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Investigating the energy consumption and carbon footprint in mung bean production ecosystems in Iran

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ABSTRACT

Energy consumption is one of the main issues in production systems because of its role in production costs and environmental impacts. This investigation was conducted to assess the environmental aspect of mung bean farms in the 2022-2023 crop year. The data from 78 mung bean farms in Darreh Shahr, Ilam, Iran were collected. Input-output materials were obtained and energy indicators and carbon footprint were calculated based on them. The results showed that the carbon footprint of mung bean production was 2.74 ton CO_2 eq. ha^{-1} (2.42 kg CO_2 eq. kg^{-1}). The total amount of input and output energy in mung bean production was 12586.49 and 16604.40 MJ ha^{-1}, respectively. The most important energy-intensive inputs in mung bean production were nitrogen fertilizer, fuel, and electricity with the shares of 32.57, 25.88, and 24.43%, respectively. The value of energy proportion was 1.32. Energy productivity and net energy gain efficiency had the values of 0.09 kg MJ^{-1} and 0.32 MJ MJ^{-1}, respectively. Given the low share of renewable energy (3.49%), increasing renewable energy consumption is necessary for mung bean production.

1. Introduction

Legumes are beneficial in terms of human diet, animal nutrition, and soil fertility. One of the members of the legume family is the mung bean (*Vigna Radiata* L.) which is an annual, short-day, thermophilic, short-growing, and summer plant cultivated in tropical and subtropical regions. Also, this crop is a rich source of vegetable protein (Gilani et al., 2021). Like most legume families, mung bean has a high nitrogen absorption capacity and is therefore considered an important crop in agriculture (Hunady and Hochman, 2014; Kazemi et al., 2016). Mung bean has a worldwide cultivation area of 7.3×10^{6} ha with an annual yield of 5.3×10^{6} ton (Nair and Schreinemachers, 2020). Its farm area is 25,000 ha in Iran (FAOESTAT, 2023).

Sustainability is a main issue in production systems due to the limited resources (Kheiralipour, 2022). Energy and carbon footprint are the key elements in the sustainable production path. With the increasing world population and resource limitations, access to sufficient energy will be more difficult in the future (Khodaei et al., 2022). Currently, ensuring food security for the growing world population by preserving basic land and water resources with minimal environmental impacts has become one of the fundamental challenges in sustainable agriculture (Mohammadzadeh et al., 2017). The limited energy sources and the impacts of the misuse of non-renewable energy sources such as fossil fuels on the environment and human health are certain which emphasizes the study of energy consumption patterns and energy-intensive inputs in ecosystems (Snyder et al., 2009; Kheiralipour et al., 2017, 2018).

Energy is the ability to create change in the form of work or heat. The energy status is studied in different production systems to decrease energy consumption and increase energy productivity. It is basically consumed in two different forms: renewable and nonrenewable. The goal of sustainable production is to increase the share of renewable energy sources and decrease the share of nonrenewable energy sources to conserve the environment.

In agriculture, like other sectors, energy is directly consumed to conduct different operations such as soil preparation (leveling and plowing), planting, protecting, harvesting, and postharvest processing. Also, it is indirectly consumed in the production of inputs in production units such as pesticides, chemical fertilizers, machinery, fuel, and seed (Kheiralipour and Sheikhi, 2020; Fathi et al., 2020; Khodaei et al., 2022). Energy consumption in agricultural ecosystems has led to increased production productivity and economic growth. However, the development of industrial agriculture, especially intensive agricultural systems that are highly dependent on fertilizers, chemical pesticides, and other energy-intensive inputs has increased greenhouse gas emissions (Li et al., 2016).

On a global scale, about 5% of total energy consumption is related to the agricultural sector, but about 11% of greenhouse gas emissions are related to this sector (Smith et al., 2014). These emissions are mainly due to the consumption of fossil fuels, pesticides, chemical fertilizers, electricity, and conducting tillage operations (Camargo et al., 2013). Also, energy efficiency and the ratio of greenhouse gas emissions to the outputs in agricultural ecosystems can be affected by different factors such as the type of cropping system, cropping pattern, applied technology, population employed in agriculture, farmer knowledge, type and amount of used chemical fertilizer, and crop yield (Fathi et al., 2020; Mohammadzadeh et al., 2017). Therefore, assessing the efficiency of input use in agricultural ecosystems plays a significant role in reducing energy consumption and production costs and also in designing sustainable and environmentally friendly ecosystems (Payandeh et al., 2017; Kheiralipour, 2020; Dekamin et al., 2022; Pourmehdi and Kheiralipour, 2023).

Energy consumption of various agronomy (Molaei et al., 2008; Pourmehdi and Kheiralipour, 2024; Ramedani et al., 2024), horticultural (Hesampour et al., 2022; Dekamin and Kheiralipour, 2023), and animal (Payandeh et al., 2016; Ramedani et al., 2019; Heidarbeigi and Sheikhi, 2023) products in agriculture and food products (Kheiralipour et al., 2018; Jalilian et al., 2020, Gholamrezaee et al., 2021) have been studied in the literature. In terms of carbon footprint, Heidari et al. (2017) evaluated wheat systems in Iran. Zhang et al. (2017) calculated the carbon footprint of maize, wheat, and rice in China. Kashya and Agarwal (2021) studied rice and wheat systems in Punjab. However, Abad-Gonzalez et al. (2024) investigated the energy status of mung bean in Iran, but they did not report its energy indicators and carbon footprint. Given the importance of mung bean, it is necessary to examine how to produce this crop sustainably. Therefore, the present study aimed to investigate the status of energy and carbon footprint in mung bean farms.

2. Materials and Methods

Figure 1 depicts the steps in the present research to determine the energy status and carbon footprint of mung bean production in Darreh Shahr, Ilam, Iran.

2.1. Data collection

A questionnaire was designed to gather information on mung bean systems. Interviews with 78 ght mung bean farm owners were done in the 2022-2023 crop year in Darreh Shahr Township, Ilam. Iran. Darreh Shahr is located 135 km southeast of Ilam and 160 km. The climate of the region is temperate and mountainous, and its 30-year average rainfall is 413 mm.

2.2. Energy calculations

To calculate the energy input, the amount of materials inputs in mung bean production including human labor, machinery, electricity, diesel fuel, seeds, fertilizers, and chemical sprays per hectare was determined. Then, they were multiplied by the energy equivalent corresponding to each of them (Table 1). The contribution of each input to the total energy input was calculated, as well as the values of different energy forms. Energy indicators were calculated using the following equations (Pourmehdi and Kheiralipour, 2024)

$$ER = \frac{OE}{IE} \times 100 \quad (1)$$

$$EP = \frac{OY}{IE} \quad (2)$$

$$EI = \frac{IE}{OY} \quad (3)$$

$$NEG = OE - IE \quad (4)$$

$$NEGE = \frac{OE - IE}{IE} \quad (5)$$

where ER is the efficiency of energy consumption, EP is the productivity of energy consumption (kg MJ^{-1}), EI is the energy intensity (MJ kg^{-1}), NEG is the net energy gain (MJ ha^{-1}), NEGE is the net energy gain efficiency indicator, OE is the total output energy (MJ), IE is the total input energy (MJ), and OY is the amount of output materials (kg).

2.3. Carbon footprint calculation

Greenhouse gases (GPW) are emitted from various activities. The main GPWs in agricultural ecosystems are carbon dioxide, methane, and nitrous oxide. The effect of each of carbon dioxide, methane, and nitrous oxide on global warming is different, such that methane and nitrous oxide contribute to global warming about 21 and 310 times more than carbon dioxide, respectively (IPCC, 2007). Therefore, the amounts of these emissions are calculated as carbon dioxide equivalent. The amounts of greenhouse gases were calculated using the corresponding emission factors in Table 2. The global warming potential was calculated based on Eq. (6) (Kramer et al., 1999)

$$GWP = CO_2flux + (N_2Oflux \times 310) + (CH_4flux \times 21) \quad (6)$$

where GWP, CO_2flux, N_2flux, and CH_4flux represent the global warming potential (kg CO_2 eq. ha^{-1}), carbon dioxide, nitrous oxide, and methane emission, respectively.

3. Results and Discussion

3.1. Energy

The average values of input and output energy in mung bean production are shown in Table 3. The total yield in mung bean production was 1129.55 kg ha^{-1} and its energy equivalent was 16604.40 MJ ha^{-1}. The total energy of inputs was equal to 12586.49 MJ ha^{-1} (11142.92 MJ ton^{-1}). This amount was lower than that of mung bean production in Golestan Province, Iran (27400 MJ ton^{-1}) (Abad-Gonzalez et al., 2024). The average energy input in corn in Iran has been reported to be 53602 MJ ha^{-1} (Beheshti Tabar et al., 2010). Pourmehdi and Kheiralipour (2024) reported that the total energy input consumed in rainfed and irrigated wheat in Cherdavol township, Ilam, Iran, was 12085 and 20812 MJ ha^{-1}, respectively, and the total output (grain and straw) energy was 61933 and 132492 MJ ha^{-1}, respectively.

Trudy et al. (2018) stated that among all inputs, energy consumption related to nitrogen ranked first with 38.03% in wheat production followed by fuel and seed. In a research conducted to investigate the energy status of faba beans in Iran, it was found that the main energy contributor was nitrogen fertilizer (Kazemi et al., 2015). Pourmehdi and Khairalipour (2024) reported that diesel fuel (79.6 l ha^{-1}) was the main contributor to dryland wheat (37.13%) followed by nitrogen fertilizer (35.51%) and seeds (18.24%). The main energy contributors in wheat production in irrigated systems were electricity, fuel, nitrogen, and seeds with the shares of 29, 27, 20, and 15%, respectively.

The values of energy efficiency, energy intensively, energy productivity, net energy gain, and net energy gain efficiency are given in Table 4. Energy efficiency in mung bean cultivation was calculated to be 1.32. The energy efficiency and net energy gain in mung bean production were 0.09 kg MJ^{-1} and 4017.91 MJ ha^{-1}, respectively. Kazemi et al. (2015) reported that the energy efficiency in faba bean production was 4.70. Energy productivity, net energy gain, and energy intensity had the values of 0.23 kg MJ^{-1}, 51226.30 MJ ha^{-1}, and 4.25 MJ kg^{-1}, respectively. According to the results of Pourmehdi and Kheiralipour (2024), the energy ratios of wheat production in irrigated and dryland systems were 37.6 and 12.5, respectively. The values of the energy efficiency in the fields were 0.38 and 0.48, respectively. The net energy gain efficiency in the farms had values of 5.37 and 4.12, respectively.

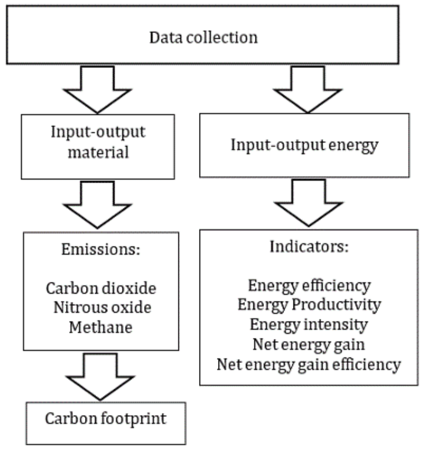

Figure 1. The steps conducted in the present research.

Table 1. The energy equivalent of input-output material in mung bean production.

Material (reference)	Unit	Equivalent energy (MJ Unit^{-1})
Input		
Diesel fuel (De et al., 2001)	l	56.31
Oil (Kitani, 1999)	l	47.80
Labor (Singh et al., 2002)	h	1.96
Machinery (Chauhan et al., 2006)	kg	62.70
Pesticide (Ozkan et al., 2004)	kg	199.00
Herbicide (Erdal et al., 2007)	kg	238.00
Nitrogen (Esengun et al., 2007))	kg	66.14
Phosphorous (Esengun et al., 2007))	Kg	12.44
Potassium (Esengun et al., 2007))	kg	11.15
Electricity (Ozkan et al., 2004))	kWh	11.93
Seed (Yousefi et al., 2014b)	kg	14.7
Output		
Mung bean (Yousefi et al., 2014a))	kg	14.7

Table 2. The greenhouse gases (g Unit^{-1}) of different input materials in mung bean production (Fathi et al., 2020; Yousefi et al., 2014a,b).

Inputs (Unit)	CO_2	N_2O	CH_4
Diesel (l)	3560.00	0.70	5.20
Nitrogen fertilizer (kg)	3100.00	0.03	3.70
Phosphate fertilizer (P_2O_5) (kg)	1000.00	0.02	1.80
Potassium fertilizer (K_2O) (kg)	700.00	0.01	1.00
Electricity (kWh)	61.20	8.82	0.02

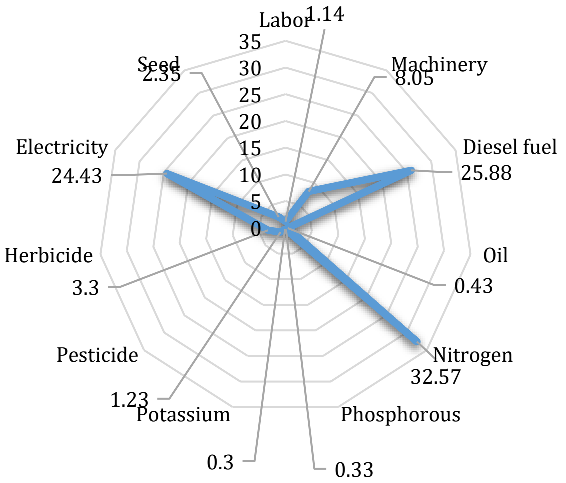

Figure 2. The energy contributors in mung bean production.

Table 3. Material and energy amounts and the shares of inputs in mung bean production.

Material	Amount (Unit ha^{-1})	Energy (MJ ha^{-1})
Input		
Labor (h)	73.09	143.26
Machinery (kg)	16.15	1012.85
Diesel fuel (l)	63.45	3256.82
Oil (l)	1.14	54.49
Fertilizer (kg)		
Nitrogen	61.99	4099.83
Phosphorous	3.33	41.47
Potassium	3.33	37.17
Sprays (l)		
Pesticide	0.65	154.96
Herbicide	1.45	415.78
Electricity (kWh)	835.99	3074.35
Water (m^3)	4134.16	-
Seed (kg)	20.10	295.51
Total	-	12586.49
Output		
Mung bean	1129.55	16604.40
Total	-	16604.40

Table 4. Energy indicators in mung bean production.

Indicator	Value
Energy efficiency	1.32
Energy productivity	0.09
Energy intensity	11.11
Net energy gain	4017.91
Net energy gain efficiency	0.32

As Figure 3 shows, the difference between the shares of direct and indirect energy was low (2%). The share of direct and indirect energy in mung bean production was 51.44 and 48.56%, respectively. In mung bean production, the direct energy included labor, diesel, and electricity, and the indirect energy included seed, machinery, fertilizer, spray, and oil. The renewable energy sources had been consumed very low (3.49%) compared to the nonrenewable sources (96.51%) (Figure 4). The nonrenewable energy sources were diesel, oil, electricity, machinery, fertilizers, and sprays, and renewable energy sources were labor and seed.

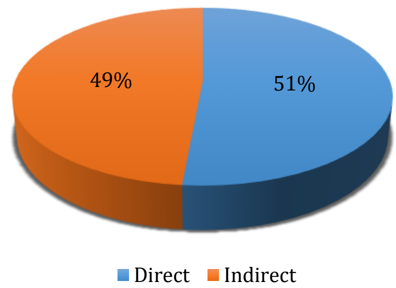

Figure 3. Direct and indirect energy forms.

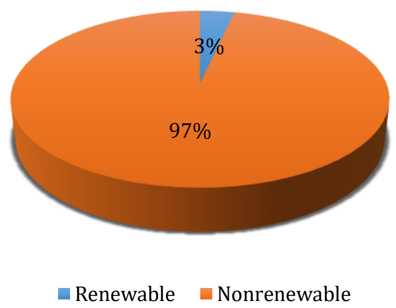

Figure 4. The shares of renewable and nonrenewable energy.

In faba bean farms, Kazemi et al. (2015) showed that indirect energy (81.23%) and non-renewable energy (74.72%) sources were more consumed than the direct (18.77%) and renewable energy forms (25.28%), respectively. Pourmehdi and Kheiralipour (2024) estimated that the share of direct and indirect energy of the total energy consumed for the production of one hectare of dryland wheat in Chardavol township was 38.05 and 61.95%, respectively. Also, the share of direct (57.14%) of the total energy consumed for the production of one hectare of wheat farms with the irrigated system was higher than that of indirect energy (42.86%).

3.2. Carbon footprint

The values of carbon footprint in mung bean cultivation are shown in Table 5. As reported in this table, the carbon footprint of mung bean was 2737.24 kg CO_2 eq. ha^{-1} (2.74 ton CO_2 eq. ha^{-1}). Since 1.13 ton of mung bean was produced in each hectare (Table 5), the carbon footprint was 2.42 kg CO_2 eq. kg^{-1}. This value is higher than the carbon footprint of wheat, maize, and rice. Heidari et al., (2017) reported 1.60 kg CO_2 eq. kg^{-1} as the mean of carbon footprint (0.80 to 3.00 kg CO_2 eq. kg^{-1}) of durum wheat production in Iran. Zhang et al. (2017) reported the carbon footprint of maize, wheat, and rice as 4052, 5455, and 11881 kg CO_2 eq. ha^{-1} respectively in China (0.48, 0.75, and 1.60 kg CO_2 eq. kg^{-1}, respectively). Kashya and Agarwal (2021) reported that the mean values of the carbon footprint of rice and wheat systems in different regions in Punjab, India, were 1.20±0.70 and 0.83±0.23 ton CO_2 eq. ton^{-1}, respectively.

The shares of the inputs in the carbon footprint of mung bean production are shown in Figure 5. The main contributors to carbon footprint were 87.23, 9.01, and 3.32% belonged to electricity, diesel fuel, and nitrogen fertilizer with the shares of 2387.59 kg CO_2 eq. ha^{-1}, 246.57 kg CO_2 eq. ha^{-1}, and 90.87 kg CO_2 eq. ha^{-1}.

4. Conclusions

The energy indicators and carbon footprint of mung bean farms in Darreh Shahr, Ilam, Iran, were investigated in the present research. The most important energy-intensive inputs in mung bean production were nitrogen fertilizer, fuel, and electricity with the shares of 32.57, 25.88, and 24.43%, respectively. The most important contributors to the carbon footprint of mung bean production were electricity, diesel fuel, and nitrogen fertilizer with the shares of 87.23, 9.01, and 3.32%, respectively. Using renewable energy sources, bio-fertilizers, and minimum tillage equipment can decrease the input energy and carbon footprint of mung bean production.

Table 5. The carbon footprint (kg CO_2 eq. ha^{-1}) in mung bean production.

Inputs	CO_2	N_2O	CH_4	Carbon footprint
Diesel	225.88	0.04	0.33	246.57
Nitrogen	88.39	1.00×10^{-3}	0.11	90.87
Phosphorous	1.53	0.00	0.00	1.60
Potassium	0.79	0.00	0.00	0.82
Herbicide	7.30	-	-	7.30
Insecticide	2.47	-	-	2.47
Electricity	52.26	7.53	0.02	2387.59
Total	378.63	7.58	0.46	2737.24
CO_2 eq.	378.63	2349.02	9.58	2737.24

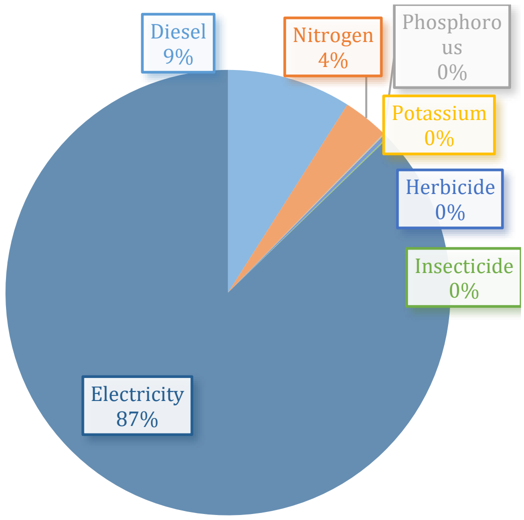

Figure 5. The share of different inputs in the carbon footprint of mung bean production.

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