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A Study on Determination of Energy Productivity and Greenhouse Gas Emissions in Wheat Production

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HIGHLIGHTS

- In this study, energy productivity and greenhouse gas emissions in wheat production were defined.
- The amount of direct and indirect energy use in wheat production and their shares in total energy consumption were defined.
- The energy use efficiency indicators and total greenhouse gas emissions were defined.
- In order to increase the ratio of renewable energy, non-renewable energy inputs should be reduced and the use of farm manure should be included in wheat production.

Abstract

In this study, energy use efficiency (EUE) and greenhouse gas emissions (GHG) in wheat production were defined, and the energy equivalents (EE) of the inputs in production per unit production area, EUE and GHG values of the product were computed. The data used in the study were obtained from 175 different wheat producing farms in 2021 by conducting face-to-face surveys according to the proportional sampling method. In the study, the amount of direct (DE) and indirect energy (IE) use in wheat production and their shares in total energy consumption were defined. According to the results of the study, total energy input (EI) in wheat production was computed as 19 024.21 MJ/ha and energy output (EO) as 80 585.40 MJ/ha. It was defined that the input with the highest energy consumption was fertilization with a value of 8748.38 MJ/ha. This was followed by seed energy input 4626.79 MJ/ha (24.32%), fuel energy 2697.25 MJ/ha (14.18%), irrigation energy 2362.50 MJ/ha (12.42%), machinery energy 309.52 MJ/ha (1.63%), chemicals energy 269.19 MJ/ha (1.41%), human labor energy 10.58 MJ/ha (0.06%). EUE, energy productivity (EP), specific energy (SE) and net energy (NE) yield values were 4.24, 0.29 kg/MJ, 3.47 MJ/kg and 61561.19 MJ/ha, respectively. Total GHG emission for wheat production was computed as 3784.60 $kgCO_{2-eq}$/ha. The highest share of total GHG emissions belonged to seed (59.41%). Seed was followed by irrigation (16.84%), nitrogen fertilizer use (14.60%), phosphate fertilizer use (3.99%), fuel use (3.49%), chemicals use (0.98%), machinery use (0.58%) and human labor (0.10%). In addition, the GHG ratio in wheat production was computed as 0.69 $kgCO_{2-eq}$/ha.

Keywords: Wheat; Energy use efficiency; GHG emission; GHG ratio; Diyarbakır

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1. Introduction

In order for agriculture to contribute to economic growth in a country, it needs to develop rapidly and continuously in accordance with the updated conditions. The desired development in agriculture depends not only on the total capital investments and agricultural supports to be made in the sector, but also on the protection and development of the resources that constitute agricultural production. Due to its strategic importance in all countries, agriculture is a sector that is supported by agricultural policies appropriate to the economic structures of the countries. The main objectives of these supports are to create an organized, highly competitive and sustainable agricultural sector that deals with the economic, social, environmental and international developments entirely for the efficient use of resources (Abay et al. 2005).

Agricultural mechanization is of great importance for increasing productivity in agriculture, reducing production costs, and solving the labor problem that arises due to the aging population. Approximately 35% of production inputs are mechanization inputs (20% mechanization + 15% fuel). Despite this high cost share, mechanization is considered less important than seeds, fertilizers, pesticides and diesel. However, considering that diesel is also a mechanization input, the importantance of the subject emerges (Günindi 2019).

Energy use, GHG emissions and their potential impacts on global climate change are among the most discussed subjects. In this context, more energy use causes significant environmental problems such as GHG emissions that affect human health, so more economical use of inputs becomes important in terms of sustainable agricultural production (Şanlı et al. 2017). In order to increase energy efficiency, it is necessary to either increase yield or reduce inputs. Fuel, chemical fertilizers, pesticides, machinery and tractor inputs, which have a large share in energy inputs, should be reduced (Çelen 2017).

According to researches and other indicators, the origin of wheat is the area between the Euphrates and Tigris rivers, which is called as the southeastern part of Turkey. It is a half-moon shaped geography starting from the southeast of Turkey (from the Taurus Mountains in the southeast), covering Syria, Lebanon and Jordan in the southwest, and the mountainous areas of Iraq and the Zagros Mountains of Iran in the southeast, and extending from these parts to the south (Anonymous 2021a).

World wheat production was around 766 million tons according to the International Grains Council (IGC) 2020-2021 season data. Approximately 66% of the total wheat was produced by the first 10 wheat producing countries. China, which ranked second in wheat production for many years, is the world's largest wheat producer with 136 million tons of wheat production in 2020/21 as a result of increased production and the decrease in production in the European Union. The European Union ranks second with 135.5 million tons, India ranks third with 107 million tons, and Turkey ranks 10th with 18.5 million tons of wheat production (Anonymous 2021b).

Diyarbakir province is one of the few provinces in Turkey in terms of cereals. It ranks third in Turkey in terms of wheat production. Diyarbakir province ranks fourth in Turkey in terms of wheat cultivation area (264000 ha, with 3.3% share), and ranks third in terms of production (845000 tons, with 4.2% share) (Pala et al. 2018).

Studies on EUE and GHG emissions were conducted and continue to be done in the world and in Turkey. Mohammadi et al. (2008), Tipi et al. (2009), Barut et al. (2011), Azarpour (2012), Alipour et al. (2012), Baran and Karaağaç (2014), Baran et al. (2015), Baran (2016), Bayhan (2016), Aydın et al. (2017), Baran et al. (2021), Çelen et al. (2017), Çıtıl et al. (2020), Aydın (2020), Demir et al. (2022), Gökduman et al. (2022), Demir and Gökdoğan (2023), Seydoşoğlu et al. (2023), Turan et al. (2023), Hacıoğlu et al. (2024) conducted studies regarding the subject.

It is important to compare the amount of energy used up for the cultivation of wheat, which is a very important crop in the world and in Turkey, with the energy content of the product obtained at the end of production in terms of EUE of the production system. For this purpose, the processes and inputs used in winter wheat production in Diyarbakır province were examined in detail. The EI used in wheat production were defined by the surveys conducted with the producers in 2021.

2. Materials and Methods

A harsh continental climate prevails in Diyarbakır. Summers are very hot, but winters are not as cold as in Eastern Anatolia Region. The main reason for this is that the Southeastern Taurus arc cuts the cold winds coming from the north. The average of the hottest month is 31 degrees and the average of the coldest month is 1.8 degrees. The average annual precipitation in the city is 496 millimeters and 2% of this precipitation falls in the summer months (Anonymous 2020).

The main material of the study consisted of primary data obtained from face-to-face surveys with wheat producers in Diyarbakır province and its districts. Since it is difficult to conduct a study in all enterprises in the region, the number of surveys was defined by using the proportional sampling method formula to define the number of producers among the farms with the characteristics that we can reach our purpose.

All calculations were performed with the data obtained from wheat producing farms. The data were collected by face-to-face survey technique and all of the surveys were conducted in the farms in Diyarbakır province and its districts. Besides, study, examinations and existing statistical data were also utilized. The collected data were first classified in an appropriate computer software and calculations were completed. Excel tabulation, graphing and analysis software were used to obtain the results from the database and the necessary formulas in the calculations. The following formula was used to define the number of farms to be studied.

In the formula, the P value can be obtained from previous researches or can be estimated intuitively. P = 0.5 should be taken to reach the maximum sample size. Values of P lower or higher than 0.5 reduce the sample size. Therefore, in cases where P is not known, P = 0.5 should be taken since studying with the maxi-mum sample volume will reduce the possible error (Miran 2003; Aksoy and Yavuz 2012). In the formula; n: Sample size, p: Ratio of the producers cultivating wheat (0.50 was taken to reach the maximum sample size), N: Number of the farms in the population, σ2 p: Variance of ratio, r : Deviation from the mean (%5), (According to 95% confidence interval and 0.05 margin of error).

$$n = \frac{(N*p*(1-p))}{(N-1)*\alpha 2p+p*(1-p)} \quad (1)$$

As a result of the calculations, the number of sample farms to be studied was found as 175. The obtained data were collected and grouped in databases to form the calculation parameters to be used in appropriate equations and calculations were performed.

In the study, the EE of the inputs and outputs given in Table 1 were used to calculate the EUE in production, and the GHG emission equivalents given in Table 2 were used to calculate the GHG emission ratio. Energy balance (EB) is given in Table 3, EUE indicators are given in Table 4, energy input types are given in Table 5, and total GHG emissions calculations are given in Table 6. EUE, SE, EP and NE were calculated using the formulas given below (Mandal et al. 2002; Mohammadi et al. 2008; Mohammadi et al. 2010).

$$\text{Energy use efficiency} = \frac{\text{Energy output } (\frac{MJ}{ha})}{\text{Energy input } (\frac{MJ}{ha})} \quad (2)$$

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

$$\text{Energy productivity} = \frac{\text{Product output } (\frac{kg}{ha})}{\text{Energy input } (\frac{MJ}{ha})} \quad (4)$$

Net energy = Energy output (MJ/ha) - Energy input (MJ/ha) (5)

The following equation was used to define the GHG emission (Hughes et al. 2011).

$$GHG_{ha} = \sum_{i=1}^{n} R(i)\, x\, EF(i) \quad (6)$$

GHG_{ha}: GHG emission ($kgCO_{2-eq}$/ha), R(i): Amount of i input ($unit_{input}$/ha), EF(i): GHG emission equivalent of i input ($kgCO_{2-eq}$/unit input).

The GHG ratio is an index defined as the amount of GHG emissions per unit kg of yield. GHG ratio was computed using the equation below (Khoshnevisan et al., 2014; Houshyar et al., 2015).

$$I_{GHG} = \frac{GHG_{ha}}{Y} \quad (7)$$

I_{GHG}: GHG ratio ($kgCO_{2-eq}$/kg) and Y: Yield (kg/ha).

Energy inputs can be classified as direct, indirect, renewable (RE) and non-renewable (N-RE) energies (Mandal et al. 2002; Singh et al. 2003; Koctürk and Engindeniz 2009). Depending on the findings and efficiency indicators defined as a result of the study, solution suggestions were given for the improvement of the current production.

Table 1. EE of inputs and outputs in agricultural production

Inputs	Unit	EE (MJ/unit)	Sources
Human labour	h	1.96	Mani et al. 2007; Karaağaç et al. 2011
Machinery	h	64.80	Singh 2002; Kizilaslan 2009
Combine harvester	h	87.63	Hetz 1992; Çanakcı et al. 2005; Tipi et al. 2009
Chemical fertilizers			
Nitrogen	kg	60.60	Singh 2002; Demircan et al. 2006
Phosphorus	kg	11.10	Singh 2002; Demircan et al. 2006
Chemicals	kg	101.20	Yaldiz et al. 1993; Demircan et al. 2006
Diesel fuel	L	56.31	Singh 2002; Demircan et al. 2006
Irrigation water	m^3	0.63	Yaldiz et al. 1993; Ozalp et al. 2018
Seed	kg	15.07	Singh 2002; Çiçek et al. 2011
Output			
Yield	kg	14.07	Singh 2002; Çiçek et al. 2011

Table 2. GHG emissions equivalents of inputs in agricultural production

Inputs	Unit	GHG emission equivalents ($kgCO_{2-eq}$/unit)	Sources*
Human labour	h	0.700	Nguyen and Hermansen 2012
Machinery	MJ	0.071	Pishgar-Komleh et al. 2012
Nitrogen	kg	4.570	BioGrace-II 2015
Phosphorus	kg	1.180	BioGrace-II 2015
Chemicals	kg	13.900	BioGrace-II 2015
Diesel fuel	L	2.760	Clark et al. 2016
Irrigation water	m^3	0.170	Lal 2004
Seed	kg	7.630	Clark et al. 2016

*Eren et al. (2019)

3. Results and Discussion

3.1. Energy balance

The data collected from the surveyed farms were evaluated and the data used in the calculations were computed by using the equations given in the method section. As a result of the evaluation of the data, the amount of the inputs used in wheat production in Diyarbakır and the yield values are given in Table 3.

Table 3. EB in wheat production

Inputs	EI per hectare (unit/ha)	Energy value (MJ/ha)	Ratio (%)
Human labour	5.40	10.58	0.06
Machinery (Total)	4.47	309.52	1.63
Machinery	3.60	233.28	1.23
Combine harvester	0.87	76.24	0.40
Chemical fertilizers (Total)	248.86	8748.38	45.98
Nitrogen	120.93	7328.36	38.52
Phosphorus	127.93	1420.02	7.46
Chemicals	2.66	269.19	1.41
Diesel fuel	47.90	2697.25	14.18
Irrigation water	3750	2362.50	12.42
Seed	294.70	4626.79	24.32
Total	-	19 024.21	100
Output/Yield	5482	80 585.40	100

According to Table 3, 10.58 MJ/ha of human energy was consumed per unit area for 1 ha area in wheat production, and the ratio of this value to total energy input constituted the lowest input with 0.06%. Among all inputs, fertilizer energy input was computed as the highest with a rate of 45.98%, consuming 8748.38 MJ/ha. This was followed by seed energy input 4626.79 MJ/ha (24.32%), fuel energy 2697.25 MJ/ha (14.18%), irrigation energy 2362.50 MJ/ha (12.42%), chemical energy input 269.19 MJ/ha (1.41%), 309.52 MJ/ha energy was consumed for machinery energy and this value corresponded to 1.63% of total energy input.

When the energy shares in the EE of wheat inputs were ranked, fertilizer energy was the first, diesel energy second, seed energy was the third, irrigation energy was the fourth, machinery energy was the fifth, chemicals (pesticide) energy was the sixth, and human labor energy was the seventh. In the study area, the use of pesticides in wheat production was not intense. EUE indicators in wheat production are given in Table 4.

Table 4. EUE indicators in wheat production

Calculations	Unit	Values
Yield	kg/ha	5482
EI	MJ/ha	19 024.21
EO	MJ/ha	80 585.40
EUE	-	4.24
EP	kg/MJ	0.29
SE	MJ/kg	3.47
NE	MJ/ha	61 561.19

According to Table 4, the total EI value per unit wheat production area was computed as 19 024.21 MJ/ha. The total EO of wheat production was computed as 80 585.40 MJ/ha. The energy use efficiency value was found as 4.24. It EP productivity and NE values were computed as 0.29 kg/MJ and 61 561.19 MJ/ha, respectively.

In EUE studies on wheat, the energy use efficiency values were computed as 3.13 by Shahin et al. (2008) in Ardabil province of Iran, 3.09 by Tipi et al. (2009) in Marmara Region of Turkey, 3.09 by Karaağaç et al. (2011)

in Hacıali district of Adana province in Turkey, 1.76 by Kardoni et al. (2013) in Kuzistan province of Iran, 2.97 by Gökdoğan and Sevim (2016) in Turkey.

In this study, wheat yield per hectare was computed as 5482 kg and in other studies on wheat, the yield was computed as 6357 kg/ha by Shahin et al. (2008), 4346 kg/ha by Tipi et al. (2009), 2587.20 kg/ha by Karaağaç et al. (2011), 4285 kg/ha by Kardoni et al. (2013) and 5237.48 kg/ha by Gökdoğan and Sevim (2016).

In other studies on wheat, Shahin et al. (2008) computed EI as 38,356.39 MJ/ha and EO as 120 097.90 MJ/ha; Tipi et al. (2009) computed EI as 20,653.54 MJ/ha and EO as 63 886.20 MJ/ha; Karaağaç et al. (2011) computed EI as 16 553.94 MJ/ha and EO as 57 985.62 MJ/ha; Kardoni et al. (2013) computed EI as 35605 MJ/ha and EO as 62 989.50 MJ/ha; Gökdoğan and Sevim (2016) computed EI as 25 876.29 MJ/ha and EO as 76 990.96 MJ/ha.

With the net energy value, it is possible to compare the energy values of the farms with a rough approach. The NE yield value was computed as 61,561.19 MJ/ha. In other studies on wheat, net energy values were computed as 81 741.51 MJ/ha by Shahin et al. (2008), 43 232.66 MJ/ha by Tipi et al. (2009), 47 332.26 MJ/ha by Karaağaç et al. (2011), 27 384.50 MJ/ha by Kardoni et al. (2013) and 51 114.67 MJ/ha by Gökdoğan and Sevim (2016).

When DE and IE sources in wheat production were examined, DE sources were computed as 5070.33 MJ/ha and IE sources as 13 953.88 MJ/ha. When evaluated proportionally, DE sources were defined as 26.65% and IE sources were defined as 73.35% (Table 5). RE input was computed as 6999.87 MJ/ha and N-RE energy as 12 024.34 MJ/ha. When evaluated proportionally, RE sources were defined as 36.79% and N-RE sources were defined as 63.21%.

Table 5. Types of EI in wheat production

Energy types	EI (MJ/ha)	Ratio (%)
DE[a]	5070.33	26.65
IE[b]	13 953.88	73.35
Total	19 024.21	100
RE[c]	6999.87	36.79
N-RE[d]	12 024.34	63.21
Total	19 024.21	100

Similarly, in other studies on wheat, Shahin et al. (2008), Tipi et al. (2009), Karaağaç et al. (2011) Kardoni et al. (2013), Gökdoğan and Sevim (2016) defined that DE was more than IE and N-RE energy was more than RE in energy inputs.

3.1. Greenhouse Gas Emissions

Calculations of GHG emissions of wheat production are given in Table 6. According to Table 6, total GHG emissions were computed as 3784.60 $kgCO_{2-eq}$/ha. The highest share in total GHG emissions inputs was seed inputs with a share of 59.41%. This was followed by irrigation inputs (16.84%) and chemical fertilizer inputs (18.59%). The GHG ratio (per kg yield) was defined as 0.69 $kgCO_{2-eq}$/kg. In similar studies, Khoshnevisan et al. (2014) computed total GHG emission as 2711.58 $kgCO_{2-eq}$/ha, Nabavi Pelesaraei et al. (2016) computed GHG emission in kiwifruit production as 1310 $kgCO_{2-eq}$/ha, Mohammadi Barsari et al. (2016) computed GHG emission in watermelon production as 460.41 $kgCO_{2-eq}$/ha, Ozalp et al. (2018) computed GHG emission in pomegranate production as 1730 $kgCO_{2-eq}$/ha.

Table 6. Total GHG emissions in wheat production

Inputs	Unit	Amount per hectare (unit/ha)	Energy value (MJ/ha)	Ratio (%)
Human labour	h	5.40	3.78	0.10
Machinery	MJ	309.52	21.98	0.58
Nitrogen	kg	120.93	552.65	14.60
Phosphorus	kg	127.93	150.96	3.99
Chemicals	kg	2.66	36.97	0.98
Diesel fuel	L	47.90	132.20	3.49
Irrigation water	m^3	3750	637.50	16.84
Seed	kg	294.70	2248.56	59.41
Total	-	-	3784.60	100
GHG ratio (per kg)	-	-	0.69	-

4. Conclusions

As a result of the study, EUE and GHG in wheat production were defined and the EE of the inputs in production per unit production area, the EUE and GHG values of the obtained product were computed. In the study, the amount of direct and indirect energy use in wheat production and their shares in total energy consumption were defined.

According to the results of the study, the total energy consumption in wheat production was computed as 19,024.21 MJ/ha and the energy input as 80 585.40 MJ/ha. It was defined that the input with the highest energy consumption belonged to fertilization with a value of 8748.38 MJ/ha. This was followed by seed energy input 4626.79 MJ/ha (24.32%), fuel energy 2697.25 MJ/ha (14.18%), irrigation energy 2362.50 MJ/ha (12.42%), chemical energy 269.19 MJ/ha (1.41%), machinery energy 309.52 MJ/ha (1.63%), human energy 10.58 MJ/ha (0.06%), respectively.

The EUE, EP, SE and NE values of wheat production were defined as 4.24, 0.29 kg/MJ, 3.47 MJ/kg and 61 561.19 MJ/ha, respectively. Total GHG emission for wheat production was computed as 3784.60 $kgCO_{2-eq}$/ha. The highest share in total GHG emissions belonged to seeds (59.41%). Seed was followed by irrigation (16.84%), nitrogen fertilizer use (14.60%), phosphate fertilizer use (3.99%), fuel use (3.49%), chemical pesticide use (0.98%), machinery use (0.58%), and human labor (0.10%), respectively. In addition, the GHG ratio in wheat production was computed as 0.69 $kgCO_{2-eq}$/ha.

The highest energy consumption in fuel-oil input was observed in tillage. Besides, it was seen that fertilizer energy took the second highest place in energy consumption. Therefore, it is thought that different and alternative tillage methods and fertilization methods should be investigated to reduce fuel and fertilizer energy in wheat production.

The use and management of land, which is today's problem, is important for the sustainability of the system. In the early 21st century, greenhouse gases and CO_2 emissions arising from agricultural applications and food safety due to soil environmental degradation caused a rapid increase in the impact of greenhouse gases. There are several carbon emission intensive agricultural applications that stand out. These include ploughing, fertilization, pesticides and irrigation. Careful evaluation is required in order to increase the EUE or decrease the usage of these applications. The conversion of ploughing to non-tillage agriculture, integrated nitrogen management and pest control applications, the improvement of water use by the adaptation of drip irrigation and subsoil irrigation methods will enable to control carbon emissions. Management of water and soil resources, such as improving the control of carbon input from a unit area, increasing its efficiency and reducing losses, is an important strategy (Çelen 2016).

In order to increase the EUE in agriculture, technologies with high EP should be used for the mechanization infrastructure of the farms, tools / machinery with a capacity suitable for the power source should be used, and the necessary power optimization for the enterprise should be provided (Öztürk et al. 2015). In order to increase the ratio of RE, N-RE inputs should be reduced and the use of farm manure should be included in wheat production.

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