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Agroecosystem Services of Saffron Fields in the Khorasan Razavi and South Khorasan Provinces, Iran

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Abstract

Evaluating and quantifying agricultural ecosystem services in saffron-based agroecosystems is essential for understanding their economic value and informing sustainable management. This study aimed to estimate and monetize multiple ecosystem services and disservices in saffron fields. Researchers collected primary data by using a structured questionnaire with saffron growers from selected counties in Khorasan Razavi and South Khorasan provinces (Mashhad, Torbat-e Jam, Torbat-e Heydarieh, Khalilabad, Bardeskan, Birjand, Zirkouh, and Boshruyeh), resulting in 120 completed questionnaires. The study estimated the value of five saffron ecosystem services—food production, oxygen production, biodiversity, conservation, and the absence of migration—and two disservices —greenhouse gas emissions and phosphorus and nitrogen leakage. Results showed that the total net value of ecosystem services in the studied fields was 39,353.6 US$/hectare per year. Prevention of rural migration, identified as a cultural service, was valued at 24,579.3 US$/hectare per year. Cultural and provisional services and biological diversity made up 62, 43, and 5.8% of the total ecosystem service value in saffron fields. These findings highlight the importance of assessing both ecosystem services and disservices in saffron agroecosystems to guide sustainable management and policy decisions.

Keywords: Biodiversity, Emission of greenhouse gases, Greenhouse gases, Oxygen production

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Introduction

Over recent decades, the intensification of agricultural systems has increased global food production but also contributed to biodiversity loss, ecosystem service degradation, and heightened greenhouse gas emissions, thereby exacerbating environmental pressures in the face of climate change (Ritchie, 2021; Smith & Johnson, 2025).

(Bennett, 2017). Therefore, adopting optimal ecological management practices with a sustainable approach is essential, and attention and exploitation of ecosystems' various functions and services seem necessary (Janse et al., 2019). Attention to the growing problems caused by the degradation and improper exploitation of nature has led researchers to try to explain the various services that result from the functioning of natural ecosystems, drawing the attention of decision-makers and high-level planners to the need for protection and developing more of these nature-given gifts (DeClerck et al., 2016). Most studies and estimates of the value of ecosystem services focus on natural ecosystems, and valuing agroecosystem services has received less attention (De Groot et al., 2012). Agroecosystems are the largest managed ecosystems in the world, and the current management of these ecosystems focuses on utilizing the services they provide, namely the food production, forage, clothing, and fuel, albeit in the process, the production of these materials in agroecosystems will also shape various types of regulatory, supportive and cultural services that are of significant value (Madureira et al., 2007). Besides, agricultural activities have many environmental effects that influence ecosystem services, including water quality, pollination, nutrient cycles, soil conservation, biodiversity, and other ecological services. They will affect agricultural production (Harvey et al., 2017; Dale & Polasky, 2007). Given the interactions between agroecosystems and natural ecosystems and the importance of agricultural production for human food security, these interactions remain poorly understood. Proper management strategies for ecosystem services in agriculture, and agroecosystems are not provided, resulting in excessive pressure on them and weakening or destroying them. The future of agricultural production and food security will endanger human beings (Hatt et al., 2018). Agroecosystems, unlike natural ecosystems, provide services and have anti-services (Zhang et al., 2007). Services and anti-services derived from the agroecosystem are strongly influenced by the management method for input consumption (Ferrarini et al., 2017). The total value of ecosystem services in low-input systems is usually higher than in high-input systems because these services are derived from ecosystem functions that are disrupted by increased consumption of external inputs. According to the context mentioned above and considering that 38% of the fields of the whole earth are allocated to agricultural lands, and about 30% of greenhouse gases belong to agriculture (Ritchie, 2021), it could be said that the agricultural sector plays a vital role in influencing ecosystem services (Soltani et al., 2013). Accordingly, studying the effects of different agricultural systems on ecosystem services and developing and promoting more sustainable systems could improve ecosystem services and enhance food security.

Saffron is a crop grown mainly in low-input systems, and its production is comparable to that in organic systems. Saffron is considered a promising investment opportunity and has been introduced as a form of traditional tourism, providing employment and socio-economic benefits to local communities and farmers (Khorramdel et al., 2018; Falahi et al., 2021). In Iran, saffron is predominantly managed as family farms. However, different agronomic methods are currently used in saffron production, which change the functions and ecosystem services. Also, since saffron is mainly produced in some areas of Iran and different

farming methods are used, the functions and services of these ecosystems may differ. Khorramdel et al. (2018) reported, by economic evaluation of the services and functions of saffron production ecosystems in Khorasan Razavi Province, that the average types of services and functions of this plant's farms, including food production, oxygen, biodiversity, and cultural services, were 54.21×106, 266.84×106, 60.24×106, and 10.58×106Rials, respectively, and the range of its negative consequences, including two groups of greenhouse gas emissions and nitrogen and phosphorus leakage, was -18.54×106to -8.18×106and -5.18×106to -4.07×106Rials, respectively. These researchers estimated the average net value of saffron farm services in Khorasan Razavi Province, deducting negative consequences - based on the value of the Rial per dollar in 2014 - to be 136.57×106Rials. Therefore, recognizing the ecosystem services of saffron production, which have been overlooked, could lead to increased attention to this crop and to other ancillary services of this ecosystem (including tourism and regulation). This study aims to estimate the economic value of ecosystem services for saffron production in the provinces of Khorasan Razavi and South Khorasan, Iran.

Materials and Methods

This study was conducted in saffron production fields across different counties of the Khorasan Razavi and South Khorasan provinces in Iran during the 2017-18 growing season. The studied counties included Mashhad, Torbat-e Jam, Torbat-e Heydariyeh, Khalilabad, Bardeskan, Birjand, Zirkouh, and Boshruyeh. The statistical population from South Khorasan and Khorasan Razavi provinces was selected based on the area under cultivation and the percentage of annual saffron production. All selected fields had an age range of 1 to 10 years. In each province, regions with minimum, maximum, and average saffron yields were included.

Information needed to evaluate ecosystem services through direct valuation was collected through questionnaires. The number of questionnaires per region was calculated using the number of saffron farmers and Cochran's formula. A total of 120 questionnairess were randomly distributed among experienced saffron farmers and agricultural experts. These were spread across the study regions to ensure representative sampling.

Questionnaires included farmers' socio-economic and managerial characteristics, such as type of ownership, annual income, number of household members, education level, and management methods. These methods include fertilizer application, weed control, windbreaks, and saffron yield. Additionally, questions were asked about ecosystem services.

In this study, the questionnaires' validity was assessed using Cronbach's alpha, which yielded a value of 0.72. Yield differences across years of exploitation were significant. Therefore, all questionnaires from the studied cities were classified by the field's operating year.

The Total Economic Value (T.E.V.) framework (Defra, 2007) is the common tool for assessing the overall economic value of an ecosystem service. The choice of valuation method generally depends on the type of service, the resources available, the time and data available for the study, and the study's purpose. Direct use values are the easiest to account for because they are often part of traditional markets. Non-use values are particularly challenging to quantify and are subject to significant uncertainty. Within the T.E.V. framework, values can sometimes be transferred from studies conducted in other locations and contexts. In the present study, value transfer was used. This is one of the prevailing methods for valuing natural and agricultural ecosystem services (Pandeya et al., 2016; Madureira et al., 2007). The evaluated services and disservices of saffron production systems are described below.

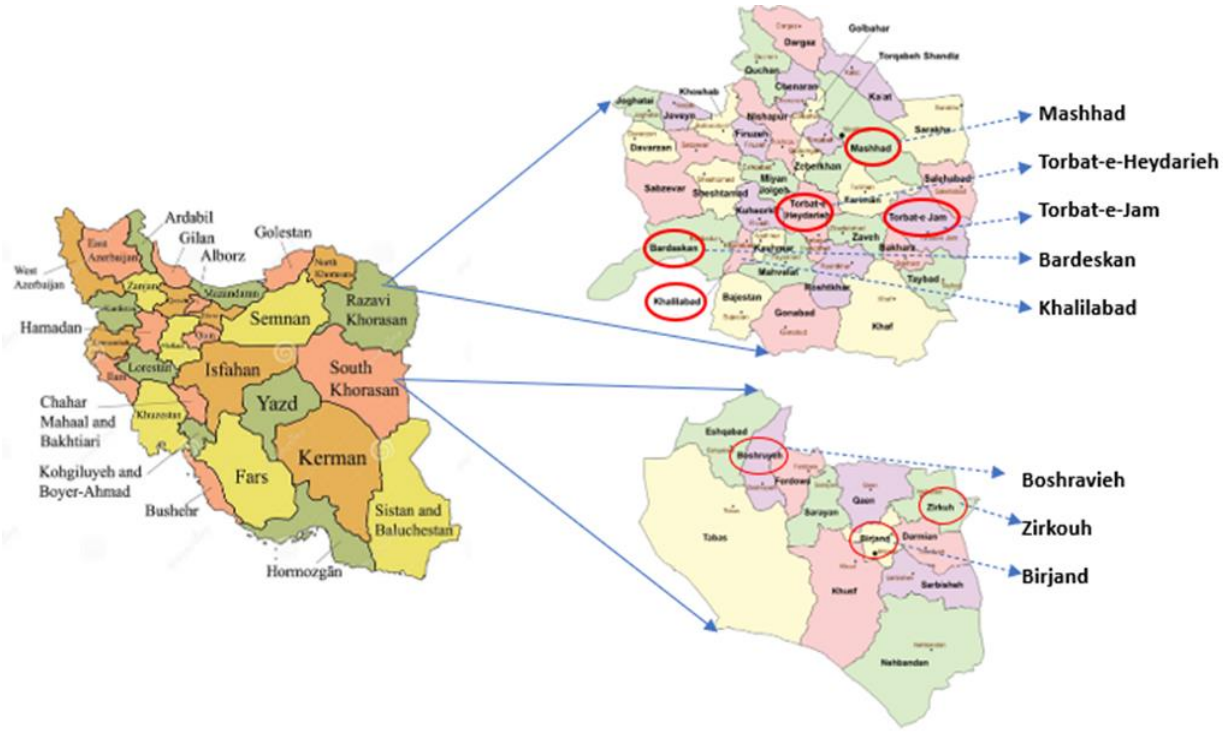

Figure 1. Location of the studied cities, Iran

Some of the studied services include:

Biodiversity

The biodiversity value in the fields where no pesticides were used was considered as the basis, and this amount is equivalent to the total value of ecosystem services from an area equal to 15% of the ecosystem area under study and about per spray, 10-15% of biodiversity was reduced (De Groot et al., 2002; M.E.A., 2005; Costanza et al., 2007; TEEB Foundations, 2010).

Pollination

Due to the vegetative reproduction of saffron crops and the lack of impact of pollination on saffron production and yield, this service was not considered in saffron fields, and the role of pollinating insects was considered only as a part of biodiversity.

Moisture preservation

According to the role of natural windbreaks in reducing evapotranspiration and reducing water consumption, in fields with medium-density tree windbreaks, the amount of water storage is equivalent to 10% of the total water consumption in saffron fields (Kumar, 2012). The reduction in water consumption was evaluated based on the price of each water unit (cubic meter). Each water unit's price was calculated based on the agricultural water currency in the studied regions and the type of water withdrawal (traditional, semi-modern, and modern) by the Iran Water Resources Management Company (Anon, 2018).

Oxygen production

The oxygen production per kilogram of plant dry matter production was about 1.2 kg of oxygen (De Groot et al., 2002; M.E.A., 2005; Costanza et al., 2007; TEEB Foundations, 2010; Koocheki et al., 2017). The amount of dry matter produced was determined, and its value was calculated based on the price per kilogram of oxygen. Since saffron corms do not seem to play a role in photosynthesis and oxygen production, only the aerial parts of the plant (including saffron leaves and flowers) were examined in this section.

Food production

The food value was determined based on yield per kilogram of dried saffron stigma and calculated as the value of the provisional services in the fields under study. The price of dried saffron stigmas was assumed to be 5,000 USD/kg.

Cultural Services

Farmers were asked about the type of economic activity, the crops they cultivate, the number of visitors to the fields, and the length of stay to calculate cultural services in the questionnaires used in this study. The results showed that among people engaged only in agriculture, 89% were involved only in saffron cultivation, suggesting that saffron cultivation significantly reduced these farmers' migration to cities. Therefore, in this study, the calculation of gross domestic product (G.D.P.) created in the study areas due to the lack of migration of farmers is calculated as an estimate of the economic value of non-migration to cities and introduced as one of the components of cultural services of saffron fields (in the following, a more detailed description is given in this regard).

Cost of environmental consequences

The environmental consequences (negative services) of the saffron ecosystem were deducted from the value of positive services to estimate the net value of ecosystem services in saffron fields.

Nitrogen and phosphorus leaching

Nitrogen and phosphorus leaching values were determined based on fertilizer uptake efficiency and soil solubility. Of the total nitrogen fertilizer used, about 60% remained in the soil, and, due to its high solubility, 40-45% was considered a source of contamination (Grandy et al., 2006). On the other hand, due to phosphorus fertilizers' lower solubility, about 17% of the used fertilizers were considered a source of contamination (Lv et al., 2010; Koocheki et al., 2017). Thus, according to the amount of fertilizer used in saffron fields under study, the amount of annual pollution was estimated, and its value was determined based on the world standard price of environmental costs of pollution N and P (F.A.O., 2013; F.A.O., 2018; Von Blottnitz et al., 2006; Koocheki et al., 2017).

Emission of greenhouse gases

Equation 1 calculated greenhouse gas emissions (equivalent to CO2) per hectare of saffron fields.

$V_{GHG} = CT \times TC_{equ}$ (Eq. 1)

VGHG is the price of greenhouse gases, C.T. is the carbon tax (price per unit of CO2 based on the world standard price), and TCequ is the total emitted CO2(World Bank, 2020).

The value of TCequ was obtained from Equation 2:

$TC_{equ} = (E_{N2O} + N_2O_{equ}) + E_{CO2} \times CO_{2Equ}$ (Eq.2)

Where EN2O is the emission rate of N2O, ECO2 is the CO2 emission rate, N2Oequ is equivalent to CO2 for N2O gas, which, according to IPCC, was equal to 310, and CO2Equ is equivalent to CO2, which was considered equal to 1 (Koocheki et al., 2017). All prices were determined based on the U.S. dollar exchange rate.

Results and discussion

Estimating the services' value

According to the results, less than 4% of the surveyed fields were operating in the eleventh to sixteenth years. Due to the low frequency of these fields, their data were not examined and were removed from the calculations. Among other collected information, 50% of the land was in the third and fourth operation years (Figure 2).

The biodiversity study is essential in estimating agroecosystems' services because all ecosystem services result from different biodiversity functions (Carpenter et al., 2006). For example, the average services provided by biodiversity in the saffron fields of Khorasan Razavi and South Khorasan provinces were 2294.5 US$/hectare per year, with a range of 1554.3–3363.4 US$/hectare per year. Among the different years of saffron field operation, the third and fourth years and the ninth and tenth years had the highest and lowest economic values for biodiversity, respectively (Figure 3).

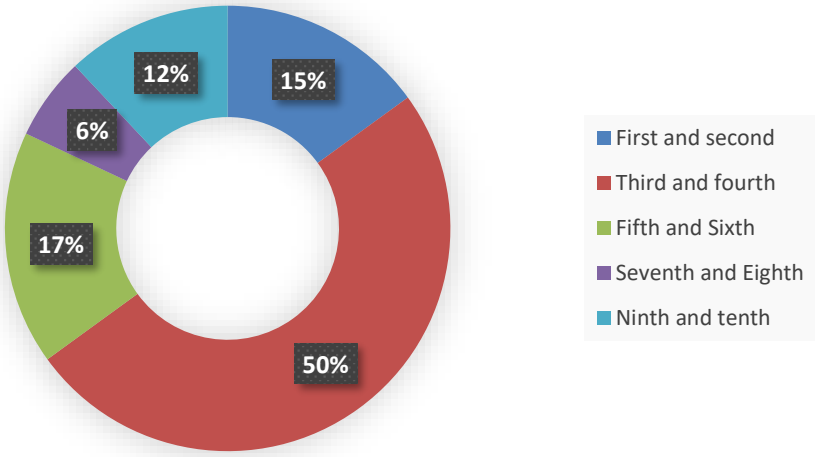

Figure 2. Frequency of the operation year of saffron fields in Razavi and South Khorasan provinces, Iran

The economic value of biodiversity in saffron fields is strongly associated with field age, being higher in the early years of cultivation (1–4) due to low input use, low soil compaction, and the persistence of diverse microhabitats that support soil organisms, pollinators, and associated plant species. After year four, biodiversity value declines as input intensity increases, soil quality deteriorates due to compaction and nutrient depletion, and older fields exhibit stronger allelopathic effects. These ecological and management-related factors explain the observed pattern and emphasize the importance of adaptive practices, such as crop rotation, organic amendments, and reduced input intensity, to maintain biodiversity and its economic value in saffron agroecosystems. Some researchers have considered biodiversity an essential factor in the provision of ecosystem services (Kumar, 2012; Faucon et al., 2017).

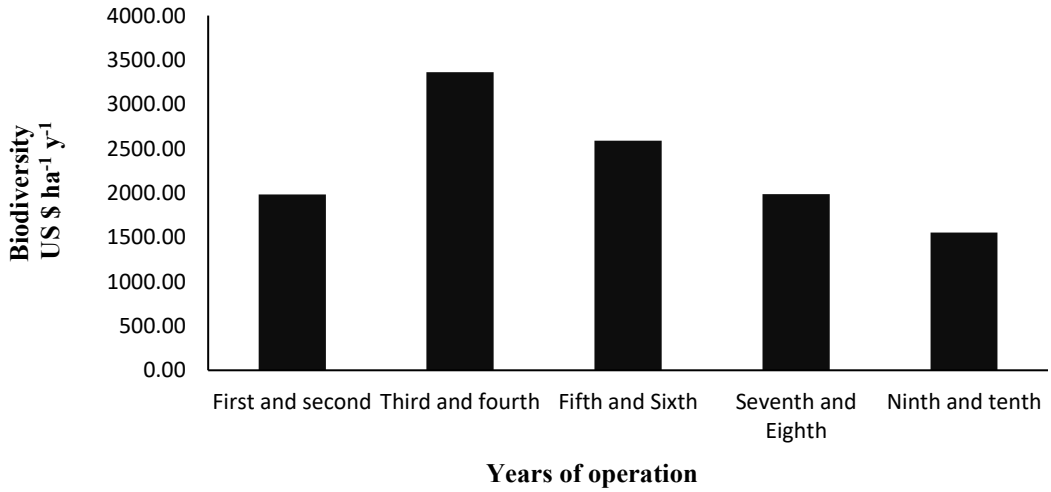

Figure 3. The economic value of biodiversity in different operational years of saffron fields

Due to the non-use of saffron forage in the studied fields, the value of the provisional services was calculated based on kilograms of dried saffron stigma. The average yield of dried stigmas in saffron fields was estimated at 3 kg.ha^{-1}. So, the highest stigma yield was in the third and fourth operation years, with 4.37 kg.ha^{-1}, and the lowest in the ninth and tenth operation years, with 1.9 kg.ha^{-1} (Figure 4). The average value of provisional service in the studied fields was estimated at 17042.07 US$/hectare per year, based on the saffron stigma price in 2018.

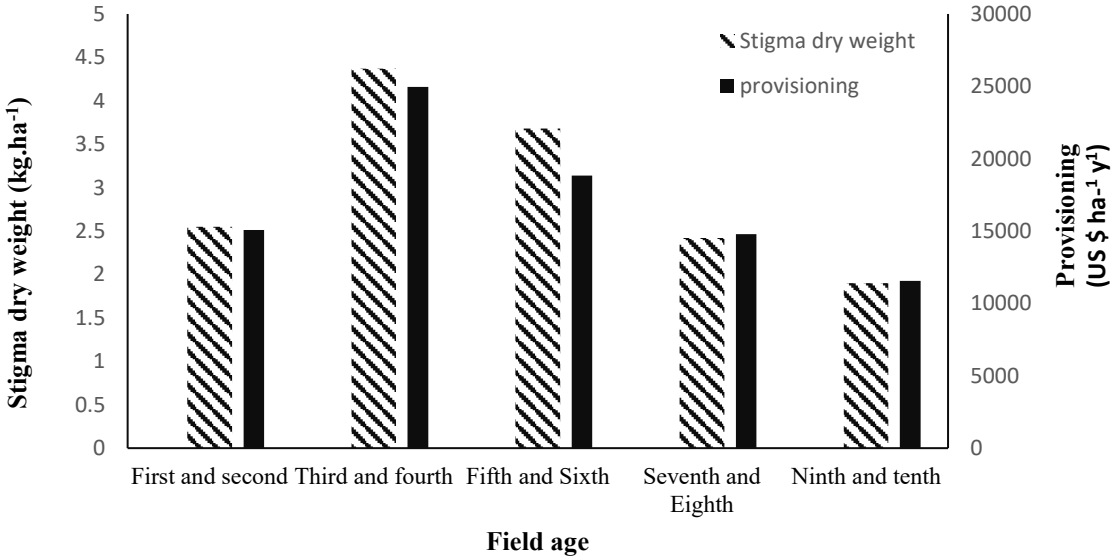

Figure 4. Dried stigma yield and economic value of provisional services in different ages of saffron

Based on the information obtained from the questionnaires, an average of four tourists in 40% of the saffron fields studied during the plant growth period was announced. Considering that 40% of saffron fields were located at a distance of fewer than 600 meters from orchards, it seems that the attractions of these orchards had fascinated tourists to saffron fields as well. Therefore, it could be said that, due to the lack of agro tourism in Iran, the value of tourism in the cultural services of agroecosystems is insignificant and can be ignored. Various researchers have reported this issue (Madureira et al., 2007; Koocheki et al., 2017).

Based on the questionnaires' data, in 83% of the surveyed fields, women were active at different stages of saffron sowing and harvesting. The information obtained from the questionnaires also showed that in 75% of the fields surveyed, more than four family members cooperated in different stages of saffron sowing and harvesting, so it seems that saffron could be a product based on family farming and supported agriculture, which has a great impact on the social and cultural structure of rural communities. Among the families studied, 78.3% had a diploma or lower level of education (Figure 5).

Also, the questionnaires indicated that 89% of the surveyed farmers were engaged solely in saffron cultivation and did not produce other agricultural products. For this reason, it could be said that saffron cultivation has significantly prevented farmers' migration to cities. Therefore, calculating the amount of G.D.P. generated by the absence of farmers' migration could estimate the economic value of not migrating to cities and could be considered one of the factors in the cultural services of saffron fields.

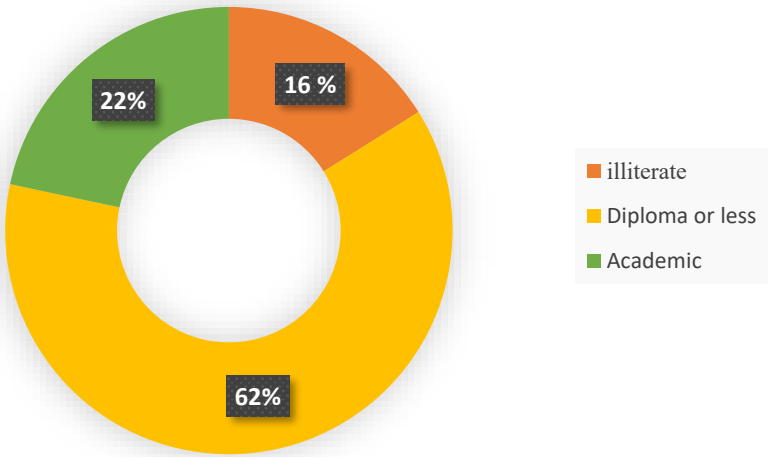

Figure 5. Averaged education level of farmers in saffron fields in Razavi Khorasan and South Khorasan provinces, Iran

According to information obtained in 2018, the total number of rural households in the studied regions was 214911, of which 89% (191271 households) were engaged solely in saffron cultivation (Ministry of Agriculture-Jihad, 2018). As a result, the saffron cultivation area in the studied regions in 2018 was equal to 27543 hectares (Agricultural-Jihad Center of Khorasan Razavi and Southern Khorasan, 2020). Considering that rural households' average per capita agricultural production is equal to 3536.58 US$ (Agricultural-Jihad Center of Khorasan Razavi and Southern Khorasan, 2020), if saffron is not cultivated in the region, the G.D.P. will be reduced by 24579.3 US$/hectare per year. The lack of farmers' migration due to saffron cultivation in the study area is introduced as a factor affecting the ecosystem's cultural services.

Based on the results from questionnaires, 86, 10, and 4% of saffron fields had been irrigated by surface, furrow-ridge, and drip irrigation, respectively. Based on irrigation method (traditional, modern, and semi-modern) and water volume used, each farm's irrigation cost was calculated using water charges proposed by the Ministry of Energy for each region (Iran Water Resources Management, 2018). The results showed that 14% of fields have windbreaks and that the water stored in these fields accounts for 10% of the total water consumption of saffron fields (Kumar, 2012). Due to the low percentage of windbreak use in the fields studied, this service's value was estimated at an average of only 0.70 US$/hectare per year. Studies showed that this service's value is significant (Koocheki et al., 2016). Sandhuet al. (2008) estimated the value of windbreaks in conventional and organically managed fields in Canterbury, Australia, at $200 and $88 per hectare per year, respectively.

An alternative regulatory service for agricultural systems is oxygen production. Because saffron corms do not seem to play a role in photosynthesis and oxygen production, only the aerial parts of the plant (including saffron leaves and flowers) were examined in this section. This service's economic value was calculated based on oxygen production per kilogram of plant dry matter. The economic value of oxygen production was estimated between 135.97 and 289.63, with an average of 185.97 US$/hectare per year.

3.2 Cost of environmental consequences

The amount of N2O gas emitted from different field crops, reported by De Groot et al. (2002), was about 0.03-0.04 kg per square meter per year. This paper assumes this gas's emissions equal 360 kg per hectare per year. The annual N2O emission per

hectare was calculated as CO2 (310 g per square meter). CO2 emissions from some United States of America crops have been around 270-300 g per square meter (De Groot, 2002). Accordingly, this study used 2650 kg/ha/yr. to calculate the annual emission of this gas per hectare. Thus, the total amount of CO2 emitted from the soil of the saffron fields under study, based on a carbon tax rate of $21 per ton of carbon, was equivalent to 654.26 US$/hectare per year.

In agroecosystems, about 60% of the total nitrogen fertilizer applied remains in the soil, and, due to its high solubility, 40-45% is considered a source of pollution (Grandy et al., 2006). In this study, about 17% of phosphorus fertilizers were considered a contamination source due to their lower solubility (Lv et al., 2010; Koocheki et al., 2017). Therefore, the negative values of chemical fertilizers in soil and water resources were calculated at about 4094.5 US$/hectare per year. Therefore, the environmental consequences (negative services) due to greenhouse gas emissions and nutrient leakage in the saffron fields under study were estimated at 4748.78 US$.

In the studied saffron fields, the relative value of services, i.e., the ratio of net service value to marketable service value (Koocheki et al., 2017), ranged from 1.7 to 2.7 (Figure 6). The R2 value was estimated to exceed 95%, indicating that changes in the relative value of services depend significantly on yield. Based on the data, increasing saffron yield was associated with a decline in the relative value of services (Figure 6). The results also showed that the increase in yield in the studied fields was positively and significantly correlated with the cost of negative consequences (anti-services) (Figure 7). Therefore, achieving a higher yield by consuming more inputs has led to increased costs and negative consequences in the studied ecosystems, ultimately decreasing the relative value of services.

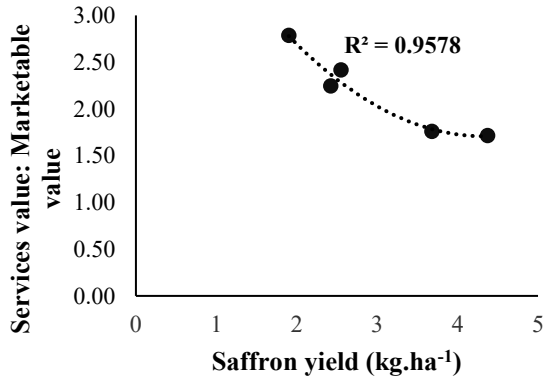

Figure 6. Relationship between saffron yield and services value: Marketable value

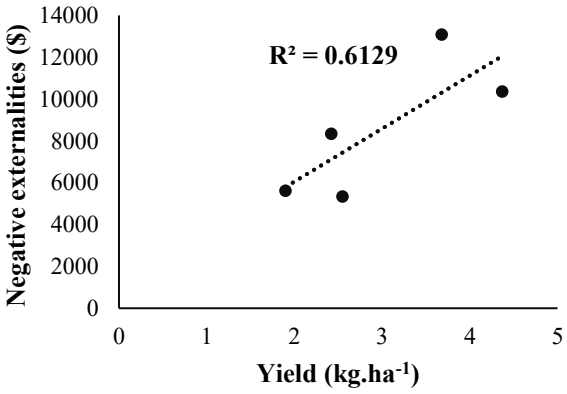

Figure 7. Relationship between yield and negative externalities of saffron Fields

3.3 Balance the value of services

In this study, the total value of ecosystem services was calculated by deducting the value of the consequences of negative services (greenhouse gases, nitrogen, and phosphorus leakage) in saffron production systems, equal to 39353.66 US$/hectare per year (Table 1). The net value of non-marketable services from saffron production systems was calculated at 27060.98 US$/hectare per year, 1.5 times the value of the stigmas produced in these fields.

Table 1. The estimated amounts for the value of various ecosystem services and environmental consequences in saffron production systems in Khorasan Razavi and South Khorasan provinces, Iran

Type of services	Value of services (US$/hectare per year)		
	Min.	Max.	Mean
Biodiversity	1554.26829	3363.4146	2294.5122
Food production	11565.2439	24952.439	17042.073
Oxygen production	135.97561	289.63415	185.97561
Moisture preservation	0	0.9146341	0.6907561
Cultural	24579.2683	24579.268	24579.268
Total value	37834.7561	53185.366	44102.439
Negative externalities			
Emission of greenhouse gases	-654.268293	-654.26829	-654.26829
Nitrogen and phosphorus leaching	-3171.95122	-9977.439	-4094.5122
Total value	-3826.21951	-10648.171	-4748.7805
Net services value	34008.53659	41439.634	39353.659

The results showed that the average of cultural services is about 62% of the total value of services in saffron production systems. In contrast, the value of food produced in these fields includes, on average, 43% of the total value of services (Figure 8). Biodiversity accounted for about 5.8% of the total value of services in the studied systems (Figure 8). Negative consequences in the studied fields reduced the value of ecosystem services by 1.5-24%; on average, 10% of this reduction was attributed to nitrogen and phosphorus leakage.

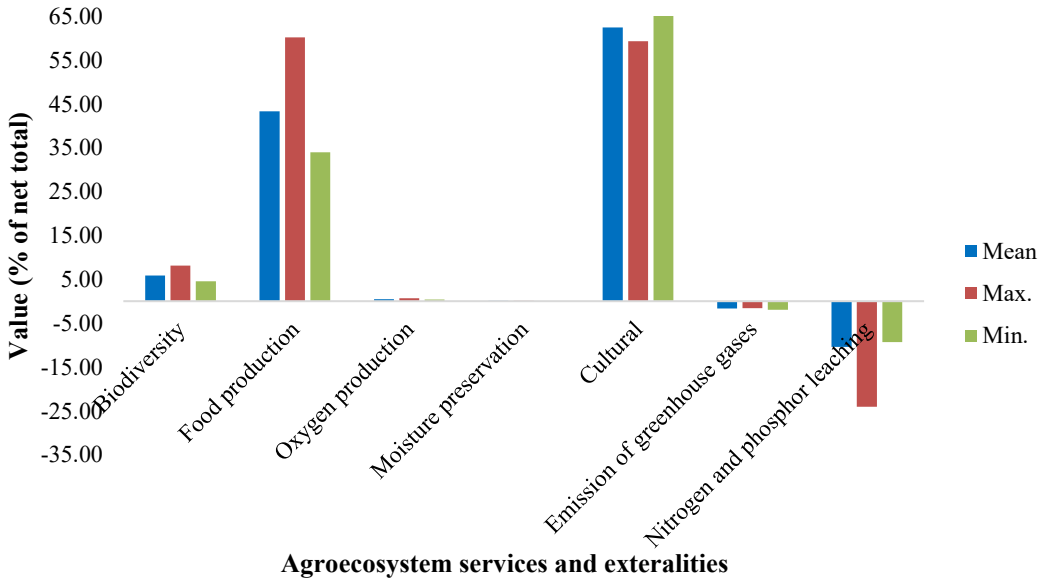

Figure 8. The value of various ecosystem services and their negative consequences in the ecosystem of saffron systems in Khorasan Razavi and South Khorasan provinces, as a percentage of the total value of services

The value of crop ecosystem services depends on the time scale, so continued compression reduces the value of services across different ecosystems (Tilman et al., 2002). Since saffron is an annual plant in perennial fields, the operation year of saffron fields significantly impacts this crop. Therefore, in Figure 9, the effect of the operating year on service value was examined. Among the different operation years, the highest average value of comprehensive services was observed in the third and fourth years (42829.6 US$/hectare per year) (Figure 9).

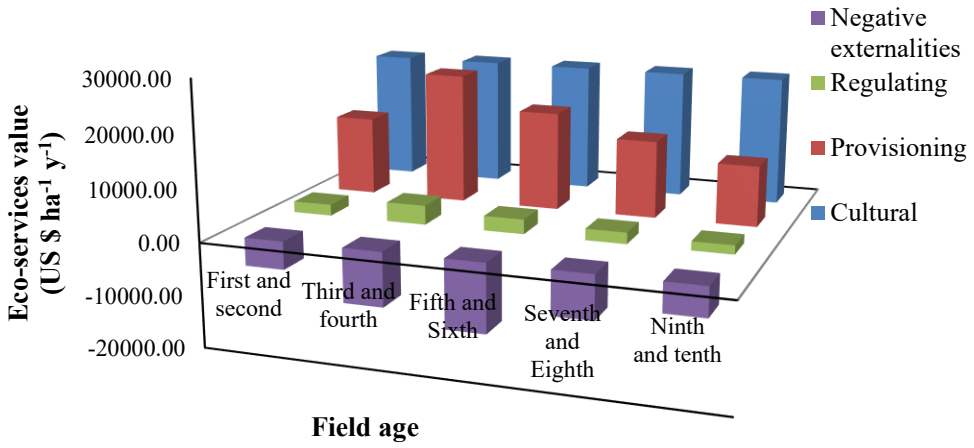

Figure 9. The value of ecosystem services in saffron production ecosystems based on the years of field operations

The higher level of provisioning services in the third and fourth years increased the total value of services in these two years. The highest rates of negative consequences in the studied ecosystems were in the fifth and sixth years of operation (-13083.89 US$/hectare per year) and in the third and fourth years of operation (-10355.99 US$/hectare per year) (Figure 9).

The pattern observed in Figure 9, where both ecosystem service value and negative consequences peak in years 3 and 4, is due to the combination of high yield and management intensity. During these years, higher crop yields increase the value of positive ecosystem services, while higher inputs, such as fertilizers and water, amplify negative impacts, such as greenhouse gas emissions and nutrient leaching, explaining the simultaneous peaks. The results of the study also showed that with the extent of farm area, the number of negative consequences of ecosystems increased, so that the average value of negative consequences of the studied ecosystems in fields less than three hectares, between three and six hectares, and more than six hectares were equivalent to -3826.83, -4917.68 and -10631.7 US$/hectare per year, respectively.

Conclusion

This study estimated the economic value of ecosystem services in saffron fields in Razavi Khorasan and South Khorasan provinces using survey data and field performance. The results indicated that cultural services, food production, and biodiversity accounted for the largest share of total ecosystem service value, while negative impacts from greenhouse gas emissions and nitrogen and phosphorus leakage reduced the average service value by approximately 10%. These findings highlight the importance of considering both positive and negative services to fully understand the value of agroecosystems.

The relationships between positive and negative services were examined using Pearson correlation and simple linear regression analyses, revealing that increases in saffron yield were associated with greater negative consequences, thereby reducing the relative value of services. This correlation underscores the key role of yield management in optimizing ecosystem service value and emphasizes the need to evaluate environmental trade-offs alongside production gains.

Optimal yield levels were determined based on actual field performance data and regression analysis of net service value, with the highest net service value observed during the third and fourth years of cultivation, when production was high but negative impacts remained limited. These findings suggest that excessive yield increases, without consideration of environmental consequences, can reduce net ecosystem service value, indicating that management recommendations should be based on empirical data and quantitative analysis rather than assumptions.

Furthermore, the active participation of women and family members at various stages of saffron cultivation and their exclusive engagement in saffron production had significant effects on social structure and on preventing rural migration. The economic value of this cultural service, estimated by the GDP contributions from prevented migration, underscores the important social and cultural role of saffron cultivation**.** Thus, understanding the economic and social dimensions of saffron production simultaneously can inform comprehensive and sustainable policy-making.

Given that this study was limited to Razavi Khorasan and South Khorasan provinces, the results and recommendations are only directly applicable to these regions, and generalization to other saffron-producing areas requires additional studies and local contextual evaluation. This limitation underscores the need to tailor policies and management strategies to each region's local conditions.

Overall, maintaining optimal yield levels in combination with careful input management, including fertilizers, water, and other resources, can enhance total ecosystem service value while reducing negative impacts. These conclusions indicate that precise planning and integrated resource management are key to improving the sustainability of agroecosystems and preserving their ecosystem services.

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