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Determination of Energy Use Efficency and Indicators of Dry Bean (*Phaseolus vulgaris* L.) Production

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Abstract
The aim of this study is to determine the energy use efficiency in dry bean production. Energy use efficiency calculations were made for the 2023 production season. The study was carried out in the Central district of Kırklareli province of Turkey. Within the scope of the study, total energy input was calculated as 16717.86 MJ ha^{-1} and total energy output was calculated as 34440 MJ ha^{-1}. Energy use efficiency in dry bean production was calculated as 2.06, specific energy as 9.71 MJ kg^{-1}, energy efficiency as 0.10 kg MJ^{-1} and net energy as 17722.14 MJ ha^{-1}. Energy input types in dry bean production were examined. It was observed that it consists of 6633.38 MJ ha^{-1} (39.68 %) direct energy, 10084.48 MJ ha^{-1} (60.32 %) indirect energy, 2507.99 MJ ha^{-1} (15 %) renewable energy and 14209.87 MJ ha^{-1} (85 %) non-renewable energy. According to the 2023 production season study data, dried beans production can be said to be profitable in terms of energy use.

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1. Introduction

Beans are high in protein and delicious. For this reason, it is widely consumed as fresh, canned, fresh grains and dried grains in the world and in Türkiye. Its dry grains contain 23-34 % protein, 60 % carbohydrates, 5 % crude fibre, 1.7 % fat and 3.6 % ash. It is one of the legume plants that can fill the animal protein gap of our country, especially due to its high protein content (Abacı and Kaya, 2018). In addition, it is a plant whose grains are rich in potassium, phosphorus, calcium, magnesium, sulphur, iron and manganese minerals and vitamins A, B and D (Şehirali, 1988; Pekşen and Artık, 2005; Sirat, 2020).

Food and Agriculture Organization (FAO) data for 2020 shows that 27.55 million tons of dry beans were produced in an area of 34.80 million hectares with an average yield of 790 kg ha^{-1}. India, Myanmar and Brazil are in the top three world production rankings. Türkiye ranks 19th in the world production rankings in 2020 and 12th in the productivity rankings. Among the dried legumes produced in Turkey, beans rank third after chickpeas and lentils. According to TÜİK data, dry bean production reached 305 thousand tons in 2021, with an increase of 9 % compared to the previous year (Anonymous, 2024a).

Energy use in agriculture is of great importance in terms of efficiency and sustainability. Despite the food demand of the increasing world population, the decrease in agricultural areas necessitates the purchase of more products per unit area. Therefore, intensive energy use in agriculture is inevitable. Achieving maximum efficiency with minimum energy inputs in agricultural production is desirable in every period (Alam et al., 2005; Dilay, 2021). While financial savings will be made through efficient energy use in agriculture, fossil fuel consumption and air pollution will also be reduced. In this way, sustainable agricultural production will be achieved (Uhlin, 1998; Azarpour et al., 2013; Dilay, 2021).

The following studies can be presented as examples of defining energy use efficiency in agricultural production. Soybean (Mandal et al., 2002), sugar beet (Hacıseferoğulları et al., 2003; Baran and Gökdoğan, 2016), dry bean (Sonmete and Demir, 2007), wheat (Tipi et al., 2009), chickpea (Marakoğlu et al., 2010), garlic (Samavatean et al., 2011, Baran et al., 2023), forage pea, (Turan et al., 2023), bean (Kazemi et al., 2015), sunflower (Bayhan, 2016), chickpea (Baran and Gökdoğan, 2017), onion (Ozbek et al., 2021), maize (Dilay, 2021), cotton (Baran et al., 2021), grape (Uzun and Baran, 2022), persimmon (Baran, 2022), guar and lupin (Gökdoğan et al., 2017), summery vetch (Baran, 2016), rice (Baran et al., 2015) etc. The aim of this study is to determine the energy use efficiency of dry beans by calculating the energy use efficiency indicators for the 2023 production season in the Central district of Kırklareli province.

2. Materials and Methods

Kırklareli is located in the Thrace Region of Turkey on the European Continent. It lies between 41°44' - 42°00' northern latitudes and 26°53' - 41°44' eastern longitudes. It has a land size of 6,555 km^2. Bulgaria is located to the north with a border length of 159 km. It is surrounded by the Black Sea in the east with a coastline of 58 km, Edirne in the west, Istanbul in the southeast, and Tekirdağ in the south. 48 % of the land is mountainous, 35 % is wavy land, and 17 % is plain (Anonymous, 2024b). Continental climate prevails in the center of Kırklareli. Black Sea climate is seen in the north-facing parts of the Yıldız Mountains. Accordingly, summers are cool and winters are cold. In the inland areas away from the sea, a continental climate is observed. Summers are hot, winters are cold and occasionally snowy (Anonymous, 2024c).

In Kırklareli province, the annual average temperature for many years was 13.3 ^{0}C, and the average monthly total precipitation amount (mm) was 583.7 (Anonymous, 2024d). This study was carried out in the Central district of Kırklareli province of Turkey in the 2023 production season. The production area covered 0.20 hectares, and a randomized complete-block design with three replications was employed in a working area of 0.20 hectares.

Since it was aimed to determine fuel consumption, the full tank method was used. The tank for a given area is completely filled. Immediately after the machine finished the job, the tank was filled to its original level again using a scaled container. The amount of fuel consumed per unit area was determined by measuring the treated area and the amount of fuel filled (Göktürk, 1999; El Saleh, 2000; Sonmete and Demir, 2007). A three-stopwatch measurement set was used in time measurements and field work efficiency calculations (Sonmete, 2006). Area work efficiency is calculated as effective area work efficiency. Work efficiency (ha^{h-1}) was calculated using the effective working time (tef) spent while processing the trial plots (Güzel, 1986; Özcan, 1986; Sonmete, 2006).

Various energy inputs such as human labour, machinery, chemicals, chemical fertilizers, diesel fuel, seeds, electricity and irrigation water (Table 1) were quantified in terms of their usage per hectare within dry bean production. With regards to calculating the total energy inputs, the usage of inputs per hectare have been multiplied by their respective energy equivalents. The acquired output was dry bean. With the purpose of obtaining the EUE of dry bean production, the inputs and outputs of the table have been combined. The following formulae have been used to calculate the EUE, SE, EP and NE in dry bean production (Mandal et al., 2002; Mohammadi et al., 2008; Mohammadi et al., 2010). Koctürk and Engindeniz (2009) reported that forms of energy input are involved in dry bean production, including direct, indirect, renewable, and non-renewable sources.

$$\mathrm{EUE} = \frac{\text{Energy output } (\frac{\text{MJ}}{\text{ha}})}{\text{Energy input } (\frac{\text{MJ}}{\text{ha}})} \qquad \text{Eq(1)}$$

$$\mathrm{SE} = \frac{\text{Energy input } (\frac{\text{MJ}}{\text{ha}})}{\text{Product output } (\frac{\text{kg}}{\text{ha}})} \qquad \text{Eq(2)}$$

$$\mathrm{EP} = \frac{\text{Product output } (\frac{\text{kg}}{\text{ha}})}{\text{Energy input } (\frac{\text{MJ}}{\text{ha}})} \qquad \text{Eq(3)}$$

$$\mathrm{NE} = \text{Energy output (MJ ha}^{-1}) - \text{Energy input (MJ ha}^{-1}) \qquad \text{Eq(4)}$$

Table 1. Energy equivalents in agricultural production

Inputs	Unit	Energy equivalent (MJ unit^{-1})	References
Human labour	h	1.96	Singh et al., 2001; Ozalp et al., 2018
Machinery	h	64.80	Singh, 2002; Kizilaslan, 2009
N	kg	60.60	Singh, 2002; Demircan et al., 2006
P	kg	11.10	Singh, 2002; Demircan et al., 2006
K	kg	6.70	Singh, 2002; Demircan et al., 2006
Herbicide	kg	288	Kitani, 1999; Ekinci et al., 2020
Insecticide	kg	363.60	Pimentel, 1980; Ekinci et al., 2020
Diesel Fuel	l	56.31	Singh, 2002; Demircan et al., 2006
Irrigation water	m^3	0.63	Yaldiz et al.,1993; Ekinci et al., 2020
Electricity	kWh	3.60	Özkan et al., 2004
Seed	kg	21	Awad Alla et al., 2014; Kazemi et al., 2015
Dry bean	kg	20	Awad Alla et al., 2014; Kazemi et al., 2015

3. Results and Discussion

Table 2 presents the energy balance of dry bean production. The total energy input for dry bean production has been established as 16717.86 MJ ha^{-1}, while the energy output has been established as 34440 MJ ha^{-1}. The energy inputs consist of 7128 MJ ha^{-1} (42.64 %) chemical fertilizer energy, 3885.39 MJ ha^{-1} (23.24 %) diesel fuel energy, 1458 MJ ha^{-1} (8.72 %) electricity energy, 1217.60 MJ ha^{-1} (7.34 %) chemical energy, 1218 MJ ha^{-1} (7.29 %) seed energy, 907.20 MJ ha^{-1} (5.43 %) irrigation water energy, 510.88 MJ ha^{-1} (3.06 %) machinery energy and 382.79 MJ ha^{-1} (2.29 %) human labour energy. The output energy has been established as 34440 MJ ha^{-1}. Similarly, Kazemi et al. (2015) has reported the chemical fertilizer input in bean production as 56.17 %, Tipi et al. (2009) reported the chemical fertilizer input in wheat production as 34.21 %, Ozbek et al. (2021) as 60.43 % in onion production.

Table 2. EUE of dry bean production

Inputs	Unit	Input used per hectare (unit ha^{-1})	Energy value (MJ ha^{-1})	Ratio (%)
Human labour	h	195.30	382.79	2.29
Machinery	h	7.88	510.88	3.06
Chemical fertilizers			7128	42.64
N	kg	100	6060	36.25
P	kg	60	666	3.98
K	kg	60	402	2.40
Chemicals			1217.60	7.34
Herbicide	kg	3	864	5.17
Insecticide	kg	1	363.60	2.17
Diesel fuel	l	69	3885.39	23.24
Irrigation water	m^3	1440	907.20	5.43
Electricity	kWh	405	1458	8.72
Seed	kg	58	1218	7.29
Total (Input)			16717.86	100
Total (Output) Dry bean	kg	1722	34440	100

EI, EO, EUE, SE and NE values for dry bean production are presented in Table 3. They are based on the production of 1722 kg of dry bean. The total energy input has been established as 16717.86 MJ ha^{-1}, while the total energy output has been established as 34440 MJ ha^{-1}. The EUE has been established as 2.06, with a SE of 9.71 MJ kg^{-1}, an EP of 0.10 kg MJ^{-1} and a net energy value of 17722.14 MJ ha^{-1}. In previous studies, various values for EUE in agricultural production have been reported. Kazemi et al. (2015) calculated the efficiency as 4.70 bean, while Tipi et al. (2009) reported a value of 3.09, Ozbek et al. (2021) obtained a value of 2.21 for onion production.

Table 3. EUE calculations in dry bean production

Calculations	Unit	Values
Dry bean	kg	1722
Energy input	MJ ha^{-1}	16717.86
Energy output	MJ ha^{-1}	34440
EUE	-	2.06
SE	MJ kg^{-1}	9.71
EP	kg MJ^{-1}	0.10
NE	MJ ha^{-1}	17722.14

The energy inputs in dry bean production are categorized into four group. These are, direct, indirect, renewable and non-renewable, corresponding to 6633.38 MJ ha^{-1} (39.68 %), while the indirect energy inputs have been established as 10084.48 MJ ha^{-1} (60.32 %). Furthermore, renewable energy inputs have been established as 2507.99 MJ ha^{-1} (15 %), and non-renewable energy inputs have been established as 14209.87 MJ ha^{-1} (85 %) (Table 4). Similarly, in studies on bean, wheat, onion production, it has been found that non-renewable energy inputs exceeded renewable energy inputs (Kazemi et al., 2015; Tipi et al., 2009; Ozbek et al., 2021).

Table 4. Energy inputs in the forms of energy for dry bean production

Energy groups	Energy input (MJ ha^{-1})	Ratio (%)
DE	6633.38	39.68
IDE	10084.48	60.32
Total	16717.86	100
RE	2507.99	15
NRE	14209.87	85
Total	16717.86	100

4. Conclusion

Within the scope of this study, energy use efficiency, specific energy, energy efficiency and net energy calculations were made as energy use efficiency indicators in dry bean production in Kırklareli province. In addition, classifications and calculations of energy input types have been made. The total energy input in dry bean production has been established as 16717.86 MJ ha^{-1}, while energy output has been established as 34440 MJ ha^{-1}. Under the scope of the study, 1722 kg of dry beans has been yielded per hectare. Based on the energy use efficiency indicator calculations, energy use efficiency has been established as 2.06 specific energy as 9.71 MJ kg^{-1}, energy productivity as 0.10 kg MJ^{-1} and net energy as 17722.14 MJ ha^{-1}. Energy input types consists of 6633.38 MJ ha^{-1} (39.68 %) direct energy, 10084.48 MJ ha^{-1} (60.32 %) indirect energy, 2507.99 MJ ha^{-1} (15 %) renewable energy and 14209.87 MJ ha^{-1} (85 %) non-renewable energy. According to the calculations of energy use efficiency indicators, it can be said that dry bean production is a profitable production in terms of energy use efficiency (2.06) as of the 2023 production season trial run. There are a number of ways to further increase efficiency, and one of them could be said to be using farm manure instead of cemical fertilisers, which constitute the highest input at 14209.87 MJ ha^{-1} (85 %). This current study has been the first of its kind, as it examined dry bean energy balance and will contribute to future studies and literature. When there is a shortage of energy and it should be economical, sustainable and productive, then energy management becomes even more significant. The conclusions of various studies indicate that reduction in diesel fuel, electricity, chemicals and fertilizer consumptions are important for energy saving and decreasing the environmental risk problem. Chemicals and fertilizer energy are applied as there is a lack of pest analysis and soil analysis, The use of such materials lead to unconscious usage of chemicals and total fertilizer. On the other hand, machinery is extensively used for soil preparation, spraying activities and transportation in production process leading to a high level of required diesel fuel energy (Rafiee et al., 2010). These recommendations can be taken into consideration to increase energy use efficiency in dry bean production.

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