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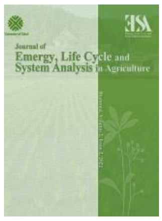

Energy and economic analysis of quinoa production in Iran: A case study in Iranshahr Region

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ABSTRACT

Food and energy shortages, as well as environmental pollution, are the three fundamental challenges of many countries. On the one hand, optimal energy utilization decreases input consumption, while on the other hand, it reduces environmental damage. Energy analysis is a scientific tool for gauging the stability of an ecosystem devoted to crop production. The objective of the present study was to assess the amount of input and output energy, the proportion of direct, indirect, renewable, and nonrenewable energy types, and the energy use efficiency of the quinoa production system in the Iranshahr region of southern Iran. In 2020, the required information was gathered by administering a questionnaire and conducting an interview with the quinoa farmer at the Agricultural Research and Agricultural Jihad Center. This study collects data from 35 farms and is based on two outputs (grain and straw yields) and eight inputs. Evaluations of energy and economics revealed that the total energy input and output for quinoa production were 39122.99 MJ ha^{-1} and 90741.78 MJ ha^{-1}, respectively. For the cultivation of one hectare of quinoa, the values for energy use efficiency (2.32), energy productivity (0.17 kg MJ^{-1}), specific energy (5.83 MJ kg^{-1}) and net energy gain (51618.79 MJ ha^{-1}) were determined. Diesel fuel accounted for the largest portion of energy usage (26.39%). The results of the economic research also revealed that the average consumption expenses for producing one hectare of quinoa were \$1668.93 ha^{-1}, while the average net income of the farmer was approximately \$1451.86 ha^{-1}. In terms of energy consumption and profitability, this plant is therefore suited for cultivation in the research region. Compared to wheat and barley, quinoa requires significantly less energy to produce in this location. However, with improved management, the energy efficiency of quinoa can be increased and the proportion of nonrenewable energy used in production can be decreased.

Highlights

- This study assessed the input and output energy, proportion of direct, indirect, renewable, and nonrenewable energy kinds of the quinoa production system in Iranshahr.
- The energy consumption efficiency, energy productivity, specific energy, and net energy gain of quinoa were determined to be 2.32, 0.17, 5.83, and 51618.79 MJ/ha, respectively.
- The economic investigation found that the average cost to produce one ha of quinoa was \$1668.93, whereas the average farmer netted \$1451.86.
- With better management, quinoa's energy efficiency and nonrenewable energy use can be boosted.

1. Introduction

Today, food and energy resources shortages and environmental pollution are the three main problems in the world (McGuire, 2013). As the population grows, the demand for food and energy resources also increases, so the need for new knowledge to study the effects of agricultural

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production systems in the form of sustainability criteria is vital (Ruviaro et al., 2012). In this regard, agriculture must have minimal negative effects on climate, soil, water, air, biodiversity, and human health, as well as adhere to the principles of sustainable agriculture (De Boer, 2003). Cultivating drought and salinity -tolerant plants is one of the approaches that help human beings achieve sustainable agricultural goals. In this regard, the quinoa plant has the ability to grow in harsh conditions (Amiryousefi et al., 2021). Quinoa (*Chenopodium quinoa* Willd) is an annual broadleaf plant, one to two meters high, and part of the cereal-like plants native to Latin America. This plant is resistant to a variety of environmental stresses such as salinity, drought, and cold. Also, due to the high efficiency of this plant in water resource use (Präger et al., 2018), it can be a suitable plant for areas with limited water resources and very saline soils (Amiryousefi et al., 2021) Therefore, quinoa cultivation as a plant that can grow in poor soils (Jacobsen et al., 2009) and marginal lands (Präger et al., 2018), causes diversity in crops, increases production sustainability, farmers' incomes, and food security. Also, because quinoa is a medicinal and gluten-free plant, it is a valuable food and will also contribute to community health (Bonales-Alatorre et al., 2013). One of the most important approaches to achieving sustainable agriculture is the optimal use of energy in agriculture, which leads to reduced fossil fuel consumption, reduced environmental pollution, and also economic savings (Uhlin, 1998). According to economic principles, producers achieve sustainable production and maximum profit if they use inputs optimally (Cetin & Vardar, 2008). But a research has shown that with the development of agriculture, energy consumption in this sector has increased significantly (Abbas et al., 2020). In other words, most farmers use more energy to increase production (Ozkan et al., 2004). The reason for this can be attributed to the strong dependence of agricultural activity on various inputs such as fossil fuels, electricity, machinery, seeds, fertilizers, and chemical pesticides (Hamedani et al., 2011; Sefeedpari et al., 2014). Due to the improper use of energy and natural resources and its adverse effects on human health and the environment, one of the vital issues in the agricultural sector is the study of energy consumption patterns (Hatirli et al., 2005). The trend of energy changes in the agricultural sector can be monitored and managed by calculating energy efficiency and effectiveness. Therefore, the analysis of input and output energies is necessary for the optimal management of scarce resources in order to determine efficient and economical production activities. In this way, the amount of energy consumed at each stage of the production process can be determined (Chaudhary et al., 2006). This will determine how much energy has been used effectively (Moghimi et al., 2013). Energy circulation is one of the topics of agricultural ecology and so far many researches in this direction has been done by researchers all over the world, including Iran (Amiryousefi et al., 2021; Lotfalian Dehkordi & Forootan, 2020) quinoa, (Abbas et al., 2020) maize, (Nasseri, 2019) wheat, (Kazemi et al., 2018) cotton, (Jafari et al., 2018) pistachio, (Yildizhan, 2018) strawberry, (Zangeneh et al., 2010) potato, (Lu et al., 2010) rice and (Ghorbani et al., 2011) wheat.

Due to the fact that agriculture and the production of horticultural and agricultural products are the main activities of rural communities in Iran, most of the energy consumed in rural areas is spent on agriculture (Amiryousefi et al., 2021). In this regard, it seems necessary to analyze the pattern of energy consumption and its efficiency in the agricultural system and finally provide solutions for optimal energy consumption. Quinoa is well cultivated in different parts of Baluchestan, which has limited water resources and lands with low fertility and relatively high salinity and is able to produce a suitable crop. So far, very limited studies have been conducted in the fields of energy consumption and economic analysis of quinoa. Therefore, considering the adaptation and cultivation of this plant in the Iranshahr region and its great importance in the fields of food security, energy efficiency, increasing farmers' incomes and production sustainability, the purpose of this study is to evaluate the energy of inputs and outputs and determine the share of direct, indirect, renewable and non-renewable energy types in the quinoa production system in the Iranshahr region.

2. Materials and methods

The present study was conducted in the Iranshahr region, located in southeastern Iran. Iranshahr city (60 degrees and 41 minutes' east longitude and 27 degrees and 12 minutes' north latitude) is located in the central part of Sistan and Baluchestan province. Figure 1 shows the location of the study area on a map of Iran.

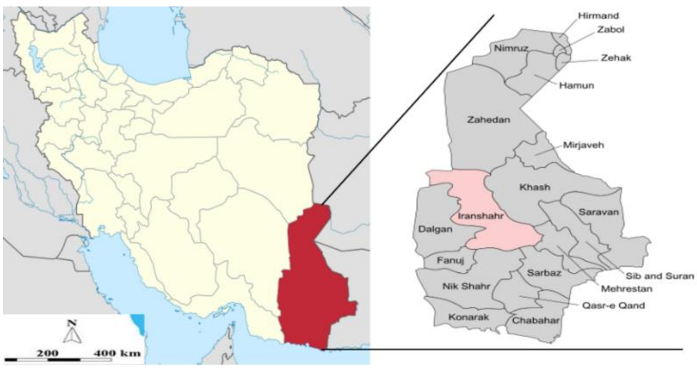

Figure 1. Location of the study region on the map of Iran

The necessary research data were gathered through the completion of a questionnaire and face-to-face interviews with quinoa producers, the Agricultural Research Center, and the Baluchestan Agricultural Jihad. The statistical population in this study was 35 quinoa farmers. In these fields, seed sowing is started in the second half of November and continued until the end of December, and the harvest is done after 140-120 days on average, depending on the type of cultivars. Input energies for quinoa production in the study area included seeds, chemical fertilizer, manure, insecticide, machinery, diesel fuel, water for irrigation and labor, and output energies included grain and crop residues (the production process is summarized in Figure 2). In order to calculate the input and output energies, the input and output data were converted to MJ ha^{-1} using the energy equivalents listed in Table 1.

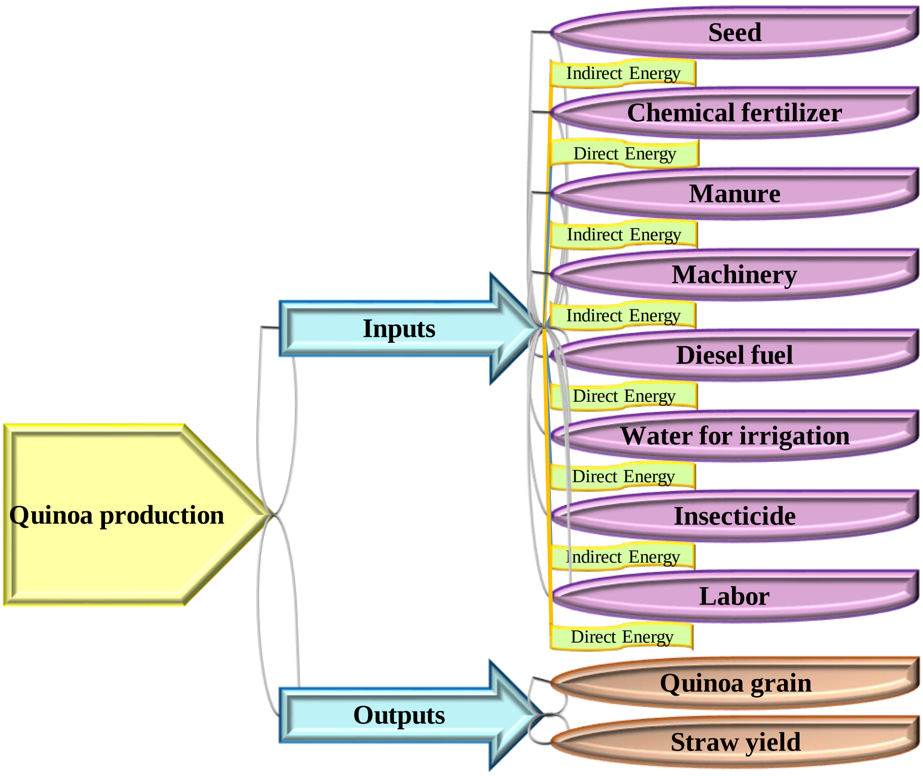

Figure 2. Inputs and outputs for the production of quinoa in Iranshahr, Iran

Table 1. Energy equivalents of inputs and outputs for the production of quinoa in one hectare

Particulars	**Energy equivalent (MJ $unit^{-1}$)**	**Refs**
A. Inputs		
1. Seeds (kg)	17.21	(Lotfalian Dehkordi & Forootan, 2020)
2. Chemical fertilizer (kg)		(Abbas et al., 2020)
(a) Nitrate (N)	78.1	
(b) Phosphate (P2O5)	17.4	
(c) Potassium (K2O)	13.7	
3. Animal manure (kg)	0.3	(Mobtaker et al., 2010)
4. Insecticide (kg)	101.2	(Elhami et al., 2016)
5. Machinery (h)		(Lotfalian Dehkordi & Forootan, 2020)
(a) Tractor	93.61	
(b) Machinery (plows and discs)	62.70	
(c) Combine	87.63	
6. Diesel fuel (L)	47.8	(Elhami et al., 2016)
7. Water for irrigation (m3)	1.02	(Pishgar-Komleh et al., 2012)
8. Labor (h)	1.96	(Elhami et al., 2016)
B. Outputs (kg)		
1. Quinoa grain	17.21	(Lotfalian Dehkordi & Forootan, 2020)
2. Straw yield	12.13	(Lotfalian Dehkordi & Forootan, 2020)

2.1. Energy analysis

After collecting energy data and equivalence of units, the most important variables and energy indices were calculated. In general, energy consumption in agriculture is divided into four groups: 1) direct energy (labor, diesel fuel, irrigation water, and electricity), 2) indirect energy (chemical fertilizer, manure, insecticide, seed, and machinery), 3) renewable energy (labor, manure, seed, and irrigation water); and 4) non-renewable energy (diesel fuel, machinery, chemical fertilizer, insecticide and electricity) (Kazemi et al., 2015).

Also, energy indices in this study include energy use efficiency, energy productivity, specific energy and net energy gain, which were calculated according to relationships 1 to 4 (Abbas et al., 2020).

$$Energy\ use\ efficiency = output\ energy\ (MJ\ ha^{-1})\ /\ input\ energy\ (MJ\ ha^{-1}) \quad (1)$$

$$Energy\ productivity = quinoa\ output\ (kg\ ha^{-1})\ /\ input\ energy\ (MJ\ ha^{-1}) \quad (2)$$

$$Specific\ energy = input\ energy\ (MJ\ ha^{-1})\ /\ quinoa\ output\ (kg\ ha^{-1}) \quad (3)$$

$$Net\ energy\ Gain = output\ energy\ (MJ\ ha^{-1})\ -\ input\ energy\ (MJ\ ha^{-1}) \quad (4)$$

2.2. Economic analysis

For economic analysis of farms in the study area, conventional economic indicators including net return, gross return, benefit - to - cost ratio, productivity, gross value of production, and total cost of production according to relationships 5 to 10 were used (Asgharipour et al., 2012). The fixed cost of production included one year's rent of arable land and water for irrigation, and the variable cost of production also included chemical fertilizer, insecticide, diesel fuel, labor, and economic yield, including quinoa grain and straw yield. The price of input and output was based on the average price in 2020 (226000IRR-1USD).

$$Net\ return = Gross\ value\ of\ production\ (\$\ ha^{-1})\ -\ Total\ cost\ of\ production\ (\$\ ha^{-1}) \quad (5)$$

$$Gross\ return = Gross\ value\ of\ production\ (\$\ ha^{-1})\ -\ Variable\ cost\ of\ production\ (\$\ ha^{-1}) \quad (6)$$

$$Benefit\text{-}to\text{-}cost\ ratio = Gross\ value\ of\ production\ (\$\ ha^{-1})\ /\ Total\ costs\ of\ production\ (\$\ ha^{-1}) \quad (7)$$

$$Productivity = Quinoa\ yield\ (kg\ ha^{-1})\ /\ Total\ costs\ of\ production\ (\$\ ha^{-1}) \quad (8)$$

$$Gross\ value\ of\ production = Quinoa\ yield\ (kg\ ha^{-1}) \times Quinoa\ price\ (\$\ kg^{-1}) \quad (9)$$

$$Total\ cost\ of\ production = Variable\ cost\ of\ production\ (\$\ ha^{-1}) + Fixed\ cost\ of\ production\ (\$\ ha^{-1}) \quad (10)$$

3. Results and discussion

3.1. Energy analysis

The energy content of the consumed inputs and the share of energy of each of them in the total input energy are presented in Table 2 and Figure 3. A total of 39122.99 MJ ha^{-1} input energy and 90741.78 MJ ha^{-1} output energy were calculated. The highest share of energy consumption was observed in diesel fuel (26.39%), nitrate fertilizer (25.95%) and manure (19.17%), and the lowest share of energy consumption was observed in seeds (0.33%), insecticide (0.39%) and combined (0.52%). Due to the higher consumption of nitrate among the chemical fertilizers used in the quinoa production system, this fertilizer had the highest energy share (25.95%). As can be seen in Table 3, about 45.53% of the total input energy for the production of one hectare of quinoa is direct energy and 54.47% is indirect energy. Among them, the share of renewable energy is 38.64% and non-renewable energy is 61.36% of the total input energy. The reason for the high share of indirect energy and non-renewable energy in this study is the high energy consumption of nitrate fertilizer and diesel fuel (Figure 4).

Table 2. Consumed and produced energy for the production of quinoa in one hectare

Particulars	Average quantity (unit ha^{-1})	Consumption energy (MJ ha^{-1})
A. Inputs		
1. Seeds (kg)	7.50	129.08
2. Chemical fertilizer (kg)	259.00	
(a) Nitrate (N)	130.00	10153.00
(b) Phosphate (P2O5)	68.00	1183.20
(c) Potassium (K2O)	61.00	835.70
3. Manure (kg)	25000.00	7500.00
4 Insecticide (kg)	1.50	151.80
5. Machinery (h)	17.30	
(a) Tractor	7.00	655.27
(b) Machinery	8.00	501.60
(c) Combine	2.30	201.55
6. Diesel fuel (L)	216.00	10324.80
7. Water for irrigation (m3)	7100.00	7242.00
8. Labor (h)	125.00	245.00
Total inputs energy		39122.99
B. Outputs (kg)		
1. Quinoa grain	1850.00	31838.50
2. Straw yield	4856.00	58903.28
Total outputs energy	6706.00	90741.78

Source :research findings

The results of the present study are consistent with the results of other researchers who have reported that in crop systems, the ratio of direct energy to indirect energy is higher and the rate of consumption of non-renewable energy is higher than renewable energy (Asgharipour et al., 2012; Baran & Gokdogan, 2016; Lotfalian Dehkordi &

Forootan, 2020). Also, Unakıtan and Aydın (2018), Abbas et al. (2020), Ghorbani et al. (2011), GÖKDOĞAN and SEVİM (2016), Imran and Ozcatalbas (2021), Lotfalian Dehkordi and Forootan (2020), Nabavi-Pelesaraei et al. (2018)) obtained similar results in their studies and reported chemical fertilizers and diesel fuel as inputs with the highest share of energy consumption.

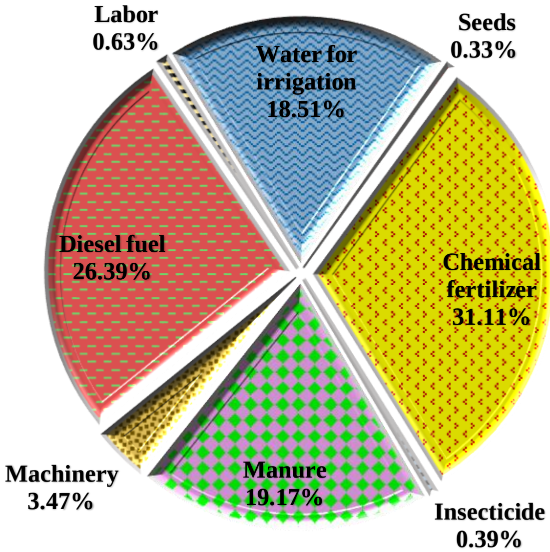

Figure 3. The share of energy input for quinoa production of Iranshahr, Iran

In this study, an energy use efficiency of 2.32 was calculated to produce one hectare of quinoa. In other words, the total output energy was greater than the total input energy. Therefore, it can be said that the production of quinoa in this region is profitable. Energy productivity was 0.17 kg MJ^{-1}, which means that this crop system produces 0.17 kg of quinoa for every megajoule of energy consumed.The specific energy in this system is 5.83 MJ kg^{-1}. The implication of this indicator is that 5.83 MJ of energy is consumed to produce one kg of quinoa. The net energy gain of 51618.79 MJ ha^{-1} was calculated. Therefore, considering the positive rate of net energy gain in this study, it seems that the cultivation of quinoa in this region can be justified in terms of energy balance (Table 3).

Table 3. Total energy input-output in the form of direct, indirect, renewable energy and calculated energy indices for quinoa production in Iranshahr, Iran.

Indices and types of energy	Units	Quantity of energy indices	Contribution of energy Forms (%)
Energy input	MJ ha^{-1}	39122.99	100
Energy output	MJ ha^{-1}	90741.78	100
Direct energy	MJ ha^{-1}	17811.80	45.53
Indirect energy	MJ ha^{-1}	21311.19	54.47
Renewable energy	MJ ha^{-1}	15116.08	38.64
Non-renewable energy	MJ ha^{-1}	24006.92	61.36
Energy use efficiency	-	2.32	
Energy productivity	kg MJ^{-1}	0.17	
Specific energy	MJ kg^{-1}	5.83	
Net energy gain	MJ ha^{-1}	51618.79	

In this regard, a previous study compared the energy consumption of wheat and barley in Sistan and Baluchestan province in Iran. In that study, energy use efficiency for wheat and barley was calculated as 1.49 and 1.94, and energy productivity was 0.056 and 0.066 kg / mJ, respectively (Ziaei et al., 2015). Based on this, it can be stated that less energy is consumed in this region for quinoa production compared to wheat and barley production. In other words, for every megajoule of energy consumed in this region, more quinoa is produced than wheat or barley. Therefore, quinoa can be introduced as a good alternative for these products in this region.

In other studies, the energy use efficiency index for irrigated wheat was 1.44 (Ghorbani et al., 2011) and 1.92 (Naderloo et al., 2012) and 2.3 (Rahman & Hasan, 2014), for paddy production 1.28 (Nabavi-Pelesaraei et al., 2018) was obtained. These results also indicate that quinoa consumes less energy than irrigated wheat and paddy production.

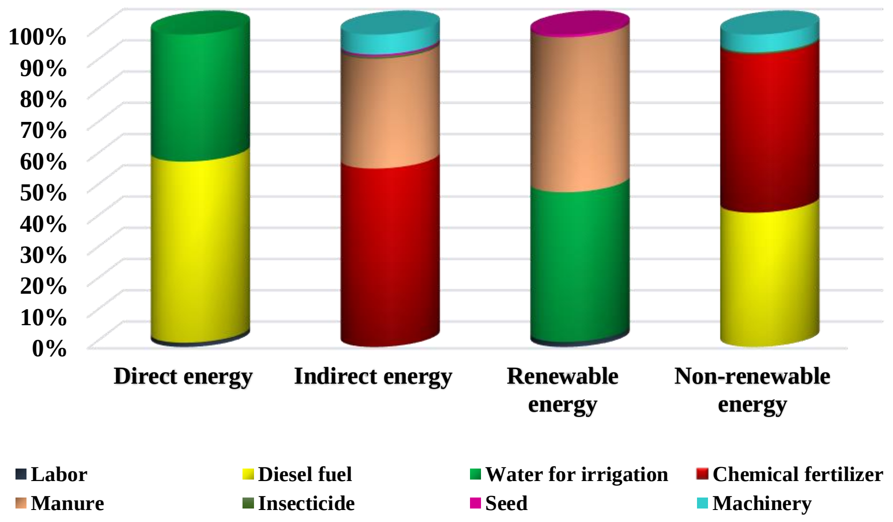

Figure 4. Contribution of inputs to consume energy forms in quinoa production of Iranshahr, Iran

3.2. Economic analysis

Maximizing profits and a successful production process is one of the most important motivations for farmers. Economic analysis is used to calculate the profitability of the agricultural system. As shown in Table 4, the total cost of producing one hectare of quinoa was 1668.93$ ha^{-1}. Among these, the highest costs were related to land rent, machinery, and labor. The results of the economic analysis of quinoa production in the Iranshahr region are presented in Table 4.

Table 4. Economic analysis of Quinoa production in Iranshahr, Iran

Cost and return components	Unit	Value
Grain yield	Kg ha^{-1}	1850.00
Sale price	$ kg^{-1}	1.11
Straw yield	Kg ha^{-1}	4856.00
Sale price	$ kg^{-1}	0.22
Gross value of production	$ ha^{-1}	3120.80
Variable cost of production	$ ha^{-1}	952.32
Fixed cost of production	$ ha^{-1}	716.62
Total cost of production	$ ha^{-1}	1668.93
Gross return	$ ha^{-1}	2168.48
Net return	$ ha^{-1}	1451.86
Benefit - to - cost ratio	-	1.87
Productivity	kg $$^{-1}$	1.11

4. Conclusions

In the present study, the status of energy consumption in the quinoa production system in southeastern Iran was evaluated. The results showed that this plant is suitable for cultivation in the study area in terms of energy consumption and profitability. Agricultural activity is energy dependent. In this regard, the most important inputs are water, fuel, pesticides, and chemical fertilizers that have made the agricultural sector energy-intensive. The results of this study showed that the total input energy was 39122.99 MJ ha^{-1}, of which diesel fuel, with 26.39%, was the most energy consumed. urea and manure were also in the next ranks. Also, of the total input energy, the share of indirect energy was higher than direct energy, and non-renewable energy was higher than renewable energy. In this regard, farmers on most farms do not use chemical fertilizers, particularly urea, based on soil tests and scientific evidence. Rather, they use it based on experience and the notion that the higher the application of chemical fertilizer, the higher the yield. Most of the agricultural machinery and tools used in this area were worn and old. This in turn leads to increased fuel consumption as well as environmental pollution. Therefore, in order to increase the share of direct energy and renewable energy, chemical fertilizers can be used optimally or in combination with organic fertilizers to increase renewable energy and plant yield on the one hand and reduce biological risks on the other hand. In addition, with timely repair and proper maintenance of agricultural machinery, the amount of diesel fuel consumed and environmental hazards caused by its use can be reduced. Generally, it is recommended to reduce the use of chemical fertilizers and fossil fuels by using crop residue management, conservation agriculture, and low tillage methods as sustainability strategies. Also, the value of the energy productivity index (0.17 kg MJ^{-1}) obtained in this study indicates that if management methods, product production, and energy consumption are monitored and efforts are made to increase production per unit area, Productivity can be increased.

Data availability: The data is accessible from the corresponding author (Mahmoud Ahmadpour Borazjani) upon request.

Consent to participate: Not applicable.

Consent for publication: The authors have provided consent to publish this work.

Competing interests: The authors declare no competing interests.

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