International Journal of Agriculture, Environment andFoodSciences

e-ISSN: 2618-5946 https://dergipark.org.tr/jaefs

DOI: https://doi.org/10.31015/jaefs.2024.3.17 Int. J. Agric. Environ. Food Sci. 2024; 8(3): 642-649

Determination of energy usage and greenhouse gas (GHG) emissions in artichoke production

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Article History
Received: July 28, 2024
Revised: September 10, 2024
Accepted: September 13, 2024
Published Online: September 20, 2024
Final Version: September 29, 2024

Article Info
Article Type: Research Article
Article Subject: Agricultural Energy Systems

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Available at
https://dergipark.org.tr/jaefs/issue/86361/1523776

DergiPark AKADEMIK

Abstract

This study has been conducted with the purpose of determining the energy usage (EU) and greenhouse gas (GHG) emissions of artichoke production. It has been conducted in Efeler district of Aydın province of Türkiye during the 2022 production period. According to the results of the study, total input energy (EI) was calculated to be 32 211.48 MJ/ha and output energy (OE) was calculated to be 5 460 MJ/ha. EI in artichoke production were 15 718.20 MJ/ha (48.80%) chemical fertilizers energy, 8 896.98 (27.62%) diesel fuel energy, 3 832.27 (11.90%) machinery energy, 1 958.40 (6.08%) electricity energy, 1 036.35 (3.22%) irrigation water energy, 329.55 (1.02%) human labour energy, 294 MJ/ha (0.91%) plant energy and 145.73 (0.45%) chemicals energy, respectively. Energy use efficiency (EUE), specific energy (SE), energy productivity (EP) and net energy (NE) values were found as 0.17, 4.72 MJ/kg, 0.21 kg/MJ and -26 751.48 MJ/ha, respectively. The total energy inputs that were involved in artichoke production were classified as: 37.94% (12 221.28 MJ/ha) direct (IE), 62.06% (19 990.20 MJ/ha) indirect (IDE), 5.15% (1 659.90 MJ/ha) renewable (RE) and 94.85% (30 551.58 MJ/ha) non-renewable (NRE). Total GHG emission was calculated as 1 401.64 $kgCO_{2eq}$/hafor artichoke production with the greatest share for diesel fuel (31.11%). GHG ratio value was calculated as 0.21 $kgCO_{2eq}$/kg in artichoke production.

Keywords: Artichoke, Energy usage, Net energy, Specific energy

Cite this article as: Demir, C., Baran, M.F., Elicin A.K. (2024). Determination of energy usage and greenhouse gas (GHG) emissions in artichoke production. International Journal of Agriculture, Environment and Food Sciences, 8(3), 642-649. https://doi.org/10.31015/jaefs.2024.3.17

INTRODUCTION

The ancient perennial plant species Artichoke (Cynara scolymus L.) is native to the Mediterranean Basin and has been known since the first century AD. It was widely spred in the southern Mediterranean area during the Middle Ages (Sgroi et al., 2015) by Arabs.Artichoke is particularly widespread in the Mediterranean Basin, where the climate is characterized by warm summers and mild winters (D'Asaro and Grillone, 2012; Leskovar et al., 2013; Sgroi et al., 2015).Artichoke, which has various benefits for human health, is also widely used in the pharmaceutical industry. Artichoke has a diuretic effect. In addition, it is known to be used for purposes such as shedding kidney stones, treating jaundice, increasing bile perception, protecting against arteriosclerosis, and reducing blood fat levels (Eser, 2002; Kenenoğlu Bektaş and Saner, 2013).

Artichoke is a significant vegetable of economic importance in the Asteraceae family. In 2018, a total of 1,680,992 tons of artichoke was produced in 127,472 hectares of land in the world. The countries that produce the most artichokes are Italy, Egypt and Spain. In Turkey, 39,477 tons of artichoke was produced in 3,065 hectares of land in 2018 (FAO, 2018; TÜİK, 2019; Duman and Nas, 2020). İzmir, Aydın, Bursa and Sakarya stand out as the provinces with the highest production in our country. The share of these four provinces constitutes 82% of the total production in Turkey (TÜİK, 2019; Duman and Nas, 2020).

The energy balance sheet to be made in terms of agricultural production is an important approach in defining and grouping agricultural systems in terms of energy consumption. The ratio between the energy equivalent of the product per unit area in any agricultural production branch and the energy equivalent spent for production can be used as an indicator and a benchmark for successful and profitable production. In addition, it also constitutes an important value in terms of the efficient use of energy in today's world where environmental sensitivity is rapidly increasing (Topdemir, 2018; Candemir, 2020).

Energy consumption per unit area in agriculture is directly related to the available technological level and production. The inputs such as fuel, electricity, machinery, seed, fertilizer and chemical take significant share of the energy supplies to the production system in modern agriculture. The use of intensive inputs in agriculture and access to plentiful fossil energy has provided an increase for standards of living and food production. However, some problems in agricultural production have been faced mainly due to high level dependency on fossil energy. In recent years, energy use and associated greenhouse gas emissions and their potential impacts on the global climate change have become worldwide concerns. Improving the end-use energy efficiency is one of the most effective ways to reduce energy consumption in the industrial, commercial, transportation, utility, residential and agricultural sectors and their associated pollutant emissions (Dyer and Desjardins, 2003; Oren and Ozturk, 2006).

Carbon dioxide gas has a significant share in the warming of the world and 80% of this gas originates from fossil fuels. In this sense, reducing our dependence on fossil fuels and increasing the share of renewable energy are very important in the fight against global warming. In our age, fossil fuel prices have increased significantly and, together with concerns arising from climate change, have brought about a series of innovations in the energy sector in terms of both supply and demand. In this context, developments aimed at expanding the use of renewable energy sources are also gaining momentum on a global scale. Carbon dioxide emission is defined as the emission of carbon dioxide resulting from the combustion of carbon-containing fuels (fossil fuels: oil, natural gas, coal, etc.) into the atmosphere. In addition to negatively affecting air quality, the formation of greenhouse gases is also an important problem. Carbon dioxide is not the only gas that causes the temperature of the earth to increase. Various gases such as methane, carbon monoxide, and nitrogen oxides also cause a similar effect (Çelen, 2016).

Several studies have been conducted on EUE and GHG of agricultural production, for instance;on vegetable (Ozkan et al., 2004), on carrot (Celik et al., 2010),on tomato (Ozkan et al., 2011), on lettuce (Kamburoğlu Çebi et al., 2017), on onion (Ozbek et al., 2021), pepper (Baran et al., 2022), garlic (Baran et al., 2023), etc. A review on the literature has been performed and it concluded that no studies were conducted on the EUE and GHG emission of artichoke in the area and therefore the significance of this current study is important.

MATERIALS AND METHODS

The district's altitude above sea level is 40 meters and its surface area is 631 km^2. Efeler district covers the Büyük Menderes Valley, which narrows from west to east. Its elevation is 130 meters in the middle parts and 30 meters in front of Gümüş Mountain. The plain is surrounded by the Aydın Mountains to the north and the northern part of the mountainous Menteşe region to the south. Summers are very hot and winters are mild in the plain parts of the district. The average temperature in summer is 28.3 °C and in winter is 8.1 °C (Anonymous, 2024a). The district is located at 37.8402 latitude and 27.8379 longitude (Anoymous, 2024b).

This current study has been conducted in Efeler district of Aydınprovince in Türkiye during the 2022 production period. The area that was studied spanned over a 0.10 ha artichoke production area. Randomized complete-block design with three replications has been performed. The amount of fuel usage wascalculated and full-tank method wasusaged to achieve this. The amount of fuel used per unit area was determined to measure the trial area and the amount of fuel that was placed in the tank (Göktürk, 1999; El Saleh, 2000; Sonmete and Demir, 2007).

The work productivity for the area wascalculated and it was deemed to be an effective productivity. Work productivity in (ha/h) was achieved by calculating the effective working time (t_{ef}) (Güzel, 1986; Özcan, 1986; Sonmete, 2006).

Time durations weredetermined in the study with the help of a chronometer (Sonmete, 2006).The energy equivalents and GHG equivalents of inputs in artichoke productionwere shown in Table 1 and Table 2, respectively. According to Mohammadi et al. (2010); EUE, SE, EP and NE were calculated by using the formulates (Mandal et al., 2002; Mohammadi et al., 2008).

$$\text{Energy use efficiency} = \frac{\text{Energy output } (\frac{\text{MJ}}{\text{ha}})}{\text{Energy input } (\frac{\text{MJ}}{\text{ha}})} \quad (1)$$

$$\text{Specific energy} = \frac{\text{Energy input } (\frac{\text{MJ}}{\text{ha}})}{\text{Product output } (\frac{\text{kg}}{\text{ha}})} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{Product output} \left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Energy input} \left(\frac{\text{MJ}}{\text{ha}}\right)} \quad (3)$$

Net energy = Energy output (MJ/ha) - Energy input (MJ/ha) (4)

Table 1. Energy equivalents in artichoke production.

Inputs	Unit	Energy Equivalent (MJ/unit)	References
Human labour	h	1.96	Mani et al. 2007; Karaağaç et al. 2011
Machinery	h	64.80	Singh,2002; Kizilaslan, 2009
Chemical fertilizers			
N	kg	60.60	Singh, 2002; Ekinci et al., 2020
P	kg	11.10	Singh, 2002; Ekinci et al., 2020
K	kg	6.70	Singh, 2002; Demircan et al., 2006
Chemicals	kg	101.20	Yaldız et al., 1993; Demircan et al., 2006
Diesel fuel	L	56.31	Singh 2002; Demircan et al., 2006
Irrigation water	m^3	0.63	Yaldız et al., 1993
Electricity	kWh	3.60	Ozkan et al., 2004
Plant	Unit	0.28	Canakci and Akinci, 2006
Output	kg	0.80	Ozkan et al., 2004

Table 2. GHG emissions coefficients in artichoke production.

Inputs	Unit	GHG Equivalent ($kgCO_{2eq}$/unit)	References
Machinery	MJ	0.071	Dyer, J.A. and Desjardins, 2006; Ekinci et al., 2020
N	kg	1.300	Lal, 2004;Ozalp et al., 2018
P	kg	0.200	Lal, 2004;Ozalp et al., 2018
K	kg	0.200	Taghavifar and Mardani 2015; Ozalp et al., 2018
Chemicals	kg	13.900	Biograce, 2015; Eren et al., 2019
Diesel fuel	L	2.760	Clark et al., 2016; Eren et al., 2019
Electricity	kWh	0.608	Khoshnevisan et al., 2013; Ozalp et al., 2018

Eren et al. (2019) concluded that the GHG emissions ($kgCO_{2eq}$/ha) that take place through the inputs usaged to grow 1 ha of fruit werecomputed as follows, as adapted by Hughes et al. (2011).

$$GHG_{ha} = \sum_{i=1}^{n} R(i)\, x\, EF(i) \quad (5)$$

Eren et al. (2019) stated as follows, ∑ where *R(i)* is the application rate of input *i* ($unit_{input}$/ha) and EF(*i*) is the GHG emission coefficient of input *i* ($kgCO_{2-eq}/unit_{input}$). However, an index is defined to evaluate the amount of emitted $kgCO_{2-eq}$ per kg yield. This is indicated in the following formula adapted Houshyar et al. (2015) and Khoshnevisan et al. (2014), where I_{GHG} is GHG ratio and Y is the yield as kg per ha.

$$I_{GHG} = \frac{GHG_{ha}}{Y} \quad (6)$$

The input energy can be categorized into D, IDE, RE and NRE forms(Mandal et al., 2002; Singh et al., 2003; Koctürk and Engindeniz, 2009). Energy balance, energy utilization efficiency computations, energy inputs types, GHG emissions of inputs related to artichokeproduction are presented in Tables 3 to 6, respectively.

RESULTS AND DISCUSSION

In this study, the average amount of artichoke produced per hectare was calculated as 6 825 kg for the 2022 production season. As indicated in Table 3, EI in artichoke production, 15 718.20 MJ/ha (48.80%) chemical fertilizers energy, 8 896.98 (27.62%) diesel fuel energy, 3 832.27 (11.90%) machinery energy, 1 958.40 (6.08%) electricity energy, 1 036.35 (3.22%) irrigation water energy, 329.55 (1.02%) human labour energy, 294 MJ/ha (0.91%) plant energy and 145.73 (0.45%) chemicals energy, respectively. Total EIwascalculated as 32 211.48 MJ/ha,OEwas calculated as 5 460 MJ/ha.

In previous studies, Celik et al. (2010) determined fertilizer energy had the biggest share by33.19% in carrot (conventional)production, Ozkan et al. (2004) determinedfertilizer energy had the biggest share by 29.42% in pepper production, Ozkan et al. (2011) determined fertilizer energy had the biggest share by 38.22% in tomato production,etc.Yield, EI, EO, EUE, SE, EP and NE in artichoke production were calculated as 6 825 kg/ha, 32 211.48 MJ/ha, 5 460 MJ/ha, 0.17, 4.72 MJ/kg, 0.21 kg/MJ and -26 751.48 MJ/ha, respectively (Table 4). In previous studies, Celik et al. (2010) determined (conventional carrot) EUE as 1.30, Ozkan et al. (2004) determined (pepper) EUE as 0.99, Ozkan et al. (2011) determined (tomato) EUE as 0.80.

Table 3. Energy usagein artichoke production.

Inputs	Unit	Energy Equivalent (MJ/unit)	Input Per Hectare (Unit/ha)	Energy Value (MJ/ha)	Ratio (%)
Human labour	h	1.96	168.14	329.55	1.02
Machinery	h	64.80	59.14	3832.27	11.90
Chemical fertilizers				15 718.20	48.80
N	kg	60.60	207	12544.20	38.94
P	kg	11.10	161	1787.10	5.55
K	kg	6.70	207	1386.90	4.31
Chemicals	kg	101.20	1.44	145.73	0.45
Diesel fuel	L	56.31	158	8896.98	27.62
Irrigation water	m^3	0.63	1645	1036.35	3.22
Electricity	kWh	3.60	544	1958.40	6.08
Plant	Number	0.28	1050	294	0.91
Total inputs	-	-	-	32 211.48	100
Output	Unit	Energy equivalent (MJ/unit)	Output per hectare (unit/ha)	Energy value (MJ/ha)	Ratio (%)
Product	kg	0.80	6 825	5 460	100
Total output	-	-	-	5 460	100

Table 4. EUE computations in artichoke production.

Calcutations	Unit	Values
Product	kg/ha	6 825
EI	MJ/ha	32 211.48
EO	MJ/ha	5 460
EUE	-	0.17
SE	MJ/kg	4.72
EP	kg/MJ	0.21
NE	MJ/ha	-26 751.48

As seen in Table 5, the total EIusaged in artichoke production could be classified as 37.94% (12 221.28 MJ/ha) DE, 62.06% (19 990.20 MJ/ha) IDE, 5.15% (1 659.90 MJ/ha) RE and 94.85% (30 551.58 MJ/ha) NRE. NRE was bigger than the ratio of RE in EI of artichoke production. Similarly, in previous studies on tomato (Ozkan et al., 2011), on onion (Ozbek et al., 2021), on pepper (Baran et al., 2022), among others, yielded results where the ratio of NRE was higher than the ratio of RE.

Table 5. EIin the forms of energy for artichoke production.

Energy Types	EI (MJ/Ha)	Ratio (%)
DE	12 221.28	37.94
IDE	19 990.20	62.06
Total	32 211.48	100
RE	1 659.90	5.15
NRE	30 551.58	94.85
Total	32 211.48	100

The results of GHG emissions of artichoke production are given in Table 6. The total GHG emission was calculated as 1 401.64 kgCO_{2eq}/ha (0.21 tonCO_{2eq}/ha). The results of the study given to the fact that the share of diesel in total GHG emissions had the highest value 31.11%, machinery 19.41, N (nitrogene) 19.20% held the second and third place. GHG ratio (per kg) wascalculated as 0.21. In previous studies on the subject, Ozbek et al. (2021) calculated the total GHG emission of artichoke production as 2.92 tonCO_{2eq}/ha, Baran et al. (2022)

calculated the total GHG emission of pepper production as 3.70 tonCO_{2eq}/ha, Baran et al. (2023) calculated the total GHG emission of garlic production as 8.63 tonCO_{2eq}/ha.

Table 6. GHGEmissions in artichoke production.

Inputs	Unit	GHG Coefficient (kgCO_{2eq}/unit)	Input usaged per area (unit/ha)	GHG Emissions (kgCO_{2eq}/ha)	Ratio (%)
Machinery	MJ	0.071	3 832.27	272.09	19.41
N	kg	1.300	207	269.10	19.20
P	kg	0.200	161	32.20	2.30
K	kg	0.200	207	41.40	2.95
Chemicals	kg	13.900	1.44	20.02	1.43
Diesel fuel	L	2.760	158	436.08	31.11
Electricity	kWh	0.608	544	330.75	23.60
Total	-	-	-	1401.64	100.00
GHG ration (per kg)	-	-	-	0.21	-

CONCLUSION

This current study aimed todeterminethe energy balance and GHG emissions in artichoke production. Study results are summarized below. EUE, SE, EP and NE in artichoke production werecalculated as 0.17, 4.72 MJ/kg, 0.21 kg/MJ and -26 751.48MJ/ha, respectively.

The highest energy input in artichoke production was determined to be chemical fertilizers energy by 48.80% (12 544.20 MJ/ha). The total energy inputs usage in artichoke production could be classified as 5.15% RE and 94.85% NRE. Usage of chemical fertilizers usage can be deemed and usage of farm fertilizers should be increased in order to riseEUE. The total GHG emissions werecalculated as 1 401.64 kgCO_{2eq}/ha (1.40 tonCO_{2eq}/ha) and GHG rate (per kg) as 0.21.

The findings of thestudyshowed that the ratio (NRE) of diesel fuel in total GHG emissions had the highest value by 31.11%.

According to Akbolat et al. (2014), artichoke production is not a profitable production activity in terms of EUE (0.17). Machinery-use related fuel expenses could be deemed by using RE terms (Yıldız, 2023).

The conscious use of fertilizers and chemical inputs will ensure more efficient use of energy. According to the results of the energy production function estimation, machinery and diesel use showed negative impacts on energy production. These results are likely related to the excessive use of inputs. Consequently,machinery and diesel inputs should be used more carefully to increase energy productivity and efficiency in the research area. The variability in input use among pomegranate producing farmers was relatively high, determining the need to improve individual farm management abilities (Ozalp et al., 2018).

By taking the above recommendations into consideration, EUE in artichoke production can be increased, production can be made economical in terms of energy use and GHG emissions can be reduced.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of Interests

The authors declared that there is no conflict

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the text, figures, and tables are original and that they have not been published before.

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