Energy Use Efficiency and Greenhouse Gas Emission of Cotton Cultivation in Turkey

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Research

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Abstract

In this research, the energy use efficiency (EUE) and greenhouse gas emissions (GHG) of cotton cultivation in Beşiri region of Batman province in Turkey were determined. This research was conducted through face-to-face surveys with 64 farms selected by simple random sampling method in the 2018–2019 cultivation season. The energy input (EI) and energy output (EO) in cotton cultivation were calculated as 52,302.62 MJ/ha and 60,341.03 MJ/ha. Energy inputs consist of electricity energy with 19,948.86 MJ/ha(38.14%), chemical fertilizers energy with 14,163.83 MJ/ha (27.08%), diesel fuel energy with 13,218.49 (25.27%), irrigation water energy with 2563.79 MJ/ha(4.90%), machinery energy with 1071.14 MJ/ha(2.05%), chemicals energy with 797.96 MJ/ha (1.53%), seed energy with 291.46 MJ/ha (0.56%) and human labour energy with 247.09 MJ/ha(0.47%), respectively. Total energy inputs in cotton cultivation can be categorized as 68.79% direct, 31.21% indirect, 5.93% renewable and 94.07% non-renewable. EUE, specific energy (SE), energy productivity (EP) and net energy (NE) in cotton cultivation were calculated as 1.15, 10.23 MJ/kg, 0.10 kg /MJ and 8038.41 MJ/ ha, respectively. Total GHG was calculated as 3742.59 kgCO2-eq ha^{-1} for cotton cultivation with the greatest share taken by nitrogen (26.19%). Nitrogen was followed by electricity (24.73%), irrigation water (18.48%), diesel fuel (17.31%), seed (5.04%), chemicals (2.93%), phosphorous (2.74%), human labour (2.36%), potassium (0.19%) and machinery (0.03%), respectively. GHG ratio value was calculated as 0.73 kgCO2-eq kg^{-1} in cotton cultivation.

Introduction

The cotton plant has a widespread use and its use is often mandatory. It has great economic importance for the producing countries with the added value and employment opportunities it creates. Few countries in the world have ecology suitable for cotton farming. For this reason, approximately 80% of world production is carried out by a small number of countries, including Turkey (Anonym 2019). According to the predictions of the International Cotton Advisory Board (ICAC) for the 2021/22 season, world cotton cultivation areas are 33.2 million ha, yield is 775 kg/ha, and cotton production is 25.7 million tons. It is estimated that the USA will have the largest share in the increase in production, increasing it to 3.96 million tons with an increase of 780 thousand tons compared to the previous season (ICAC 2021; Anonym 2022a). According to ICAC data, cotton consumption in Turkey in 2018/19 season is estimated to increase by 10% compared to the previous year and reach 1.6 million tons. With a production of this scale, Turkey will rank 5th in world cotton consumption. Almost all of the cotton cultivation in Turkey is carried out in the Aegean Region, Southeastern Anatolia Region, Çukurova and Antalya regions (Anonym 2019). Batman / Beşiri region, where the research was conducted, is located in the Southeastern Anatolia Region (Anonym 2022b).

Global warming is the most burning problem of the current century. It is described as the continuous rise in the average temperature of Earth's atmosphere and oceans and is caused by increased concentrations of greenhouse gases in the atmosphere, which are caused by human activities such as deforestation and burning of fossil fuels. On a scientific level, there is a consensus that global warming will continue to be one of the most significant environmental challenges in the future. There is no doubt that greenhouse gases (GHG) originate from fossil fuel consumption (Pathak and Wassmann 2007; Pishgar-Komleh et al. 2012a). Agricultural production in greenhouse is the most intensive global method, owing to its high yield and high amount of energy consumption per hectare (Sethi and Sharma 2007; Pishgar-Komleh et al. 2013). Agricultural production is conducted by using various input types, which consequently lead to some output energies and greenhouse gases (GHGs) in the process. Therefore, energy balance in agricultural crops and GHG emission arising from inputs are as important as the economic aspects of agricultural products. The type of crop has an impact on determining energy use and productivity of agricultural crops (Tsatsarelis, 1991; Afzalinia 2020).

There is no doubt that excessive use of fossil fuels, agrochemicals, machinery, electricity and other such inputs with the sole purpose of achieving a significant increase in food and fibre yield and improving nutrition has led to agricultural intensification. But on the other hand, extensive use of energy poses a threat to human health and the environment. Hence, a precondition of a sustainable agriculture is to ensure more efficient use of energy (Yilmaz et al. 2005; Kazemi et al. 2018). Getting to know the dynamics of energy usage in agricultural production is critical. Energy related problems are too many to mention but the main ones could probably be listed as insufficient resources, high production costs, erroneous resource allocation and the ever-growing national and international competition in agricultural trade. Hence, awareness of such restrictions is vital when it comes to implementing a sustainable agricultural production and self- sufficient resource allocation in cotton production (Dagistan et al. 2009). The efficiency and environmental impacts of a production system is usually determined through an energy input-output analysis. The results of such an analysis are important as they can be used to make the necessary improvements to ensure a more efficient and environment-friendly production system (Ozkan et al. 2003, Ozkan et al. 2004a; Oren and Akturk 2006).

Studies on EUE and GHG emissions have been made and continue to be done in the world and in Turkey. The examples include cotton (Singh et al. 2000; Yilmaz et al. 2005; Oren and Ozturk 2006; Kousar et al. 2006; Dagistan et al. 2009; Khan et al. 2009; Dalgaard et al. 2011; Zahedi et al. 2014; Kazemi et al. 2018; Sami and Reyhani 2018; Semerci et al. 2019; Afzalinia 2020), tobacco (Moraditochaee 2012; Loghmanpour-zarini and Abedi-firouzjaee 2013; Baran and Gokdogan 2015), sugar beet (Hacıseferoğulları et al. 2003; Erdal et al. 2007; Baran and Gokdogan 2016), potato (Mohammadi et al. 2008; Pishgar-Komleh et al. 2012a; Gokdogan et al. 2018), sunflower (Baran et al. 2016; Bayhan 2016; Akdemir et al. 2017), canola (Unakitan et al. 2010; Baran et al. 2014), olive (Guzman and Alonso 2008; Gökdoğan and Erdoğan 2021), soybean (Mandal et al. 2002) etc. In the current research, calculations have been made on the EUE of cotton production and the results have been used to make assessments. In the current research area, it is important to make a detailed research on the efficiency of energy use in cotton production and GHG emissions, as it contributes to the literature.

Materials And Method

Batman province is located between 41° 10' and 41° 40' east longitudes and 38° 40' and 37° 50' north latitudes (Anonym 2022b). Beşiri district of Batman, where the research was conducted, is the closest district to the centre and is considered the centre of industry and agriculture in Batman (Anonym 2022c).

Material

This research was carried out with cotton growing agricultural enterprises in Beşiri district of Batman province of Turkey for the 2018–2019 production season and the number of participating enterprises was calculated as 64 according to the simple random sampling method and face-to-face surveys, observations and field studies were conducted with these enterprises.

Method

Sampling Method

The formula (Eq. 1) of the method that was used to determine is given below (Çiçek and Erkan 1996).

$$n = \frac{N \times s^2 \times t^2}{(N-1)d^2 + (s^2 \times t^2)}$$

1

In the formula

n = Sample Size

s = Standard Deviation

t = "t value" Related to the Selected Confidence Limit

N = Total Number of Units for Sampling Frame

d = Acceptable margin of error (%)

Agriculture and Forestry Directorate. Previous studies have been used to calculate energy inputs and outputs and to determine the energy equivalent coefficients of inputs and outputs. The energy equivalents of the inputs and outputs used in agricultural production are given in Table 1. Energy output / input ratio (energy use efficiency), specific energy, energy productivity and net energy were calculated using the formulas given below (Equations 2–5) (Mandal et al. 2002; Mohammadi et al. 2008; 2010). All the data obtained in the research were transferred to the Excel program and evaluated.

Table 1
Energy equivalents used in agricultural production

Inputs	**Unit**	**Energy equivalent (MJ/ unit)**	**References**
Human labour	h	1.96	Mani et al. (2007); Karaağaç et al. (2011)
Machinery	h	64.80	Singh (2002); Kizilaslan (2009)
Chemicals	kg	101.20	Yaldiz et al. (1993); Ozkan et al. (2004b)
Chemical fertilizers			
Nitrogen	kg	60.60	Singh (2002); Demircan et al. (2006)
Phosphorus	kg	11.10	Mandal et al. (2002); Ozalp et al. (2018)
Potassium	kg	6.70	Mandal et al. (2002); Ozalp et al. (2018)
Micro elements	kg	120	Singh (2002);Canakci and Akinci (2006); Banaeian et al. (2011)
Irrigation water	m^3	0.63	Yaldiz et al. (1993); Demircan et al. (2006)
Electricity	kWh	3.60	Ozkan et al. (2004b)
Diesel fuel	l	56.31	Singh (2002); Demircan et al. (2006)
Seed	kg	11.80	Singh (2002); Yilmaz et al. (2005)
Output	**Unit**	**Energy equivalent (MJ/ unit)**	**Reference**
Cotton	kg	11.80	Singh (2002); Yilmaz et al. (2005)

$$\text{Energy use efficiency} = \frac{\text{Energyoutput}\left(\frac{\text{MJ}}{\text{ha}}\right)}{\text{Energyinput}\left(\frac{\text{MJ}}{\text{ha}}\right)} \quad (2)$$

$$\text{Specific energy} = \frac{\text{Energyinput}\left(\frac{\text{MJ}}{\text{ha}}\right)}{\text{Yieldoutput}\left(\frac{\text{kg}}{\text{ha}}\right)} \quad (3)$$

$$\text{Energy productivity} = \frac{\text{Yieldoutput}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Energyinput}\left(\frac{\text{MJ}}{\text{ha}}\right)} \quad (4)$$

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

GHG values are calculated by multiplying the inputs with their GHG equivalent emission values. The results of the calculations are shown in Table 2. A production related GHG table has been composed and the GHG ratio calculation has been made. With regards to Karaağaç et al. (2019); the following formula (Eq. 6) adapted by Hughes et al. (2011) over the suggestion of was used to determine the GHG emission.

Table 2
GHG emissions coefficients in agriculture production*

Inputs	Unit	GHG coefficients ($kgCO_{2-eq}$ $unit^{-1}$)	References
Human labour	h	0.700	Nguyen and Hermansen (2012)
Machinery	MJ	0.071	Pishgar-Komleh et al. (2012a)
Chemicals	kg	13.900	BioGrace-II (2015)
Nitrogen	kg	4.570	BioGrace-II (2015)
Phosphorus	kg	1.180	BioGrace-II (2015)
Potassium	kg	0.640	BioGrace-II (2015)
Irrigation water	m^3	0.170	Lal (2004)
Electricity	kWh	0.167	BioGrace-II (2015)
Diesel fuel	l	2.760	Clark et al. (2016)
Seed	kg	7.630	Clark et al. (2016)

*Adapted from Eren et al. (2019)

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

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GHG_{ha} : GHG ($kgCO_{2-eş}$ ha^{-1})

R(i) : Application amount of (i) input ($unit_{input}$ ha^{-1})

EF(i) : GHG emission equivalent of (i) input ($kgCO_{2-eq}$ $unit_{input}^{-1}$)

GHG ratio is an index defined as GHG emission quantity per kg yield. Calculation of GHG ratio has been based on the formula (Eq. 7) given below and adapted by Karaağaç et al. (2019), Houshyar et al. (2015) and Khoshnevisan et al. (2014).

$$I_{GHG} = \frac{GHG_{ha}}{Y}$$

7

I_{GHG}: GHG ratio ($kgCO_{2-eş}$ kg^{-1})

Y : Yield (kg/ ha)

Input energy is classified as direct, indirect, renewable and non-renewable. While indirect energy consists of pesticide and fertiliser, direct energy includes man and animal power, diesel and electric energy used during the production process. Non-renewable energy consists of oil, diesel, electric, chemicals, fertilisers and machinery. Renewable energy, on the other hand, includes man and animal power (Mandal et al. 2002; Singh et al. 2003; Koctürk and Engindeniz 2009). Energy balance, energy use efficiency calculations, energy input types and GHG calculations in cotton production are given in Table 3–6.

Table 3
EB in cotton cultivation

Inputs	Input used per hectare (unit / ha)	Energy value (MJ/ha)	Ratio (%)
Human labour	126.07	247.09	0.47
Machinery	16.53	1071.14	2.05
Chemicals	7.89	797.96	1.53
Chemical fertilizers	313.50	14,163.83	27.08
Nitrogen	214.51	12,999.31	24.85
Phosphorus	87.02	965.92	1.85
Potassium	10.93	73.20	0.14
Micro elements	1.05	125.40	0.24
Irrigation water	4069.52	2563.79	4.90
Electricity	5541.35	19,948.86	38.14
Diesel fuel	234.75	13,218.49	25.27
Seed	24.70	291.46	0.56
Total inputs	-	52,302.62	100.00
Output	**Output per hectare (unit/ha)**	**Energy value (MJ/ ha)**	**Ratio (%)**
Cotton	5113.65	60,341.03	100.00
Total output	-	60,341.03	100.00

Table 1

Table 2

Results And Discussion

The average cotton yield per hectare of the 64 cotton enterprises that took part in the research has been calculated as 5113.65 kg/ ha. Energy balance (EB) in cotton cultivation is given in Table 3. According to Table 2, the inputs in cotton production are electricity energy by 19,948.86 MJ/ha (38.14%), chemical fertilizers energy by 14,163.83 MJ/ ha (27.08%), diesel fuel energy by 13,218.49 MJ/ha (25.27%), irrigation water energy by 2563.79 MJ/ha (4.90%), machinery energy by 1071.14 MJ/ha (2.05%), chemicals energy by 797.96 MJ/ha (1.53%), seed energy by 291.46 MJ/ha (0.56%) and human labour energy by 247.09 MJ/ha (0.47%). Similar results were found in other researches on cotton cultivation. Semerci et al. (2019), Afzalinia (2020) calculated the ratio of electricity as 58.77% among the most used energy inputs. In other researches, Dagistan et al. (2009), Pishgar-Komleh et al. (2012b), Sami and Reyhani (2018) calculated the chemical fertilizers as the most used energy inputs.

Table 3

In this research, EUE, SE, EP and NE were calculated as 1.15, 10.23 MJ/kg, 0.10 kg/MJ and 8038.41 MJ/ha, respectively (Table 4). In other researches relating to cotton cultivation, Pishgar-Komleh et al (2012b) calculated EUE, SE, EP and NE as 1.85, 9.31 MJ/kg, 0.11 kg/ MJ and 27,218 MJ/ha; Zahedi et al. (2014) calculated EUE, SE, EP and NE as 0.7, 19.2 MJ/kg, 0.1 kg/MJ and − 15,625.2 MJ/ha; Dagistan et al. (2009) calculated EUE, SE, EP and NE as 2.36, 4.99 MJ/kg, 0.20 kg/MJ and 26,663 MJ/ha; Sami and Reyhani (2018) calculated EUE, SE and EP as 1.21, 9.8 MJ/kg, 0.1 kg/MJ; Semerci et al. (2019) calculated EUE, SE, EP and NE as 1.11, 10.66 MJ/kg, 0.09 kg/MJ and 6136.29 MJ/ha^{-1}, respectively.

Table 4
Calculations of EUE in cotton cultivation

Calculations	Unit	Values
Cotton	kg/ha	5113.65
Energy input	MJ/ha	52,302.62
Energy output	MJ/ha	60,341.03
Energy use efficiency	-	1.15
Specific energy	MJ/kg	10.23
Energy productivity	kg/MJ	0.10
Net energy	MJ/ha	8038.41

Table 4

The consumed total energy input was grouped as 68.79% DE, 31.21% IE, 5.93% RE and 94.07% N-RE (Table 5). Similarly, in other researches relating to cotton cultivation, Zahedi et al. (2014), Kazemi et al. (2018), Semerci et al. (2019), Afzalinia (2020), Baran et al. (2021) calculated DE ratio to be higher than IE. Similarly, N-RE energy ratio was calculated to be higher than RE by Dagistan et al. (2009), Yilmaz et al. (2010), Zahedi et al. (2014), Kazemi et al. (2018), Sami and Reyhani (2018), Semerci et al. (2019), Afzalinia (2020), Baran et al. (2021) in cotton cultivation.

Table 5
Calculations of energy input types in cotton cultivation

Energy groups	Energy input (M ha)	Ratio (%)
Direct energy[a]	35,978.23	68.79
Indirect energy[b]	16,324.39	31.21
Total	52,302.62	100.00
Renewable energy[c]	3102.34	5.93
Non-renewable energy[d]	49,200.28	94.07
Total	52,302.62	100.00
[a]Includes human labour, diesel fuel, irrigation water and electricity,		
[b]Includes machinery, chemical fertilizers, chemicals and seed,		
[c]Includes human labour, irrigation water and seed,		
[d]Includes machinery, diesel fuel, chemical fertilizers, chemicals and electricity.		

Table 5

The GHG emission values are shown in Table 6. Total GHG emissions were calculated as 3742.59 $kgCO_{2-eq}ha^{-1}$ for cotton cultivation and GHG ratio as 0.73. GHG emissions have been related to nitrogen by 26.19%, electricity by 24.73%, irrigation water usage by 18.48%, diesel fuel usage by 17.31%, seed usage by 5.04, chemicals usage by 2.93%, phosphorous usage by 2.74%, human labour usage by 2.36%, potassium usage by 0.19% and machinery usage by 0.03%, respectively. A study conducted by Pishgar-Komleh et al (2012b) calculated the total GHG emission of cotton cultivation as 1195.25 $kgCO_{2-eq}ha^{-1}$, Sami and Reyhani (2018) calculated the total GHG emission of cotton cultivation as 2075.5 $kgCO_{2-eq}ha^{-1}$, Pishgar-Komleh et al (2012a) calculated the total GHG emission of potato production as 992.88 $kgCO_{2-eq}ha^{-1}$.

Table 6

Table 6
GHG emissions in cotton cultivation

Inputs	Unit	GHG coefficients ($kgCO_{2-eq}$ $unit^{-1}$)	Input (unit/ha)	GHG emissions ($kgCO_{2-eq}$ ha^{-1})	Ratio (%)
Human labour	h	0.700	126.07	88.25	2.36
Machinery	MJ	0.071	16.53	1.17	0.03
Chemicals	kg	13.900	7.89	109.60	2.93
Nitrogen	kg	4.570	214.51	980.31	26.19
Phosphorus	kg	1.180	87.02	102.68	2.74
Potassium	kg	0.640	10.93	6.99	0.19
Irrigation water	m^3	0.170	4069.52	691.82	18.48
Electricity	kWh	0.167	5541.35	925.41	24.73
Diesel fuel	l	2.760	234.75	647.90	17.31
Seed	kg	7.630	24.70	188.46	5.04
Total inputs	-	-	-	3742.59	100.00
GHG ratio	-	-	-	0.73	-

Conclusion

The findings of this study can be summarised as follows.

In this research, total energy input and output were calculated as 52,302.62 and 60,341.03 MJ/ ha, respectively. The electricity energy, chemical fertilizers and diesel fuel had the highest share in energy usage for cotton cultivation, amounting to 19,948.86, 14,163.83, 13,218.49 MJ/ ha. EUE, SE, EP and NE were calculated as 1.15, 10.23 MJ/kg, 0.10 kg/MJ and 8038.41 MJ/ ha, respectively.

The consumed total energy input was grouped as 68.79% DE, 31.21% IE, 5.93% RE and 94.07% N-RE.

Total GHG emissions were calculated as 3742.59 $kgCO_{2-eq}ha^{-1}$ for cotton cultivation and GHG ratio as 0.73.

Efficiency usage of energy source is important to decrease operating cost and decrease emissions of air contaminants and greenhouse gases (Demirbas and Urkmez 2006; Mujeebu et al. 2009a; 2009b; Ekinci 2011). Taking the recommendations proposed by this study into consideration can contribute to better energy use efficiency in the future.

Decreasing electricity, chemical fertilizer and diesel fuel usage are the priorities in cotton cultivation for EUE. For this purpose, according to Pishgar-Komleh et al. (2012b), applying soil analysis to determine soil fertilizer needs (to reduce high chemical fertilizers energy utilization and GHG emission), matching equipment to tractors, fuel efficiency and applying minimum or zero tillage (to reduce diesel fuel utilization) is proposed.

Declarations

Ethics approval and consent to participate: Ethical approval was not required in this study.

Consent to participate

All farmers voluntarily participated in the survey studies.

Author Contributions: M.F.B;O.G; Problem identification and construction, manuscript writing and, M.F.B;O.G; data retrieval, M.F.B;O.G; data analysis and data interpretation. M.F.B;O.G.; All authors have read and agreed to publish the version of manuscript.

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