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ORIGINAL ARTICLE / ORIGINALBEITRAG

Energy Balance and Greenhouse Gas (GHG) Emissions of Organic Fig (*Ficus carica* L.) Production in Turkey

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Abstract

This study was conducted in an organic fig farm in the 2017 production season in Adıyaman, Tut, at the Southeast Anatolia in Turkey. According to the findings, the energy inputs of organic fig production were calculated respectively as 2217.57 MJ ha^{-1} (38.07%) human labour energy, 2025 MJ ha^{-1} (34.76%) farmyard manure energy, 858.73 MJ ha^{-1} (14.74%) diesel fuel energy, 545.29 MJ ha^{-1} (9.36%) machinery energy, 79.72 MJ ha^{-1} (1.37%) electricity energy, 49.56 MJ ha^{-1} (0.85%) transportation energy and 49.30 MJ ha^{-1} (0.85%) irrigation water energy. The energy yield of organic fig was calculated as 12,900 MJ ha^{-1}. The energy output-input ratio, specific energy, energy productivity, and net energy calculations were calculated as 2.21, 1.08 MJ kg^{-1}, 0.92 kg MJ^{-1}, and 7074.83 MJ ha^{-1}, respectively. Total input energy consumption in organic fig production was classified as 55.02% direct, 44.98% indirect, 73.67% renewable, and 26.33% non-renewable. Total GHG emission was calculated as 1109.02 kg$CO_{2\text{-eq}}$ha^{-1}. The most significant portion was human labor (71.41%). The second most significant value was farmyard manure usage (17.65%), and others were as follows: diesel fuel consumption (3.80%), machinery usage (3.49%), electricity consumption (2.38%), water consumption of irrigation (1.20%) and transportation (0.07%). Additionally, GHG ratio value was calculated as 0.21 kg$CO_{2\text{-eq}}$kg^{-1} in organic fig.

Keywords Energy balance · GHG emissions · GHG ratio · Organic fig · Specific energy · Fig · *Ficus carica* · Turkey

Energiebilanz und CO_2-Emissionen (THG) beim öklogischen Anbau von Feigen (*Ficus carica* L.) in der Türkei

Schlüsselwörter Energiebilanz · CO_2-Emmissionen · Treibhausgas · Ökologischer Feigenanbau · Spezifische Energie · Türkei · Feige · *Ficus carica*

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Introduction

Fig has a remarkable nutritional value due to being a rich deposit of carbohydrates. Figs contain essential amino acids as they are rich in vitamins and minerals A, B1, B2 and C (Sadhu 1990; Javanmard and Mahmoudi 2008). The fig tree (*Ficus carica* L.) is a unique ficus variety that is widespread in tropical and subtropical regions with edible fruits. Fig production is either located around the Mediterranean Sea or in the countries with a regional mediterranean climate like California (USA), Australia, or South America. Turkey is in the first place in the world in terms of fig production and exportation (Çobanoğlu 2010). The fresh fig production of Turkey is 305,450 tons in the 2016/2017 season while total production of the world is 1,050,459 tons (Anonymous 2018).

Current agricultural production heavily depends on non-renewable fossil fuels—consumption of fossil energy results in indirect emissions of CO_2 and other burnout gases. Also, there are other negative impacts on the environment like pollution, climate change, and high input prices. Searching for agricultural production methods with a higher energy productivity is a popular topic today as it was 20 years ago (Pimentel et al. 1973; Refsgaard et al. 1998). According to the Brundtland Commission, the total consumption of energy has to be dropped by 50% before 2035 (Refsgaard et al. 1998). Fossil resources are limited and hazardous to the environment. This leads researchers to evaluate the energy efficiency of different crops in different regions (Houshyar et al. 2015; Eren et al. 2019).

Energy usage in agricultural production is becoming more and more each day due to the intensity of modern practices, chemical inputs, pesticides, machinery, and electricity to ensure rapidly growing population's demands are met. However, more intense energy usage has caused some significant human health and environment problems such as greenhouse gas emissions. Proper and efficient usage of input has a crucial role in sustainable agricultural production (Yılmaz et al. 2005). A greenhouse gas (GHG) is a gas in the atmosphere that absorbs and spreads radiation within the thermal infrared range. The greenhouse gas (GHG) emissions of agriculture come from several sources such as machinery, diesel fuel, chemical fertilizers, biocides, and electricity. So, the rise in energy inputs can cause a rise in the greenhouse (GHG) emissions in agricultural action (Nabavi-Pelesaraei et al. 2016).

Different studies were done as energy balance of horticulture products. For example, studies were defined on the energy balance of fig (Çobanoğlu 2010), organic farming (Gündoğmuş and Bayramoğlu 2006), organic apricot (Gündoğmuş 2013), organic olive (Kaltsas et al. 2007), organic black carrot (Celik et al. 2010), organic grape (Baran et al. 2017a), organic mulberry (Gökdoğan et al. 2017), apricot (Gezer et al. 2003), lemon (Özkan et al. 2004a), avocado (Astier et al. 2014), almond (Beigi et al. 2016), pear (Aydın et al. 2017), peach & cherry (Aydın and Aktürk 2018) etc. Several studies on greenhouse gas emissions were had on horticulture crops such as olive (Rajaeifar et al. 2014), nectarine (Qasami-Kordkheili and Nabavi-Pelesaraei 2014), peach (Nikkhah et al. 2017), pomegranate (Özalp et al. 2018), apple (Taghavifar and Mardani 2015), watermelon (Nabavi-Pelesaraei et al. 2016), grape (Mardani and Taghavifar 2016), strawberry (Khoshnevisan et al. 2013) and different fruits (Eren et al. 2019). Although many experimental studies were defined on energy balance on agriculture, there was no study on the energy balance and greenhouse gas emissions (GHG) of organic fig production in Turkey. In this study, it has been aimed to define the energy balance and greenhouse gas emissions (GHG) of organic fig.

Materials and Method

Description of the Study Area

Southern part of the Adıyaman province has hot and dry during summer months and rainy and cold during winter months. Center of Adıyaman is located at 37° 45′ north latitude and 38° 16′ eastern longitude. Adıyaman's altitude from sea level is 672 m. The daily difference is between the highest, and the lowest temperature is about 10 °C (Anonymous 2016a). The general soil structure of Adıyaman is clayed-loamy (¾) (Anonymous 2016b). The study area is a 2-hectare organic fig farm, located at Adıyaman-Tut region. The data obtained for this study contains 2017 pro-

Fig. 1 Harvested organic figs

Table 1 Energy equivalents in agriculture production

Inputs	**Unit**	**Energy equivalent ($MJ\ unit^{-1}$)**	**References**
Human labor	h	1.96	Mani et al. (2007); Karaağaç et al. (2011)
Machinery	h	64.80	Singh (2002); Kızılaslan (2009)
Diesel fuel	l	56.31	Singh (2002); Demircan et al. (2006)
Farmyard manure	kg	0.30	Singh (2002)
Irrigation water	m^3	0.63	Yaldız et al. (1993); Ertekin et al. (2010)
Electricity	kWh	3.60	Özkan et al. (2004b)
Transportation	MJ $(ton\text{-}km)^{-1}$	9.22	Acaroğlu (2004)
Output	**Unit**	**Values ($MJ\ unit^{-1}$)**	**References**
Organic fig yield	kg	2.40	Strapatsa et al. (2006); Çobanoğlu (2010)

duction season. This study was carried out as a randomized complete block design with three replicates (3 recurrences). Human labor energy, machinery energy, diesel fuel energy, farmyard manure energy, irrigation water energy, electricity energy, and transportation energy were calculated as inputs. Organic fig yield was calculated as the output. Images of organic figs were given in Fig. 1.

The units shown in Tables 1 and 2 are the inputs of organic fig production. Previous energy balance and greenhouse gas emissions (GHG) studies were evaluated when defining the energy equivalent and greenhouse gas emissions (GHG) coefficients.

Energy balance values and related calculations are presented in Table 3. Energy balance indicators in organic fig production were shown in Table 4. Total fuel consumption of each parcel was calculated as $l\ ha^{-1}$. Full tank method was used to measure the amount of fuel used (Göktürk 1999; El Saleh 2000; Sonmete 2006). Labor yield of area ($ha\ h^{-1}$) was calculated by the total time in the trial area (Sonmete 2006; Güzel 1986; Özcan 1986). Chronometers were used to measure the time spent during agricultural operations (Sonmete 2006). In order to define the energy balance in organic fig production, Mohammadi et al. (2010) reported that energy use efficiency, energy productivity, specific energy, and net energy were calculated by using the following formulates (Mohammadi et al. 2008; Mandal et al. 2002):

$$\text{Energy efficiency} = \text{Energy output}(\text{MJ ha}^{-1}) / \text{Energy input}(\text{MJ ha}^{-1}) \quad (1)$$

$$\text{Specific energy} = \text{Energy input}(\text{MJ ha}^{-1}) / \text{Yield output}(\text{kg ha}^{-1}) \quad (2)$$

$$\text{Energy productivity} = \text{Yield output}(\text{kg ha}^{-1}) / \text{Energy input}(\text{MJ ha}^{-1}) \quad (3)$$

$$\text{Net energy} = \text{Energy output}(\text{MJ ha}^{-1}) - \text{Energy input}(\text{MJ ha}^{-1}) \quad (4)$$

Koçtürk and Engindeniz (2009) reported that the input energy is also classified into direct and indirect, and renewable and non-renewable forms. The indirect energy consists of pesticide and fertilizer, while direct energy includes human and animal labor, diesel, and electricity used during the production process. Non-renewable energy includes petrol, diesel, electricity, chemicals, fertilizers, machinery, while renewable energy consists of human and animal labor (Mandal et al. 2002; Singh et al. 2003). Energy inputs of organic fig production, in the form of direct and indirect, as well as renewable and non-renewable energy were given in Table 5.

Greenhouse gas (GHG) emissions of inputs in organic fig production were shown in Table 6. The greenhouse emissions (GHG) ($kgCO_{2\text{-}eq}ha^{-1}$) united with the inputs to grow-

Table 2 Greenhouse gas (*GHG*) emissions coefficients in organic fig production

Inputs	Unit	GHG coefficients ($kgCO_{2\text{-}eq}\ unit^{-1}$)	References
Human labor	h	0.700	Nguyen and Hermansen (2012)
Machinery	MJ	0.071	Pishgar-Komleh et al. (2012)
Diesel fuel	l	2.760	Clark et al. (2016)
Farmyard manure	kg	0.029	Houshyar et al. (2017)
Irrigation water	m^3	0.170	Lal (2004)
Electricity	kWh	1.190	Clark et al. (2016)
Transportation	ton-km	0.150	Meisterling et al. (2009)

Table 3 Energy balance in organic fig production

Inputs	Unit	Energy equivalent (MJ unit^{-1})	Input used per hectare (unit ha^{-1})	Energy value (MJ ha^{-1})	Ratio (%)
Human labor	–	–	1131.42	2217.57	38.07
Tillage	h	1.96	8.42	16.49	0.28
Fertilizer application	h	1.96	41.25	80.85	1.39
Pruning-collecting	h	1.96	38.75	75.95	1.30
Hoeing	h	1.96	149	292.04	5.01
Harvesting-class. Etc	h	1.96	894	1752.24	30.08
Machinery	h	64.80	8.42	545.29	9.36
Diesel fuel	l	56.31	15.25	858.73	14.74
Farmyard manure	kg	0.30	6750	2025	34.76
Irrigation water	m^3	0.63	78.25	49.30	0.85
Electricity[a]	kWh	3.60	22.15	79.72	1.37
Transportation	MJ (t-km)^1	9.22	5.38	49.56	0.85
Total inputs	–	–	–	5825.17	100
Output	**Unit**	**Energy equivalent (MJ unit^{-1})**	**Output per hectare (unit ha^{-1})**	**Energy value (MJ ha^{-1})**	**Ratio (%)**
Organic fig yield	kg	2.40	5375	12,900	100.00
Total output	–	–	–	12,900	100.00

[a]Pump electricity consumption (Mrini 1999, Mrini et al. 2002)

ing 1 ha of organic fig were calculated as following, adapted by (Hughes et al. 2011):

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

Table 4 Energy balance indicators in organic fig production

Indicators	Unit	Values
Organic fig yield	kg ha^{-1}	5375
Energy input	MJ ha^{-1}	5825.17
Energy output	MJ ha^{-1}	12900
Energy output-input ratio	–	2.21
Specific energy	MJ kg^{-1}	1.08
Energy productivity	kg MJ^{-1}	0.92
Net energy	MJ ha^{-1}	7074.83

Table 5 Energy inputs in the forms of energy for organic fig production

Organic fig production	Energy input (MJ ha^{-1})	Ratio (%)
Direct energy[a]	3205.32	55.02
Indirect energy[b]	2619.85	44.98
Total	5825.17	100.00
Renewable energy[c]	4291.87	73.67
Non-renewable energy[d]	1533.30	26.33
Total	5825.17	100.00

[a]Includes human labor, diesel, electricity and irrigation water
[b]Includes farmyard manure, machinery, and transportation
[c]Includes human labor, farmyard manure, and irrigation water
[d]Includes diesel, machinery, electricity, and transportation

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

$\sum$ Where $R(i)$ is the application rate of input, I (unit$_{input}$ha^{-1}), and EF (i) is the GHG emission coefficient of input i (kg$CO_{2\text{-eq}}$unit$_{input}^{-1}$). Table 2 is the GHG emissions coefficients of agricultural inputs. However, an index is determined to evaluate the amount of emitted kg $CO_{2\text{-eq}}$ per kg yield as following 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.

Results and Discussion

As a result of this study, fig produced per hectare in the 2017 season was 5375 kg. As shown in Table 3, energy inputs in organic fig production were as follows: 2217.57 MJ ha^{-1} (38.07%) human labour energy, 2025 MJ ha^{-1} (34.76%) farmyard manure energy, 858.73 MJ ha^{-1} (14.74%) diesel fuel energy, 545.29 MJ ha^{-1} (9.36%) machinery energy, 79.72 MJ ha^{-1} (1.37%) electricity energy, 49.56 MJ ha^{-1} (0.85%) transportation energy and 49.30 MJ ha^{-1} (0.85%) irrigation water energy. Production output organic fig yield was calculated as 12,900 MJ ha^{-1}. Human labor input was calculated as 1131.42 h ha^{-1}. Human labor energy and diesel fuel energy were used for tractor and farm operations. Farm operations were tillage, fertilizer application, pruning-collecting, hoeing, harvesting classification, or similar. As organic fertilizer, farmyard manure was performed 6750 kg ha^{-1}, and farmyard manure

Table 6 Greenhouse gas (*GHG*) emissions in organic fig production

Inputs	Unit	GHG coefficient (kg CO_{2eq} unit^{-1})	Input used per area (unit ha^{-1})	GHG emissions (kg CO_{2eq} ha^{-1})	Ratio (%)
Human labor	h	0.700	1131.42	791.99	71.41
Machinery	MJ	0.071	545.29	38.72	3.49
Diesel fuel	l	2.760	15.25	42.09	3.80
Farmyard manure	kg	0.029	6750.00	195.75	17.65
Water of Irrigation	m^3	0.170	78.25	13.30	1.20
Electricity	kWh	1.190	22.15	26.36	2.38
Transportation	ton-km	0.150	5.38	0.81	0.07
Total	–	–	–	1109.02	100.00
GHG ratio (per kg)	–	–	–	0.21	–

was the second input. Organic fig yield was produced as 5375 kg ha^{-1}.

Organic fig yield, energy input, energy output, energy output-input ratio, specific energy, energy productivity and net energy in organic fig production were calculated as 5375 kg ha^{-1}, 5825.17 MJ ha^{-1}, 12,900 MJ ha^{-1}, 2.21, 1.08 MJ kg^{-1}, 0.92 kg MJ^{-1} and 7074.83 MJ ha^{-1}, respectively (Table 4). Similarly, in previous studies related to organic agricultural production, Baran et al. (2017b) calculated the energy output-input ratio as 0.25 in organic strawberry, Celik et al. (2010) calculated the energy output-input ratio as 1.90 in organic black carrot, Gündoğmuş (2006) calculated the energy output-input ratio as 2.22 in organic apricot.

The distribution of inputs used for the production of organic fig, in accordance with direct, indirect, renewable, and non-renewable energy groups were given in Table 5. The consumed total energy input in organic fig production can be classified as 55.02% direct, 44.98% indirect, 73.67% renewable, and 26.33% non-renewable. Similarly, organic black carrot (Celik et al. 2010), organic apricot (Gündoğmuş 2006) and organic strawberry (Baran et al. 2017b) yielded results where the ratio of direct energy was higher than the ratio of indirect energy. In this study, the ratio of renewable energy (73.67%) was higher than the ratio of non-renewable (26.33%) energy because usage of farmyard manure was used instead of chemical fertilizers.

The results of greenhouse gas (GHG) emissions of organic fig production are tabulated in Table 6. The total GHG emissions were calculated as 1109.02 kg$CO_{2\text{-eq}}$ha^{-1}. The results of the study showed that the share of human labor in total GHG emissions was the highest (791.99 kg$CO_{2\text{-eq}}$ha^{-1}), farmyard manure (195.75 kg$CO_{2\text{-eq}}$ha^{-1}) and machinery (38.72 kg$CO_{2\text{-eq}}$ha^{-1}) held the second and third. GHG ratio (per kg) was determined as 0.21. In a similar study, Taghavifar and Mardani (2015) calculated the total GHG emissions of apple production as 1200 kg$CO_{2\text{-eq}}$ha^{-1}, Özalp et al. (2018) calculated the total GHG emissions of pomegranate production as 1730 kg$CO_{2\text{-eq}}$ha^{-1} and Mardani and Taghavifar (2016) calculated the total GHG emissions of grape production as 860 kg$CO_{2\text{-eq}}$ha^{-1}.

Conclusion

In this study, the energy balance of organic fig production was defined. According to the results, organic fig production is a profitable activity (2.21) in terms of energy balance in 2017 production season. Organic fig production consumed a total of 5825.17 MJ ha^{-1} energy; the highest share is human labor energy (38.07%). The energy input of farmyard manure comes second (34.76%) and diesel fuel energy third (14.74%) in total inputs. Organic fig yield, energy input, energy output, energy output-input ratio, specific energy, energy productivity and net energy in organic fig production were calculated as 5375 kg ha^{-1}, 5825.17 MJ ha^{-1}, 12,900 MJ ha^{-1}, 2.21, 1.08 MJ kg^{-1}, 0.92 kg MJ^{-1} and 7074.83 MJ ha^{-1}, respectively. The consumed total energy input in organic fig production was classified as 55.02% direct, 44.98% indirect, 73.67% renewable, and 26.33% non-renewable. The total greenhouse gas (GHG) emissions were determined as 1109.02 kg$CO_{2\text{-eq}}$ha^{-1} and 0.21 of GHG ratio (per kg). The results of the study showed that the share of human labor in total GHG emissions was the highest (791.99 kg$CO_{2\text{-eq}}$ha^{-1}), farmyard manure (195.75 kg$CO_{2\text{-eq}}$ha^{-1}) and diesel fuel (42.09 kg$CO_{2\text{-eq}}$ha^{-1}) held the second and third. Energy balance and GHG emissions were increased because the usage of farmyard manure was used instead of chemical fertilizers. Celen (2016) reported that "reducing the usage of nitrogen by lowering erosion, leakage, and evaporation, using more bio-nitrogen, using farmyard manure and other bio-fuels, implementing waste and left-over management in harvest residues and having minimum soil processing are compulsory".

Conflict of interest H.I. Oğuz, M.F. Baran, O. Gökdoğan, Ö. Eren and M. Solak declare that they have no competing interests.

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