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A Review of Energy Use Efficiency in Apple Cultivation: Case Study of Kırklareli Province

Cihan DEMİR [1*]
[1] Kırklareli University, Vocational School of Technical Sciences, Department of Mechanical and Metal Technologies, Kırklareli
[*]Corresponding author: cihan.demir@klu.edu.tr

Abstract
This study aims to reveal the energy use efficiency (EUE) in apple cultivation. It has been conducted in Kırklareli province of Türkiye during the 2022-2023 production season. A number of calculations related to apple cultivation have been performed to determine the EUE and EUE indicators. According to these calculations in apple cultivation, total energy input (EI) has been found to be 27214.44 MJ ha^{-1}, total energy output has been found to be 53125.92 MJ ha^{-1}, EUE has been found to be 1.95, specific energy (SE) has been found to be 1.21 MJ kg^{-1}, energy productivity (EP) has been found to be 0.82 kg MJ^{-1} and net energy (NE) has been found to be 25911.49 MJ ha^{-1}. EI in apple cultivation consisted of direct energy (DE) with 12425.70 MJ ha^{-1} (45.66 %), indirect energy (IDE) with 14788.74 MJ ha^{-1} (54.34 %). renewable energy (RE) with 4040.47 MJ ha^{-1} (14.85 %) and non-renewable (NRE) with 23173.97 MJ ha^{-1} (85.15 %). In can be concluded that apple cultivation in the trial area has been an economic activity in the 2022-2023 production season.

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1. Introduction

Apple is known as the first fruit in human history and is a very beneficial fruit in terms of nutrition and health. It consists of 85% water and 12 % sugar. It also contains pectin, organic acids, soda, phosphorus, tannin, potassium and vitamins A, B1, B2, C, E (Anonymous, 2002; Kahya and Arın, 2019). TÜİK data for 2023 show that a total of 4493264 tons of apples were produced in Turkey. (Golden, Starking, Amasya, Granny Smith, other apples varieties). 2998 tons of apples were produced in 3386 decares of land in Kırklareli province and 561 tons of apples were produced in 662 decares of land in the central district (TÜİK, 2024).

Energy is a very important concept for the continuation of the life cycle and, as a result, for the development of civilizations. In addition, energy is necessary for economic activities of different sizes belonging to various production sectors that are decisive in national development processes. In agricultural enterprises, it is of great importance to have sufficiently detailed statistical data on the values and types of energy consumed according to the type of production and product groups in order to make appropriate management decisions that will increase profitability correctly and on time (Güceyü, 2020).

In order for companies to maintain their activities at the desired level of profitability, it is imperative that mechanisation practices, which have an impact on overall cultivation efficiency, are evaluated at the end of each cultivation season on the basis of scientific principles, with accurate recording and correct calculation methods. One of the main objectives of this study is to compare the intensity and efficiency of the use of mechanisation by companies producing similar crops, both in the same region and in different countries. (Erdoğan, 2009; Şehri, 2012; Bolat, 2024).

A number of EUE studies have been conducted on apple (Çelen et al., 2017; Ekinci et al., 2020), on grape (Uzun and Baran, 2022), on pistachio (Gökdoğan et al., 2022), pumpkin seed (Baran and Gökdoğan, 2020), on fig (Oğuz et al.,2022), on sweet cherry (Demircan et al., 2006), on cherry (Kizilaslan, 2009), on corn silage (Barut et al., 2011), on sunflower (Bayhan, 2016), guar and lupin (Gökdoğan et al, 2017), summery vetch (Baran 2016), on rice (Baran et al.,2015) , on chickpea (Baran and Gökdoğan, 2017), on pomegranate (Ozalp et al., 2018), on potato (Gökdoğan et al., 2018), on onion (Ozbek et al., 2021), on orange (Saltuk et al., 2022), on avocado (Gökduman et al., 2022), on persimmon (Baran, 2022), etc.

2. Materials and Methods

The province of Kırklareli is located in the Thrace region of the European continent of Turkey, between 41°44' - 42°00' north latitudes and 26°53' - 41°44' east longitudes, and has a land area of 6555 km2. It is surrounded by Bulgaria with a border length of 159 km to the north, the Black Sea with a coastline of 58 km to the east, Edirne to the west, Istanbul to the southeast, and Tekirdağ to the south. 48% of the land is mountainous, 35% is wavy, and 17% is plain (Anonymous, 2024a). According to measurements made between 1959-2023, the annual average temperature in Kırklareli Province is 13.3 ^{0}C, the average number of rainy days is 98.7, and the annual total rainfall is 583.7 mm (Anonymous, 2024b).

The current study has been conducted in the Merkez district of Kırklareli province of Türkiye during the 2022-2023 cultivation period. The trial took place within a 1 ha area. Randomized complete-block design has been conducted in three repetitions as part of the study. This has been done by calculating the amount of fuel consumption and using the full-tank method. Calculations have been made to find out the amount of fuel used per unit area and to measure the trial area and the amount of fuel that was placed inside the tank (Göktürk, 1999; El Saleh, 2000; Sonmete and Demir, 2007).

The area has been studies in terms of work productivity and the obtained value of productivity has been deemed to be sufficient. Calculation of work productivity in (ha/h) has been performed by computing the effective working time (t_{ef}) (Güzel, 1986; Özcan, 1986;

Sonmete, 2006). Durations of time have been measured by using a chronometer (Sonmete, 2006). Energy inputs in the apple cultivation activity were diesel fuel, electricity, human labour, machinery, chemical fertilizers, chemicals and irrigation water. Apple fruit has been obtained, which is deemed to be the energy output. Energy balance (EB), EUE, SE, EP and NE calculations have been performed in relation to apple cultivation. Such calculations have been performed by using the following formulas (Mandal et al., 2002; Mohammadi et al., 2008; Mohammadi et al., 2010).

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

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

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

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

The various types of EIs in apple cultivation have been calculated by Yılmaz et al. (2010) with respect to DE, IDE, RE and NRE. Energy balance in apple cultivation has been calculated using the figures given in Table 1.

Table 1. Energy equivalents in apple cultivation

Inputs	Unit	Energy Equivalent (MJ unit^{-1})	References
Human labour	h	1.96	Mani et al. 2007; Karaağaç et al. 2011
Machinery	h	64.80	Singh, 2002; Kizilaslan, 2009
N	kg	60.60	Singh, 2002; Demircan et al., 2006
P	kg	11.10	Singh, 2002; Demircan et al., 2006
K	kg	6.70	Singh, 2002; Demircan et al., 2006
S	kg	1.12	Nagy, 1999; Mohammadi et al., 2010
Mineral fertilizers	kg	6.50	Mudahar and Hignett, 1987a, 1987b; Ekinci et al., 2020
Chemicals			
Fungicide	kg	99	Fluck, 1992; Ekinci et al., 2020
Insecticide	kg	363.60	Pimentel, 1980; Mrini et al., 2002
Herbicide	kg	288	Kitani, 1999; Ekinci et al., 2020
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., 2004
Transportation	MJ/ton.km	4.50	Fluck and Baird 1982; Kitani 1999
Output (Apple product)	kg	2.37	Ekinci et al., 2020

3. Results

The relevant EB and EUE values in apple cultivation are given in Table 2. A total of 22416 kg of apples has been produced within the season. The total energy input has been calculated as 27214.44 MJ ha^{-1} and the energy output has been calculated as 53125.92 MJ ha^{-1} in apple cultivation. Different types of energy inputs have been revealed. Chemical fertilizers energy value was with 6082.50 MJ ha^{-1} (22.35

%), diesel fuel energy was 4364.03 MJ ha^{-1} (16.04 %), electricity energy was 4021.20 MJ/ha (14.78 %), machinery energy was 3450.60 MJ ha^{-1} (12.68 %), chemicals transportation energy was 2017.44 MJ ha^{-1} (7.41 %) and human labour energy was 1410.22 MJ ha^{-1} (5.18 %).

Table 2. Energy balance of apple cultivation

Inputs	Unit	Energy equivalent (MJ $unit^{-1}$)	Input per unit area (ha)	Energy equivalent (MJ ha^{-1})	Ratio (%)
Human labour	h	1.96	719.50	1410.22	5.18
Machinery	h	64.80	53.25	3450.60	12.68
Chemical fertilizers				6082.50	22.35
N	kg	60.60	75	4545	16.70
P	kg	11.10	75	832.60	3.06
K	kg	6.70	75	502.50	1.85
S	kg	1.12	175	196	0.72
Mineral fertilizers	kg	6.50	1	6.50	0.02
Chemicals				3238.20	11.90
Fungicide	kg	99	6	594	2.18
Insecticide	kg	363.60	4.50	1636.20	6.01
Herbicide	kg	288	3.50	1008	3.70
Diesel fuel	L	56.31	77.50	4364.03	16.04
Irrigation water	m^3	0.63	4175	2630.25	9.66
Electricity	kWh	3.60	1117	4021.20	14.78
Transportation*	MJ/ ton.km	4.50	448.32	2017.44	7.41
Total				27214.44	100
Output					
Apple	kg	2.37	22416	53125.92	100

*: 20 km

A number of other studies have been conducted in on the subject of energy inputs, where Çelen et al. (2017) determined the highest energy input in apple cultivation to be chemical fertilizers input by 17 078 MJ/ha (29.02 %); Ozalp et al. (2018) determined the highest energy input in pomegranate cultivation to be chemical fertilizers input by 18217.7 MJ ha^{-1} (35.80 %); Ekinci et al. (2020) determined the highest second energy input in conventional apple cultivation to be chemical fertiliser input with 6618.78 MJ ha^{-1} (22.67 %). EI, EO, EUE, SE, EP and NE calculations in apple cultivation are shown in Table 3.

Table 3. Energy use efficiency indicators in apple cultivation

Indicators	Unit	Values
Product	Kg ha^{-1}	22416
EI	MJ ha^{-1}	27214.44
EO	MJ ha^{-1}	53125.92
EUE	-	1.95
SE	MJ kg^{-1}	1.21
EP	Kg MJ^{-1}	0.82
NE	MJ ha^{-1}	25911.49

An analysis of the obtained EUE values and calculations in apple cultivation revealed that a total of 22416 kg of apple have been produced. The total EI has been calculated as 27214.44 MJ ha^{-1}, total EO has been calculated as 53125.92 MJ ha^{-1}, EUE has been calculated as 1.95, SE has been calculated as 1.21 MJ kg^{-1}, EP has been calculated as 0.82 kg MJ^{-1} and NE has been calculated as 25911.49 MJ ha^{-1}. A number of studies have been conducted on the subject of EUE in apple cultivation, where Fadavi et al. (2011) calculated the EUE as 0.44 in apple cultivation, Çelen et al. (2017) calculated the EUE as 1.56 in apple cultivation and Ekinci et al. (2020) calculated the EUE as 3.31 in conventional apple cultivation. Different types of energy inputs in apple cultivation have been categorized as DE, IDE, RE and NRE (Table 4). With regards to apple cultivation, DE inputs have been calculated as 12425.70 MJ ha^{-1} (45.66 %), IDE inputs have been calculated as 14788.74 MJ/ha (54.34 %), RE inputs have been calculated as 4040.47 MJ/ha (14.85 %) and NRE energy inputs have been calculated as 27214.44 MJ ha^{-1} (985.15 %). In other similar studies; Çelen et al. (2017) calculated the RE in apple cultivation, Ekinci et al. (2020) calculated the RE in conventional apple cultivation, and they obtained similar outcomes. The NRE has been determined to be higher than the RE in those studies.

Table 4. Energy input types in apple cultivation

Energy types	Energy input (MJ ha^{-1})	Ratio (%)
DE	12425.70	45.66
IDE	14788.74	54.34
Total	27214.44	100
RE	4040.47	14.85
NRE	23173.97	85.15
Total	27214.44	100

4. Conclusion

EUE, SE, EP and NE have been calculated in apple cultivation within the scope of this current study. The findings of the study have been summarized and presented below. Total EI and EO in apple cultivation have been calculated as 27214.44 MJ ha^{-1} and 53125.92 MJ ha^{-1}. In apple cultivation, an average of 22416 kg of apples are produced per hectare. EUE, SE, EP and NE have been calculated as 1.95, 1.21 MJ kg^{-1}, 0.82 kg MJ^{-1} and 25911.49 MJ ha^{-1}. Among the inputs in apple production, the rate of chemical fertiliser use is the highest by 22.35 %. With regards to the studied apple cultivation, EI consisted of DE with 12425.70 MJ ha^{-1} (45.60 %), IDE with 14788.74 MJ ha^{-1} (54.34 %), RE with 4040.47 MJ ha^{-1} (14.85 %) and NRE with 23173.97 MJ ha^{-1} (85.15 %). NRE inputs in apple cultivation have been found to be higher than RE. In case EUE is desired to be increased, it is necessary to decrease the amount of chemical fertilizers used. EUE (1.95), apple cultivation was a profitable one based on the 2022-2023 cultivation season. In conclusion, it is clear that decreased use of fertiliser, diesel fuel and electricity shall increase energy use efficiency.

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