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Impact of Depression Areas and Land-Use Change in the Soil Organic Carbon and Total Nitrogen contents in a Semi-Arid Karst Ecosystem

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SILVICULTURE

ABSTRACT

Background: Depression areas are essential structural components of Karst ecosystems. Their influence in the carbon and nitrogen dynamics under different land uses, which could be effectively used to define management strategies aiming to combat global warming, however, is not clear. This study investigated the changes in selected soil attributes across four land use types (forest, degraded forest, rangeland and cropland) both in depressed and non-depressed areas in a karst ecosystem in Kahramanmaras, Turkey. Soil attributes investigated in this study included soil pH, soil moisture (SM), soil organic carbon (SOC), total nitrogen content (TN), available water (AW), hydraulic conductivity (HC), root rate (RR) and C/N ratio.

Results: Discriminant analyses showed that N, AW, SOC, pH and landuse were the most effective variables affecting the distinction between depression and none-depression areas in karstic ecosystems. According to the structural matrix, the most important single factor affecting the distinction between depression and none-depression areas was SOC, with a correlation coefficient of 0.62. Highest values for SOC, TN and other attributes were found in forest and rangeland land use types, while minimum values were found in cropland land use in most comparisons. Depression areas reduced the negative effects of land use in terms of C, TN, C/N, SM, and RR.

Conclusion: As a result, while constructing restoration plans, the study area should be evaluated from a geo-ecological perspective. Ecological capabilities of depression areas should be considered especially in karst environments.

Keywords: Depression area, Soil management, Karst environment, Discriminant analysis, Carbon, Nitrogen

HIGHLIGHTS

Different land uses in karst ecosystems can affect the dynamics of carbon and nitrogen dramatically in the soil.
Soil remediation strategies should focus on carbon nitrogen balance in depressed areas
First reclamation strategy is reducing the pressure on agricultural areas in the karst ecosystem.
Depressed area can provide resistance in the fight against global warming.

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INTRODUCTION

A large part of the world population, estimated to be around 25%, lives in areas underlied by carbonate rocks making the water supply from karst ecosystems of vital and strategic importance at a global scale. Karst areas are represented in most regions of the world and occupy about 12% of the global land area and 30% of Turkey (Nazik, 2004; Liu, 2009). In karstic areas, water accumulation occurs not only on the surface but also in the cracks naturally formed in these systems. As a result, and although karst areas are vulnerable ecosystems (Trájeret al., 2020) with soils that are typically shallow and stony, cracks in these soils have the potential to store adequate water and nutrients for plant growth.Therefore, optimal landuse is very important in karst environment (Atalay, 1998; Kantarcı, 2000. Although different type of land uses can be found in karst ecosystems, cropland and pasture are the main forms of land use in karst areas, as soil depth and soil properties are typically good (Zhang et al., 2011). However, cultivation of intensive crops has the potential to drastically reduce the SOC and TN in these fragile environments (Franzluebbers and Stuedemann, 2009). Thus, judicious management of the soil C and N pools in karst ecosystems requires extra attention compared to other systems that typically are more resilient (Chen et al., 2012). Moreover, losses in soil quality attributed to intensitve cultivation in agricultural areas occurred more rapidly in the calcareous than in red soils of karst ecosystems (Wahba et al., 2019; Ozgul and Dindaroglu, 2021).

Nitrogen is one of the main nutrients for most annual and perennial crops (Ketterings and Czymmek 2007; Adeyemi et al., 2020). Soil microorganisms can release nutrients such as N, P and zinc (Zn) to the crops grown under ideal conditions in soils with a carbon-to-nitrogen (C/N) ratio of 24:1. At the same time, the amount of soil protective residue cover remaining in the soil is influenced by this ratio. The C/Nratio of 24:1 provides with a balance between theC and N needs of the microbes and those from the plants (USDA-NRCS, 2011). Changes in this ratio can have a negative effect on the rate of organic matter decomposition and the nutrient cyclingin soils. If a higher C to N ratio exists, more N must be temporarily retained from the soil to be utilized by the microorganisms to offset the excess C, while the organic resource is consumed. This can create a temporary N deficit (immobilization) in soils,until those microorganisms die and the N in their structures as mineralized (mineralization) and released back to the soil (Tugel et al., 2000; Babur et al., 2021; Kara and Bolat, 2008). Trivedi et al. (2016) stated that soil health (total C and N; C/N ratio) is directly related to the productivity and the diversity of the soil microbial population. Moreover, carbon conservation is not only an important measure of soil quality, but also an important tool in reducing climate change (Kumar et al., 2019). However, high emissions from the soil can be offset under some management practices and environmental factors (Battagliaet al., 2021; Babur and Dindaroglu, 2020).

Karst ecosystems remain poorly understood in regard to the soil microbial processes and factors that limit heir level of activity in these ecosystems (Chen et al., 2018). Although different degrees of rocky desertification in the Karst areas can greatly change the spatial variance of soil properties related to the soil C and Npools (Yang et al., 2019), the dinamics of root ratios in karstic soils with fragile geology and intense human intervention has been poorly studied (Su et al., 2019). Soil C and N management has become more complex in the Mediterranean Karst ecosystem as local temperature anomalies are linked to excessive anthropogenic activities. In this context, the investigation of some soil attributes in depression and none-depression areas in Karstic ecosystems have the potential to provide with relevant data to assess the ecological impact of different activities to be performed in these fragile ecosystems. Therefore, the objective of this study was to evaluate the impact of depression area and land use change on the Carbon, Nitrogen and other selected attributes of soil in Karstic ecosystems.

MATERIAL AND METHODS

The research site was located in the city of Andırın, Kahramanmaraş,Turkey between 37° 35′50″-37° 33′ 00″ N latitude, and 36° 24′18″ - 36° 21′ 38″ E longitude. The size of the research area is 1156 ha, and its average elevation is 1050 m (Figure 1). Average temperature was13 **°C,** and the average annual rainfall 729 mm (Anonymous, 2020). According to the Blumental (1941), Permo-Carboniferous, Jurassic and Cretaceous rocks are the basic components in the Andırın region of Turkey, thus situating the formation of the current morphology of the region during Alp Orogeny phase in the late Mesozoic and Cenozoic eras. The geological composition of the Andirin Sarimsak Mountain study area consists of Andirin limestone (Kozluet al., 1987). In a previous research conducted by Dindaroglu and Vermez (2019) in the same study area, 39 ecological soil series and four habitat characteristics were determined and mapped on different soil types formed on different bedrock (limestone, marble, breccia, diabase and quartzite). The common soil class in the research area is Aridisol (USDA 1999). In this previous research, over 58% of the study area was identified as an "arid" site environment.

Many tree species are spread on forest site in the study area such as; *Abies cilicica* subsp. *Cilicica*, *Pinus brutia* Ten, *Quercus cerris* L. var. cerris, *Cedrus libani* A. *Rich, Fraxinus* ornus L. subsp. cilicica (Lingelsh.) Yalt., *Juniperus foetidissima* Willd, *Fagus orientalis* Lipsky, *Cornus sanguinea* L., *Juniperus excels* Bieb, *Alnus glutinosa* (L.), *Styrax officinalis* L., *Laurus nobilis*, *Quercus cerris* L. var. cerris, *Quercus infectoria* Oliv. subsp. boissieri, *Cercis siliquastrum* L., *Quercus coccifera* L., *Juniperus foetidissima* Willd., *Quercus ilex*, *Cotinus coggygria, Olea europaea* L., *Arceuthos drupacea* (Vermezet al., 2018).

Distribution of Depression areas and Landuse/Land cover

According to the D8 algorithm, 3450 depression units were identified in the research site (Dindarogluet al., 2019) (Table 1 and Figure 2a). To verify the land use classification previously assumed in each case, an accuracy assesment consisting of 270 control points was used at random points across the whole experimental area.

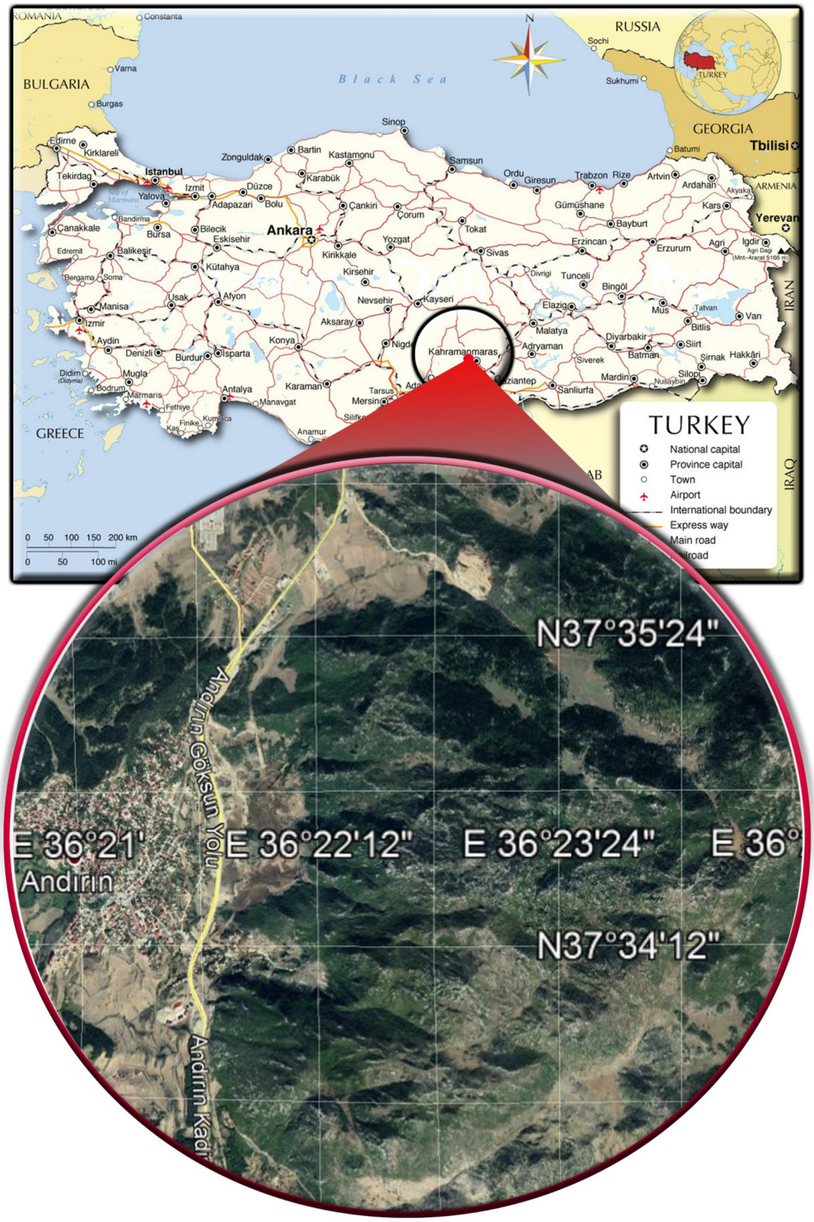

Fig. 1 Location maps of the study area .

The overall accuracy and kappa ratio (Jensen 2001) were determined. The overall accuracy rate was 86% and the value of kappa was 0.80. Both index values measure the reliability of the comparative agreement between the model and the actual values at the control points. The land cover and use map and depression area map were previously produced by Dindaroglu et al. (2019) in the same area according to the above-mentioned criteria. Forests, degraded forest, croplands, rangelands, settlement and rocky areas were identified according to the land cover and land use map created (Table 1 and Figure 2b).

Depression areas (36.7% of the total study area) are covered with different land use type such as forest areas (41.3%), degraded forest (20.1%), rangeland (3.9%) and cropland areas (34.6%). None-Depression areas covered 63.3% of the total study area (Table 1).

Soil Sampling and Analyses

Soil samples were collected according to the ICP Manual (UNECE 2003) utilizing an Area-Frame Randomized Soil Sampling (AFRSS) methodology that was previously

Tab. 1 Land-use in the depression area and none-depression area.

Land use type	Depression Area		None-Depression Area	
	Area	Area	25o46'N	
	Ha	%	Ha	%
Forest	175.3	41.3	412.4	56.3
Degarded Forest	85.4	20.1	189.1	25.8
Cropland	146.6	34.6	102	13.9
Rangeland	16.7	3.9	28.8	3.9
Total/Mean	424.2	100	732.3	100

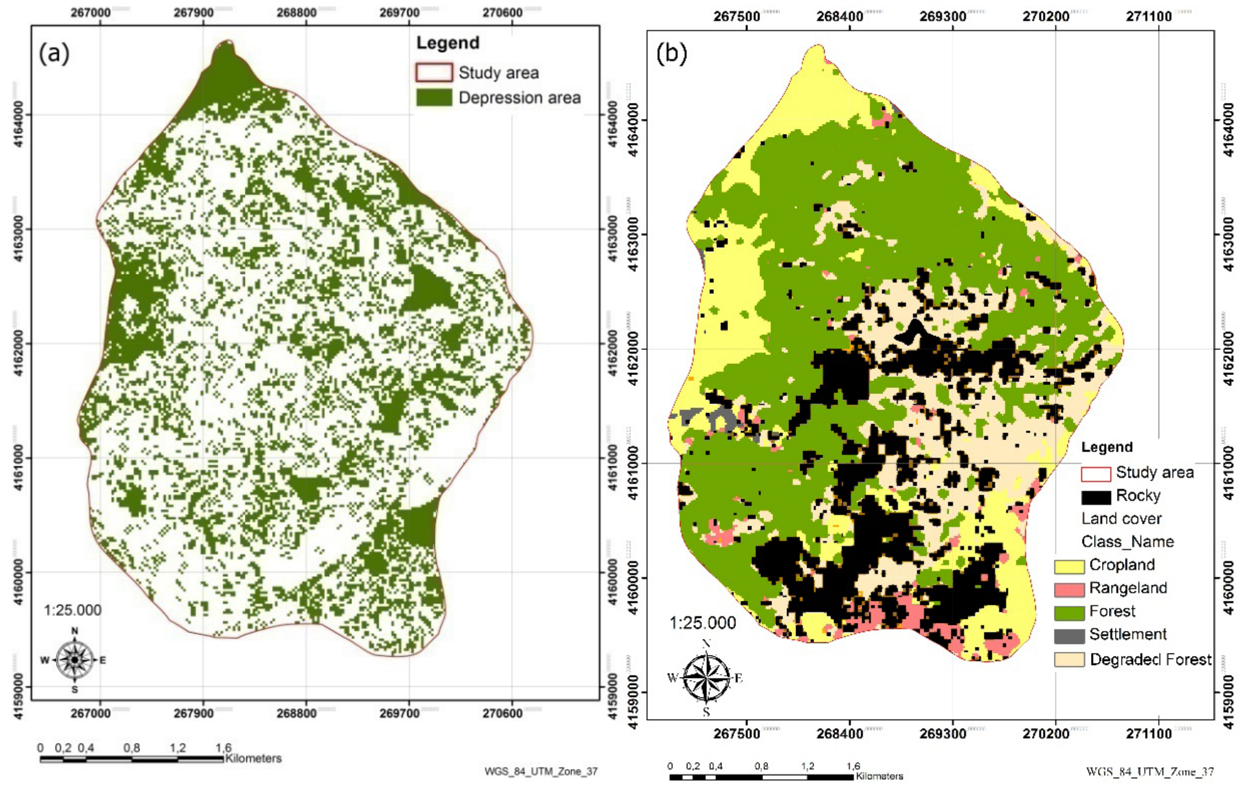

Fig. 2 Distribution of depression areas (a) and land use (b) (Dindaroglu et al., 2019).

used in other cropland and rangeland studies (Stolbovoyet al., 2007). A total of 108 soil samples were randomly collected in the topsoil (0-10cm depth) across the four different land uses (the rangeland, cropland, forest and degraded forest) in depression areas and none-depression areas. Soil samples were collected, stored in plastic bags air-dried until constant mass weight and then ground to pass a 2-mm sieve. Rocks and soil particles <2-mm were discarded. Air-dried soil sampleswere used for determination of the following attributes. Soil moisture content was obtained by using the gravimetric method (Janzen, 2004). Soil organic carbon (SOC) was determined by the wet burning method (Walkley-Black, 1934), pH in a 1:1 v/v soil water solution (Janzen, 2004) byusing the glass electrode method. Total Nitrogen (TN) content was determined with the micro-Kjheldal method (Bremner and Mulvaney, 1982). Hydraulic conductivity (HC) was measured according to Klute and Dirksen (1986), and available water content (AW) according to Cassel and Nielsen (1986). Soil moisture (SM) content was determined by using the gravimetric method (Irmak 1966) and root rate (RR) was calculated as rates (Root covering rate; root number in10cmX10cm) from the topsoil in the field (Cepel, 1988).

Statistical Analyses

Descriptive statistical analysis was performed for the four different land uses and the two depression areas to evaluate some specific properties (LU, DA, pH, SOC, TN, C/N ratio, RR, SM, AW, and HC) of analyzed soils. The normality test of the data set was performed using the Kolmogorow-Smirnow (K-S) method. Pearson correlation analysis was used to assess the relationship between land use and some specific soil characteristics. One-way analysis of variance (ANOVA) was used to calculate the significance of the difference between multiple independent means.

In the discriminant analysis, objects are separated into classes, with the objective to minimize the variance within the same class, maximizing the variance between classes and finding the linear combination of the original variables, also called directions or discriminnat functions (Canizo et al., 2019). In this study, discriminant analysis was applied to determine the effects of some soil properties that might be effective in the separation of Depression from None-Depression areas.

Canonical discriminate function is a linear combination of discriminating variables and is defined as follows (Fisher, 1936; Johnson, 1998, Hastie et al., 2019). Equality f_{km}; canonical discriminant function value for observation "*m*" of group k, u_i; discriminant coefficient reflecting the weight of the variable, X_{pkm}; X_p is the value of the distinguishing variable for the "*m*" observation of the group *k*, and *p*; refers to the number of distinguishing variables.

$$f_{km}=u_0+u_1X_{1km}+u_2X_{2km}+\cdots\ldots\ldots\ldots+u_pX_{pkm} \quad [1]$$

All statistical evaluations were made using SPSS software (SPSS, 2008).

RESULTS AND DISCUSSION

Descriptive statistics of some soil characteristics that play an active role in the decomposition processes in depression and non-depression areas in rangeland, cropland, and forest and degraded forest land use areas are presented in Tables 2 and Table 3. Soil analysis in the depressed rangeland area indicated that soil pH ranged between 7.05 and 7.63 (average 7.37), SOC between 3.3% and 4.5% (average 3.79), TN between 0.13% and 0.19% (average 0.08%), C/N ratio between 20.11 and 29.69 (average 23.51) and the SM varied between 4.3% and 8.0% (average 6.2%) (Table 2). In the non-depressed rangeland area, on the other hand, soil pH ranged between 6.81 and 8.45 (average 7.74), SOC between 0.63% and 2.37% (average 1.42%),TN between 0.04% to 0.15% (average 0.02%), the C/N ratio between 13.93 and 21.04 (average 8.06), and the SM varied between 2.38% and 9.78%(average 5.61).The average C/N rate in the depressed and non-depressed rangeland areas was 23.51 and 18.06 (average 18.06) (Table 2), respectively. Soil pH in the depressed cropland area fluctuated between 6.50 and 7.56 (average 7.24) (Table 2). In the depressed cropland area, SOC varied between 1.42% to 2.63% (average 2.11%), TN between 0.07% and 0.12% (average 0.10%), C/N ratio between 19.15 and 23.54 (average 21.01), and SM between 2.9% and 8.1% (average 6.50) (Table 2). In the non-depressed cropland area values tended to be smaller in most comparisons. Here, soil pH ranged between 7.30 and 8.30 (average 7.85), SOC varied from 0.11% to 1.11% (average 0.72%), TN between 0.01% and 0.06% (average 0.04%), C/N ratio between 11.0 and 20.07 (average 16.64), and SM ranged between 4.3%-12.2% (average 5.6). Average C/N ratio was 21.01 in the depressed and 16.64 in the non-depressed cropland use type (Table 2). Soil pH in the depressed forest areas ranged between 6.54 and 8.05 (average 7.28), SOC from 3.98% to 8.05% (average 6.37%), TN between 0.21% to 0.35% (average 0.27%), C/N ratio between 16.59 and 32.0 (average 23.39), and SM varied from 3.1% to 14.6% (average 7.7%) (Table 3). In the non-depressed forest area, soil pH oscilated between 6.70 and 8.03 (average 7.43), SOC between 0.31% to 7% (average 3.73%), TN between 0.02% and 0.43% (average 0.21%), C/N ratio between 10.89 and 39.09 (average 18.79), and SM from 4.2% to 13.0% (average 6.80%) (Table 3). Average C/N ratios were 23.39 and 18.79 in the depressed and non-depressed forest areas, respectively (Table 3).

Finally, soil pH in the depressed degraded forest area fluctuated between 6.93 and 8.07(average 7.56), SOC between 2.68% to 4.55% (average 3.33%), TN between 0.16% and 0.17% (average 0.16%), C/N ratio from 16.57 to 28.46 (average 21.36), and SM between 4.2%-16.9% (average 8.90%) (Table 3). In the non-depressed degraded forest area, soil pH ranged between 7.15 and 7.67, (average 7.40) SOC between 0.52% to 2.28% (average 1.56%),TN from 0.06% to 0.11% (average 0.09%), C/N ratio between 8.4 and 23.3 (average 16.95), and SM varied in the range 3.2%-6.3% (average 4.70%). The average C/N ratios were 21.36 in the depressed and 16.95 in the non-depressed degraded forest land use, respectively (Table 3). According to these results (Table 2-3), there was an evident impact of the karstic depression areas on most of the soil characteristics in all land uses reported in this study. Soil pH, SOC, TN, C/N ratio and SM ranges, maximum and average values were higher in the depressed than the non-depressed areas in most comparisons across the different land uses (Table 2-3). This difference in the study area is the result of the effects of topography, which is one of the main soil forming factors modeling the lanscape features in karstic ecosystems (Dindaroglu et al., 2021).

Previous research has also shown that topography has a consistent effect on the SOC and TN in soils, attributes that in turn affect the decomposition of plant materials, plant nutrient uptake and overall soil fertility (Cepel, 1988). The soil C/N ratios were also altered by land-use change in our study, similar to findings from Li et al.(2018). In a previous study by Dindaroglu et al. (2019) in the same field, a dramatic decline (68%) of carbon stocks was detected in the transition from depression areas in agricultural areas to other non-depression areas. In our study, the C/N ratio was lower in non-depression areas of all land uses. In the depressed areas, highest average C/N ratio was found in rangeland (23.51) (Table 2) and forest land use types (23.39) (Table 4), followed by degraded forest (21.34) (Table 5), and then cropland land use (21.01) (Table 3). Similar patterns were observed across the four land use types in the non-depressed areas, where highest average C/N ratios were found in the forest (18.79) (Table 3) and rangeland (18.06) (Table 2), followed by degraded forest (16.95) (Table 2), and cropland land use (16.64) (Table 2). Lowest C/N ratios were always found in the cropland land use type in both depressed and non-depressed areas.

Tillage operations physically break down soil organic matter and increase aeration, which not only reduces the overall soil SOC stocks but also enhances the activity of decomposers such as aerobic microorganisms, which further increases the oxidation rates of soil organic matter (Winowiecki et al., 2016). Moreover, SOC and TN were highest in the forest, with values ranging from intermediate to low in the cropland, rangeland and degraded forest. Mueller et al. (2017) reported that, in a forest area, relatively higher C levels and the presence of phenolic structures acting as agents that bind micro-aggregates together can promote the sequestration of organic matter by aggregation and sorption, which can help to explain the overall better soil quality for forest land use in most of our comparisons. Su et al.(2019) analyzed the C and N changes in karst areas across four different land uses (primary forest, secondary forest, scrub and grassland). Different to our results, they found no meaningful change in the total C concentration in all four plant species and three fine-root soil layers, while the total N concentration reached a maximum value in the secondary forest and a minimum value in the pasture. This may be because depression areas are not considered as variables in the SOC and TN sampling design. Clearly, only specific reclamation activities may have the potential to increase the decreased soil C-N balances in degraded karst ecosystems. For this purpose, it is necessery to identfy and apply suitable target plant species that can grow in degraded karst ecosystems as ecological networks (corridors) for reclamation. If at least 1/3 of the geomorphological unit is the width of the ecological corridors, it would be more functional. The continuity of ecological corridors should be ensured through the species' umbrella effect, where target species can be protected by other plant species that are less demanding in terms of resources (Dindaroglu, 2020). Karst ecosystems have different dynamics and formation characteristics than other ecosystems.

Restoration planning should not be made by focusing only on soil attributes and plant productivity in the management of these areas. Kiernan (1988) in his research in Australia, Tasmania; a decrease in recharge following a change in vegetation from grassland to pine forest was correlated with the subsequent drying and 'fossilization' of the speleodes in the lower caves; but in another cave in Tasmania, the above forest clearing resulted in restored calcite deposits. As a result, there are doubts as to the effect of forest clearing on speleothem growth. According to Urich (2002), there is a tendency to reduce speleothem growth in karst areas under forest cover; this could discourage supporters of forest rehabilitation to preserve the underlying karst ecosystem. Moreover, we hypothesize that the combined effect of both higher C/N ratios and soil water content in the depressed areas resulted in slower decomposition rates of organic matter, and thus, the higher SOC and TN contents in these areas compared to non-depressed areas. According to Cepel (1988), if the C/N ratio is lower than 20, the decomposition rate of the organic matter occurs at a fast rate. Conversely, when this ratio is between 20 and 30, decomposition rates are intermediate, while ratios over 30 results in slow decomposition rates. Also, the rate of organic matter decomposition is closely related to the presence of waterin the soil profile (Chen et al., 2018). Depression areas in karstic ecosystems differ from other depression areas.

Karstic ecosystems tend to develop a hydraulic system linked to subsurface water systems and, although the water table is lowered in dry seasons, plant roots in karstic pockets can reach the subsurface water. Highest TN content for both depressed (0.27%) and non-depressed areas (0.21%) were measured in the forest land use type (Table 4). Brookshire et al. (2012) stated that, while N in tropical and subtropical regions has been shown to be relatively rich, N-saturated habitats were uncommon and were only present in some lowland forest ecosystems. In the non-karst forest, N limitation is widely distributed (LeBauer & Treseder, 2008; Chen et al., 2018). In this study, different land uses are evaluated located in the Karst ecosystem. However, in order to better understand the relationship between SOC and TN, it is necessary to briefly examine the Karst and Non-karst situation.Chen et al. (2018) indicated that the modeling rate of decomposition and respiration in the karst forest was significantly higher than in the non-karst forest. In addition, ecoenzymatic stoichiometry findings showed that the karst forest was more limited in carbon than the non-karst forest. Wen et al., (2016) found that SOC concentration in karst soils was very high in their previous studies, but much of the C of the soil was in mineral-associated fractions (over 90%as average), a C pool that is more difficult to use for both microbes and plants.

According to the results of the one-way ANOVA based on the factor depression area (DA) significant differences were found between the depressed and non-depressed areas in terms of pH, SOC, TN, C/N ratio and RR values (Table 4).

To understand the effects of depression areas on soil properties, average values across all land uses were compared for both the depressed and non-depressed areas for the five parameters reported in Table 4. According to Figure 3, pH ranged from 7.34 to 7.53, SOC between 4.65 and 2.52, total N values from 0.20 to 0.14, C/N ratios were between 22.23 and 18.06, and average RR values between 37.82 and 27.16 (Figure 3).

Because of the shallow soil depth in the karst ecosystem, agricultural activities are usually restricted. Depressed areas with deep soils are constantly subjected to anthropogenic pressures as a result of intensive agricultural activities, which has resulted in an increase in the bulk density and a decrease in the SOC content in these areas (Dindarogluet al., 2019).

Correlation analysis showed the existence of a negative low significant correlation (-0.203) between DA and pH, that is, pH was found to be lower in the depression areas, as a result of the high hydrogen ion concentration in depression areas that are tipically flooded or have excessive water content with partial aerobic or complete anaerobic conditions across the soil profile. Significant strong and positive correlations were found between the DA factor and

Tab. 2 Descriptive Statistics of depressed and non-depressed rangeland land use type.

Soil parameters	Depressed area in rangeland		Non-depressed area in rangeland		Depressed area in cropland		Non-depressed area in cropland	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
pH	7.37	0.22	7.74	0.50	7.24	0.36	7.85	0.39
SOC (g.kg^{-1})	3.79	0.49	1.42	1.6	2.11	0.36	0.72	0.35
TN (g.kg^{-1})	0.16	0.02	0.08	0.03	0.10	0.01	0.04	0.01
C/N	23.51	3.85	18.06	2.06	21.01	1.40	16.64	3.12
RR (%)	48	8.30	35.45	8.20	35.7	7.87	33.3	6.05
SM (%)	6.2	1.45	5.61	2.56	6.5	1.73	5.6	2.67
AW (cm cm^{-1})	0.10	0	0.10	0.02	0.10	0.01	0.10	0.03
HC (mm/h)	2.42	1.07	20.84	28.62	1.91	0.46	13.11	15.17

H: Soil Reaction, SOC: Soil Organic Carbon, TN: Total Nitrogen, C/N: Carbon/Nitrogen, RR: Root Rate, SM: Soil Moisture, AW: Available Water, HC: Hydraulic Conductivity; SD= Standard Deviation

Tab. 3 Descriptive statistics of depressed and non-depressed forest and degraded forest land use type.

Soil parameters	Depressed area in forest		Non-depressed area in forest		Depressed area in degradedforest		Non-depressed area in degraded forest	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
pH	7.28	0.47	7.43	0.34	7.56	0.47	7.40	0.24
SOC ($g.kg^{-1}$)	6.37	1.04	3.73	1.47	3.33	0.84	1.56	0.64
TN ($g.kg^{-1}$)	0.27	0.04	0.21	0.10	0.16	0.00	0.09	0.02
C/N	23.39	3.26	18.79	5.54	21.36	5.59	16.95	5.92
RR (%)	37.6	11.94	24.63	11.33	33.75	7.5	21.2	8.37
SM (%)	7.7	2.68	6.8	2.02	8.9	5.77	4.7	1.24
AW ($cm\ cm^{-1}$)	0.11	0.02	0.11	0.02	0.09	0.04	0.08	0.02
HC (mm/h)	17.72	25.30	8.17	15.35	16.55	13.81	8.03	7.84

H: Soil Reaction, SOC: Soil Organic Carbon, TN: Total Nitrogen, C/N: Carbon/Nitrogen, RR: Root Rate, SM: Soil Moisture, AW: Available Water, HC: Hydraulic Conductivity; SD= Standard Deviation

Tab. 4 One-way ANOVA results of the significant soil parameters for the depression area factor.

Soil parameters	p values
pH	0.02
SOC ($g.kg^{-1}$)	0.00
TN ($g.kg^{-1}$)	0.02
C/N	0.00
RR (%)	0.00

SOC: soil organic carbon, TN: total nitrogen, RR: root rate, Factor: DA, Depended list: LU, pH, SOC, TN, C/N, RR, SM, AW, HC

SOC (0.322), N (0.244), C/N (0.366), and RR (0.266) (Table 5). As a practical implication, these results implied that SOC, N, RR and C/N werehigher in the depression than in the non-depressed areas. A higher C/N ratio in the depressed areas could be mainly explained by a considerable reduction in the mineralization rate ocurring in these topoghrapic areas compared to more elevated areas (Cepel, 1988).

Different effects of soil C stocks, C/N ratios and soil pH on biodiversity were shown by studies in temperate and boreal forests (Gucklandet al., 2009). However, the relationship between the variety of tree species and soil

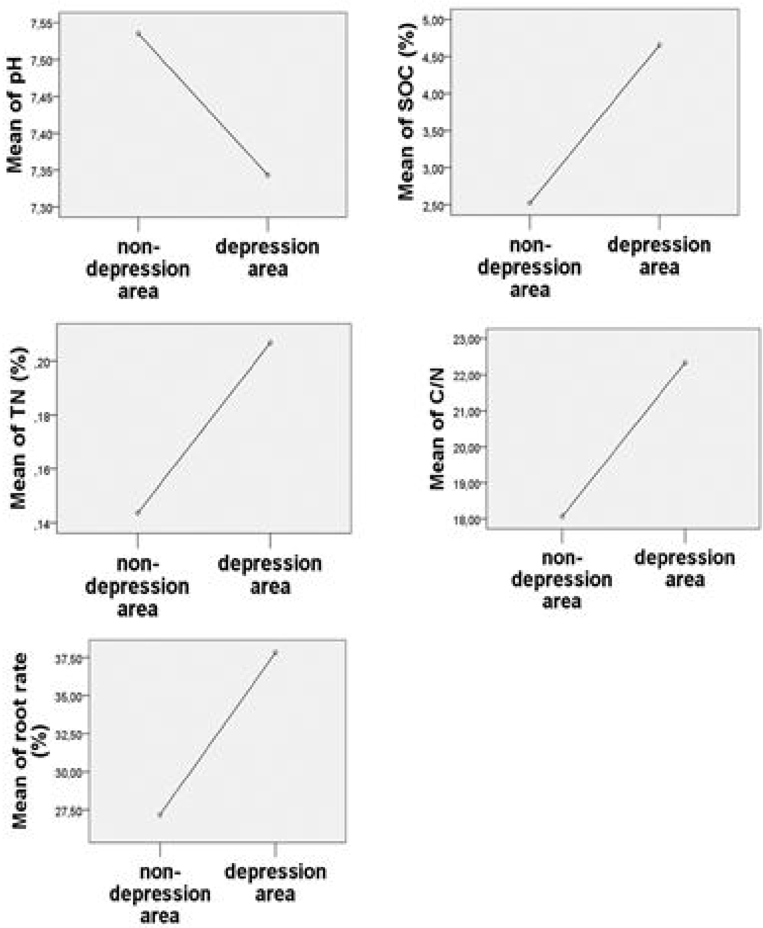

Fig. 3 The variation of average soil properties (pH, SOC, TN, C/N and RR in non-depression and depression areas.

Tab. 5 Correlation analyses among the selected soil attributes, land use type, and depression area and non-depression area.

	LU	DA	pH	SOC	TN	C/N	RR	SM	AW	HC
LU	1.000	0.019	0.215*	-0.081	-0.103	-0.093	0.154	-0.291**	-0.259*	0.022
DA		1.000	-0.203*	0.322**	0.244*	0.316**	0.266*	0.057	0.179	0.070
pH			1.000	-0.294**	-0.294**	-0.281**	-0.281**	-0.302**	-0.134	0.088
SOC				1.000	0.902**	0.869**	0.189	0.056	0.221*	0.015
TN					1.000	0.675**	0.173	0.089	0.192	0.013
C/N						1.000	0.153	0.023	0.188	0.016
RR							1.000	0.137	0.187	0.118
SM								1.000	0.154	-0.158
AW									1.000	0.104
HC										1.000

*. Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed). LU: land use, DA: depression area, SOC: soil organic carbon, TN: total nitrogen, RR: root rate, SM: soil moisture, AW: available water, HC: hydraulic conductivity.

C/N ratios is not clear (Scheibeet al., 2015). The higher soil C/N ratios in the sub-layers of various forest cover may be related to an increased N immobilization in soil organic matter and ectomycorrhiza mining (Phillips et al., 2013). Root growth in deeper soil layers under mixed forest stands leads to higher accumulation of root litter in across different soil profile layers, and this could result in a higher accumulation of carbon stocks in the soil (Brassard et al., 2013).

The strongest correlation was found between SOC and TN, but no significant correlation was found between SOC-landuse and TN-landuse (Table 5). According to Kopittke et al. (2018),microbial weathering may eliminate differences in the composition of OM in source material across different land use types. However, in our study area, significant correlations were found between SOC-depression area and TN-depression area.

According to the multivariate test results, four different multivariate statistics results for group variables ($p < 0.05$) were found to be significant. Based on this, a significant difference between the two groups on the linear combination of dependent variables was found (Table 6). In the multivariate test result table, Eta-squared value was 0.48 for Landuse, and 0.60 for Depressed areas in Wilks' Lambda method. Thus, 48% of the change in Landuse dependent

Tab. 6 Result of multivariate tests.

Wilks' Lambda	Error df	p	Partial Eta Squared
Landuse	235.52	0.00	0.48
Depressed and None-Depressed area	81.00	0.00	0.60

SOC: soil organic carbon, TN: total nitrogen, RR: root rate, Factor: DA, Depended list: LU, pH, SOC, TN, C/N, RR, SM, AW, HC

variables and 60% of the change in the depression dependent variables can be explained by group variables.

According to the univariate ANOVA analysis, OC, N, RR and AW were significantly affected by Landuse. Depression areas, on the other hand, affected soil pH, OC, N, C / N ratio and RR (Table 7).

The change in the estimated marginal means of some soil properties for different landuse and depressed areas is presented in Figure 4. To understand the effects of depression areas on soil properties, estimated marginal

Tab. 7 Results of the test of between-subject effects.

Source	Dependent Variable	p	Partial Eta Squared
Landuse	pH	0.16	0.05
	OC	0.00	0.67
	N	0.00	0.58
	CN	0.13	0.06
	RR	0.00	0.18
	SM	0.12	0.06
	AW	0.00	0.17
	HC	0.69	0.01
Depression area	pH	0.02	0.05
	OC	0.00	0.54
	N	0.00	0.23
	CN	0.00	0.21
	RR	0.00	0.24
	SM	0.16	0.02
	AW	0.17	0.02
	HC	0.61	0.00

SOC: Soil Organic Carbon (g.kg-1), TN: Total Nitrogen (g.kg-1), C/N: Carbon/Nitrogen, RR: Root Rate (%), SM: Soil Moisture (%), AW: Available Water (cm cm^{-1}), HC: Hydraulic Conductivity (mm/h).

means across all land uses were compared for both the depressed and non-depressed areas for the seven parameters reported in Figure 4. According to our results, SOC, N, C/N, RR, SM, AW, HC had a consistent higher value across the four landuses in the depressed areas, while soil pH had a higher value in the none-depressed area areas across the four landuse types (Figure 4).

Result of Canonical Discriminant Functions

According to the Wilks' Lambda test, the discriminant processeswas statistically significant ($p < 0.001$).

In this study, since the dependent variable has two categories, only one discriminant function was created and therefore one eigenvalue was obtained. Although there is no definite limit, eigenvalues higher than 0.40 can be accepted as "good" (Kalayci, 2010). Canonical correlation measures the relationship between the groups in which the dependent variable is formed and the discriminant function, and shows the total variance explained. The

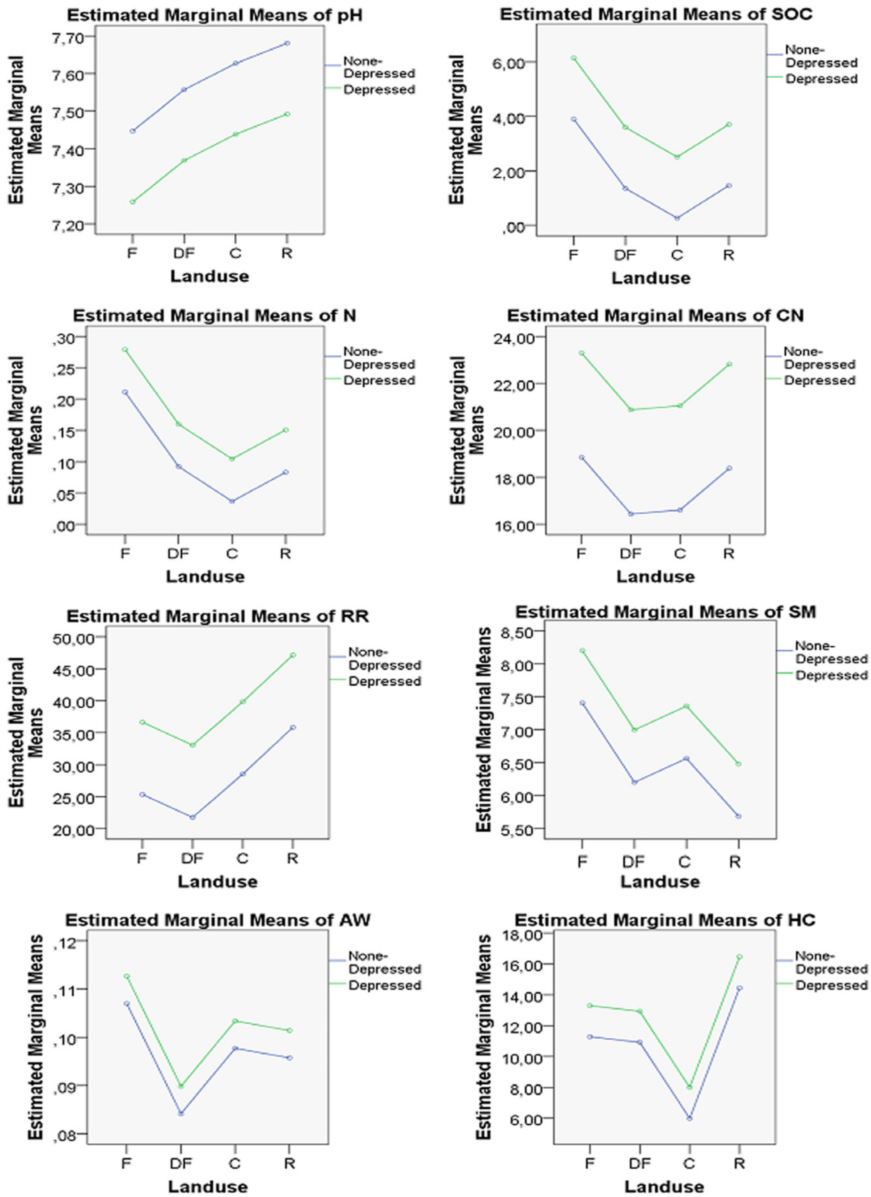

Fig. 4 Multivariate analyses for selected soil properties in the depressed and none-depressed areas across four different landuse types (F: Forest, DF: Degraded Forest, C: Cropland, R: Rangeland).

greater the canonical correlation is, the higher is the relationship between groups and the discriminant function. Our results indicate an eigenvalues of 0.90 and a canonical correlation coefficient of 0.69. In order to interpret this value, the correlation coefficient was squared, resulting in a value of 0.48. As a result, our model explains 48% of the total variability in our model.

After this we evaluated the discriminant function coefficients. All the variables under evaluation, with the exception of AW, were important in grouping (Table 8). The high numbers in the table indicate a significant contribution, while the low numbers reflect a minor contribution. The symbols for coefficients have no special significance (Cangul, 2006). With a coefficient of 2.03, SOC was the independent variable that contributed the most to separating groups, followed by N (-1.26), Landuse (0.53), pH (-0.38), RR (0.24), SM (0.18), CN (-0.12), HC (0.11) and AW (-0.05) (Table 8).

The structure matrix is used to evaluate the importance of independent variables. This matrix shows the correlation of each variable with the discriminant function (Cangul, 2006). In our analysis, the independent variable with the highest correlation with the discriminant function was SOC (0.62), while the independent variable with the lowest correlation was the Landuse (-0.03) (Table 9).

Thus, the most important variable affecting the distinction between depression and none-depression areas is SOC (0.62). According to the Dindaroglu et al. (2019), land use and depression areas are the most important factors controlling the size of the organic carbon stock in soils. In their study, carbon stocks in the topsoil (10 cm) of depressed areas (48.7 MgC ha^{-1}) was 79% greater than that in the non-depressed areas (27.2 MgC ha^{-1}).

In order to determine the discriminant function, we evaluated the non-standardized coefficients of

Tab. 8 Standardized Canonical Discriminant Function Coefficients.

Variables	SOC	N	LU	pH	RR	SM	HC	C/N	AW
Function	2.03	-1.26	0.53	-0.38	0.24	0.18	0.11	-0.12	-0.05

SOC: Soil Organic Carbon (g.kg^{-1}), TN: Total Nitrogen (g.kg^{-1}), C/N: Carbon/Nitrogen, RR: Root Rate (%), SM: Soil Moisture (%), AW: Available Water (cm cm^{-1}), HC: Hydraulic Conductivity (mm/h), Landuse: LU

Tab. 9 Structure Matrix .

Variables	SOC	RR	C/N	N	pH	SM	AW	HC	LU
Function	0.62	0.52	0.51	0.35	-0.25	0.16	0.13	0.03	-0.03

SOC: Soil Organic Carbon (g.kg^{-1}), TN: Total Nitrogen (g.kg^{-1}), C/N: Carbon/Nitrogen, RR: Root Rate (%), SM: Soil Moisture (%), AW: Available Water (cm cm^{-1}), HC: Hydraulic Conductivity (mm/h), Landuse: LU

the variables. Table 12 contains information on non-standardized coefficientsfor the distinction between depressed and none-depressed area. According to Canonical Discriminant Function Coefficients (Table 10), the following linear discriminant function was obtained, where N representstotal Nitrogen (g.kg^{-1}), AW; theavailable water (cm cm^{-1}), SOC; the soil organic carbon (g.kg^{-1}), pH; the soil reaction, LU; the landuse, C/N; the carbon/nitrogen, RR; theroot rate HC; thehydraulic conductivity (mm/h).

$$y = 4.16 - 13.53x_N - 2.82x_{AW} + 1.14x_{SOC} - 0.95x_{pH} - 0.46x_{LU} + 0.06x_{SM} - 0.02x_{C/N} + 0.02x_{RR} + 0.01x_{HC} \quad [2]$$

In the discriminant analysis,the higher is the estimation rate in the classification, the higher is the analysis success. (Table 11). According to this analysis, we conclude that depression and none-depression areas were classified correctly at a rate of 80.6% with the original model established, which further indicates that the used model was highly effective. Cross validation is done only for those cases in the analysis. However, it can be investigated how the predictive success of the model would be if more ecological variables would have been used. Quiroga et al. (1998), Ramos et al. (2011), Ayoubi et al. (2018) used discriminant functions to effectively distinguish between some soil properties and groups. Also,discriminant functions were effectively used by Asgari et al. (2018) to distinguish soil moisture regimes.

CONCLUSIONS

In this study, although the most effective variables in the discriminant function analysis were N, AW, SOC, pH and LU, according to the structure matrix SOC was found to be the most effective variable in distinguishing between depressed and non-depressed areas. Depression areas reduced the detrimental effect that change in land use typically have in terms of C, TN, C/N, SM, and RR. Therefore, strategic conservation of these areas has an advantage and is of paramount importance in combating present and future climate change. Cropland land use has the potential to severaly impact soil Carbon and Nitrogen both in depressed and non-depressed areas in karstic ecosystems. As a result, additional soil protection measures should be taken when agriculture is practiced in these areas. Detailed classification of karst forest ecosystems according to ecological factors and determination of their functions will ensure success in forestry activities in these areas and overall ecosystem sustainability. Finally, ecological restoration plans should take advantage of the depression areas, especially in improving soil health.

Tab. 11 Classification accuracy in discriminant analysis .

			Predicted Group Membership		Total
			NDPRS	DPRS	
Original	Count	NDPRS	55	6	61
		DPRS	15	32	47
	%	NDPRS	90.2	9.8	100.0
		DPRS	31.9	68.1	100.0

NDPRS: None- Depressed, DPRS: Depressed

AUTHORSHIP CONTRIBUTION

Project Idea: TD, EB, OSU, MB, MS, RR

Funding: TD, EB

Database: TD, EB, OSU, MB,

Processing: TD, EB, OSU

Analysis: TD, EB, OSU, MS

Writing: TD, EB, OSU, MB, MS, RR

Review: TD, EB, OSU, MB, MS, RR

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Tab. 10 Canonical Discriminant Function Coefficients (Unstandardized coefficients).

Variables	SOC	N	LU	pH	RR	SM	HC	C/N	AW
Function	2.03	-1.26	0.53	-0.38	0.24	0.18	0.11	-0.12	-0.05

SOC: Soil Organic Carbon (g.kg^{-1}), TN: Total Nitrogen (g.kg^{-1}), C/N: Carbon/Nitrogen, RR: Root Rate (%), SM: Soil Moisture (%), AW: Available Water (cm cm^{-1}), HC: Hydraulic Conductivity (mm/h), Landuse: LU

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