Energy Analysis and Greenhouse Gas Emission from Strawberry Production under Two Irrigation Systems

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Abstract

The aims of this study were to estimate the energy indices, greenhouse gas (GHG) emission and compare the energy balance of open field strawberry production under furrow and drip irrigation systems in Kurdistan province, west of Iran. Data used in this study were obtained from 24 strawberry growers using a face to face questionnaire method in 2014. In order to convert inputs and output into energy equivalents, energy equivalent coefficients were applied. The results indicate that total energy consumption in strawberry production was 16,206.83 and 16,525.69 MJ.ha^{-1}, whereas the total energy output was 38,950.00 and 52,385.70 MJ.ha^{-1} in furrow and drip irrigation systems, respectively. Energy use efficiency and net energy in the drip irrigation system were higher than the furrow irrigation system. Nitrogen fertilizer was the major energy consumer in both of the irrigation systems. From an environmental viewpoint, the total GHG emissions were 764.28 and 1,284.19 kg CO_2 equivalent ha^{-1} in the furrow and drip systems, respectively. In the furrow system, the nitrogen fertilizer and diesel fuel had the highest share in GHG emissions, with 51.76 and 20.72 percent of the total, respectively, but in the drip system, machinery had the highest share in GHG emissions, with 53.11 percent of the total.

Keywords: Energy use efficiency, net energy, strawberry production, GHG emissions

Introduction

Agriculture production is the process of converting the energy of solar radiation into metabolisable forms of energy and nutrients through photosynthetic pathways, aided by external inputs in the form of seeds, tillage, water, nutrients, weed control, and other practices aimed at improving the growing conditions for the crops [1]. Energy use in the agricultural sector has become more intensive due to the use of fossil fuels, chemical fertilizers, pesticides, machinery and electricity to provide substantial increases in food production. However, more intensive energy use has brought some important human health and environment problems so efficient use of inputs has become important in terms of sustainable agricultural production [2].

Increasing the use of energy inputs in cropping systems led to numerous environmental problems like GHG emissions, loss of biodiversity, high consumption of non-renewable energy resources and pollution of the environment [3,4]. There are both financial and environmental reasons to improve energy use efficiency in agricultural systems. From an environmental viewpoint, energy use in agriculture is associated with carbon dioxide (CO_2) emissions which has serious implications for climate change. From a financial viewpoint, energy generally costs money [5].

Nowadays, global warming is one of the most important issues. Burning fossil fuels results in the emission of CO_2, nitrous oxide (N_2O) and methane (CH_4) that act as barriers to thermal radiation and prevent it from leaving the earth's atmosphere [6]. Agricultural GHG emissions account for 10 - 12 % of all anthropogenic GHG emissions. So, use of different forms of energy and its negative effects are

indivisible [4]. A reduction in GHG emissions by minimising the amount of fossil fuels burnt is therefore vital to reduce global warming [7].

Current farming systems have become very energy intensive. There is a great need to balance the use and availability of energy, particularly in the agricultural sector [8]. The energy balance approach for determination of agronomic efficiency requires quantification of the total energy of external inputs expended on crop production and the energy yield in the form of human appropriated yield [1]. Total input of energy in cropping systems increases with an increase in management intensity. Therefore, selection of an appropriate method includes evaluation of the system's efficiency control [9]. In India, a study was conducted to assess the EUE and GHG emissions of different tillage practices in pigeon pea-castor systems under semi-arid rainfed regions. Results showed that the use of fossil fuels in zero tillage was 58 and 81 % lower than conventional tillage in pigeonpea and castor cropping systems, respectively [10]. In Iran, Banaeian *et al.* reported that greenhouse strawberry production consumed in total 121,891.33 MJ.ha^{-1} [5]. In this research, the energy ratio, specific energy, net energy and energy intensiveness were 0.15, 12.55 MJ.kg^{-1}, 683,488.37 MJ.ha^{-1} and 8.18 MJ.\$$^{-1}$, respectively. In another paper, Royan *et al.* studied the energy balance between the energy inputs and yield in peach production in Golestan province, northeastern Iran as a case study. The results showed that total energy consumption in peach production was 37,536.96 MJ.ha^{-1} where the diesel fuel with about 26.32 % was the major energy consumer [11]. Ren *et al.* investigated the energy productivity and input sensitivity of sweet sorghum as compared with cotton and maize, at 2 coastal saline-alkali sites in Shandong province, China. The energy balance analysis showed that sweet sorghum had a lower energy input requirement than maize and cotton in these sites. The results of this study revealed that the diesel fuel and nitrogen fertilizer energy inputs had a significantly positive impact on the sweet sorghum energy output [12].

Surface, sprinkler, and gravity drip irrigations are 3 common systems in Iran. Surface irrigation is the oldest and most common system in this country. It does not require special technology and equipment. Surface irrigation is applied as basin, border or furrow irrigations. Drip irrigation has proved very satisfactory in irrigating plants in sandy soils where it is not feasible to apply common surface or sprinkler irrigation systems. In this irrigation method, the plant receives chemical fertilizers directly, and then the fertilizer and water use efficiency are increased. Drip irrigation systems produce excellent results with crops such as grapes, peanuts, pistachios, apples and watermelons [13]. Strawberries are produced both on open field and under cover in greenhouses in Iran. It is mostly cultivated on open fields with a furrow irrigation system in Kurdistan province, west of Iran. In this province, open field strawberry production as a conventional method has been used to supply the domestic demand for this crop. The total land area cultivated for strawberries was 2,553 ha in Kurdistan province and this amount was 1,610 ha in Sanandaj township in 2013. In this year, the total strawberry production was 33,243 tones in this province, about 63 % of total strawberry production obtained from Sanandaj township [14].

The energy analysis shows the methods to minimize the energy inputs and therefore to increase the energy productivity [15]. Several studies have evaluated the energy balance in different crops' production [16-21] but very few studies have combined the energy analysis and GHG emissions for strawberry production under different irrigation systems. Therefore, the aims of this research were to undertake energy analysis and determine GHG emission from strawberry production under furrow and drip systems in Kurdistan province.

Materials and methods

Description of the site and agricultural practices

The study was carried out in Kurdistan province within 34° 44′ - 36° 30′ north latitude and 45° 31′ - 48° 16′ east longitude. Kurdistan is one of the most mountainous regions in Iran and the total area of this province is 2,820,300 ha. It is located in the west of Iran, and bound by Iraq on the west, the province of West Azerbaijan to its north, Zanjan to the northeast, Hamedan to the east and Kermanshah to the south. Sanandaj township is the capital of Kurdistan province. Other townships with their major cities are Marivan, Saqqez, Bijar, Baneh, Sarvabad, Diwandarreh, Kamyaran, Qorveh and Dehgolan. In these

regions, wheat, barley, strawberries, food legumes and fruits are the main agricultural products. The average annual rainfall of this province is 450 mm.

According to results of surveyed fields, the average farm size was 0.587 ha ranged from 0.2 to 1 ha. Land preparation and soil tillage, were generally done by a Massey Ferguson tractor using a moldboard plow and disc harrows. In the strawberry fields, land is tilled once and is disked 2 times. In this region, strawberries are mostly irrigated by furrow irrigation. Plant protection starts with application of pesticide and herbicide. Chemical fertilizers are applied approximately 1 - 2 times. On average, the strawberry crop is hoed 1 - 2 times by hand during the period of growth and harvested by hand during May-June.

Data collection

Data were collected from open field strawberry farmers in Kurdistan province using a face to face questionnaire performed in August-September 2014. Sample farms were randomly selected from the villages in the study area by using a random sampling technique. The equation is as below [17].

$$n = (\sum N_h S_h) / (N^2 D^2 + \sum N_h S_h^2) \tag{1}$$

where n is the required sample size; n is the number of total holdings in the population; N_h is the number of the population in h; S_h^2 is the variance of h stratification; $D^2 = d^2/z^2$; d is the precision where $(\bar{x}\_\bar{X})$; and, z is the reliability coefficient.

The permissible error in the sample size was defined to be 5 % for 95 % confidence and the sample size was calculated as 24 farms. Human labor, machinery, diesel fuel, chemical fertilizers, and chemicals and output yield values of crop have been used to investigate the energy flow. The quantity of inputs is demonstrated in **Table 1**. The energy used in applying each machine was calculated from the total weight and the economic life of the machine and the time needed to complete that operation [22]. Basic information on energy inputs and strawberry yields were entered into Excel spreadsheets.

Table 1 Energy equivalent of inputs and output in strawberry production.

A. Inputs	Unit	Energy equivalent (MJ.unit^{-1})	Reference
Human labor	h	1.96	[2,8]
Machinery	h	64.70	[21]
Diesel fuel	L	56.31	[34]
Fertilizers			
Nitrogen (N)	kg	66.14	[5]
Phosphate (P_2O_5)	kg	12.44	[5]
Potassium (K_2O)	kg	11.15	[5]
Micro-elements	kg	120.00	[26]
Chemicals	kg	120.00	[26]
Water for irrigation	m^2	1.02	[36]
B. Output			
Strawberry	kg	1.9	[5]

Energy analysis

Energy equivalents of inputs and outputs (**Table 1**) were exercised to assess the total energy inputs and outputs. Diesel fuel, machinery, fertilizers, chemicals, water for irrigation, human labor and output yield values of strawberry have been used to estimate the energy ratio. Different sources of energy have different energy values. Since the inputs were measured in different units, it was necessary to convert

them into a common energy unit by using various energy coefficients. Energy coefficients for various sources of energy may thus be defined as energy equivalence of such sources of energy, taking into account all forms of energy inputs to their production. **Table 1** gives energy values of different sources of energy. These coefficients have been recognized and accepted by various scientific communities as indicated in the last column.

The amounts of input were calculated per hectare and then, these input data were multiplied with the coefficient of energy equivalent. The total input equivalent can be calculated by adding up the energy components of all inputs in MJ. In this order the energy equivalents of the inputs and output, the energy use efficiency, energy productivity, net energy and the specific energy were calculated [17,21];

Energy use efficiency = [Energy output (MJ.ha^{-1}) / Energy input (MJ.ha^{-1})]   (2)

Energy productivity = [Production (kg.ha^{-1}) / Energy Input (MJ.ha^{-1})]   (3)

Specific energy = [Energy Input (MJ.ha^{-1}) / Production (kg.ha^{-1})]   (4)

Net energy = Energy Output (MJ.ha^{-1}) - Energy Input (MJ.ha^{-1})   (5)

The input energy was divided into renewable and non-renewable and direct and indirect forms. Non-renewable energy includes diesel fuel, chemicals, chemical fertilizers, and machinery and renewable energy consists of human labor and water. Direct energy is directly used on fields. Indirect energy included energy embodied in seed, chemical, machinery and fertilizers while direct energy covered diesel fuel, human, water for irrigation and human labor used in the production process [18,19].

GHG emission analysis

The amounts of GHG emissions from energy inputs in strawberry production per hectare were calculated by using CO_2 emissions coefficient of agricultural inputs (**Table 2**). The amount of produced CO_2 was calculated by multiplying the input application rate (chemical fertilizers, diesel fuel, machinery and fungicide) by its corresponding emission coefficient that is given in **Table 2**. Ultimately, GHG emissions were calculated and reported per hectare [4].

Results and discussions

Energy analysis

The results revealed that 1,276.80 and 1,112.83 h of human labor and 8.50 and 38.21 h of machine power are required per hectare for strawberry production in furrow and drip systems, respectively (**Table 3 and 4**). The majority of human labor in the strawberry farms was used in the harvest, weeding, and planting operations. In Kurdistan province, the sources of human labor in strawberry farms are either family members or seasonal laborers. Introducing new machines reduced human labor in the industry, but in field activities human labor still plays a key role. Even now, human power is the main source (73 %) of energy in agricultural operations in many developing countries [23].

Total machinery power consumed for land preparation consisted of plowing, disking, land leveling and transportation. The amount of input energies from different sources and output energy are presented in **Tables 3** and **4**. These results showed that the total energy input in the drip system was 16,525.69MJ ha^{-1}, and it was higher than the furrow system (16,206.83 MJ ha^{-1}). The lower energy consumption in the furrow system was due to lower inputs of diesel fuel and machinery (**Table 3**).

Table 2 GHG emission coefficients of agricultural inputs [4].

Input	Unit	GHG coefficient (kg CO_{2eq} unit^{-1})
1. Diesel fuel	L	2.76
2. Nitrogen fertilizer (N)	kg	1.3
3. Phosphorous fertilizer (P_2O_5)	kg	0.2
4. Potash fertilizer (K_2O)	kg	0.2
5. Fungicide	kg	6.3
6. Machinery	h	71

Table 3 Amounts of inputs, output and energy inputs and output for strawberry production with furrow irrigation system in Kurdistan province, Iran.

Inputs and output	Unit	Quantity per unit area (ha)(min-max)	Total energy equivalent (MJ.ha^{-1})	Percentage
A. Inputs				
1. Human labor	h	1,276.80(672-2,688)	2,502.53	15.44
2. Machinery	h	8.50(7-10)	532.95	3.29
3. Diesel fuel	l	53.33(30-80)	3,003.01	18.53
4. Chemical fertilizers	kg			
a. Nitrogen		89.70(82.8-93)	5,932.76	36.61
b. Phosphate (P_2O_5)		31.20(24-48)	388.13	2.39
c. Potassium (K_2O)		23.00(20-27)	256.45	1.58
d. Micro elements		8.00(5-10)	960.00	5.92
5. Chemicals	kg	4.50(3-6)	540.00	3.33
6. Water for irrigation	m^3	2,050(900-3,400)	2,091.00	12.90
The total energy input	MJ	-	16,206.83	100
B. Output				
1. Strawberry fruit	kg	20,500(17,000-25,000)	3,8950.00	
The total energy output	MJ	-	3,8950.00	100

The contribution of different input energies used in strawberry production is illustrated in **Tables 2** and **3**. The results showed that nitrogen fertilizer with 36.61 and 30.25 % has the highest share of total energy input from furrow and drip systems, respectively. Also, according to the data collected from all surveyed fields, energy input of nitrogen fertilizer has the highest share within all the chemical fertilizers. It indicates that average fertilizer use in the furrow and drip systems is 89.70 and 75.57 kg.ha^{-1} for nitrogen and 31.20 and 30.90 kg.ha^{-1} for P_2O_5, respectively. It has been reported that energy input of nitrogen fertilizer has the biggest share of the total energy inputs in crops production [16-21]. However, in the Kurdistan region, the highest energy use belonged to diesel fuel, followed by nitrogen fertilizer which accounted about 18.53 and 24.70 % of total energy consumption in furrow and drip systems (**Tables 3** and **4**). One of the main reasons for high consumption of diesel fuel is a temporal depreciation of machinery particularly in the pumps and tractors. In general, reduction of chemical fertilizers and fuel consumption are the most important ways of better energy management in strawberry production in the studied region. Based on the results, we recommend that the consumption of nitrogen fertilizers and diesel fuel are limited so that they can be effectively replaced by appropriate management practices. Djevic and

Dimitrijevic determined that 92 % of total energy in greenhouse lettuce production is diesel energy in Yugoslavia [24].

Table 4 Amounts of inputs, output and energy inputs and output for strawberry production with drip irrigation system in Kurdistan province, Iran.

Inputs and output	Unit	Quantity per unit area (ha)(min-max)	Total energy equivalent (MJ.ha^{-1})	Percentage
A. Inputs				
1. Human labor	h	1,112.83(537.59-1,612.79)	2,181.15	13.20
2. Machinery	h	38.21(8-80)	2,395.77	14.50
3. Diesel fuel	l	72.50(30-100)	4,082.48	24.70
4. Chemical fertilizers	kg			
a. Nitrogen		75.57(46-138)	4,998.20	30.25
b. Phosphate (P_2O_5)		30.90(19-48)	384.40	2.33
c. Potassium (K_2O)		20.00(17-22)	223.00	1.35
d. Micro elements		5.00(5-5)	600	3.63
5. Chemicals	kg	3.70(2-5)	444.00	2.69
6. Water for irrigation	m^3	1,192.85(500-1,650)	1,216.71	7.36
The total energy input	MJ	-	16,525.69	100
B. Output				
1. Strawberry fruit	kg	27,571.42(18,000-50,000)	52,385.70	
The total energy output	MJ	-	52,385.70	100

Table 5 The energy indices of strawberry production under 2 irrigation systems in Kurdistan province, Iran.

Items	Unit	Quantity	
		Furrow system	Drip system
Energy use efficiency	-	2.40	3.17
Energy productivity	kg.MJ^{-1}	1.26	1.67
Specific energy	MJ.kg^{-1}	0.79	0.60
Net energy	MJ.ha^{-1}	22,743.17	35,860.01

The energy of the irrigated water (2,091.00 and 1,216.71 MJ.ha^{-1}) constituted 12.90 and 7.36 % of total input energy in furrow and drip systems, respectively (**Tables 1** and **2**). In this study, average strawberry yield in the furrow and drip systems was 20,500 and 27,571.42 kg.ha^{-1}, while the calculated total output energy was 38,950.00 and 52,385.70 MJ.ha^{-1}, respectively (**Table 5**). These results showed that the chemical energy in the drip system was 540.00 MJ ha^{-1}, and was higher than furrow system (444.00 MJ.ha^{-1}) (**Tables 3** and **4**).

The energy use efficiency, specific energy, energy productivity, and net energy of strawberry production in Kurdistan province were calculated using Eqs. (2) - (5) and tabulated in **Table 5**. Energy use efficiency was calculated as 2.40 in furrow system and 3.17 in drip system. The value of this index in the Kurdistan region indicated that strawberry fields with the drip irrigation system are more efficient in

the use of energy. The energy efficiency of growing strawberries proved considerably higher in our experiment than that found by Banaeian *et al.* [5] because of the cost of fuel. The energy use efficiency gives an indication of how much energy was produced per unit of energy utilized. It varies greatly according to the species, the age of the crop and the agronomic inputs [25]. The rate of net energy in the furrow system (22,743.17 MJ.ha^{-1}) was lower than the drip system (35,860.01 MJ.ha^{-1}). Also, the average energy productivity of strawberry was as 1.26 kg.MJ^{-1} in the furrow system and 1.67 kg.MJ^{-1} in the drip system (**Table 5**). This means that 1.26 and 1.67 units of output were obtained per unit energy in the furrow and drip system, respectively. In general, optimum energy use in agriculture is reflected in 2 ways, i.e. an increase in productivity with existing level of inputs or conserving energy without affecting the productivity [20].

In this research, the specific energy was 0.79 MJ.kg^{-1} in the furrow system and 0.60 MJ.kg^{-1} in the drip system. This means that 0.79 and 0.60 MJ were needed to obtain 1 kg of strawberries in the furrow and drip systems, respectively. Canakci *et al.* reported that the specific energy for field crops and vegetable production in Turkey, was 5.24 for wheat, 11.24 for cotton, 16.21 for sesame, 0.98 for melon, 0.97 for water-melon and 1.14 for tomato [26].

The total energy input consumed in both furrow and drip irrigation systems could be classified as direct energy (46.86 vs. 45.26 %), indirect energy (53.13 vs. 54.74 %), renewable energy (28.34 vs. 20.56 %) and non-renewable energy (71.66 vs. 79.44 %), respectively (**Table 6**). Results showed that strawberry growing consumed more indirect energy than direct energy and more non-renewable energy than renewable energy in both systems. The water for irrigation and diesel fuel consumed were the main reason for the difference between direct and indirect energy inputs in strawberry production. The high ratio of non-renewable energy in the total energy inputs causes negative effects on the sustainability of agricultural production. Therefore, it is important to better utilize the renewable energy sources for increasing energy efficiency, so renewable energy production stimulates the agricultural land rural economy, improves the environment and enhances national energy security [5]. Several researchers have shown that, for different crops in Iran, indirect and non-renewable energies are higher than that of direct and renewable energies, respectively [5,16-21]. Wider use of renewable energy sources, increase in energy supply and efficiency of use can make an important contribution to meet sustainable energy development targets [27]. Integrated arable farming systems have been introduced to lessen the environmental impact of cropping and to promote sustainable resource use while maintaining crop production and farm incomes. These systems use a holistic approach of the principles and procedures known to reduce agronomic inputs and to diversify crops [28]. In Iran, the impacts of direct, indirect and renewable and non-renewable energies on cucumber yield were estimated as 0.39, 0.61, 0.27 and 0.37, respectively [20].

Table 6 Some energy forms in strawberry production under furrow and drip irrigation systems, in Kurdistan province, Iran.

Item	Quantity (MJ.ha^{-1})			
	Furrow system	**Percentage**	**Drip system**	**Percentage**
Direct energy	7,596.54	46.86	7,480.33	45.26
Indirect energy	8,610.29	53.13	9,045.36	54.74
Total	16,206.83	100	16,525.69	100
Renewable energy	4,593.53	28.34	3,397.85	20.56
Non-renewable energy	11,613.30	71.66	13,127.84	79.44
Total	16,206.83	100	16,525.69	100

Table 7 GHG emissions (kg CO_2 equivalent ha^{-1}) from strawberry production under 2 irrigation systems in Kurdistan province, Iran.

Item	Furrow system	Percentage	Drip system	Percentage
1. Diesel fuel	158.39	20.72	215.33	16.77
2. Nitrogen (N)	395.57	51.76	333.26	25.95
3. Phosphorous (P_2O_5)	28.32	3.71	28.12	2.19
4. Potash (K_2O)	12.65	1.66	11.00	0.86
5. Fungicide	17.55	2.30	14.43	1.12
6. Machinery	151.72	19.85	682.05	53.11
Total	764.28	100	1,284.19	100

GHG emissions

Table 7 shows the amount and percentage of GHG emitted derived from production of strawberries. The total amount of GHG emissions were 764.28 and 1,284.19 kg CO_2 equivalent ha^{-1} in the furrow and drip systems, respectively. Cerutti *et al.* found that emission of 1 kg CO_2-equivalents in an apple orchard produced 6.1 kg of apples [29]. In the furrow system, nitrogen fertilizer and diesel fuel had the highest share in GHG emissions, with 51.76 and 20.72 percent of total, respectively, but in the drip system, machinery had the highest share in GHG emissions, with 53.11 percent of the total (**Table 7**). Reducing the energy derived from fossil fuels within agricultural systems has important implications for decreasing atmospheric emissions of greenhouse gases, thus assisting the arrest of global warming. The identification of crop production methods that maximise energy use efficiency and minimise greenhouse gas emissions is very important [6]. Kehagias *et al.* reported that organic farming can minimize greenhouse gas emissions in agricultural systems [30].

Among the different agricultural practices, soil tillage is one of the greatest fossil fuel energy consumers and contributes to about 30 % of the total energy use in crop production and in turn increases GHG emissions [31,10]. Tillage strategies need further evaluation not only during seedbed preparation, but also within the framework of the entire cropping system's mechanical operations [28]. Niu *et al.* showed a positive relationship between energy consumption and CO_2 emissions in 8 Asian economies [32]. About 25 % of global GHG emissions result from land clearance, crop production and fertilization. In contrast, large amounts of carbon can be fixed in the soil-crop system through photosynthesis and might increase soil organic carbon (SOC) storage to offset parts of the above GHG emissions [33].

Conclusions

The value of energy use efficiency in the Kurdistan region indicates that strawberry fields under a drip irrigation system are more efficient in the use of energy. Energy inputs in strawberry production were higher in the drip system than the furrow system. The main difference in energy consumption between the furrow and drip systems comes mainly from machinery and diesel fuel. We conclude that the high ratio of non-renewable energy in the total used energy inputs causes negative effects on the sustainability in agroecosystems and energy use efficiency which was calculated to be 2.40 in the furrow system and 3.17 in the drip system. These results highlight that the energy use efficiency can be increased by raising the crop yield and/or by decreasing energy inputs. The total GHG emissions were 764.28 and 1,284.19 kg CO_2 equivalent ha^{-1} in the furrow and drip systems, respectively. From the environmental viewpoint, reduction of energy needs by integrated farming is a highly promising climate change mitigation option. In fact, lower fossil fuel inputs for crop management can deliver substantial and long-term GHG emission reductions [28] The limited water resources and the widespread use of unscientific and traditional irrigation systems which result in up to 3 times higher water consumption than actually needed for production of crops, are the major constraints facing agriculture in Iran [12]. Finally, from the water and energy consumption viewpoint, the drip irrigation system is suitable for strawberry production in Iran. This method is more nature-friendly, but also more costly to apply in the studied region.

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