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Greenhouse gas emission and energy analysis of vetch (*Vicia sativa* L.) cultivation

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ABSTRACT

Background: Agricultural production accounts for a major share of global energy consumption and greenhouse gas emissions (GHG). However, the information on energy use and GHG emissions from various crops is contradictory. Climate change is expected to increase the GHG emission from different crops; therefore, selection of the crops with lower GHG emission could be helpful in reducing the emission and energy consumption. A major focus of energy policy should be on improving energy efficiency. Saving money and lowering GHG emissions are only two benefits of using energy efficiently. However, these are unknown for the vetch cultivation in Siirt province of Turkey.
Methods: This study investigated energy consumption efficiency and GHG emissions of vetch (*Vicia sativa* L.) production under dry circumstances in Siirt province, Turkey during 2021. Seed rate was kept 120 kg/ha in the current study. The amount of fertilizer applied was 92.0 kg/ha pure phosphorus and 36.0 kg/ha pure nitrogen. To calculate the energy efficiency of vetch production in Siirt, energy inputs and energy outputs were computed.
Results: The energy intake and output were 8205.02 MJ/ha and 90388.56 MJ/ha, respectively. The energy inputs were: 37.1 % diesel fuel energy, 31.2 % fertilizer energy, 21.2 % seed energy, 9.6 % equipment energy, and 0.9 % labor energy. The results revealed that energy consumption efficiency was 11.02, specific energy was 0.34 MJ/kg, energy efficiency was 2.90 kg/MJ, and net energy was 82183.54 MJ/ha in vetch production. Total GHG emissions from vetch production was 205.19 $\mathrm{kgCO_{2\text{-}eq}\ ha^{-1}}$, with diesel fuel accounting for the lion's share (72.88 %). Diesel fuel was followed by the consumption of nitrogen fertilizer (26.33 %), phosphorous (0.47 %) and machinery (0.42 %). Additionally, GHG ratio was 0.009 $\mathrm{kg\ CO_{2\text{-}eq}\ kg^{-1}}$ in vetch production.
Conclusion: It is concluded that encouraging the farmers to produce vetch as an alternative to the production of conventional forage crops and rotation in fodder production will be beneficial. It will reduce GHG emissions with lesser energy consumption.

1. Introduction

Animals and animal products are very important factors for the maintenance of human life. Livestock farming has been one of the earliest occupations and still occupies this position. Feeds are the major inputs in livestock farming, which are divided into two types, i.e., concentrates and roughages (Derner et al., 2017). A balanced amount of concentrate feeds is provided for daily energy and protein requirements of the animals; however, roughages are the most essential feed groups to increase the animal health and meat-milk yield. The use of roughages is important for improving animals' performances, prevention from several feeding-welded metabolic diseases and high-quality animal products (Derner et al., 2017).

Industrialization and rapid adaptation to mechanized life has rendered infinite challenges on earth and greenhouse gases' emission-mediated climate change is the major hassle faced globally (Al-Ghussain, 2019). Climate change is a complex phe-

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nomenon, mainly derived from human-mediated greenhouse gases' (GHG) emission that adversely affects various processes. Feed-based livestock production helps to provide high quality foods for human beings at affordable price (Derner et al., 2017). Economic animal production is impossible without adequate forage crops utilization in the livestock production, which occupies an important place in Turkey's agriculture (Altın et al., 2009). Feed expenses constitute of a large part of the inputs in the livestock sector. Nearly 70–78 % of feed expenses are met by roughages and 22 % by concentrate feeds (Harmanşah, 2018). Forage crops have an important share in field crop cultivation in the developed countries. For example, forage crops are cultivated on 49.8 % of the croplands in Australia, 36.5 % in Germany, 31.4 % in the Netherlands, 25.8 % in France, 25.4 % in England and 23.0 % in the USA. Similarly, forage crops are cultivated on 17.0 % of croplands in Romania, 11.7 % in Greece and 6.3 % in Bulgaria (FAO, 2022). Hence, advancements in agriculture and cultivation of forage crops are linearly related. The fodder crops are grown on 2.1 million hectares in Turkey with annual production of 55.4 million tons (TÜİK, 2022).

The main forage crop produced in Turkey are alfalfa, silage maize, vetch and sainfoin. Vetch (*Vicia sativa* L.) is a legume plant with high forage yield and good nutritional value (Sohail et al., 2021). Vetch species are generally grown in Turkey to produce roughage. However, these are also grown for concentrate feeds as their seeds contain high protein. The forage produced by vetch plant does not cause swelling in animals. The dry forage obtained from vetch dry harvested at the beginning of the flowering contains approximately 12–20 % crude protein, 6–10 % crude ash, 25–26 % crude fiber and 45–46 % nitrogen-free core material (Sohail et al., 2021). The vetch grown in Turkey is used to obtain green or dry forage and grown as green manure and silage plant.

Energy efficiency is one of the most important issues in energy policies. Efficient use of energy reduces costs and GHG emissions and protects environment (Klikocka et al., 2019). The GHG emissions from agriculture will continue to increase in the future. The GHG originating from agricultural production could not be neglected when compared to other sectors. One of the fundamental requirements of sustainable agriculture is the effective use of energy. The usage of energy in agricultural operations is growing (Altuntaş et al., 2019). Limited arable land for an expanding population and high living standards have resulted in the heavy use of fertilizers, mechanization, and pesticides. Concentrated energy consumption endangers human health and ecological environments. Increasing agricultural energy efficiency will reduce environmental hazards, minimize environmental damage, and improve agricultural sustainability as an economic production system (Erdal et al., 2007). Increased energy use, on the other hand, produces severe environmental challenges that have an impact on human health. Therefore, efficient input use is crucial for long-term agricultural output.

Several studies have been conducted on energy use efficiency of forage crops such as wheat (Altuntaş et al., 2019), barley, corn silage (Carman et al., 2021), vetch (Baran, 2016; Baran and Gökdoğan, 2017), alfalfa, triticale (Klikocka et al., 2019), and oat (Nassir et al., 2021). There are some studies on determination of GHG emissions in forage crop production, i.e., corn silage, winter wheat, oats, barley, wheat, and rye, barley, vetch and wheat, and chickpea (Eren et al., 2019; Houshyar et al., 2015; Syp et al., 2015). The highest energy inputs were fertilizer and fuel consumption in all these studies. Furthermore, fertilizer and fuel consumption had the highest share towards GHG emissions. Balanced fertilization programs based on soil and plant analyzes can play an important role in reducing GHG emissions from agricultural activities. Furthermore, reduced tillage methods would be beneficial in lowering fuel input.

It is necessary to reduce the N_2O emissions in the soil, which is the only source of GHG emissions that directly occur in agriculture. Indirect GHG emissions can be reduced by avoiding mineral fertilizers. The potential and sustainability for reducing GHG emissions can be determined by qualitative evaluation of organic farming management. Long-term solutions for CO_2 emissions and new energy conservation methods must be developed. This study has been conducted to analyze energy use efficiency and GHG emission of vetch cultivation in Siirt province Turkey. In addition to calculating efficiency and GHG emission in energy use, this study has also proposed some suggestions to increase energy use efficiency and reducing GHG emission.

2. Materials and methods

2.1. Materials

This study was conducted during 2021 in Siirt province Turkey. Siirt province lies in the southeastern Anatolian region. The province is situated at 41° 57′ East longitude and 37° 55′ North latitude. The province topography is mountainous and hilly. However, a part of Kurtalan district is a plain. Botan Stream has formed 150–200 m valleys on the route it flows. There are detached plains stretching from the Kurtalan district center to the Batman provincial border.

2.2. Methods

2.2.1. Crop sowing

The seed rate of vetch cultivation in Turkey varies between 100 and 150 kg/ha depending on the interrow, intra-row spacings and seed size. Seed rate was kept 120 kg/ha in the current study. The amount of fertilizer applied was 92.0 kg/ha pure phosphorus and 36.0 kg/ha pure nitrogen. Weeds were not managed in the experiment. No pesticides were applied in the study.

2.2.2. Energy consumption and GHG emission

The energy efficiency of the vetch crop in Siirt was calculated by estimating energy inputs and energy outputs. A total 3 drivers worked for the tillage, 1 worker for manual works, 1 driver and 1 assistant worker for planting and fertilization, 1 worker for manual harvesting and 1 for machine harvesting. The quantity of inputs (seed, fertilizer, fuel, human labor, machinery) utilized in study were determined. The quantity was converted to per hectare to determine the inputs using coefficients (Table 1).

The coefficients for vetch production's energy use, energy efficiency, specific energy, energy productivity, and net energy were determined using Eqs. (1)–(4). Specific energy is the amount of energy required to generate a given quantity of a product, whereas energy productivity measures the converse. The formulas below were used to calculate the vetch manufacturing process's energy efficiency.

Table 1
Energy equivalents to be used as input and output in vetch production.

Inputs	Unit	Values (MJ / unit)	References
Human labour	h	1.96	Uzun and Baran (2022)
Machinery	h	64.8	Kizilaslan (2009)
Fertilizers			
Nitrogen	kg	60.6	
Phosphorus	kg	11.1	Bayhan (2016)
Diesel fuel	l	56.3	Baran (2016)
Seeds	kg	14	Baran (2016)
Output	Unit	Value (MJ/unit)	
Vetch plant	kg	17.240	Baran (2016)

$$\text{Energy use efficiency} = \frac{\text{Energy Output (MJ ha}^{-1})}{\text{Energy Input (MJ ha}^{-1})} \tag{1}$$

$$\text{Energy productivity} = \frac{\text{Yield (kg ha}^{-1})}{\text{Energy Input (MJ ha}^{-1})} \tag{2}$$

$$\text{Specific energy} = \frac{\text{Energy Input (MJ ha}^{-1})}{\text{Yield (kg ha}^{-1})} \tag{3}$$

$$\text{Net energy} = \text{Energy output (MJ ha}^{-1}) - \text{Energy input (MJ ha}^{-1}) \tag{4}$$

The Eq. (5) was used to determine the total energy input (Farrell et al., 2006).

$$\text{AEI} = \sum\nolimits_{i=1}^{n} \text{R (i)} \times \text{E}_{\text{eq}}\text{ (i)} \tag{5}$$

Here, AEI = Agricultural energy input (MJ/ha), R(i) = the amount (i) input ($\text{unit}_{\text{input}}$ ha^{-1}), and Eeq(i) = energy equivalent to (i) input (MJ $\text{unit}_{\text{input}}^{-1}$).

The Eq. (6) was used to determine the energy output.

$$\text{AEO} = \text{Y} \times \text{LHV} \tag{6}$$

Here, AEO = Agricultural energy output (MJ/ha), Y = Yield (kg/ha), and LHV = Lower heating value (MJ/kg).

Input-output energy equivalents in vetch production are detailed in Table 1. The units demonstrated in Table 2 are the inputs for vetch production. The GHG emission (kg $\text{CO}_{2\text{-eq}}$ ha^{-1}) to grow 1 ha of vetch were calculated by following (Hughes et al., 2011) as given below in Eq. (7).

$$\text{GHG}_{\text{ha}} = \sum\nolimits_{i=1}^{n} \text{R (i)} \times \text{EF(i)} \tag{7}$$

Here, GHG_{h} = greenhouse gas emission (kg $\text{CO}_{2\text{-eq}}$ ha^{-1}), R (i) = Amount of i input ($\text{unit}_{\text{input}}$ ha^{-1}), and EF(i) = GHG emission equivalent of i input (kg $\text{CO}_{2\text{-eq}}$ $\text{unit}_{\text{input}}^{-1}$).

Table 2 lists GHG emissions coefficients of agricultural inputs. In addition, an index equation (Eq. (8)) is given for calculating the amount of kg $\text{CO}_{2\text{-eq}}$ per kg yield (Houshyar et al., 2015).

$$\text{I}_{\text{GHG}} = \frac{\text{GHG}_{\text{ha}}}{\text{Y}} \tag{8}$$

3. Results and discussion

3.1. Energy use efficiency

The energy balance is shown in Table 3, while consumption and efficiency data are shown in Tables 4 and 5. Fuel and fertilizer consumption were determined to account for the majority of energy inputs. Use of fuels and fertilizers was also a major contributor to greenhouse gas emissions. In order to reduce greenhouse gas emissions from agricultural activities and promote environmental sustainability and responsible energy use, it may be essential to implement balanced fertilization plans based on soil and plant research. In addition, reducing the amount of land disturbed by tilling is a good strategy for saving money on gasoline. Based on the results of this study, efforts should be made to reduce the quantity of fertilizer and fuel oil required to grow vetch.

Table 2
Greenhouse gas coefficients in the calculation of agricultural production.

Inputs	Unit	GHG coefficients (kg $\text{CO}_{2\text{q}}$ Unit^{-1})	References
Machinery	h	0.070	Pishgar-Komleh et al. (2012)
Fertilizers			
Nitrogen	kg	1.300	Çelen et al. (2017)
Phosphorus	kg	0.200	Ozalp et al. (2018)
Diesel fuel	l	2.760	Dyer and Desjardins (2006)

Table 3 reveals that 71.34 MJ/ha of human energy was consumed per unit area, and the ratio of this value to the total energy input constituted the lowest input value (0.87 %). A total 784.08 MJ energy was consumed by machines for 1 ha area, which corresponds to 9.56 % of the total energy. The consumed fuel energy was 3050.88 MJ/ha and was the highest (37.18 %). Fertilizer energy input corresponded to 2562.56 MJ/ha with 31.23 % share. Seed energy input was 1736.17 MJ/ha with 21.16 % share. Similarly, agricultural energy input was 8205.02 MJ/ha and agricultural energy output as 90388.56 MJ/ha.

The computed values for yield, energy input, energy output, energy usage efficiency, specific energy, energy productivity, and net energy in vetch production were 23833 kg/ha, 8205.02 MJ/ha, 90388.56 MJ/ha, 11.02, 0.34 MJ/kg, 2.90 kg/MJ, and 82183.54 MJ/ha, respectively (Table 4). Baran and Gökdoğan (2017) reported 2.58 energy ratio in chickpea produced in Adıyaman province, Turkey. Likewise, Baran et al. (2019) noted 1.82 energy ratio for chickpea in Adana province, Turkey. In the same way Baran et al. (2019) recorded 1.94 energy ratio for peanut in Adana. Similarly, Kokten et al. (2017a) reported an energy ratio of 2.53 in field pea produced in Bingöl province, Turkey. Energy productivity in vetch production under Siirt conditions was 2.90 kg/MJ considering the seeds harvested. In the production of fodder peas under Siirt conditions, 0.27 kg of vetch seeds are produced for every 1 MJ energy consumed. The production for every 1 MJ energy consumed was 0.14 in feed peas (Kokten et al., 2017a). The rapid shift to a more automated lifestyle and the resulting increase in greenhouse gas emissions have created a global climate change crisis (Al-Ghussain, 2019). Human-caused emissions of greenhouse gases (GHGs) are the primary source of this complex phenomenon, and they have detrimental effects on a wide range of systems. Low-cost, high-quality human food is produced in part by animal husbandry that relies on feed (Derner et al., 2017). Turkey's livestock industry plays a crucial role in the country's agricultural sector, but it's difficult to raise animals economically without access to enough feed crops (Altn et al., 2009).

Baran and Gökdoğan (2017) reported 2.58 energy ratio for chickpea produced in Adıyaman province, Turkey. Likewise, Baran et al. (2019) noted 1.82 energy ratio for chickpea in Adana province, Turkey. In the same way Baran et al. (2019) recorded 1.94 energy ratio for peanut in Adana. Similarly, Kokten et al. (2017a) reported an energy ratio of 2.53 in field pea produced in Bingöl province, Turkey. Turkey often raises a variety of species for roughage. But they are also manufactured for concentrate feeds because to the high protein content of their seeds. The vetch plant does not cause animals to bulge when used as feed. The dry fodder prepared from vetch that was dry harvested at the beginning of flowering has 12–20 % crude protein, 6–10 % crude ash, 25–26 % crude fiber, and 45–46 % nitrogen-free core material (Sohail et al., 2021).

Net energy efficiency in vetch production under Siirt conditions was calculated as 82183.54 MJ/ha, considering only seed production. Similarly, Kokten et al. (2017a) determined net energy value of 21675.59 MJ/ha for fodder peas. Likewise, Kokten et al. (2017b) reported net energy value of 28987.50 MJ/ha for common vetch. In the same way Baran (2016) indicated net energy value of 76360.66 MJ/ha for vetch. When it comes to energy planning, energy efficiency is one of the biggest obstacles. Costs, GHG emissions, and environmental damage may all be mitigated by improving energy efficiency. The GHG emissions from agriculture will rise in the years to come which could not be ignored. One of the most

Table 3
Energy analysis in the production of vetch plant.

Inputs	Unit	Energy equivalent (MJ / unit)	Input used per hectare (unit ha^{-1})	Energy value (MJ/ha)	Rate (%)
Human labour	h	1.96	36.40	71.34	0.87
Machinery	h	64.80	12.10	784.08	9.56
Fertilizers			46.24	2562.56	31.23
Nitrogen	kg	60.60	41.40	2508.84	
Phosphorous	kg	11.10	4.84	53.72	
Diesel fuel	l	56.31	54.18	3050.88	37.18
Seed				1736.17	21.16
Vetch plant seed	kg	10	124.68	1736.17	
Total inputs				8205.02	100
Outputs					
Yield	kg	17.239 (22% dry matter)	23,833	90388.56	100

Table 4
Energy and yield results for vetch plant.

Calculations	Unit	Values
Vetch production	Kg / ha	23.83
Inputs' energy	MJ / ha	8205.02
Outputs' energy	MJ / ha	90388.56
Energy use efficiency		11.02
Specific energy	MJ / kg	0.34
Energy productivity	Kg / MJ	2.90
Net energy	MJ / ha	82183.54

Table 5
Energy input in the form of direct, and direct renewable and non-renewable energy for vetch plant production.

Type of energy	Energy input (MJ/ha)	Ratio (%)
Direct energy [a]	3122.22	38.10
Indirect energy [b]	5082.80	61.90
Total	8205.02	100
Renewable energy [c]	1807.50	22.00
Non-renewable energy [d]	6397.52	78.00
Total	8205.02	100

[a] Includes human labour, diesel; [b] Includes seed, chemical fertilizers and machinery.
[c] Includes human labour and seed; [d] Includes diesel, chemical fertilizers and machinery.

important aspects of eco-friendly farming is energy conservation. There has been a rise in the amount of energy needed to power farming. As the world's population and quality of living rise, unprecedented levels of agricultural inputs including fertilizers, machinery, and pesticides are being used. High energy consumption habits are widely used, endangering human and environmental health. Agriculture has the potential to become a more resilient economic production system and decrease environmental dangers by increasing its energy efficiency (Erdal et al., 2007). However, increased energy use brings up critical ecological concerns that might endanger human health. This means that sustainable agricultural production is dependent on effective utilization of inputs.

To produce vetch, the rates of direct, indirect, renewable, and nonrenewable energy were computed as 38.10 %, 61.90 %, 22.00 %, and 78.00 %, respectively (Table 5). In feed peas, indirect energy was less than direct energy, and renewable energy was less than non-renewable energy, according to Kokten et al. (2017a). As shown in Table 5, the total amount of energy used to produce vetch may be divided into two categories: direct energy input (38.10 %) and indirect energy input (61.90 %). Previous research showed that in canola, wheat, lentil, barley, and dry land wheat, the ratio of indirect energy is larger than the ratio of direct energy (Azizi and Heidari, 2013; Baran and Gokdogan, 2014). Table 5 demonstrates that 22.00 % of the total energy input used may be classified as renewable and 78.00 % as non-renewable. The ratio of non-renewable energy in wheat, maize, barley, and lentil has also been shown to be higher than the ratio of renewable energy (Azizi and Heidari, 2013).

3.2. Greenhouse gas (GHG) emission

Table 6 shows the findings of GHG emissions from vetch production. Total GHG emissions and GHG ratio were 205.19 kgCO_2-eq ha^{-1} and 0.009, respectively. The GHG emissions were caused by diesel (72.88 %), nitrogen (26.23 %), phosphorous (0.47 %), and equipment (0.42 %). In other studies, Ozbek et al. (2021) reported that total GHG emission from onion cultivation was 2920.73 kg CO_2-eq ha^{-1}. Similarly, Dilay and Gökdoğan (2021) calculated the total GHG emission of quinoa production as 382.42 kg CO_2-eq ha^{-1}. Likewise, Baran et al. (2019) calculated the total GHG emission of chickpea production was 1638.85 kg CO_2-eq ha^{-1}. It was observed that the highest energy inputs were fertilizer and fuel consumption. Fertilizer and fuel consumption had the highest share in GHG emissions.

Table 6
GHG emissions in vetch cultivation.

Inputs	Unit	GHG Coefficient (kgCO_{2eq} unit^{-1})	Input (unit ha^{-1})	GHG emissions (kg $CO_{2\text{-}eq}$ ha^{-1})	Ratio (%)
Machinery	MJ	0.071	12.10	0.86	0.42
Chemical fertilizers					
Nitrogen	kg	1.30	41.40	53.82	26.23
Phosphorous	kg	0.20	4.84	0.97	0.47
Diesel	l	2.76	54.18	149.54	72.88
Total	–	–	–	205.19	100.00
GHG ratio	–	–	–	0.009	–

Soil nitrous oxide emissions are the only direct source of GHG emissions from agricultural practices. By reducing the use of mineral fertilizers, indirect GHG emissions may be reduced. Reducing GHG emissions could be possible and sustainable, and a qualitative analysis of organic agricultural management might reveal this. New methods of reducing energy use and carbon dioxide emissions must be developed. This study looked at how efficiently energy was used in vetch farming in Turkey's Siirt area, as well as how much greenhouse gases were released throughout the process. In addition to calculating efficiency and GHG emission in energy consumption, this study has offered various suggestions to increase energy use efficiency and minimize GHG emission.

4. Conclusions

One of the most crucial challenges in energy strategies is energy efficiency. Energy efficiency decreases expenses, safeguards the environment, and cuts GHG emissions. The biggest energy inputs were found to be gasoline usage and fertilizer use. Additionally, the biggest percentage of GHG emissions were caused by fuel and fertilizer use. Programs for balanced fertilization that are based on assessments of the soil and plants may be crucial in lowering GHG emissions. This study showed that more research should be prioritized to decrease the amount of fertilizer and fuel oil used to produce vetch.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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