit in Paris in December 2015. Therefore, the SOC stock has been proposed as an indicator for monitoring land and soil degradation and a globally applicable indicator for land and soil degradation within the SDGs framework (Lorenz & Lal, 2016). These land conversions cause negative ecological impacts on rural land sustainability; in the long run, it causes food security to be adversely affected (Long & Liu, 2016).

Karst ecosystems in arid–semiarid regions are very important and sensitive to carbon management. It was determined that there was a capacity increase in carbon stocks by up to 68% in karst-depressed areas compared to other areas. Forest ecosystems are more stable than others in sequestering carbon (Dindaroglu et al., 2019).

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Due to the poor soil and water conservation capabilities of karst ecosystems and their susceptibility to erosion, karst soils may experience rapid and complex biogeochemical processes involving carbon. It suggests that pedogenic carbonate is rapidly dissolved and then redeposited in karstic soil, particularly in the overcultivated layers. These results demonstrated that SOC is both unstable and vulnerable to changes in land use in karst regions (Qin et al., 2022). One of the reasons that negatively affect SOC is the destruction of forest areas and improper land use. As a result of land degradation, soil functions, especially soil productivity, will be weakened. For this, first of all, it is necessary to establish land use policies and to determine the planning principles of basins within the framework of these policies (Cagnarini et al., 2019; Erol, 2007). Gebremedhin et al. (2018) found significant differences between changes in land use and soil properties in their research. The bulk density has varied over the past 20 years. The values of soil chemical properties such as electrical conductivity, SOC, total nitrogen, usable phosphorus, and usable potassium were found to be higher in pasture areas compared to all cultivated areas.

This research focused on the study of land use transitions, especially the transition from forest to agricultural use. Land use changes are determined by the interaction of natural and socioeconomic factors in time and space and are driven by many factors. For this reason, besides monitoring and determining land use changes, it is important to explain the guiding factors and their interactions within the scope of cause–effect relationships to understand the main causes of these changes. In addition, as a result of the changes in the guiding factors, obtaining reliable scenarios for possible future land use changes plays a vital role in taking appropriate plan decisions. This research was carried out to determine how some soil carbon stocks are affected in the semiarid karstic ecosystem in the Mediterranean region, which was converted from forest to cropland by cadastral applications 30 years ago.

Material and Methods

Study Site

The research area is Başkıf, Bekirli, Çorlu, Etekli, Gildirli, Kaledağ, Kıralan, Kocaveliler, Maraşlı, and Nuhlu villages of Karaisalı district of Adana province. Karaisalı is located between 37° North parallel and 35° East meridian. Karaisalı has a warm and temperate climate (Figure 1A–D). In winter, there is much more rainfall than in summer. According to Köppen–Geiger, the climate is Cold Semi-Arid (Csa) (semiarid). This indicates a climate with mild winters and very hot and dry summers. The annual average temperature of the Karaisalı district is 15.56°C. The annual total rainfall is 972 mm (Anonymous, 2021). The hottest month of the year in Karaisalı is August with 26.4°C. The lowest

Figure 1.
Location of the Study Site (A), Degraded Karst Forest (B), Converted to Crop Land (C), and Cropland (D).

temperature is 0.3 in January. The amount of average precipitation is 81 mm (Table 1).

In the research area, there are species adapted to the Mediterranean habitat, predominantly, red pine. The main species included in the forest ecosystems in the field surveys are *Pinus brutia* Ten., *Quercus cerris, Juniperus excelsa, Juniperus oxycedrus, Platanus orientalis, Populus alba, Acaciacyanophylla, Cupressus sempervirens, Cercis siliquastrum, Quercus coccifera, Palichurus* L., *Pistacia terebinthus, Olea oleaster, Laurus nobilis, Phillyrea latifolia* L., *Sytrax officinalis* L., *Santalum album, and Nerium oleander*. Terra rossa soil type dominates the study area (Previtali et al., 2017). In the basin that covers the study area, the tertiary is represented by sedimentary rocks deposited in the Oligocene–Pliocene time interval and unconformably overlies a rough topography formed by Paleozoic–Mesozoic basement rocks forming the Taurus orogenic belt. This topography affected the sedimentation in Miocene and characterizes the completely terrestrial river and lake environment in the Oligocene–Early Miocene phase, from the valleys and depressions at the edge of the basin (Schmidt, 1961). Karaisalı Formation consists of white-cream-colored, algae, coral, gastropods, lamellibranch, echinaceous, and most massive reefal limestones. Also, pack stones containing fragments of algae and coral detached from the core of the reef are common. As it progresses toward the basin, an increase in planktic foraminifera (*Globigerina* sp.) is observed. The Karaisalı limestone outcropping in the study area has a durable feature and has formed extremely steep slopes topographically. At these levels, especially in the uppermost parts of the succession, many large and small karst melting voids and lapse and squares are observed (Bulut, 1998). All of the study areas are located on the clastic and carbonate rock formation, which forms the Karaisalı karst formations (Figure 2).

Soil Sampling

The forest cadastre of the Karaisalı district of Adana province has been completed in 1992 in ten villages (Başkıf, Bekirli, Çorlu, Etekli, Gildirli, Kaledağ, Kıralan, Kocaveliler, Maraşlı, and Nuhlu villages) chosen as

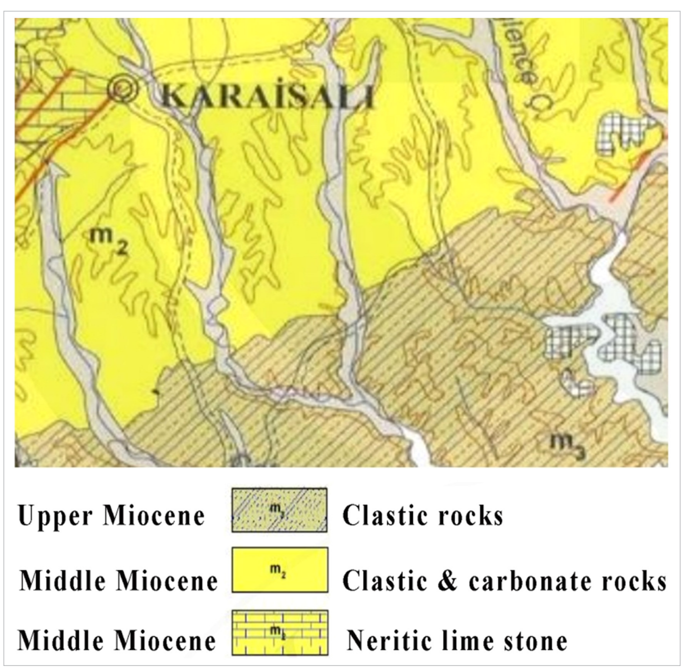

Figure 2.
Geology of Study Sites (MTA, 2022).

Table 1.
The Climate Data of the Study Site (Anonymous, 2021)

	January	February	March	April	May	June	July	August	September	October	November	December
Average temperature (°C)	4.5	6	9.7	13.9	18.5	23.1	26.4	26.4	22.8	17.7	11.3	6.5
Minimum temperature (° C)	0.3	1.1	3.9	7.7	12.1	16.6	19.9	20.3	16.6	11.9	6.3	2.4
Maximum temperature (° C)	9.3	11.3	15.2	19.3	23.8	28.6	32.4	32.3	28.9	23.7	17.2	11.6
Precipitation (mm)	141	115	106	89	78	41	29	30	33	45	93	172
Moisture (%)	71%	70%	67%	66%	64%	59%	57%	58%	56%	56%	61%	68%

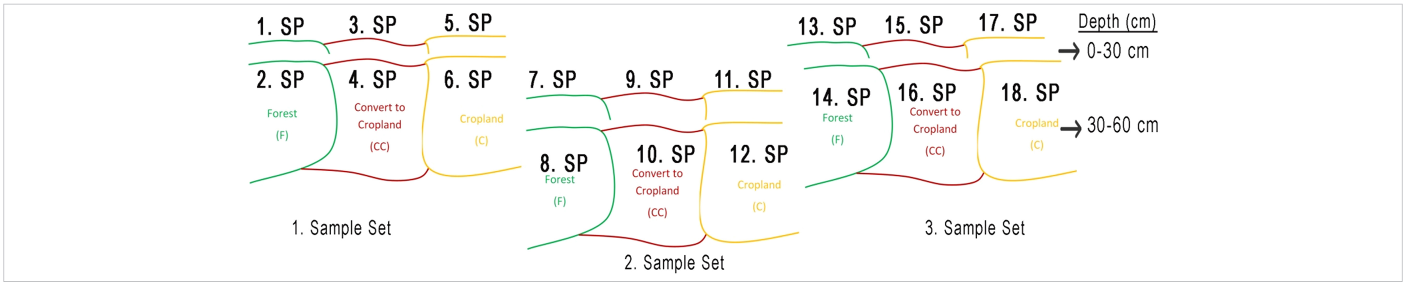

Figure 3.
Sampling Point (SP) Method.

sample areas. In these villages, the areas that are taken out of the forest boundary have been determined by the 2/B article of forest law no. 6831. A total of 90 soil pits were dug from three different land use types (forest, 2/B, and Cropland) adjacent to each other in each village. A total of 180 disturbed and 180 undisturbed soil samples were taken from two depth levels (0–30 cm, 30–60 cm) from the soil pits. Soil samples were collected according to the International Co-operative Programme (ICP) Manual (UNECE, 2003) in forest and Area-Frame Randomized Soil Sampling (AFRSS) methodology (EC, 2009; IPCC, 2003; Stolbovoy et al., 2007) (Figure 3).

Laboratory Analysis

Organic matter and bulk density analyzes were performed on the soils collected from the study area (Table 2).

Calculation of Total Soil Organic Carbon Stocks

Soil organic carbon stocks were calculated using the following formula based on AFRSS method (1) (Stolbovoy et al., 2007):

$$\mathrm{TSOC} = \sum(\mathrm{SOC}*\mathrm{BD}*\mathrm{D}*(1-\mathrm{frag}))*\mathrm{Ap} \quad (1)$$

where,

TSOC: total SOC stocks (kg/m^2), SOC: soil organic carbon (%), BD: bulk density (kg/m^3), D: soil depth (cm), Ap: area of the plot (m^2), frag: volume of coarse (larger than 2 mm diameter stone) fragments (% of mass or stone cm^3/soil cm^3). In the study area, the frag value was evaluated as none due the inhomogeneous stoniness in the soil profiles did not represent the selected Karst area.

Statistical Analysis

Under the 2/B article of Forest Law No. 6831, descriptive statistical analyses were made for the physical and chemical properties of the village based on the analysis of the soil samples taken from the lands removed from the forest (degraded area) and the adjacent forest and agricultural lands. Whether the values obtained as a result of the analyses show a normal distribution based on villages was tested with the Kolmogorov–Smirnov analysis method. Duncan's test, one of the one-way analyses of variance, was used to compare independent group differences. The statistical significance level was accepted as $p < .05$.

Results

Descriptive statistics of some soil characteristics that play an active role in the decomposition processes in the forest (F), converted to cropland (CC), and cropland (C) land use areas are presented in Tables 3 through 5. Soil analysis in the forest area indicated that SOC fluctuated between 0.78% and 6.94%, and BD varied between 1.04 (g/cm^3) and 1.83 (g/cm^3) (Table 3). In the converted to cropland area (CC), SOC ranged between 0.54% and 4.51%. Bulk density fluctuated between 1.24 (g/cm^3) and 1.88 (g/cm^3) (Table 4). In the cropland area, SOC varied between 0.44% and 4.13%. Bulk density ranged between 1.40 (g/cm^3) and 1.94 (g/cm^3) (Table 5). Vermez et al. (2018) in their research on karst ecosystems determined that the soils developed on the fossiliferous and

Table 2.
Soil Analysis Protocols

Soil Properties	Abbreviations	Unit	Reference
Organic carbon	OC	%	Walkley and Black (1934)
Bulk density	BD	(g/cm^3)	Blake (1965); Irmak (1954)

Table 3.
Descriptive Statistical Analysis Results of Topsoil (0–30) of Forest Areas

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Standard Error
SOC (%)	0.78	6.94	3.08	0.33
BD (g/cm^3)	1.04	1.83	1.50	0.03

Note: BD = Bulk density; SOC = Soil organic carbon stocks.

Table 4.
Descriptive Statistical Analysis Results of Topsoil (0–30) of Converted to Cropland Areas

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Standard Error
SOC (%)	0.54	4.51	1.62	0.17
BD (g/cm^3)	1.24	1.88	1.65	0.03

Note: BD = Bulk density; SOC = Soil organic carbon stocks.

Table 5.
Descriptive Statistical Analysis Results of Topsoil (0–30) of Cropland Areas

	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Standard Error
SOC (%)	0.44	4.13	1.48	0.15
BD (g/cm^3)	1.40	1.94	1.67	0.02

Note: BD = Bulk density; SOC = Soil organic carbon stocks.

porous limestone bedrock are moderately basic (pH 8.1), have sufficient organic matter content (4.33%), calcareous (10.77%), and have sufficient cation exchange capacity (32.6 cmol kg–[1]). Litterfall and fine roots are the primary components of SOC formation in a forest. The forest can increase plant primary productivity, thereby increasing SOC sources, by increasing litter quantity and quality, fine root density, and turnover (Laik et al., 2009; Pang et al., 2016).

Change in Soil Organic Carbon Stocks

Research Area Topsoil (0–30 cm) Total Carbon Stocks

The amount of TSOC in the topsoil (0–30 cm) of the study area was found between 14.44 and 301.88 tC ha–[1]; also the average of TSOC is 78.96 tC ha–[1] (Table 6). According to the ANOVA test results, statistically ($p < .01$), the highest mean TSOC amount was determined in the F area (101.56%), CC area (69.06%), and agricultural area (66.25%), respectively. It was determined that the TSOC content in the F area was statistically ($p < .01$) different from the other two areas (Table 7 and Figure 4A–D).

Table 6.
Descriptive Statistics of Topsoil (0–30 cm)

	Minimum	Maximum	Mean	Standard Deviation
N:90	Statistic	Statistic	Statistic	Statistic
TSOC tC ha^{-1} (30 cm depth)	14.44	301.88	78.96	51.28

Note: TSOC = Total soil organic carbon stocks.

In their study, Adhikari et al. (2019) determined an average of 90 Mg ha–[1] SOC stocks in Wisconsin soils. However, carbon stocks change as land uses differ. For example, the gain soil C was determined to be

Table 7.
Analysis of Variance Test Summary of Topsoil (0–30 cm)

N: 90	Land use					
Variables	F	CC	C	Mean Square (Between Groups)	F (Between Groups)	Significance
SOC (%)	2.27[a]	1.41[b]	1.32[b]	16.599	12.36	0.00
BD (g/cm^3)	1.69[a]	1.68[a]	1.57[b]	0.268	9.58	0.00
TSOC (tC ha–[1])	101.56[a]	69.06[b]	66.25[b]	23107.33	9.63	0.00

Note: BD = Bulk density; C = Cropland; CC = Converted to cropland; F = Forest; SOC = Soil organic carbon stocks; TSOC = Total soil organic carbon stocks.

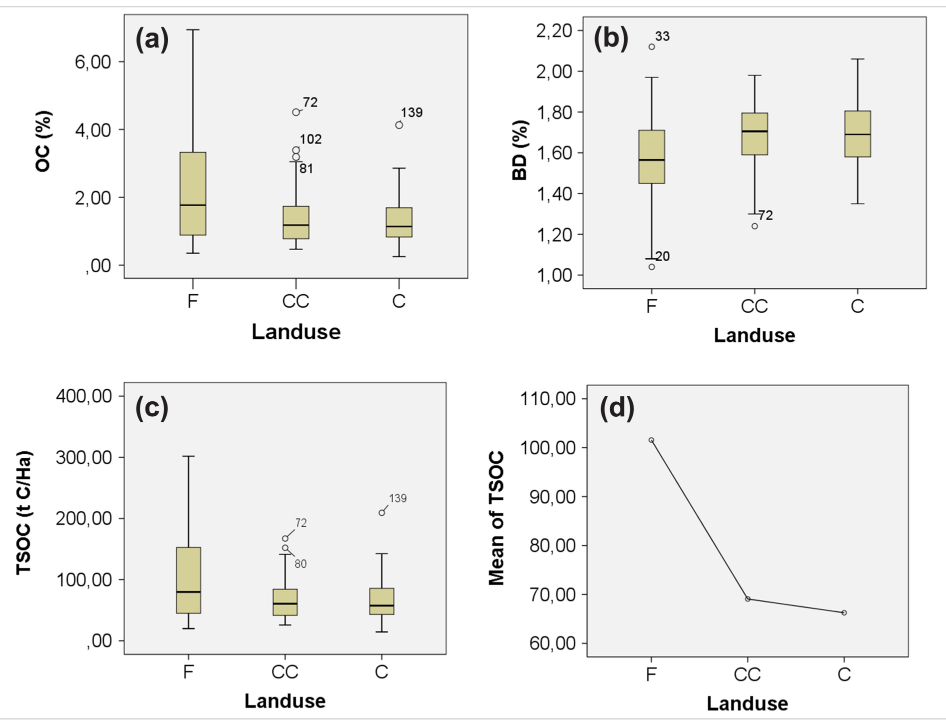

Figure 4.
Graphs of Carbon Stocks and Components (±SD) in the Topsoil (0–30 cm). OC and land use (A), BD and land use (B), TSOC and land use (C), average TSOC and land use (D). Note: BD = Bulk density; C = Cropland; CC = Converted to cropland; F = Forest; OC = Organic carbon; TSOC = Total soil organic carbon stocks.

Table 8.
Descriptive Statistics of 0–60 cm Soil Depth

N: 180	Minimum	Maximum	Mean	Standard Deviation
TSOC tC ha^{-1} (0–60 cm depth)	40.05	398.58	159.31	85.66

Note: TSOC = Total soil organic carbon stock.

approximately 43.2 MgC ha–^{1} to a depth of 30 cm in pasture area over 16 years (dos Santos et al., 2019).

Total Carbon Stocks of 0–60 cm Depth of Soil

Total soil organic carbon stock values were founded between 40.05 and 398.58 tC ha–^{1} in the soil (0–60 cm) of the study area. The average TSOC is 159.31 tC ha–^{1} (Table 8). According to the ANOVA test results, the highest mean TSOC amount statistically ($p < .01$) in the soil at a depth of 0–60 cm was determined as (206.57%) in the F area, in the CC area (138.79%), and the C area (132.57%), respectively. It was determined that the TSOC content in the F area was statistically ($p < .01$) different from the other land usages (Table 9 and Figure 5A–D). When the relations of the soils of the study area with TSOC and its components, land use, and soil depth are examined, the TSOC values ($p < .01$) decrease with depth at the significance level. Changes in land use ($p < .01$) in lands converted from forests and towards agricultural lands caused a decrease in the level of importance (Table 10).

Effect of Land Use Change on Total Soil Organic Carbon Stock (TSOC) from the Forest (F) to Cropland (CC) in Topsoil (0–30 cm) and Whole Soil Profile (0–60 cm)

The following formulas were used to calculate the changes in TSOC from forest areas to cropland areas (2 and 3).

Table 9.
Analysis of Variance Test Summary of 0–60 cm Soil Depth

N: 180	Land Use					
Variables	F	CC	C	Mean Square (Between Groups)	F (Between Groups)	Significance
SOC (%)	2.27^{a}	1.41^{b}	1.32^{b}	8.30	9.28	0.00
BD (g/cm^{3})	1.69^{a}	1.68^{a}	1.57^{b}	0.13	6.71	0.02
TSOC tC ha–^{1} (0–60 cm depth)	206.57^{a}	138.79^{b}	132.57^{b}	50550.28	7.96	0.01

Note: BD = Bulk density; C = Cropland; CC = Converted to cropland; F = Forest; SOC = Soil organic carbon stock; TSOC = Total soil organic carbon stock.

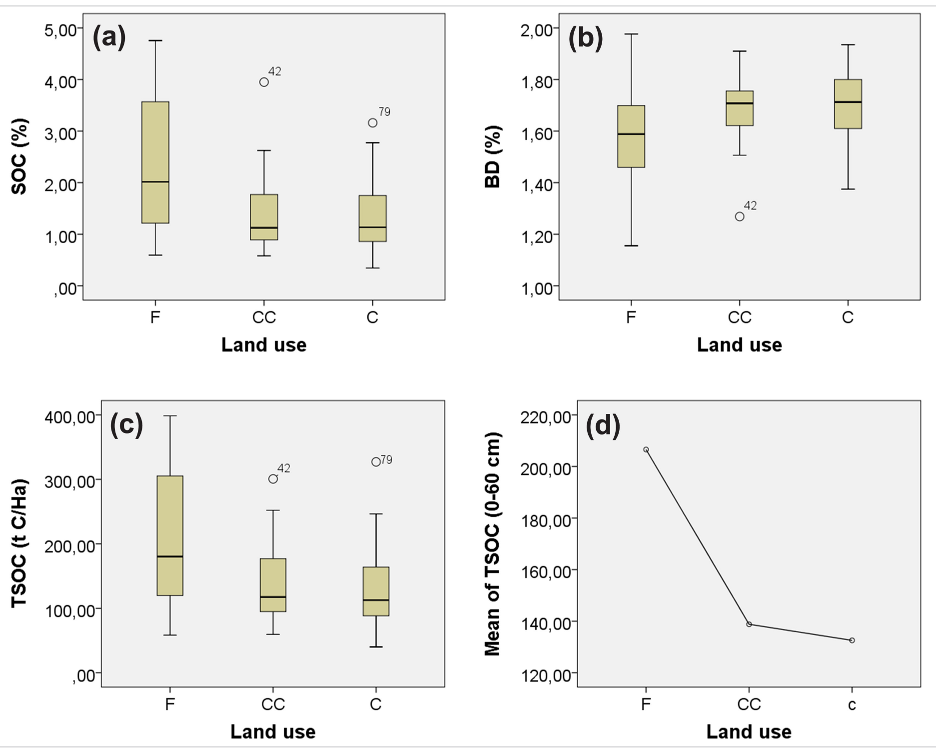

Figure 5.
Charts of Variation (±SD) of Carbon Stocks and Components in the Soil Profile (0–60 cm). OC and land use (A), BD and land use (B), TSOC and land use (C), average TSOC and land use (D). Note: BD = Bulk density; C = Cropland; CC = Converted to cropland; F = Forest; SOC = Soil organic carbon; TSOC = Total soil organic carbon stock.

Table 10.
Pearson's Correlations of 0–60 cm Soil Depth

N = 180	Land Use	Depth
SOC (%)	−0.379*	−0.314*
BD (g/cm³)	0.331*	0.256*
TSOC tC ha⁻¹ (0–60 cm depth)	−0.355*	−0.310*

Note: Land use 1: F; 2: CC; 3: C.
BD = Bulk density; SOC = Soil organic carbon stock; TSOC = Total soil organic carbon stock.
*Correlation is significant at the 0.01 level (two-tailed).

Table 11.
Change of Total Soil Organic Carbon Stock in Forests to Converted to Cropland

Land Use Type	Change of TSOC	$\Delta TSOC_{land\ use\ type}$ tC ha−¹	% Δ
F to CC (0–30 cm depth)	$\Delta TSOC_{F\ to\ CC}$	101.56 − 69.06 = 32.50	32.00
F to CC (0–60 cm depth)	$\Delta TSOC_{F\ to\ CC}$	206.57 − 138.79 = 67.78	32.81

CC = Converted to cropland; F = Forest; TSOC = Total soil organic carbon stock.

$$\Delta TSOC_{land\ use\ type} = T\bar{SO}C_{stock\ F} - T\bar{SO}C_{stock\ CC} \quad (2)$$

$$\%\ \Delta = (\Delta TSOC/T\bar{SO}C_{stock\ F}) \times 100 \quad (3)$$

$T\bar{SO}C_{stock\ F}$: Average of total SOC stocks in the forest

Changing of TSOC in the soil in the forest to converted cropland area was identified as

$\Delta T\bar{SO}CF$ to CC = 101.56 − 69.06 = 32.50 tC ha−¹, % Δ = 32.00% in the study area. The TSOC changes were identified as % Δ = 32.81 from F areas to CC in soil (0–60 cm) (Table 11).

Discussion

Changes in land use in karstic ecosystems can have a significant impact on the spatial variation of total SOC stocks. Soils from highlands and sloping areas are removed and deposited in depression areas that provide ideal conditions for plant growth (Dindaroglu et al., 2019, 2022). On average, the orchard grass area significantly increased TSOC stocks by 21.47% compared to tillage (Xiang et al., 2022). On the other hand, mixed-species plantations could significantly increase the TSOC stocks by 28% (Gong et al., 2021a). Furthermore, silvicultural thinning operations significantly increased TSOC stocks in planted forests by 7.2% (Gong et al., 2021b).

Cropland areas demonstrated a significant change in carbon stocks, while forest areas indicated the least change. Under intense agricultural usage, soil aggregates easily separate and speed up the breakdown of organic matter, drastically reducing the soil's organic carbon stocks. These findings are in line with those of the Kyoto Protocol (UNFCCC, 1998), which established bilateral agreements for decreasing emissions of greenhouse gases caused by humans. The "Land Use, Land-Use Change, and Forestry" guidelines specifically mention example uses. In this perspective, countries are required to enforce land use policies that reduce greenhouse gas emissions (IPCC, 2003).

Conclusion

This article examines the impact of land use transitions on carbon stocks over many years. Carbon stocks in lands converted from degraded forest to cropland decreased from 101.56 tC ha−¹ to 69.06 tC ha−¹. There was an average of 32% reduction in soil carbon stocks of lands that were converted to other land uses by removing degraded forest areas. An active, significant change in carbon stocks in soil occurred in topsoil (0–30 cm). It has been determined that the soils converted from degraded forest to cropland have resembled agricultural land characteristics for about 30 years but still do not fully exhibit agricultural soil characteristics.

Degraded forest areas should not be transformed into different land uses; soil losses should be prevented and rehabilitated. To ensure sustainable land management, policymakers need to adjust their land management policies to take into account the ecological consequences of changes in land use transitions.

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