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Determination of Energy Utilization Efficiency and Greenhouse Gas Emission in Apple Production: Case of Isparta

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HIGHLIGHTS

- Energy use and greenhouse gas emissions in apple production were determined.
- Energy use efficiency indicators in apple production were determined.
- Greenhouse gas emission calculations were made in apple production.
- Energy utilization indicators were determined.

Abstract

The purpose of this study is to determine the energy utilization and greenhouse gas emission in apple production. Within the scope of the study, energy utilization efficiency indicators and greenhouse gas emission calculations were made in apple production. Total energy input in apple production has been calculated as 35338.97 MJ/ha, totals energy output as 60038.50 MJ/ha, energy utilization efficiency as 1.70, specific energy 1.39 MJ/kg, energy productivity as 0.72 kg/MJ and net energy value as 24699.53 MJ/ha. Energy inputs in apple production consisted of direct energy with 11958.05 MJ/ha (33.84%). indirect energy with 23380.92 MJ/ha (66.16%). renewable energy with 3486.55 MJ/ha (9.87%) and non-renewable with 31852.42 MJ/ha (90.13%). In apple production greenhouse gas emission arising from inputs has been calculated as 1718.90 kgCO_{2eq}/ha while greenhouse gas emission rate has been calculated as 0.07 kgCO_{2eq}/kg. In respect to energy utilization efficiency, it is possible to claim that apple production was efficient for the 2021 production season.

Keywords: Apple; Isparta; greenhouse gas emission; specific energy; energy utilization efficiency.

1. Introduction

Türkiye is one of the leading manufacturers of fruit. Türkiye accounted for 2.67% of the world fruit production, which was 865590060 tons in 2017. With this production share, Türkiye ranks fifth after China, India, Brazil and the USA (Anonymous 2020; Bayav and Karlı 2020). According to the 2021 data of the Turkish Statistical Institute in Türkiye, apple cultivation is carried out on an area of 1688105 decares and

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4493264 tons of apples (Golden, Starking, Amasya, Granny Smith, Other apples) have been produced. In Isparta province, 1130424 tons of apples were produced in an area of 222852 decares and Isparta province provides 25.16% of Türkiye's apple production. In Gönen district, where the study was conducted, apple production is carried out on an area of 9000 decares and 32345 tons of apples were produced (TÜİK 2024).

Apple is a fruit that is widely grown in the world due to its high yield per decare area, its variety, its resistance to cold climate conditions and its ability to be used in many different ways in the industry. In this context, it is the third most produced fruit after bananas and grapes in terms of production. The homeland of the apple, which is a very beneficial fruit containing many vitamins and minerals, is the South Caucasus, which includes Anatolia. While the number of apple varieties grown in the world exceeds 6500, this number is around 460 in Türkiye (Şenyurt et al. 2015; Karakaya and Kızıloğlu 2021).

Apple is an important nutritional element due to the mineral nutrients and vitamins it contains. 84% of fresh apple fruit consists of water. Dry matter includes carbohydrates, proteins, vitamins, pectins and mineral substances. Vitamins A and C found in apples and elements such as potassium, calcium, magnesium and sodium combine to form a number of salts. When the organic parts of these salts, that is, organic acids, are oxidized in the blood to provide energy, base components remain behind. Thus, apple has a positive effect on the acid-base balance in the blood. As a matter of fact, a study conducted in England found that eating an apple a day significantly reduces the risk of cancer (Anonymous 2008; Oğuz and Karaçayır 2009).

In terms of agricultural production diversity, Türkiye is among the few countries in the world. The products grown in each production area and the techniques used in their cultivation vary within certain limits. When assessing the carbon footprint resulting from crop production, it is important to obtain basin and product-based calculations with real field data and monitor them in line with the targets. The impact of the same product produced in different basins on environmental pollution is another topic that needs to be evaluated. In addition, determining the change in the carbon footprint of a single product produced in the same basin as a result of using different production techniques is also important in long-term monitoring and planning (Pan 2023).

In order to indicate how effectively energy is used, the total energy input consumed for agricultural production in a hectare area, including the main product and by-products taken as output, must be compared with its energy equivalent. The decrease in the total energy input for any agricultural production branch compared to the total product energy evaluated proportionally as output means that the level of mechanization increases. Most of the problems, from increasing production costs to disruption of natural balance and global warming, are related to ineffective energy utilization. For this reason, in the coming years, it is highly likely that it will be effectively used as an indicator of agricultural mechanization in all areas of agricultural production, without being limited to field and garden agriculture (Güceyü 2020). Related to the subject, energy balance and greenhouse gas emission studies have been conducted by Yılmaz et al. (2010), Rafiee et al. (2010), Çelen et al. (2017), Aydın et al. (2019), Ekinci et al. (2020) on apple, by Aydın et al. (2017) on pear, by Ozkan et al. (2004a) on citrus, by Saltuk et al. (2022) on orange, by Ozkan et al. (2005) on grape, Mardani and Taghavifar (2016) on grape, by Gökduman et al. (2022) on avocado, Baran (2022) on persimmon, by Şimşek et al. (2022) on grape, by Demir (2023) on watermelon etc.

2. Materials and Methods

Gönen is 24 km north of Isparta Province (Fig 1). It neighbours Atabey in the east, Keçiborlu in the west, and Uluborlu in the north. There is also the province of Burdur in the southwest. The district's surface area is 372 km² and its altitude is 1020 m. Mediterranean climate prevails in the district (Anonymous, 2024a). This current study has been conducted in Gönen district of Isparta of Türkiye during the 2021 production period. The studied area spans over a 0.75 ha area where apple is cultivated. Granny Smith (0.435 ha), Breaburn (0.1 ha) and Pink Lady (0.215 ha) apple varieties grafted on M9 rootstock were selected as material in this area. Randomized complete-block design with three replications has been employed in the study. The amount of fuel consumption has been calculated and full-tank method has been used to achieve this. The amount of fuel used per unit area has been determined to measure the trial area and the amount of fuel that has been placed inside the tank (Göktürk 1999; El Saleh 2000; Sonmete and Demir 2007). The work productivity for the area has been calculated and the productivity level has been deemed to be effective. Work productivity in (ha/h) has been achieved by calculating the effective working time (tef) (Güzel 1986; Özcan 1986; Sonmete 2006). Time durations have been measured in the study with the help of a chronometer (Sonmete 2006).

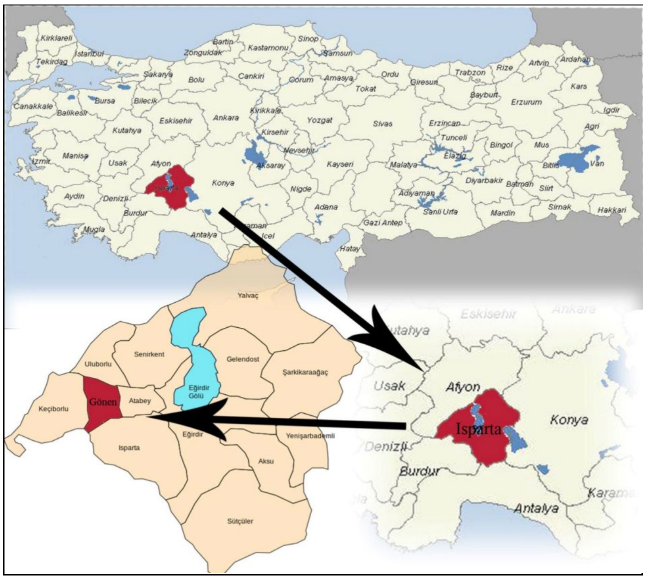

Figure 1. Gönen's location on the map (Anonymous, 2024b).

Human labour, tractor/machinery, chemical fertilisers, chemicals, diesel fuel, electricity and irrigation water have been used as energy inputs in apple production. The total of energy inputs has been calculated by multiplying the use of these inputs per hectare and their energy equivalents. Apple fruit has been deemed to be the energy output. Along with the energy balance sheet, energy utilization efficiency, specific energy, energy efficiency and net energy calculations have been made in apple production. Energy utilization efficiency, specific energy, energy efficiency and net energy calculations in apple production have been calculated by using the following formulas (Mandal et al. 2002; Mohammadi et al. 2008; Mohammadi et al. 2010).

$$\text{Energy utilization efficacy} = \frac{\text{Energy output}\ (\frac{\text{MJ}}{\text{ha}})}{\text{Energy input}\ (\frac{\text{MJ}}{\text{ha}})}, \quad (1)$$

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

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

$$\text{Net energy} = \text{Energy output (MJ/ha)} - \text{Energy input (MJ/ha)}, \quad (4)$$

The energy input types in apple cultivation have been calculated in terms of direct, indirect, renewable and non-renewable as per Yılmaz et al. (2010). Energy balance and GHG in apple production were created using the calculations given in Table 1-2. In calculating greenhouse gas emissions resulting from inputs in apple production, the following formula adapted from Hughes et al. (2011) by Karaağaç et al. (2019) was used.

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

GHG_{ha} : Greenhouse gas emission ($kgCO_{2eq}/ha$)
R(i) : Application amount of i input ($unit_{input}/ha$)
EF(i) : GHG emission equivalent of i input ($kgCO_{2eq}/unit_{input}$)

GHG rate is an index defined as the amount of GHG emissions per kg of yield. In calculating the GHG rate, the following formula, adapted by Karaağaç et al. (2019) from Houshyar et al. (2015) and Khoshnevisan et al. (2014) has been used.

$$I_{GHG} = \frac{GHG_{ha}}{Y} \tag{6}$$

I_{GHG} : GHG rate ($kgCO_{2eq}/kg$)
Y : Yield (kg/ha)

Table 1. Energy equivalents in apple production

Inputs	Unit	Energy Equivalent (MJ/unit)	References
Human labour	h	1.96	Mani et al. 2007; Karaağaç et al. 2011
Tractor	h	25.40	Singh, 2002; Akbolat et al., 2014
Rotary tiller	h	23.60	Singh, 2002; Akbolat et al., 2014
Sprayer	h	21.40	Singh, 2002; Akbolat et al., 2014
N	kg	60.60	Singh, 2002; Demircan et al., 2006
S	kg	1.12	Nagy, 1999; Mohammadi et al., 2010
Chemicals			
Fungicide	kg	99	Fluck, 1992; Ekinci et al., 2020
Insecticide	kg	363.60	Pimentel 1980; Mrini et al., 2002
Diesel fuel	L	56.31	Singh, 2002; Demircan et al., 2006
Irrigation water	m^3	0.63	Yaldız et al., 1993; Ozalp et al., 2018
Electricity	kWh	3.60	Ozkan et al., 2004b
Apple fruit (Output)	kg	2.37	Ekinci et al., 2020

Table 2. GHG emissions coefficients in apple 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
S	kg	0.370	Maraseni et al. 2010; Eren et al. 2019
Fungicide	kg	3.900	Graefe et al. 2013; Ozalp et al. 2018
Insecticide	kg	5.100	Lal 2004; Ozalp et al. 2018
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

3. Results

The energy balance of apple production is given in Table 3. A total of 25332.70 kg of apples has been produced. Inputs include human labour, tractor/machinery power, chemical fertilisers, chemicals, diesel fuel, electricity and irrigation water. Apple fruit was obtained as output. Pruning in apple production was not done in this production season.

Table 3. Energy balance of apple production

Inputs	Unit	Energy Equivalent (MJ/unit)	Input per unit area (ha)	Energy Equivalent (MJ/ha)	Rate (%)
Human labour	h	1.96	252.07	494.05	1.40
Tractor and machinery				2353.72	6.66
Tractor	h	25.40	49.40	1254.76	3.55
Rotary tiller	h	23.60	19	448.40	1.27
Sprayer	h	21.40	30.40	650.56	1.84
Chemical fertilisers				17376.40	49.02
N	kg	60.60	280	16968	48.01
S	kg	1.12	320	358.40	1.01
Chemicals				3700.80	10.47
Fungicide	kg	99	8	792	2.24
Insecticide	kg	363.60	8	2908.80	8.23
Diesel fuel	L	56.31	64.20	3615.10	10.23
Irrigation water	m^3	0.63	4750	2992.50	8.47
Electricity	kWh	3.60	1349	4856.40	13.74
Total				35338.97	100
Output					
Apple	kg	2.37	25332.70	60038.50	100

In apple production, the total energy input was calculated as 35338.97 MJ/ha and the energy output was calculated as 60038.50 MJ/ha. Energy inputs were, respectively, chemical fertilisers energy with 17376.40 MJ/ha (49.02%), electricity energy with 4856.40 MJ/ha (13.74%), chemicals energy with 3700.80 MJ/ha (10.47%), diesel fuel energy with 3615.10 MJ/ha (10.23%), irrigation water energy with 2992.50 MJ/ha (8.47%), tractor/machinery energy with 2353.72 MJ/ha (6.66%) and human labour energy with 494.05 MJ/ha (1.40%).

In other similar studies conducted on energy inputs, Yılmaz et al. (2010) reported the highest energy input in apple cultivation to be chemical fertiliser input with 17974.79 MJ/ha (44.97%), Çelen et al. (2017) reported the highest energy input in apple cultivation to be chemical fertiliser input with 17 078 MJ/ha (29.02%), Ozkan et al. (2004a) reported the highest energy input in lemon cultivation to be chemical fertiliser input with 31290.97 MJ/ha (49.68%), Baran (2022) reported the highest energy input in persimmon cultivation to be chemical fertiliser input with 20950.42 MJ/ha (44.04%) while Mohammadshirazi et al. (2012) reported the highest energy input in tangerine cultivation to be chemical fertiliser input with 32630.30 MJ/ha (2.40%). Energy input, energy output, energy utilization efficiency, specific energy, energy efficiency and net energy calculations in apple production are presented in Table 4.

Based on the energy utilization efficiency calculations in apple production, a total of 25332.70 kg of apple have been produced, total energy input has been calculated as 35338.97 MJ/ha, total energy output has been calculated as 60038.50 MJ/ha, energy utilization efficiency has been calculated as 1.70, specific energy has been calculated as 1.39 MJ/kg, energy productivity has been calculated as 0.72 kg/MJ and net energy value has been calculated as 24699.53 MJ/ha. In other studies related to the energy utilization efficiency in apple cultivation, Yılmaz et al. (2010) calculated the energy utilization efficiency in apple cultivation as 2.26, Rafiee et al. (2010) calculated the energy utilization efficiency in apple cultivation as 1.16, Çelen et al. (2017)

calculated the energy utilization efficiency in apple cultivation as 1.56, Aydın et al. (2019) calculated the energy utilization efficiency in apple cultivation as 1.36, and Ekinci et al. (2020) calculated the energy utilization efficiency in traditional apple cultivation as 3.31.

Table 4. Energy utilization efficiency indicators in apple production

Indicators	Unit	Values
Product (Apple)	kg	25332.70
Energy input	MJ/ha	35338.97
Energy output	MJ/ha	60038.50
Energy utilization efficiency	-	1.70
Specific energy	MJ/kg	1.39
Energy productivity	kg/MJ	0.72
Net energy	MJ/ha	24699.53

Energy inputs in apple production are grouped as direct, indirect, renewable and non-renewable energies (Table 5). In apple production, direct energy inputs have been calculated as 11958.05 MJ/ha (33.84%), indirect energy inputs have been calculated as 23380.92 MJ/ha (66.16%), renewable energy inputs have been calculated as 3486.55 MJ/ha (9.87%), and non-renewable energy inputs have been calculated as 31852.42 MJ/ha (90.13%).

Table 5. Energy input types in apple production

Energy types	Energy input (MJ/ha)	Rate (%)
Direct energy	11958.05	33.84
Indirect energy	23380.92	66.16
Total	35338.97	100
Renewable energy	3486.55	9.87
Non-renewable energy	31852.42	90.13
Total	35338.97	100

In other similar studies conducted, Yılmaz et al. (2010) calculated the renewable energy input in apple production as 8.38%, Rafiee et al. (2010) calculated the renewable energy input in apple production as 34.07%, Aydın et al. (2019) calculated the renewable energy input in non-good practise apple production as 8.53%, Ekinci et al. (2020) calculated the renewable energy input in traditional apple cultivation as 13.58%, and Baran (2022) calculated the renewable energy input in persimmon production as 21.79%. They all reported the non-renewable energy inputs to be higher than the renewable energy inputs.

In apple production, greenhouse gas emission consisted of electricity with 820.19 kgCO_2eq/ha (47.72%), of N with 364 kgCO_{2eq}/ha (21.18%), of diesel fuel with 177.19 kgCO_{2eq}/ha (10.31%), of tractor/machinery with 167.11 kgCO_{2eq}/ha (9.72%), of S with 118.40 kgCO_{2eq}/ha (6.89%), of insecticide with 40.80 kgCO_{2eq}/ha (2.37%) and of fungicide with 31.20 kgCO_{2eq}/ha (1.82%). Total greenhouse gas emission has been calculated as 1718,90 kgCO2-eq/ha and emission rate has been calculated as 0.07 kgCO_{2eq}/kg (Table 6). In other studies conducted, Ekinci et al. (2020) calculated the greenhouse gas emission rate in traditional apple cultivation as 0.04 kgCO_{2eq}/kg, Baran (2022) calculated the greenhouse gas emission rate in persimmon cultivation as 0.18 kgCO_{2eq}/kg and Saltuk et al. (2022) calculated the greenhouse gas emission rate in orange cultivation as 0.08 kgCO_{2eq}/kg.

Table 6. Greenhouse gas emission equivalents in apple production

Inputs	Unit	Greenhouse gas equivalent ($kgCO_{2-eq}$/unit)	Input per unit area (br)	Greenhouse gas emission ($kgCO_{2-eq}$/ha)	Rate (%)
Tractor, machinery	MJ	0.071	2353.72	167.11	9.72
N	kg	1.300	280	364	21.18
S	kg	0.370	320	118.40	6.89
Fungicide	kg	3.900	8	31.20	1.82
Insecticide	kg	5.100	8	40.80	2.37
Diesel fuel	L	2.760	64.20	177.19	10.31
Electricity	kWh	0.608	1349	820.19	47.72
Total				1718.90	100
GHG rate (per kg)				0.07	

4. Conclusions

In this study, conducted in Isparta province, the local energy utilization efficiency, specific energy, energy efficiency, net energy values, greenhouse gas emissions and greenhouse gas emission rate have been calculated in apple production.

The summarised conclusions of the study are presented below.

Total energy input in apple production was calculated as 35338.97 MJ/ha and energy output was calculated as 60038.50 MJ/ha.

In apple production, an average of 25332.70 kg of apples was produced per hectare. According to energy utilization efficiency calculations, energy utilization efficiency was calculated as 1.70, specific energy as 1.39 MJ/kg, energy productivity as 0.72 kg/MJ and net energy value as 24699.53 MJ/ha.

Chemical fertilisers rank first among energy inputs in apple production with 17376.40 MJ/ha (49.02%).

In apple production, energy inputs consisted of direct energy with 11958.05 MJ/ha (33.84%), indirect energy with 23380.92 MJ/ha (66.16%), renewable energy with 3486.55 MJ/ha (9.87%) and non-renewable energy with 31852.42 MJ/ha (90.13%). Non-renewable energy inputs in apple production have been found to be higher than renewable energy inputs.

Total greenhouse gas emission has been calculated as 1718.90 $kgCO_{2eq}$/ha and greenhouse gas emission rate has been calculated as 0.07 $kgCO_{2eq}$/kg.

In order to increase energy utilization efficiency and reduce greenhouse gas emissions, it is necessary to increase the use of renewable energy sources and increase the use of organic and farm fertilisers in production inputs instead of chemical fertilisers.

With respect to energy utilization efficiency (1.70), apple cultivation has been a profitable one based on the 2021 production season data.

In conclusion, despite the fact that several energy indicators have been taken into account in this study, in addition to others that are commonly being used in energy analysis research, a fundamental next step ought to be taken to achieve a correct cropping system design, to help at the policy level (Alluvione et al. 2011).

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