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Investigation the energy indices and greenhouse gases emission in soybean production, Golestan Province

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Introduction: Inputs such as chemical fertilizers, fossil fuels, electricity, seed, and machinery consume energy in soybean production. This energy consumption is expected to cause Greenhouse Gases Emissions (GHG). Increasing the concentration of these gases in the atmosphere could lead to Global Warming. The purpose of this study was to investigate the energy consumption and GHG in soybean production in Golestan Province, Iran.

Material and methods: In this study, 140 farmers were selected to investigate the soybean production systems in Golestan Province in northeastern Iran. The data of consumed energy (machines, seeds, fertilizers, fuel, pesticides, human labor, and electricity) were collected by a questionnaire. Then fuel, input and output energy, energy indices, and global warming potential (kg eq-CO_2/ha) were calculated by related coefficients.

Results and discussion: Based on results, fuel and energy requirements for soybean production were estimated 210.83±0.09 L/ha and 19036.08±2.53 MJ/ha, respectively. Also, GHG emissions were calculated 2306.85±3.17 kg eq-CO_2/ha. Fossil fuel and electricity consumption had the highest energy consumption and GHG emissions values, respectively, so that 62% of the total energy consumption and 75% of the total GHG emission belonged to electricity and fossil fuel consumption, respectively. Energy output derived from soybean

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was 42124.95±0.73 MJ/ha. The output-input ratio was estimated 2.21±0.01. Net energy gain was raised by increasing the seed yield and decreasing the input consumption such as electricity, fossil fuel, and N-fertilizer. Energy productivity was calculated 0.147±0.01 Kg/MJ. On average, 2306.85±3.17 kg eq-CO_2/ha greenhouse gases were released into the atmosphere for soybean seed production.

Conclusion: Focusing on optimal consumption of fossil fuels and decreasing the electricity consumption in irrigation is essential for reducing the energy consumption and greenhouse gas emissions for soybean production in Golestan Province, Iran.

Keywords: Energy use efficiency, Global warming potential, Greenhouse gas emission, Input energy

Introduction

Nowadays, the agricultural sector is largely dependent on energy consumption as a result of responding to increasing food requirements for the growing population of the Earth and providing adequate and appropriate foods (Hatirli *et al*., 2006). In order to evaluate agriculture sustainability, energy efficiency can be considered in cropping systems. The intensive use of inputs leads to environmental problems that threaten the health of society (Barut *et al*., 2011). However, further crop production without considering the environmental issues and lack of evaluation of the energy indices does not seem logical (Moreno *et al*., 2011). On the other hand, the high price and limitation of energy resources used in agricultural products are also other important reasons for energy analysis in agricultural ecosystems. Also, the energy shortage and importance of agriculture in feeding the world’s population have gained the attention of many researchers to evaluate the quantities of fuel and energy in different products and sites. Energy use in agriculture can be divided into two components as direct and indirect energy. Direct energy is the consumption of fuels, electrical, water, and human energy in various cropping operations. The indirect component is the necessary energy for the production and delivery of farm inputs (fertilizers and chemicals), machinery and equipment, etc. (Mohammadi *et al*., 2008; Barut *et al*., 2011).

Consideration of environmental impacts of crop production, including GHG emission which has a very important role in the climate change process, is also a very noticeable aspect in terms of ecological concepts. Crop management practices such as tillage, pesticides, fertilizing, crops, and rotations used within a crop production system may affect the energy balance of that system.

In some low input farming system, e.g. in large areas of Africa, the energy input is lower than 1 GJ/ha, whereas in some modern high-input farming systems in Western Europe, it can exceed 30 GJ/ha (Khaledian *et al*., 2010; Barut *et al*., 2011). In Iran, several studies have been conducted on fuel and energy consumption in some crops. Among these investigations, Alimagham *et al*. (2017), Ramedani *et al*. (2011), Rjayifar *et al*. (2014), Mousavi-Avval *et* *al*. (2011), Soltani *et al*. (2013), Kazemi *et al*. (2015), Kazemi *et al*. (2016), Beheshti Tabar *et al*. (2010), etc. can be noted. However, research on GHG emissions in different crops is less conducted than energy analysis investigations (Soltani *et al*., 2013; Alimagham *et al*., 2017). Ramedani *et al*. (2011) carried out an investigation with aim of energy analyses and input sensitivity evaluation in soybean production. Their result showed that the fuel consumption was estimated 200.64 L/ha that was 64 % of the total energy inputs. Also, input and output energies were calculated 18026.50 and 71228.86 MJ/ha, respectively. The share of fossil fuels was recorded highest with 67.66%, followed by N-fertilizers and water consumption with 14.32% and 18.6%, respectively. They stated that one of the reasons for high fuel consumption in soybean production is the use of worn-out tractors, which could increase fuel consumption in various farming operations (Ramedani *et al*., 2011).

In another study, fuel consumption for soybean production was estimated 285.69 L/ha with a share of 50.65 % from total energy inputs. They found that improving the efficiency of electric motors and providing educational guides for farmers to choose the best management approaches can reduce energy consumption equal to 34.9% in electricity, 8.6% in fertilizers, and 8.9% in diesel fuel consumption for soybean production (Rajaeifar *et al*., 2014). Also, lack of proper leveling of agricultural land leads to water losses at the farm and, consequently, more fuel consumption (Mousavi-Avval *et al*., 2011). Electricity energy equivalent for Iranian electricity production is higher than developed countries because Iran’s electricity grid is highly dependent on fossil fuels, so that 95% of the electrical energy in Iran is generated in thermal power plants using fossil fuels sources (Rajaeifar *et al*., 2014). Also, the electricity transmission system is too old (Rajaeifar *et al*., 2014, Tabatabaie *et al*., 2013). This situation shows the necessity of using new sources in electric power plants (such as wind power) and substituting new transmission lines in the electricity grid (Rajaeifar *et al*., 2014). On the other hand, one of the main reasons for the increased fuel consumption in inefficient soybean production is the excess consumption of inputs due to the lack of accurate knowledge when they use it. Also, cheaper inputs such as fossil fuels and lack of consideration to consumed costs are the other reasons. As a result, the further use of machinery and equipment increases, and consequently, fuel consumption will increase. So, increasing the knowledge of inefficient farmers and realizing the prices of the agricultural inputs, including fossil fuels, can reduce the excessive consumption of fuels in soybean production (Mousavi-Avval *et al*., 2011).

Soni *et al*. (2013) examined the use of fossil fuels in the production of various plants. They estimated 64.70, 88.70, 76, 179.10, 86.20, and 224.40 L/ha fuel consumption for soybean, transplanted rice, corn, cassava, banana, and red pepper production, respectively. Therefore, fuel consumption in soybean production was less than other plants.

Ferraro (2012) in a long-time trial found that reducing energy use in the tillage operation and using improved cultivars will increase energy efficiency in soybean production in Argentina. However, the use of improved cultivars with high production potential requires the use of more water and chemical fertilizers, but the increase in crop production relative to the increase of these inputs has increased the energy efficiency.

In another study, Soltani *et al*. (2013) revealed that a better crop management production scenario was the cleaner production scenario for wheat in terms of energy use and environmental impact. This production scenario used a 38% lower amount of nitrogen fertilizer, consumed 11% less input energy, and produced 33% more seed yield and output energy compared to the usual production scenario.

Hence, in order to analyze the energy consumption and GHG emission, our objectives of this research were: (1) to examine the quantity of energy used for soybean production, (2) to estimate the amount of GHG emissions from energy consumption, and (3) to identify measures to reduce energy use and GHG emissions.

Material and methods

Description of the site

The study was conducted in Golestan Province, which is located within the latitudes of 36' 44º N and 38' 05º N and the longitudes of 53' 51º E and 56' 14º E. The climate of this province is under the influence of the Alborz Mountains, Caspian Sea, the southern wildernesses of Turkmenistan, and forests. According to De-Martonne advanced climate classification system, the province contains five different climates: Mediterranean, arid-desert, semi-arid, humid, and semi-humid. In this region, total annual precipitation is 250-750 mm and it increases from north to south regardless of the altitude (Kazemi *et al*., 2016). Soybean growing months are from June to November. In fact, soybean is usually sown after wheat crop as the second crop in a double-cropping system.

Data collection

Data were collected from 140 soybean-grown fields in ten cities such as Gorgan, Aliabad-e-Katul, Ramian, Azadshahr, Khan Bebin, Galikash, Minoodasht, Kalale, Kordkouy, and Bandar-e-Gaz counties using face-to-face surveys in Golestan Province. Systematic random sampling was used for this purpose so that the number of samples was determined based on the area under cultivation in each city, then the number of fields in each city was selected randomly. Environmental sources of energy such as radiation, rain, etc. were not considered. Diesel fuel, electricity, machinery, chemical fertilizers, pesticides, human labor, and seed amount as inputs and soybean seed yield amount as output have been used to survey the energy analysis. Basic information on energy inputs and soybean yields was entered into Excel spreadsheets. After recording all aforementioned parameters in each field, the data were analyzed in terms of the energy flow and greenhouse gas emissions.

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, indirect, renewable, and non-renewable energy groups in many studies (Rathke *et al*., 2007; Tipi *et al*., 2009; Kaltsas *et al*., 2007).

Direct energy (MJ/ha) includes (1) fuel consumption for machines in various field operations including land preparation, sowing, fertilizing, plant protection, irrigation, and harvesting; (2) electricity for water pumping; and (3) the use of manpower (human labor) for each field operation. 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). On the other hand, renewable energy (MJ/ha) includes human labor, seed and non-renewable energy (MJ/ha) includes machinery, diesel fuel, electricity, chemical fertilizers, and pesticides (Mondani *et al.*, 2017). Firstly, energy consumed in each field based on Mega Joule per hectare (MJ/ha) was calculated as follows. In order to calculate fuel energy, the working time machine was recorded separately at the beginning of any operation from start to end of the production process in each field. Then, fuel consumption was calculated by the following equation (1) according to the past experiences of machinery drivers.

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

FT: fuel needed to perform the field operation in one hectare (L/ha); t: working time of the machine; FH: fuel needed to perform the field operation in an hour (L/h).

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

Table 1. The energy content of inputs and output.

Input	Unit	Energy (MJ/unit)	Reference
Human labor	h	1.96	(Ozkan *et al*., 2004; Turhan *et al*., 2008)
Soybean seed	kg	30.50	(Alimagham *et al*., 2017)
Machinery*	kg	142.70	(Kaltsas *et al*., 2007)
N fertilizers	kg N	60.60	(Akcaoz *et al*., 2009; Ozkan *et al*., 2004)
P fertilizers	kg P_2O_5	6.70	(Akcaoz *et al*., 2009; Ozkan *et al*., 2004)
K fertilizers	kg K_2O	11.10	(Akcaoz *et al*., 2009; Ozkan *et al*., 2004)
Diesel	L	38	IIES, 2007)(
Electricity	kWh	3.6	(Alimagham *et al*., 2017)
Losses electricity	kWh	9.86	(Alimagham *et al*., 2017)
Insecticide	kg active ingredient	237.00	(Alimagham *et al*., 2017)
Herbicide	kg active ingredient	278.00	(Alimagham *et al*., 2017)
Output			
Soybean seed	kg	15.05	(Alimagham *et al*., 2017)

*: Includes energy required for manufacture, repair, maintenance, and transportation of machines.

The electricity consumption for water pumping was measured based on the functioning of meters wells during irrigation operation in terms of kilowatt per hour. To calculate the electricity energy consumed:

$$EIE = t \times P \times UE \qquad (2)$$

EIE: energy amount of electricity consumption (MJ/ha); t: duration of the use of electromotor (h/ha); P: electromotor power (kWhkWh); UE: energy equivalent of each kWh (MJ) (Table 1).

The energy equivalent assigned to labor was 1.96 MJ/h (Table 1). Time spent for driving agricultural machines by drivers was also included in the above calculation.

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

$$EM = \left(E \times \frac{W}{Lt}\right) t \qquad (3)$$

EM: machinery and equipment energy for farming operations (MJ/ha); E: Energy for manufacturing, repair, maintenance, and transportation of machinery and equipment (MJ/kg); W: machinery and equipment weight (kg); Lt: the useful lifetime for machinery and equipment (hours); t: time needed for operation (h/ha); E: constant value and equal to 142.7 MJ/kg (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 of the pesticides. 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 insecticides and herbicides 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 to energy consumption. Pesticides transportation to their consumption place requires energy that is not considerable (Clements *et al*., 2005).

To calculate the energy consumption in fertilizer application, 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), and sulfur (S) in each fertilizer. 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 soybean seed by its energy equivalents (Table 1). Based on the total energy equivalents of the inputs nd output, energy use efficiency, energy productivity, specific energy, and net energy were calculated using the following equations (4-7) (Kazemi *et al*., 2015b):

$$\text{Energy use efficiency} = \frac{\text{Output energy (MJ/ha)}}{\text{Input energy (MJ/ha)}} \qquad (4)$$

$$\text{Energy use productivity (kg/MJ)} = \frac{\text{Seed yield (kg/ha)}}{\text{Input energy (MJ/ha)}} \qquad (5)$$

$$\text{Specific energy (MJ/kg)} = \frac{\text{Input energy (MJ/ha)}}{\text{Seed yield (kg/ha)}} \qquad (6)$$

$$\text{Net energy (MJ/ha)} = \text{Output energy (MJ/ha)} - \text{Input energy (MJ/ha} \qquad (7)$$

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 amount of energy 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 presented by Green (1987). Then, using CO_2, N_2O, and CH_4 gas emission factors of 1-, 310-, and 21-kilograms 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). For electricity, a conversion factor of 0.1453 kg eq-CO_2 per MJ was used (IEA, 2009). GHG emissions were determined per each hectare of land, each tone of soybean seed, and per each MJ of total energy input and output (Soltani *et al*., 2013).

Results and discussion

Energy consumption and GHG emissions derived from inputs

Tables 2 and 3 summarize quantity per unit area, total energy, and GHG emissions equivalents of soybean production in terms of different inputs, respectively. The consumed energy derived from fossil fuels for farming operation and irrigation had the greatest share (50%) of the total energy consumption. Consumed energy for electricity, fertilizers, seed, machinery, human labor, and pesticides indicated the highest to the lowest energy consumption amount. Accordingly, the largest GHG emissions were recorded for use of electricity, followed by fossil fuel consumption, machinery, chemical fertilizers, and pesticides.

Table 2. Used inputs and the obtained output for soybean production in Golestan Province, Iran.

Inputs	Unit	Mean±SD
N fertilizers	Kg/ha	41.56±0.30
P fertilizers	Kg/ha	35±0.04
K fertilizers	Kg/ha	1±0.05
S fertilizers	Kg/ha	4.27±1.69
Herbicide	Kg active ingredient/ha	0.43±0.01
Insecticide	Kg active ingredient/ha	1.06±0.06
Seed	Kg/ha	65.18±0.02
Machinery	h/ha	69.15±0.05
Fossil fuel for farming operations	l/ha	120.10±1.04
Fossil fuel for irrigation	l/ha	90.73±0.90
Total fossil fuel	l/ha	210.83±0.09
Electricity	kWh/ha	280.33±0.19
Human labor	h/ha	230.37±0.07
Output		
Soybean yield	Kg	2799.64±4.17

Table 3. Energy inputs (MJ/ha) and GHG emissions (kgCO_2eqha) for soybean production in Golestan Province, Iran

	Mean±SD (percent of total)	
Inputs	**Energy**	**GHG emissions**
N fertilizers	2519.01±0.29 (13.23)	203.37±0.08 (8.81)
P fertilizers	388.60±0.12 (2.04)	32.16±0.12 (1.40)
K fertilizers	6.17±0.04 (0.03)	0.51±0.01(0.22)
S fertilizers	19.68±0.08 (0.10)	7.20±0.06 (0.31)
Total fertilizers	2913.47±0.29 (15.41)	243.34±0.08 (10.55)
Herbicide	127.31±0.15 (0.67)	17.51±0.04 (0.76)
Insecticide	251.58±0.11(1.32)	40.57±0.05 (1.76)
Total pesticide	379.89±0.131(1.99)	58.19±0.05 (2.51)
Seed	2181.53±0.14 (11.45)	-
Machinery	1335.82±0.17 (7.01)	286.59±0.07 (12.43)
Fossil fuel for farming operations	4557.38±0.24 (23.49)	355.58±0.08 (15.41)
Fossil fuel for irrigation	3449.64±0.54 (18.12)	268.91±0.15 (11.65)
Total fossil fuel	8011.60±0.54 (42.06)	624.49±0.15 (27.07)
Electricity	3773.24±1.28 (19.82)	1094.24±0.15 (47.43)
Human labor	426.12±0.10 (2.26)	-
Total input	19036.08±2.53 (100)	2306.85±3.17 (100)

Ramedani *et al*. (2011) found that the energy input of diesel fuels and chemicals (pesticides) had the highest (66.67 %) and lowest (1.30%) share of the total energy input for soybean production in Kordkouy county (located in Golestan Province), respectively. Rajaeifar *et al*. (2014) reported that electricity and nitrogen fertilizers ranked first and second in energy consumption in soybean production. They stated that low efficiency of energy conversion in electric motors that were used for irrigation in the study area was the main reason for high energy consumption in the electricity section. Khoshnevisan *et al*. (2013) revealed that the electricity consumption (49.3 %) had the highest share for wheat production in Esfahan Province, Iran.

Seed

Results indicated that 13% of the total energy consumption for soybean production was due to seed consumption (Table 3). Therefore, as much as possible, unnecessary seed consumption should be avoided for soybean production. It was recorded that the seed consumption amount for soybean production was 68 kg with 2074 MJ energy equivalent in the present study (Tables 2 and 3). Ramedani *et al*. (2011) and Mousavi-Avval *et al*. (2011) reported that the seed consumption amount for soybean production was 62 and 68.80 kg with 1900 and 2105 MJ energy equivalent, respectively. One of the reasons for high seed consumption is the lack of proper seedbeds that farmers often use more seeds and then, they will perform thinning operations in the early stages of soybean growth. Also, the use of planter such as centrifuge planter is another reason for high seed consumption in the present study. It seems that seed consumption and energy input can be saved and unnecessary costs will decrease by new equipment such as a combination of tillage and planter implements.

Fertilizers

The total energy equivalent of the chemical fertilizer’s consumption was recorded as the second component among energy inputs and constituted 2913.47±0.29 MJ/ha of the total energy input which 87% of them belonged to N-fertilizers application mainly due to high-energy sequestered in N-fertilizers which were used extensively. Fertilizers containing phosphorus, potassium, and sulfur showed much lower contribution than N-fertilizers (Table 3). In some investigations energy consumption for N-fertilizers application was reported 32 and 94 Kg with 2147 and 6281 MJ/ha (Ramedani *et al*. 2011; Mousavi-Avval *et al*. 2011). In dryland and rain-fed crop production such as canola and wheat, the energy input of N-fertilizers has the greatest share of the total energy input. In contrast, in irrigated crop production, total fuel consumption (electricity and fossil fuel) for irrigation is the first component among energy inputs (Soltani *et al*., 2014; Pishgar-Komleh *et al*., 2011; Kazemi *et al*., 2015; Kazemi *et al*., 2016; Safa *et al*., 2011; Khoshnevisan *et al*., 2013). Mondani *et al.* (2017) found there was a direct relation between precipitation and chemical fertilizer utilization in the dryland agroecosystem for wheat production. It could be the main reason for higher chemical fertilizers consumption.

GHG emissions derived from fertilizers were obtained 236.04±0.08 kg CO_2eq that N-fertilizers had the greatest share in fertilizer application (Table 3). Rajaeifar *et al.* (2014) evaluated that GHG emissions derived from N-fertilizers were 123 kg CO_2eq. It seems that since N-fertilizers are responsible for 15.41% of energy consumption and 10.55% of GHG emission, therefore, decreasing the use of these fertilizers can be moderately effective in reducing the energy consumption and GHG emissions in soybean production. Insufficient availability and higher cost of manure compared to chemical fertilizers and tangible increase in yield achieved by increased application of fertilizers are the main reasons for mineral fertilizer application (Beheshti Tabar *et al.*, 2010).

In another study, nitrogen fertilizers application had the highest share of the difference between efficient and inefficient farms due to the wrong opinion that an increase in nitrogen fertilizers consumption would result in an increase in yield, while overuse of these not only did not increase the rice yield but also decreased it (Nabavi-Pelesaraei *et al.*, 2014).

Unfortunately, nitrogen fixation bacteria were not used for soybean production in the region. In many studies, it has been reported that nitrogen-fixing bacteria could have a positive role in reducing the use of N-fertilizers (Salvagiotti, 2008; Bahadur *et al.*, 2007; Remus *et al*., 2000; Ahmadi-Rad *et al.,* 2016; Zahir *et al*., 2004; Maikhuri *et al*., 2016; Kazemi *et al*., 2015a) and consequently, decrease the direct and indirect emission of N_2O. In order to improve the use of N-fertilizers and to reduce environmental pollution in agriculture, several integrated N-management strategies have been developed (Wiesler *et al.*, 2001). Taking these into consideration improved N-supply due to varied crop rotations, cultivation of N-efficient cultivars, optimized crop management practices to improve N-efficiency, optimized rate and timing of N-fertilization, application of organic fertilization versus mineral fertilization, placing nitrogen at the main rooting depth, and foliar-applied of nitrogen (Rathke *et al*., 2006).

Pesticide

Results showed that energy consumption derived from production, packaging, storage, and transportation of pesticides were calculated 379.87±0.13 MJ/ha, so that 66 and 34 % of them belonged to insecticides and herbicides application, respectively (Table 3). Also, 58.19±0.05 kg CO_2eq were emitted in pesticide applications (Table 3). Several stages of insecticide application were used in fields with the highest energy consumption and GHG emission in pesticide application. The share of pesticides was only 1.99% and 2.51% of total energy consumption and GHG emissions in soybean production in Golestan Province, respectively. The important point is that although this contribution is negligible, the use of pesticides can have destructive environmental impacts such as water and soil pollution, which will have a negative impact on human health. Alimagham *et al*. (2017) in studying the different scenarios of soybean production found that the energy consumption varied from 543 to 1497 MJ/ha. Also, these researchers reported that the share of pesticide application ranged from 6.6 to 10.9 % of total GHG emissions. They stated that in scenarios with normal application of pesticide and performing the weeding instead of herbicide application, energy consumption and GHG emission were lower than other scenarios. Mousavi-Avval *et al.* (2011) compared the superior efficient farmers and inefficient farmers in terms of energy consumption in soybean production. They found that superior efficient farmers used 18% and 44% lower herbicides and insecticides than inefficient farmers, respectively. Also, they calculated that optimum use of pesticides can reduce up to 23% of energy consumption in this sector. Alhajj Ali *et al.* (2013) found that no-tillage systems consumed more energy in terms of applying herbicides, but it finally saved energy in human power, machinery, and diesel fuel compared to other tillage systems. Using resistant cultivars to diseases and pests, reasonable usage of pesticides (Alluvine, 2011), knowledge of the on-time usage of the inputs such as pesticides and apply them at the proper amount, and plowing the soil with disk harrow or moldboard plow instead of chemical agents (Nabavi-Pelesaraei *et al*., 2016) are some ways to decrease the application of the pesticide.

Fossil fuel and electricity

On average, 210.83±0.09 L/ha fossil fuel and 280.33±0.19 kWh/ha electricity were consumed for 1 ha soybean production (Table 2). The greatest shares of energy input with 8011.60±0.54 MJ/ha and 3773.24±1.28 MJ/ha belonged to the fossil fuel and electricity consumption, respectively (Table 3). According to the data collected from all surveyed soybean fields, GHG emission for fossil fuel and electricity consumption were calculated 624.49±0.15 and 1094.24±0.15 MJ/ha, respectively (Table 3). It is worth noting that fossil fuel was used for farming operations and irrigation, and electricity was used only for irrigation. The energy consumption for fossil fuel was 2.12 times greater than electricity, but GHG emission for fossil fuel was 1.75 times less than electricity. In fact, although the use of electricity can reduce energy consumption for irrigation in one ha soybean production, it will enhance the GHG emission. In Iran, electric energy used in agriculture is produced mainly from non-renewable sources, especially fossil fuels. Also, non-renewable sources are still the main fuel in power plants (Kazemi *et al*., 2015). On the other hand, the use of irrigation pumps with low efficiency of energy conversion in electric motors and low cost of electricity are other reasons for high electricity consumption. So, reducing the energy consumption in irrigation by using efficient pumps on one hand and increasing the energy efficiency of electric power plants, on the other hand, can play an important role in reducing GHG emissions concerning electricity consumption. Rajaeifar*et al*. (2014) in a study on soybean production reported that the electricity contribution was the highest due to the low efficiency of energy conversion in electric motors, which were used for irrigation. Mousavi-avval *et al*. (2011) reported that up to 78% of energy consumption can be saved by optimal use of electricity. Mousavi-avval *et al*. (2011), Rajaeifar *et al*. (2014), Alimgham *et al*. (2013), Ramadani *et al*. (2011) found that the fuel consumption for soybean production were 103, 103, 129, 201 Lha^{-1}, respectively. Also, the amount of electricity consumed for irrigation in one hectare of soybean production was reported 1335, 812, 449, and 111 kWh, respectively. Therefore, researchers who reported higher fossil fuel consumption recorded less electricity consumption. As almost half of fossil fuel consumption was used for soybean irrigation operation, the use of electricity will reduce fossil fuel consumption. So, this is the reason for variation in reports of fuel consumption for soybean production.

Results from energy consumption and GHG emission for fossil fuel in farming operations showed that irrigation had the highest share of the total energy consumption and GHG emission, followed by seedbed preparation, harvest, crop protection, sowing, fertilizing, and weeding (Table 4). In fact, irrigation alone represented nearly half of fossil fuel consumption in soybean production. The use of old irrigation pumps, incompatibility of pump power with well depth, low groundwater level and requiring long-term irrigation, low summer precipitation, and lack of farmers' access to electricity in a lot of farms were the main reasons for high fossil fuel consumption in irrigation. Canakci *et al.* (2005) evaluated the energy consumption for irrigation of tomato, melon, and watermelon in the range of 3610–5870 MJ/ha. Seedbed preparation had the second rank in fossil fuel consumption. So, considering the reduction in fuel consumption in irrigation and seedbed preparation can have a very significant contribution to reducing energy consumption and GHG emission.

Safa *et al.* (2011) in New Zealand reported that the tillage operation had the highest proportion of fuel consumption. It was responsible for about 45% of the total fuel consumption in wheat production. In another study, the conservation tillage systems consumed 75% less energy for seedbed preparation and planting than conventional tillage systems in wheat production. Also, conservation tillage can achieve better environmental performance than conventional tillage systems because of mitigation in tillage intensity (Houshyar and Grundmann, 2017). Sarauskis *et al.* (2014) assessed the various maize cultivation technologies in terms of energy consumption and their environmental impact, and revealed that the largest amount of diesel fuel (approximately 24.5 L/ha) was used in deep plowing of soil. The reduced-tillage technologies had similar fuel input requirements, which were 12.9-20.5% lower than the conventional tillage. These researchers found that no-tillage system caused the least CO_2 pollution. The reduced tillage technologies produced twice as much CO_2 pollution. Also, the largest amount of CO_2 pollution (approximately 253 kg/ha) was emitted when applying the conventional deep plowing technology. Alimagham *et al.* (2017) reported that seedbed preparation was one of the main consumers of fuel in soybean cultivation in various scenarios of soybean production. Also, the amount of fuel consumption in the no-tillage system scenario was lower than the minimum and conventional tillage scenarios. Barut *et al.* (2011) revealed that the differences in fuel consumption between the tillage systems were significant. The lowest fuel consumption was 3.2 L/ha in the no-tillage method and the highest fuel consumption was 43.34 L/ha in the reduced tillage method. The intensive machine traffic in the reduced-tillage method caused more fuel consumption (Barut *et* *al*., 2011). Alimagham *et al.* (2013) found that the application of combined tillage relative to moldboard plow and light tandem disk could reduce 39 and 70 L/ha fuel consumption, respectively. The mentioned researchers and other researchers (Kumar *et al*., 2013; Mileusnic *et al*., 2011; Hamzei and Seyyedi, 2016) stated that performing the conservation tillage could have an important effect on fuel and energy consumption and consequently GHG emission. Moreover, applying a better machinery management technique, proper tractor selection to reduce diesel fuel requirement, or technological upgrade to substitute fossil fuels with renewable energy sources help to minimize the fossil fuel usage and thus to reduce the environmental footprints (Mousavi-Avval *et al*., 2011). Also, applying new machinery and irrigation pumps with more energy efficiency would decrease the amount of energy usage in fuel consumption (Pishgar-Komleh *et al*., 2011).

Machinery

On average, 1335.82±0.17 MJ/ha energy input of machinery was used for the manufacturing, repair, maintenance, and transportation of machinery and equipment (Table 3). Irrigation with 43% had the highest and weeding with less than 1% had the lowest shares in the energy input of machinery application and the resulted GHG emission (Table 3). In this regard, Mousavi-avval *et al.* (2011) also reported that the energy consumption of machinery was 963 MJ/ha that using the optimal application of machinery can save 0.5 % of total energy inputs. In another study, Alimagham *et al.* (2017) in various scenarios of soybean production reported that energy input of machinery for all scenarios ranged from 1272.3-2985.2 MJ/ha depending on the intensity of tractors and implements applications. Kazemi *et al.* (2016) revealed that 1170.14 MJ/ha of machine energy is needed per hectare of canola production in rainfed farms of Golestan Province. The greater value of machinery than human labor share is a sign of the improved agricultural practices in this province. Barut *et al.* (2011) in silage corn production indicated that the machine energy input for the cultural practices was the highest in the reduced tillage method with the value of 975.75 MJ/ha and it was 47.57% higher than the no-tillage method. Ramedani *et al*. (2014) found that the quantity of machinery power required in soybean production was 16.30 h/ha with 1025.88 MJ/ha that constituted 6.69 % of the total energy input (Table 5). The majority of machinery power was used in soil preparation. There were some ways to reduce the energy input of machinery application and the resulted GHG emission: using wider machinery and implement and less turning around (Pishgar-Komleh *et al*., 2011), proper machine size and suitable tractors (Nassiri *et al*., 2009), and no-tillage system (Alhajj Ali *et al*., 2013).

Human labor

Human labor had little impact on total energy input. As observed in Table 3, 426.12±0.10 MJ/ha labor energy input on average was needed for soybean production, which comprised 2.64 of total energy inputs. This amount in some studies was evaluated 2.49 (Ramedani *et al*., 2014) and 2.60 (Alimagham *et al*., 2013) that were similar to the present study and 1.1 (Mousavi-avval *et al*., 2011) that was lower. Mentioned researchers stated that weeding, irrigation, and harvesting were highly labor energy-intensive. In the present study, weeding operation was the most energy-intensive, and sowing had the lowest need for labor energy (Table 5). When farmers used weeding operations by labor instead of using herbicides to control weeds, labor energy consumption increased and pesticide energy and its use decreased. This issue can reduce GHG emissions and other harmful effects of pesticide use on human health and living organisms. But since the use of herbicides instead of labor working will increase the production costs, and on the other hand low income of farmers, soybean producers often prefer to use herbicide and such a substitution is less common.

Dal Ferro *et al*. (2017) in soybean production evaluated that human labor had little impact on total energy requirements. A study reported that irrigated wheat agroecosystem requires more human labor than dryland wheat agroecosystem. This is probably because of more operations during irrigated wheat agroecosystem compare to dryland wheat agroecosystem (Mondani *et al*., 2017).

Table 4. Quantity (L/ha), energy consumption (MJ/ha), and GHG emissions (kgCO$_2$eq/ha) of fossil fuel input in each operation of soybean production, Golestan Province, Iran.

	Mean±SE		
Operations	**Quantity**	**Energy consumption**	**GHG emission**
Seedbed preparation	48.60±0.03	1846.62±0.19	144.06±0.05
Sowing	6.41±0.02	243.47±0.09	18.99±0.03
Fertilizing	0.84±0.01	31.96±0.05	2.49±0.02
Crop protection	30.77±0.03	1169.08±0.18	91.26±0.05
Weeding	0.39±0.01	14.93±0.07	1.16±0.02
Irrigation	90.73±0.09	3447.64±0.54	268.91±0.15
Harvesting	33.10±0.02	1256.99±0.13	98.04±0.04
Total operations	210.83±0.09	8011.29±0.51	625.43±0.15

Table 5. Energy consumption (MJ/ha) and GHG emissions (kgCO$_2$eq/ha) of machinery and labor application in soybean production, Golestan Province, Iran.

	Mean±SE		
	Energy consumption		**GHG emission**
Operations	Machinery	human labor	Machinery
Seedbed preparation	368.72±0.06	8.77±0.01	84.60±0.03
Sowing	48.63±0.04	2.89±0.01	6.20±0.02
Fertilizing	5.83±0.01	4.86±0.02	1.32±0.01
Crop protection	349.27±0.07	23.70±0.03	80.80±0.06
Weeding	3.17±0.01	165.25±0.01	0.80±0.01
Irrigation	394.22±0.17	111.74±0.06	72.69±0.07
Harvesting	165.58±0.04	128.90±0.07	38.34±0.03
Total operations	1335.82±0.16	446.12±0.10	289.55±0.04

Energy forms and indices

The results revealed that the average total energy consumed in soybean production was 19036.08±2.53 MJ/ha (Table 6), so that direct, indirect, renewable, and non-renewable energy forms were calculated 64, 36, 14, and 86 percent of total energy input, respectively. As can be seen, the share of direct and non-renewable energy in soybean production was higher than indirect and renewable energy.

Energy consumption in the fields with high input energy was 5 times higher than in the fields with low input energy. In fact, farmers with high consumed energy used nitrogen fertilizers 1.9 times and fossil fuels 2.8 times more than farmers with low consumed energy. It seems that reducing fossil fuels and electricity based on the mentioned methods in the previous section can reduce the share of direct energy. Also, by reducing the use of chemical fertilizers and replacing it with manure and compost fertilizers, the use of non-chemical methods to control pests and diseases and reduce direct input energy also will decrease non-renewable energy. In general, to achieve a sustainable system of food production, the amount of energy efficiency and the share of renewable energy should be increased in fields (Moore, 2010).

Alluvione *et al.* (2011) found that balancing N fertilization rates with the actual crop requirements and adopting minimum tillage, use of crop residue, catch-crop adoption in light of their potential to reduce N-leaching and impact on soil organic matter and integrated farming techniques can reduce the energy requirement for crop production.

Based on the average seed yield, which was 2799.64±4.17 kg/ha (Table 2), its energy equivalent was calculated to be 2306.85±3.17 MJ/ha (Table 6). In energy balances, the energy ratio is frequently used as an index to evaluate energy efficiency in crop production systems (Mondani *et al.*, 2017). The energy use efficiency of soybean production has been evaluated by the energy ratio between the outputs and inputs. The average energy use efficiency amount obtained in this research was 2.21indicating that 2.21 times more energy was produced per unit of consumed energy. Energy use efficiency was evaluated 4.6 in Ramedani et al. (2014) investigation. Hamzei and Seyyedi (2016) in soybean production with minimum tillage by chisel, minimum tillage by disc, and conventional tillage reported that energy use efficiencies were 6.60, 6.14, and 5.89, respectively. Dal Ferro *et al.* (2017) calculated the energy use efficiency value equal to 5.4 in Italy based on conventional soybean production. Alluvione *et al.* (2011) evaluated the energy use efficiency value equal to 6.2 in soybean production. These researchers reported higher energy use efficiency than the present study. One of the most important factors that cause low energy efficiency in the region is low soybean seed yield, to which less attention is paid, so that if with the same amount of energy consumed per hectare, soybean yield would increase, it could enhance energy use efficiency. The gathering of soybean residue for livestock feeding as the economic component is another way to increase the energy use efficiency of soybean production. Alimagham *et al.* (2017) calculated the range between 1.53-3.18 energy use efficiency for four soybean production scenarios. The lowest value was evaluated for the mechanized scenario with the gun sprinkler system and the highest value was calculated for the conventional scenario. They found that the soybean seed yield was approximately similar in mentioned scenarios. Therefore, by increasing the mechanization level without increasing seed yield, soybean production will not be energy-efficient in the region. The new generation of powerful combines and tractors can work faster with wider equipment and platforms and leading to a reduction in fuel consumption. Although, selecting a tractor in line with its equipment can increase energy efficiency and reduce fuel consumption up to 30 % (Safa *et al*., 2010).

Beheshti Tabar et al. (2010) in a study on energy balance in Iran's agronomy reported that irrigated soybean seed yields were 2000 kg ha^{-1} with an energy ratio of 1.78 and rain-fed soybean seed yield were 1700 kg/ha with an energy ratio of 4.46 in the period of 1990–2006. It seems that the lack of fuel consumption for irrigation in rain-fed soybean production was the main factor in reducing the energy ratio. In the present study, farmers with low energy use efficiency performed more irrigation than high energy use efficiency.

Ramedani et al. (2014) stated that by increasing the annual yield of soybean production and/or decreasing the energy consumption, especially diesel fuel energy, soybean production will be efficient. Pishgar-Komleh *et al*. (2011) in rice farming found that by fewer government subsidies, teaching farmers about the less chemical fertilizer consumption and increasing cultivated area, the high energy consumption of chemical fertilizer and fuel energy will be controlled, hence this act leads to improvement in energy indices. Nabavi-Pelesaraei *et al.* (2016) suggested the selection of appropriate water distribution in the farms, imports of standard machinery, timely maintenance, and reduction of chemical fertilizers (mainly nitrogen) for increasing the energy use efficiency in wheat production.

Energy use efficiency in other agricultural crop productions with respect to the type of crop, growing season, farming system, mechanization level, location, climate constraints of crop production, irrigation level, organic or inorganic fertilizers application, farm size, etc. have been reported as 4.2, 3.73 and 3.44 for canola in Iran (Soltani *et al*., 2014; Mousavi-Avval *et al.*, 2017; Kazemi *et al*., 2016), 6.50 and 0.45 for wheat in Iran (Soltani *et al*., 2013; Khoshnevisan *et al.*, 2013), 3.26-4.22 for winter rapeseed in northeastern Poland (Budzynski *et al*., 2015), 7.71-23.81 for rainfed durum wheat in southern Italy (Alhajj Ali *et al*., 2013), 7.07 for winter maize and 9.56 for summer maize in Bangladesh (Rahman and Rahman, 2013), 1.53 for rice in Iran (Pishgar-Komleh *et al.,* 2011), 15.7 for wheat, and 9.1 for maize in western Italy (Alluvione *et al*., 2011).

As can be seen in Table 6, 0.147 kg soybean seed was produced for each megajoule of energy input consumption. The average soybean seed yield for farmers with energy productivity of less than 0.15 Kg/MJ was 2500 Kg/ha and for other farmers was 3300 Kg/ha. On the other hand, the total energy of machinery and fuel consumption in fields with less than 0.15 Kg/MJ energy productivity was calculated 12400 MJ/ha, which was reduced to 7800 MJ/ha in fields with more than 0.15 Kg/MJ energy productivity. Therefore, according to the results, higher-yielding farms, as well as lower use of machinery and fuel consumption, caused more energy production. Although, reducing fuel consumption and implement energy in the irrigation sector is one of the main ways to increase energy productivity in irrigated fields. Since specific energy is the inverse of energy productivity, by increasing the seed yield and reducing the energy input, the amount of specific energy will also decrease. Based on the results, 6.05 MJ energy was consumed per one kg of soybean production (Table 6). The average net energy per one hectare of soybean was calculated 25995 MJ (Table 6). Fields with a net energy of more than 3000 MJ/ha had an average seed yield of more than 3500 Kg/ha. At the same amount of net energy, this value dropped to 2400 Kg/ha in other fields.

Barut et al. (2011) in an investigation on the tillage effects on energy indices for corn silage in the Mediterranean Coast of Turkey found that there were not any differences between conventional tillage and other tillage systems such as band tillage, minimum tillage, ridge tillage, and no-tillage for energy productivity. In another study, it was reported that the rate of energy productivity, net energy, and specific energy would be improve by about 12.50%, 68.08%, 19.82%, and 19.80% using converting inefficient to efficient energy consumption (Nabavi-Pelesaraei *et al.*, 2014). Alluvione *et al.* (2011) indicated that net energy for soybean was 31.9% of net energy for maize in western Italy.

Alimagham *et al.* (2017) stated that specific energy increased with the increase in management intensity, which was greatly affected by seed productivity in soybean production. Hence, they found that the highest specific energy belonged to the mechanized scenario with the gun sprinkler system with 9.84 MJ/kg.

Alhajj Ali et al. (2013) evaluated the energy productivity in conventional and low tillage systems 0.61 and 0.36 Kg/MJ in wheat production, respectively. They stated that the reason for higher energy productivity in conventional tillage than minimum tillage despite the higher energy consumption in conventional tillage is the high seed yield in the conventional tillage. Soltani *et al.* (2013) calculated 0.27 Kg/MJ for average energy productivity in the six scenarios for wheat production in Gorgan, Iran. Also, Soltani *et al.* (2014) evaluated 0.15 Kg/MJ for energy productivity in canola production in the region.

GHG emissions

Estimates of GHG emissions are presented in Table 7. Based on results average current GHG emissions per one hectare of soybean production was evaluated 2306.85±3.17 kg eq-CO_2, and per one Kg was estimated 0.823±0.001 kg eq-CO_2. In comparison to other studies, our findings are much higher than some results for GHG emissions of one kg of soybean production such as 186 g eq-CO_2 in Brazil (Raucci *et al.*, 2014), 247.6 g eq-CO_2 in Canada (Pelletier *et al.*, 2008), and 140-320 g eq-CO_2 in Argentina-Brazil (Castanheira and Freire, 2013). This high difference may be caused by the large consumption of electrical energy for irrigation, which enhances GHG emissions into the atmosphere. Some researchers such as Rajaeifar *et al.* (2014) revealed that electricity had the highest value of GHG emission in the agricultural soybean production with the share of 61%. In the present study, this share was 47% of total GHG emissions. Iranian electricity producers should reduce non-renewable energy recourses for electricity production (Nabavi-Pelesaraei *et al.*, 2014).

As indicated in Table 7, GHG emissions per one MJ of energy input and output in soybean production were evaluated 0.121±0.001 and 0.055±0.001 kg eq-CO_2/MJ, respectively. Raucci *et al.* (2014) illustrated that the large fields had 14% less GHG emission per one kg of soybean production than small fields. Castanheira and Freire (2013) found that soybean cultivation in tropical and warm temperate moist regions had higher GHG emissions (190-320 g eq-CO_2/kg) compared to the warm temperate dry regions (140-190 g eq-CO_2/kg). This difference was due to the use of limestone and greater quantities of fertilizer. Patthanaissaranukool and Polprasert (2016) reported that the major sources of carbon emissions come from diesel application in the watering process and fertilizer application contributing to 37% and 25% of total emissions in soybean production, respectively. They stated that using biodiesel to replace fossil diesel for heavy machines in land tillage, watering, and threshing may reduce carbon emissions by 38%, which represents the highest potential for reducing carbon emissions. Dornburg *et al.* (2005) revealed that the lowest value of GHG emissions obtained without fertilizer and pesticide use in wheat and hemp production in the Netherland and Poland.

Khakbazan *et al.* (2009) calculated the GHG emissions from wheat production and found that they can be ranged from 410 to 1130 kgCO_2eq/ha depending on fertilizer rate, location, and seeding system. Also, they stated that emissions were much lower for pea (250 kgCO_2eq/ha) than wheat as less N-fertilizer was applied to pea. In fact, increasing the rate of N-fertilizer application increased total CO_2 emissions, but the corresponding increase in above-ground plant biomass carbon did not completely offset these emissions.

Konyar (2001) evaluated the impact of changes in cropping patterns, acreage, output, and resource on determine the changes in GHG emissions from crop production. Their results showed that the CO_2 emissions decreased by 26.8% while N_2O emissions dropped by 15%, for a total of 20.1% decrease in the two GHGs. The fuel combustion component accounted for a 31.3% decrease in CO_2 emissions, while the reduced use of nitrogen, phosphorous, and potassium contributed to a 19.3% decrease in CO_2 emissions. The larger CO_2 decrease from fuel combustion was due to a substantial decline in irrigation electricity use. Nabavi-Pelesaraei e*t al.* (2014) indicated that diesel fuel had the highest potential for the reduction of total GHG emission with 59.57%, followed by electricity (12.20%) and nitrogen (10.41%) in rice production. As can be found from the results of other studies, by increasing the yield and field size, decreasing the fossil fuel consumption, electricity, and nitrogen fertilizers, replacing the fossil diesel with biodiesel for heavy machinery and electricity production, converting conventional farming to the organic farming system, changing the cropping patterns, and placing legumes in rotation can reduce the GHG emission from soybean and other crops production.

Table 6. Energy indices for soybean production in Golestan province, Iran.

Indices	Unit	Mean±SD
Direct energy	MJ/ha	12210.96±0.54
Indirect energy	MJ/ha	6810.71±0.49
Renewable energy	MJ/ha	2607.65±0.43
Non-renewable energy	MJ/ha	16414.02±0.68
Input energy	MJ/ha	19036.08±2.53
Output energy	MJ/ha	42124.95±0.73
Energy use efficiency	-	2.21±0.01
Net energy	MJ/ha	23088.87±1.76
Energy productivity	Kg/MJ	0.147±0.01
Specific energy	MJ/kg	6.80±0.01

Table 7. GHG emissions for soybean production in Golestan Province, Iran.

GHG emissions	Unit	Mean±sd
per unit area	kgCO_2eq/ha	306.85±3.17
per unit weight	kg eq-CO_2/kg	0.823±0.001
per unit energy input	kg eq-CO_2/MJ	0.121±0.001
per unit energy output	kg eq-CO_2/MJ	0.055±0.001

Relationship between seed yield and energy consumption

Seed yield did not indicate a significant relationship with energy consumption derived from fuel for land preparation, sowing, fertilization, and irrigation. However, seed yield had a negative significant relationship with crop protection and a positive significant correlation with energy derived from fuel consumption in harvest operation. The lack of significant relationships between seed yield and mentioned cultural operations indicates that increasing or decreasing the fuel consumption on soybean yield was unaffected. Therefore, the fuel consumption can be reduced for land preparation, sowing, fertilizing, and irrigation without a significant reduction in soybean yield. Rajabi Hamedani *et al.* (2011) by studying the energy consumption for potato production in Hamadan Province (Iran), found that increase or decrease the energy consumption of fossil fuels had no effect on tubers' yield. Combined implements such as combined tiller can be used in the land preparation operation and using the heavier implements and machines with less operating time and less soil tillage number to reduce fuel consumption. Also, the use of a combined drill that performs tillage and sowing simultaneously, led to a reduction in total fuel consumption and did not have a significant effect on soybean yield. Ramedani *et al*. (2011) reported that one percent reduction in fossil fuel consumption could affect up to 0.3 % reduction in seed yield. However, they did not study the effect of fuel consumption on each cultural operation.

Based on the results, per one megajoule of fuel consumed in crop protection operations, 0.26 kg of seed yield was reduced (Fig. 1a). The existence of such a relationship can be justified due to a plenty of pests and more frequent uses the chemical. Spraying is mainly done when pests are more prevalent. So the number of spraying will inevitably increase, however, most pests often had an effect on reducing yield prior to spraying in a timely manner. So, by increasing the spraying number, excessive fuel consumption and seed yield will decrease. Another reason to increase fuel consumption is that farmers mainly use lance sprayers instead of turbine sprayers to control soybean pests, which increases fuel consumption by up to 3 times. As increasing the energy derived from fuel consumption in crop protection was effective in reducing soybean yield, increasing greenhouse gas emissions due to fuel consumption will also reduce seed yield. Hence, each kilogram of carbon dioxide emissions from fuel consumed in crop protection reduced 3.33 kg of yield in soybean production. So, by timely spraying, followed by a reduction in the number of sprays, using turbine sprayers instead of lance sprayers can be used to reduce fuel consumption for crop protection.

As mentioned above, the relationship between soybean yield and energy and greenhouse gas emissions in soybean harvest was positively and significantly evaluated, so that by increasing each liter of consumed fuel, seed yield increased by 44 kg (Fig. 1b). One of the reasons is that in farms that had a higher yield, more time was spent on harvest operations. Hence, energy and greenhouse gas emissions will increase.

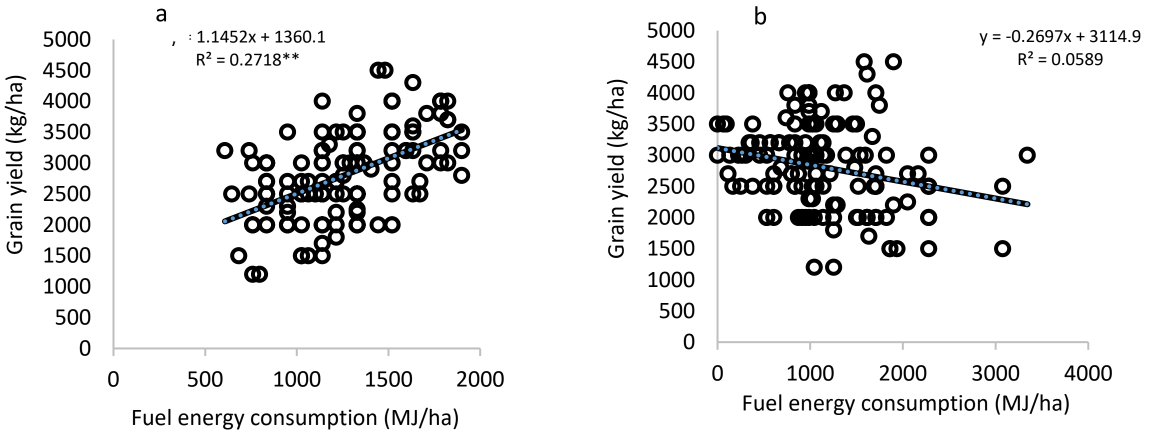

Fig. 1- Relationship between seed yield and fuel consumption for crop protection (a) and harvest (b) in soybean production in Golestan Province

Based on the results of Fig. 2, it can be stated that increasing and decreasing seed energy consumption will not affect the soybean yield. Hence, new equipment such as a combination of tillage and planter implements reduce seed usage and seed energy consumption by up to 23 % compared to hand spraying, 14 % compared to the use of centrifugal planter, and 11 % compared to row drill (data not shown). The use of a combination of tillage and planter implements not only decreased the use of soybean seeds but also reduced fuel consumption compared to other planting methods, so that performing the soil tillage and soybean cultivation simultaneously could reduce fuel consumption by up to 50% compared to other conventional methods in the area. Hatirli *et al.* (2006) also reported in greenhouse tomato production that increase or decrease in the seed energy consumption did not affect the yield.

In relation to the energy consumption derived from chemical fertilizers, it can be said that energy consumption derived from N-fertilizers had a positive and significant relationship with seed yield. Since more than 13.23 and 8.81 % of the energy consumption, and GHG emissions derived from fertilizers, respectively, due to the use of N-fertilizers, thereby reducing the use of N-fertilizers should be evaluated on the reduction of seed yield. By increasing each megajoule of N-fertilizers energy, seed yield increased equal to 80 g (Fig. 2), so that if 50 kg of urea fertilizer was used in the soybean field, its energy was approximately 3000 megajoule, and thus the yield would increase by 240 kg per hectare. One way to reduce the use of N-fertilizers without negative effects on soybean seed yield is increasing the fertilizer use efficiency and using nitrogen-fixing bacteria in soybean production in Golestan Province. Ramedani *et al.* (2011) found that by increasing the one percent growth in energy derived from N-fertilizers, the soybean yield increased by 0.03. Rajabi-Hamedani *et al*. (2011) also expressed this amount for potato production in Hamedan Province, which was 0.17 %.

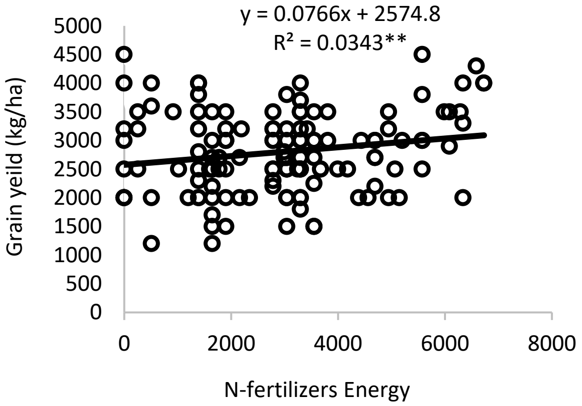

Fig. 2- Relationship between seed yield and N-fertilizers energy in soybean production in Golestan Province

Conclusion

Fossil fuel consumption had the greatest share in total energy consumption with 42.06%. Irrigation consumed more energy input than other operations. Using electricity instead of fossil fuels reduced energy consumption, but increased GHG emissions. So, Iranian electricity producers should reduce non-renewable energy recourses for electricity production. Improving irrigation systems and reducing irrigation time are other suggested methods for reducing energy consumption and GHG emissions in the region. Also, changing the conventional tillage system to reduced tillage or no-tillage systems can be decreased the energy consumption and GHG emission in soybean production. Soybean fertilizing at the needed time, soil sampling before soybean cultivation, and determination of crop fertilizer requirement based on it are other factors for decreasing energy consumption and GHG emission. The use of Rhizobia bacteria in symbiosis with soybean roots and biological nitrogen fixation can be effective in reducing the use of N-fertilizers and consequently, energy consumption and GHG emission.

Energy use efficiency for soybean production in the region was lower than other mentioned regions. Lower soybean yield in the region was the main reason for the low efficiency of energy consumption. In fact, it can be said that increasing the yield along with reducing inputs consumption, especially fossil fuels, can be effective in increasing energy efficiency. Seed yield did not indicate a significant relationship with energy fuel consumption for land preparation, sowing, fertilization, and irrigation. On the other hand, seed yield had a negative significant correlation with crop protection and a positive significant correlation with energy derived from fuel consumption in harvest operation.

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References

Ahmadi-Rad, S., Gholamhoseini, M., Ghalavand, A., Asgharzadeh, A. and Dolatabadian, A., 2016. Foliar application of nitrogen fixing bacteria increases growth and yield of canola grown under different nitrogen regimes. Rhizosphere. 2, 34-37.

Akcaoz, H., Ozcatalbas, O. and Kizilay, H., 2009. Analysis of energy use for pomegranate production in Turkey. Journal of Food, Agriculture and Environment. 7, 475-480.

Alhajj Ali, S., Tedone, L. and Mastro, G. 2013. A comparison of the energy consumption of rainfed durum wheat under different management scenarios in southern Italy. Energy. 61, 308-318.

Alimagham, S.M., Soltani, A., Zeinali, E. and Kazemi, H., 2017. Energy flow analysis and estimation of greenhouse gases (GHG) emissions in different scenarios of soybean production (Case study: Gorgan region, Iran). Journal of Cleaner Production. 149, 621-648.

Alimagham, M., Soltani, A. and Zeinali, E., 2013. Evaluation of fuel and energy use and their environmental impacts in soybean production at Gorgan. MS.c. thesis. Gorgan University of Agricultural Sciences and Natural Resources Gorgan, Iran. 196 Pp. (In Persian with English abstract).

Alluvione, F., Moretti, B., Sacco, D. and Grignani, C., 2011. EUE (energy use efficiency) of cropping systems for a sustainable agriculture. Energy. 36, 4468-4481.

Bahadur, U.P., Singh, B.K., Sarma, D.P., Singh , K.P. and Singh, A., 2007. Foliar application of plant growth-promoting rhizobacteria increases antifungal compounds in pea (*Pisum sativum*) against Erysiphepisi. Mycobiology. 35, 129-134.

Barut, Z.B., Ertekin, C. and Karaaga, H.A., 2011. Tillage effects on energy use for corn silage in Mediterranean Coastal of Turkey. Energy. 36, 5466-5475.

BeheshtiTabar, I., Keyhani, A. and Rafiee, SH. 2010. Energy balance in Iran’s agronomy (1990–2006). Renewable and Sustainable Energy Reviews. 14, 849–855.

Budzynski, W.S., Jankowski, K.J. and Jarocki, M., 2015. An analysis of the energy efficiency of winter rape seed biomass under different farming technologies. A case study of a large-scale farm in Poland. Energy. 90, 1272-1279.

Canakci, M., Topakci, M., Akinci, I. and Ozmerzi, A., 2005. Energy use pattern of some field crops and vegetable production: case study for Antalya region, Turkey. Energy Conversion and Management. 46, 655–666.

Castanheira, E.G. and Freire, F., 2013. Greenhouse gas assessment of soybean production: implications of land use change and different cultivation systems. Journal of Cleaner Production. 54, 49-60.

Clements, D.R., Weise, S.F., Brown, R., Stonehouse, D.P., Hume, D.J. and Swanton, C.J., 2005. Energy analysis of tillage and herbicide inputs in alternative weed management-systems. Agriculture, Ecosystem and Environment. 52, 119-128.

Dal Ferro, N., Zanin, G. and Borin M., 2017. Crop yield and energy use in organic and conventional farming: A case study in north-east Italy. European Journal of Agronomy. 86, 37–47.

Dornburg, V., Termeer, G. and Faaij, A.P.C., 2005. Economic and greenhouse gas emission analysis of bioenergy production using multi-product crops—case studies for the Netherlands and Poland. Biomass and Bioenergy. 28, 454–474.

Ferraro, D.O., 2012. Energy use in cropping systems: A regional long-term exploratory analysis of energy allocation and efficiency in the Inland Pampa (Argentina). Energy. 44, 490-497.

Green, M., 1987. Energy in pesticide manufacture, distribution and use. In: Helsel Z.R. (Ed). Energy in Plant Nutrition and Pest Control. Amsterdam, Elsevier, pp: 165-177.

Hamzei, J. and Seyyedi, M., 2016. Energy use and input –output costs for sunflower production in sole and intercropping with soybean under different tillage systems. Soil and Tillage Research. 15, 73-82.

Hatirli, S.A., Ozkan, B. and Fert, C., 2006. Energy inputs and crop yield relationship in greenhouse tomato production. Renew. Energy. 31, 427-438.

Houshyar, E. and Grundmann, P., 2017. Environmental impacts of energy use in Wheat tillage systems: A comparative Life Cycle Assessment (LCA) study in Iran. Energy. 122, 11-24.

IIES, Institute for International Energy Studies. 2007. Iran Hydrocarbons Energy Balance, Ministry of oil and gas. Available online at: https://www.iea.org

International Energy Agency (IEA). Electricity/Heat in Iran, Islamic Republic of in 2009. Available online at: http://iea.org/ stats/electricitydata.asp? COUNTRY_CODE¼ IR; 2010 [verified on 5/13/2012].

IPCC. Climate change 2007: impacts, adaptation and vulnerability. In: Parry M.L., Canziani O.F., Palutik of JP, van der Linden P.J., Hanson C.E., Editors. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, p. 976.

Kaltsas, A.M., Mamolos, A.P., Tsatsasarelis, C.A., Nanos, G.D. and Kalburtji, K.L., 2007. Energy budget in organic and conventional olive groves. Agriculture, Ecosystem and Environment. 122, 243-251.

Kazemi, H., Kamkar, B., Lakzaei, S., Badsar, M. and Shahbyki, M., 2015. Energy flow analysis for rice production in different geographical regions of Iran. Energy. 84, 390-396.

Kazemi, H., Hassanpour Bourkheili, S., Kamkar, B., Soltani, A., Gharanjic, K. and Nazari, N.M., 2016. Estimation of greenhouse gas (GHG) emission and energy use efficiency (EUE) analysis in rainfed canola production (case study: Golestan province, Iran). Energy. 116, 694-700.

Kazemi, H., Shahbyki, M. and Baghbani, S., 2015a. Energy analysis for faba bean production: A case study in Golestan province, Iran. Sustainable Production and Consumption. 3, 15-20.

Kazim, K., 2001. Assessing the role of US agriculture in reducing greenhouse gas emissions and generating additional environmental benefits. Ecological Economics. 38, 85-103.

Khaledian, M.R., Mailho, J.C., Ruelle, P., Mubarak, I. and Perret, S., 2010. The impacts of direct seeding into mulch on the energy balance of crop production system in the SE of France. Soil and Tillage Research. 106, 218-226.

Khoshnevisan, B., Rafiee, S., Omid, M., Yousefi, M. and Movahedi, M., 2013. Modeling of energy consumption and GHG (greenhouse gas) emissions in wheat production in Esfahan province of Iran using artificial neural networks. Energy. 52, 333-338.

Kumar, I., Saharawat, Y.S., Gathala, M.K., Jat, A., Singh, S.K., Chaudhary, N. and Jat, M.L., 2013. Effect of different tillage and seeding methods on energy use efficiency and productivity of wheat in the Indo-Gangetic Plains. Field Crops Research 142, 1–8.

Maikhuri, R.K., Dangwal, D., Negi, V.S. and Rawat, L.S., 2016. Evaluation of symbiotic nitrogen fixing ability of legume crops in Central Himalaya, India. Rhizosphere. 1, 26-28.

Maraseni, T.N. and Cockfield, G., 2011. Does the adoption of zero tillage reduce greenhouse gas emissions? An assessment for the seeds industry in Australia. Agricultural System. 104, 451-458.

Mohammadi, A., Rafiee, S., Jafari, A., Dalgaard, T., Knudsen, M.T., Keyhani, A., Mousavi-Avval, S.H. and Hermansen, J.E., 2013. Potential greenhouse gas emission reductions in soybean farming: a combined use of Life Cycle Assessment and Data Envelopment Analysis. Journal of Cleaner Production. 54, 89-100.

Mohammadi, A., Tabatabaeefar, A., Shahin, S., Rafiee, S. and Keyhani, A., 2008. Energy use and economic analysis of potato production in Iran a case study: Ardabil province. Energy Conversion and Management. 49, 3566-3570.

Mondani, F., Aleagha, S., Khoramivafa, M. and Ghobadi, R., 2017. Evaluation of greenhouse gases emission based on energy consumption in wheat Agroecosystems. Energy Reports. 3, 37-45.

Moore, S.R., 2010. Energy efficiency in small-scale bio intensive organic onion production in Pennsylvania, USA. Renewable Agriculture and Food Systems. 25, 181-188.

Moreno, M., Corcoles, J., Tarjuelo, J. and Ortega, J., 2010. Energy efficiency of pressurized irrigation networks managed on-demand and under a rotation schedule. Biosystem Engineering. 107, 349-363.

Mousavi-Avval, S.H., Rafiee, S., Sharifi, M., Hosseinpour, S. and Shah, A., 2017. Combined application of Life Cycle Assessment and Adaptive Neuro-Fuzzy Inference System for modeling energy and environmental emissions of oilseed production. Renewable and Sustainable Energy Reviews. 78, 807-820.

Mousavi-Avval, S.H., Rafiee, S., Jafari, A. and Mohammadi, A., 2011. Optimization of energy consumption for soybean production using Data Envelopment Analysis (DEA) approach. Appleid Energy. 88, 3765-3772.

Nabavi-Pelesaraei, A., Hosseinzadeh-Bandbafha, H., Qasemi-Kordkheili, P., Kouchaki-Penchah, H., and Riahi-Dorcheh, F., 2016. Applying optimization techniques to improve of energy efficiency and GHG (greenhouse gas) emissions of wheat production. Energy. 103, 672-678.

Nabavi-Pelesaraei, Abdi, R., Rafiee, Sh. and Taromi, K., 2014. Applying data envelopment analysis approach to improve energy efficiency and reduce greenhouse gas emission of rice production. Engineering in Agriculture, Environment and Food. 7, 155-162.

Nassiri, S.M. and Singh, S., 2009. Study on energy use efficiency for paddy crop using Data Envelopment Analysis (DEA) technique. Applied Energy. 86, 1320-5.

Ozkan, B., Akcaoz, H. and Fert, C., 2004. Energy input –output analysis in Turkish agriculture. Renewable Energy. 29, 39-51.

Patthanaissaranukool, W. and Polprasert, C., 2016. Reducing carbon emissions from soybean cultivation to oil production in Thailand. Journal of Cleaner Production. 131, 170-178.

Pelletier, N., Arsenault, N. and Tyedmers, P., 2008. Scenario modeling potential eco-efficiency gains from a transition to organic agriculture: life cycle perspectives on Canadian Canola, Corn, Soy, and Wheat production. Environmental Management. 42, 989-1001.

Pishgar-Komleh, S.H., Sefeedpari, P. and Rafiee, S., 2011. Energy and economic analysis of rice production under different farm levels in Guilan province of Iran. Energy. 36, 5824-5831.

Rahman, S. and Rahman, M.S., 2013. Energy productivity and efficiency of maize accounting for the choice of growing season and environmental factors: An empirical analysis from Bangladesh. Energy. 49, 329-336.

Rajabi Hamedani, S., Shabani, Z. and Rafiee, S., 2011. Energy inputs and crop yield relationship in potato production in Hamadan province of Iran. Energy. 36, 2367-2371.

Rajaeifar, M.A, Ghobadian, B., Safa, M. and Heidari, M.D., 2014. Energy life-cycle assessment and CO_2 emissions analysis of soybean-based biodiesel: a case study. Journal of Cleaner Production. 66, 233-241.

Ramedani, Z., Rafiee, S. and Heidari, M.D., 2011. An investigation on energy consumption and sensitivity analysis of soybean production farms. Energy. 36, 6340-6344.

Rathke, G.W., Behrens, T. and Diepenbrock, W., 2006. Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (*Brassica napus* L.): A review. Agriculture, Ecosystems and Environment. 117, 80–108.

Rathke, G.W., Wienhold, B.J., Wilhelm, W.W. and Diepenbrock, W., 2007. Tillage and rotation effect on corn–soybean energy balances in eastern Nebraska. Soil and Tillage Research. 97, 60–70.

Raucci, G.S., Moreira, C.S., Alves, P.A., Mello, F.F.C., Frazão, L.A., Cerri, C.E.P. and Cerri, C.C., 2014. Greenhouse gas assessment of Brazilian soybean production: a case study of Mato Grosso State. Journal of Cleaner Production. 96, 411-425.

Remus, R., Ruppel, S., Jacob, H.J., Hecht-Buchholz, C. and Merbach, W., 2000. Colonization behavior of two enterobacterial strains on cereals. Biology and Fertility of Soils. 30, 550-557.

Safa, M. and Samarasinghe, S., 2011. Determination and modeling of energy consumption in Wheat production using neural networks: A case study in Canterbury province, New Zealand. Energy. 36, 5140–5147.

Safa, M., Samarasinghe, S. and Mohsen, M., 2010. Determination of fuel consumption and indirect factors affecting it in wheat production in Canterbury, New Zealand. Energy. 35, 5400-5405.

Salvagiotti, F., Cassman, K.G., Specht, J.E., Walters, D.T., Weiss, A. and Dobermann, A., 2008. Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. Field Crops Research. 108, 1–13.

Sarauskis, E., Buragien, S., Masilionyt, L., Romaneckas, K., Avizienyt, D. and Sakalauskas, A., 2014. Energy balance, costs and CO_2 analysis of tillage technologies in maize cultivation. Energy. 69, 227-235.

Soltani, A., Maleki, M.H.M. and Zeinali, E., 2014. Optimal crop management can reduce energy use and greenhouse gases emissions in rainfed Canola production. Int. Journal of Plant Production. 8, 587-604.

Soltani, A., Rajabi, M.H., Zeinali, E. and Soltani, E., 2013. Energy inputs and greenhouse gases emissions in wheat production in Gorgan, Iran.

Energy. 50, 54 -61.

Soni, P., Taewichit, C. and Salokhe, V.M., 2013. Energy consumption and CO_2 emissions in rainfed agricultural production systems of Northeast Thailand. Agricultural System. 116, 25–36.

Strapatsa, A.V., Nanos, G.D. and Tsatsarelis, C.A., 2006. Energy flow for integrated apple production in Greece. Agriculture, Ecosystem and Environment. 116, 176-180.

Tabatabaie, S.M.H., Rafiee, S.H., Keyhani, A. and Heidari, M.D., 2013. Energy use pattern and sensitivity analysis of energy inputs and input costs for pear production in Iran. Renewable Energy. 51, 7-12.

Tipi, T., Cetin, B. and Vardar, A., 2009. An analysis of energy use and input costs for wheat production in Turkey. Journal of food Agriculture and Environment. 7, 352-356.

Turhan, S., Cananozbag, B. and Rehber, E., 2008. A comparison of energy use in organic and conventional tomato production. Journal of food Agriculture and Environment. 6, 318-321.

Wiesler, F., Behrens, T. and Horst, W.J., 2001. The role of nitrogen-efficient cultivars in sustainable agriculture. In: Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy, The Scientific World. DOI 10.1100/tsw.2001.264

Zahir, A.Z., Arshad, M. and Frankenberger, W.T., 2004. Plant growth promoting Rhizobacteria: applications and perspectives in agriculture. Advances in Agronomy. 81, 97-168.

فصلنامه علوم محیطی، دوره نوزدهم، شماره ۲، تابستان ۱۴۰۰

۲۴۱-۲۶۸

بررسی سنجه‌های انرژی و انتشار گازهای گلخانه¬ای در تولید سویا، استان گلستان، ایران

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رضوان طلب، ن.، ا. سلطانی، ا. زینلی، س. دستان و ع.ر. فروغ نیا. ۱۴۰۰. بررسی سنجه‌های انرژی و انتشار گازهای گلخانه‌ای در تولید سویا، استان گلستان، ایران. فصلنامه علوم محیطی. ۱۹(۲): ۲۴۱-۲۶۸.

مقدمه: نهاده‌هایی مانند کودهای شیمیایی، سوخت فسیلی، الکتریسیته، بذر و ماشین‌های کشاورزی در تولید سویا انرژی مصرف می‌کنند. این مصرف انرژی سبب انتشار گازهای گلخانه‌ای خواهد شد که افزایش غلظت این گازها در جو می‌تواند منجر به گرم شدن کره زمین شود. هدف از این مطالعه بررسی سنجه های انرژی و انتشار گازهای گلخانه ای در تولید محصول سویا در استان گلستان بود.

مواد و روش‌ها: در این مطالعه، ۱۴۰ مزرعه برای تولید سویا در استان گلستان در شمال شرق ایران انتخاب شدند. داده‌ها شامل ماشین‌آلات، بذر، کود، سوخت و آفت‌کش‌ها می‌باشند که با استفاده از پرسشنامه جمع‌آوری شدند. سپس سوخت، انرژی ورودی و خروجی، سنجه‌های ارزیابی انرژی و پتانسیل گرم شدن کره زمین (kg CO_2/ha) با استفاده از ضرایب مربوطه محاسبه شد.

نتایج و بحث: براساس نتایج، نیازهای سوخت و انرژی مورد نیاز برای تولید سویا به ترتیب ۲۱۰/۸۳±۰/۰۹ لیتر در هکتار و ۱۹۰۳۶/۲±۰۸/۵۳ مگاژول در هکتار بود. همچنین انتشار گازهای گلخانه‌ای به میزان ۲۳۰۶/۸۵±۳/۱۷ معادل کیلوگرم دی‌اکسیدکربن در هکتار محاسبه شد. مصرف سوخت فسیلی و الکتریسیته، بیشترین میزان مصرف انرژی و انتشار گازهای گلخانه‌ای را در پی داشت. به‌طوریکه ۶۲ درصد کل مصرف انرژی و ۷۵ درصد کل انتشار گازهای گلخانه‌ای به مصرف الکتریسیته و سوخت فسیلی مرتبط بود. میزان انرژی خروجی سویا ۴۲۱۲۴/۰±۹۵/۷۳ مگاژول در هکتار بود. نسبت انرژی ورودی به خروجی ۲/۲۱±۰/۰۱ برآورد شد. افزایش تولید خالص با افزایش عملکرد دانه و کاهش مصرف نهاده‌ها مانند الکتریسیته، سوخت فسیلی و کود نیتروژن افزایش یافت. بهره‌وری انرژی ۰/۱۴۷±۰/۰۱ کیلوگرم بر مگاژول محاسبه شد. به‌طور متوسط از هر هکتار دانه سویای تولید شده، ۲۳۰۶/۸۵±۳/۱۷ کیلوگرم معادل دی اکسیدکربن منتشر شد.

نتیجه‌گیری: تمرکز بر مصرف بهینه سوخت‌های فسیلی و کاهش مصرف الکتریسیته در آبیاری برای کاهش مصرف انرژی و انتشار گازهای گلخانه‌ای در تولید سویا در استان گلستان ضروری است.

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واژه‌های کلیدی: انتشار گازهای گلخانه‌ای، انرژی ورودی، پتانسیل گرمایش جهانی، کارایی مصرف انرژی