Sacred Groves: A Pattern of Zagros Forests for Carbon Sequestration and Climate Change Reduction

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Abstract

Background: Rising atmospheric carbon dioxide has led to the global consequences of climate change. Biological carbon sequestration through vegetation and soils is one of the cost-effective ways to reduce this gas. Forest's ecosystems are the most important carbon pools among terrestrial ecosystems and play a sustainable and long-term role in reducing climate change. Among forest ecosystems, sacred groves are less-disturbed and they can be a pattern of successful forest management for carbon sequestration and climate change reduction. In the present study, for the first time, the amount of carbon content in sacred grove and silvopastoral lands were investigated to determine the capacity of Zagros oak forests in carbon sequestration and climate change reduction. The aim of this study was to estimate the amount of carbon reserves in mentioned land-uses in order to obtain a systematic attitude towards management of these different land-use types and attain a suitable solution to counter the climate change crisis and ultimately sustainable environmental development.

Results: The results showed that each of the studied variables in the two studied land use is significantly different from each other. The mean of each of these biomass or carbon pools in silvopastoral is significantly lower than sacred groves. The results indicate that the common utilizations in the forests of the study area cause a significant reduction ($P \leq 0.01$) in the forest biomass value and respective carbon content. Sacred grove currently absorbs 826.96 tons of carbon dioxide per hectare more than silvopastoral lands and this is a sign of high degradation in the forests of the study area.

Conclusions: According to the results obtained in this study, forest ecosystems that are protected against human intervention play a significant role in long-term carbon storage. Any interference with the natural conditions of the ecosystem has a significant negative impact on carbon reserves. Therefore, by selecting appropriate measures, local communities should be empowered to reduce their dependence on low incomes obtained from deforestation and conversion.

Keywords: Zagros forests, Sacred groves, Silvopastoral lands, carbon sequestration

1. Introduction

Climate change and global warming due to rising greenhouse gas concentrations is one of the major challenges in sustainable development. The increase of concerns about global warming and climate change have led to special attention being paid to forests, soils, and their ability to carbon sequestration sustainably [1, 2]. Vegetation and the soils covered by them are permanent pools and play a significant role in sequestering atmospheric carbon, thus reducing the effects of climate change [3]. The high capacity of forest ecosystems to decrease greenhouse gas emissions makes carbon management a key component of future natural climate solutions [4-6]. Forests are good criteria for controlling the carbon value of the atmosphere because they are the most important carbon pools for carbon sequestration [7]. Forests reserve more than twice the value of carbon in the atmosphere [8, 9], about 70% of global soil organic carbon and approximately 80 % of aboveground carbon [10, 11]. Therefore, these worth ecosystems are the most important carbon pools among terrestrial ecosystems and play a sustainable and long-term role in reducing climate change [12].

Disruptions are one of the factors that play a key role in the ecosystem carbon dynamics [13]. Natural and human-caused disruptions in forest ecosystems significantly affect ecosystem performance [14, 15], and carbon balance [13]. One of the most desirable and cost-effective approach for carbon sustainability in forests, as well as counter with disruptions such as deforestation and degradation, is the conservation and development of protected forests, which has been proposed globally [16]. Protected areas are the best strategy for biodiversity protection when faced with degradation, fragmentation and ecosystem detriment [17, 18]. Sacred groves are tested and proven procedure to preservation; as a result, it can be an important and vital part of protected areas [17].

Zagros forests with an area of more than five million hectares are considered the natural ecosystems of Iran and their economic value in terms of carbon sequestration is quite vital. Despite severe and continuous traditional exploitation of the Zagros forests, some parts of forests which are believed to be sacred religious areas and cemeteries have remained untouched (less-disturbed). These areas are defined as sacred groves [17, 19]. In fact, sacred groves are forests that are less disturbed and are of special spiritual importance to people and communities. The actual appearance of the Zagros forests can be found in these sacred groves [20, 21]. In sacred groves of study area about 250 plant species have been recorded [17].

These areas (sacred groves) offer a valuable opportunity to researchers to obtain useful data on the real appearance of the Zagros forests through investigative research. With this information, these forests can be guided toward sustainability through medium- and long-term planning. Many studies offer strategies to minimize deforestation, prevent forest land use change, increase sequestration by increasing forest growth, and reduce carbon emissions to maintain or strengthen forest carbon stock [6]. Therefore, in this study, the amount of carbon content in sacred grove and silvopastoral lands were investigated to determine a model of the capacity of Zagros oak forests in carbon sequestration and climate change reduction. The aim of this study was to estimate the amount of carbon reserves in mentioned land-uses in order to obtain a systematic attitude towards management of these different land-use types and attain a suitable solution to counter the climate change crisis and ultimately sustainable environmental development.

2. *Materials and Methods*

Study site description

The study area includes sacred groves and silvopastoral lands in Baneh County. This region is embedded in North West part of Iran (In the Zagros Mountains) which is located within 35º 48′ 02″ – 36˚ 11́ 40″ north and 45˚ 32́ 45″ – 46˚ 10́ 25″ East (Fig.1). The climate is semi-humid and cold, with long and cold winters and moderate summers. The average elevation was 1550 m and total precipitation recorded was 600–800 mm. The average min. and max. Temperatures are −1.5 and 26.4°C respectively.

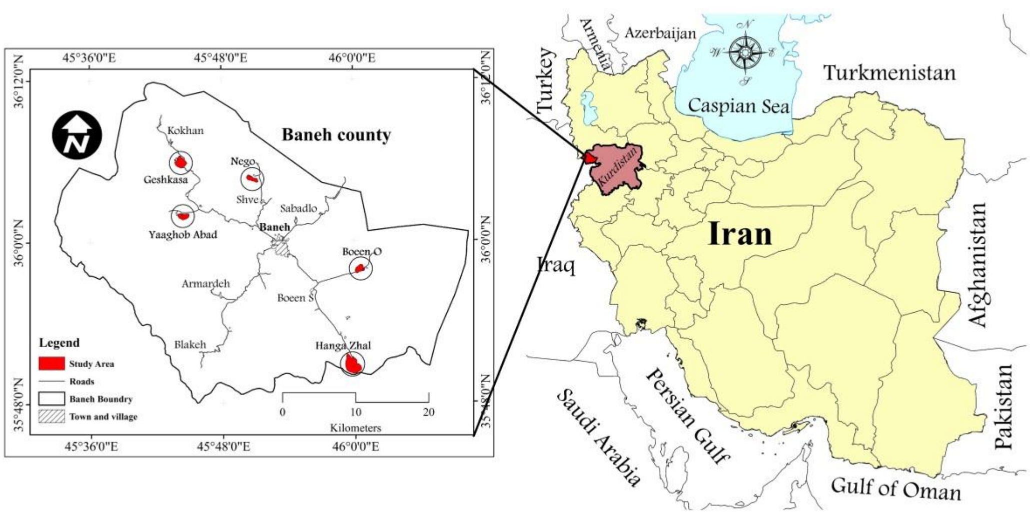

Fig. 1 Geographical location of the study area

Dominant tree species are three kinds of oak, comprising *Quercus brantii* Lindel*, Quercus libani* Olive *and Quercus infectoria* Olive. Species of *Cerasus* sp., *Crataegus* spp., *Pistacia atlantica*, *Amygdalus* spp. and *Lonicera* sp. are the main companion woody species in these forests.

This study focused on 5 village's forests, include Hange Jal, Booien Olya, Nejo, Yaghoub Abad and Gashkese, as five sites (Fig.1). In each selected sites, those cemeteries that had an area of more than 1 hectare were selected as sacred groves. There are strict rules in the sacred groves that forbid the cutting of trees, hunting, animal grazing, collecting herbage, firewood or other plant products. Therefore this area includes less-disturbed forest stands. In fact, it can be said that these stands are a view of real forests of the study area (Fig. 2). In order to compare the carbon content of sacred groves with the exploited forests, the parts of the forests around these stands, that had the same physiographic conditions with the sacred groves, were selected as Silvopastoral lands. This land use is the forest that, Galazani system [22], livestock grazing and also some usages such as harvesting the wood, is done by forest residents (Fig. 2).

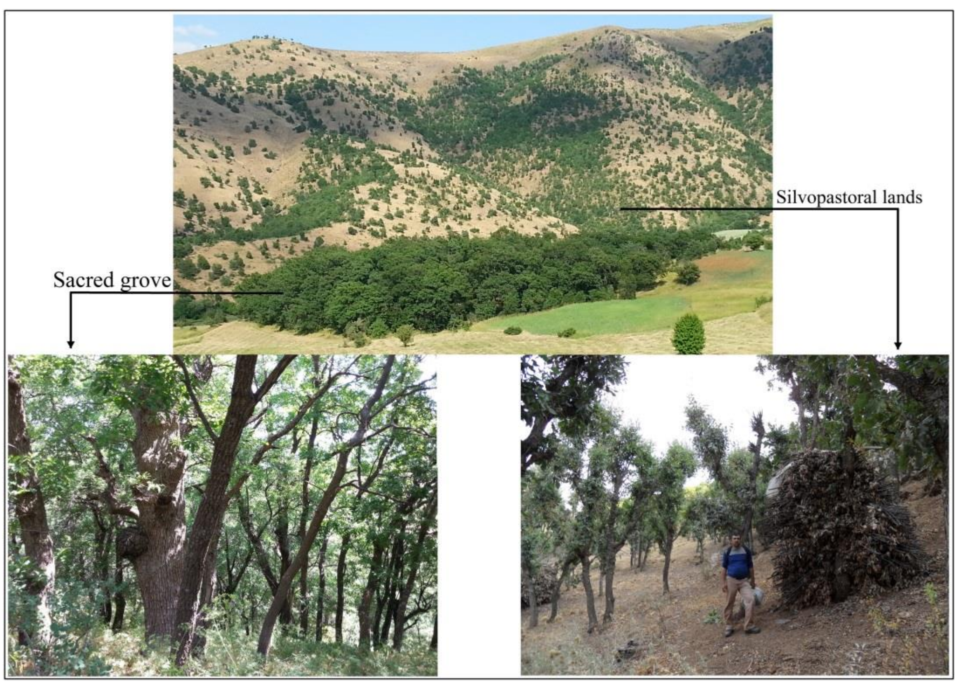

Fig 2 View of the two land uses studied (Sacred groves and Silvopastoral lands).

Sampling design

The nested plot was used in the sampling design [3, 23]. As shown in Figure 3, in concentric nested circular plots, multiple sub plots are settled for specific aims: a large circular plot (250 m^2 with an 8.2 m radius) was established for measure the trees. Inside of large plot, a sub plot (100 m^2 with a 5.65 m radius) was used to sapling measurement. Also, a sub-plot (3.14 m^2 with a 1 m radius) was set up to count regeneration and a small sub plot (0.56 m radius) was established for collecting leaf litter, herbs, grass, and soil samples.

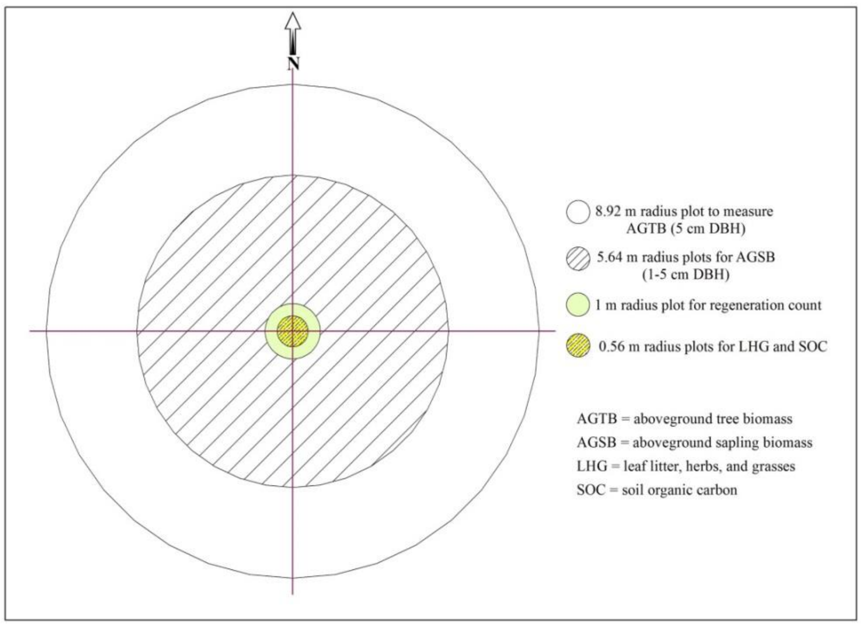

Fig. 3 Concentric nested circular plots

Measurement of forest carbon stock

Carbon pools measured in both land use include: Above-ground tree biomass (AGTB), Above-ground sapling biomass (AGSB), Below-ground biomass (BB), Soil organic carbon (SOC), Leaf litter, herbs, and grass (LHG) and Dead wood and fallen stumps (DWS). Therefore, the total carbon content for each land use was measured using the following equation [23]:

$$TC = C\,(AGTB) + C\,(AGSB) + C\,(LHG) + C\,(BB) + C\,(DWS) + SOC \qquad (1)$$

Where,

TC = total carbon stock for each land use [tC ha^{-1}]

C ($AGTB$) = carbon content in aboveground tree biomass [tC ha^{-1}]
C ($AGSB$) = carbon content in aboveground sapling biomass [[tC ha^{-1}]
C (LHG) = carbon content in leaf litter, herb and grass [tC ha^{-1}]
C (BB) = carbon content in belowground biomass [tC ha^{-1}]
C (DWS) = carbon content in deadwood and stumps [tC ha^{-1}]
SOC = soil organic carbon [tC ha^{-1}]

Later, the total forest carbon stock was converted into carbon dioxide (CO_2) equivalent by multiplying by 3.67 [24].

The methods for estimating carbon stock for each mentioned pools are explained in the following sections.

Aboveground tree biomass (AGTB)

In both land use studied, the diameter at breast height (DBH) and height of individual trees (≥5 cm DBH) were measured. Then all measured trees were recorded and classified according to species. The biomass equation suggested by Chave et al. 2005 and ICIMOD et al. 2010, was used to calculate the aboveground tree biomass. This equation (2) is as follows:

$$AGTB = 0.112 * (\rho D^2 H)^{0.916} \qquad (2)$$

Where,

AGTB = Above-ground tree biomass [Kg]

ρ = wood specific gravity [g cm-3]

D = Tree diameter at breast height [cm]

H = Tree height [m]

In both land use separately, the wood-specific density (ρ) for different tree species was determined in the laboratory. After attained the biomass stock density in kg m^{-2}, this value was multiplied by 10 and converted to t ha^{-1}. Then, by multiplying the biomass content per 0.47, the carbon stock was obtained [3, 23, 26].

Above-ground sapling biomass (AGSB)

All saplings with a diameter 1-5 cm were measured in sub-plot with a 5.64 m radius. The following formula was used to obtain the stems biomass of sapling:

$$AGSB = \left(\frac{\pi}{4} * D^2 * H * f\right) * \rho \qquad (3)$$

Where,

AGSB = Above-ground sapling biomass (stems biomass) [Kg]

D = Sapling diameter [cm]

H = Sapling height [m]

f = form quotient of Sapling (0.4)

ρ = wood specific gravity [g cm^{-3}]

The calculation of wood-specific density (ρ) as well as the conversion of kg m^{-2} to t h^{-1} was performed as mentioned in equation 2. Biomass value was converted to carbon stock using the carbon fraction of 0.47 [3, 23, 26].

Leaf litter, herbs, and grass biomass (LHG)

The biomass of leaf litter, herbs, and grass (LHG) were determined in nested sub-plot of 0.56 m radius. For this purpose, at first live components and all litter were gathered separately from these small plots. Then, the weight of fresh samples was measured and recorded in the field. Finally, a mixed sample (100 g) was placed in a marked bag to determine the oven dry weight in laboratory. Following equation was used to given the amount of biomass [23, 25]:

$$LHG = \frac{W_{field}}{A} * \frac{W_{subsample.dry}}{W_{subsample.wet}} * 10{,}000 \qquad (4)$$

Where,

LHG = biomass of leaf litter, herb and grass [t ha^{-1}]

W_{field} = weight of the fresh field sample of leaf litter, herb and grass [g]

A = Sample plot area in which leaf litter, herbs, and grass were gathered [m^2]

$W_{subsample,\ dry}$ = weight of the oven-dry sample of leaf litter, herb and grass [g]

$W_{subsample,\ wet}$ = weight of the fresh sample of leaf litter, herb and grass [g]

At the end, LHG carbon content was obtained by multiplying with the default carbon fraction 0.47.

Belowground biomass (BB)

Belowground biomass (BB) is difficult to measure, time consuming and has a lot of uncertainty. The following formula (5) has been proposed for estimating belowground biomass by Cairns et al. 1997. This equation is based on the relationship between belowground and aboveground biomass and can be used for a variety of species and climatic conditions. In this study, the belowground biomass was calculated using this equation, which is as follows:

$$BB = exp[-1.085 + 0.9256 \times \ln(AGTB)] \qquad (5)$$

Where,

BB = Belowground biomass [Kg]

AGTB = Above-ground tree biomass [Kg]

Finally, BB carbon content was calculated by multiplying with the default carbon fraction 0.47.

Dead wood and stumps (DWS)

In the whole 250 m^2 plots, all stumps from logged trees, standing dead trees, fallen stems, and fallen branches with a diameter at DBH and/or diameter ≥5 cm were measured. These dead parts of trees are important carbon pools that must be taken into account. Therefore, the diameter, length or height of each of the mentioned sections was recorded according to Instruction of ICIMOD et al. 2010 and Pearson et al. 2007. The amount of biomass and carbon obtained from this section was also calculated according to the mentioned instructions.

Soil organic carbon (SOC)

At each land-use site, a five plate center (sub-plot of 0.56 m radius) was chosen for soil sampling. Soil sampling was carried out separately at tow depths (0-15 and 10-30 cm). Then, five well-mixed samples of soil for the first depth and five well-mixed samples of soil for the second depth (about 2 kg) were prepared for each land use. Finally, 100 samples of prepared soil in plastic bags were transferred to laboratory [28, 29]. To determine the percentage of soil organic carbon, the Walkley and Black (1934) method was employed [30, 31]. After measuring the percentage of organic carbon, the amount of soil organic carbon stock at each depth was calculated separately for each land-use type and site through the following formula [3, 23]:

$$SOC = \rho \times d \times \%C \qquad (6)$$

Where,

SOC = soil organic carbon stock per unit area [t ha^{-1}]

ρ = soil bulk density [g cm^{-3}]

d = depth the soil sample was taken [cm]

$\% C$ = carbon concentration [%]

Statistical analysis

All analyses were conducted using SPSS software, version 23. The normality of the data and residuals was checked. Then, after examining the homogeneity of variances, comparison of the mean of the studied parameters in the two studied land use was performed by t-test (independent samples t-test).

3. Result

In each of the two studied land use, 50 plots of 250 m^2 were measured. Table 1 gives a detailed summary of statistics for biomass and carbon as well as the results of T-test in the two studied land uses. The results showed that each of the studied variables in the two studied land use is significantly different from each other ($P \leq 0.01$). The mean of each of these biomass or carbon pools in silvopastoral is significantly lower than sacred groves.

Table 1 Summary of statistics for biomass and carbon at the studied land uses

Variables	Land use	Mean	Standard error	T-Test		
				T	df	Sig
AGTB	sacred groves	348.63^{a}	31.15	8.79	98	0.000
	silvopastoral	70.97^{b}	5.1			
BB	sacred groves	63.3^{a}	5.27	9.27	98	0.000
	silvopastoral	13.6^{b}	0.92			
AGSB	sacred groves	0.27^{a}	0.032	6.47	98	0.000
	silvopastoral	0.05^{b}	0.009			
Herbs and grass	sacred groves	1.03^{a}	0.12	3.97	98	0.000
	silvopastoral	0.42^{b}	0.09			
Leaf litter	sacred groves	11.55^{a}	0.82	7.70	98	0.000
	silvopastoral	4.17^{b}	0.49			
DWS	sacred groves	29.04^{a}	7.09	4.06	98	0.000
	silvopastoral	0.20^{b}	0.12			
TFBI	sacred groves	453.84^{a}	37.14	9.67	98	0.000
	silvopastoral	89.43^{b}	6.23			
TFC	sacred groves	213.3^{a}	17.45	9.67	98	0.000
	silvopastoral	42.03^{b}	2.93			
TSC	sacred groves	125.49^{a}	8.45	5.97	98	0.000
	silvopastoral	71.44^{b}	3.23			
TC	sacred groves	338.79^{a}	20.89	10.53	98	0.000
	silvopastoral	113.48^{b}	4.51			

Similar Roman letters beside means of any parameter indicates no difference at 5% level between attributes. TFBI: Total forest biomass; TFC: Total forest Carbon; TSC: Total soil organic carbon and TC: Total carbon

In the next sections, the pools of forest biomass and carbon stocks measured in the two land use are briefly reported.

Biomass content

The mean of total biomass for both sacred groves and silvopastoral lands was estimated to be 453.8 t ha^{-1} and 89.4 t ha^{-1}, respectively. The results indicate that the common utilizations in the forests of the study area cause a significant reduction ($P \leq 0.01$) in the forest biomass value and respective carbon content. Although the total biomass content in the Silvopastoral is significantly less than the sacred groves, the amount of biomass in each of the pools in both land use was almost the same (table 2). In both land use, most of the biomass value is related to the AGTB and the least amount is related to the AGSB. The difference between the amounts of DWS biomass in the two land use is significant; so that its amount was more in the sacred groves (table 2). Another important difference was that, the LHG biomass value in the sacred groves was significantly higher than the silvopastoral, but the proportion of LHG biomass in total biomass was higher in the silvopastoral lands.

Table 2 Biomass value and its proportion at the studied land uses

Variables	Sacred groves		Silvopastoral	
	Biomass value (tha^{-1})	Proportion	Biomass value (tha^{-1})	Proportion
AGTB	348.63	**76.82**	70.97	**79.38**
BGB	63.30	**13.95**	13.61	**15.22**
ABSB	0.27	**0.06**	0.05	**0.06**
LHG	12.59	**2.77**	4.58	**5.12**
DWS	29.04	**6.40**	0.20	**0.22**
TFBI	453.83	**100.00**	89.41	**100.00**

TFBI: Total forest biomass

Carbon content

As shown in table 1, the carbon content in each of the carbon pools in the two studied land uses were significantly different from each other. The average total carbon content was estimated to be 338.79 tC ha^{-1} and 113.46 tC ha^{-1} respectively in the sacred grove and silvopastoral lands. Carbon proportion in carbon pools is not the same in two studied land uses, unlike the similar distribution of biomass content (table 3). The AGTB and soil had maximum share of the total forest carbon stock, while the ABSB contributed the lowest share in both land use. Average soil organic carbon was significantly lower (71.44 tC ha^{-1}) in silvopastoral lands, than in sacred groves (125.49 tC ha^{-1}). The important point was that, unexpectedly, in silvopastoral lands the soil carbon value (62.96% of total carbon) is higher than that of above-and belowground carbon (37.04% of total carbon) (Fig. 4).

The mean total sequestered carbon dioxide (CO_2) was 1243.36 tCO_2h^{-1} in sacred grove and 416.4 tCO_2h^{-1} in silvopastoral lands. This is a significant reduction, i.e. the reduction of carbon dioxide absorption capacity in forests by incorrect operations.

Table 3 Carbon content and its proportion at the studied land uses

Variables	Sacred groves		Silvopastoral	
	Carbon content (tha^{-1})	Proportion	Carbon content (tha^{-1})	Proportion
AGTB	163.86	48.37	33.36	29.40
BGB	29.75	8.78	6.39	5.64
ABSB	0.13	0.04	0.02	0.02
LHG	5.92	1.75	2.15	1.90
DWS	13.65	4.03	0.09	0.08
TFC	**213.30**	**62.96**	**42.02**	**37.04**
TSC	**125.49**	**37.04**	**71.44**	**62.96**
TC	338.79	100.00	113.46	100.00

TFC: Total forest Carbon; TSC: Total soil organic carbon and TC: Total carbon

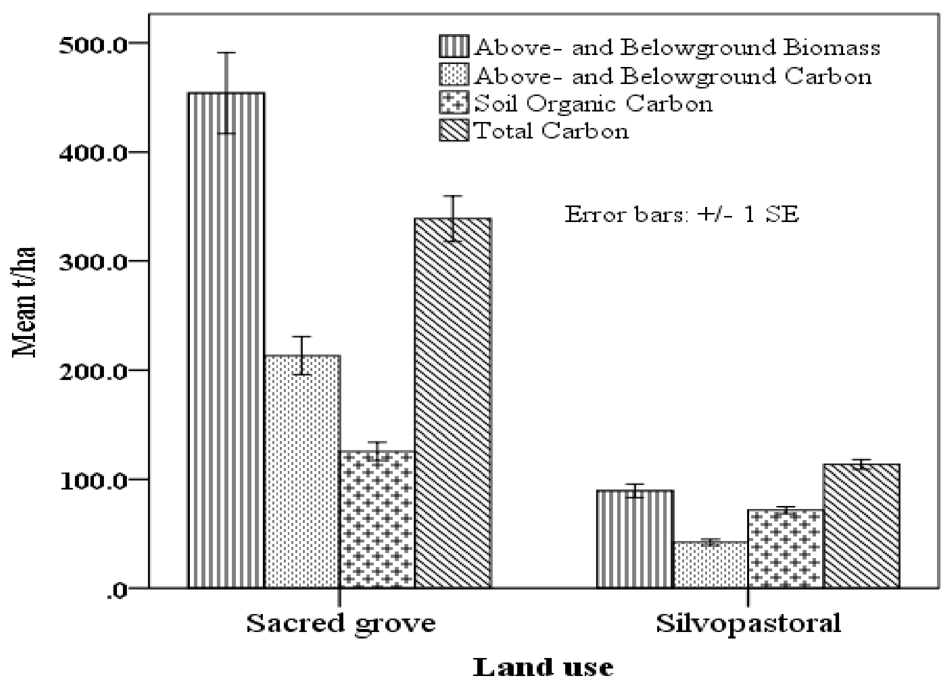

Fig 4 Comparison of studied variables in two land use

4. *Discussion*

Rising atmospheric carbon dioxide has led to the global consequences of climate change. Biological carbon sequestration through vegetation and soil is one of the cost-effective ways to reduce this gas [32]. Forests are one of the most important elements of the global carbon cycle [33]. Carbon deposits in the forest include plant biomass and carbon in the soil. In the present study, for the first time, the amount of biomass and carbon storage in sacred groves in Zagros forests were estimated and compared. Aboveground biomass as well as the amount of carbon in all carbon pools in sacred groves was significantly higher than silvopastoral lands. There was no human intervention in sacred groves and so in this land use, multi-storey tree cover, trees with great height and diameter, dense canopy, abundant leaf litter, high deadwood, rich grass cover under the canopy and species diversity led to very favorable conditions. However, grazing traditionally occurs in silvopastoral lands. Because animal husbandry is carried out using traditional methods, in addition to the grass cover of the forest floor, the branches and leaves of the trees in these forests are used for grazing livestock through the pollarding system. In this land use, the tree production and growth capability was reduced due to pollarding. The low foliage production, forest floors bare of leaf litter, poor grass cover, high soil erosion and soil surface compaction consequently lead to poor biomass and equilibrium of carbon inputs and storage which were much lower than expected in the silvopastoral lands under study.

The amount of carbon stored in plants is strongly related to the amount of biomass [7]. The higher the production capacity of above- and belowground biomass in different species and habitats, the higher the carbon storage in the body of trees, leaf litter and soil.

When the density of the forest changes under the influence of human intervention, the amount of carbon per unit area also changes [16]. Therefore, the significant difference between biomass and carbon in the two studied uses was due to human intervention. These mismanaged interventions significantly reduced the amount of biomass and carbon associated with it.

Various studies have shown that carbon is stored in different parts of the forest ecosystem, mostly in wood [7, 34]. In this study, in the above- and belowground biomass section, the highest carbon percentage was in the AGTB section, but in the sacred groves it was significantly higher than silvopastoral lands. Another important point is the percentage of each carbon pool in the total carbon stored. In sacred groves, the percentage of total carbon in above- and belowground was 62.96% while the percentage of soil carbon was 37.04%. In total contrast, in silvopastoral lands, the percentage of soil carbon was greater (62.96) than the percentage of total carbon above- and below-ground (37.04). This indicates a decrease in tree density, seedlings and regeneration and much destruction due to improper use of silvopastoral lands.

The amount of soil carbon in sacred groves was approximately 1.8 times that of silvopastoral lands. The change in the amount of soil carbon sequestration depends on the amount of carbon entering the soil through plant debris and the amount of carbon loss through decomposition [35]. Many researchers [1, 35-37], have pointed to the relationship between soil organic carbon sequestration and vegetation percentage, leaf litter and crop residues, land use and management. The significant difference of soil carbon in the two land uses studied in this study was also due to the difference in the return of organic matter to the soil and its small amount in silvopastoral lands. The results of this study indicate that sacred groves with high biodiversity are part of the Zagros forests. In fact, if the forests of the Zagros were less degraded or properly managed, they would be in a similar situation to sacred groves today. If this were the case, these forests would have a greater impact on carbon sequestration and climate change. Sacred grove use currently absorbs 826.96 tons of carbon dioxide per hectare more than silvopastoral lands and this is a sign of high degradation in the forests of the study area. Appropriate management would prevent further degradation and make use of the good potential of these forests to reduce atmospheric gases through carbon sequestration.

5. *Conclusions*

Forest ecosystems have the greatest potential for atmospheric carbon sequestration. Improper human intervention in forest ecosystems accelerates the process of global warming. Accelerating global warming is the most important factor in future climate change. According to the results obtained in this study, forest ecosystems that are protected against human intervention play a significant role in long-term carbon storage. Any interference with the natural conditions of the ecosystem has a significant negative impact on carbon reserves. Therefore, by selecting appropriate measures, local communities should be empowered to reduce their dependence on low incomes obtained from deforestation and conversion. In addition to carbon storage, sacred groves are the most important centers for biodiversity conservation as more formal methods for protected areas have often failed. The number of sacred groves in the forests of the North Zagros is significant. According to the above, the Zagros forests in western Iran have essential carbon reserves and biodiversity that are of great environmental importance. Taking into consideration the vast and significant area of the Zagros forests in western Iran, the role of this natural and valuable ecosystem in dealing with recent climate change becomes more apparent.

Abbreviations

AGTB: Above-ground tree biomass; AGSB: Above-ground sapling biomass; BB: Below-ground biomass; SOC: Soil organic carbon; LHG: Leaf litter, herbs, and grass; DWS: Dead wood and fallen stumps; TC: Total carbon stock; DBH: Diameter at breast height; ρ: wood-specific density.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Author contributions statement

AM designed the research, gathered and analyzed the data under scientific advice of Dr. N Sh. AM wrote the manuscript and N Sh. thoroughly reviewed and edited the manuscript**. Compliance with ethical standards**

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Not applicable

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Figures

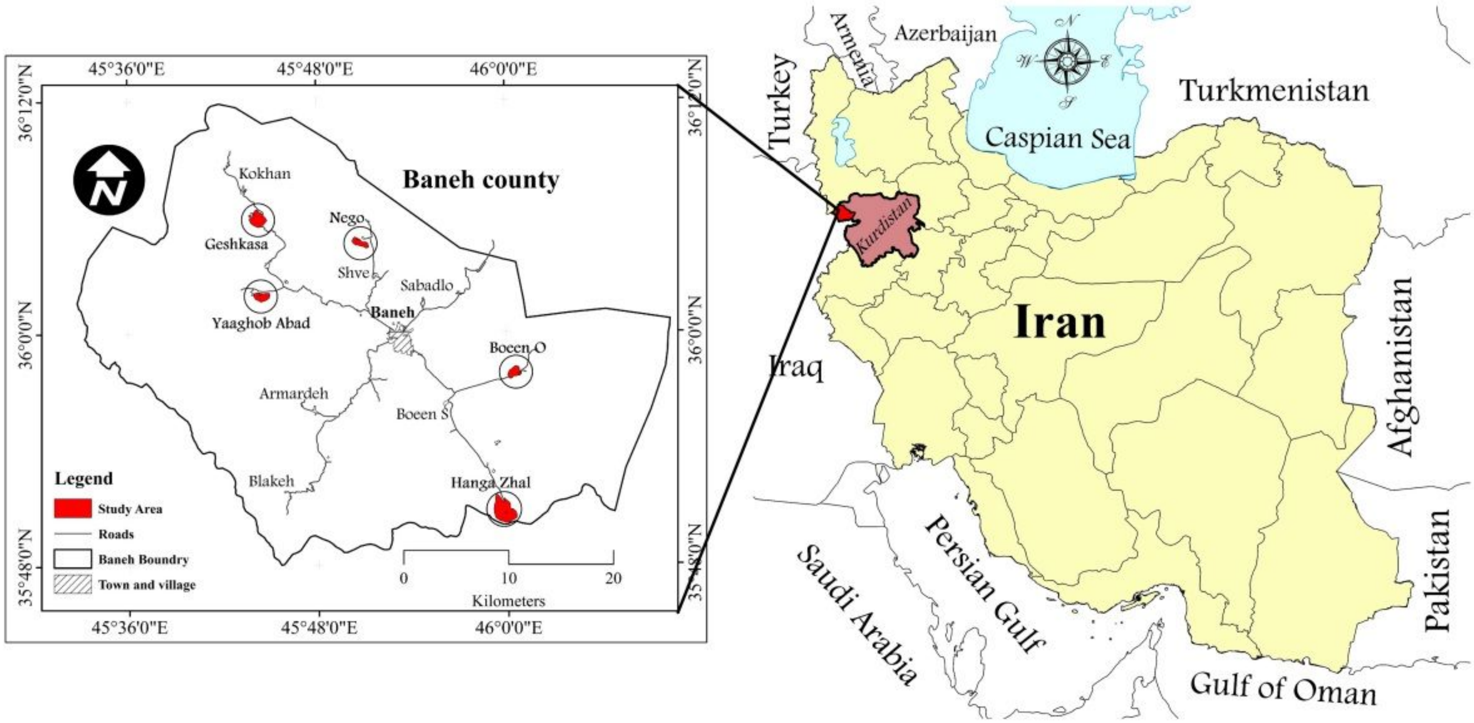

Figure 1

Geographical location of the study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

View of the two land uses studied (Sacred groves and Silvopastoral lands).

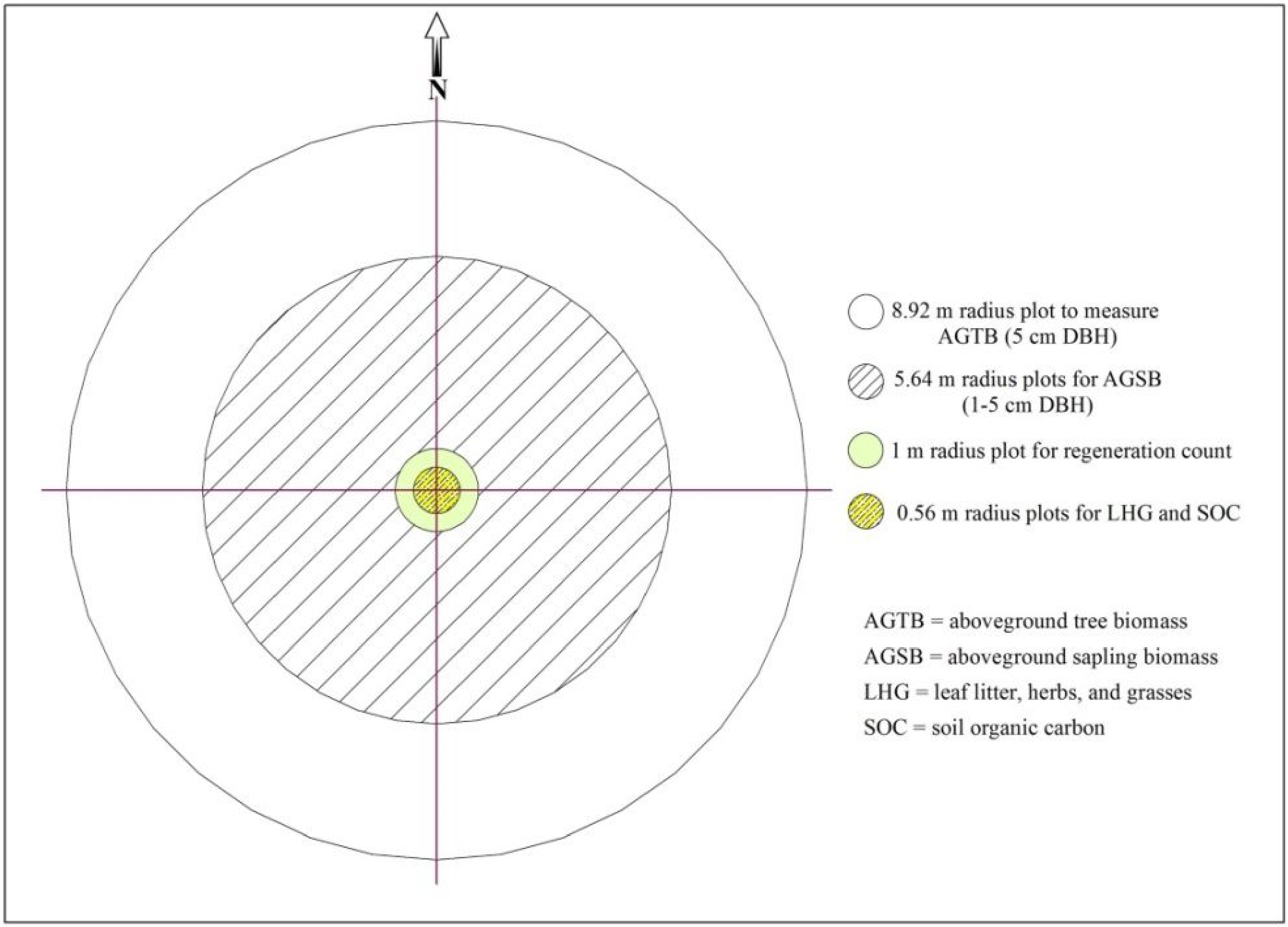

Figure 3

Concentric nested circular plots

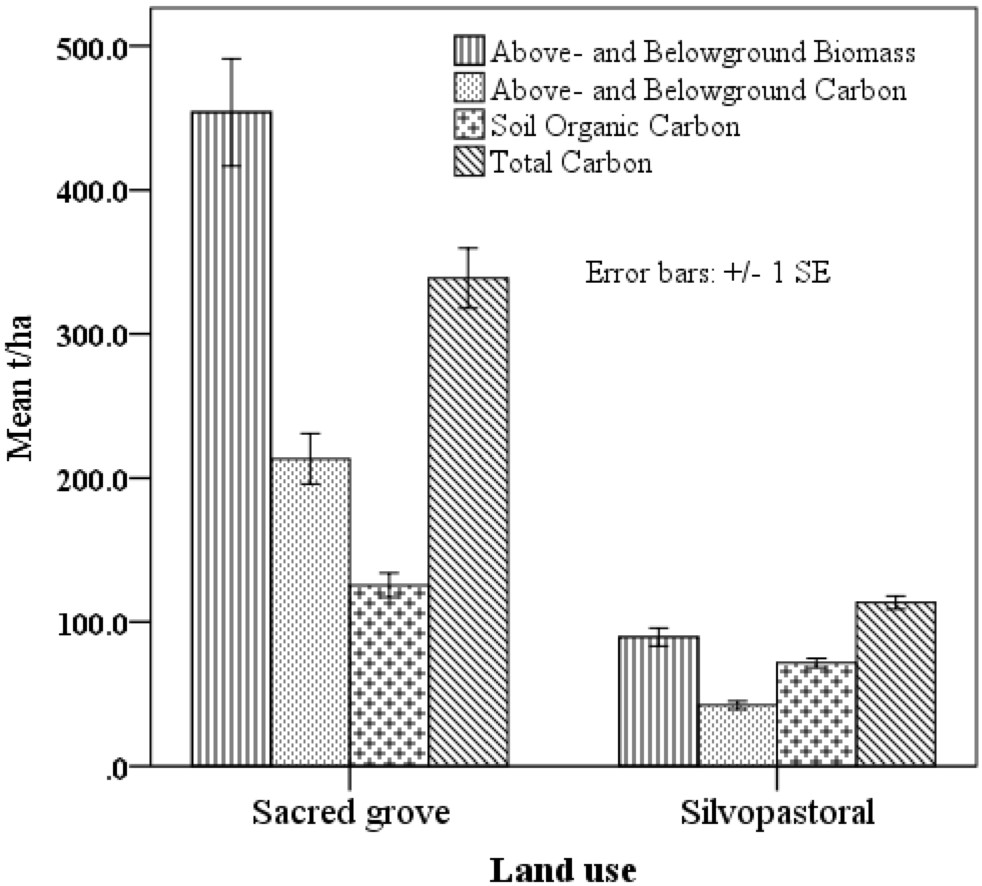

Figure 4

Comparison of studied variables in two land use