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A Comparative Study on Water and Energy Indicators for Irrigated and Rain-Fed Canola Production Systems in Iran

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Abstract: In this study energy consumption for canola production under irrigated and rain-fed conditions was investigated. Also energy and water indicators were analyzed to better understand the main effects of energy use in different production systems. For this purpose data were collected from 130 canola farms from Golestan province, the main center of oilseed production in Iran. The results revealed that, total energy input under irrigated and rain-fed conditions was 31809.9 and 15078.5 MJ ha^{-1}, respectively. The main energy consumer inputs in irrigated conditions were electricity (45.3%), chemical fertilizers (28.3%) and diesel fuel (15.2%); also, about 85% of total energy input in rain-fed conditions was consumed by chemical fertilizers and diesel fuel inputs. Under irrigated and rain-fed conditions, the energy use efficiency was calculated as 1.85 and 3.5 and the energy intensity was found to be 13.54 and 7.13 MJ kg^{-1}, respectively. Moreover, for irrigated conditions the water energy use efficiency and water productivity were calculated as 3.67 and 1.55 kg m^{-3}, respectively. In order to reduce energy consumption and improve energy use efficiency and water productivity, it is suggested that canola production in the region shift to rain-fed conditions. Also, suitable design schemes for high irrigation efficiency and improving energy efficiency of water pumping systems are proposed to make the canola production more sustainable and to reduce its environmental impacts.

Keywords: Canola production; Energy input; Environmental impact; Irrigation; Water productivity.

1. Introduction

In the modern world, energy is an essential input to every production, transport, and communication process and is thus a driver for economic as well as social development [1]. The relationship between agriculture and energy is very close. Agriculture itself is an energy user and energy supplier in the form of bio-energy [2]. It uses large quantities of locally available non-commercial energies, such as seed, farmyard manure and animate energy, and commercial energies directly and indirectly in the form of electricity, diesel, chemical fertilizers, plant protections, irrigation water and machinery [3]. Nowadays, energy usage in agricultural activities has been intensified in response to continued growth of human populations and tendency for an overall improved standard of living within a limited supply of arable land [4].

Rational and effective use of energy resources in agriculture is one of the principal requirements for sustainable development; it will minimize environmental problems, prevent destruction of natural resources, and promote sustainable agriculture as an economical production system [4]. The analysis of energy usage is important to ascertain more efficient and environment friendly production systems [5]. The energy use in agricultural production has been studied for different crops such as soybean [6], cotton [7], potato [8] and sunflower [9].

Irrigation operations are the major user of energy in agricultural production [10-11]. Energy for water pumping alone may be several times greater than for all other agricultural field operations. Energy requirements for agricultural production increase as water usage become more inefficient [12]. Efficient use of energy resources is vital in terms of increasing crop production, water productivity and competitiveness of agricultural production [10].

In a previous study on energy consumption of alfalfa production, the electricity used in the irrigation system was the highest energy consumer, contributing about 76% of the total energy input [13]. Using groundwater resources and applying the ancient methods of water application were reported as the reasons for the high consumption of electrical energy in the studied region [13]. In another study, Khan et al. [10] investigated the energy inputs for wheat, rice and barley production under different irrigation systems in Australia. They concluded that improving energy use efficiency and water productivity of crop production are the two possible pathways for reducing the environmental footprints of water and energy inputs.

Considering the importance of energy, water and oilseeds in Iran, the main objective of this study was to analyze the energy and water indicators for canola production under irrigated and rain-fed conditions in Golestan province, the main center of oilseed production in Iran. Also, the energy consumption in the two systems was investigated.

2. Experimental

2.1. Data collection

A survey approach was used to collect quantitative information on all direct and indirect energy inputs and water usage. The survey design included the selection of sample farms, choice of survey method, design of questionnaire, administration of questionnaire and analysis of survey data. A simple random sampling procedure was adopted to determine the sample size [3] which was found to be 130 farms. The surveyed population was divided into two groups; canola produced under irrigated conditions and rain-fed canola.

2.2. Energy balance analysis method

The energetic efficiency of the agricultural system was evaluated by the energy ratio between output and input. Chemical fertilizers (nitrogen, phosphate, potassium and sulphur), biocides (herbicides, fungicides and insecticides), diesel fuel, electricity, farmyard manure, irrigation water, human labor and machine power were the energy inputs while the outputs were the value of canola grain. For calculating the energy equivalents of inputs and output the energy conversion factors shown in Table 1 were used. The sources of mechanical energy used on the selected farms included tractors and diesel oil. The mechanical energy was computed on the basis of total fuel consumption (L ha^{-1}) in different operations. Therefore, the energy consumption was calculated using conversion factors (1L diesel = 56.31 MJ) and was expressed in MJ ha^{-1} [4].

The energy requirement for canola production was classified as direct and indirect as well as renewable and non-renewable energy forms. Direct energy inputs include those quantities that are consumed during the crop production period. The actual energy contained in diesel fuel, electricity, irrigation water and human labor is characterized as direct energy inputs. Indirect energy included energy embodied in seeds, farmyard manure, chemical fertilizers, biocides and machinery. On the other hand, the non-renewable energy sources include diesel, chemical, chemical fertilizers, electricity and machinery, while renewable energy consists of human labor, seeds and farmyard manure [8]. Energy obtained from sunlight was not quantified [10].

Energy for irrigation operations was consumed in both direct and indirect forms; direct energy for irrigation was mostly consumed as electricity, diesel fuel and human labor. Indirect energy for irrigation consists of the energy consumed for manufacturing the materials for the dams, canals, pipes, pumps, and equipment as well as the energy for constructing the works and building the on-farm irrigation system [10]. In this study both the direct and the indirect energy uses in irrigation operation were considered to evaluate the full environmental footprint.

Table 1. Energy conversion factors of inputs and output in canola production.

Inputs	Unit	Conversion factor (MJ $unit^{-1}$)	Reference
A. Inputs			
1. Human labor	h	1.96	[14]
2. Machinery	kg		
a. Tractor		93.61	[15]
b. Self propelled		87.63	[15]
c. Other machinery		62.70	[15]
3. Diesel fuel	L	47.80	[16]
4. Biocides	kg		
a. Herbicides		238.00	[14]
b. Insecticides		101.20	[14]
5. Fertilizer	kg		
a. Nitrogen		66.14	[4]
b. Phosphate (P_2O_5)		12.44	[4]
c. Potassium Oxide (K_2O)		11.15	[9]
d. Sulphur (S)		1.12	[9]
e. Farmyard manure		0.30	[17]
6. Water for irrigation	m^3	1.02	[4]
7. Electricity	kWh	11.93	[17]
8. Seed	kg	3.60	[18]
B. Output			
1. Canola	kg	25.00	[18]

2.3. Introducing water and energy indicators

Based on the energy equivalents of input and output, the energy indices including energy use efficiency, energy productivity, energy intensity and net energy return were calculated using the following Eqs. [4]:

$$\text{Energy use efficiency} = \frac{\text{Total energy output (MJ ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})} \quad (1)$$

$$\text{Energy productivity (kg MJ}^{-1}) = \frac{\text{Canola yield (kg ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})} \quad (2)$$

$$\text{Energy intensity (MJ kg}^{-1}) = \frac{\text{Total energy input (MJ ha}^{-1})}{\text{Canola yield (kg ha}^{-1})} \quad (3)$$

$$\text{Net energy return (MJ ha}^{-1}) = \text{Total energy output (MJ ha}^{-1}) - \text{Total energy input (MJ ha}^{-1}) \quad (4)$$

In an energy balance report, the energy use efficiency (energy ratio) is often used as an index to examine the energy efficiency in crop production [19].

Also, the water use indicators in canola production were assessed using the following Eqs. [10]:

$$\text{Water energy use efficiency} = \frac{\text{Total energy output (MJ ha}^{-1})}{\text{Water energy input (MJ ha}^{-1})} \quad (5)$$

$$\text{Water productivity (kg m}^{-3}) = \frac{\text{Canola yield (kg ha}^{-1})}{\text{Water applied (m}^3\text{ ha}^{-1})} \quad (6)$$

$$\text{Water intensity (m}^3\text{ kg}^{-1}) = \frac{\text{Water applied (m}^3\text{ ha}^{-1})}{\text{Canola yield (kg ha}^{-1})} \quad (7)$$

Water productivity and water intensity can be useful indices for formulating recommendations for rationalizing water consumption and help to achieve optimal environmental outcomes.

3. Results and Discussion

3.1. Source wise energy consumption for irrigated and rain-fed canola production

The amount of energy input and output in canola production under different production systems are presented in Table 2. The results revealed that the use of human labor under rain-fed conditions was lower than those of irrigated systems. Moreover, irrigation water and electricity used under irrigated conditions were 1511.1 m^3 and 1207.3 kWh respectively, while they were not used in rain-fed conditions. However, the canola yield values under irrigated and rain-fed systems were found to be 2349 and 2114 kg ha^{-1}, respectively.

Table 2. Amounts of inputs and output in canola production in Golestan, Iran.

Item (Unit)	Irrigated (Unit ha^{-1}) (A)	Rain-fed (Unit ha^{-1}) (B)	Difference (%) [(A-B) /B]*100
A. Inputs			
1. Human labor (h)	106.5	73.4	45.1
2. Machinery (kg)	11.6	11.8	-1.7
a. Tractor	3.7	3.6	2.8
b. Self propelled combine	5.1	5.4	-5.6
c. Agricultural machinery	2.8	2.8	0
3. Diesel fuel (L)	100.9	101.6	-0.7
4. Biocides (kg)	2.6	2.6	0
a. Herbicides	1.1	1.3	-15.4
b. Fungicides	1	0.9	11.1
c. Insecticides	0.6	0.4	50
5. Chemical fertilizer (kg)	199.5	184.5	8.1
a. Nitrogen	124	109	13.8
b. Phosphate	49.2	50.9	-3.3
c. Potassium	16.3	12.8	27.3
d. Sulphur	10	11.8	-15.3
6. Farmyard manure (kg)	985.7	1746.8	-43.6
7. Irrigation water (m^3)	1511.1	0	-
8. Electricity (kWh)	1207.3	0	-
9. Seeds (kg)	9.1	8.1	12.3
B. Output			
1. Canola (kg)	2349	2114	11.1

Table 3 shows the average amounts of source wise energy inputs and outputs under different systems of canola production. The results revealed that the total energy input in irrigated and rain-fed canola production systems was 31809.9 and 15078.5 MJ ha^{-1}, respectively, giving an excess energy of 110% in irrigated conditions. The main energy inputs in irrigated conditions were electricity (45.3%), chemical fertilizers (28.3%) and diesel fuel (15.2%), while in rain-fed condition they were chemical fertilizer (53%) and diesel fuel (32.2%). The results also revealed that, under irrigated systems the energy input of chemical fertilizers was higher than that of rain-fed systems, while use of farmyard manure energy input was higher in rain-fed conditions. Total output energy was calculated as 58726.2 and 52849.1 MJ ha^{-1} for irrigated and rain-fed productions, respectively.

From these results it is suggested that improving the energy efficiency of water pumping systems and using renewable energy resources such as manure instead of chemical fertilizer could be the pathways to make the use of aforementioned inputs more environmental friendly and thus to reduce their environmental impacts.

Table 3. Energy equivalents of inputs and output in canola production in Golestan, Iran.

Item	Irrigated (MJ ha^{-1}) (A)	Rain-fed (MJ ha^{-1}) (B)	Difference (%) [(A-B) /B]*100
A. Inputs			
1. Human labor	208.7	143.8	45.1
2. Machinery	970.3	988.2	-1.8
3. Diesel fuel	4825	4855.6	-0.6
4. Biocides	528.8	539.2	-1.9
5. Chemical fertilizer	9004.9	7998.6	12.6
6. Farmyard manure	295.7	524	-43.6
7. Irrigation water	1541.4	0	-
8. Electricity	14402.5	0	-
9. Seeds	32.7	29	12.8
Total energy input	31809.9	15078.5	111
B. Output			
Total energy output	58726.2	52849.1	11.1

3.2. Operation wise energy consumption under different production systems

Table 4 shows the energy consumption in different operations of canola production under different production systems. The results indicated that total operational energy consumption was 22004.1 and 5982.8 MJ ha^{-1} for irrigated and rain-fed systems, respectively. The high energy requirement in irrigated systems was mainly due to the fact that irrigation operations had the highest share from total energy input. This was followed by tillage and harvesting operations; however in rain-fed conditions the highest share of operational energy was required for tillage operations, followed by harvesting and application operations. In both the production systems the share of weeding operational from total energy input was the lowest. The results revealed that energy consumptions due to tillage, sowing and weeding operations in irrigated condition were higher than those of rain-fed systems. However, the energy consumption for application, harvesting and transporting operations in rain-fed systems was higher than in irrigated systems.

Table 4. Energy consumption in different operations for irrigated and rain-fed canola production.

Energy inputs	Irrigated (MJ ha^{-1}) (A)	Rain-fed (MJ ha^{-1}) (B)	Difference (%) [(A-B) /B]*100
1. Tillage	2682.8	2526.4	6.2
2. Sowing	396.0	384.5	3
3. Irrigation	16053.7	0	-
4. Weeding	94.5	81.0	16.7
5. Application	676.4	706.2	-4.2
6. Harvesting	1689.2	1780.4	-5.1
7. Transportation	411.3	498.9	-17.6
Total operational energy	22004.1	5982.8	267.8

3.3. Investigating the water and energy indicators

The analysis of energy indicators in canola production under irrigated and rain-fed conditions are shown in Table 5. The distribution of energy inputs used in the production of canola according to the direct, indirect, renewable and non-renewable energy forms was also investigated. The energy use efficiency under irrigated and rain-fed conditions was found to be 1.85 and 3.5 respectively. Furthermore, the specific energy was calculated as 13.54 and 7.13 MJ kg^{-1} for irrigated and rain-fed production systems. Energy use efficiency and specific energy are integrative indices indicating the potential environmental impacts associated with the production of crops [10]. These parameters can be used to determine the optimum intensity of view. Our results also revealed that the average energy productivity of canola production was 0.07 and 0.14 kg MJ^{-1} for irrigated and rain-fed production systems, respectively. This low energy productivity was mainly due to the high energy use in irrigation operations. This also results in the net energy return in irrigated conditions being 28.7% lower than that of rain-fed conditions. The energy use efficiency in some agricultural crop productions was reported as 1.5 for sesame, 2.8 for wheat, 3.8 for maize, 4.8 for cotton [20], 2.95 for canola production in Turkey [21] and 2.26 for rice [22]. Also, the calculation of energy productivity rate is well documented in the literature as 0.06 for cotton [7] and 0.18 for soybean [23].

Table 5. Analysis of energy indicators in canola production in Golestan, Iran.

Item	Unit	Irrigated (A)	Rain-fed (B)	Difference (%) [(A-B) /B]*100
Energy use efficiency	-	1.85	3.5	-47.1
Energy productivity	kg MJ^{-1}	0.07	0.14	-50
Energy intensity	MJ kg^{-1}	13.54	7.13	89.9
Net energy return	MJ ha^{-1}	26916.3	37770.6	-28.7
Direct energy	MJ ha^{-1}	20977.5	4999.4	319.6
Indirect energy	MJ ha^{-1}	10832.4	10079.1	7.5
Renewable energy	MJ ha^{-1}	14939.5	696.9	2043.7
Non-renewable energy	MJ ha^{-1}	16870.4	14381.6	17.3

The results from distribution of energy forms revealed that under irrigated conditions the ratio of direct energy was higher than that of indirect forms; while, in rain-fed conditions most energy was consumed in indirect forms. Moreover, the contribution of non-renewable energy forms was higher than that of renewable energy in both the production systems. Additional use of non-renewable energy sources to boost agricultural productions in developing countries with low levels of technological knowledge not only results in environmental deterioration, but also confronts us with the dilemma of a rapid rate of depletion of energetic resources [24]. Renewable energy sources, however, can be used indefinitely with minimal environmental impacts associated with their production and use [25]. Development of renewable energy usage technologies such as farm machinery or water pumping systems using biodiesel or solar power and utilization of alternative sources of energy such as organic fertilizers (compost, manure, etc.) may be the pathways to substitute the non-renewable energy forms with renewable energy resources and so reduce the environmental footprint of crop production.

The results from investigating the water and energy indicators are presented in Table 6. Water energy use efficiency in irrigated conditions was 3.67. This indicates that on average an increase of 1 MJ ha^{-1} in both irrigation direct or indirect energy inputs under irrigated systems, would lead to an additional increase in output energy of 3.67 MJ ha^{-1}. Also, the water productivity and water intensity were calculated as 1.55 kg m^{-3} and 0.64 m^3 kg^{-1}, respectively, implying that on average, 1.55 kg canola grain is obtained per unit of water consumption. Water productivity has been reported as 1.71 and 3.27 kg m^{-3} for wheat and barley production, respectively [10]. The water productivity of irrigated canola production was lower than that of barely and wheat, moreover, a comparison between different canola production systems implies that in rain-fed condition there was no requirement for water application while in irrigated conditions on average 0.64 m^3 water is required to produce one kg of canola grain. There was a common belief between the farmers that increased input usage, such as irrigation water, will increase the yield value. Moreover, the irrigated canola producers in the region mainly used flood irrigation systems so the amount of water consumption was not controllable, resulting in excess use of water and energy in the form of electricity.

Table 6. Energy and water indicators in irrigated canola production in Golestan, Iran.

Item	Unit	Quantity
Water energy use efficiency	-	3.67
Water productivity	kg m^{-3}	1.55
Water intensity	m^3 kg^{-1}	0.64

Effective of use of irrigation water can be achieved by informed and efficient production systems. Extension programs toward the development of such systems should be put into effect. Technological upgrade in water pumping systems is required to reduce the electrical energy consumption of water lifting. Improving timing, amount and reliability of water applications to boost yield and improve the quality of production helps to increase the water productivity. Also, more efficient water use through technological change such as gravity-fed drip and sprinkler irrigation and water saving irrigation practices such as alternative wet and dry irrigation are proposed to improve energy productivity and to reduce the environmental footprint of energy use in canola production in the region.

4. Conclusions

In this research the source wise and operation wise energy consumption under irrigated and rain-fed canola production systems in Golestan province of Iran was investigated. Also the energy and water indicators were analyzed. The results revealed that total energy input under irrigated production system was more than two times greater than that of rain-fed production systems. The high difference between total energy inputs in the two production systems was mainly due to the high electricity energy consumption of irrigation operations. The output energy in irrigated conditions was about 11% higher than that of rain-fed systems; therefore for irrigated and rain-fed conditions, the energy use efficiency was calculated as 1.85 and 3.5, respectively.

The results from this study revealed that development of energy conservation technologies such as biogas run water pumps, solar photovoltaic pumps and the use of windmills for water lifting instead of electrical pumps can help to improve energy productivity in the region.

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