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The study of energy indices and greenhouse gas emissions in some crops production in the east of Golestan Province, A case study: Minoodasht township

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ABSTRACT

Increasing the CO_2, N_2O and CH_4 concentrations cause the global warming. Therefore, the fuel consumption, energy and greenhouse gas emissions in wheat, canola and sunflower productions in Minoodasht township were investigated. Data were collected from 60 wheats, 25 canola and 10 sunflower fields in 2021-2022 growing season. Energy input and greenhouse gas emissions per hectare was analyzed based on the fuel and input consumptions per each agricultural operation by related coefficients. Findings revealed that 140.46, 100.00 and 158.00 l/ha fuel diesel were needed to wheat, canola and sunflower production. Land preparation in wheat and canola production and harvesting the sunflower had the highest energy requirements and greenhouse gas emissions. The output to input energy ratio was calculated as 4.84, 4.94 and 3.69 in wheat, canola and sunflower productions, respectively. Also, in the wheat, canola and sunflower production, net energy was 62,743, 39,885 and 31,177 MJ, respectively, energy efficiency was 0.21, 0.19 and 0.13 respectively, and specific energy was 4.76, 5.26, 7.69 MJ/kg, respectively. According to the results, 1238, 904 and 1070 kg $eqCO_2$/ha were emitted from wheat, canola and sunflower fields, respectively. On average, 76, 89, and 92 g greenhouse gases were emitted for one MJ/ha energy consumed in wheat, canola, and sunflower productions, which is equivalent to 16, 18, and 25 g energy output, respectively. Finally, according to the obtained results, the chemical fertilizers consumption, especially nitrogen fertilizers, as well as the fossil fuels consumption account for an important part of energy consumption and greenhouse gases emissions.

Highlights

- Wheat uses 140.46 L/ha fuel, canola 100 L/ha, sunflower 158 L/ha in Minoodasht, 2021-2022.
- Energy efficiency: wheat 4.84, canola 4.94, sunflower 3.69; net energy highest in wheat.
- GWP: wheat 1238, canola 904, sunflower 1070 kg eqCO2/ha; N-fertilizers, fuel key emitters.
- Land prep in wheat/canola, harvest in sunflower lead energy use and GHG emissions.
- Wheat emits 76 g GHG/MJ input, canola 89 g, sunflower 92 g; optimizing inputs cuts emissions.

1. Introduction

Energy consumption has become more than before in agriculture by increasing the population growth and more fossil fuels demands (Fei and Lin, 2017). In addition, it is predicted that the energy consumption will increase due to the increased economic growth, soil degradation, climate change and global warming, as well as labor shortages. It is worth mentioning that high energy consumption will be a dangerous threat to maintain the agriculture sustainability, public health and environmental functions (Bergtold et al., 2017). Efficient consumption of energy is one of the main demands for sustainable agriculture

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(Ghorbani et al., 2011). The higher energy efficiency will provide the natural resources saving, reducing environmental damage and developing the sustainable agriculture (Yuan et al., 2018). Energy analysis of agricultural ecosystems is a useful method to determine the energy and environmental sustainability. Furthermore, optimizing the natural resources by more energy-efficient crop cultivation technologies, is needed to enhance the cost benefits and mitigate the environmental consequences (Gong et al., 2021). Accordingly, reducing the energy consumption and increasing the energy efficiency is very necessary to ensure the food sustainability and environmental security. The analysis of energy input and output is a promising assessment for analyzing energy flow and determining the optimal use of energy in crop productions (Kizilaslan, 2008). Sustainable environment dependent on the sustainable agriculture. Environmental factors have a great contribution to agriculture as compared to other. Higher energy use efficiency will promote sustainable agriculture by minimizing environmental problems and preventing the destruction of natural resources. (Imran et al., 2020).

The agricultural sector is important because it can be useful as a global solution to reduce the greenhouse gas emissions caused by human activities (Yuan et al., 2018). The share of agricultural activities in the greenhouse gas emissions is 10-12% of the total greenhouse gas emission (Brownea et al., 2011). Increasing the greenhouse gas concentrations in the atmosphere will cause the earth to warm up, and as a result, the atmosphere and oceans average temperatures will also increase (Pishgar-Komleh, 2012).

The production, transportation, storage and distribution of inputs as well as the use of machinery causes the combustion of fossil fuels, which results the greenhouse gas emissions into the atmosphere and global warming. Therefore, it is very necessary to know the intensity of greenhouse gas emissions based on the kilogram of carbon dioxide equivalent in various tillage operations, use of chemical fertilizers and pesticides, irrigation and harvesting methods (Lal, 2004).

The share of the world's arable land for grain cultivation is about 52%, which is approximately equivalent to 707 million hectares. The most cultivated area of wheat species in the world is common wheat (Triticum aestivum L.) or bread wheat, so that it includes approximately 95% of the wheat cultivated area in the world (Pourazri et al., 2013). Canola is the second oilseed crop in the world after soybean with 68 million ton productions (FAO, 2023). Sunflower is often cultivated as a source of vegetable oil. Its nutritional value and quality are often more than other oil crops. Sunflower has 40 to 60% edible oil. At present, more than 90% of the edible oil needed in the country is supplied through imports, therefore, it is important to cultivate the oil crops, including sunflower and canola, in Iran, especially in Golestan Province (Mousavi-Avval et al., 2011).

The reports indicated the different amounts of fuel consumption in wheat production. The fuel consumption calculated 65.00, 126.00 and 93.40 l/ha by Safa et al. (2011), Taghavifar and Mardani (2015) and Wang et al. (2014), respectively. The amount of greenhouse gases emissions due to the fuel consumption was evaluated as 460.06 ± 0.15 kg eq-CO_2 ha^{-1} (Rezvantalab et al., 2015), while some researchers estimated to be 203 and 455.2 kg eq-CO_2 ha^{-1} (Safa and Samarasinghe, 2012; Mohammadi et al., 2014).

A study evaluated the energy consumption in rain-fed wheat cultivation in China, stating that 56%, 22%, 14%, 4%, and 4% of the total energy consumption in rain-fed wheat production was attributed to the use of chemical fertilizers, pesticides, seeds, machinery, and human labor, respectively. The total energy consumption and energy efficiency were calculated 18200 MJ ha^{-1} and 2.9, respectively. This study considered the use of sandy mulch to increase the rain-fed wheat grain yield, which was able to enhance the energy use efficiency and net energy (Wang et al., 2019). In the terrace region of Turkey, by comparing energy indices in wheat production, energy use efficiency was reported 3.77. The main reason for the increased energy use efficiency was attributed to the higher wheat grain yield in the region. Additionally, the chemical fertilizers and fossil fuels consumptions were among the most significant sources of energy consumption in wheat production (Unakotan and Aydin, 2018). In a study aimed at assessing the environmental impact of sunflower production in the Halilan County of Ilam Province, Iran, was observed that the global warming potential for sunflower production was 2417.42 kg eq-CO_2 ha^{-1}. Electricity consumption, diesel fuel, and nitrogen fertilizers were the main sources of greenhouse gas emissions in sunflower production. Greenhouse gas emissions from electricity consumption were higher than from other inputs due to the use of the old electric pumps in the irrigation system. The carbon efficiency coefficient for sunflower cultivation was calculated 2.06 (Azizpanah et al., 2023).

The Minoodasht twonship, located in Golestan Province, Iran, has 25200 hectares of arable lands. So, 20,800, 950, and 105 hectares are allocated annually to the cultivation of wheat, canola, and sunflower, respectively. This study will examine fuel consumption, energy use, and greenhouse gas emissions, comparing these factors across wheat, canola, and sunflower to identify the best crop in terms of fuel consumption and reducing greenhouse gas emissions.

2. Materials and Methods

2.1. Data collection

Data were collected from 60 wheats, 25 canola and 10 sunflower fields in 2021-2022 growing season. The study was conducted in Minoodasht township using a random sampling method. The required data was collected through face-to-face interviews with the producers and by taking notes on all agricultural operations. The operations included plowing, disking, cultivating, chemical spraying, etc. Information was recorded based on the duration of each agricultural operation, the amount of fuel consumed per hectare for each operation, the types of machinery used, the number of operations, the variety and seeds used amount, the types of chemical fertilizers, the types of pesticides used to control weeds, pests, and diseases, and finally the yield of the agricultural products mentioned in each sampled fields. At the end of the survey, information such as the area under cultivation and the type of pervious crop planted was recorded in each field. After recording the mentioned information, an assessment of energy flow and greenhouse gas emissions was conducted.

2.2. Energy analysis

Energy flow in the fields can be divided into energy input and energy output which the energy input (consumable) was classified in direct and indirect energy in many studies (Rathke et al., 2007; Tipi et al., 2009; Kaltsas et al., 2007).

Direct energy (MJ/ha) includes (1) the fuel consumption in various field operations including land preparation, sowing, fertilizing, plant protection, irrigation, and harvesting; (2) electricity for water pumping; and (3) the use of human labor. Indirect energy (MJ/ha) includes (1) the energy used for manufacturing, warehousing, and transportation of chemical fertilizers; (2) the energy used for manufacturing, warehousing, and transportation of chemical pesticides; (3) the energy used to manufacture, repair and maintenance of equipment and agricultural machinery; (4) Energy in seeds, as well as the need for winnowing energy, packaging, and storage (Rathke et al., 2007).

Firstly, energy consumed in each field based on Mega Joule per hectare (MJ/ha) was calculated as follows.

In order to calculate the fuel energy, the working time of machine was recorded separately at the beginning of any operation from start to end of the production process. Then, fuel consumption was calculated by the following equation (1) according to the past experiences of machinery drivers.

$$FT = t * FH \quad (1)$$

FT: fuel needed to perform the field operation (L ha^{-1}); t: working time of the machine; FH: fuel needed to perform the field operation (L h^{-1}).

Energy conversion ratios were used to calculate the fuel amounts to the consumed energy (Table 1).

Energy for agricultural machinery and equipment was calculated as mentioned above:

$$EM = (E \times W Lt) t \quad (2)$$

EM: machinery and equipment energy for farming operations (MJ ha^{-1}); E: Energy for manufacturing, repair, maintenance, and transportation of machinery and equipment (MJ kg^{-1}); W: machinery and equipment weight (kg); Lt: the useful lifetime for machinery and equipment (hours); t: time needed for operation (h ha^{-1}); E: constant value and equal to 142.7 MJ kg^{-1} (Table 1) (Kaltsas et al., 2007).

In order to assess the energy consumption for chemical pesticide application, the percentage of active ingredients was identified in each pesticide (Table 2). Also, specific gravity was determined for liquid pesticides. Then, used net weight values were calculated by multiplying the specific gravity in the percentage of the active ingredient. Afterwards, the total energy consumed for each of the pesticide was calculated based on the amount of energy used for the production of each pesticide (Table 1). Formulating the pesticides also requires energy, which added 20 MJ kg^{-1} to energy consumption. Pesticides transportation to their consumption place requires energy that is not considerable (Clements et al., 1995).

To calculate the fertilizer energy consumption, fertilizer types and amounts were recorded. Then, the main ingredient of fertilizers was determined based on nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) in each fertilizer (Table 3). Total energy consumption was calculated by multiplying the amount of consumed energy in the main substance (Table 1).

In order to calculate the energy consumption for seed, seed amount (kg) per hectare was determined. In the next stage, the energy per one kilogram of seed was determined (Table 1). The energy consumption for seed was calculated by multiplying two parameters in each field.

The energy output was assessed by multiplying the harvested seed by its energy equivalents (Table 1). Based on the total energy equivalents of the inputs and output, energy use efficiency, energy productivity, specific energy, and net energy were calculated using the following equations (4-7) (Kazemi et al., 2015b):

Energy use efficiency=Output energy (MJ/ha)/Input energy (MJ/ha) (3)

Energy use productivity (kg/MJ)=Seed yield (kg/ha)/Input energy (MJ/ha) (4)

Specific energy (MJ/kg)=Input energy (MJ/ha)/Seed yield (kg/ha) (5)

Net energy (MJ/ha)=Output energy (MJ/ha)−Input energy (MJ/ha) (6)

GHG emissions can be calculated and represented per unit of the land used in crop production, per unit weight of the produced seed, and unit of the energy input or output. Firstly, the energy amount of each fuel source used in the manufacture and transportation of production inputs including seed, machinery, fertilizer, and pesticide, and fuel consumption in production operations was obtained using proportions. Then, using CO_2, N_2O, and CH_4 gas emission factors including 1, 310, and 21 kg CO_2, the total GHG emission was calculated equivalent to CO_2 (Soltani et al., 2013).

For these calculations, it was assumed that the electricity in Iran is generated by sources in the following proportions: 0.18% from coal, 16.6% from oil, 80.8% from natural gas, 2.3% from water generators, and 0.09% from wind generators (IEA, 2009). GHG emissions were determined per one hectare, one tone of crop produced, and one MJ of total input and output energy (Soltani et al., 2013).

3. Results of discussion

3.1. Wheat

The results indicated that the filed areas under wheat cultivation varied from 1 to 22 hectares, 85 percent was less than 10 hectares. Wheat planting typically took place from 30th November to 10th December. For the initial seedbed, 90 percent of farmers used a single plowing, while 10 percent used double plowing. The number of secondary tillage operations recorded between 1 to 3 times. The most common planting tool was the row seed drill. The average amount of seed used for planting was 200 kg ha^{-1} depending on the seed quality, planting date, and type of planting equipment. Overall, farmers applied fertilizer 3 times (in the form of base and top-dressing). Most farmers used urea fertilizer as a base fertilizer (Table 3). Top-dressing was mainly applied during tillering, stem elongation, and flowering, depending on the plant's demand. A total of 3 types of pesticides were used. The pesticides used included Topik, Granstar, Tilt, and Diazinon. A boom sprayer was primarily used for weed control, while a tractor-mounted sprayer was used for pest and disease management. Wheat harvesting took place from mid to late June. The harvest date depended on the crop maturity, seed moisture content, weather conditions, and availability of the combine harvester. On average, wheat grain and straw yields were recorded at 3500 and 4000 kg ha^{-1}, respectively.

Table 1. Energy equivalents for inputs and outputs in wheat, canola and sunflower production.

Inputs	Unit		References
Wheat grain	kg	15.7	(Pimental and Pimental, 2008)
seed Canola	kg	25	(Mousavi-Avval et al., 2011)
Sunflower	kg	28.5	(Sheikh and Houshyar, 2009)
Human labor	h	1.96	(Turhan et al., 2008)
Machinery	kg	142.7	(Kaltsas et al., 2007)
N	kg	60.6	(Akcaoz et al., 2009)
P2O5	kg	11.1	(Akcaoz et al., 2009)
K2O	kg	6.7	(Akcaoz et al., 2009)
Fossil fuel	l	38	(Hydrocarbon balance sheet of Iran, 2006)
Herbicides	kg i.e	287	(Tzilivakis et al., 2005)
Fungicide	kg i.e	99	(Strapatsa et al., 2006)
Insecticides	kg i.e	237	(Tzilivakis et al., 2005)
Outputs			
Wheat grain	kg	14.7	(Singh et al., 2007)
Wheat straw	kg	6.9	(Singh et al., 2007)
Canola seed	kg	25	(Mousavi-Avval et al., 2011)
Sunflower seed	kg	28.5	(Sheikh and Houshyar, 2009)

Table 2. Specific weight and percentage of effective substance of different pesticides used in crop production.

Chemical types	Chemical name	Specific weight	Effective ingredient (%)
herbicides	Granstar	-	75
	Topik	1.6	35
	Terflan	2.5	48
	2,4,D	1.22	67.5
Fungicides	Tilt	0.99	25
	Alto100	1.3	60
	Rural	1	52
Insecticides	Diazinon	1.18	60
	Larvin	1.40	80
	Malation	1.23	57
	Cypermethrin	1.24	40
	Select super	1	1.15

Table 3. The percentage of main elements in different fertilizers used

Fertilizer types	Chemical ingredient
Diammonium phosphate	P2O5(46%), Nitrogen (18%)
Triple superphosphate	P2O5(46%)
Macro	P2O5(8%), Nitrogen (15%), Potassium (15%)
Sulfate of potassium	Potassium (48%)
Urea	Nitrogen (46%)

3.2. Canola

In canola cultivation, the field areas varied from 0.5 to 5 hectares, 80 percent was less than 5 hectares. The most common crop grown before canola was soybean. The planting date typically extended from mid-November to mid-December. All farmers used a single plowing for the initial seedbed preparation. The number of secondary tillage operations was recorded as 1 to 3 times. The seed amount used by farmers recorded 4 kg ha^{-1}. Overall, farmers applied fertilizer to canola fields 2.95 times (in both base and top-dressing). In most canola-cultivated fields, urea fertilizer was used as the base fertilizer. The average top-dressing was recorded as approximately 2 times per field in rosette and seed filling stages. The pesticides used included the herbicides Cypermethrin and Select Super, as well as the fungicide Rural. A boom sprayer was mainly used for weed control, while a tractor-mounted sprayer was used for disease management. The canola harvest took place from early to late June. On average, 2000 kg was harvested per hectare.

3.3. Sunflower

According to the findings, the field areas cultivated under sunflowers was recorded as 2-12 hectares, 90 percent of fields was less than 10 hectares. The most common crops grown before sunflowers were wheat and barley, which accounted for 80 percent of the fields. The final harvest of wheat and barley was completed by the end of June. Sunflower planting generally began in early July and completed by July 10. Only one plowing was performed to initial seedbed preparation. The number of secondary tillage operations for sunflower cultivation was 1-3 times. The most common planting method for sunflowers was hand broadcasting. The amount of seed used was 7-8 kg ha^{-1}. The Hyson cultivar was the only variety used for sunflower cultivation. Overall, farmers applied fertilizer to their sunflower fields twice (as a base and top-dressing). Most farmers used urea fertilizer as the base fertilizer. The top-dressing was mainly applied once, during the 4-5 leaf stage, depending on the plant's needs. Two types of herbicides were recorded, including Select Super and Terflan. A tractor-mounted sprayer was used for weed control before planting, and a boom sprayer was used after germination. Sunflower harvesting took place in late September. On average, 1500 kg ha^{-1} sunflower seeds were harvested.

3.4. Energy Consumption and greenhouse gas emissions from inputs

Tables 4, 5, and 6 indicate the amount of input consumption, energy consumption, and greenhouse gas emissions resulting from the use of inputs in one hectare of wheat, canola, and sunflower fields. In wheat production, the energy consumed from chemical fertilizers, fossil fuels, seed usage, machinery, pesticide consumption, and human labor were ranked from the highest to lowest energy consumption, with fossil fuel and chemical fertilizer consumption accounting for a total of 76 percent of the overall energy consumption. Consequently, the highest level of greenhouse gas emissions was attributed to the chemical fertilizers and fossil fuels consumption, followed by the machinery application and chemical pesticides. Energy consumption in the rain-fed wheat production in China indicated that 56, 22, 14, 4, and 4 percent of total energy consumption was related to the chemical fertilizer consumption, chemical pesticides, seeds for planting, machinery application, and human labor utilization, respectively (Wang et al., 2019). The present results showed that the energy derived from chemical fertilizers, fossil fuel consumption, machinery application, pesticide use, and human labor were ranked from the highest to lowest in canola production (Table 5). As a result, the chemical fertilizers consumption, fossil fuels, machinery application, and pesticide also corresponded to the highest to lowest levels of greenhouse gas emissions. In sunflower production, the highest energy consumption was attributed to fossil fuel and chemical fertilizer use, while machinery application, pesticide consumption, and human labor were evaluated in the subsequent ranks. Azizanpah et al (2023) reported that the electricity consumption, fossil fuels, and nitrogen fertilizers were the main sources of carbon dioxide emissions in sunflower production in Ilam, Iran.

The energy derived from wheat seeds accounted for 19.25% of total energy consumption (Table 4). Therefore, it is essential to avoid unnecessary use of wheat seeds for planting as much as possible. A study conducted in Gorgan reported that the combinate seeder in wheat planting was associated with lower seed consumption, while the use of a centrifugal seed broadcasting was linked to higher seed consumption. Ultimately, they stated that by using new equipment such as combinate seeder, it is possible to save on seed and input energy consumption as well as unnecessary costs in crop production (Rezvantalab et al., 2015). The share of seed energy in canola and sunflower cultivation constituted 0.61% and 1.22% of the total energy, respectively, which is very minimal (Table 5). Mousavi Avval et al., (2011) also assessed the share of seeds used in sunflower production by 2.4%.

By examining the findings in the section on energy consumption resulting from chemical fertilizers in wheat production, it can be stated that the energy consumed averaged 6624.6 MJ ha^{-1}, with nitrogen-containing fertilizers accounting for 24.89 percent. Additionally, the energy consumption from phosphorus and potassium-containing fertilizers was 17.8 and 57.2 percent, respectively (Table 5). It is worth mentioning that nitrogen fertilizers were used in all fields, while phosphorus and potassium fertilizers were used in 93 and 50 percent of the fields, respectively. The studies showed that the organic fertilizers were not used in any of the wheat-cultivated fields. The chemical fertilizers application resulted 510.35 kg eq-CO_2 ha^{-1} greenhouse gas emissions in each wheat-cultivated farms, with the highest emission levels associated with the use of nitrogen-containing fertilizers, similar to the energy consumption patterns. Other chemical fertilizers had a lesser role in greenhouse gas emissions (Table 6). Since the share of energy consumption and greenhouse gas emissions is high by nitrogen fertilizers consumption, it can be said that reducing the nitrogen-containing fertilizer consumption in each wheat-cultivated field will have a very significant impact on reducing energy consumption and greenhouse gas emissions. In canola cultivation, 49.56 percent of total energy consumption was attributed to the use of chemical fertilizers, with nitrogen fertilizer consumption estimated 83.38 percent. Phosphorus and potassium-containing fertilizers accounted for 10 and 6.24 percent of energy consumption, respectively (Table 5).

In canola cultivation, the application of chemical fertilizers resulted 15.398 kg eq-CO_2 ha^{-1} greenhouse gas emissions, was the highest by use of nitrogen-based fertilizers. Table 6 illustrate that other chemical fertilizers had a significantly lower role in greenhouse gas emissions compared to the nitrogen-based fertilizers application. Accordingly, nitrogen-based fertilizers application was a key factor in energy consumption and greenhouse gas emissions. Therefore, reducing the use of nitrogen fertilizers, a significant role can be played in decreasing energy consumption and greenhouse gas emissions in canola production.

In sunflower production, 29.5 percent of input energy was allocated to chemical fertilizers, especially nitrogen-based fertilizers, with the shares of nitrogen, phosphorus, and potassium-based chemical fertilizers evaluated 82, 11.22, and 7 percent, respectively (Table 5). Also, organic fertilizers were not used in sunflower production fields. As observed in the sunflower production, chemical fertilizers led to 17.274 kg eq-CO_2 ha^{-1} greenhouse gas emissions, was the most closely associated with the nitrogen-based fertilizers application. Other chemical fertilizers also had a minor role in greenhouse gas emissions (Table 5 and 6). In the sunflower production, the share of fossil fuel in input energy consumption and greenhouse gas emissions was determined to be 51.87 and 47.73 percent, respectively. Therefore, the fossil fuel and the greenhouse gas emitted in the sunflower production were higher compared to other inputs, including nitrogen chemical fertilizers (Tables 5 and 6).

In New Zealand, Safa and Samarasinghe (2012) estimated that the greenhouse gas emissions from the chemical fertilizers consumption in wheat production amounted to 52 percent, equivalent to 539 kg eq-CO_2 ha^{-1}, with 48 percent attributed to nitrogen-based fertilizers. Omidmehr (2018) calculated the energy consumed for nitrogen fertilizer in sunflower production as 4960 Mj ha^{-1}, which accounted for 47 percent of the total energy consumption. Jankowski et al (2015) assessed the share of energy consumption from chemical fertilizers was 80 percent of input energy in canola production. The intensity of nutrient input (N mainly) and intensity of all the inputs during the vegetation period play a role in the overall environmental impact (Bernas et al., 2023).

Various methods have been proposed to reduce energy consumption and greenhouse gas emissions originating from chemical fertilizers, particularly nitrogen-based fertilizers in agricultural production such as the proper implementation of crop rotation, attention to the production methods of chemical fertilizers that have higher fuel and energy efficiency, improving the application methods of chemical fertilizers—especially nitrogen fertilizers—such as multi-stage application and timing that aligns with the crop growth, and producing chemical fertilizers that have higher absorption efficiency and are non-leachable. Additionally, the use of nitrification inhibitors and urease inhibitors, better irrigation management conducted at appropriate times alongside the application of chemical fertilizers, soil sampling before planting to accurately determine the nutrient requirement of plants, and the selection and breeding of plants with lower nutrient requirements (Safa and Samarasinghe, 2012; Pimental and Pimental, 2008; Nemecek et al., 2008; Ahmadi and Aghajani, 2012).

According to Table 5, the energy required to control weeds, insects, and fungi with chemical pesticides was 164.31, 167.59 and 24.51 Mj ha^{-1} respectively. In total, 356.60 Mj ha^{-1} energy was consumed to control pests, diseases, and weeds during wheat production. In the wheat-producing fields that consumed the most energy with chemical pesticides, several fungicides were often used.

In the production of canola, 233.43 MJ ha^{-1} energy were consumed due to the use of chemical pesticides, with the share of insecticides being zero percent. Additionally, the greenhouse gas emissions from each hectare of canola were reported 37.61 kg eq-CO_2 ha^{-1}. In sunflower production, where only herbicides and insecticides were used, 456.65 Mj ha^{-1} energy were consumed, and greenhouse gas emissions amounted to 73.57 kg eq-CO_2 ha^{-1}. Therefore, the energy consumption and greenhouse gas emissions originating from chemical pesticides in sunflower production were estimated the highest, while in canola were the lowest (Table 6). Omidmehr (2018) also reported the amount in the Miyai County for sunflower production as 199 MJ ha^{-1}. Among the methods, the application of natural methods for controlling pests and plant diseases can be noted to reduce the use of chemical pesticides. These methods include increasing the resistance genes of crops to pests, diseases, and weeds, strengthening their natural enemies, properly implementing crop rotation, practicing conservation tillage, and producing forage plants and planting trees in fields (Pimental and Pimental, 2008; Safa et al., 2011).

Fossil fuel consumption was 140.46, 100.00, and 158.00 l ha^{-1} in wheat, canola, and sunflower production, respectively (Table 4). In various studies, fuel consumption in wheat production was evaluated 92, 126, 93, 125, and 65 l ha^{-1} (Soltani et al., 2013; Taghavifar and Mardani, 2015; Wang et al., 2019; Safa et al., 2011; Safa and Samarasinghe, 2012). Safa and Samarasinghe (2012) reported the greenhouse gas emissions from fuel in wheat production as 203 kg eq-CO_2 ha^{-1}, while Mohammadi et al. (2014) reported 2.455 kg eq-CO_2 ha^{-1}. In wheat, canola, and sunflower productions 5367, 3804, and 6004 MJ ha^{-1} energy from fossil fuel were consumed, respectively (Table 5). Consequently, 33.73%, 32.85%, and 43.70% of greenhouse gas emissions were attributed to fossil fuel consumption (Table 5, 6). According to the results, the share of machinery uses in wheat, canola, and sunflower productions were estimated 7.06%, 7.46%, and 9.69% of the total input energy, respectively (Table 5). Also, 17.90, 18.20, and 32.08 labor hours were required in wheat, canola, and sunflower production, respectively (Table 4), and the share of energy consumption was 44.37%, 210.3%, and 351% of the total input energy, respectively (Table 5).

Therefore, based on the findings presented, the use of appropriate amounts of fossil fuels and chemical fertilizers, especially nitrogen-based fertilizers to reduce energy consumption and greenhouse gas emissions in wheat production, seems essential because 71 percent of energy consumption and 66 percent of greenhouse gas emissions were attributed to the use of nitrogen fertilizers and fossil fuels. A study suggested reducing the consumption of nitrogen fertilizers and fossil fuels for cleaner wheat production in terms of energy consumption and greenhouse gas emissions in Golestan Province (Soltani et al., 2013). In canola production, optimal use of chemical fertilizers and fossil fuels can significantly save energy consumption and prevent the excessive greenhouse gas emissions. Additionally, in sunflower production, 30.00 percent and

52.04 percent of energy consumption and greenhouse gas emissions, respectively, were due to the use of chemical fertilizers and fossil fuels. By optimizing the use of chemical fertilizers, especially nitrogen fertilizers, and fossil fuels, particularly in land preparation and harvesting, energy consumption and greenhouse gas emissions can be significantly reduced.

In evaluation under Pannonian climate conditions reported that the energy efficiency indicator NEO, which shows the area-based energy gain, was estimated highest with 160.2 kg N ha^{-1} , which is from the point of soil N accumulation and potential N emission (N_2O into the atmosphere and NO_3-N leaching into the aquifer) not sustainable for this pedo-climatic region. From the ecological point of view, zero N fertilization showed the best indicators energy use efficiency, energy input, and energy productivity (Moitzi et al., 2024).

Table 4. Amounts of input consumption in wheat, canola and sunflower production in Minodasht.

Inputs	Unit (per hectare)	Wheat	Canola	Sunflower
N	kg	92	69	46
P_2O_5	kg	46	46	34.5
K_2O	kg	24	48	36
Herbicides	kg	0.58	0.63	0.78
Fungicides	kg	0.25	0.52	-
Insecticides	kg	0.71	-	0.70
Seed	kg	200	4	8
Machinery	h	26.8	19.05	26.5
Fossil fuel	l	140.46	100	158
Human labor	h	17.9	15.2	32.08
Crop yield	kg	3500	2000	1500

Table 5. Amounts of energy consumption (MJ ha^{-1}) in wheat, canola and sunflower production in Minodasht.

Energy consumption	Wheat	Canola	Sunflower
N	5575	4181	2788
P_2O_5	510.6	511	383
K_2O	161	322	241
Total energy of fertilize	6246.6	5014	3411.75
Herbicides	164.31	181.96	255.43
Fungicides	24.51	51.48	-
Insecticides	167.59	-	201.22
Pesticides	356.60	233.43	456.65
Seed	3140	100	228
Machinery	1152	755.31	1122
Fossil fuel	5367	3804	6004
Human labor	35.08	29.79	351
Input energy	16307	10115	11573
Output energy	79050	50000	42750

Table 6. Amounts of greenhouse gas emissions (kg eq-CO2 ha^{-1}) in wheat, canola and sunflower production in Minodasht.

Inputs	Wheat	Canola	Sunflower
N	446.32	329.85	223.32
P_2O_5	41.9	41.9	31.41
K_2O	13.2	26.4	19.76
Total energy of fertilize	501.38	398.15	274.17
Herbicides	26.42	29.31	41.51
Fungicides	3.95	8.30	-
Insecticides	26.99	-	32.42
Pesticides	57.36	37.61	73.57
Machinery	261.62	171.53	254.81
Fossil fuel	418.62	296.72	468.32
Total Greenhouse gasses emission	1238.98	904.01	1070.87

3.5. Energy indices

The energy consumed in wheat production was recorded as 16307 MJ ha^{-1}, with direct and indirect energy shares evaluated 68% and 32%, respectively (Table 7). In the present study, the use of nitrogen-based fertilizers and fossil fuels accounted for 70% of the total energy consumption in wheat production; therefore, reducing energy consumption in these two parameters would significantly decrease overall energy use. In Golestan Province, the total input energy consumed in wheat production was assessed 15411 MJ ha^{-1}, with direct and indirect energy shares reported 65% and 35%, respectively. In a study conducted on wheat production in northern Khuzestan Province, the total energy consumed was reported as 16500 MJ ha^{-1}, with chemical fertilizers, fossil fuels, and seeds accounting for 60%, 25%, and 15% of energy consumption, respectively. It is noteworthy that in the aforementioned study, the share of energy from nitrogen-based fertilizers constituted 95% of the total energy consumed from fertilizer application (Kiani and Houshyar, 2012). In canola production, 10115 MJ ha^{-1} energy were utilized, with direct and indirect energy shares reported at 60% and 40%, respectively (Table 7). Additionally, the results showed that the largest portions of direct and indirect energy were due to the consumption of fossil fuels and nitrogen-based fertilizers, respectively (Table 7).

Therefore, the entry of excess energy was significantly prevented by optimizing the use of fossil fuels. The findings indicated that the total energy input consumed for the sunflower production was evaluated at 11573 MJ ha^{-1}, with direct and indirect energy contributions accounting for 55% and 45%, respectively. Additionally, based on the results, the consumption of fossil fuels and nitrogen-based fertilizers had the highest shares of direct and indirect energy, respectively (Table 7).

The energy output was estimated 79050 MJ ha^{-1}, in wheat production. Rezvantalab et al. (2015) reported an output energy was 50200 MJ ha^{-1} in wheat production in Golestan Province. The findings showed that the output energy for canola and sunflower production were 50000 and 42,750 MJ ha^{-1}, respectively. The energy output to input for wheat, canola, and sunflower production were evaluated 4.84, 4.94, and 3.69, respectively (Table 7). It can be said that the lower seed yield in sunflower compared to the two crops of wheat and canola, along with the higher consumption of fossil fuels in sunflower production, has led to a decrease in energy output and an increase in energy input, ultimately resulting in a reduced ratio of energy output to input in sunflower production.

In a study conducted in Iran, the energy efficiency in the production of irrigated and rain-fed wheat was estimated 1.32 and 1.20, respectively, from 1999 to 2006 (Beheshti Tabar et al., 2010). They also reported energy efficiency for some crops in Iran for irrigated products such as wheat (1.32), barley (1.22), potatoes (0.85), corn (1.81), onions (0.86), sugar beets (1.77), lentils (0.70), chickpeas (0.73), watermelons (0.93), soybeans (1.78), cucumbers (0.38), tomatoes (0.47), and cotton (0.49).

According to the results presented in Table 7, the net energy in wheat production compared to canola and sunflower productions was 2.63 and 4.9, respectively. This indicated that a higher total output energy led to an increase in the net energy received compared to wheat and canola. Zenter et al (2004) also reported the net energy received for wheat cultivation between 32 to 40 MJ ha^{-1}, specifically for the seed production. Higher energy output and lower energy input in crop production systems increased net energy gain (Bhunia et al., 2021). In wheat, canola, and sunflower production 0.21, 0.19, and 0.13 kilograms were produced per each mega joule of energy consumed per hectare, respectively (Table 7).

The increased use of nitrogen-based fertilizers and fossil fuels will be a significant factor in reducing the productivity. Since specific energy has an inverse relationship with energy efficiency, it can be said that by increasing yield and reducing energy consumption in the use of chemical fertilizers and fossil fuels for agricultural operations, energy consumption per kilogram of product can be reduced. Soltani et al. (2013) reported an average energy efficiency as 0.27 in six scenarios evaluated for wheat production in Gorgan. The results showed that higher yields and lower energy inputs led to increased energy efficiency and reduced specific energy. Additionally, Rezvantalab et al. (2015) found that the using more efficient machinery can reduce the duration of machinery use and ultimately fuel consumption, which can increase energy efficiency and the energy output/input ratio per hectare, thereby reducing energy consumption per kilogram of grain.

They also stated that using cultivars with higher yield potential and better agricultural management in the wheat and soybean productions, which leads to increased yields, can also enhance energy efficiency and the energy output/input ratio.

3.6. GWP indices

As the results, the total greenhouse gas emissions in wheat, canola, and sunflower production were 1238, 904, and 1070 kg eq-CO_2 ha^{-1}, respectively (Table 8). GWP per kilogram of product decreased by increasing the crop yield. Therefore, higher grain yields in wheat production resulted the lower greenhouse gas emissions per kilogram of product compared to canola and sunflower production (Table 8). The calculated GWP per one mega joule of energy input used in wheat production was higher than the other two crops due to the higher energy consumption for producing the wheat compared to canola and sunflower (Table 8). Additionally, the GWP per unit of energy output was also assessed to be greater, because higher energy output in wheat production compared to canola and sunflower production (Table 8). In Golestan Province, 160 g eq-CO_2 were emitted into the atmosphere in one kilogram of wheat produced. Furthermore, for each mega joule of energy consumed directly or indirectly in wheat production, 80 g eq-CO_2 equivalent were released, resulting in 14 g MJ^{-1} of energy output (Rezvantalab et al., 2015). Ultimately, it can be said that paying attention to the optimal use of nitrogen fertilizers and fossil fuels can play a significant role in reducing greenhouse gases emissions. As previously mentioned, using high-horsepower tractors and equipment with greater working width and penetration depth can lead to energy savings and consequently reduce greenhouse gas emissions.

Table 7. Energy indices in wheat, canola and sunflower production in Minoodasht.

Energy indices	Wheat	Canola	Sunflower
Direct energy	5411	4014	6355
Indirect energy	10869	6101	5218
Total input energy	16307	10115	11573
Total output energy	79050	50000	42750
Output energy/input energy	4.84	4.94	3.69
Net energy	62743	39885	31177
Energy productivity	0.21	0.19	0.13
Specific energy	4.76	5.26	7.69

Table 8. Energy indices in wheat, canola and sunflower production in Minoodasht.

GWP indices	Wheat	Canola	Sunflower
GWP per hectare	1238	904	1070
GWP per crop yield	0.35	0.45	0.71
GWP per input energy	0.076	0.089	0.092
GWP per output energy	0.016	0.018	0.025

4. Conclusion

The results showed that wheat production requires less energy compared to canola and sunflower, and consequently, fewer greenhouse gas will be emitted into the atmosphere. The land preparation operations for wheat and canola cultivation, as well as the harvesting of sunflower, had the highest energy requirements and greenhouse gas emissions. For each hectare of wheat, canola, and sunflower produced, 76, 89, and 92 g greenhouse gases were emitted per mega joule of energy consumed, respectively, while the estimated emissions for energy output were 16, 18, and 25 g, respectively. Finally, total energy input in wheat production was more than in canola and sunflower productions. But energy use efficiency in wheat and canola productions were more than in sunflower production. Ultimately, it can be stated that the use of chemical fertilizers, particularly nitrogen-based fertilizers, as well as fossil fuels, accounted for the majority of energy consumption and greenhouse gases emissions. If the consumption of these inputs is optimized, there will be a significant reduction in energy consumption and greenhouse gases emissions for wheat, canola, and sunflower production.

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