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Determination of Energy Efficiency in Almond Production According to Variety: A Case Study in Turkey

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Abstract
This study aimed to identify the energy input–output ratios for the 'Ferragnes,' 'Ferraduel,' and 'Lauranne' almond varieties and to perform an economic analysis. The study used data from an almond orchard established on 17.2 ha in Adıyaman province of Turkey from 2014 to 2021. The results revealed that 35,706.0 MJ ha^{-1} were used during the establishment period, and 57,663.4 MJ ha^{-1} were used during the mature planting period. The energy outputs of 'Ferragnes,' 'Ferraduel,' and 'Lauranne' varieties were 13,651.9, 12,641.1, and 14,801.6 MJ ha^{-1} in the establishment period and 45,073.8, 40,566.7, and 70,559.1 MJ ha^{-1} in the mature planting period, respectively. Although the energy efficiency varied according to the period and varieties, it was calculated to be between 0.38 and 1.22. The rate of renewable energy for the total consumed energy was 4.62% in the establishment period and 6.52% in the mature planting period. The results of the economic analysis showed that almond cultivation was profitable in all three varieties. Net profit was the highest in the 'Lauranne' variety, at $4785.55 ha^{-1}, followed by 'Ferragnes' at $2337.73 ha^{-1} and 'Ferraduel' at $1870.75 ha^{-1}. The benefit–cost ratios were 3.05, 2.00, and 1.80, respectively. In this study of a situation in which energy efficiency is low and profitability is high, it is concluded that policies that will maintain current profitability but increase energy efficiency should be put into practice.

Keywords Almond · Input–output energy · Economic analysis · Turkey · Productivity

Introduction

Rapid population growth has brought about concern about how this population would be fed. In particular, epidemics and global climate change have caused this concern to increase even more. On the other hand, economic development necessitates the efficient and effective use of natural resources. The lack of new areas for agriculture in the world intensifies the effort to get more productivity from the unit area.

The fruit sector is an important subsector within agriculture in terms of contributing to a balanced diet, supplying raw materials to the agriculture-based industry, and creating employment, national income, and exports. Turkey is one of the most important fruit-producing countries in the world. Bayav and Karlı (2020) reported that Turkey accounted for 2.67% of global fruit production and ranks fifth in the world.

The most important nuts in Turkey's climate zone are hazelnut, walnut, almond, pistachio, and chestnut. According to the data for 2021, approximately 1.4 million tons of nuts were produced in Turkey. With a production amount of 178,000 tons, almond is the third most-produced nut after hazelnut and walnut (TURKSTAT 2022a). The homeland of almonds lies in the mountainous regions of Central and Western Asia. From here, almond trees spread to China, India, Iran, Syria, and the Mediterranean countries (Küden 1998). Almond cultivation, which has an important place in the world's nut production, is becoming increasingly common in Turkey. Although it was limited to the Aegean, Mediterranean, and Eastern Anatolian regions at first, it has been expanding in recent years with the establishment of

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new orchards in other regions. The high adaptability to difficult conditions and the high demand in the market make almond cultivation attractive. In recent years, there has been an increase in new almond orchards, especially in the southeastern Anatolia region (Anonymous 2022a). Southeastern Anatolia provides approximately 33% of Turkey's almond production. Adıyaman, where the study was carried out, ranks first in almond production in Turkey.

The leading country in almond production is the United States, with more than half (57.3%) of world almond production, followed by Spain with 10.1%, Australia with 5.4%, Iran with 4.0%, and Turkey with 3.9% (FAOSTAT 2022).

Almonds (*Prunus dulcis*) are described by the U.S. Food and Drug Administration as an excellent source of vitamin E and manganese. They are also a good source of magnesium, copper, phosphorus, fiber, riboflavin, and protein. In addition, they have a high arginine content (Chen et al. 2006; Richardson et al. 2009; Barreca et al. 2020). Almonds can be used raw or roasted, whole or ground; they can be used in pastry and confectionery products and as flavoring agents in beverages and ice cream (Chen et al. 2006; Wijeratne et al. 2006).

Fossil energy is used in most agricultural activities. Many studies have stated that the use of fossil energy directly leads to adverse environmental effects because of CO_2 emissions (Menegaki and Tsagarakis 2015; Xing et al. 2019; Ali et al. 2021). Since agricultural production is dependent on energy, agricultural production increases to feed the growing population, increasing energy consumption. Nevertheless, with the extra use of energy resources, some public health and environmental problems such as global warming, greenhouse gas emissions, pollution of water resources, and land degradation arise (Beigi et al. 2016). Moreover, the continuous increase in energy prices threatens the global agriculture sector. Therefore, supporting the agricultural sector is necessary for the efficient use of energy resources (Mohammadi et al. 2010). Kendall et al. (2015) reported that fossil energy inputs are also used in almond cultivation.

According to the greenhouse gas emission statistics published by TURKSTAT, Turkey's amount of greenhouse gas emissions reached 506.1 million tons of CO_2 equivalent in 2019. The highest total greenhouse gas emissions rate was energy-related emissions, at 72%. Energy-related emissions were followed by the agricultural sector's energy-related emissions at 13.4%, industrial processes and product use at 11.2%, and the waste sector at 3.4%. It was reported that agricultural sector emissions increased by 47.7% in 2019 compared with 1990 and reached 68 million tons of CO_2 equivalent (TURKSTAT 2022b).

Many studies have been carried out to determine energy efficiency in crop production. Energy efficiency has been determined in apricot (Esengün et al. 2007a; Gündüz 2016), pear (Aydın et al. 2017), peach and nectarine (Göktolga et al. 2006; Oğuz et al. (2019), pistachio (Külekçi and Aksoy 2013), canola (Unakıtan et al. 2010; Mousavi-Avval et al. 2011), tomato (Esengün et al. 2007b; Pahlavan et al. 2011), sugar beet (Asgharipour et al. 2012), wheat (Arvidsson 2010; Çiçek et al. 2011), soybean (Singh et al. 2008), and paddy (Nassiri and Singh 2009).

Two studies have been done on energy efficiency in almond cultivation. The first of these studies was carried out by Torki-Harchegani et al. (2015) and the second by Beigi et al. (2016) in Iran's Chaharmahal-Va-Bakhtiari province. Unfortunately, no study has been found to determine the energy use efficiency of almond cultivation in Turkey.

This study aimed to determine where savings could be made without affecting production or profitability, considering energy efficiency; savings on nonrenewable energy inputs such as pesticides, diesel, and fertilizer; and various solutions.

Material and Method

The study included data obtained from an almond orchard of 17.2 ha. The data used in the study were obtained from the almond orchard established in Adıyaman province, Besni district, between 2014 and 2021. The almond orchard was established on GF677 rootstock with 'Ferragnes,' 'Ferraduel', and 'Lauranne' varieties. The first 5 years from the establishment of the orchard (2014–2018) were considered the establishment period, and the next 3 years (2019–2021) were considered the mature planting period. The orchard was irrigated with a drip irrigation system. Tillage was carried out with a cultivator in February and November. Fertilizers were applied by drip irrigation and foliar in March, April, May, June, and September. Spraying was used in April, May, and June. Almonds were harvested in August and September. Adıyaman is located at the transition point of the Mediterranean and Continental climates. Although the southern parts of the province have a Mediterranean climate, winters are generally cold and rainy, and summers are hot and dry. Precipitation in the province takes place mostly in the winter and spring. The average annual temperature is about 17.4 °C, and the total precipitation is 716.2 mm (Anonymous 2022b).

Energy use efficiency is calculated by comparing the energy equivalents of inputs and outputs in farms. Information is obtained by calculating energy efficiency regarding how efficiently the input resources are used and how effectively these resources are transformed into output. In this context, the energy equivalent of each input and the energy output of the obtained product were calculated. Inputs in almond production are labor, machinery, diesel, chemical fertiliz-

Table 1 Energy equivalents in agricultural production for various inputs and outputs

Input (unit)	Energy equivalent (MJ unit^{-1})	Reference
Labor (h)	1.96	Yaldız et al. (1993)
Machinery (h)	62.70	Yaldız et al. (1993)
Diesel (l)	56.31	Singh et al. (2002)
Fertilizer (kg)		
Nitrogen (N)	66.14	Pervanchon et al. (2002)
Phosphorus (P_2O_5)	12.44	Beigi et al. (2016)
Potassium (K_2O)	11.15	Pishgar-Komleh et al. (2011)
Chemicals (kg)		
Insecticides	101.2	Yaldız et al. (1993)
Fungicides	216.0	Özkan et al. (2004)
Water (m^3)	0.63	Yaldız et al. (1993)
Electricity (kWh)	11.93	Singh et al. (2002)
Output (kg)		
Almond nut	24.08	Beigi et al. (2016)
Shell	19.38	Beigi et al. (2016)

ers, pesticides, irrigation water, and electricity. The output is based on almond yield (almond nut and shell). Energy values were computed using the energy equivalents listed in Table 1 to estimate the quantity of each input and output per hectare.

After determining the energy input and output, energy efficiency, energy productivity, specific energy, and net energy were calculated (Singh et al. 1997; Mandal et al. 2002). The mentioned energy rates were calculated separately for the establishment period (2014–2018) and the mature planting period (2019–2021), and the following equations were used:

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

$$Energy\,productivity = \frac{\text{Almond output}(kg\,ha^{-1})}{\text{Energy input}(MJ\,ha^{-1})} \quad (2)$$

$$Specific\,energy = \frac{\text{Energy input}(MJ\,ha^{-1})}{\text{Almond output}(kg\,ha^{-1})} \quad (3)$$

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

The input energy can be divided into four parts: direct energy, indirect energy, renewable energy, and nonrenewable energy. Direct energy includes labor, diesel, water, and electricity, while indirect energy includes fertilizers, pesticides, and machinery. Renewable energy sources are labor and water. Nonrenewable energy sources are diesel, electricity, fertilizers, pesticides, and machinery.

All cost elements were taken into account in the economic analysis. Production costs were divided into variable and fixed costs. The following equations were used in the calculation of economic indicators such as gross production value, gross return, net return, and benefit–cost ratio (Kıral et al. 1999):

$$Gross\,production\,value = \text{Yield}(kg\,ha^{-1})\,x\,\text{Price}\,of\ \text{almond}(\$kg^{-1}) \quad (5)$$

$$Gross\ return = \text{Gross production value}(\$ha^{-1}) - \text{Variable cost}(\$ha^{-1}) \quad (6)$$

$$Net\ return = \text{Gross production value}(\$ha^{-1}) - \text{Total production cost}(\$ha^{-1}) \quad (7)$$

$$Benefit\,to\,cost\ ratio = \frac{\text{Gross production value}(\$ha^{-1})}{\text{Total production cost}(\$ha^{-1})} \quad (8)$$

Results and Discussion

Input and output amounts used in almond production are presented in Table 2. Since the used input amounts were applied equally to the almond orchard, the input amounts were the same based on variety. However, the output varied according to the varieties. The 'Lauranne' variety provided the highest output in the establishment period and the ma-

Table 2 Input and output amounts in almond production (per hectare)

Input–output	Establishment period	Mature planting period
Labor (h)	704.2	1494.6
Machinery (h)	88.4	94.5
Diesel (l)	44.9	43.7
Fertilizer (kg)	64.0	275.6
Nitrogen (N)	15.3	89.1
Phosphorus (P_2O_5)	12.6	66.2
Potassium (K_2O)	36.1	120.3
Chemicals (kg)	17.0	30.1
Insecticides	15.8	25.9
Fungicides	1.2	4.2
Water (m^3)	429.4	1320.3
Electricity (kWh)	1890.6	2844.1
Output (kg)		
Output Ferragnes	653.7	2152.0
Almond nut (Ferragnes)	209.2	716.6
Shell (Ferragnes)	444.5	1435.4
Output Ferraduel	605.3	1936.8
Almond nut (Ferraduel)	193.7	645.0
Shell (Ferraduel)	411.6	1291.8
Output Lauranne	704.0	3373.3
Almond nut (Lauranne)	246.4	1103.1
Shell (Lauranne)	457.6	2270.2

Table 3 Equivalent energy amounts (MJ ha^{-1}) and percentages of inputs and outputs in almond production

Input–output	Establishment period	Establishment period (%)	Mature planting period	Mature planting period (%)
Labor	1380.2	3.9	2929.4	5.1
Machinery	5542.7	15.5	5925.2	10.3
Diesel	2528.3	7.1	2460.7	4.3
Fertilizer	1571.2	4.4	8057.9	14.0
Nitrogen	1011.9	2.8	5893.1	10.3
Phosphorus	156.7	0.5	823.5	1.4
Potassium	402.5	1.1	1341.3	2.3
Chemicals	1858.2	5.2	3528.3	6.1
Insecticides	1599.0	4.5	2621.1	4.5
Fungicides	259.2	0.7	907.2	1.6
Water	270.5	0.8	831.8	1.4
Electricity	22,554.9	63.2	33,930.1	58.8
Total input	35,706.0	100.0	57,663.4	100.0
Output				
Output Ferragnes				
Almond nut (Ferragnes)	5037.5	36.9	17,255.7	38.3
Shell (Ferragnes)	8614.4	63.1	27,818.1	61.7
Total output (Ferragnes)	13,651.9	100.0	45,073.8	100.0
Output Ferraduel				
Almond nut (Ferraduel)	4664.3	36.9	15,531.6	38.3
Shell (Ferraduel)	7976.8	63.1	25,035.1	61.7
Total output (Ferraduel)	12,641.1	100.0	40,566.7	100.0
Output Lauranne				
Almond nut (Lauranne)	5933.3	40.1	26,562.6	37.6
Shell (Lauranne)	8868.3	59.9	43,996.5	62.4
Total output (Lauranne)	14,801.6	100.0	70,559.1	100.0

ture planting period when evaluated according to the output. 'Ferragnes' and 'Ferraduel' varieties followed 'Lauranne.'

The energy values and ratios of the inputs and outputs used in almond production from the establishment of almond orchards based on varieties are presented in Table 3. The total energy consumption for almond production was 35706 MJ ha^{-1} for the establishment period and 57,663.4 MJ ha^{-1} for the mature planting period. With a share of 63.2% in the establishment period and 58.8% in the mature planting period, electricity accounted for the highest energy consumption among the inputs in almond production. Torki-Harchegani et al. (2015) determined that the share of electricity in total energy consumption varied between 48.02% and 58.45% according to the 6–10, 11–15, and 16–20 age groups in the study conducted on 'Safied,' 'Mamaei,' 'Shahrodi 12,' and 'Rabei' almond varieties in Iran. Beigi et al. (2016), on the other hand, reported that electricity had a share of 58.45% total energy consumption in 6–10-year-old almond orchards, 56.87% in 11–15-year-old almond orchards, and 54.04% in 16–20-year-old almond orchards in almond production in Iran. In addition, many studies have emphasized that electricity accounted for a high share of total energy consumption (Göktolga et al. 2006; Nassiri and Singh 2009; Pahlavan et al. 2011; Mousavi-Avval et al. 2011; Asgharipour et al. 2012).

Fertilizers, machinery, and pesticides followed electricity. Excluding diesel, all inputs involved a greater share of total energy consumption during the mature planting period than in the establishment period. Fertilizers constituted 4.4% of the total energy input during the establishment period and 14% during the mature planting period. Nitrogen had the highest share among chemical fertilizers. Beigi et al. (2016) reported that chemical fertilizers in almond production constituted 19.39%, 16.83%, and 16.76% of the total energy input in the 16–20, 11–15, and 6–10 age groups, respectively. Torki-Harchegani et al. (2015) also emphasized that the energy input of chemical fertilizers changed depending on the variety and age of almond production. Esengün et al. (2007a) calculated that the energy equivalent of chemical fertilizers in dried apricot production constituted 23.56% and 30.06%, respectively, in large (>3.1 ha) and small (0.1–3 ha) farms.

Irrigation water constituted the smallest share of energy input in almond production. The results of this study were compatible with those of studies of Beigi et al. (2016) and Torki-Harchegani et al. (2015). Beigi et al. (2016) deter-

Table 4 Energy input–output ratios in almond production

Item	Unit	Variety	Establishment period	Mature planting period
Energy input	MJ ha^{-1}	Ferragnes	35,706.0	57,663.4
		Ferraduel	35,706.0	57,663.4
		Lauranne	35,706.0	57,663.4
Energy output	MJ ha^{-1}	Ferragnes	13,651.9	45,073.8
		Ferraduel	12,641.1	40,566.7
		Lauranne	14,801.6	70,559.1
Energy efficiency	–	Ferragnes	0.38	0.78
		Ferraduel	0.35	0.70
		Lauranne	0.41	1.22
Energy productivity	kg MJ^{-1}	Ferragnes	0.018	0.037
		Ferraduel	0.017	0.034
		Lauranne	0.020	0.058
Specific energy	MJ kg^{-1}	Ferragnes	54.62	26.80
		Ferraduel	58.99	29.77
		Lauranne	50.72	17.09
Net energy	MJ ha^{-1}	Ferragnes	–22,054.1	–12,589.6
		Ferraduel	–23,064.9	–17,096.7
		Lauranne	–20,904.4	12,895.7

mined that the energy input related to irrigation water varied between 1.30% and 2.01% according to tree age, and Torki-Harchegani et al. (2015) determined that it was between 1.19% and 2.01% according to variety and age. Esengün et al. (2007a) reported that this rate was 1.19% on small farms and 1.90% on large farms in dried apricot cultivation.

Labor was the primary power source in almond cultivation. It provided energy input of 1380.2 MJ ha^{-1} (3.9%) in the establishment period and 2929.4 MJ ha^{-1} (5.1%) in the mature planting period. Beigi et al. (2016) determined that it varied between 1230.80 and 1692.76 MJ ha^{-1} according to tree age, while Torki-Harchegani et al. (2015) determined it to be between 2412 and 5586 MJ ha^{-1} according to variety and tree age. This value was found to be 1826.29 MJ ha^{-1} (6.11%) in nectarine cultivation (Oğuz et al. (2019). It has been reported that the energy input of labor was 2034.58 MJ ha^{-1} (7.10%) for small farms and 1179.73 MJ ha^{-1} (6.60%) for large farms in dried apricot cultivation (Esengün et al. 2007a).

Regarding total energy input, the machinery and diesel usage ratios were 15.5%–7.1% and 10.3%–4.3% in the establishment and mature planting periods, respectively. Beigi et al. (2016) reported that the ratio of machinery in energy input in almond cultivation varied between 3.19% and 3.66% depending on tree age, and they calculated the ratio of diesel to be between 4.10% and 4.76%. Torki-Harchegani et al. (2015) calculated the machinery rate in almond cultivation as 3.19%–3.97% depending on the variety and age, and 4.10%–5.22% for diesel. These rates were high in this study because of mechanization in cultivation resulting from technological developments in recent years.

In almond cultivation, total energy output during the establishment period was calculated as 13,651.9, 12,641.1, and 14,801.6 MJ ha^{-1} in 'Ferragnes,' 'Ferraduel,' and 'Lauranne' varieties, respectively and 45,073.8, 40,566.7, and 70,559.1 MJ ha^{-1} in the mature planting period.

The energy input–output ratios in almond cultivation are given in Table 4. The energy efficiency was 0.38–0.78, 0.35–070, and 0.41–1.22 for 'Ferragnes,' 'Ferraduel,' and 'Lauranne' varieties for the establishment and mature planting periods. The amount of energy received per unit of energy input is energy efficiency. In other words, for each unit of energy input spent on the 'Ferragnes' variety, 0.38 unit of energy output was obtained during the establishment period and 0.78 unit of energy output during the mature planting period. More output energy used was obtained during the establishment period than in the mature planting period only for the 'Lauranne' variety. Beigi et al. (2016) found this rate to be 0.62 for 6–10-year-old almond orchards, 1.12 for 11–15-year-old orchards, and 0.81 for 15–20-year-old orchards. Torki-Harchegani et al. (2015) reported that the lowest energy efficiency was 1.25 in the 6–10-year-old 'Safied' almond variety, and the highest was in the 16–20-year-old 'Rabei' almond variety, 3.29. It was reported that the energy efficiency was 1.54 in kiwi cultivation (Mohammadi et al. 2010), 25.75 in sugar beet (Erdal et al. 2007), 1.24 in dried apricot cultivation on small farms, 1.31 in in dried apricot cultivation on large farms (Esengün et al. 2007a), and 0.80 in tomato cultivation (Esengün et al. 2007b).

Table 5 Amounts and percentages of various types of total input energy used in almond production (MJ ha^{-1})

Type of energy	Establishment period		Mature planting period	
	Quantity (MJ ha^{-1})	%	Quantity (MJ ha^{-1})	%
Direct energy[a]	26,733.93	74.87	40,152.07	69.63
Indirect energy[b]	8972.04	25.13	17,511.38	30.37
Renewable energy[c]	1650.75	4.62	3761.21	6.52
Nonrenewable energy[d]	34,055.22	95.38	53,902.24	93.48
Total energy input	35,705.97	100.00	57,663.44	100.00

[a]Includes human labor, diesel, electricity, water for irrigation
[b]Includes fertilizers, chemicals, machinery
[c]Includes human labor, water for irrigation
[d]Includes diesel, electricity, chemicals, fertilizers, machinery

Energy productivity is an indicator of energy efficiency in production. A high measure indicates a high level of energy efficiency, and a low measure indicates a low level. According to the results, the energy efficiency was very low. The highest energy efficiency was calculated to be 0.058 kg MJ^{-1} in the 'Lauranne' variety during the mature planting period. The lowest energy efficiency was calculated to be 0.017 kg MJ^{-1} in the 'Ferraduel' variety during the establishment period. Mohammadi et al. (2010) reported that this ratio was 0.81 for kiwi cultivation in Iran. A study carried out in Turkey calculated the efficiency to be 0.50 and 0.44, respectively, in farms that had or did not have good agricultural practices in pear cultivation (Aydın et al. 2017).

The specific energy was also calculated, indicating the amount of energy (MJ) consumed to produce a product's unit amount (kg). The specific energy amounts for 'Ferragnes,' 'Ferraduel,' and 'Lauranne' were 54.62, 58.99, and 50.72 MJ kg^{-1}, respectively, for the establishment period and 26.80, 29.77, and 17.09 MJ kg^{-1} for the mature planting period. The results showed an energy input of 54.62 MJ in the 'Ferragnes' variety, 50.72 MJ in the 'Lauranne' variety, and 58.99 MJ in the 'Ferraduel' variety were used to produce 1 kg of almonds during the establishment period. The increase in yield naturally reduces the input used for unit production in the mature planting period. In the study carried out in Iran, the specific energy of almond production was calculated to be 110.31 MJ kg^{-1} for 6–10-year-old trees, 60.91 for 11–15-year-old trees, and 83.93 MJ kg^{-1} for 16–20-year-old trees (Beigi et al. 2016).

Another parameter that emphasizes energy efficiency is net energy. A positive net energy amount indicates that more energy is produced than the energy spent. In this study, net energy was negative in varieties except for the 'Lauranne' variety in the mature planting period. In other words, it was understood that it was inefficient in terms of energy consumption and that energy was lost throughout the production process. Beigi et al. (2016) found the net energy in almond cultivation to be –21,791.99, 7184.69, and –1158406 MJ ha^{-1} for trees aged 6–10 years, 11–15 years, and 16–20 years, respectively, in a study conducted in Iran. In another study on almonds in Iran, calculations were made for three age groups and four almond varieties. The results showed that the lowest net energy amount was 14164 MJ ha^{-1} in 6–10-year-old 'Safied' variety, and the highest net energy amount was 157612 MJ ha^{-1} in 16–20-year-old 'Rabei' variety (Torki-Harchegani et al. 2015). Aydın et al. (2017) determined that the net energy was 5953.36 MJ ha^{-1} on farms that had good agricultural practices and 1488.08 MJ ha^{-1} on farms that did not. In the study conducted on kiwifruit in Iran, it was reported to be 16,354.23 MJ ha^{-1} (Mohammadi et al. 2010).

Table 5 shows the distribution of almond production inputs by direct, indirect, renewable, and nonrenewable energy sources. The rate of used direct energy was higher than indirect energy in both the establishment and the mature planting periods; 74.87% of the total energy in the establishment period and 69.63% in the mature planting period were directly consumed. Another noteworthy situation shown in Table 5 was the low rate of renewable energy within the total amount of energy used. The rate of renewable energy used in almond production was calculated to be 4.62% and 6.52% during the establishment and mature planting periods, respectively. Beigi et al. (2016) in Iran determined that the total energy used in almond cultivation was 10.26% in 6–10-year-old trees, 11.84% in 11–15-year-old trees, and 12.01% in 16–20-year-old trees. In another study carried out in Iran, the amount of renewable energy in almond cultivation varied between 28.23% and 31.66%, depending on the variety and tree age (Torki-Harchegani et al. 2015). Esengün et al. (2007a) reported that the rate of renewable energy in dried apricot cultivation was 23.13% on small farms and 24.83% on large farms. In research on pears in Turkey, the rate of renewable energy was 8.42% on farms with good agricultural practices and 8.24% on farms that did not use such practices (Aydın et al. 2017).

Economic analysis indicators related to almond production are given in Table 6. The data used in the economic analysis of almond production were calculated based on the average for 2019, 2020, and 2021. Since the costs did not

Table 6 Economic analysis of almond production

Cost and return components	Unit	'Ferragnes'	'Ferraduel'	'Lauranne'
Yield	kg ha^{-1}	2152.00	1936.80	3373.30
Sale price	\$ kg^{-1}	2.17	2.17	2.11
Gross production value	\$ ha^{-1}	4669.84	4202.86	7117.66
Variable production cost	\$ ha^{-1}	1825.94	1825.94	1825.94
Fixed production cost	\$ ha^{-1}	506.17	506.17	506.17
Total production cost	\$ ha^{-1}	2332.11	2332.11	2332.11
Total production cost	\$ kg^{-1}	1.08	1.20	0.69
Gross return	\$ ha^{-1}	2843.90	2376.92	5291.72
Net return	\$ ha^{-1}	2337.73	1870.75	4785.55
Benefit to cost ratio	–	2.00	1.80	3.05

vary according to the varieties, the costs for all three varieties were equal. The yield and sale price created the difference between the varieties in terms of economic analysis. While the sale price of 'Ferragnes' and 'Ferraduel' varieties was $2.17 per kilogram, 'Lauranne''s sale price was $2.11. Although the highest yield (3373.30 kg ha^{-1}) was obtained from the 'Lauranne' variety, the lowest (1936.80 kg ha^{-1}) was obtained from the 'Ferraduel' variety. While 78.30% of the total costs were variable costs, 21.70% were fixed costs. In the study carried out in Iran, fixed and variable cost rates were close to each other (Beigi et al. 2016). The benefit to cost ratio was calculated to be 3.05 in 'Lauranne,' 2.00 in 'Ferragnes,' and 1.80 in 'Ferraduel'. Beigi et al. (2016) reported that the benefit to cost ratio for almonds was 4.19 for 6–10-year-old trees, 6.30 for 11–15-year-old trees, and 4.76 for 16–20-year-old trees in their study in Iran. This study's benefit to cost ratios were lower than the rates reported by Beigi et al. (2016). Esengün et al. (2007a) calculated the benefit to cost ratio in dried apricot farms to be 1.11 for small farms and 1.19 for large farms, and Külekçi and Aksoy (2013) calculated it to be 1.52 for small and 1.69 for large pistachio farms.

In terms of gross production value, 'Lauranne' had the highest value at $7117.66, followed by 'Ferragnes' at $4669.84 and 'Ferraduel' at $4202.86. Gross returns were $2843.90, $2376.92, and $5291.72 for 'Ferragnes', 'Ferraduel,' and 'Lauranne,' respectively, while net returns were $2337.73, $1870.75, and $4785.55. Although the profitability based on variety is different, the results show that almond cultivation is a profitable investment.

Conclusions

This study determined the energy input–output level of almond production in Adıyaman province, where almond production has shown rapid development in recent years; in addition, economic analysis of almond cultivation was performed. A limitation of the study is that it was not a field study. However, it has advantages and disadvantages compared with the survey study. The most important advantage is that all accounting records had been kept since the establishment period, and it is an example of a modern almond orchard. It was difficult to obtain data from the establishment period with the survey. On the other hand, since the data obtained by the survey is considered the average of different applications, it can be considered to represent a region better.

In the establishment and mature planting periods, the energy consumption level for 'Ferragnes,' 'Ferraduel,' and 'Lauranne' almond varieties was evaluated. Except for the mature planting period of 'Lauranne,' the input energy was higher than the output energy in all three varieties, both in the establishment period and in the mature planting period. The most significant energy inputs were electricity, fertilizers, and machinery. In particular, electricity input constituted more than half of the total energy consumption. The rate of renewable energy in almond cultivation was very low in terms of total energy. In addition, energy efficiency was low. The limited areas for agriculture necessitate making the unit area more efficient. This situation increases the use of inputs. With increasing input use, energy consumption also increases. However, it should be questioned whether energy efficiency is low while energy consumption increases.

The results of the economic analysis show that almond cultivation is a profitable investment. However, this profitability causes inefficient use of energy. On the one hand, applications that increase profits should be encouraged; on the other hand, energy use efficiency should be ensured. Otherwise, it is not possible to talk about sustainability in agriculture. It is important to support organic agriculture and good agricultural practices, which some studies have determined to be highly energy efficient.

Conflict of interest A. Yılmaz and A. Bayav declare that they have no competing interests.

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