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Impacts of non-timber forest products on soil quality following land-use change in Zagros oak forest

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ABSTRACT

We conducted this research to assess how the cultivation of economically and ecologically valuable species such as *Narcissus tazetta* and Amygdalus scoparia affects soil properties, aiming to identify land-use strategies that support both soil restoration and sustainable livelihoods. We sampled land use types (LUT) along a restoration gradient. Two forest types represented the natural oak forests (FOR) forests not subjected to intensive management and the degraded oak forests (DEF) following overexploitation. Three types represented restoration measures on degraded abandoned lands: 10-year-old almond tree plantations (AMP), and *Narcissus tazetta* cultivation after 5 years (SCN) and 15 years (LCN). Soil samples were gathered from every type, and 15 different chemical, physical, and biological attributes were analyzed. In addition, the soil quality index (SQI) was assessed. A multivariate analysis (PCA) revealed that the different LUTs could be clearly differentiated according to their soil characteristics. The highest value of soil biological activity (basal respiration: 0.33 mg CO_2. g^{-1} dm. 24 h^{-1}, substrate-induced respiration: 0.44 mg CO_2. g^{-1} dm. 24 h^{-1} and microbial biomass carbon: 3.71 mg biomass-C. 100 g^{-1} dm) was consistently highest in FOR, while DEF indicated the lowest level. Soil organic carbon followed the same trend, increasing from 0.5% in DEF to 2.0% in FOR. Conversely, the lime content showed an opposite trend, ranging from 50% in DEF to 20% in FOR. Among the soil chemical variables, available phosphorus and potassium were highest in LCN. LCN and FOR also exhibited significantly reduced soil bulk density compared to the other studied areas. The SQI decreased significantly in the order FOR > LCN > AMP > SCN = DEF. This research highlights the importance of integrated land management that considers biological, physical, and chemical soil properties to prevent further degradation and sustain soil fertility.

Key words: Land use change, abandonment, cultivation, soil quality index, oak forests.
Article type: Research Article.

INTRODUCTION

Land degradation has long been a global concern, particularly in forest ecosystems, where it reduces soil fertility, alters soil structure, and threatens the sustainability of forest productivity, with an estimated 2 billion hectares of previously biologically productive land degraded globally over the past millennium (Nkonya *et al.* 2016). The worldwide population is growing, which increases the demands for different natural resources including forests, pastures, soil and water (Maja & Ayano 2021). Almost all terrestrial ecosystems in both developed and developing countries are affected by land-use change and degradation (Partel *et al.* 2024). Forest land use change is increasing with the removal of trees and natural vegetation as soil cover, especially in industrial and intensive agricultural systems, without adopting more sustainable management practices (Aneseyee *et al.* 2020; Ma *et al.* 2023). Land use change, as one of the most important drivers of terrestrial ecosystem degradation, leads to structural and physical changes in the soil, including alterations in pore characteristics, decomposition processes, nutrient balance, soil organic matter content, and the functioning of soil biota (Wang *et al.* 2021; Gowthamchand *et al.* 2023). Thus, land degradation signifies a progressive decline in soil quality (Kooch *et al.* 2023). Deforestation can degrade SQ, and appropriate management measures that improve SQ and reduce erosion are crucial for restoring the structure and functioning of forest ecosystems. In this context, the cessation of cultivation and the process of forest regeneration provide an opportunity to restore the forest landscape. However, unfavorable soil conditions in some areas can considerably slow down or even prevent vegetation dynamics. The depletion of soil nutrients on abandoned farmland is one of the main obstacles to secondary succession and the restoration of forests (Florentine & Westbrooke 2004; Newaj *et al.* 2020). Therefore, one of the management priorities for such lands should be restoring soil fertility through appropriate restoration measures to place them in the path of secondary succession (Rodríguez-León *et al.* 2021). Among these measures, planting diverse species including fruit and forest trees, crops, and medicinal or fodder plants has been used to restore soil fertility and improve productivity on deforested or low-productivity lands (Ojha *et al.* 2022, Singh *et al.* 2024). Although promising, these approaches have sometimes failed to establish a balanced relationship between food security, rural livelihoods, and ecosystem services (Hanaček & Rodríguez-Labajos 2018; Pawlewicz & Pawlewicz 2023). Some alternative strategies have focused on less intensive approaches such as introducing nurse or pioneer species on abandoned lands, and even incorporating species suited to low-input agriculture. These measures can help improve soil fertility and create better habitat conditions for other plants, while also reducing human pressure on remaining forests. However, it is still necessary to evaluate the effect of such restoration activities on plant habitats and SQ (Francisco *et al.* 2016). Soil quality is defined as the capacity of soil to perform essential functions within an ecosystem, including sustaining biological productivity and supporting the well-being of plants, animals, and humans (Doran & Safley 1997). Human behaviors such as deforestation and unsustainable agricultural practices (e.g. overgrazing) have severely degraded and reduced the quality of soil in different regions including the Zagros forests in western Iran (Jarideh *et al.* 2021; de Souza Medeiros *et al.* 2023; Moradi & Shabanian 2023). However, several studies have shown that degraded soils can be restored in terms of quality through appropriate management strategies (Lal 2015; Sileshi *et al.* 2020). Successful soil restoration of degraded areas has the potential to provide more sustainable agricultural land, thereby limiting deforestation and protecting remaining natural forests and soils at risk of overexploitation (Gupta *et al.* 2020). Among the possible restoration techniques, introducing appropriate plant species provides the conditions for soil restoration by providing organic matter and supporting nutrient recycling (Wang *et al.* 2017). However, our knowledge in this area is still limited. For example, selecting suitable plant species for planting in degraded areas requires detailed studies of soil attributes and vegetation changes (Reubens *et al.* 2011). Additionally, the socioeconomic issues of the local residents should also be included as a guarantee of sustainable management of forest resources. The study conducted by Houérou (2006) indicated that the establishment of trees and shrubs in landscapes of degraded areas provides numerous benefits such as decreasing soil erosion, enhancing soil fertility, and providing feed for livestock. Sovu *et al.* (2012) demonstrated that restoring forest landscapes on abandoned lands through mixed-species planting and biochar application offers a promising approach for ecological rehabilitation, diversification of landowner livelihoods, and maintaining ecosystem services. Additionally, Yu & Wang (2018) showed that planting *Haloxylon ammodendron* in an arid region significantly increased soil physical properties and nutrients. Similarly, DeBruyne (2009) showed that planting *Gleditsia triacanthos* in North America significantly enhanced SQ and microbial N, C, and K compared to open degraded pastures. The Zagros oak forests in Iran are among the ancient oak forests of the world. This forest ecosystem provides valuable ecosystem services but this area is also threatened by intense human practices. The livelihood of a significant population has historically depended on the direct and indirect services of these forests. Nevertheless, the shift in land use from forests to cultivated land has largely increased in recent decades (Heidarlou *et al.* 2019). Intensive agriculture in the understorey of these forests in the form of rainfed agriculture (especially wheat cultivation) has caused the destruction and fragmentation of these forests (Beygi Heidarlou *et al.* 2021). Indeed, farmers intentionally clear more forested areas in order to expand their croplands. Over the past few decades, the reduction in soil fertility of these lands and the low economic returns from agriculture have led to farmer migration and land abandonment (Heydari *et al.* 2020). These abandoned lands have been naturally colonized by a ligneous vegetation. However, due to the decline of SQ and dry summer conditions, the potential for their natural and even assisted regeneration – especially for dominant climax woody species i.e. *Quercus brantii* Lindl – is compromised (Heydari *et al.* 2022; Kaybondori *et al.* 2022). The restoration efforts are particularly complex and one promising method involves establishing a plant cover alongside planting trees or shrubs. Among the species chosen for plant cover, the genus *Narcissus* has been more particularly used. It belongs to the Amaryllidaceae family and includes important aromatics, medicinal and ornamental plants whose species grow in many regions worldwide, notably in the Mediterranean (Kebeli & Çelikel 2013; Khan *et al.* 2013). *Narcissus tazetta* grows naturally in some provinces of Iran and has been developed and cultivated by locals in some fields of the country (Nakhaei *et al.* 2008). Cultivation of *Narcissus tazetta* requires only low-intensity soil preparation, without the need for annual ploughing or heavy fertilization, and provides valuable economic returns. In some parts of the Zagros, local farmers and former landowners, with government support, have combined the planting of this species with drought-tolerant shrubs or trees, such *as Amygdalus scoparia*. Beyond their economic benefits, these species were selected for their potential to improve soil quality: the perennial roots of Narcissus and almond can enhance soil structure and porosity, their litter contributes organic matter and nutrients to the soil, and they can support microbial activity, facilitating nutrient cycling and long-term fertility restoration. Despite these potential benefits, the short- and long-term effects of these species on key soil attributes and overall soil quality have not yet been thoroughly evaluated. This research seeks to fill this knowledge gap by investigating how soil properties and overall SQ change over time following the planting of Narcissus bulbs and almond trees in degraded and abandoned forest of the Zagros forest ecosystem. For comparison, we studied other LUTs, ranging from natural forests to degraded stands, to evaluate how effective the cultivation of a non-timber forest product is in improving SQ in the study area. In part, this research seeks to address the following questions:

1) How do different land-use types (LUTs), including Narcissus and almond cultivation, affect key soil chemical, physical, and biological properties?

2) How does the soil quality index (SQI) vary among these LUTs, and which management practices are most effective in improving soil quality?

MATERIALS AND METHODS

Study area description

This research was conducted in an oak-dominated forest within a semi-arid climate zone called Zagros forest ecosystem in west of Iran, Darehshahr County (Fig. 1). Persian oak (*Quercus brantii* Lindl.) is the dominant woody species in this region, associated with some woody species such as *Cerasus microcarpa* Boiss. and *Amygdalus scoparia* Spach. The herbaceous vegetation is typically composed of annual and perennial grasses and forbs. According to the Amberge classification, the climate of this region is semi-arid, with an average annual rainfall of 427 mm and an average annual temperature of 21.4 °C. The study area was originally oak woodland and has historically been converted by local communities into arable land with intensive rainfed cereal cultivation under the canopy or between woody individuals, which has gradually caused a reduction in forest cover. Many of these arable fields have been abandoned, especially in recent decades, due to the decrease in soil fertility and the inefficiency of traditional agricultural practices (Heidarlou *et al.* 2019). Abandoned fields have created landscapes without trees or with sparsely distributed natural woody species in the study area. Given the need for low-input, economically viable, and ecologically beneficial plant species to restore abandoned lands, Narcissus tazetta and *Amygdalus scoparia* have been introduced in some abandoned fields. With the support of the Ministry of Natural Resources, narcissus (*Narcissus tazetta* L.) bulbs were distributed to farmers for cultivation in abandoned fields. In some locations of the study region, small patches of ancient historical Narcissus cultivation have remained.

We selected five different types of land use along a gradient of abandonment and agricultural management:

(I) Natural oak forests (FOR) which represent the forest stage before degradation and abandonment. The forest stands exhibit an oak forest (coppice form) with an overstory cover of more than 25%.

(II) Degraded and abandoned forests (DEF). These oak forests have been intensively exploited before abandonment. In particular, the forest cover was drastically reduced and rainfed cereals were cultivated. But due to low productivity or a lack of workforce (or both), the system was eventually abandoned. In this type, the cover of the overstory is less than 10% and the understory is absent. The forest floor is composed of ground bare soil or covered by a thin grass layer.

(III) 10-year-old plantations of *Amygdalus scoparia* (AMP). In abandoned fields, almond trees were planted with a spacing of 3 meters by 4 meters. In this type, no agricultural interventions (cultivation, tillage, irrigation, etc.) are carried out. The presence of scattered oak trees bears witness to a past of forestry.

(IV) Long-term cultivation of *Narcissus* (LCN). *Narcissus tazetta* bulbs were planted in abandoned fields about 15 years ago. The system is similar to the previous one (i.e. no agricultural operations are carried out) and scattered rare oak trees are occasionally visible. Every year, the flowers are harvested for sale, providing a significant income source for local communities who manage these areas.

(V) Short-term Narcissus cultivation (SCN): Similar to the long-term system but more recently established, about 5 years ago.

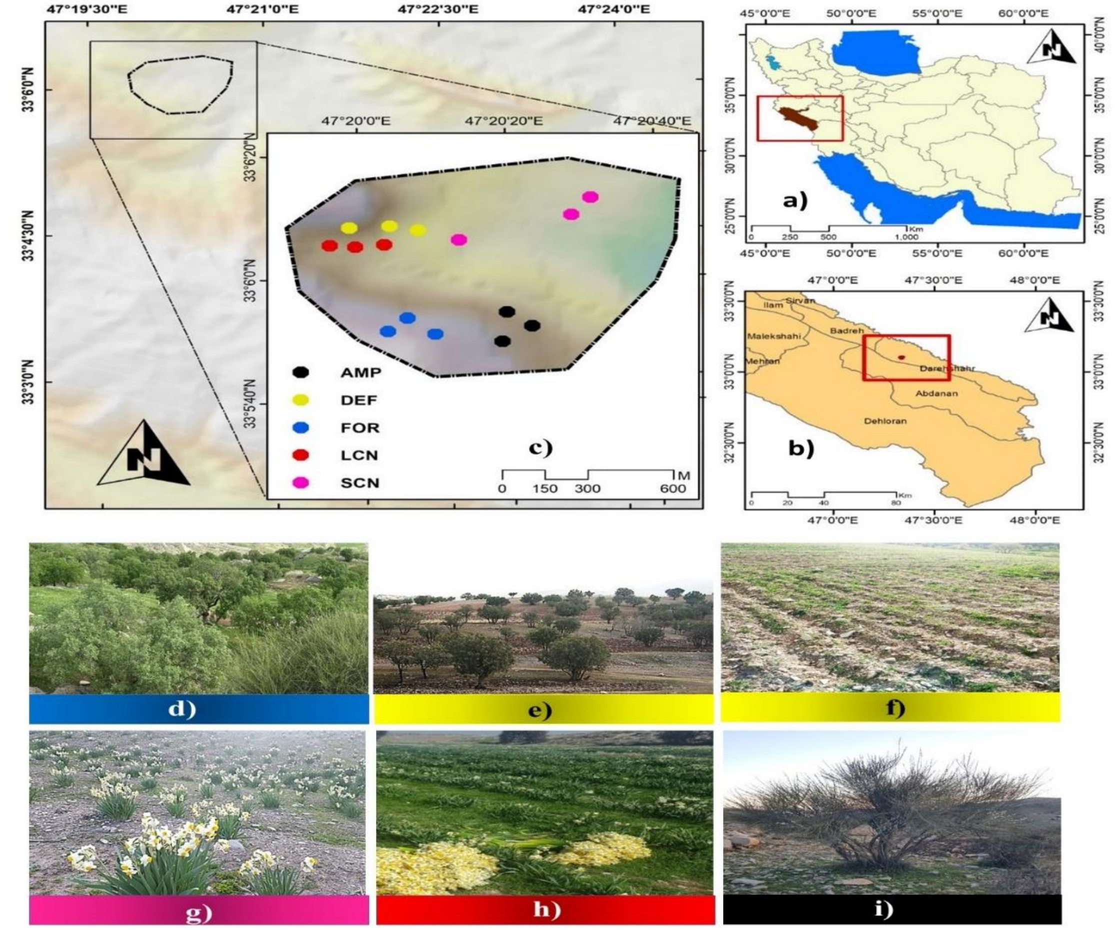


Fig. 1. Location of the study area in Zagros, western Iran, location of the sampling plots in the study area according to the different land use categories (a-c). Views of the land use types: natural oak forest: FOR (d), degraded and abandoned forest: DEF (e, f), short-term *Narcissus* cultivation: SCN (g), long-term *Narcissus* cultivation: LCN (h), plantation of *Amygdalus scoparia*: AMP (i).

Experimental design and soil sampling

Three sites in each land-use type (LUT) were selected (three sites per LUT are independent replicates), all characterized by nearly identical physiographic conditions (slope less than 25%, mean elevation ± standard deviation of 964± 49 m a.s.l.). In every LUT, two perpendicular transects, each measuring 40 m in length, were randomly established. Five sampling points were determined along these transects, including two points on each transect and one at their intersection, resulting in a total of 5 LUTs × 3 replicates × 5 sampling points = 75 sampling points.

Soil sampling and laboratory methods

At each sampling position, a single soil sample was collected in April 2023 from a depth of 25 cm using a metallic cylinder of known dimensions to evaluate physical, chemical, and biological soil properties (Eslaminejad *et al.* 2023). The collected soil samples were separately put in a plastic bag and after being labeled, they were stored in a foam box containing dry ice until they were transferred to the cold room of Ilam University for later analysis. Soil samples were passed through a 2 millimeter mesh and split into two sub-samples. One of the subsample was preserved at 4°C to assess soil microbial activity. Another air-dried soil subsample was used to analyze the soil physical and chemical attributes. The hydrometer approach was employed to determine soil texture (Bouyoucos 1962). Bulk density (BD) was measured as the ratio of the air-dried soil weight to the volume of the cylinder. Soil organic carbon (SOC) was determined according to Walkley-Black method (Walkley & Black 1934). Soil pH and electrical conductivity (EC) were measured with electrometrically and conductivity probes in filtered extracts (Kalra & Maynard 1991). Kjeldahl method was used to measure total nitrogen (Ntot; Bremner & Mulvaney 1982). The available phosphorus (Pava) was assessed through $NaHCO_3$ extraction (Olsen & Sommers 1982). The method of flame photometry was utilized to determine the available potassium (Kava) (Isaac & Kerber 1971). Lime content (total neutralizing value; TNV) was analyzed via titration with NaOH (Allison & Moodie 1965). Soil moisture content was calculated via drying a fresh soil subsample at a temperature of 105 °C for a duration of 24 hours (Famiglietti et al. 1998). Soil basal respiration (BR) was determined by capturing and quantifying the CO_2 released during 5 days (Alef & Nannipieri 1995). Soil microbial biomass carbon (MBC) was assessed through fumigation-extraction (Anderson & Ingram 1993). In order to determine substrate-induced respiration (SIR), we incorporated glucose (1%) as the substrate and measured the CO_2 evolved following 8 hours of incubation (Anderson & Domsch, 1978).

Soil quality index

The soil quality index (SQI; weighted additive soil quality index) was assessed using a total data set (TDS) including fifteen key soil properties (BD, clay, silt, sand, SP, TNV, EC, pH, Pava, Kava, SOC, Ntot, BR, MBC, and SIR). These soil factors were selected owing to their well-documented effects on oil fertility, nutrient availability, root development, soil porosity, and structure, all of which mainly affect soil ecology and plant growth (Heydari *et al.* 2020b; Bazgir *et al.* 2021). We used standard scoring functions to assign scores to each variable (Andrews *et al.* 2004), ranging from 0 to 1 (Nabiollahi *et al.* 2017). In this way, the soil variables are divided into three types of categories: 1) More is better i.e. soil properties that promote plant growth and soil health such as soil organic carbon 2) Less is better, i.e. soil properties that become detrimental to plant growth and soil health when their levels are too high such as bulk density and EC and 3) Optimal range, i.e. soil properties (e.g. pH) that have a specific range within which they are most useful for plant growth and soil health (Armenise *et al.* 2013). The weighting values of each soil attribute were allocated based on the ratio of each indicator communality to the total sum of all indicators communalities considered in the TDS approach using factor analysis (Johnson & Wichern 1992; FA; Shahab *et al.* 2013), which was conducted via SPSS 21 software. The communality value of each variable ranges between 0-1, with a higher of the indicator communality reflect a greater contribution of this indicator in explaining the examined phenomenon (Johnson & Wichern 1992).

The calculation of SQI was performed using the following equation (Doran and Parkin, 1994):

$$SQI = \sum_{i=1}^{n} \mathrm{Wi} \times Si \qquad \text{Eq1}$$

where Wi is the weighting value of soil attributes, and Si is the indicator score for soil attribute, and (n) is the total number of soil attributes.

Finally, SQ indices were then classified to assess the status of each land use by using the following classification (Cantú *et al.* 2007; Table 1).

Table 1. Classification of soil quality index

Soil quality classes				
Very low	**Low**	**Moderate**	**Good**	**Very good**
0.00-0.19	0.20-0.34	0.35-0.59	0.60-0.79	0.8-1

Statistical analysis

Prior to performing any analysis, the Kolmogorov–Smirnov test was employed to assess the normality of the dataset. Additionally, the homogeneity of variance was evaluated through Levene's test. The difference in soil characteristics among the LUTs was investigated by one-way analysis of variance (ANOVA) in conjunction with Duncan's multi-range test. To summarize the data, we also used principal component analysis or PCA on the correlation matrix of soil properties from each LUT through the use of the "FactoMineR" package (Husson *et al.* 2017). The PCA aimed to transform the initial soil variables into new axes variables explaining the data variation, indicating the correlation of each variable (or vector) with the PCA axes. Discriminant analysis (DA) was then performed to determine the significance of the difference in soil properties between the LUTs and to check the correctness of classification based on these soil properties. These statistical analyzes were performed in SPSS 21 and R statistical environment (FactoMineR and factoextra).

RESULTS

Difference of soil attributes among LUTs

According to the results of one-way analysis of variance (ANOVA), all biological, chemical (except pH), physical soil attributes and SQ indicated significant differences between the different LUTs (Table 2).

Table 2. Results of the one-way analysis of variance (ANOVA) of the biological, chemical, physical soil properties and soil quality according to the different land use types.

Soil properties		D	F	Sig
Biological soil properties	SIR (mg CO_2 g^{-1} dm 24 h^{-1})	۴	31.76	0.000 **
	BR (mg CO_2 g^{-1} dm 24 h^{-1})	۴	28.28	0.000 **
	MBC (mg Biomass-C. 100 g^{-1} dm)	۴	25.14	0.000 **
Chemical soil properties	EC (dS m^{-1})	۴	5.21	0.001 **
	pH (1:1 H_2O)	۴	2.50	0.06 ns
	Kava (ppm)	۴	48.48	0.000 **
	Pava (ppm)	۴	15.37	0.001 **
	Lime (%)	۴	28.63	0.000 **
	SOC (%)	۴	73.74	0.000 **
	Ntot (%)	۴	28.03	0.000 **
Physical soil properties	BD (g cm^{-3})	۴	10.89	0.000 **
	SP (%)	۴	6.22	0.000 **
	Sand (%)	۴	23.50	0.000 **
	Clay (%)	۴	8.51	0.000 **
	Silt (%)	۴	10.74	0.002 **
	SQI	۴	13.82	0.000 **

Note: Significant differences are indicated by (*) $P<0.05$ or (**) $P<0.01$. SIR: substrate-induced respiration, BR: basal respiration, MBC: microbial biomass carbon, EC: electrical conductivity, Kava: available potassium, Pava: available phosphorus, SOC: soil organic carbon, Ntot: total Nitrogen, BD: bulk density, SP: saturation moisture, and SQI: soil quality index.

Mean comparison of soil attributes among LUTs

Chemical soil attributes

EC was significantly higher in SCN than in DEF, while no significant differences were observed among the other LUTs. In addition, Pava and Kava were highest in LCN, followed by FOR, and then decreased in the order DEF > AMP > SCN. The content in lime peaked in DEF and is the lowest in FOR, while it did not vary significantly in the other types. SOC and Ntot were the highest in FOR and the lowest in DEF and SCN respectively, while the other types showed intermediate values (Fig. 2).

Physical soil attributes

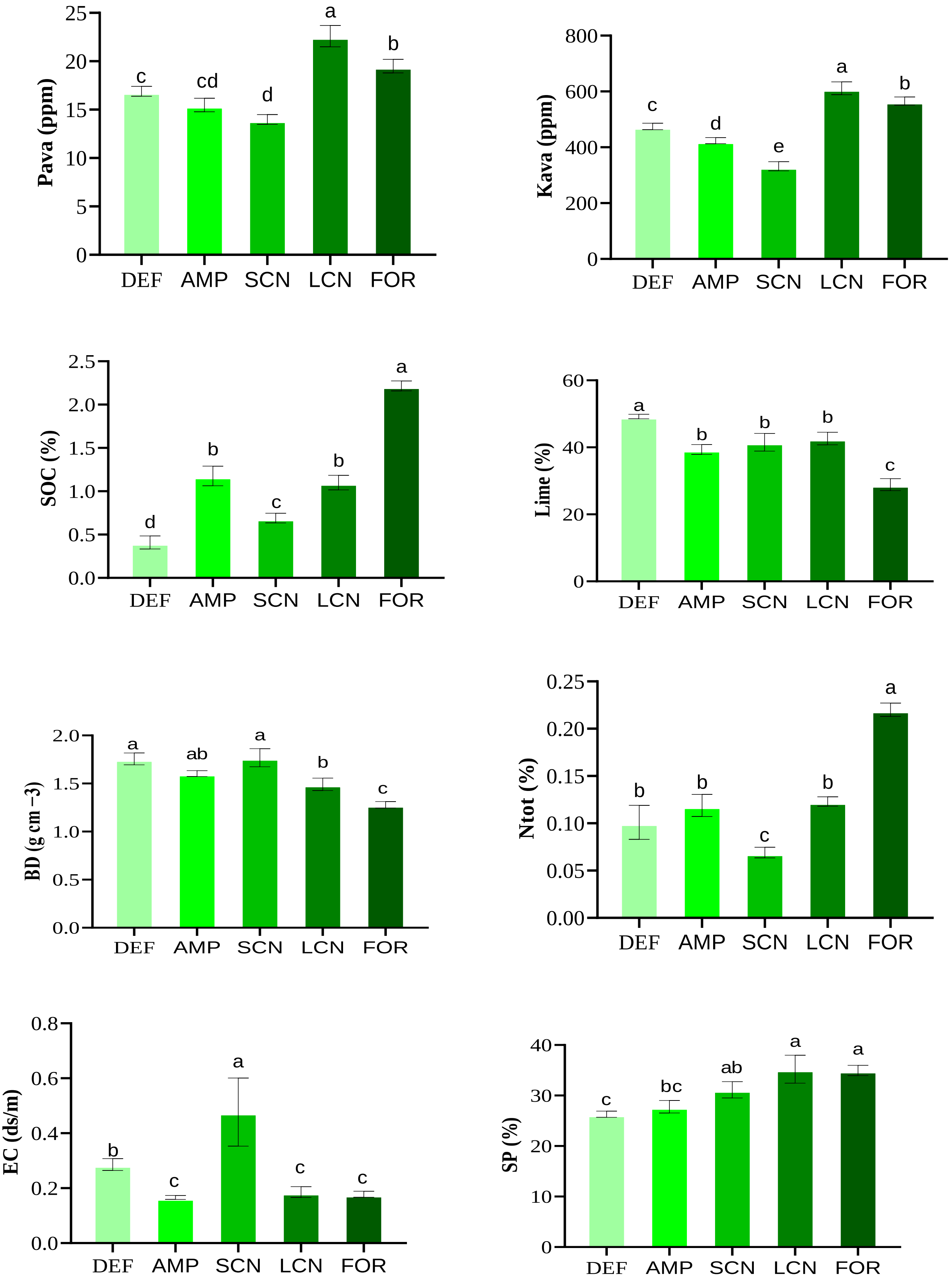
BD was highest in DEF and SCN and lowest in FOR, while SP was highest in FOR and LCN and minimal in DEF. Sand content was highest in AMP, followed by FOR, and decreased in the other LUTs, although differences were not statistically significant. Clay content was higher in FOR, LCN, and SCN than in DEF and AMP. Conversely, silt content was lower in FOR and AMP than in the remaining LUTs (Fig. 2).

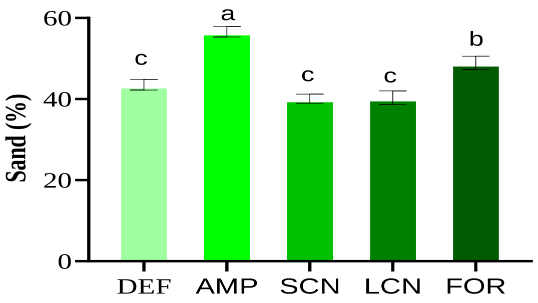
Biological soil attributes and soil quality index

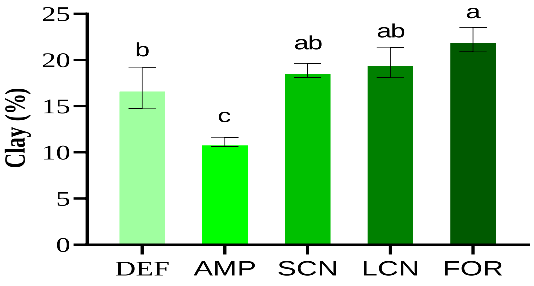
Duncan's multiple-range test indicated that basal respiration (BR), microbial biomass carbon (MBC), and substrate-induced respiration (SIR) were highest in FOR and lowest in DEF and SCN, with intermediate values observed in AMP and LCN (Figure 2). SQI decreased in the order FOR > LCN > AMP > SCN = DEF. According to the SQI classification (Cantú et al. 2007), FOR (0.63) was classified as good, LCN (0.53) and AMP (0.46) as medium, and DEF (0.32) and SCN (0.29) as low.

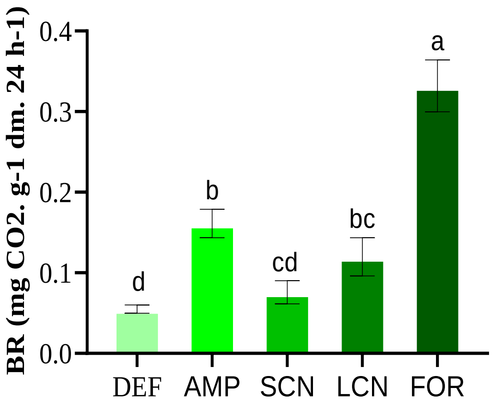
Multivariate analysis of soil attributes in the different LUTs

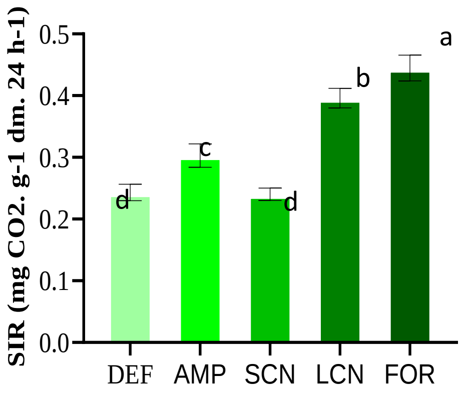
The contribution of soil attributes to the variation in LUT distribution along the first two principal axes of the PCA is shown in Fig. 3. PC1 and PC2 explained 51.8% of the total variance (37.5% and 14.3%, respectively). SOC, BR, SIR, MBC, Ntot, SQI, lime, and BD contributed most to PC1, while Pava, Kava, sand, and silt contributed most to PC2 (Fig. 4). PC1 was positively correlated with BR, SIR, MBC, Ntot, Kava, SP, and SQI, and negatively correlated with pH, EC, silt, BD, and lime. PC2 revealed positive correlations with Pava, Kava, silt, SP, clay, lime, and SIR, and negative correlations with pH and sand (Table S1). PCA results showed a clear separation among LUTs based on soil attributes.

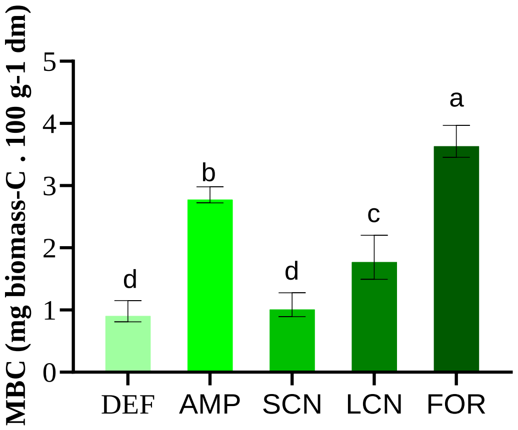


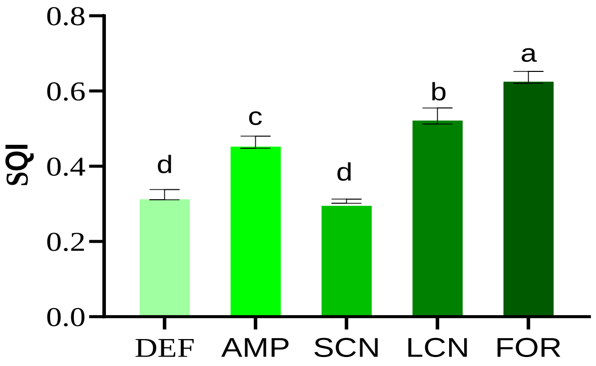

Sand (%)
0
20
40
60
c
a
c
c
b
DEF
AMP
SCN
LCN
FOR


Clay (%)
0
5
10
15
20
25
b
c
ab
ab
a
DEF
AMP
SCN
LCN
FOR


BR (mg CO2. g-1 dm. 24 h-1)
0.0
0.1
0.2
0.3
0.4
d
b
cd
bc
a
DEF
AMP
SCN
LCN
FOR


SIR (mg CO2. g-1 dm. 24 h-1)
0.0
0.1
0.2
0.3
0.4
0.5
d
c
d
b
a
DEF
AMP
SCN
LCN
FOR


MBC (mg biomass-C . 100 g-1 dm)
0
1
2
3
4
5
d
b
d
c
a
DEF
AMP
SCN
LCN
FOR


SQI
0.0
0.2
0.4
0.6
0.8
d
c
d
b
a
DEF
AMP
SCN
LCN
FOR

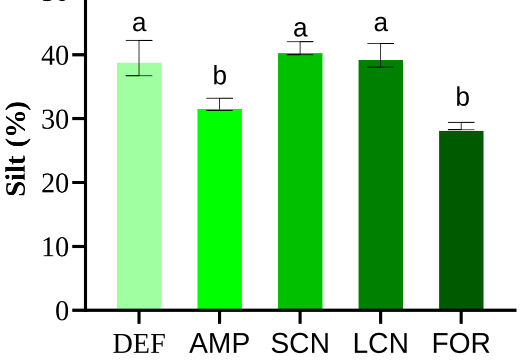

Silt (%)
0
10
20
30
40
50
a
b
a
a
b
DEF
AMP
SCN
LCN
FOR

Fig. 2. Mean values (± standard error) of biological, chemical, physical properties and soil quality index between the land use types: a same letter indicates no significant difference. FOR: natural oak forests, DEF: degraded and abandoned forests, AMP: Plantation of *Amygdalus scoparia*, LCN: long-term cultivation of Narcissus and SCN: short-term cultivation of Narcissus (SCN); BR: basal respiration, SIR: substrate-induced respiration, MBC: microbial biomass carbon, EC: electrical conductivity, Pava: available phosphorus, Kava: available potassium, SOC: soil organic carbon, Ntot: total Nitrogen, BD: bulk density, SP: saturated moisture, and SQI: soil quality index.

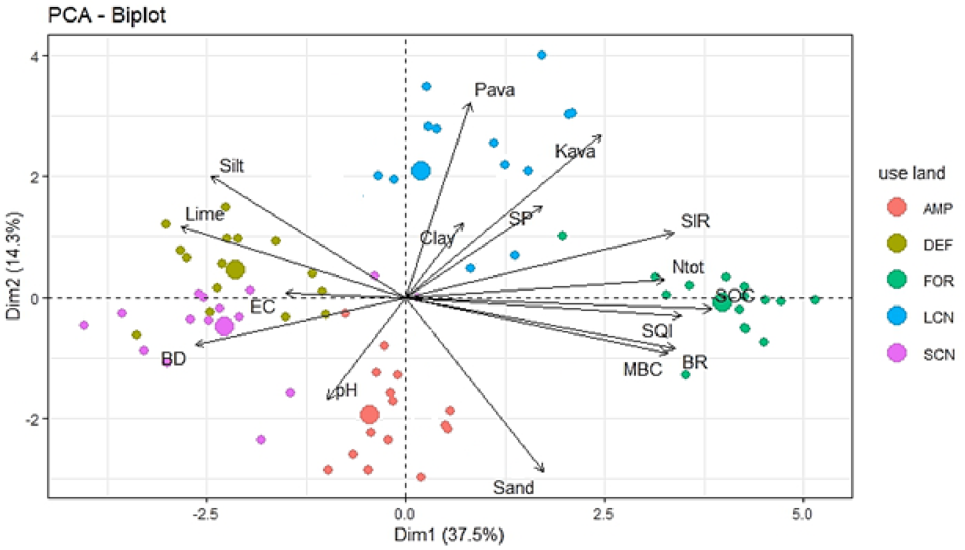


Fig. 3. Principal Component Analysis (PCA) ordination diagrams showing distribution of the plots (represented by points, the largest point being the centroid) in the different land use types along the first two axes based on soil properties (represented by arrows); FOR: natural oak forests, DEF: degraded and abandoned forests, AMP: Plantation of *Amygdalus scoparia*, LCN: long-term cultivation of *Narcissus* and SCN: short-term cultivation of *Narcissus*; BR: basal respiration, SIR: substrate-induced respiration, MBC: microbial biomass carbon, EC: electrical conductivity, pH: soil acidity, Pava: available phosphorus, Kava: available potassium, SOC: soil organic carbon, Ntot: total Nitrogen, BD: bulk density, SP: saturated moisture, and SQI: soil quality index.

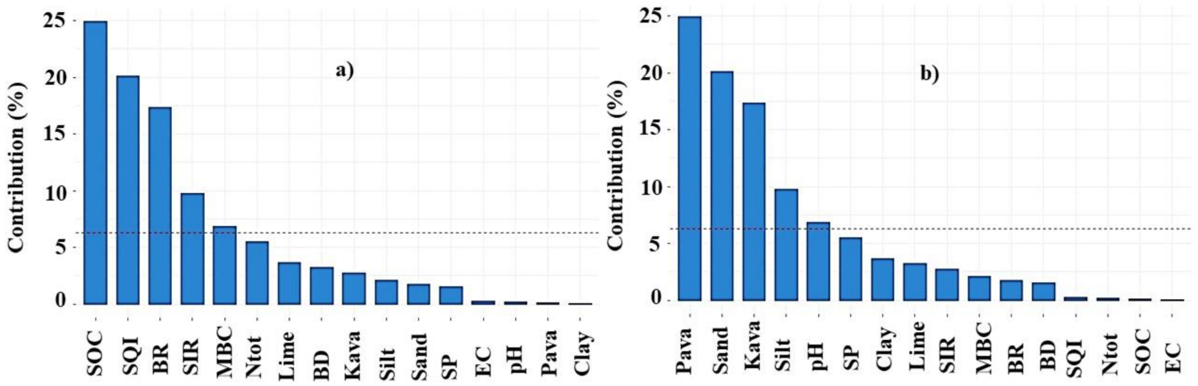


Fig. 4. Contribution of the different soil properties to the first axis (a) and second axis (b) of the principal component analysis (PCA). The dashed line represents the average expected contribution. SOC: soil organic carbon, Ntot: total nitrogen, BD: bulk density, Kava: available potassium, Pava: available phosphorus SP: saturated moisture, EC: electrical conductivity, pH: soil acidity, and BR: basal respiration, SIR: substrate induced respiration, MBC: microbial biomass carbon and SQI: soil quality index.

For plots clustered along the positive side of PC1, reflecting higher soil fertility compared to other types. LCN plots were distributed along the positive side of PC2 and extended in the positive direction of PC1, indicating relative similarity to FOR in terms of soil properties, especially Pava, SP, clay, silt, and SIR. DEF and SCN plots grouped together without clear separation along PC1, indicating similar soil properties. High EC, silt, BD, and lime values in these LUTs were associated with lower biological activity and nutrient content. Similarly, plots of the AMP (Almond plantation) type are grouped in the negative direction of axis 2. Soils of this type had a high sand content and pH indicating soils with a low nutrient content and a low biological activity (Fig. 3).

Table S1. Pearson's coefficients of correlation between PC1 and PC2 with the different soil properties. Notations: SIR: substrate-induced respiration, BR: basal respiration, MBC: microbial biomass carbon, EC: electrical conductivity, Kava: available potassium, Pava: available phosphorus, SOC: soil organic carbon, Ntot: total Nitrogen, BD: bulk density, SP: saturation moisture, and SQI: soil quality index.

Axis-1		**Axis-2**	
Soil properties	**Correlation coefficient**	**Soil properties**	**Correlation coefficient**
Kava	0.577**	Pava	0.631**
Lime (%)	0.666**-	Kava	0.756**
pH	0.332*-	Lime (%)	0.273*
SIR	0.791**	pH	0.396*-
MBC	0.775**	SIR	0.252*
BR	0.796**	Silt (%)	0.472**
SOC (%)	0.903**	Sand (%)	0.680**-
Ntot (%)	0.766**	Clay (%)	0.290*
EC (dS/m)	0.356*-	SP (%)	0.356*
SP (%)	0.404*		
Silt (%)	0.575**-		
BD	0.622**-		
SQI	0.815**		

Note: * and ** represent significant correlation at 0.05 and 0.01.

The dissimilarity of the LUTs based on soil attributes

The discriminant analysis using soil variables resulted in four functions (Table 3). The functions 1 and 2 had the highest eigenvalues which explained 70.3 and 20.8 % of the total variance, respectively. Therefore, these two functions were used to interpret and model the relationships within the data (Table 3).

Table 3. Summary of statistics related to the functions of the Discriminant Analysis (DA).

Functions	**DF**	**Eigenvalue**	**Canonical correlation coeficent**	**Explained variance**	**Chi-Square**	**Wilks Lambda**	**Sig.**
F1	64	19.18	0.97	70.3	403.3	0.002	0.000**
F2	45	5.68	0.92	20.8	212.5	0.035	0.000**
F3	28	1.97	0.81	7.3	91.9	0.235	0.000**
F4	13	0.42	0.54	1.6	22.6	0.700	0.047*

Note: * and ** represent significance at 0.05 and 0.01, respectively.

The Kappa coefficient indicated that the matching of plots in the different LUTs with the groups obtained from the DA based on the soil properties was 0.806 (80.6%). It indicates that the grouping by DA based on soil variables was particularly accurate. Function 1 was primarily associated with lime (negative), BR, SOC, SP, and SQI (positive), while Function 2 was mainly associated with SIR and Kava (positive; Table 4). Discriminant analysis revealed that Function 1 provided a clearer separation among LUTs than Function 2 (Fig. 5). Function 1 showed a significant positive correlation with BR, SOC, SP and SQI, and a significant negative correlation with lime. Plots of FOR were discriminated on the right part of the function 1 in relation with higher values of BR, SOC, SP and SQI compared to plots of the types DEF and SCN on the left end of the axis. Similarly, the position in the positive part of the second function of DA of plots of the LCN type indicates that SIR and Kava values were higher than in the AMP type in the negative part of function 2. Among the soil properties analyzed, BR, SOC, SP, SQI, Kava, and lime exhibited the strongest correlations with LUT variations.

Relationships between physical, chemical, biological properties and soil quality

Pearson's correlation analysis indicated significant positive correlations among the SQI and BR, SIR, MBC, SOC, Kava, Ntot, and SP. Conversely, SQI exhibited significant negative correlations with EC, lime, and BD (Figure 6). Soil biological indicators (BR, SIR and MBC) revealed a positive correlation with Ntot, Kava, SOC, and SP and a significant negative correlation with EC, lime, BD, and silt (Fig. 6).

Table 4. Correlation between each soil variable and any discriminant functions; *: Largest absolute correlation between each variable and any discriminant function. SIR: substrate-induced respiration, BR: basal respiration, MBC: microbial biomass carbon, EC: electrical conductivity, Kava: available potassium, Pava: available phosphorus, SOC: soil organic carbon, Ntot: total Nitrogen, BD: bulk density, SP: saturation moisture, and SQI: soil quality index.

Soil properties	Functions			
	1	2	3	4
SIR (mg CO_2 g^{-1} dm 24 h^{-1})	0.188	0.219*	0.153	0.067-
BR (mg CO_2 g^{-1} dm 24 h^{-1})	0.419*	0.017-	0.134	0.026
MBC (mg biomass-C. 100 g^{-1} dm)	0.040	0.128	0.193*	0.116-
EC (dS/m)	0.019	0.040-	0.093	0.098*-
pH (1:1 H_2O)	0.186-	0.088-	0.373*-	0.170
Kava (ppm)	0.260	0.773*	0.156	0.086-
Pava (ppm)	0.051-	0.101	0.142	0.164*-
Lime (%)	*0.398-	0.268	0.044-	0.058-
SOC (%)	0.673*	0.038	0.136	0.636-
Ntot (%)	0.297	0.156	0.164	0.583*
BD (gcm^{-3})	0.074	0.041-	0.087*	0.025
SP (%)	0.122*	0.024	0.086	0.005-
Sand (%)	0.143	0.230-	0.924*	0.013
Clay (%)	0.0107	0.136	0.518*-	0.226
Silt (%)	0.224-	0.076	0.340*-	0.229-
SQI	0.533*	0.224	0.128	0.154-

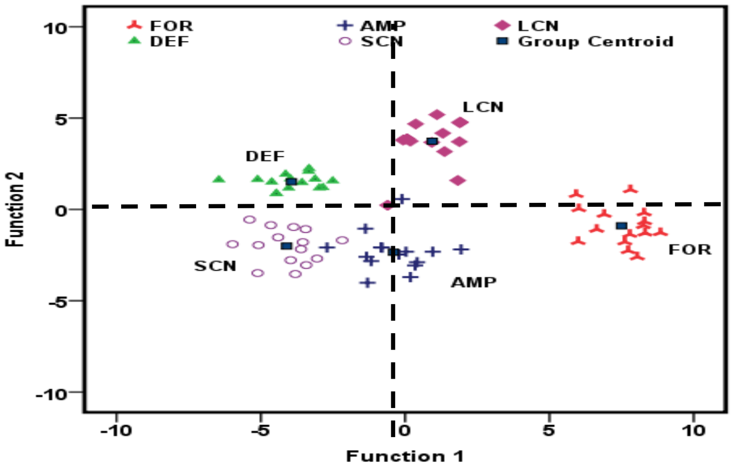


Fig. 5. Scatter plot of the first two discriminant functions for the different land use types; FOR: natural oak forests, DEF: degraded and abandoned forests, AMP: Plantation of *Amygdalus scoparia*, LCN: long-term cultivation of *Narcissus* and SCN: short-term cultivation of *Narcissus.*

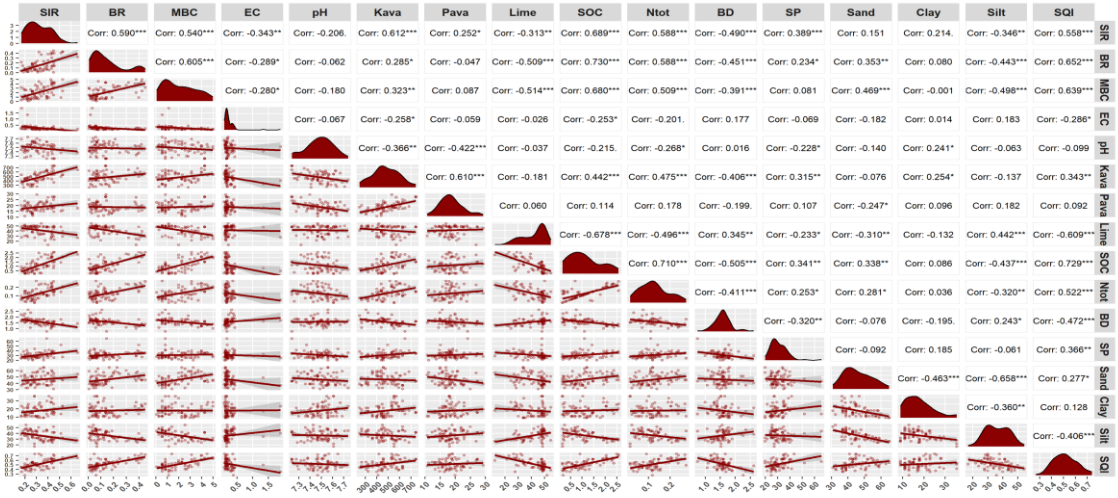


Fig. 6. Pearson's correlation coefficients between physical, chemical, biological properties and soil quality; the color denotes the strength and direction of the relationship BR: basal respiration, SIR: substrate-induced respiration, MBC: microbial biomass carbon, EC: electrical conductivity, pH: soil acidity, Pava: available phosphorus, Kava: available potassium, SOC: soil organic carbon, Ntot: total Nitrogen, BD: bulk density, SP: saturated moisture, and SQI: soil quality index.

DISCUSSION

A major challenge in Mediterranean semi-arid forest areas is the conversion of forest to agriculture followed by abandonment due to reduced productivity and low income (Delgado-Artés *et al.* 2022). This land use change can cause soil erosion and a decrease in soil quality (SQI), ultimately leading to degradation of local ecosystems. In this context, restoration strategies involving local community participation can be an effective approach to protect and restore the ecosystem. Introducing intensive cultivation of economically valuable, high-demand crops such as Narcissus can incentivize local participation gradually improving the growth substrate and facilitating the restoration of degraded forest areas, thereby reducing pressure on remaining natural forests.

Soil chemical properties

The findings showed that closed-canopy forests (FOR) and long-term *Narcissus* cultivation (LCN) exhibit more favorable nutrient concentrations. Specifically, average available phosphorus and potassium levels were highest in LCN and FOR, short-term *Narcissus* cultivation showed lower amounts (SCN). These nutrients are essential for plant growth (Johnson *et al.* 2022; Khan *et al.* 2023). Traditional annual tillage disrupts nutrient cycling, increases soil erosion, and reduces soil water and nutrient retention capacity (Alewell *et al.* 2020; Tiruneh *et al.* 2021). Additionally, converting forests into agricultural lands decreases cation exchange capacity by reducing organic matter and destroying soil structure, which can lead to the loss of soil phosphorus and potassium. Studies indicate that microbial biomass phosphorus (MBP) declines significantly after tillage compared with forest soils (Jahan et al. 2025), thereby impacting phosphorus availability (Awoonor *et al.* 2023). This aligns with research showing that deforestation and agricultural expansion deplete exchangeable potassium over time by altering pH and organic carbon, both essential for potassium retention (Samra & Swarup 2002; Azadi & Shakeri 2020). The higher available phosphorus (Pava) and available potassium (Kava) in LCN and FOR are likely attributable to their greater organic matter and clay content, as soils richer in these components possess a greater nutrient retention capacity through efficient surface adsorption and reduced erosion (Najafi-Ghiri 2011). These results emphasize that proper land use management and maintenance of vegetative cover can help stabilize soil phosphorus and potassium reserves. In fact, long-term narcissus cultivation has improved nutrient cycling due to the absence of tillage, consistently adding organic matter each year, and the creation of a more permanent surface cover. We also found that nitrogen and organic carbon levels were highest in FOR and lowest in SCN and DEF. Forests with high biomass contribute a large input of organic matter to the soil each year, which is a rich source of nitrogen (Pan *et al*. 2011). The continuous vegetation cover in forests helps retain soil nutrients, including soil nitrogen, by adding organic matter and protecting the soil from erosion (Mushinski *et al.* 2021). Kalambukattu *et al.* (2013) showed that forest conserves more particulate organic carbon through carbon sequestration due to the more stable soil conditions. In contrast, the conversion of forests to cropland often involves tillage. This practice disrupts soil structure, increases the decomposition rate of organic matter. This can lead to nitrogen losses through volatilization and leaching (Zhu *et al.* 2021a; Leul *et al.* 2023). The relative increase of organic carbon and nitrogen in LCN and almond plantation (AMP) in this study may be related to the elimination of tillage, the gradual accumulation of organic matter, and the enhancement of soil biological activities (Zong *et al.* 2024). Meanwhile, the decrease of microbial activities and altered organic matter stability are implicated in nitrogen decline in degraded areas and under intensive agriculture (Ji *et al.* 2020). Supporting this, Sainepo *et al.* (2018) showed that land use change significantly impacts soil organic carbon stocks, with shrublands exhibiting higher levels than pastures and croplands due to higher litter inputs and reduced soil degradation. Soil microorganisms are crucial in the nitrogen cycle (Zhu *et al.* 2015; Chen *et al.* 2024), and the conversion of forest to arable land can alter the microbial community and its activity, reducing the rate of nitrogen fixation and increasing denitrification, ultimately leading to soil nitrogen depletion (Zhu *et al.* 2024). Soil electrical conductivity (EC) was higher in DEF and SCN than in FOR, AMP, and LCN. Land use change associated with agricultural practices, such as tillage, may dramatically enhance the concentration of total dissolved salts and electrical conductivity because electrical conductivity is directly related to the concentration of total dissolved salts (Sünnemann *et al.* 2021). The reduction of soil coverage (canopy cover) in degraded areas, especially in arid and semi-arid regions, increases moisture loss and also soil EC. Consistent with our results, studies by Stroosnijder (2003) and Tejada & Gonzalez (2008) showed that conversion of forest to agricultural land leads to an increase in soil EC. The results showed that the lime content was greatest in DEF and least in FOR. The land use change forests to arable land causes soil displacement during plowing, which can increase the lime content of the topsoil, given the presence of carbonated soil layers near the surface in this area (DEF). However, in FOR soil stability and greater soil permeability has caused dissolution and washing of lime and reduced its content (Heydari *et al.* 2020c).

Soil physical attributes

The lowest soil moisture content was observed in the DEF, likely due to its degraded structure characterized by its high bulk density and low organic matter content. Years of cultivation and erosion in the DEF have reduced its clay and organic matter content, diminishing its water retention capacity. This aligns with findings showing that forest conversion increases bulk density and decreases soil porosity thereby limiting soil moisture retention (Lal 1996; Tebebu *et al.* 2017). The importance of clay in soil structure and water/nutrient holding capacity (Kome *et al.* 2019) explains why reduced clay content in the eroded DEF lowers water retention. Conversely, forests maintain high soil moisture due to extensive root systems and litter cover (Neary *et al.* 2009) and Tebebu *et al.* (2017) linked organic matter and changes in fine particle such as clay to soil moisture variations in agricultural and forest soils. The most soil bulk density (BD) was recorded in DEF, SCN and AMP, while the least BD was observed in LCN and especially in FOR. Increased BD in DEF likely results from tillage activities, topsoil disturbance, soil compaction, reduction of organic matter and destruction of soil structure (Bizuhoraho *et al.* 2018). This increase in BD, as a result of forest conversion to agricultural land, has been documented in earlier studies (e.g. Göl 2009) and is known as an indicator of soil degradation (Guilser 2006). It seems that long-term Narcissus cultivation, while improving soil organic matter, has caused a decrease in soil bulk density due to the elimination of agricultural operations such as tillage. While soil texture is generally considered stable, long-term land use changes can indeed alter particle ratios (clay, silt and sand) in soil texture. The findings showed higher sand content in AMP than in other areas, and higher clay content in FOR, LCN, and SCN than in DEF and AMP. The decline in organic matter and disaggregation of soil particles following forest land use changes typically leads to the erosion of finer particles like clay, especially in areas with less vegetation cover such as degraded agricultural lands. This erosion consequently increases the proportion of coarser particles such as sand in the soil texture (Ayoubi *et al.* 2011). Conversely, the higher clay content observed in Narcissus cultivation areas, particularly LCN and FOR, may be attributed to better soil cover, reduced surface erosion, and gradual accumulation of clay at the base of the densely cultivated Narcissus bushes.

Soil biological attributes

Land use change significantly reduced the soil microbiome and its activity, thereby affecting nutrient cycling (Díaz-Vallejo *et al.* 2021). This was reflected in altered microbial biomass and soil respiration, with the highest basal respiration (BR), substrate-induced respiration (SIR), and microbial biomass carbon (MBC) in forest (FOR) and the lowest in degraded forest (DEF). Soil respiration, a key process in the global carbon cycle, involves CO_2 release from microbial metabolism and indicates soil fertility and nutrient availability (Rodtassana *et al.* 2021; Chen *et al.* 2024; Liu *et al.* 2025). MBC, representing the carbon in living microorganisms, is a vital component for nutrient cycling and soil functioning, and serves as a measure of microbial community size (De Vries *et al.* 2018; Patoine *et al.* 2022). The positive correlation between BR and MBC in FOR suggests both are influenced by factors like soil organic carbon and microbial composition (Cheng *et al.* 2013; Smith *et al.* 2018). Higher MBC in FOR and Leymus chinensis (LCN) sites was likely due to the quality and quantity of organic inputs, which stimulate microbial activity and mineralization, supported by positive correlations among MBC, organic carbon, and soil moisture (Potard *et al.* 2017; Anokye *et al.* 2021; Agbeshie *et al.* 2025; Yuan *et al.* 2025). Conversely, degraded ecosystems like DEF experience reduced organic inputs and soil organic carbon depletion, directly lowering microbial activity (Wang *et al.* 2014; Sharma *et al.* 2024), a finding consistent with our correlation analysis. Deforestation and agricultural conversion expose soils, increasing temperatures and accelerating SOC decomposition, which leads to long-term carbon loss and reduced microbial function (Sun *et al.* 2013; Guo *et al.* 2023). These changes often degrade soil structure, reduce vegetation cover, and lower water-holding capacity. Given the critical role of soil moisture for microbes, the moisture deficit in DEF likely contributed to its reduced respiration (Wood *et al.* 2013; Sivaranjani *et al.* 2025). Degraded lands typically exhibit poor structure, low organic matter, and biodiversity loss, impairing soil functions (Jensen *et al.* 2020; Wang *et al.* 2024). Natural succession and restoration, such as planting pioneer shrubs, can improve soil quality and microbial activity, as belowground organisms drive initial succession in degraded sites (Zhang *et al.* 2024; Zhou *et al.* 2024). The higher respiration in Ampelopsis (AMP) and LCN likely reflects their restored condition compared to DEF, due to improved soil structure from no-tillage, organic matter return, and better soil cover. Supporting this, Zhang *et al.* (2024) found planting *Leymus chinensis* in degraded grassland increased bacterial diversity and nitrogen-cycle enzyme activities, while Li *et al.* (2024) showed pioneer shrubs like *Lycopodium japonicum* enhanced heterotrophic bacteria and organic matter decomposition in mined sites. Thus, long-term planting on converted lands, such as with narcissus, appears to improve soil biological activity and the microbiome.

Multivariate analysis of soil attributes

Principal component analysis revealed that FOR exhibited higher soil biological activity (BR, SIR, and MBC), nutrients (Ntot and Kava) and saturated moisture. Discriminant analysis further separated FOR and LCN from DEF and SCN with SOC, SP, BR, SIR, Kava, and a higher SQI being key distinguishing factors for FOR and LCN. LCN showed similar soil characteristics to FOR. Higher SP, SOC, Pava, Kava, and Ntot in FOR and LCN enhanced soil fertility and microbial activity, consistent with higher MBC, BR, and SIR (Song et al. 2018). Increased nutrients in these areas are linked to greater amounts of organic carbon, which provide a substrate for microbial population growth, increases the rate of decomposition of organic matter, and releases more nutrients (Shi *et al.* 2021). The positive relationship between MBC and SOC in FOR confirms that forests have greater biological activity due to high organic matter and water retention (Bai *et al.* 2018). Other research also confirms that forest soils have greater biological activity due to high organic matter and water retention (Gangwar *et al.* 2022) and that finer texture and high organic matter soils support higher enzymatic and microbial activity (Zhu *et al.* 2021b). In contrast, DEF and SCN clustered together characterized by lower nutrient and water storage, increased EC, lime content, and bulk density, all factors that reduce microbial activity and soil quality (Morrissey *et al.* 2014). This finding is in line with the study by Urbański & Jakubiak (2017), which showed that forest degradation reduces nutrients and increase soil compaction, thereby reducing biological activity and soil fertility and with the study by Liu *et al.* (2022) showing that conversions from forest to agricultural or degraded land decreases organic carbon, total nitrogen and available potassium, negatively impacting microbial diversity and activity. The positive relationship between biological indicators and soil organic carbon and nutrients in this study confirms previous literatures. Therefore, appropriate land management including forest conservation/restoration and sustainable low-tillage agriculture on abandoned lands can prevent further soil degradation by improving organic matter, biological activity and fertility (Leeuwen *et al.* 2017). The soil quality (SQ) survey categorized FOR as "good," LCN and AMP as "average," and SCN and DEF as "poor" Land use change causes nutrient depletion and soil structural weakness. Intensive traditional cultivation like rainfed wheat in forest areas leads to soil erosion and degradation, decrease of organic matter, and reduced microbial diversity which lowers SQ and health. Consistent with our findings, Nabiollahi *et al.* (2018) reported higher SQI in forests than in croplands and significant SQ reduction due to deforestation. Agbeshie et al. (2025) also showed that cocoa agroforestry improved SQ compared to croplands, although SQ was higher in natural forest lands. Therefore, appropriate management measures that preserve SQ and reduce erosion are crucial for restoring degraded soils and maintaining SQ and productivity in these areas.

Relationship between SQI and soil attributes along different land uses

Correlation analysis revealed that SQ positively correlated with SOC, Ntot, MBC, BR, SIR, SP, Kava and Sand. SOC is crucial for SQ, enhancing microbial activity, moisture retention, and structure (Bashir *et al.* 2021). MBC, an indicator of soil biological activity, correlated positively with SQ due to its role in processes like organic matter decomposition (Emami *et al.* 2012). Conversely, SQ showed a negative and significant relationship with BD, EC, lime and silt. Increased BD limiting microbial activity and plant growth (Samuel-Rosa *et al.* 2013). High electrical conductivity (EC) also can limit plant growth and reduce SQ (Bilgili *et al.* 2017). In addition, high lime can reduce the availability of some nutrients and reduce SQ by increasing soil pH (Glinscaya *et al.* 2024). These findings align Xie *et al.* (2020) and Samuel-Rosa *et al.* (2013), who also observed that increased SOC and Ntot improve SQ, while salinity (related to EC) and bulk density have detrimental effects. Soil biological indices (BR, SIR, and MBC) had a positive and significant relationship with Kava, SOC, and SP, while showing a negative and significant correlation with EC, lime content, BD, and silt content. These results align with Devi & Yadava (2004) who reported a positive and significant correlation among soil moisture and soil microbial biomass, and with Manral *et al.* (2023) who found a high positive relationship among MBC and soil water content, organic carbon, and phosphorus. Our results also indicate a negative correlation between soil biological activities and salinity, which can be attributed to salinity's detrimental effects on the membrane system, metabolism, and nutrient uptake of soil organisms (Bui, 2013). Reduced soil salinity generally improves metabolic conditions and increases soil respiration, a finding supported by Yang *et al.* (2019).

CONCLUSION

Land degradation and forest conversion in the Zagros oak forests severely compromise soil health. This study demonstrates that soil quality (SQ) is fundamentally linked to land use, with natural forests maintaining "good" SQ through superior organic matter and microbial activity. In contrast, degraded abandoned lands and short-term Narcissus cultivation result in "poor" SQ due to nutrient depletion, salinity, and compaction. Our findings directly address core research questions by quantifying how different land uses alter soil properties. The key innovation is identifying the specific soil attributes that drive these changes: SQ is positively correlated with SOC, total N, MBC, and available phosphorus, but negatively with EC, lime, and bulk density. Crucially, the strong link between biological indicators and SQ highlights that degradation is first signaled by a collapse in microbial ecosystem functions. While long-term Narcissus cultivation and almond plantations show moderate SQ improvement, they do not restore the original forest soil quality. Therefore, sustainable strategies must enhance critical attributes like SOC. We propose nature-based solutions such as polyculture (Narcissus with almonds), reduced tillage, and using pioneer species to stabilize soils and support livelihoods. Ultimately, protecting remaining forests is paramount. For degraded lands, restoration must integrate biological, physical, and chemical dimensions of soil health. Long-term monitoring is essential to ensure such practices deliver lasting ecosystem resilience against climate change and human disturbance, balancing economic needs with environmental sustainability.

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