Analyses of energy use and greenhouse gas emissions (GHG) in watermelon production

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Abstract: The aim of this research is to conduct an energy use efficiency and greenhouse gas (GHG) emission analysis in watermelon production that took place in Kırklareli Province of Turkey during the 2021 production season. This research contains calculations of Energy use efficiency, specific energy, energy productivity and net energy, energy input types, GHG emissions and GHG ratio. Survey, observation and data calculations are related to the 2021 production season. The data used in the research were collected from 30 different (accessible) farms through face-to-face surveys with full count method. EI and EO were calculated as 15 698.99 MJ/hm^2 and 104 784.91 MJ/hm^2, respectively. In relation to production inputs, 24.29% of the energy inputs consisted of chemical fertilizers energy (3813.34 MJ/hm^2), 20.04% consisted of transportation energy (3146.19 MJ/hm^2), 10.63% consisted of diesel fuel energy (1668.52 MJ/hm^2), 7.44% consisted of human labour energy (1168.09 MJ/hm^2), 6.50% consisted of plant energy (1021.02 MJ/hm^2), 5.76% consisted of electricity energy (904.50 MJ/hm^2), 5.18% consisted of machinery energy (813.44 MJ/hm^2), 3.36% consisted of irrigation water energy (527.63 MJ/hm^2), 2.85% consisted of organic fertilizer energy (446.72 MJ/hm^2), 2.40% consisted of farmyard manure energy (376.62 MJ/hm^2) and 0.67% consisted of chemicals energy (105.67 MJ/hm^2). Energy use efficiency, specific energy, energy productivity and net energy were calculated as 6.67, 0.28 MJ/kg, 3.51 kg/MJ and 89 085.91 MJ/hm^2, respectively. The utilized total energy input in production was grouped as 27.19% direct energy, 72.81% indirect energy, 22.55% renewable energy and 77.45% non-renewable. Total GHG emissions and GHG ratio were determined as 492.82 kg CO_2-eq/hm^2, 0.01 kg CO_2-eq/kg, respectively.
Keywords: energy use, GHG analysis, GHG ratio, Turkey, watermelon
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1 Introduction

The concepts of energy consumption and greenhouse gas emissions are interrelated. There are ways to save energy in agricultural operations such as changing the volume and mix of produced commodities and reducing energy intensities, or in other words, the amount of energy used per unit of commodity. A combination of these yields a heterogeneous and complex set of strategies. These strategies have multi-aspects that are technological, economic, and cultural. Then there is also complexity, which is the outcome of strong interdependencies between different options and from cross-sectoral impacts. Environmental and other external effects are tried to be reduced through various means. There are a number of agricultural strategies that are being more popularly employed in recent decades to achieve this[1]. One of these strategies point to the importance of efficient energy consumption as a common practice. This is an inexpensive way to lower energy consumption and consequently greenhouse gas emissions. There are various institutions worldwide, both domestic and international, that provide consultancy on energy efficiency measures. When applied, such recommended measures can make significant contributions to reduce greenhouse gas emissions while reducing costs and providing potential net benefits[2,3]. The amount of global emission is continuously rising with a threat of many potential problems on global warming. As a result, governments are forced to take measures to contribute to the global efforts of reducing total emissions[3,4].

Watermelon (*Citrullus lanatus*), which is an important vegetable among summer vegetables and whose ripe fruit is edible in Turkey, is a species belonging to the Cucurbitaceae family. It is very popular because of its cooling properties. Each 100 g of watermelon contains 26 calories, 0.62 g protein, 6.4 g carbohydrates and 0.2 g fat, 600 IU A, 0.05 mg B1, 0.06 mg B2, 0.02 mg B5, 8 mg vitamin C. Watermelon, which has a juicy and fibrous flesh structure, contains 100 mg K, 11.50 mg P, 4 mg Na, 11.50 mg Mg, 8 mg Ca and 0.22 mg Fe[5-7]. A total of 100 million t of watermelon is produced annually in 3 million hm^2 of land in the world[8]. According to FAO[9] data, the most grown fresh fruit in the world in 2020 is banana, while watermelon ranks second. In 2020, 89% of the world's watermelon production was met by China with a production figure of 60 million t. China is followed by Turkey with 3.4 million t of production. Global average in watermelon productivity is 33.3 t/hm^2. According to FAO data, Turkey only covers 3% of all watermelon cultivation lands in the world but in terms of productivity Turkey ranks second (40.7 t/hm^2) after China. Watermelon is usually consumed domestically. In the 2020/2021 period, a total of 90 thousand t of watermelon was exported to 48 countries, and the total value of this export is 22 million dollars[8]. According to the data of 2021, the cultivation area of watermelon in Turkey is 729 485 hm^2 and the production amount is 3 468 717 t. The watermelon cultivation area of Kırklareli, where the study was conducted, is 2851 hm^2 and the production amount is 12 757 t[10].

A number of studies have been conducted in the world and in Turkey on EUE and GHG emissions in agricultural production. These include watermelon[11-19], melon[14,20], carrot[21], potato[22,23],

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bean[24,25], pumpkin seed[26,27], cucumber[28], onion[29,30], corn[31,32], lettuce[33], pepper and eggplant[34], wolfberry[35], grape[36,37], apple[38,39], olive[40,41], quinoa[42], sunflower[43,44], guar[45], black cumin[46], wheat[47,48], cotton[49,50], lavender[51], field crops[52,53], poultry[54,55], pomegranate[56], pistachio[57,58] etc. The aim of this study is to calculate the EUE and GHG emissions in watermelon production for Kırklareli Province. By the same token, it is important to define the EUE and GHG emissions rate in terms of taking place in the literature.

2 Materials and methods

Kırklareli Province is situated in Thrace Region, on the European side of Turkey. It is between the 41°44'-42°00'N and 26°53'-41°44'E. It has an area of 6555 km^2[59]. This study has been conducted in 2022 for the 2021 production season in Kırklareli Province of Turkey. The survey, observation and research works have been performed in agricultural farms of the Central district of Kırklareli and they were determined on the basis of 2021 data provided by the Kırklareli Provincial Directorate of Agriculture and Forestry. The data provided by the study were attained from 30 farms (accessible) through face-to-face surveys and observations with full count method suggested by Karagölge and Peker[60]. Energy equivalents (EE) used in agriculture production are listed in Table 1. The total energy input was provided by multiplying the EE of the EI used per hectare and the total EO was provided by multiplying the output from the hectare with the EE. EUE, SE, EP and NE were determined by using the formulas in Equations (1)-(4)[24,61,62]. EI types were grouped as DE, IE, RE and N-EN[24,63,64]. GHG emissions coefficients of inputs in agricultural production are listed in Table 2. Energy balance (EB), EUE, EI types, GHG emissions and GHG ratio calculations are listed in Tables 3-6.

Table 1 Energy inputs-output in watermelon production and coefficients

Inputs and Output	Unit	EE/(MJ·unit^{-1})	Reference
Human labour	h	1.96	[69, 70]
Machinery	h	64.80	[71, 72]
Chemicals	kg	101.20	[73, 74]
Nitrogen	kg	60.60	[71, 56]
Phosphorous	kg	11.10	[24, 56]
Potassium	kg	6.70	[24, 56]
Micro elements	kg	120	[24, 80]
Electricity	kW·h	3.60	[34]
Diesel fuel	L	56.31	[71, 74]
Farmyard manure	kg	0.30	[75, 56]
Organic fertilizer	kg	10.50	[40, 76]
Irrigation water	m^3	0.63	[73, 56]
Transportation	t·km	4.50	[77, 78]
Plant		0.18	[11]
Output (Watermelon)	kg	1.90	[71, 11]

Table 2 GHG emissions in watermelon production and coefficients

Inputs	Unit	GHG coefficients (kgCO$_2$eq unit^{-1})	Reference
Machinery	MJ	0.071	[79, 80]
Chemicals	kg	13.900	[81, 82]
Nitrogen	kg	1.300	[83, 56]
Phosphorous	kg	0.200	[83, 56]
Potassium	kg	0.200	[84, 56]
Electricity	kW·h	0.608	[68, 80]
Diesel fuel	L	2.760	[79, 56]
Transportation	t·km	0.150	[85, 82]

Table 3 EB in watermelon production

Inputs	Unit	Energy equivalent/ (MJ·unit^{-1})	Input/ (unit·hm^{-2})	Energy value/(MJ·hm^{-2})	Rate/%
Human labour	h	1.96	595.97	1168.09	7.44
Machinery	h	64.80	12.55	813.34	5.18
Chemicals	kg	101.20	1.04	105.67	0.67
Nitrogen	kg	60.60	54.02	3273.61	20.85
Phosphorous	kg	11.10	39.57	439.23	2.80
Potassium	kg	6.70	15.00	100.50	0.64
Micro elements	kg	120	14.23	1707.35	10.88
Electricity	kW·h	3.60	251.25	904.50	5.76
Diesel fuel	L	56.31	29.63	1668.52	10.63
Farmyard manure	kg	0.30	1255.41	376.62	2.40
Organic fertilizer	kg	10.50	42.54	446.72	2.85
Irrigation water	m^3	0.63	837.50	527.63	3.36
Transportation*	t·km	4.50	699.15	3146.19	20.04
Plant		0.18	5672.34	1021.02	6.50
Total	-	-	-	15 698.99	100.00
Output	**Unit**	**Energy equivalent/ (MJ·unit^{-1})**	**Yield/ (br·hm^{-2})**	**Energy value/ (MJ·hm^{-2})**	**Rate/%**
Yield	kg	1.90	55149.55	104784.91	100.00
Total	-	-	-		100.00

*Average distance calculated (12.68 km), (55.14 t * 12.68 km).

Table 4 Calculations of EUE in watermelon production

Calculations	Unit	Values
Yield	kg/hm^2	55 149.95
EI	MJ/hm^2	15 698.99
EO	MJ/hm^2	104 784.91
EE	-	6.67
SE	MJ/kg	0.28
EP	kg/MJ	3.51
NE	MJ/hm^2	89 085.91

*EI: Energy input, EO: Energy output, EUE: Energy use efficiency, SE: Specific energy, EP: Energy productivity; NE: Net energy.

Table 5 Energy input types in watermelon production

Energy types	Energy input/(MJ·hm^{-2})	Rate/%
DE	4268.74	27.19
IE	11 430.25	72.81
Total	15 698.99	100.00
RE	3540.08	22.55
N-RE	12 158.92	77.45
Total	15 698.99	100.00

DE: Direct energy, IE: Indirect energy; RE: Renewable energy, N-RE: Non-renewable energy.

Table 6 GHG emissions in watermelon production

Inputs	Unit	GHG Coefficient/ (kg CO_{2eq}·unit^{-1})	Input/ (unit·hm^{-2})	GHG emissions/ (kg CO$_2$.eq·hm^{-2})	Ratio/%
Machinery	MJ	0.071	813.34	57.75	11.72
Chemicals	kg	13.900	1.04	14.51	2.95
Nitrogen	kg	1.300	54.02	70.23	14.25
Phosphorous	kg	0.200	39.57	7.91	1.61
Potassium	kg	0.200	15	3	0.61
Diesel fuel	L	2.760	29.63	81.78	16.59
Electricity	kWh	0.608	251.25	152.76	31
Transportation	ton.km	0.150	699.15	104.87	21.28
Total	-	-	-	492.82	100
GHG ratio (per kg)	-	-	-	0.01	-

$$EUE = \frac{\text{Energy output}\left(\text{MJ/hm}^2\right)}{\text{Energy input}\left(\text{MJ/hm}^2\right)} \quad (1)$$

$$SE = \frac{\text{Energy intput}\left(\text{MJ/hm}^2\right)}{\text{Product output}\left(\text{kg/hm}^2\right)} \quad (2)$$

$$EP = \frac{\text{Product output}\left(\text{kg/hm}^2\right)}{\text{Energy intput}\left(\text{MJ/hm}^2\right)} \quad (3)$$

$$NE = \text{Energy output}(\text{MJ/hm}^2) - \text{Energy input}(\text{MJ/hm}^2)(4) \quad (4)$$

GHG values were calculated by multiplying the inputs with their GHG equivalent emission values. The outcomes of the calculations are listed in Table 2. A GHG schedule was formed in production and the GHG ratio calculation was done. The following formula in Equation (5), adapted by Hughes et al.[65] was used to determine the GHG emission[66].

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

where, GHG_{ha} is GHG emissions in unit area, kg $CO_{2\text{-eq}}$/hm². $R(i)$ is implementation amount of input i, $\text{unit}_{\text{input}}$ /hm²; $EF(i)$ is GHG emissions equivalent of input i, kg $CO_{2\text{-eq}}/\text{unit}_{\text{input}}$.

The GHG ratio was the index defined as the amount of GHG emissions per kg yield. In the calculation of GHG ratio, the following formula was used, adapted by Houshyar et al.[67] and Khoshnevisan et al.[68], based on the recommendation of Karaağaç et al.[66]

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

where, I_{GHG} is GHG ratio, $\text{kgCO}_{2\text{-eq}}$/kg; Y is yield, kg/hm².

3 Results and discussion

Watermelon yielded an average of 55 149.95 kg/hm² during the 2020-2021 production season. The EB in 2020-2021 is given in Table 3. EI was calculated as 15 698.99 MJ/hm², EO was calculated as 104 784.91 MJ/hm². With regards to the inputs in 2020-2021, 24.29% of the energy inputs consisted of chemical fertilizers energy (3813.34 MJ/hm²), 20.04% consisted of transportation energy (3146.19 MJ/hm²), 10.63% consisted of diesel fuel energy (1668.52 MJ/hm²), 7.44% consisted of human labour energy (1168.09 MJ/hm²), 6.50% consisted of plant energy (1021.02 MJ/hm²), 5.76% consisted of electricity energy (904.50 MJ/hm²), 5.18% consisted of machinery energy (813.44 MJ/hm²), 3.36% consisted of irrigation water energy (527.63 MJ/hm²), 2.85% consisted of organic fertilizer energy (446.72 MJ/hm²), 2.40% consisted of farmyard manure energy (376.62 MJ/hm²) and 0.67% consisted of chemicals energy (105.67 MJ/hm²).

Machinery energy are energy spent for the construction of the machine and repair. The harvest is done by hand and the watermelons are loaded with human labor. Human labor energy is MJ per h. In this research, subsoiler, plough, disc harrow, cultivator, rotary tiller were used as soil tillage machinery. Weed control was done with a sprayer and a back pump. Chemical fertilizers were deemed to be the biggest energy input. Similar results were found in other studies on watermelon production. Namdari[12] calculated (I. group) the ratio of chemical fertilizers as 44.49% among the most used energy inputs, Moraditochaee et al.[13] calculated the ratio of chemical fertilizers as 44.26% in energy inputs, Baran and Gökdoğan[14] calculated the ratio of chemical fertilizers as 57.26% in energy inputs, Moradi et al.[15] calculated the ratio of chemical fertilizers as 35.22% in energy inputs and Mohammadi-Barsari et al.[16] calculated the ratio of chemical fertilizers as 75.20% in energy inputs.

In this research, energy use efficiency (EUE), specific energy (SE), energy productivity (EP) and net energy (NE) were calculated as 6.67, 0.28 MJ/kg, 3.51 kg/MJ and 89 085.91 MJ/hm², respectively (Table 4). In other studies related to watermelon production, Namdari[12] calculated EUE, SE, EP, NE as 1.26, 1.51 MJ/kg, 0.66 kg/MJ, 17 549.87 MJ/hm²; Moraditochaee et al.[13] calculated EUE, SE, EP, NE as 1.75, 1.09 MJ/kg, 0.92 kg/MJ, 22 733 MJ/hm²; Baran and Gökdoğan[14] calculated EUE, SE, EP, NE as 4.74, 0.40 MJ/kg, 2.49 kg/MJ, 41 980.34 MJ/hm²; Moradi et al.[15] calculated (reduced irrigation) EUE, SE, EP, NE as 4.08, 19.55 MJ/kg, 0.051 kg/MJ, 9638.7 MJ/hm² and Mohammadi-Barsari et al.[16] calculated EUE, SE, EP, NE as 2.19, 0.87 MJ/kg, 1.15 kg/MJ, 19 680.60 MJ/hm².

In this research, the utilized total energy input was calculated as 27.19% direct energy (DE), 72.81% indirect energy (IE), 22.55% renewable energy (RE) and 77.45% non-renewable energy (N-RE) (Table 5). Similarly in other studies on watermelon production Namdari[12], Baran and Gökdoğan[14] and Mohammadi-Barsari et al.[16] calculated DE ratio to be higher than IE. Similarly in other studies on watermelon production Namdari[12], Moraditochaee et al.[13], Baran and Gökdoğan[14], Moradi et al.[15] and Mohammadi-Barsari et al.[16] calculated N-RE energy ratio to be higher than RE.

The results of GHG emissions are listed in Table 6. Total GHG emissions were calculated as 492.82 kg CO_2eq/hm² for watermelon production. GHG emissions consisted of electricity 31%, transportation 21.28%, diesel fuel 16.59%, nitrogen 14.25%, machinery 11.72%, chemicals 2.95%, phosphorous 1.61% and potassium 0.61%, respectively. In previous studies, Mohammadi-Barsari et al.[16] calculated the total GHG emission of watermelon production as 460.41 kg CO_2eq/hm², Nabavi-Pelesaraei et al.[17] calculated the total GHG emission of watermelon production as 868.81 kg CO_2eq/hm² and Gökduman et al.[86] calculated the total GHG emission of avocado production as 6145.31 kg CO_2eq/hm².

4 Conclusions

This research has determined the EUE and GHG emission levels in watermelon production and the results along with suggestions are summarized below.

EI and EO are calculated as 15 698.99 MJ/hm² and 104 784.91 MJ/hm², respectively. The highest EI is chemical fertilizer input by a ratio of 24.29%. EUE, SE, EP and NE are calculated as 6.67, 0.28 MJ/kg, 3.51 kg/MJ and 89 085.91 MJ/hm², respectively. According to these results, watermelon production is a profitable production in terms of EUE in Kırklareli Province (6.67).

DE, IE, RE and N-RE energy inputs are calculated 27.19%, 72.81%, 22.55% and 77.45% of the total energy input, respectively. Total GHG emissions and GHG ratio are calculated as 492.82 kg CO_2eq/hm², 0.01 kg CO_2eq/kg, respectively.

One of the burning issues of modern times is to ensure efficient, sustainable and economic use of energy, which can be achieved through energy management. Having a sound energy management and thus ensuring efficient, sustainable and economic use of energy can contribute to reduce the negative impacts on environment, human health, sustainability and production costs, while also leading to higher productive efficiency[87].

RE ratio can be increased and this can be done by using greater amounts of farm manure and organic fertilizers. According to Nabavi-Pelesaraei[88] "High amount of non-renewable energy is serious danger for our environment. So, their use should be reduced by incorporating the biofuels instead of fossil fuels and using by-products as fertilizers."

Accurate and timely use of nitrogen through chemical fertilizer can be achieved by conducting simple soil tests. Use of nitrogen through chemical fertilizers can also be achieved by using biological alternatives such as bio-fertilizers, farmyard, and green manures. These alternatives may improve energy efficiency and mitigate GHG emissions in watermelon production[16].

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