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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Analysis of Energy Use Efficiency and Greenhouse Gas Emission in Rainfed Canola Production (Case study: Çanakkale Province, Turkey)

Kuruda Kanola Üretiminin Enerji Kullanım Verimliliği ve Sera Gazı Emisyonun Analizi (Örnek Çalışma: Çanakkale ili, Türkiye)

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Abstract

Agriculture and energy are two closely related issues, agriculture not only consumes energy, but it also supplies energy. While increasing energy use in agriculture causes environmental problems such as greenhouse gas emissions, it also leads to the depletion of non-renewable energy resources. On the other hand, decreasing greenhouse gas emissions and enhancement the efficiency of energy use is among the important issues of sustainable agriculture. Therefore, this study was done to determine the energy inputs and greenhouse gas emissions in rainfed canola production. Data were collected by conducting face-to-face interviews in the period of 2021-2022 in 42-farm in Çanakkale province, located in the northwest of Turkey. Results introduced that the energy use efficiency and net energy gain were 3.63 and 72786.16 MJ ha^{-1}, respectively. In energy consumption, the highest rate of 46.62% belongs to fuel, and then nitrogen with 40.44%. The consumption of total energy is obtained as direct (46.46%), indirect (53.54%), renewable (1.07%) and non-renewable (98.93%). It has been determined that the energy requirements of the farms belong to non-renewable energy with an amount of 27384.03 MJ ha^{-1}, and this is especially prominent in diesel fuel and nitrogen fertilizer. The results show that the agricultural production in the area where the study is carried out mostly depends on non-renewable energy sources, whereas the use of renewable energy is very low. Total greenhouse gas emissions per hectare were equivalent to 1921.66 kg CO_2, and the highest amount was determined to belong to machinery and diesel fuel, with 53.20% and 32.66%, respectively. According to the results obtained in the farms where the study was carried out, it was revealed that the economic use and sustainability of energy can be strongly recommended in rainfed canola production using mechanization, especially considering the non-renewable energy inputs.

Keywords: Energy use in agriculture, Input energy, Output energy, Carbon dioxide emission, Canola

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Öz

Tarım ve enerji birbiriyle yakından ilişkili iki konu olup, tarım sadece enerji tüketmekle kalmıyor, aynı zamanda tarımsal üretim için gerekli enerji üretimini de sağlıyor. Tarımda enerji kullanımının artması, sera gazı emisyonları gibi çevresel sorunlara neden olurken, yenilenemeyen enerji kaynaklarının da tükenmesine yol açmaktadır. Öte yandan, sera gazı emisyonlarının azaltılması ve enerji kullanım verimliliğinin artırılması sürdürülebilir tarımın önemli konuları arasında yer alıyor. Bu nedenle, bu çalışma, kuru koşullarda kanola üretiminde enerji girdilerini ve sera gazı emisyonlarını belirlemek amacıyla ele alınmıştır. 2021-2022 üretim döneminde Türkiye'nin kuzeybatısında yer alan Çanakkale ilinde bulunan 42 kanola üretimi yapan çiftlikte yüz yüze görüşmeler yapılarak gerekli olan veriler elde edilmiştir. Sonuçlar, enerji kullanım verimliliği ve net enerji kazancının sırasıyla 3.63 ve 72786.16 MJ ha^{-1} olduğunu göstermiştir. Enerji tüketiminde en yüksek oran %46.62 ile dizel yakıtına ait olup, onu %40.44 ile azotlu gübrenin izlediği saptanmıştır. Toplam enerji tüketimi doğrudan (%46.46), dolaylı (%53.54), yenilenebilir (%1.07) ve yenilenemez (%98.93) olarak elde edilmiştir. Kanola üretimi yapan çiftliklerin enerji ihtiyacının 27384.03 MJ ha^{-1} miktarı ile yenilenemeyen enerjiye ait olduğu ve bunun özellikle dizel yakıtı ve azotlu gübre ile öne çıktığı belirlenmiştir. Elde edilen veriler, çalışmanın yürütüldüğü alanda tarımsal üretimin büyük ölçüde yenilenemeyen enerji kaynaklarına bağlı olduğunu, yenilenebilir enerji kullanımının ise çok düşük düzeyde kaldığını göstermiştir. Hektar başına toplam sera gazı emisyonu 1921.66 kg CO_2 eşdeğer olduğu, en yüksek miktarın sırasıyla %53.20 ve %32.66 ile makine ve dizele yakıtına ait olduğu saptanmıştır. Çalışmanın yürütüldüğü çiftliklerde elde edilen sonuçlara göre, özellikle yenilenemeyen enerji girdileri dikkate alındığında, mekanizasyon kullanılarak kuru koşullarda kanola üretiminde enerjinin ekonomik kullanımının ve sürdürülebilirliğinin tavsiye edilebileceği sonucu ortaya çıkmıştır.

Anahtar Kelimeler: Tarımda enerji kullanımı, Girdi enerjisi, Çıktı enerjisi, Karbondioksit salınımı, Kanola

1. Introduction

Energy consumption, environmental quality and even the economy are reciprocally interdependent issues. There is also a significant relevance between agriculture and energy, which is heavily dependent on non-renewable and other sources (Pimentel and Pimentel, 2007). The use of more energy than necessary in agriculture leads negative effects on the environment; in this respect, while agriculture creates climate change, it has an impact on the environment and is also affected by climate change. In recent years, the rapid increase in the world's population and, the spread of new techniques in agriculture and the amount of energy required for their application has led to a continuous increase (Kitani, 1999). Thus, energy is an important component in agriculture and an essential input for every cultivation, transport, and social development. In this respect, agriculture will become heavily dependent on energy use in future times to ensure food for the steadily growth of world peoples. Energy efficient in agriculture is one of the necessities of sustainable agriculture, and it will be also had positive effects on the use of fuels and the protection of natural resources (Mousavi-Avval et al., 2010). While agriculture consumes energy directly on the farms as diesel fuel to run equipment, it is used indirectly to produce the machinery and chemicals (fertilizers, pesticides) out of farm (Pimentel and Pimentel, 2007). Energy is needed on farms, especially in field practices such as seedbed preparation, sowing, intercultural practices, water pumping, harvesting and transportation (Lal, 2004). Field practices require a huge energy to operate machinery (Pishgar-Komleh et al., 2012), for example, tillage is a field practice that consumes about 30% of the total energy use in agriculture (Lal, 2004). The high use of energy resources like fertilizers, pesticides, and fuel which constitute a high energy input, causes significant threats to environmental pollution. The use of low energy input also reduces the amount of CO_2 gas emissions, which have negative effects on the environment (Khoshnevisan et al., 2013). The emissions as greenhouse gas from agriculture are 19.9 Giga tons of CO_2 equivalent annually, which corresponds to 24% of the total global amount (IPCC, 2014), while this rate for Turkish agriculture is quite small with 3% (TUIK, 2021). From this point of view, agriculture is considered to have a great function in the gas emissions due to the acquisition of inputs used and the applications with tractor-driven equipment (Mousavi-Avval et al., 2017). However, in the last two decades, the application of high inputs in conventional production systems and the intensive use of agricultural machinery (Pishgar-Komleh et al., 2012) have further increased the emissions as greenhouse gas (Choudhary et al., 2017). Considering all these, the efficient use of energy resources and the development environmental appearances of agricultural production in order to reduce the emissions are the basic requirements of sustainable agriculture (Lal, 2004). So far, lots of studies have been done to calculate the energy use to produce field crops in Turkey or other countries, but very few have been combined with the analysis of energy and greenhouse gas emissions for canola under rainfed conditions. According to the results obtained in a study on rainfed potato production in Iran, it has been revealed that the total input energy of 47 thousand MJ ha^{-1} causes about 993 kg of CO_2 emissions per hectare (Pishgar-Komleh et al., 2012). In another study conducted by Soltani et al. (2014) for many rainfed canola production systems in Iran, energy and greenhouse gas emissions analysis were carried out. They showed that the conventional system consumes 12953 MJ ha^{-1} of energy, resulting in an energy output of 52355 MJ ha^{-1} and greenhouse gas emissions equivalent to 1028.1 kg of CO_2 per hectare. They also recorded that energy efficiency, productivity and net return were 4.1, 0.14 kg MJ^{-1} and 39402 MJ ha^{-1}, respectively. In a study conducted by Unakitan et al. (2010) in Turkey, an energy use of canola was analysed using three farm size scenarios. The results showed that total energy input on average farm size was 18297.61 MJ ha^{-1}, which about 65% of this was related to chemical fertilizers. The average of energy efficiency, net and productivity energy are 4.68, 67259.36 MJ ha^{-1} and 0.17 kg MJ^{-1}, respectively, and these values increase with the size of the farm. Optimizing energy efficiency and reducing energy input, applying nitrogen with actual crop requirements, and adopting reduced tillage are the most efficient techniques (Ozpinar, 2006). Ozpinar and Ozpinar (2015) concluded that under long-term tillage and crop rotation with wheat-vetch/maize using green manure in both rainfed and irrigation conditions can increase the maize grain yield without chemical fertilizer application.

Canola is produced in an area of approximately 38 million hectares in the world and 75 million tons of production is made per hectare. The most important rate belongs to Canada, followed by China, India, Germany, France, Australia, Poland, and other countries in the Mediterranean basin (FAOSTAT, 2020). In the countries in basin, the yield per unit area and thus the production amount is lower than the rainy middle European part (Rathke and Diepenbrock, 2006). For example, in Turkey, which does not have a long history in canola cultivation, it has increased amount of canola, which was 110 thousand tons in 2012, to over 125 thousand tons in 2020 on an area of 45 hectares (TUIK, 2021), with the support provided by the government for fertilizers, diesel fuel and certified seeds per kilogram or hectare. Canola is mainly grown in the European part of Turkey, but also in other parts of the country, mostly for oil and rarely for animal feed. While winter varieties are grown in Thrace, Marmara and Black Sea regions located in the northwest of the country, spring varieties can be grown in Mediterranean, Aegean, Central and Southeastern Anatolia regions. Çanakkale, partly in the Thrace region, is one of the provinces at the coast to the Marmara Sea and is the third canola producing province in the region. It produces approximately 39% of the country's canola production with an average yield of 3550 kg per hectare, but yield reaches over 4000 kg ha^{-1} in well-irrigated areas (TUIK, 2021). In this regard, in rainfed conditions of the study area, canola, which is an alternative to sunflower, is produced in rotation with cereals such as winter wheat in order to increase the yield per unit area under sustainable production systems and to enrich the soil in terms of organic matter. On the other hand, the canola-cereals cropping system is the largest system in the area under conventional systems require vigorous number of inputs, which contributes high energy and results in low economic returns. Despite the sustainable characteristics of canola, widespread cultivation of the product has various harmful effects on the environment, such as consumption of natural resources and gas emissions. So, it has become important to analyse rainfed canola production in terms of energy and greenhouse gas emissions as CO_2. While studies on different products with energy analysis have been published for different regions of the country (Baran et al., 2021), there have been studies on only olive (Özpınar, 2020) and rice (Ozpinar, 2022) in Çanakkale province. However, none of these studies have been analysed by combining energy and greenhouse gas emissions using conventional production systems under rainfed conditions, further, the results of studies in other parts of the country are not representative of the country's remaining larger production areas. For this reason, it has been concluded that there is a need for energy use data, which can be a reference and guide for energy saving and reducing gas emissions in agriculture, both in the country and in the canola production area where the study was conducted. Thus, this study was undertaken in Çanakkale, located in the northwest of Turkey, to fill the lack of data on the efficient use of energy for canola production in the country. In this regard, it is necessary to carry out energy analysis studies that will contain environmental effects in canola production in the study area. This energy analysis was conducted using questionnaire data from canola producing farms, as well as other data from field observation studies. Moreover, the aim of the study is to determine the energy inputs, output, energy efficiency, gas emissions of rainfed canola production and to guide the technological developments necessary to reach the high energy use efficiency of the existing production systems in the study area.

2.Materials and Methods

2.1. Study area

The study was carried out in the Çanakkale province, northwest of Turkey, which is located within 25°40′-27°30′ east longitude and 39°27′-40°45′ north latitude. The total area of the province is 993 thousand hectares, of which approximately 332 thousand hectares are belongs to agricultural areas. Most of these areas are covered with rainfed agriculture, usually the canola crop is grown in rotation with wheat, barley, and sunflower, except in irrigated areas where usually maize/corn, rice, vegetables, and orchard crops such as peaches, apples, cherries are grown (Özpınar and Ürkmez, 2017). The climate is under the influence of Ida Mountain, Marmara and Aegean Seas where is semiarid subtropical. While the northern parts of the province are under the influence of a colder climate, the southern parts have a more obvious tropical climate, the summer period is between May and September and the winter is between October and April. Annual average of maximum temperature is about 28°C (in August) according to the long-term period (*Figure* 1), and annual average of minimum temperature is 6 °C (in January) (*Figure* 1). The annual rainfall increases from south to north part regardless of the altitude and varying from 460 mm to 715 mm according to years, and about 65% of annual rainfall events occur from December to May (*Figure 2*). For studied farms for the canola production, agricultural practices commonly include tillage, sowing, fertilizing, weed and pest control, and harvesting. Seedbed preparation is one of the main practices in the studied area where is under conventional production systems using mainly mouldboard plough. For this reason, the soil is first tilled by plough at 20-25 cm followed by twice double action disk harrowing in opposite directions at 10 cm between 15 September and 30 October, and then roller application. Finally, sowing is done using pneumatic drills or grain row-planter at average rate of around 8.20 kg ha^{-1} of seed with varying 4 and 9 kg ha^{-1} usually using DK Exstorm hybrid. Soil preparation is very effective practice to reduce weeds which can be controlled by using herbicide with 1.63 litre ha^{-1} on average using a tractor mounted sprayer. Trifluralin is usually applied to the soil two weeks before sowing, while Azotrax is used for narrow-leaved weeds such as wheat and oats at the sowing, Agil Extra and Formula Super after canola emergence, and Lontrel Extra for broad-leaved weeds. Considering the fertilizer application, only nitrogen and phosphorus are applied since potassium is sufficient in the soils. Basic fertilizers in canola production are usually urea (46% N), triple super phosphate (43-46% P_2O_5).

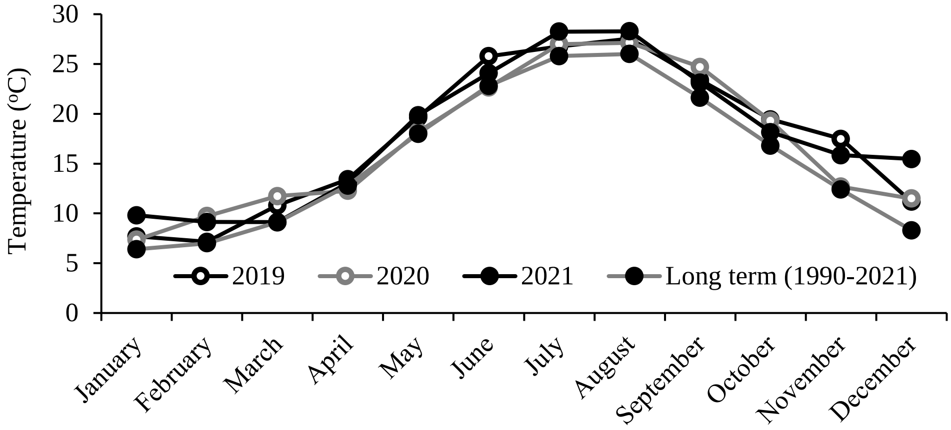

Figure 1. Average temperature according to months for three years and long-term

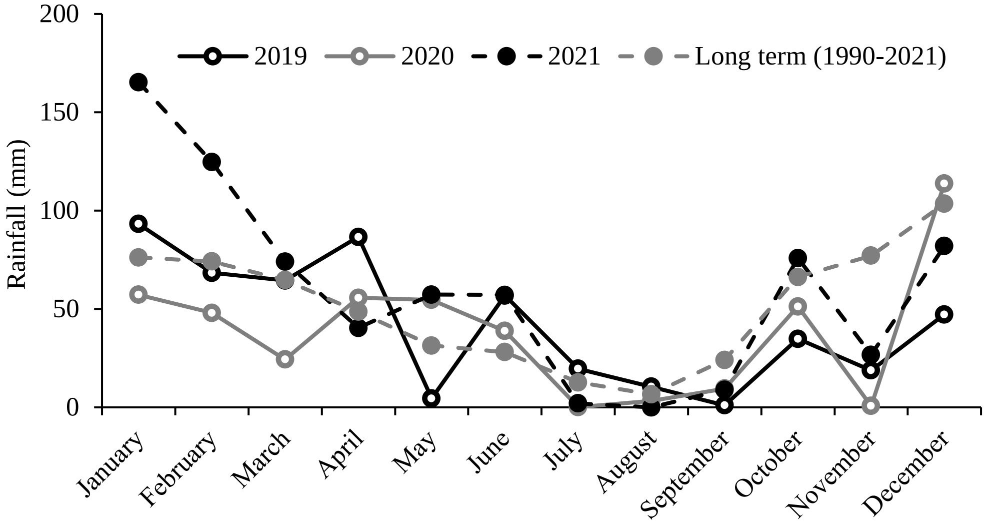

Figure 2. Rainfall distribution according to months for three years and long-term period

Thus, canola needs relatively higher levels of both nitrogen and phosphorus fertilizers. Nitrogen was applied (150-175 kg ha^{-1}) as 1/3 at the seeding stage [the September-October/November (%21 N as 18-46-0/20-20-0 DAP compound)], 1/3 at the stem elongation [December-January (%46 N urea) and March-April (%26 N ammonium nitrate)], and 1/3 before flowering in studied farms *(Table 1).* Phosphorus fertilizer was used only during the sowing stage and in the amount of 50-80 kg per hectare. Canola is harvested in the last quarter of May with a self-propelled grain combine.

2.2. Data collection and evaluation

Data were obtained from farms by visiting 42-farmer producing canola in 15 villages of the districts (Bayramiç, Biga, Eceabat, Lapseki, Ezine) of Çanakkale province during the June-September 2021 period. Most of the district areas is generally in flat lands with cereal fields, and the economy is mostly based on agriculture. In order to collect the necessary data about various inputs (seed, fertilizer, herbicide, fuel, etc.), a questionnaire containing detailed information about the inputs including working time and machinery usage, and canola grain yield, etc. was prepared. Some of the data was taken from similar studies and statistics published by relevant organizations such as Turkish Statistical Institute and Agricultural Ministry, and some of it was measured in farmer fields or directly on machinery. For farms, the random method was used for sampling and the sizes of sample were determined as 42 farms from the population using the Neyman method equation (Yamane, 1967).

Table 1. Amount of inputs used in canola production and output

Inputs/output	Amount of input (ha^{-1})	
	Average	**Lowest-Highest**
Human labour (h)	28.85	27-35
Diesel fuel (l)	227.40	220-230
Nitrogen (N, kg)	184.70	160-190
Phosphorous (P_2O_5, kg)	85.00	70-87
Herbicide (active ingredient) (l)	1.63	1-2
Machinery (h)	14.40	10-18
Seed rate (kg)	8.20	8-9
Grain yield (kg)	3550	2500-4550

2.3. Energy and greenhouse gas emissions analysis

The considered inputs and output have been converted to energy values using their energy equivalents *(Table 2)*. The determination of energy efficiency was based on the energy rate between output and inputs. Inputs include seeds, fertilizers and herbicides, diesel fuel, machinery and human labour, and output consists of the yield of canola grain. Energy consumption was obtained from the amount of input application *(Table 1)* by the energy equivalents *(Table 2)* and expressed in MJ per hectare. Classical mathematical equations (1-8) were used to calculate the equivalent energy of rainfed canola production. Labour is used at various stages of canola production on farms, for example, tillage, sowing, application of fertilizers and herbicides, harvesting and operating agricultural machinery. Labour energy input is calculated by multiplying the person number doing work in an operation (Kösemani and Bamgboye, 2020). The total hours (H_h, h ha^{-1}) for the operations *(Table 1)* were multiplied by the energy equivalent *(Table 2)* for human (H_{eqv}, MJ h^{-1}).

$$E_h = H_h \text{ x } H_{eqv} \qquad \text{(Eq.1)}$$

The diesel fuel energy (Ed) is obtained by multiplying the total amount of fuel (l ha^{-1}) *(Table 1)* consumed in all cultural operations with the heating value of the fuel *(Table 2).*

$$E_d = D \text{ x } F_{eqv} \qquad \text{(Eq.2)}$$

Where, E_d, the diesel energy consumed (MJ ha^{-1}); D, the fuel used for operations (l ha^{-1}) *(Table 1);* F_{eqv}, fuel energy equivalent (MJ l^{-1}) *(Table 2).* To calculate energy for the machinery manufacturing in the farms, it is assumed that the embodied energy will be depreciated during the economic lifetime (L, h). So, the machinery weight (W, kg ha^{-1}) to produce one-hectare canola was calculated using the time used (W_h, h ha^{-1}) in farm.

$$W = \frac{M \text{ x } W_h}{L} \qquad \text{(Eq.3)}$$

The machinery energy was calculated by determining the production energy for tractors and machinery.

$$E_m = \frac{M \text{ x } E}{L \text{ x } C_e} \qquad \text{(Eq.4)}$$

Where, E_m, total farm machinery input energy in the lifetime for one hectare (MJ ha^{-1}); M, the machinery weight (kg); E, the energy equivalent of the machinery weight; L, the machinery life (h); C_e, the field capacity of farm machinery (ha h^{-1}). Energy equivalent for machinery considered energy used to produce the raw materials (22-60 MJ kg^{-1} for steel), the manufacturing process (86.38 MJ kg^{-1}), the transportation (8.8 MJ kg^{-1}). The amount of fuel used for tillage operations depending on the depth and width of tillage, the type of soil and moisture content, the size of tractor and machinery. Effective field capacity of farm machinery (C_e) calculated using following equation.

$$C_e = \frac{V \text{ x } W \text{ x } F_e}{10} \qquad \text{(Eq.5)}$$

Where W, the working width (m); V, the working speed (km h^{-1}); F_e, the field efficiency. Chemical energy input was obtained from the amount (kg) of fertilizers and herbicides used. Total energy input for fertilizers was obtained by using the amount of fertilizer *(Table 1)* by the energy value *(Table 2).*

$$E_{fert} = \sum_{n=1}^{n} \left(\frac{N x N_{eqv}}{SA} + \frac{P_2O_5 x P_{eqv}}{SA} \right) \qquad \text{(Eq.6)}$$

Where, E_{fert}, input for the fertilizer; N_{eqv}, the energy value of N; P_{eqv}, the energy value of P_2O_5; N, the fertilizer as percentage of N ingredient (kg); P_2O_5, the fertilizer as percentage of P_2O_5 ingredient (kg); SA, the area (ha); n, the application number nth. The NPK 20:20:0 was widely used in the study area because of K_2O sufficient in the area soils, thus, it was not considered in the calculation. The amount of the herbicide applied *(Table 1)* were multiplied with the energy value *(Table 2)* to get the energy of the herbicide.

$$E_{herb} = H_h \text{ x } H_{eqv} \quad \text{(Eq.7)}$$

Where, E_{herb}, the energy input for herbicide (Mj ha^{-1}); H_h, the quantity of herbicide applied (kg ha^{-1}); H_{eqv}, the energy equivalent value of herbicide (MJ kg^{-1}). The energy input of the seed was obtained by using the number of seed used (S_s, kg ha^{-1}) *(Table 1)* and the energy equivalent (S_{eqv}, MJ kg^{-1}) *(Table 2).*

$$E_s = S_s \text{ x } S_{eqv} \quad \text{(Eq.8)}$$

The output energy (E_o, MJ ha^{-1}) is estimated by multiplying the canola grain yield ($Q_{grain\text{-}yield}$, kg ha^{-1}) *(Table 1)* by energy equivalent (Q_{eqv} MJ kg^{-1}) *(Table 2).*

$$E_o = Q_{grain\text{-}yield} \text{ x } Q_{eqv} \quad \text{(Eq.9)}$$

Energy indicators in an agricultural production include various parameters such as energy use efficiency, energy productivity (kg MJ^{-1}), specific energy (MJ kg^{-1}) and net energy (MJ ha^{-1}).

$$\text{Energy use efficiency} = \frac{\text{Total energy output (MJ ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})} \quad \text{(Eq.10)}$$

$$\text{Energy productivity (kg MJ}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})} \quad \text{(Eq.11)}$$

$$\text{Specific energy (MJ kg}^{-1}) = \frac{\text{Total energy input (MJ ha}^{-1})}{\text{Grain yield (kg ha}^{-1})} \quad \text{(Eq.12)}$$

$$\text{Net energy (MJ ha}^{-1}) = \text{Energy output} - \text{Energy input} \quad \text{(Eq.13)}$$

Table 2. Energy equivalents for inputs and output

Input/Output	Equivalent	Reference
Human labour (MJ man h^{-1})	1.96	Kitani, 1999
Diesel fuel (MJ l^{-1})	56.31	Kitani, 1999
Nitrogen (N) (MJ kg^{-1})	60.60	Kitani, 1999
Phosphate (P_2O_5) (MJ kg^{-1})	11.10	Kitani, 1999
Herbicides (active ingredient) (MJ kg^{-1})	238.00	Mousavi-Avval et al., 2017
Machinery (MJ kg^{-1})⸸	142.70	Alimagham et al., 2017
Seed (MJ kg^{-1})	3.60	Mousavi-Avval et al., 2010
Grain yield (MJ kg^{-1})	28.30	Rathke and Diepenbrock, 2006

⸸ The value was considered for manufacturing (86.38 MJ kg^{-1}), repairs, maintenance (0.55 x energy for manufacture), and transportation (8.8 MJ kg^{-1}) energy for tractors and machinery.

Table 3. Equivalents of CO_2 emissions from canola farms

Input	Emission equivalent⸸		
	Mean	Range	References
Diesel fuel (l MJ^{-1})	2.76		Dyer and Desjardins, 2003
Nitrogen (N) (kg MJ^{-1})	1.30	0.9-1.8	Lal, 2004
Phosphorous (P_2O_5) (kg MJ^{-1})	0.20	0.1-0.3	Lal, 2004
Herbicide (kg MJ^{-1})	6.30	1.7-12.6	Lal, 2004
Machinery (kg MJ^{-1})	0.071		Dyer and Desjardins, 2003
Labour (kg MJ^{-1})	0.36		Nguyen and Hermansen, 2012

⸸ kg CO_2 equivalent per unit; including production, transportation, storage and transfer.

Energy sources used in agriculture consist of two main groups: natural and supplementary. Natural energy is essential for crop growth and includes solar energy and various forms of chemical energy stored biologically in the soil. The supplementary energy was divided into renewable and non-renewable forms, and direct and indirect forms. Direct energy contains those quantities that are consumed during the canola production period such as human labour and diesel fuel, while indirect energy includes seed, fertilizer, pesticide, and machinery. Renewable energy consists of human labour and seed, while non-renewable energy consists of diesel fuel, pesticide, fertilizer, and machinery. The greenhouse gas emissions were obtained by using CO_2 emission factor of agricultural inputs *(Table 3)*. The amount of produced CO_2 was calculated by using the input application rates *(Table 1)* and the emission equivalent *(Table 3)* and expressed as kg $CO2_{eq}$. ha^{-1} (Pishgar-Komleh et al., 2012; Soltani et al., 2014).

3.Results and Discussion

3.1. The energy inputs and output in canola production

The total energy input is calculated as 27678.84 MJ ha^{-1} and the output as 100465.0 MJ ha^{-1} *(Table 4)*. The energy input varied from 24812.72 to 28807.00 MJ ha^{-1} according to the amount of highest and lowest inputs comparable with the range of 5187.98-27887.15 MJ ha^{-1} to produce canola in Iran (Mousavi-Avval et al., 2017), 7420-16100 MJ ha^{-1} in Germany (Rathke and Diepenbrook, 2006). In another study, the highest energy input was reported as 30889 MJ ha^{-1} for irrigated canola production (Sheikh-Davoodi and Houshyar, 2009), while Taheri-Garavand et al. (2010) reported the total energy input and output values lower than the present study as 28705.3 MJ ha^{-1} and 41230 MJ ha^{-1}, respectively. Considering the energy consumption according to the energy requirement of the inputs, it is evident that fuel is the highest, dominating about 12805 MJ ha^{-1} with 47% of total energy *(Table 4)*. In previous studies, fuel founded for the highest rate of input energy (Rabiee et al., 2021), which agrees with this study results *(Table 4)*. One of the main reasons using the high diesel is coming from more field operations performed by machinery, for example for seedbed preparation and intercultural practices because of using fuel mainly for all tractor operations. Another reason is a temporal depreciation of agricultural machinery due to the use of dated machinery and equipment. It may be decreasing the amount of energy input by applying new machinery or equipment with more energy efficiency. Beyond diesel fuel, fertilizers (nitrogen, phosphorous) were among the other high energy inputs contributing to the consumption of 12136.32 MJ ha^{-1} (43.85%) of the total energy, for example nitrogen with 40.44% *(Table 4)*. There are two important reasons for the high fertilizer consumption. One of the reasons is the lack of knowledge of the farmers about the use of fertilizers. They do not know the amount of chemical fertilizer required for different crops, and they have a common belief that excessive use of fertilizer will increase the yield without soil analysis. Another reason is the prices of government subsidies which is significantly affected the amount of fertilizer use, especially during the pandemic period of the last two years, as it increased market prices and reduced the amount of use per unit area. As a result of the inefficient (more than crop need) use of chemical fertilizers, it will cause soil and water, and as well as air pollution. Some researchers indicated that energy used in the production of chemical fertilizer accounts approximately 40% of total energy used in agricultural production in developed countries (Pishgar-Komleh et al., 2012). Others have also reported that fertilizer and fuel were the most intensive energy inputs in canola production (Mousavi-Avval et al., 2017; Soltani et al., 2014) because canola has relatively high demands for nitrogen (N) per yield unit. Similarly, the others found the highest rate of nitrogen in total energy input was related to canola (37%) (Mohammadzadeh et al., 2017) and (47%) Mousavi-Avval et al. (2017). In this study, diesel and fertilizer were the two highest energy inputs and accounted as 92.14%. The energy inputs required for canola production in different countries strongly supports this view (Khoshnevisan et al., 2013; Mousavi-Avval et al., 2017). This study is also in agreement with the findings of Mousavi-Avval et al. (2010) and Mousavi-Avval et al. (2017) who reported that 85% and 81% of total energy input in canola production is consumed by both fuel and fertilizer. This was higher (96%) in the study of Taheri-Garavand et al. (2010) and lower (59%) in the study of Sheikh-Davoodi and Houshyar (2009) compared with the present study. Taheri-Garavand et al. (2010) was also found that the fertilizers (usually N) had the highest rate in the total energy with a rate of 65.5% (average of 18809.8 MJ ha^{-1}) followed by fuel with 30% (8604.2 MJ ha^{-1}). According to Rathke and Diepenbrock (2006) the rate of nitrogen ranges between 20% and 51% depending on the amount of nitrogen in winter canola production in Germany. The results of energy analysis in canola production of the north Iran led to the highest rate of energy input for nitrogen (42.9%) and fuel (39.81%) (Kazemi et al., 2016), which agrees with the results of the study *(Table 4)*. In this study, therefore, it is necessary to focus more on fuel and fertilizer consumption due to high energy inputs than the other components to effectively reduce energy consumption in canola production under rainfed conditions. Because fertilizer and fuel are closely related to the profitability of canola production in the study area, farmers are also highly receptive to integrated machinery and nitrogen-saving technologies that can achieve high energy use efficiency. It is also necessary to reduce the use and consumption of the machinery operation and diesel consumption in the production systems to overcome the growing energy demands in agriculture because intensive tillage operations accounted for higher machinery use and fuel consumption (Yadav et al., 2018).

Table 4. Energy of inputs and output for various operations in rainfed canola production

Input/Output	Average		Lowest		Highest	
	(MJ ha^{-1})	(%)	(MJ ha^{-1})	(%)	(MJ ha^{-1})	(%)
Human labour	55.37	0.20	52.92	0.21	68.60	0.24
Diesel fuel	12804.89	46.62	12388.20	49.93	12951.30	44.96
Nitrogen (N)	11192.82	40.44	9696.00	39.08	11514.00	39.97
Phosphorous (P_2O_5)	943.50	3.41	777.00	3.13	965.70	3.35
Herbicide	387.94	1.40	238.00	0.96	476.00	1.65
Machinery	2054.88	7.42	1427.00	5.75	2568.60	8.92
Seed	239.44	0.87	233.60	0.94	262.80	0.91
Total	27678.84	100.00	24812.72	100.00	28807.00	100.00
Grain yield	100465.00		70750.00		128765.00	

It can be supported with different applications to reduce the energy input of fertilizer without reducing the yield and production, for example, by using appropriate types of fertilizer sources such as legumes to reduce chemical fertilizer use, especially nitrogen (Ozpınar and Ozpınar, 2015). The use of nitrogen in the required amount has an important effect on ensuring the nutrient balance in the soil, increasing the efficiency of nitrogen use and maintaining the yield of canola. In contrast, excessive use of nitrogen can lead to serious problems such as the leakage of nitrogen into the environment and polluting the food chain and increasing carbon emissions in the atmosphere (Soltani et al., 2014). Therefore, to reduce the fertilizer and fuel use in agriculture, inclusion of legumes in crop rotation (Ozpinar and Baytekin, 2006), increment of soil organic matter and using efficient machinery (Rathke and Diepenbrock, 2006) are apparently a reasonable integrated approach. The results revealed that 55.37 MJ ha^{-1} (0.20%) of labour energy, varying from 52.92 to 68.60 MJ ha^{-1} in lowest and highest input amounts, respectively, and 2054.88 MJ ha^{-1} (7.42%) of machinery energy are needed per hectare *(Table 5)*. The higher value of machinery than labour can be mainly attributed the increasing tractor and machinery working operations and hours. Similar results have been reported in previous studies, labour and as well as herbicide energy inputs are low in total energy (Alimagham et al., 2017). In agreement with previous studies (Kazemi et al., 2016; Mousavi-Avval et al., 2017), the data revealed that in addition to machinery, nitrogen also has a high contribution with 14553.2 MJ ha^{-1} to total energy consumption. Bonari et al. (1995) indicated that reducing of tillage resulted in 55% less fuel consumption than conventional tillage without a significant difference in yield. Similarly, Rabiee et al. (2021) concluded that conventional tillage increased total energy input and greenhouse gas emissions compared reduced or no-tillage at the different fertilizer level. Seed energy has the lowest energy with 0.87% among all the inputs *(Table 4)*. One of the practices for further reduction of seed energy is to use less seed per hectare by using qualified varieties which may also reduce the possibility of weed infestation and the energy needed for weeding. Herbicides are another input with the lowest energy consumption with 1.40%. The yield of canola grain was considered as 3550 kg ha^{-1} from the questioned farms, and the energy was resulted to be 100465.00 MJ ha^{-1}, ranging from 70750.00 to 128765.00 MJ ha^{-1} due to the different input amounts of the farms, in agreement with Rabiee et al. (2021) because of similar canola grain yield from unit area by 3458 kg ha^{-1}. These results were higher than in others (Mousavi-Avval et al., 2017) due to higher grain yield per hectare who declared that 2076.76 kg ha^{-1} produced 56695.6 MJ ha^{-1}, varying from 23205 MJ ha^{-1} to 107016 MJ ha^{-1}, while lower energy output of 50091 MJ ha^{-1} and 41230 MJ ha^{-1} for canola have been reported by (Kazemi et al. (2016) and Taheri-Garavand et al. (2010), respectively.

3.2. Energy indicators and forms

Efficiency of use of energy is an index of environmental impacts, which is related to crop production systems (Rathke and Diepenbrock, 2006) and expresses how much energy is produced in return for the energy used *(Table 5)*. Efficiency of use of energy calculated especially for the canola grain was found to vary between 2.85 and 4.47

in all the farms studied, with an average of 3.63. This is similar to the 3.50 (Mousavi-Avval et al., 2010) and 3.73 (Mousavi-Avval et al., 2017) in Iran, but it is lower than the 4.68 (Unakitan et al., 2010) in Turkey. This is also lower than the values reported by Soltani et al. (2014) who founded 4.1 for the common canola production system which represents about 70% of farmers using in the Gorgan region, Iran. In order to improve the of energy use in the farms, it can be achieved by including applications such as crop rotations, green manure production systems and reduced tillage that increase soil fertility. Lal (2004) indicated that energy efficiency tends to increase with the reduction of tillage operations which can lead to reduced fuel consumption and the time and energy needed for seedbed preparation. In general, for a sustainable crop production, the renewability and efficiency of energy should be increased in farms (Rathke and Diepenbrock, 2006). In *Table 5*, the energy productivity was found to be 0.13 kg MJ^{-1}, which means that 0.13 kg of canola grain are produced per one MJ of energy. These are in accordance with Rabiee et al. (2021) and Mousavi-Avval et al. (2010) as the averages of 0.13 kg MJ^{-1}, while Mousavi-Avval et al. (2017) reported that this value was 0.14 kg MJ^{-1}. Furthermore, a previous study by (Kazemi et al., 2016) reported energy efficiency as 0.12 for canola production. The energy per amount of product was found as 7.80 MJ kg^{-1} with the highest and lowest of 6.33 and 9.93 MJ kg^{-1}, respectively *(Table 5).* Similarly, Soltani et al. (2014) reported that this was 7.80 MJ kg^{-1} for canola while Kazemi et al. (2016) and Mousavi-Avval et al. (2010) found higher as 8.26 and 7.13 MJ kg^{-1}, respectively. Net energy gain recorded as 72786.16 MJ ha^{-1} on average, while it varied from 45937.28 to 99958.00 MJ ha^{-1} in lowest and highest quantities, respectively *(Table 5).*

Table 5. Energy indicators of canola production

Indicator	Average	Lowest	Highest
Energy use efficiency (dimensionless)	3.63	2.85	4.47
Energy productivity (kg MJ^{-1})	0.13	0.10	0.16
Specific energy (MJ kg^{-1})	7.80	9.93	6.33
Net energy (MJ ha^{-1})	72786.16	45937.28	99958.00

Table 6. Energy inputs for different energy forms

Energy form	Average		Lowest		Highest	
	(MJ ha^{-1})	(%)	(MJ ha^{-1})	(%)	(MJ ha^{-1})	(%)
Direct	12860.26	46.46	12441.12	50.14	13019.90	45.20
Indirect	14818.58	53.54	12371.60	49.86	15787.10	54.80
Total	27678.84	100.00	24812.72	100.00	28807.00	100.00
Renewable	294.81	1.07	286.52	1.15	331.40	1.15
Non-renewable	27384.03	98.93	24526.20	98.85	28475.60	98.85
Total	27678.84	100.00	24812.72	100.00	28807.00	100.00

Energy as indirect is found slightly higher than direct with 14818.58 MJ ha^{-1} (53.54%) and 12860.26 MJ ha^{-1} (46.46%) respectively *(Table 6).* In previous studies conducted by Kazemi et al. (2016) and Taheri-Garavand et al. (2010), the corresponding values were of 59.91% and 40.09%, 69.8 % and 30.2%, respectively. *Table 6* shows that the renewable and non-renewable energy were obtained as 1.07% and 98.93%, respectively. Considering this issue ecologically, non-renewable energy resources will eventually deplete (Rathke and Diepenbrock, 2006). This is not only specific to the area where the study was conducted, but also the results of a long-term study in the country made it clear that agriculture is largely dependent on non-renewable energy (Unakitan et al., 2010). The rates of non-renewable and renewable energy were found to be 97.98% and 2.02%, respectively by Kazemi et al. (2016) and these are in accordance with the findings of this study. In general, the country has a great potential for renewable energy sources (solar, wind, etc.) due to the existence of different geographical regions. Despite the energy long history in energy production from wind, renewable resources are used very low, mainly due to the lack of suitable technology for renewable resources, as well as no-government subsidies.

3.3. Greenhouse gas emissions

The management of energy consumption in agriculture, the use of non-renewable energy in various applications (use of machinery, water pumping and irrigation, fertilization, chemical spraying, etc.) have recently been the subject of interest because of growing greenhouse gas emissions all over the world. The total amount of the emissions was determined as 1921.66 kg CO_2 equivalent per hectare *(Table 7)*. This is mainly due to the intensive machinery use, the application of high amounts of fuel and nitrogen. It can be indicated that one of the applications of reducing greenhouse gas emissions is the reduction of field operations where a significant portion of fuel is consumed, and the other is the use of less nitrogen in canola production are issues to be considered. In a canola production study conducted in the northern regions of Iran, the value of 1063.5 kg CO_2 equivalent per hectare (Mohammadi et al., 2014) was lower than this study value. In this study, the highest emissions belonged to machinery with 53.20% and then 32.66% of fuel and 13.37% of nitrogen, and the rate of all remaining emissions remained below 1.5% *(Table 7)*. The lowest emissions were belonging to herbicide with 0.53% represents 10.27 kg CO_2 equivalent ha^{-1}. Alimagham et al. (2017) reported that emissions from machinery using for soybean was very important for production systems using full mechanization varying from 10.2% to 22.8% in total, except for the electricity consumption used in irrigation. However, they also concluded that in conventional soybean production systems typically labour-intensive, while fuel (33.6-40.7%) and electricity consumption (29.8-33.6%) were the predominant greenhouse gas emitters. The same authors noted that conventional soybean production in comparison with mechanized systems, produce less greenhouse gas emissions per kg of grain, indicating that conventional systems are more environmentally. In the present study, nitrogen had the first rank in greenhouse gas emissions of 12.49% followed by phosphorus with portion of 0.88%. Lal (2004) reported that the nitrogen accounting for 20% and 30% in large and small-scale farms, respectively. On the other hand, the reason for the high emissions of fuel in farms may be attributed to the use of worn-out tractors, improper machinery-tractor matching, as well as intensive tillage and intercultural operations with high energy consumption (Dyer and Desjardins, 2003). These are consistent with the findings concluded by Soltani et al. (2014) who presented that canola produces 1028.1 kg of CO_2 equivalent ha^{-1} due to the use of intensive machinery and fertilizers. They also reported that nitrogen (48%), fuel used in field operations (25%) and machinery (14%) are the most important contributors in terms of increasing emissions. Moreover, the same researchers concluded that a better seedbed preparation and selection of appropriate sowing methods can help reduce energy inputs, which can contribute to reducing greenhouse gas emissions. Further, they suggested that introducing appropriate machinery that can work in conservation tillage systems such as reduced tillage or no-tillage would help as measures to reduce input energy. Mousavi-Avval et al. (2017) reported that fertilizers, especially nitrogen, are the main energy consuming inputs and this is the main reason that increases greenhouse gas emissions. A study was managed to determine the greenhouse gas emissions of the simplified tillage practices by Saljnikov et al. (2014). They found that shallow tillage, which maintains higher levels of soil nutrients, reduces CO_2 emissions compared to intensive and deep tillage. Lal (2004) indicated that the reduction of nitrogen and the using of no-tillage methods may be advantageous to reduce global warming without reducing crop yield.

Table 7. CO_2 emissions from inputs used in canola production

Input	CO_2 emission (kg CO_2 equivalent ha^{-1})	Percentage (%)
Diesel fuel	627.62	32.66
Nitrogen (N)	240.11	12.49
Phosphorous (P_2O_5)	17.00	0.88
Herbicide	10.27	0.53
Machinery	1022.40	53.20
Seed		
Total emission	1921.66	100.00

4.Conclusions

Energy inputs and output were investigated for rainfed canola in Çanakkale province, northwest Turkey. While the average, lowest and highest energy inputs per hectare were 27678.84, 24812.72 and 28807.00 MJ ha^{-1}, respectively, the values for net energy were 72786.16, 45937.28 and 99958.00 MJ ha^{-1} with the same order. Diesel fuel energy consumption contributed the highest rate of 46.62%, 49.93% and 44.96% to the total, while labour had the lowest of 0.20%, 0.21% and 0.24%, respectively. It was determined that the production of canola mainly depends on non-renewable (98.93%) and indirect (53.54%) energy, especially on fertilizer and diesel. Direct energy in average, lowest and highest input quantities were 46.46%, 50.14% and 45.20%; while indirect were 53.54%, 49.86% and 54.80%, respectively. Energy productivity ranged from 0.10 in lowest to 0.16 in highest kg MJ^{-1} while the energy per produced product ranged from 6.33 to 9.93 MJ kg^{-1} for the same ranges, respectively. Corresponding values for the energy use efficiency was from 2.85 to 4.47. In the study area, it should be tried to increase the production by shifting the energy use from non-renewable sources to renewable to reach a self-sufficient and sustainable production for canola. For example, it has been concluded that practices such as reduced tillage systems and effective fertilizer use will lead to significant improvements in energy efficiency.

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