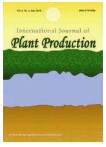

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Optimal crop management can reduce energy use and greenhouse gases emissions in rainfed canola production

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Abstract

Energy use and greenhouse gases (GHG) emissions in rainfed canola production in north eastern Iran were analyzed to find measures to reduce energy use and GHG emissions. Four production scenarios, i.e. a high-input, a low-input, a better crop management and a usual scenario, evaluated. All activities and production processes were monitored and recorded over three consecutive years. The usual scenario consumed 13 GJ ha^{-1} energy input, resulted in 52 GJ ha^{-1} energy output and GHG emissions of 1028 kg CO_2-eq ha^{-1} and 556 kg CO_2-eq t^{-1}. The key factors relating to energy use and GHG emissions were nitrogen fertilizer and fuel for field operations. Compared to the usual production scenario, the better crop management production scenario was significantly more efficient; it consumed 25% less input energy, needed 17% lower amount of nitrogen fertilizer, but resulted in 35% more grain yield and output energy. This scenario also resulted in 26% less GHG emissions per unit field area and 45% less GHG emissions per ton of grain. Measures of improvement in energy use and GHG emission were identified.

Keywords: Canola; Crop management; Energy; Environment; GHG emission.

Introduction

Energy is a key component in modern agriculture as it heavily depends on fossil and other energy resources (Safa and Samarasingh, 2011). Energy is required for field operations such as tillage, sowing, harvesting and transport or stationary operations such as pumping water and drying grain.

In addition, energy is needed for manufacturing, packing and storage of fertilizers and pesticides and for activities such as acquisition of raw materials and fabrication of equipment and farm buildings (Lal, 2004). Due to the use of high yielding varieties, increased use of fertilizers and chemicals and mechanized farming, energy use in agriculture has been increasing (Singh et al., 2004; Tipi et al., 2009), faster than in many other sectors (Safa and Samarasingh, 2011; IPCC, 2007).

Direct and indirect consumption of fossil fuels results in the emission of greenhouse gases, i.e. carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) (IPCC, 2007). Agriculture contributes to production of these harmful greenhouse gases (Johnson et al., 2007). Greenhouse gases (GHG) from agriculture and other human activities absorb infrared radiation in the atmosphere, trapping heat and warming the earth's surface (Snyder et al., 2009). This warming effect has led to an increase in the global temperature during the 20th century by 0.6 ± 0.2 °C at an average rate of increase of 0.17 °C per decade since 1950 (IPCC, 2007). Global warming as a result of greenhouse gases is one of the most important environmental challenges in the world today that threatens future life on earth (IPCC, 2007).

Fossil fuel combustion is considered responsible for more than 75% of human-caused GHG emissions and land use change (primarily deforestation) is responsible for the remainder (Snyder et al., 2009). Reducing the use of fossil energy in agriculture is therefore an attractive subject mainly because of problems with emissions of the greenhouse gases to the atmosphere. It is also important for sustainable agricultural production, to minimize production cost and to preserve limited fossil fuel reserves for future generations (Pervanchon et al., 2002; Rathke and Diepenbrock, 2006). Better knowledge of fossil energy use in agricultural systems is needed to develop production systems that need low inputs of fossil energy while maintaining high levels of output that would help to reduce greenhouse gases emissions (Rathke and Diepenbrock, 2006; Tzilivakis et al., 2005; Dalgaard, 2000).

In a review of agricultural opportunities to mitigate greenhouse gas emissions Johnson et al. (2007) stated that there are still geographic regions and agricultural systems that have not been well characterized with respect to GHG emission. They emphasized the need to estimate GHG emissions and global warming potential across a wide range of agricultural systems.

Energy use in canola crops has been evaluated in Iran (Mousavi-Avval et al., 2010; Mousavi-Avval et al., 2011abc; Monjezi and Zakidizaji, 2012;

Taheri-Garavand et al., 2010; Sheikh-Davoodi and Houshyar, 2009; Azarpour, 2012) as well as in other countries (Rathke and Diepenbrock, 2006; Unakitan et al., 2010). However, these studies suffer from two limitations: (a) they have not evaluated energy use by different production operations and (b) they have not evaluated energy use in different production scenarios and presented average energy input over many farmers. In addition, no studies have yet been published on greenhouse gases emissions in canola production in Iran.

Canola production in Iran has increased from about 9,000 tons in 2000 to more than 200,000 tons in 2010 (FAO, 2012).The Gorgan region is located in northeast Iran at the southeast coast of the Caspian Sea, in Golestan province. Golestan province is the first canola producing province of Iran that has produced about 37% of Iran's canola grain from 2000 to 2010. About 46,000 tons of canola is produced from about 32,000 ha of sown land. Rainfed production is dominant in the region.

There is an immediate need to undertake an assessment of energy use and its environmental impact in terms of GHG emissions so that future steps to be taken for improvement in canola production in this respect. Therefore, the objectives of this research were: (1) to examine the quantity of energy input in canola production in the region for different production scenarios, (2) to estimate the amount of GHG emissions from energy consumption and (3) to identify measures to optimize energy use and to reduce GHG emissions.

Materials and Methods

Description of the site

The study was conducted in the Gorgan region, Golestan province, Iran. The region is located along the southeastern coast of the Caspian Sea in northeastern Iran. The region is located within 36^{o} 44' and 38^{o} 05' north latitude and 53^{o} 51' and 56^{o} 14' east longitude. It borders the Alborz Mountain range to the south and the Caspian Sea to the north. The climate is temperate sub-humid. Mean annual temperature and solar radiation are 17.6 ^{o}C and 15.7 MJ m^{-2} d^{-1}. Total annual precipitation is 607 mm. Canola is sown in the autumn during the months of November and December. Averages of maximum and minimum temperatures and rainfall during canola growing season, December to June, are 17.2 and 7.3 ^{o}C and 340 mm, respectively. The crop is harvested during May and June, after which a soybean crop or another summer crop is usually sown as the second crop in a double cropping system. Thus, the growing season is limited and the cropping system is intensive. Other crops grown in the region are wheat, barley, maize and cotton.

Description of production scenarios

Six fields, representative of major canola production scenarios in the region, were selected for this research. These fields were chosen among many fields after preliminary evaluation and consulting with local agricultural organizations, consultants and agricultural experts. In this paper, we further combined data from three fields into one as they were much similar in terms of production processes and inputs used. Table 1 includes more information about the selected fields/scenarios. All activities and production processes were monitored and recorded from seedbed preparation to delivery of produced crop to local storages/silos without any intervention in farmers' activities. Data presented in this study is representative of typical and/or average data recorded over the three consecutive years of 2008-2010. For statistical analysis, year was considered as block and scenarios as treatments and then a randomized complete bock design was used for analysis of variance. Scenarios means were compared using least significant difference (LSD) test.

Table 1. Description of each canola production scenario.

Scenario	Description
I	A better crop management scenario by some progressive farmers; simultaneous sowing and base fertilizer application using a seed-fertilizer drill (about 6% of farmers).
II	The usual production scenario; represents many farmers in the region (about 70% of farmers).
III	A low-input scenario; less use of fertilizers; using man power to broadcast seed and base fertilizer; a little less use of machinery (about 4% of farmers).
IV	A higher input scenario; a tendency to use more fertilizer (about 16% of farmers).

Scenario I represents progressive farmers in the region that have a better management of their crops. In this scenario, a seed-fertilizer drill was used to simultaneously put the seed and the base fertilizer in the soil. Scenario II indicates common practices that the majority of farmers (about 70%) in the region apply. Scenario III is a low-input production method in which minimum amount of fertilizer is used and usage of machinery is similar to the average farmers. In this scenario, seed and base fertilizer are broadcasted by hand and then incorporate into the soil by disking. Scenario IV represents those farmers that have a tendency to use higher rates of fertilizers. All scenarios use a plow for seedbed preparation; conservation tillage such as no-tillage or minimum tillage are not common in the region due to a lack of necessary machinery including high power tractors.

Common fertilizers are urea (46% N) ammonium phosphate (46% P_2O_5; 18% N), triple super phosphate (46% P_2O_5), ammonium nitrate phosphate (20% P_2O_5; 26% N), potassium chloride (60% K_2O) and a complete macro fertilizer (8% P_2O_5; 15% N; 15% K_2O). Common pesticides are Tanteral (II), Topic (III), Gallant Super (I, II, III and IV) as herbicides. In all the scenarios the canola was harvested using a combine harvester.

Energy analysis

Method of energy analysis was the process analysis (Rathke and Diepenbrock, 2006; Tzilivakis et al., 2005; Soltani et al., 2013) that included fossil energy input but not man power or solar energy. However, human labor energy was calculated here for comparison purposes. Energy inputs for storage were not considered but the energy required to transport the grain from the field to the local storages/silos was calculated. Energy removed from the soil in the form of plant nutrients or energy involved in terms of soil organic matter increases or losses were not included in the analysis (Rathke and Diepenbrock, 2006). Total fossil energy has direct and indirect. Direct energy includes energy from human, diesel and electricity and indirect energy includes energy from seed, fertilizer, chemicals and machinery.

The calculation of energy use by each scenario was based on the farmers' work schedule. For each production operation the number of laborers, types and the number of machines, all inputs and the times needed to conduct operations were all accounted for. Conversion factors presented in Table 2 were used to determine energy input related to each component in individual production activities (operations). The amount of fuel used was converted to an energy value using a conversion factor of 38 MJ l^{-1} for diesel and 37

MJ l^{-1} for petrol in Iran (Annonymous, 2008). Total energy embodied in machinery equaled 142.7 MJ kg^{-1} (Pimentel et al., 1973; Kaltsas et al., 2007) and this included energy for manufacturing (86.38 MJ kg^{-1}), for repairs and maintenance (0.55 × energy for manufacture) and energy for transportation (8.8 MJ kg^{-1}). Then, the energy used in applying each machine in each operation was calculated from the total weight and the economic life of the machine in the region and the time needed to complete that operation. Amounts of inputs used were converted to energy values using appropriate energy conversion factors (Table 2).

Energy required to do different operations were calculated for seedbed preparation, sowing, fertilizer application, plant protection, weed control, irrigation, harvest and transport to storage/silo. The energy required for each scenario was then obtained by combining energy inputs of the mentioned divisions plus energy embodied in inputs materials.

Energy output for each scenario was obtained by multiplying grain yield by its energy factor, i.e. 28.3 MJ kg^{-1} (Table 2). Energy indices were then determined using data for energy input, grain yield and energy output. These indices were: energy use efficiency as the ratio of energy output to energy input, specific energy as total energy input divided by grain yield (MJ kg^{-1}), energy productivity as grain yield divided by total energy used (kg MJ^{-1}) and energy gain as total energy output minus total energy input (GJ ha^{-1}).

Table 2. Energy content of inputs and outputs.

	Unit	Energy (MJ/unit)	Reference
Inputs			
Human labor	h	1.96	Canakci et al. (2005)
Canola seed	kg	31.13	Rathke et al. (2006)
Machinery[a]	kg	142.7	Kaltsas et al. (2007)
N fertilizers	kg N	60.6	Ozkan et al. (2004); Akcaoz et al. (2009)
P fertilizers	kg P_2O_5	11.1	Ozkan et al. (2004); Akcaoz et al. (2009)
K fertilizers	kg K_2O	6.7	Ozkan et al. (2004); Akcaoz et al. (2009)
Diesel	L	38	Annonymous (2007)
Petrol	L	37	Annonymous (2007)
Herbicide[b]	kg a.i.	287	Rathke et al. (2006); Tzilivakis et al. (2005)
Output			
Canola grain	kg	28.3	Rathke et al. (2006)

[a] includes energy required for manufacture, repair and maintenance and transportation of machines.

[b] a.i. represents active ingredient.

Greenhouse gas emission analysis

Greenhouse gases emissions were determined as outlined by Tizilivakis et al. (2005) and Soltani et al. (2013) and expressed in CO_2 equivalent. Firstly, the amount of energy of each fuel source used in 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) and Tizilivakis et al. (2005). Then, the GHG emissions that related to each item were calculated according to conversion factors from IPCC (2007) and Anonymous (2011). 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, 2010). For electricity a conversion factor of 0.1453 kg eq-CO_2 per MJ was used (IEA, 2010). GHG emissions were then calculated and represented per each hectare of land, each ton of canola grain and per each GJ of total energy input and output.

Results

Energy use in production operations

Total energy used in production operations is indicated in Table 3. This total includes energy as fuel (mainly diesel), machinery and labor. Scenarios II (average farmers) and IV (a high input scenario) consumed the greatest (4963 and 5069 MJ ha^{-1}) and scenario I (better crop management) consumed the lowest (3237 MJ ha^{-1}) operational energy. The value was 4066 MJ ha^{-1} for scenario III (a lower input scenario). Shares of labor, fuel and machinery energy in the total operational energy input were 1%, 70% and 24%, respectively (data not shown). Comparing the production operations, seedbed preparation used the greatest amount of energy, i.e. 60%. Harvest (16.5%) was also a major energy user. Transportation, fertilization and weed control each consumed about 6% of the input energy and sowing had a share of about 5%.

Table 3. Total energy input (MJ ha^{-1}) as fuel, machinery and labor for production operations for each canola production scenario. In each row, means with a common letter are not statistically different.

Operation	Scenarios				Mean±SE	Share (%)
	I	II	III	IV		
Seedbed preparation	1689^{c}	2905^{ab}	2447^{b}	3344^{a}	2596±289	59.9
Sowing	249^{a}	332^{a}	13^{b}	249^{a}	211±56	4.9
Fertilization	244^{bc}	361^{a}	279^{b}	200^{c}	271±28	6.2
Weed control	143^{b}	296^{a}	390^{a}	208^{b}	259±44	6.0
Harvest	614^{b}	747^{a}	730^{a}	772^{a}	716±28	16.5
Transportation	299^{a}	323^{a}	208^{b}	297^{a}	281±21	6.5
Total	3237^{c}	4962^{a}	4066^{b}	5069^{a}	4333±350	100.0

Energy use in materials

Table 4 lists sources used in production scenarios. Averaged across scenarios, seed rate was 8.5 kg ha^{-1} and the average fuel rate was 85 l ha^{-1}. Scenario I had a significantly lower fuel use (61 l ha^{-1}) than other production scenarios. Greater fertilizer use was evident in scenario IV (a higher input scenario) with a total of 370 kg ha^{-1}. Total fertilizer use was 178 kg ha^{-1} for scenario I (better crop management scenario) and 230 kg ha^{-1} for scenario II (usual scenario).

In terms of energy, total fertilizer energy input was 7539 MJ ha^{-1} in the usual scenario (II). Energy use on fertilizer was 12849 MJ ha^{-1} for scenario IV (a high input scenario), which was 70% higher than scenario II (usual scenario) (Table 5). In scenario III (a lower input scenario), the total energy use on fertilizer was 2293 MJ ha^{-1}, which was 30% of scenario II (average farmers scenario). Energy use on fertilizer was 6084 MJ ha^{-1} in the better crop management scenario (I), which was about 20% lower than in the average farmers scenario (scenario II).

The greatest share in sources energy input belonged to nitrogen fertilizer with an average of 51.9% across all scenarios (Table 5). The next greatest was for fuel consumption in field operations with an average share of 25.4%. Shares of energy input of machinery and phosphorus fertilizer were 8.8% and 5.7%, respectively. Other items had shares of less than 5%. Labor energy had a share of 0.5%. In scenario with a tendency to use higher rates of fertilizers (IV), the share of fertilizer out of the total sources energy was 70%. This figure was about 60% for scenarios I (better crop management scenario) and II (usual scenario), but 34% for scenario III (a lower input scenario).

Total energy input varied from 6816 MJ ha^{-1} for scenario III (low-input rainfed scenario) to 18424 MJ ha^{-1} for scenario IV (a higher input scenario) (Table 5). Total energy input was 12953 MJ ha^{-1} for usual scenario (II) and 9761 MJ ha^{-1} for better crop management scenario (I). Average energy input across scenarios was 11989 MJ ha^{-1} of which 27% was direct and 73% was indirect (Figure 1).

Table 4. Inputs used for each canola production scenario. In each row, means with a common letter are not statistically different.

Item	Unit	Scenarios				Mean±SE
		I	II	III	IV	
Seed	kg ha^{-1}	9.5^{a}	7.7^{b}	8.0^{b}	9.0^{a}	8.5±0.3
Fuel	l ha^{-1}	61^{b}	97^{a}	84^{a}	97^{a}	85±7
N fertilizer	kg N ha^{-1}	87^{b}	105^{b}	36^{c}	183^{a}	103±24
P fertilizer	kg P_2O_5 ha^{-1}	46^{c}	77^{b}	10^{d}	115^{a}	62±18
K fertilizer	kg K_2O ha^{-1}	45^{b}	48^{b}	0^{c}	72^{a}	41±12
Herbicide	kg a.i. ha^{-1}	0.500^{b}	0.742^{a}	0.726^{a}	0.788^{a}	0.69±0.05

Table 5. Energy inputs (MJ ha^{-1}) for each canola production scenario. In each row, means with a common letter are not statistically different.

Item	Scenarios				Mean±SE	Share (%)
	I	II	III	IV		
Labor	32^{b}	38^{b}	48^{b}	113^{a}	58±15	0.5
Seed	296^{a}	239^{b}	249^{b}	281^{a}	266±11	2.2
Machinery	888^{b}	1232^{a}	827^{b}	1270^{a}	1054±94	8.8
Fuel for field operations	2128^{b}	3502^{a}	3002^{a}	3534^{a}	3042±268	25.4
Fuel for transportation	190^{a}	190^{a}	190^{a}	152^{b}	181±8	1.5
N fertilizer	5272^{c}	6363^{b}	2182^{d}	11090^{a}	6227±1508	51.9
P_2O_5 fertilizer	511^{b}	855^{ab}	111^{c}	1277^{a}	688±203	5.7
K_2O Fertilizer	302^{b}	322^{b}	0^{c}	482^{a}	276±82	2.3
Pesticide	144^{b}	213^{a}	208^{a}	226^{a}	198±15	1.6
Total	9761^{bc}	12953^{b}	6816^{c}	18424^{a}	11989±2028	100.0

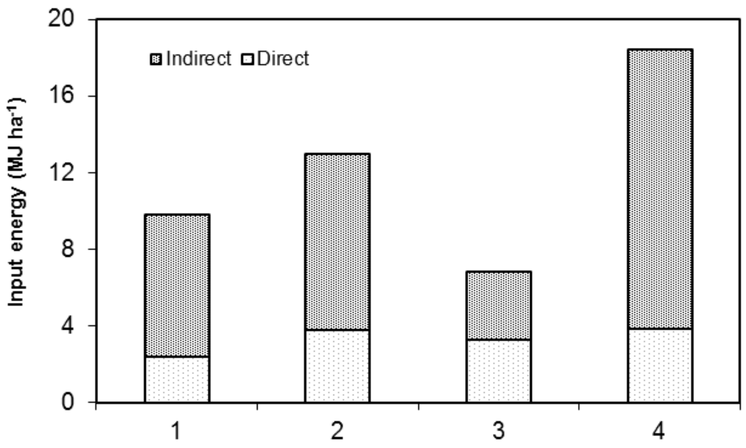

Figure 1. Total energy input as direct and indirect in each scenario of canola production.

Energy output and energy indices

The better crop management scenario had significantly higher yield (2500 kg ha^{-1}) than other scenarios. Harvested grain yield was 1850 kg ha^{-1} for scenario II (usual scenario) (Table 6). Energy output was 52355 MJ ha^{-1} for this scenario. Scenarios I and IV, the better crop management and the high input scenarios, respectively, resulted in 35% and 8% higher yield and output energy than the usual scenario (II). The lowest grain yield (610 kg ha^{-1}) and output energy (17263 MJ ha^{-1}) belonged to scenario III, the lower input scenario, which was significantly lower than other scenarios.

The highest energy efficiency (output/input ratio) belonged to scenario I (7.2), which was significantly better than other scenarios. This value was 4.0 for scenario II (Table 6). The lowest energy efficiency (2.5-3.1) belonged to scenarios III and IV, the lower input and the higher input scenarios. While scenario III (higher input scenario) produced 8% more grain yield than the usual scenario (II), its net energy production was 3% lower than the usual scenario (II). Scenario I, the better crop management scenario, was the best production scenario with regard to energy efficiency and net energy gain (Table 6). This scenario produced 55% more net energy than the usual production scenario (II). Averaged across scenarios of specific energy was 7.8 MJ kg^{-1} and the average energy productivity was 0.15 kg MJ^{-1}. The better crop management scenario (scenario I) had the lowest specific energy consumption (3.9 MJ kg^{-1}) and the greatest energy productivity (0.26 kg MJ^{-1}). The difference between this scenario and other scenarios was significant.

Table 6. Energy output and indices for each canola production scenario. In each row, means with a common letter are not statistically different.

	Scenarios				Mean±SE
	I	II	III	IV	
Outputs					
Grain yield (kg ha^{-1})	2500^{a}	1850^{b}	610^{c}	2000^{b}	1740±328
Total energy (GJ ha^{-1})	70750^{a}	52355^{b}	17263^{c}	56600^{ab}	49242±9277
Indices					
Ouput/input ratio	7.3^{a}	4.1^{b}	2.5^{c}	3.1^{bc}	4.2±0.9
Specific energy (MJ kg^{-1})	3.9^{c}	7.0^{b}	11.2^{a}	9.2^{ab}	7.8±1.3
Energy productivity (kg MJ^{-1})	0.26^{a}	0.14^{b}	0.09^{b}	0.11^{b}	0.15±0.03
Energy gain (GJ ha^{-1})	61.0^{a}	39.4^{b}	10.4^{c}	38.3^{b}	37.3±8.5

Greenhouse gases emissions

Estimates of GHG emissions for production scenarios are presented in Table 7. The estimate of GHG emissions was 1028 kg CO_2-eq ha^{-1} for scenario II (average farmers). The higher input scenario (IV) had greater GHG emissions, 1428 kg CO_2-eq ha^{-1}, which was 39% more than scenario II. The better management production scenario (I) had a GHG emission of 760 kg CO_2-eq ha^{-1}. Thus, the better crop management scenario produced 26% less greenhouse gases than the usual scenario per hectare of land. The low input scenario (III) had the lowest GHG emissions of 549 kg CO_2-eq ha^{-1}.

In terms of the share, nitrogen fertilizer (48%), fuel for field operations (25%) and machinery (14%) were the major contributors (Table 7). The share of phosphorus fertilizer was 6% and all other remaining items had a share of less than 2.5%.

GHG emission is also important per ton of harvested grain. For this indicator, scenario II (average farmers) resulted in 556 kg CO_2-eq t^{-1} (Table 8). The lower input scenario (III; 900 kg CO_2-eq t^{-1}) and the higher input scenario (IV; 714 kg CO_2-eq t^{-1}) had 62% and 28% greater GHG emissions per ton of grain than scenario II, respectively. The better crop management scenario (I) produced 45% less greenhouse gases per ton of grain (304 kg CO_2-eq t^{-1}), which was significantly lower than other scenarios. In energy scale and per unit of energy input, the production scenarios were similar with an average emission of 79 kg CO_2-eq MJ^{-1}.

Table 7. GHG emissions (kg e-CO_2 ha^{-1}) for each canola production scenario. In each row, means with a common letter are not statistically different.

Item	Scenarios				Mean±SE	Share (%)
	I	II	III	IV		
Seed	2.9^{b}	4.2^{b}	7.1^{a}	6.4^{a}	5.2±0.8	0.5
Machinery	111.1^{b}	154.1^{a}	103.5^{b}	158.9^{a}	131.9±11.7	14.0
Fuel for field operations	166^{c}	273.2^{ab}	234.2^{b}	275.7^{a}	237.2±20.9	25.2
Fuel for transportation	14.8^{a}	14.8^{a}	14.8^{a}	11.9^{b}	14.1±0.6	1.5
N fertilizer	383.9^{b}	463.3^{b}	158.9^{c}	807.5^{a}	453.4±109.8	48.2
P fertilizer	41.9^{b}	70.1^{b}	9.1^{c}	104.7^{a}	56.5±16.6	6.0
K Fertilizer	24.8^{b}	26.4^{ab}	0.0^{c}	39.5^{a}	22.7±6.7	2.4
Pesticide	14.8^{b}	21.9^{a}	21.4^{a}	23.2^{a}	20.3±1.5	2.2
Total	760.2^{bc}	1028.1^{b}	548.9^{c}	1427.8^{a}	941.2±154.7	100.0

Table 8. GHG emissions in different bases for each canola production scenario. In each row, means with a common letter are not statistically different.

GHG emission	Scenarios				Mean±SE
	I	II	III	IV	
per unit area (kg eq-CO_2 ha^{-1})	760.2^{bc}	1028.1^{b}	548.9^{c}	1427.8^{a}	941.2±154.7
per unit weight (kg eq-CO_2 t^{-1})	304.1^{c}	555.7^{b}	899.8^{a}	713.9^{ab}	618.4±103.0
per unit energy input (kg eq-CO_2 GJ^{-1})	77.9^{a}	79.4^{a}	80.5^{a}	77.5^{a}	78.8±0.6
per unit energy output (kg eq-CO_2 GJ^{-1})	10.7^{c}	19.6^{b}	31.8^{a}	25.2^{ab}	21.9±3.6

Discussion

Production operations consumed between 28% and 60% of the total energy input which amounted to 3237 and 5069 MJ ha^{-1} (Table 3). Seedbed preparation alone consumed 52% to 66% of operational energy depending on production scenario with an average of 60%. Another major energy consuming operation was harvesting (16.5%). This is in agreement with findings of other researchers in wheat (Tipi et al., 2009; Soltani et al., 2013; Canakci et al., 2005; Safa et al., 2010), a crop with similar growing season and so similar soil conditions at the time of seedbed preparation to canola. For instance, Canakci et al. (2005) indicated that seedbed preparation required the maximum operational energy (65.1%), followed by harvesting

(22.9%). Therefore, reducing energy use in seedbed preparation should be the prime objective of all programs to control high levels of energy consumption in production operations. In this study, all the production scenarios are rainfed due to sub-humid climate of the location. However, in dry areas, irrigation may become a major consumer of operational energy.

Due to the lack of appropriate machinery such as heavy tractors and combined planters that can work in stubble, farmers in the region use several plows and disks for seedbed preparation and they do not use conservation tillage. Reducing tillage intensity and field traffic reduces fuel consumption, increases energy efficiency, controls soil erosion and decreases time and energy required for seedbed preparation (Lal, 2004). There are examples in other research that support this, for example, Bonari et al. (1995) reported that in an oilseed rape crop reduced tillage resulted in 55% less fuel consumption than conventional tillage without a significant difference in crop yield.

Soltani et al. (2013) assessed energy use and GHG emissions in wheat in the Gorgan region and found that 35% of operational energy consumed by seedbed preparation. They concluded that better seedbed preparation and sowing methods can help to decrease energy inputs and contribute to lowering greenhouse gases emissions for the region. They suggested that introducing appropriate machinery that can work in stubble and conservation tillage systems such as minimum tillage or no-tillage would serve as measures to reduce input energy. A similar conclusion seems applicable for canola in the region, too. However, more studies will be required to evaluate the impact of energy saving procedures on reducing greenhouse gases emissions and the effect of conservation tillage on plant growth and yield.

Total energy input for canola production was largely influenced by fertilizers (60% of total energy input), especially nitrogen fertilizer (52% of total energy input) (Table 5). The energy input due to diesel consumption for field operations (25%) was the second most important input factor. These two, fertilizer and fuel, consumed 83% of total energy input. The finding is in agreement with the findings of other research in canola in Iran and other countries. Mousavi-Avval et al. (2010) reported that 85% of total energy input in canola production is consumed by fertilizer and fuel. This value was higher (96%) in the study of Taheri-Garavand et al. (2010) and lower (59%) in the study of Sheikh Davoodi and Houshyar (2009). According to Rathke and Diepenbrock (2006) the share of nitrogen fertilizer ranges between 20 and 51% depending on the rate of nitrogen fertilizer in winter canola production in Germany.

A notable finding of this study, which was similar to our previous finding for wheat in the same region (Soltani et al., 2013), was that a better crop management scenario (I) needed lower nitrogen fertilizer (17%) and total fertilizer (19%) in terms of energy than the usual production scenario (II) and was still more productive (Tables 5 and 6). Therefore, it can be concluded that a significant reduction of fertilizer energy input is possible without scarifying crop yield and production. Nitrogen fertilizer input can be minimized by using the appropriate type of the fertilizer and by optimizing the rate and the time of fertilizer application. The right placement of the fertilizer and calibrating fertilizer application equipment to ensure accurate delivery of prescribed nitrogen rates will help in reducing fertilizer input, as well (Johnson et al., 2007; Snyder et al., 2009). For wheat with a similar growing season to canola and in the same region, Zeinali et al. (2009) indicated that 20% of nitrogen fertilizer used by farmers is lost via nitrate leaching. Under such conditions with a high potential for loss of NO_3-nitrogen due to leaching, more reduction in nitrogen fertilizer will be possible using urease inhibitors when applying urea-containing nitrogen sources (Snyder et al., 2009).

Total energy input for canola production varied from 6816 GJ ha^{-1} (for a low input scenario; III) to 18424 MJ ha^{-1} (for a higher input scenario; IV). This figure was 12953 MJ ha^{-1} for usual production scenario (Table 7). Our estimate of energy input is comparable to those values reported by others for rainfed canola; 15078 MJ ha^{-1} by Mousavi-Avval et al. (2010), 18558 MJ ha^{-1} by Monjezi and Zakidizaji (2012) and 14528 MJ ha^{-1} by Azarpour (2012) in Iran, 18298 MJ ha^{-1} by Unakitan et al. (2010) in Turkey and 7420-16100 MJ ha^{-1} by Rathke and Diepenbrook (2006) in Germany. For irrigated canola, higher energy inputs of 28945 MJ ha^{-1} by Monjezi and Zakidizaji (2012) and 30889 MJ ha^{-1} by Sheikh Davoodi and Houshyar (2009) have been reported.

The better crop management scenario (I) consumed 19% less energy than the usual scenario (II) and resulted in 35% more production and output energy (Table 6). Energy gain (61.0 GJ ha^{-1}) of this scenario was 55% more than usual scenario (II). Thus, it can be stated that greater crop yield and output energy is not necessarily related to a higher rate of input energy for canola production in the studied region. Maximum energy gain is desirable indicator when a demand for the crop yield cannot be met because of a limited land area for crop production Tzilivakis et al. (2005), which is the case in this study.

Energy efficiency is an indicator of the environmental effects associated with the production scenarios (Rathke and Diepenbrock, 2006). Energy efficiency varied between 2.5 and 7.2 for all the scenarios, but it was 4.0 for the usual production scenario (II). This value is similar to that of 3.5 reported by Mousavi-Avval et al. (2010) in Iran and lower than the value of 4.68 reported by Unakitan et al. (2010) in Turkey. The highest energy efficiency found in this study belonged to scenario I, which was a better crop management scenario. As the same scenario (I) had the highest grain yield (2500 kg ha^{-1}), this can be considered as an important finding of the present study.

GHG emissions for production scenarios ranged between 760 to 1428 kg CO_2-eq ha^{-1} corresponding to 304 and 900 kg CO_2-eq t^{-1} (Tables 7 and 8). To our knowledge, these were the first estimates of GHG emissions for canola production in Iran. The results of different studies on energy use and GHG emission are difficult to compare because of the differences in the choice of scale and boundaries of the analysis, accuracy of energy use data and the goal of the analysis (Rathke and Diepenbrock, 2006). Estimates of the present study are slightly lower than those (1620-1720 CO_2-eq ha^{-1}) calculated by Williams et al. (2006) for canola and per area basis in the UK and the value (1020 kg CO_2-eq t^{-1}) estimated by Neufeldt and Schafer (2008) for canola and per weight basis in Germany. The lower estimates of this study might be a result of the fact that all the production scenarios considered in the study are rainfed. Previously, we estimated GHG emissions of 433 to 1612 kg CO_2-eq ha^{-1} corresponding to 173 and 474 kg CO_2-eq t^{-1} for various wheat production scenarios in the same region.

GHG emissions of average farmers scenario (II) was 1028 kg CO_2-eq ha^{-1} and 556 kg CO_2-eq t^{-1} (Table 9). The lowest GHG emissions per unit area (760 kg CO_2-eq ha^{-1}) and per ton of grain (304 kg CO_2-eq ha^{-1}) occurred in the better crop management scenario. Thus, the better crop management scenario has resulted in 26% less GHG emissions per unit field area and 45% less GHG emissions per ton of grain. As indicated above, this scenario consumed less energy and at the same time produced greater crop yield. Therefore, it can be concluded that this scenario is a cleaner production scenario with respect to energy use and environmental impact. This is the key finding of this study and similar to our previous finding in wheat in the region (Soltani et al., 2013).

As scenario II was still not the best crop management scenario, further improvement in energy efficiency and environmental impact (lower GHG emissions) of rainfed canola production is likely to be achievable by optimizing crop management practices. Fortunately, optimizing many crop management practices is largely independent of the fossil fuel energy input (Tzilivakis et al., 2005). For example, timing of field practices such as sowing date or time of pesticide application and calibrating equipment largely affects crop yield and energy output. Optimizing some other production operations can also save energy and reduce GHG emissions. Applying reduced tillage is one example of such an operation to reduce energy input (Lal, 2004). Optimizing some other operations might increase energy input but could improve energy efficiency and reduce environmental impact via increased crop yield and decreased environmental emissions. Using a split application of nitrogen fertilizer, the right source and placement of nitrogen and using urease and nitrification inhibitors (Johnson et al., 2007; Snyder et al., 2009) are examples of such operations. Optimizing nitrogen management seems to be the most important factor for energy use and to facilitate lower greenhouse gases emissions.

Conclusions

For the usual production scenario (average farmers), total energy input and output were 13.0 and 52.3 GJ ha^{-1}, respectively. GHG emission was 1028 kg CO_2-eq per hectare of land and 556 kg CO_2-eq per ton of harvested grain for the usual production scenario. These are estimated GHG emissions for rainfed canola production in Iran for the first time.

An important finding of this study was that a better crop management production scenario resulted in 35% more grain yield and output energy compared to the usual production scenario while needed 17% lower amount of nitrogen fertilizer (and 19% lower amount of total fertilizer) and consumed 25% less input energy. This production scenario also resulted in 26% less GHG emissions per unit field area and 45% less GHG emissions per ton of grain than the usual production scenario. Thus, improvement of crop management can be considered as an important strategy to reduce energy use and GHG emission and to increase crop yield and profitability.

Nitrogen fertilizers with a share of 52% and fuel for field operations with a share of 25% were the most important factors in terms of energy input and GHG emission. Seedbed preparation alone consumed about 60% of fuel for field operations. It can be concluded that introducing and implementing reduced (conservation) tillage and optimizing nitrogen management would greatly reduce energy use and GHG emission and still further improvements could be achieved by optimizing other production operations.

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