Agriculture, Environment & Society

Journal homepage: www.aes.uoz.ac.ir

Evaluation of carbon sequestration as a regulating service in a faba bean agroecosystem

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ARTICLE INFO

Article history:
Received: 24 July 2025
Accepted: 17 October 2025
Available online: 1 December 2025

Keywords:
Agroecosystem
Carbon sequestration
Faba bean
Organic matter

ABSTRACT

One of the most important ways to remove or reduce carbon dioxide is to store this gas in the form of plant biomass and add organic carbon to the soil. Faba bean is one of the oldest crops, used both for human nutrition and for carbon sequestration. In this study, our objectives were to evaluate carbon sequestration (CS) as a regulating service and to calculate its economic value. For these purposes, a field experiment was carried out as a randomized complete blocks design in the Gorgan University of Agricultural Sciences and Natural Resources (Iran) farm. In this experiment, four cultivars of faba bean are considered as experimental treatments. These common cultivars in Golestan province included Shadan, Mahta, Feyz, and Barkat. This research showed the genetic diversity of faba bean cultivars to provide CS view under the climatic conditions of Gorgan County (Semi-Mediterranean climate). Results showed that the highest soil CS was obtained in plots under Barkat (9,083.2kg/ha) and Feyz (5,877.2 kg/ha) cultivars. Also, there is a significant difference between faba bean cultivars in terms of the total economic value of CS. The economic value of CS was estimated at 494.3 $/ha, which was higher in Barkat than in other cultivars. We observed that cultivated plots under Mahta and Shadan cultivars had the lowest soil CS potential, so that the amount of soil CS was negative in plots cultivated with these cultivars. It means that carbon was transferred to the atmosphere instead of being transferred to the soil.

Highlights

- The highest CS was obtained in plots under Barkat and Feyz cultivars.
- The economic value of CS by faba bean was estimated 494.27 $/ha.
- There was no significant difference for the plant organs in terms of carbon absorption potential, except for the stem.

1. Introduction

Global warming and climate change significantly cause land destruction, reduction of agricultural products, reduction of water reserves, endangerment of human health, increase of drought, increase of evaporation and transpiration, change in precipitation pattern, increase of wind erosion, increase of soil salinity, and reducing carbon mineralization (Wilbanks et al., 2008). Among the effective human activities, it has been indicated that the burning of fossil fuels and land use change (Hutchinson et al., 2007).

Carbon dioxide as a greenhouse gas has the greatest impact on climate change. In agriculture systems, the most important factors in reducing soil organic matter are tillage and the removal of plant residues from fields [3]. In this regard, the results of some researchers show that the amount of carbon stored in no-tillage systems is higher by 67-512 kg/ha compared to conventional systems (Mc Conkey et al., 2003).

One of the most important ways to remove or reduce carbon dioxide is to store this gas in the form of plant biomass and add organic carbon to the soil. Because the soil is considered the biggest source of terrestrial carbon, the management of carbon sequestration (CS) has been introduced as the most important factor for increasing the adaptation of the ecosystems to carbon dioxide gas (Ingram

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https://doi.org/10.22034/aes.2026.536819.1109

and Fernandez, 2001). Based on the global estimates of existing carbon reserves and the prediction of the increase in greenhouse gas emissions, the importance of soil as an important storage for carbon and reducing its concentration in the atmosphere is essential (Gougoulias et al., 2014).

Plants have a special importance in CS through the photosynthesis process, seasonal absorption and release dynamics and long-term relationship with consumption processes between biomass and soil organic carbon (Lal, 2004). The position of plants in CS has been introduced in three parts, including: 1) Plant carbon storage, which is considered as the net production of ecosystems and biology; 2) Plants are considered as the path of biological CS, which includes parts such as plant biomass, biochar, phytoliths, wood burial and bioenergy products; 3) Genetic engineering approaches to increase plant deposition, including increasing photosynthesis, increasing carbon allocation to roots, increasing tolerance to living and non-living stresses, increasing biomass quality, and producing high-yielding perennial plants for agriculture (Jansson et al., 2010).

Daba and Dejan (2018) studied the role of vegetation biodiversity in CS as an ecosystem service and a method to reduce climate change and greenhouse gas emissions in Ethiopia. The results showed that the management of multiple ecosystem services, especially biodiversity, provides natural capital for sequestration and storage of carbon in ecosystems. In other study, Moushani et al. (2021) showed that the high amounts of CS were obtained in soybean fields close to the forest ecosystems. In New Hampshire (USA), Mikhailova et al., (2021) investigated the vulnerability of soil carbon due to land cover change. Their results showed that spatial and temporal analysis of land cover can identify effective and endangered vital places of soil carbon. In another study, Moukanni et al., (2022) optimized the CS through cover cropping in Mediterranean agroecosystems under different managements.

Li et al. (2023) suggested that organic material can improve both CS in saline soils and crop yield. Considering the balance of both carbon emissions and CS, organic material increased the net CS by about 5,890.7 kg CO_2-eq·hm^{-2}·100/d.

Kaushal et al., (2023) believe that changes in traditional agronomical practices have the potential to enhance the soil CS. Practices such as residue management, growing cover crops, conservation tillage, and proper nutrient management have a significant capacity to sequester carbon in the agricultural lands.

Also, Andrés et al., (2022) estimated that 31.7% of total soil organic matter stocks in the European Union are found in agricultural soils, and some sustainable agricultural practices are particularly favorable to CS in soil, such as cover crops, reduction in tillage, and plant diversity.

Some researchers calculated the economic value of CS in different ecosystems. For example, the total economic value of CS service in Retezat National Park (Romania) was estimated at 1,706,070.28 US$ per 10 years (2019–2029) (Pache et al., 2021). Marisha et al., (2020) measured the value of ecosystem services for CS and carbon stock based on the Cost of Illness in Tegalega, (Indonesia). Their results showed that the potential of green open space in absorbing carbon was equal to 126,321.96 kg CO_2/ha/year and carbon stocks in the current green open space were 47,319 kg/ha. Also, the average value of one tree with the service of absorbing and storing carbon was 1,236,566,136 IDR (Indonesian Rupiah: the official currency of Indonesia). In Denmark, Ghaley and Porter (2014) quantified and economically valued some ecosystem services including CS, food, wood production, water storage capacity, nitrogen mineralization, and soil formation. The results showed that the total economic value of these services was equal to 8,237 dollars per hectare.

Faba bean (*Vicia faba* L.) is one of the oldest crops that has been cultivated mostly in Asian and African countries, and in recent years in Europe. This crop can be used both in human nutrition and animal nutrition, which directly and indirectly provides the protein needs of humans. Golestan province is one of the centers of faba bean production in Iran, and faba bean is a suitable crop for rotation with oilseeds and cereals due to the high amount of nitrogen bio-fixation and breaking the cycle of diseases. Almost all agricultural activities in Golestan province (northeast of Iran) lead to a reduction in soil carbon stock and an increase in greenhouse gas emissions. Therefore, some strategies need to increase the carbon storage in agricultural ecosystems, such as investigating the ability and potential of crops in terms of CS, identifying the potential of common crops in the Golestan, and the role of crop residues in CS.

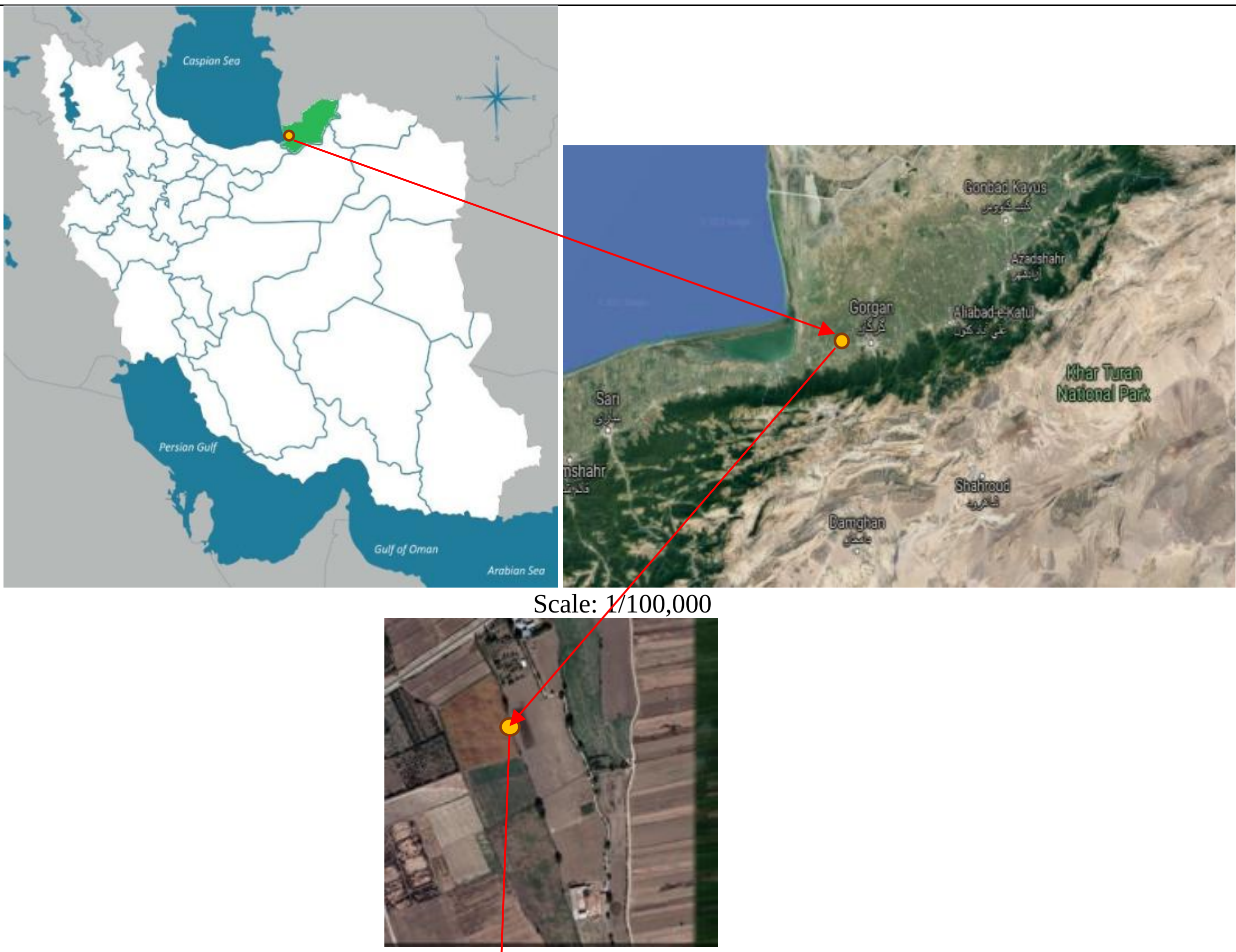
These strategies are necessary to achieve sustainable agriculture, reducing the emission of greenhouse gases into the atmosphere, global warming, and the adverse effects of climate change. Based on our objectives, we were to evaluate CS as a regulating service and estimate of CS economic value a faba bean agroecosystem as a field experiment. Therefore, the following questions were answered: What is the amount of carbon sequestration in faba bean cultivars (Shadan, Mahta, Feyz and Barkat) in Golestan province? What is the economic value of the carbon sequestration of these cultivars?

2. Materials and method

2.1 Field experiment

In this study, the potential of CS as an ecosystem regulating service in faba bean agroecosystem was evaluated. For this purpose, a field experiment is carried out as a randomized complete blocks design by three replications in research farm of Gorgan University of Agricultural Sciences and Natural Resources (Golestan, Iran), during 2021-2022 (Figure 1).

In this experiment, four cultivars of faba bean are considered as experimental treatments. These common cultivars in Golestan province included Shadan, Mahta, Feyz, and Barkat.



Replication	Treatment (cultivar)			
Replication ≠ 1	Barkat	Mahta	Feyz	Shadan
Replication ≠ 2	Feyz	Mahta	Shadan	Barkat
Replication ≠ 3	Shadan	Barkat	Feyz	Mahta

Figure 1. The plan design and location of the field experiment in Gorgan County, Iran.

2.2. The management system of faba bean production

Each experimental plot was designed with a size of 2×3 m^2, five sowing rows, and 50 cm distance between rows. The space between plants on rows was considered 15 cm, and the planting depth was 5 cm. The amount of 10 kg/ha of nitrogen from the Urea source was spread on the plots as a starter fertilizer before sowing. Seeds were sown in early December 2021. The faba bean field was weeded twice during the growth season, and plants were managed as rainfed farming and no chemical consumption (Table 1) (BBCH, 2001).

Table 1. The details of field operations in faba bean plots

Field operation	Details
Tillage	Disk plow
Sown date	early December
Planting rows per plot	5 rows
Distance between plants on each row	15 cm
Distance between rows	50 cm
Planting depth	5 cm
Plot size	2×3 m2
Number of plots	12
Weed control	Two times: late January and early March
Weed control	Manually
Pest control	It was not necessary.
Fertilizing	Only 10 kg/ha of nitrogen from a chemical source as a starter
Irrigation	Only with rainfall
Harvest	Late June
Cultivars	Shadan, Mahta, Feyz, and Barkat

2.2. Evaluation and quantification of CS

Soil sampling was done in two stages, before sowing and after crop harvest, by auger from a depth of 0-30 cm. Also, plant samples are taken at the beginning of faba bean plant maturity according to the guidelines of BBCH (2001), by a quadrat 1*1 m^2. In order to determine the conversion coefficients of CS in faba bean organs (including pods, seeds, stems, leaves, and roots), we used the combustion method (Khorramdel et al., 2016). The samples were transferred to the crop research laboratory of Gorgan University of Agricultural Sciences and Natural Resources. All samples are placed in an oven (Memmert model) at a temperature of 75° for 48 hours. Then, the organs of the faba bean plant are separated and weighed to calculate the amount of dry matter in each part. All samples are ground separately and completely powdered. Then, 2 grams of each sample is taken and placed in an electric combustion furnace (Exciton model) for 3 hours at a temperature of 500° until its organic matter is completely burned (Khorramdel et al., 2016). Finally, the amount of carbon is calculated using the following Equation:

$$\%OC=0.54 \times \%OM \quad (1)$$

Where, %OM is the percentage of soil organic matter and %OC is the percentage of soil organic carbon. To obtain the soil carbon accumulation, soil sampling was taken at depth of 30 cm in two stages; before sowing and after harvest. The Walkley-Black (1934) method was used to calculate soil organic carbon. Then, carbon accumulation was calculated based on soil depth of 30 cm, bulk density, and percentage of soil organic carbon (Equation 2). After laboratory analysis, organic carbon content was measured.

$$SOC = 10000 \times \%\ OC \times Bd \times e \quad (2)$$

Where, SOC is soil carbon storage (kg/m^2), Bd is soil bulk density (gr/cm^3), e is sampling depth (cm), and OC is soil organic carbon content (gr/kg) (Nosetto et al., 2006). Finally, the amount of carbon sequestration was determined by Equation (3):

$$CS = SOC_{after} - SOC_{before} \quad (3)$$

Where, CS is soil carbon sequestration amount, SOC_{after} is soil carbon storage after harvest, and SOC_{before} is soil carbon storage before planting (Blake,and Hartge, 1986).

2.3. Economic valuation of CS

In the current research, the carbon tax policy and carbon emission reservoirs are used as the shadow value of carbon based on suggestion of Pache et al., (2021). In this method, to determine the value of carbon sequestered in faba bean field, first the amount of carbon sequestered in the plant biomass and soil was calculated. Then, the total carbon stored by faba cultivation was determined from Equation (4).

$$C1+C2=CT \quad (4)$$

Where, C1 and C2 are the amount of carbon stored in plant organs and soil, respectively. Finally, the amount of economic value of CS was calculated based on 60 dollars' tax per ton of carbon emission (Pache et al., 2021).

2.4. Data analysis

Data were analyzed using SAS software version 9.1, based on the GLM procedure, and the means were compared using the Duncan test.

3. Results and discussion

3.1. Quantify of CS

The results showed that there is a significant difference between the cultivars in terms of soil CS. The highest CS was obtained in plots under Barkat (9,083.2 kg/ha) and Feyz (5877.2 kg/ha), and Mahta and Shadan cultivars were ranked next. It seems that due to the root system of faba bean, in addition to improving the soil structure, an amount of root remains is added to the soil, and as a result, the soil carbon is increased. Also, the results showed the amount of soil CS was negative in plots cultivated with Shadan (Table 2). It means that carbon was transferred to the atmosphere instead of being transfer to the soil. However, the reason for the decrease in carbon accumulation in the cultivated plots with Shadan can be considered as the production of low underground organs of this cultivar compared to the other faba bean cultivars. Also, among the reasons for reducing the amount of carbon accumulation in the soil, it can mention to tillage operation type, previous crop in the rotation and the removal of plant residues from the field, which reduces the soil organic matter and thus reduces the amount of carbon accumulated in the soil. In confirmation of these results, Yan et al. (2007) showed that applying management no tillage and adding 50% of the volume of plant residues to the soil could be increase the carbon accumulation potential. Basically, conservation of residues creates a physical protection against natural factors as well as stimulation of soil organisms, which results in maintaining and improving the content of carbon and organic matter in the soil and less emissions in the form of carbon dioxide (Morell et al., 2011).

The results showed that cultivars had a significant difference at the 5% probability level in terms of CS potential in the total plant biomass of faba bean. As a result, Barkat, Shadan, and Mahta cultivars were ranked in the same class, and Feyz cultivar had the lowest plant CS potential (Table 2). There was no significant difference among the plant organs in terms of carbon absorption potential, except for the stem. In other words, experimental treatments had a significant difference at the 5% probability level in terms of CS potential in stem of faba bean. So that, the highest amount of CS potential in the stems was related to Shadan, Barkat and Mahta cultivars, which were in the same statistical class, and Feyz cultivar had the lowest CS potential of the stem (Table 2). In this regard, Feng et al., (2007) reported that the highest amount of carbon conversion coefficient was in the stems and the lowest amount was in the leaves of the plants they studied, and the share of the above-ground part was more than the underground part for all cultivars .In previous researches, the average net primary production (NPP) for annual plants was reported about 360 grams per square meter Bolinder et al., (2007) and for the aerial parts of wheat in America, about 4.5 mega grams of C/ha per year has been calculated (Bhardwaj et sl., 2011). In another study in Iran showed that the effect of cultivar on plant carbon accumulation in garden pea (*Pisums sativum* L.) was not significant, and its amounts varied between 3.98 to 3.93 t/ha (Mirzad et al., 2023).

Table 2. Carbon sequestration (CS) in faba bean agroecosystem, Gorgan, Iran.

Variable	In seed	In stem	In leaves	In root	In pod	In total plant	In Soil
Block	ns	ns	ns	ns	ns	ns	**ns**
Treatment	ns	*	ns	ns	ns	*	*
Cultivar (values are expressed in kg/ha)							
Barkat	2,285.0[a]	1,361.7[a]	382.0[a]	262.0[a]	367.0[a]	4,658.2[ab]	9,083.2[a]
Shadan	2,898.7[a]	1,315.3[a]	460.2[a]	252.6[a]	439.0[a]	5,366.0[a]	-2,672.1[c]
Feyz	2,234.5[a]	798.0[b]	297.3[a]	262.3[a]	402.3[a]	3,994.6[b]	5,877.2[a]
Mahta	2,002.0[a]	1,316.3[a]	431.7[a]	323.1[a]	438.3[a]	4,511.1[ab]	2,137.7[b]
Standard Deviation	382.81	267.42	71.39	32.38	34.34	565.63	5057.02

ns: non-significant, *: significant at 5% probably levels.
The means with different letters are significantly different at 0.05 probability levels according to Duncan test.

3.2. Economic value of CS

The results showed that there is a significant difference between faba bean cultivars in terms of the total economic value of CS. The highest amount was related to the Barkat plots and the lowest was obtained in the plots under Shadan and Mahta cultivars. On average, the economic value of CS by faba bean was estimated at 494.27 $/ha (Table 3). Also, the economic value of CS related to the plant part showed that the Shadan cultivar had high value than other cultivars and Barkat and Mahta cultivars were placed in a similar rank. But, the economic value of soil CS showed that Barkat cultivar had more economic value than other cultivars (Table 3). The results showed that cultivars had a significant difference at the 1% probability level in terms of the economic value of soil CS faba bean. In this study, the economic value of the soil part in Shadan plots was negative, which shows the amount of carbon emission instead of CS. In other words, carbon has not been stored and has even been removed from the studied depth. Basically, Shadan is a new cultivar in Iran and belongs to the medium-grain group of faba bean. It is resistant to Cercospora leaf spot (*Cercospora zonata*) disease and is suitable for mechanized harvesting. This cultivar has about 3.5-5.0 t/ha grain yield with 20-28 t/ha green yield, 25 pods per plant and 27-30% protein content (Sheikh et al., 2017).

Table 3. Economic value of carbon sequestration (CS) in faba bean agroecosystem, Gorgan, Iran.

Variables	Plant CS	Soil CS	Total
Block	ns	ns	ns
Treatment	ns	**	*
Cultivar (Values are expressed in $/ha)			
Barkat	279.4[b]	544.9[a]	824.4[a]
Shadan	321.9[a]	-160.2[d]	161.6[c]
Feyz	239.6[c]	352.6[b]	592.3[b]
Mahta	270.6[b]	128.2[c]	398.8[bc]
Average	277.87	216.37	494.27
Standard Deviation	33.95	303.35	336.32

ns: non-significant, *, **: significant at 5 and 1% probability levels, respectively.
The means with different letters are significantly different at a 0.05 probability level according to the Duncan test.

In this regard, Schulp et al., (2008) confirmed that the type and composition of species affect the amount of carbon and CS continuously. Previously, the total economic value of the CS service in Retezat National Park in Romania was estimated at 1,706,070.28 US$/10 years (Pache et al., 2021). This value was calculated based on the 2018 global price of the voluntary carbon market. In other study, Canu et al., (2015) estimated the economic value of CS for the Mediterranean Sea between 127 and 1722 million Euros per year. Also, Banasiak et al., (2015) estimated the economic value of CS in US national parks at 40.45 million dollars. There are numerous management strategies for drawing carbon out of the atmosphere and holding it in the soil. These strategies vary in effectiveness across different climates, soil types, and geographies (Kane, 2015). One of them is to create positive soil carbon and nutrient budgets through the adoption of no-till farming with mulch, cover crops, integrated nutrient management and improving soil structure and tillage (Lal, 2011). According to our results and many of studies, faba bean cultivation in rotation with other crops can be important to achieve sustainable agricultural systems, due to the high amount of nitrogen bio-fixation, breaking the cycle of diseases and increase soil carbon stock.

4. Conclusion and outlook

This research showed the ability of genetic diversity of faba bean cultivars to provide CS view under climatic conditions of Gorgan County (Semi-Mediterranean climate). The highest CS was obtained in plots under the Barkat variety. Also, the economic value related to soil CS showed that Barkat cultivar had a higher economic value than other cultivars. Therefore, this cultivar with non-burning of residues and their conservation, can provide more CS as an ecosystem service for cropping patterns. In this research, there was no significant difference among the plant organs in terms of carbon absorption potential, except for the stem. The highest amount of CS potential in the stem was related to Shadan, Barkat, and Mahta cultivars, which were in the same statistical class, and Feyz cultivar had the lowest carbon potential of the stem. Also, the amount of soil CS was negative in plots cultivated with Shadan cultivar. Finally, Barkat then Feyz, and Mahta cultivars are recommended for providing more CS for Gorgan County and other similar regions. Due to the impact of climate on the amount of CS, it is suggested to repeat this research in different climates to investigate the effect of climate on the amount of greenhouse gas emissions.

Acknowledgement

We are thankful to Gorgan University of Agricultural Sciences and Natural Resources (GUASNR) for all the support.

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