Energy use efficiency and greenhouse gas emissions (GHG) analysis of garlic cultivation in Turkey

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Abstract: This study has been conducted with the purpose of determining energy use efficiency and greenhouse gas emissions of garlic cultivation during the 2020-2021 cultivation season in Adıyaman province of Turkey. Questionnaires, observations and field works were performed in 134 garlic farms in the region through simple random method. In garlic cultivation, energy input was calculated as 32 103.20 MJ/hm^2 and energy output was calculated as 30 096 MJ/hm^2. With regards to the three highest inputs in garlic production, 46.66% of the energy inputs consisted of chemical fertilizers energy (14 979.26 MJ/hm^2), 11.29% consisted of farmyard manure energy (3625.71 MJ/hm^2) and 10.48% consisted of human labour energy (3363.36 MJ/hm^2). Energy use efficiency, specific energy, energy productivity and net energy in garlic cultivation were calculated as 0.94, 1.71 MJ/kg, 0.59 kg/MJ, and −2007.20 MJ/hm^2, respectively. The total energy input consumed in garlic cultivation was classified as 27.19% direct energy, 72.81% indirect energy, 35.17% renewable energy and 64.87% non-renewable energy. Total GHG emissions and GHG ratio were calculated as 8636.60 kg $CO_{2\text{-eq}}$/hm^2 and 0.46 kg $CO_{2\text{-eq}}$/kg, respectively.

Keywords: Energy use efficiency, garlic, greenhouse gas emissions, specific energy, Turkey.
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1 Introduction

By each passing day, producing sufficient nutritional material for the ever-increasing population of the world becomes a greater issue and therefore agriculture is becoming more dependent on energy use. The facts that the fossil energy sources are limited and the effects of excessive use of fossil energy on the environment are drastic, makes the issue even further complicated[1,2]. There are a number of environmental problems, and one of the major culprits of these problems, such as global warming, is the dependence of conventional agricultural systems on severe usage of energy. Maintaining a healthy environment and sustainable agriculture is greatly dependent on efficient use of resources and energy[3,4]. Achieving an improvement on energy use efficiency is therefore crucial to reduce environmental impacts and GHG emissions, as well as to improve competitiveness via cost reduction[4,5].

Garlic (*Allium sativum*) is a member of the Alliaceae family and its culinary and medicinal benefits make it a popular product. Garlic provides potassium, calcium and phosphorus, and there are protein and vitamins A and C on its leaves[6,7]. Garlic reportedly contains antibiotic substances that inhibit the growth of certain bacteria and fungi. Garlic is a plant that is not picky when it comes to soil. It is manually planted in autumn and harvested in the following summer[6,7]. According to FAO data, 1.13×10^9 t of vegetable has been produced in the world in 2019 in an area encompassing 59.4×10^6 hm^2 and 2.7% of that amount was garlic. Garlic was produced in 101 countries in 2019. Of all the global garlic cultivation areas, 50.7% is in China, 21.9% is in India and 4.4% is in Bangladesh. China is the leading producer and has produced 75.7% of the total amount. In 2020, the dry garlic cultivation area in Turkey increased by 1.9%, compared to 2019, and rose to 12.7×10^3 hm^2[8,9].

Studies have been performed on energy use and GHG analysis of agricultural products. For example, garlic[6,7], onion[10,11], sugar beet[12,13], vegetables[14,15], lettuce[16], cotton[17], wheat[18], corn[19], sunflower[20], pumpkin seed[21], maize[22], black cumin[23], vetch[24], lavender[25] , and different fruits[26]. This study has not made any analysis regarding the energy use efficiency and GHG emission of garlic cultivation in the region in Turkey. It is clear that this study will contribute to the literature in this sense. As well as determining the energy use efficiency and greenhouse gas emission values, this study has also proposed some suggestions on increasing of energy use efficiency, increasing of renewable energy, reducing of non-renewable energy and reducing GHG emission levels.

2 Materials and methods

Adıyaman province is located within the Central Euphrates. Central Adıyaman is located at 37°45'N latitude and 38°16'E longitude. Adıyaman's altitude is 672 m above sea level and the lowest temperatures of the year are between −10°C and −2°C. The

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minimum temperature averages in winter are between 0°C and 10°C. Adıyaman province has been a residential area where people preferred to live in every period of history due to its suitable geographical features[27]. This study was performed during the 2020-2021 cultivation season. Questionnaires, observations, and field works were performed in 134 garlic farms in region with simple random method proposed by Çiçek and Erkan[28]. Through the survey, human labour, machinery, chemical fertilizers, farmyard manure, chemicals, diesel fuel, irrigation water and seed inputs and yield data were collected from 134 garlic farms. The sample size In Equation (1);

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

where, n is the sample size; N is the number of total farm; s is standard deviation; t is the reliability coefficient (1.96 which represents, 95% confidence); and d is acceptable error (5% deviation). Energy equivalents used in agriculture production are listed in Table 1. The total energy input is provided by multiplying the energy equivalents of the energy input used per hectare and the total energy output is provided by multiplying the output from the hectare with the energy equivalents. Energy use efficiency, specific energy, energy productivity and net energy were calculated by using the following Equations (2)-(5)[1,29,30]. Energy input types were classified as direct energy, indirect energy, renewable energy and non-renewable energy[1,31,32]. GHG emissions coefficients of inputs in production are given in Table 2. Energy balance, energy use efficiency, energy input types, GHG emissions and GHG ratio calculations are listed in Tables 3-6.

Table 1 Energy equivalents in agricultural production

Inputs	Unit	Values/MJ·unit⁻¹	References
Human labour	h	1.96	[37,38]
Machinery	h	64.80	[39,40]
Chemical fertilizers			
Nitrogen	kg	60.60	[41,42]
Phosphorous	kg	11.10	[41,42]
Potassium	kg	6.70	[41,42]
Farmyard manure	kg	0.30	[41,42]
Chemicals	kg	101.20	[43,14]
Diesel fuel	L	56.31	[39,44]
Irrigation water	m³	1.02	[45,30]
Seed	kg	1.60	[46,6]
Output	Unit	Values/MJ·unit⁻¹	References
Yield	kg	1.60	[46, 6]

Table 2 GHG coefficients in agriculture production

Inputs	Unit	GHG coefficients/kg $CO_{2\text{-eq}}$·unit⁻¹	References
Human labour	h	0.360	[34,49]
Machinery	h	0.071	[47,42]
Chemical fertilizers			
Nitrogen	kg	1.300	[48,49]
Phosphorous	kg	0.200	[48,49]
Potassium	kg	0.200	[50,49]
Farmyard manure	t	0.005	[5,49]
Chemicals	kg	13.900	[51,26]
Diesel fuel	L	2.760	[47,42]
Irrigation water	m³	0.270	[34,49]
Seed	kg	7.630	[52,53]

Table 3 Energy balance in garlic cultivation

Inputs	Unit	Energy equivalent/	Input used per hectare/hm⁻²*	Energy value/	Ratio/%
Human labour	h	1.96	1716	3363.36	10.48
Machinery	h	64.80	37.80	2449.44	7.63
Chemical fertilizers	kg	-	462.10	14 979.26	46.66
Nitrogen	kg	60.60	215.70	13 071.42	40.72
Phosphorous	kg	11.10	58.40	648.24	2.02
Potassium	kg	6.70	188	1259.60	3.92
Farmyard manure	kg	0.30	12 085.70	3625.71	11.29
Chemicals	kg	101.20	9.50	961.40	2.99
Diesel	L	56.31	43	2421.33	7.54
Irrigation water	m³	1.02	2885	2942.70	9.17
Seed	kg	1.60	850	1360	4.24
Total	-	-	-	32 103.20	100.00
Output	Unit	Energy equivalent/	Output per hectare/ unit·hm⁻²	Energy value/	Ratio/ %
Yield	kg	1.60	18 810	30 096	100.00

*: It is the average of 134 questionnaires.

Table 4 Calculations of energy in garlic cultivation

Calculations	Values
Energy use efficiency	0.94
Specific energy	1.71
Energy productivity	0.59
Net energy	−2007.20

Table 5 Energy input types in garlic cultivation

Garlic cultivation	Energy input/MJ·hm⁻²	Ratio/%
Direct energy[a]	8727.39	27.19
Indirect energy[b]	23 375.81	72.81
Total	32 103.20	100.00
Renewable energy[c]	11 291.77	35.17
Non-renewable energy[d]	20 811.43	64.83
Total	32 103.20	100.00

[a]Includes human labour, diesel, and irrigation water
[b]Includes chemicals, chemical fertilizers, machinery, seed, and farmyard manure
[c]Includes human labour, seed, farmyard manure, and irrigation water
[d]Includes chemicals, chemical fertilizers, diesel, and machinery.

Table 6 GHG emissions in garlic cultivation

Inputs	Unit	GHG coefficient/ kg $CO_{2\text{eq}}$·unit⁻¹	Input/ unit hm⁻²	GHG emissions/ kg $CO_{2\text{-eq}}$·hm⁻²	Ratio/ %
Human labour	h	0.360	1716	617.76	7.15
Machinery	MJ	0.071	2449.44	173.91	2.01
Chemical fertilizers					
Nitrogen	kg	1.300	215.70	280.41	3.25
Phosphorous	kg	0.200	58.40	11.68	0.14
Potassium	kg	0.200	188	37.60	0.44
Farmyard manure	t	0.005	12.08	0.06	0.01
Chemicals	kg	13.900	9.50	132.05	1.53
Diesel	L	2.760	43	118.68	1.37
Irrigation water	m³	0.270	2885	778.95	9.02
Seed	kg	7.630	850	6485.50	75.09
Total	-	-	-	8636.60	100.00
GHG ratio	-	-	-	0.46	-

$$\text{Energy use efficiency} = \frac{\text{Energy output}(\text{MJ/hm}^{-2})}{\text{Energy input}(\text{MJ/hm}^{-2})} \quad (2)$$

$$\text{Specific energy} = \frac{\text{Energy intput}(\text{MJ/hm}^{-2})}{\text{Yield output}(\text{kg/hm}^{-2})} \quad (3)$$

$$\text{Energy productivity} = \frac{\text{Yield output}(\text{kg/hm}^{-2})}{\text{Energy intput}(\text{MJ/hm}^{-2})} \quad (4)$$

$$\text{Net energy} = \text{Energy output} - \text{Energy input}(\text{MJ}\cdot\text{hm}^{-2}) \quad (5)$$

GHG values were calculated by multiplying the inputs with their GHG equivalent emission values (Table 2). The following formula adapted by Hughes et al.[33] was used to determine the GHG emission. In the calculation of GHG ratio, the following formula, adapted by Houshyar et al.[34] and Khoshnevisan et al.[35] was used. In Equations (6) and (7), GHG_{ha}: GHG (kg $CO_{2\text{-eq}}$/hm^2), R(i): implementation amount of input *i* (unit$_{input}$/hm^2), EF(i): GHG emission equivalent of input *i* (kg $CO_{2\text{-eq}}$ unit$_{input}^{-1}$), I_{GHG}: GHG ratio (kg $CO_{2\text{-eq}}$ /kg), and Y: yield (kg/hm^2)[36].

$$\text{GHG}_{\text{ha}} = \sum_{i=1}^{n} R(i)\cdot EF(i) \quad (6)$$

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

3 Results and discussion

The garlic farms yielded an average of 18 810 kg/hm^2 during the 2020-2021 cultivation season. The energy balance is listed in Table 3. Total energy input was calculated as 32 103.20 MJ/hm^2. With regards to all the inputs in 2020-2021, 46.66% formed of chemical fertilizers energy (14 979.26 MJ/hm^2), 11.29% formed of farmyard manure energy (3625.71 MJ/hm^2), 10.48% formed of human labour energy (3363.36 MJ/hm^2), 9.17% formed of irrigation water energy (2942.70 MJ/hm^2), 7.63% formed of machinery energy (2449.44 MJ/hm^2), 7.54% formed of diesel fuel energy (2421.33 MJ/hm^2), 4.24% formed of seed energy (1360 MJ/hm^2) and 2.99% formed of chemicals energy (961.40 MJ/hm^2). Energy output was calculated as 30 096 MJ/hm^2.

As indicated in Table 3, the contribution of chemical fertilizers was the highest among all energy inputs consumed (46.66%). Similar results were found in other studies on onion production. Samavatean[6] calculated that chemical fertilizers were responsible for 41.72% of energy inputs in garlic cultivation, Arın and Akdemir[10] reported the chemical fertilizers' energy use as 56.71% of the total energy inputs in onion cultivation, Ozbek et al.[11] calculated the chemical fertilizers' energy use as 60.43% of the total energy inputs in onion cultivation, and Yilmaz et al.[23] calculated 45.36% of total energy inputs were due to the chemical fertilizers in black cumin production.

Energy use efficiency, specific energy, energy productivity and net energy in garlic cultivation were calculated (Table 4). Similarly, in other studies, Samavatean et al.[6] calculated energy use efficiency as 0.665 in garlic cultivation, Sabzevari et al.[7] calculated efficiency as 0.847 in garlic cultivation, Ozkan et al.[14] calculated energy use efficiency as 0.61 in eggplant cultivation, Ozkan et al.[14] calculated energy use efficiency as 0.76 in cucumber cultivation.

The distribution of inputs used in the garlic cultivation, in terms of direct, indirect, renewable, and non-renewable energy types are given in Table 3. The total energy input consumed was classified as 27.19% direct energy, 72.81% indirect energy, 35.17% renewable energy and 64.83% non-renewable energy (Table 5). Similarly, in other studies (garlic, onion, guar), Samavatean et al.[6], Ozbek et al.[11] and Gokdogan et al.[25] calculated direct energy ratio to be higher than indirect energy and non-renewable energy ratio to be higher than renewable energy.

The GHG ratio is obtained by dividing the total GHG amount in production by the product amount. The results of GHG emissions are shown in Table 6. Total GHG emissions and GHG ratio were calculated as 8636.60 kg $CO_{2\text{-eq}}$/hm^2, and 0.46 for garlic cultivation, respectively. GHG emissions took place due to human labour 617.76 kg $CO_{2\text{-eq}}$/hm^2, machinery 173.91 kg $CO_{2\text{-eq}}$/hm^2, nitrogen 280.41 kg $CO_{2\text{-eq}}$/hm^2, phosphorous 11.68 kg $CO_{2\text{-eq}}$/hm^2, potassium 37.60 kg $CO_{2\text{-eq}}$/hm^2, farmyard manure 0.06 kg $CO_{2\text{-eq}}$/hm^2, chemicals 132.05 kg $CO_{2\text{-eq}}$/hm^2, diesel 118.68, irrigation water 778.95 kg $CO_{2\text{-eq}}$/hm^2, and seed 6485.50 kg $CO_{2\text{-eq}}$/hm^2, respectively. In other studies, Ozbek et al.[11] calculated the total GHG emission of onion cultivation as 2920.73 kg $CO_{2\text{-eq}}$/hm^2, Dilay and Gokdogan[54] calculated the total GHG emission of quinoa production as 382.42 kg $CO_{2\text{-eq}}$/hm^2, Karaağaç et al.[36] calculated the total GHG emission of chickpea production as 1638.85 kg $CO_{2\text{-eq}}$/hm^2.

4 Conclusions

In this study, the energy use efficiency and GHG emissions of garlic cultivation in the 2020-2021 cultivation season were determined. Obtained results along with suggestions are summarised below.

Energy input value was calculated as 32 103.20 MJ/hm^2 and the energy output value was calculated as 30 096 MJ/hm^2.

Energy use efficiency, specific energy, energy productivity and net energy in garlic cultivation were calculated as 0.94, 1.71 MJ/kg, 0.59 kg/MJ and −2007.20 MJ/hm^2, respectively.

The used total energy input was classified as 27.19% direct energy, 72.81% indirect energy, 35.17% renewable energy and 64.83% non-renewable energy.

Total GHG emissions and GHG ratio were calculated as 8636.60 kg $CO_{2\text{-eq}}$/hm^2, and 0.46 for garlic cultivation, respectively.

GHG ratio means that on average the production of one kg garlic in production is cause for a CO_2 emission of 0.46 kg. In order to reduce emission quantities, it is necessary to increase the use of renewable energy sources.

Obtained results indicate that garlic cultivation is not a profitable activity in terms of energy usage. The use of renewable energy in garlic cultivation is not high. Chemical fertilizers had the highest share by 46.66% among all inputs. Increasing the share of renewable energy, such as using farm manure and organic manure rather than chemical fertilisers, is vital to increase the energy use efficiency and decreasing greenhouse gas emission levels.

Using the right tractor and ensuring a good management of machinery to reduce the direct use of diesel fuel energy may be helpful in improving the energy use efficiency of production without impairing yield or profitability[44]. Keeping this proposal in mind in garlic cultivation can increase energy use efficiency and reduce GHG emissions.

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