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A comparative study on energy and water use indicators for soybean production under different irrigation systems in Iran

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ABSTRACT

In this study source wise and operation wise energy consumption for soybean production under canal and pump irrigation system conditions were investigated. Also energy and water indicators were analyzed to better understand the main effects from utilization of different irrigation systems on water and energy use. For these purposes data were collected from 94 soybean producers in Golestan province of Iran, using a face to face questionnaire method. The results revealed that under pump and canal irrigation conditions the total energy input was 38266.71 and 17255.96 MJ ha^{-1}, and energy use efficiency was 2.14 and 4.62, respectively. The three major energy consumer inputs under pump irrigation system were electricity, fertilizers and diesel fuel; while in canal irrigation conditions they were fertilizers, diesel fuel and indirect energy of irrigation, respectively. On the other hand, water energy use efficiency was calculated as 3.68 and 29.94 for pump and canal irrigation conditions, respectively. Water energy ratio under canal irrigation was found to be 58.23%, from which the shares of direct and indirect energies of irrigation were 49.08 % and 9.15%, respectively; while under canal irrigation conditions it was found to be 15.42% and the contribution of direct energy compared to indirect energy for irrigation was relatively low. In order to reduce energy consumption and improve energy use efficiency and water productivity, it is suggested to use canal irrigation systems, design suitable schemes for high irrigation efficiency and to improve the energy use efficiency for of water pumping systems.

Keywords: Irrigation system, electricity, energy input, water productivity, soybean production

1. Introduction

Soybean (*Glycine max (L.) Merrill*) is one of the leading oilseed crops that originated in Asia and was first introduced to Europe and North America. In recent years, soybean production has gained importance and it is produced in the largest amounts in the world. It is an annual legume that is primarily produced to be used as food or as a source of edible oil for human consumption (Liener, 1994; Anonymous, 2010b; Balat and Balat, 2010).

Soybean is one of the three major oilseed crops cultivated in Iran for the production of oil mainly used for human consumption. Soybean was produced about 209,000 tons in Iran, and the harvested land area was about 115,000 hectares in 2008 (Anonymous, 2010b). Golestan province ranks the first soybean producer in Iran. About 75% from total soybean production in Iran is provided from this province (Anonymous, 2010a). Soybean crop in this province is mostly cultivated in irrigated areas in spring season.

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Energy is one of the most important elements in agricultural production. Developing nations have limited resources and exponentially increasing populations. Increases in agricultural production will be necessary, requiring increases in arable land; On the other hand limited supply of arable land has led to intensive use of energy inputs and natural resources in agriculture; so, the farmers use their resources in excess and inefficiently, specially, when these are priced low or free or are available in plenty. Rational and effective use of energy 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 (Rafiee et al., 2010). The input and output of energy are two important factors for specifying the energetic and ecological efficiency of crop production. The energy analysis is important to ascertain more efficient and environment friendly production systems (Schroll, 1994; Ozkan et al., 2004). Energy efficiency improvement is the key to sustainable energy management; for enhancing the energy efficiency it must be attempted to increase the production yield or to conserve the energy input without affecting the production yield (Singh et al., 2004). Several studies have been concentrated on energy use for agricultural production (Hetz, 1992; Kallivroussis et al., 2002; Canakci et al., 2005; Hatirli et al., 2005; Sartori et al., 2005; Beheshti Tabar et al., 2010; Mobtaker et al., 2010). Khan et al. (2009) studied the energy inputs in wheat, rice and barley production for reducing the environmental footprint of food production in Australia. The results showed that barley crop seems more efficient in terms of energy and water use jointly.

Irrigation operation is the major user of energy in agricultural production (Smerdon and Hiler, 1985; Khan et al., 2009). Energy for water pumping alone may be several times greater than that of all other agricultural field operations. Energy requirements for agricultural production increase as water usage become more inefficient; furthermore, achievable efficiency for converting energy to lifted water is up to about 20% in developed parts of the world but elsewhere it is to be nearer to 12.5% (Aked, 1983); so, to achieve sustainable agricultural development, irrigation should be planned and managed in such a way as to conserve both water and energy inputs.

With considering the no study on energy and water use indicators for soybean production in Iran, the main objective of this study was to investigate the energy consumption under canal and pump irrigated system conditions and to analyze the energy and water use indicators for soybean production in Golestan province.

2. Materials and methods

2.1 Data collection and estimation of energy inputs

A survey approach was used to collect quantitative information on all direct and indirect energy inputs and water inputs. 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 find the sample size (Kizilaslan, 2009). So the sample size was found to be 94. The surveyed population was divided into two groups; the first group used pump for water lifting from wells and the second used canal or river water to irrigate the farms.

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The amount of each input used for soybean production including chemicals, fertilizers, diesel fuel, electricity, irrigation water, human power, and machine power were evaluated per hectare. In order to evaluate output and input energy, energy conversion factors of inputs and output were used to transform them into equivalent energy units (Rafiee et al., 2010). The energy conversion factors of inputs used in this study are given in Table 1.

The energy requirement for soybean 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 and human labour is characterized as direct energy inputs. Indirect energy included energy embodied in seeds, farmyard manure, irrigation water, chemical fertilizers and chemicals; also the energy consumed by machinery is classified as indirect energy. On the other hand, the non-renewable energy sources include diesel, chemicals, chemical fertilizers, electricity and machinery, while renewable energy consists of human labour, seeds and farmyard manure. Energy obtained from sunlight was not quantified (Khan et al., 2009).

Table 1: Energy conversion factor of inputs and output in soybean production

Inputs	Unit	Conversion factor ($MJunit^{-1}$)	Reference
A. Inputs			
1. Human labour	h	1.96	(Erdal et al., 2007)
2. Machinery	kg		
a. Tractor		93.61	(Hetz, 1992)
b. Self propelled combine		87.63	(Hetz, 1992)
c. Other machinery		62.70	(Hetz, 1992)
3. Diesel fuel	L	47.80	(Kitani, 1999)
4. Chemicals	kg		
a. Herbicides		238.00	(Erdal et al., 2007)
b. Insecticides		101.20	(Erdal et al., 2007)
5. Fertilizer	kg		
a. Nitrogen		66.14	(Rafiee et al., 2010)
b. Phosphate (P_2O_5)		12.44	(Rafiee et al., 2010)
c. Potassium (K_2O)		11.15	(Rafiee et al., 2010)
d. Sulfur (S)		1.12	(Rafiee et al., 2010)
e. Farmyard manure		0.30	(Singh and Mittal, 1992)
6. Water for irrigation	m^3	1.02	(Rafiee et al., 2010)
7. Electricity	kWh	11.93	(Singh and Mittal, 1992)
8. Seed	kg	3.60	(Beheshti Tabar et al., 2010)
B. Output			
1. Soybean	kg	25.00	(Beheshti Tabar et al., 2010)

Irrigation operation require energy for constructing the water supply source, providing the conveyance works, installing the field irrigation system on the farms, and operating and maintaining the system. Energy consumed in irrigation operations can be classified in both direct and indirect forms. Direct energy of irrigation includes energy that is consumed for pumping and operating the farm irrigation system; it is used mostly in the forms of electricity, diesel fuel and human labour. On the other hand, indirect energy of irrigation consist of the energy consumed for

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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 (Khan et al., 2009). In this study both the direct and the indirect energy uses in irrigation operation had considered to evaluate the full environmental footprint. For investigating the indirect energy of irrigation the coefficient of 1.02 MJ per unit of water (m3), supplied from a given source, was used; so it was considered to be the same for all the farms in a given setting. The direct energy of irrigation was considered by calculating the energy equivalent of diesel fuel, electricity and human labour used in irrigation operations.

2.2 Introducing water and energy indicators

Based on the energy equivalents of inputs and output, the energy indices including energy use efficiency, energy productivity, energy intensity, net energy return were calculated using the following equations (Rafiee et al., 2010):

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

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

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

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

Also, the water use indicators in soybean production were assessed using the following equations (Khan et al., 2009):

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

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

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

$$Water\text{-}energy\ productivity\ (kg\ m^{-3}\ MJ^{-1}) = \frac{Soybean\ grain\ yield\ (kg\ ha^{-1})}{Water\ applied\ (m^3\ ha^{-1}) \times Energy\ input\ (MJ\ ha^{-1})} \quad (8)$$

$$Water\ energy\ ratio = \frac{Energy\ input\ from\ irrigation\ water\ (MJ\ ha^{-1})}{Total\ energy\ input\ (MJ\ ha^{-1})} \quad (9)$$

$$Water\ direct\ energy\ ratio = \frac{Irrigation\ direct\ energy\ (MJ\ ha^{-1})}{Total\ energy\ input\ (MJ\ ha^{-1})} \quad (10)$$

$$Water\ indirect\ energy\ ratio\ (\%) = \frac{Irrigation\ indirect\ energy\ (MJ\ ha^{-1})}{Total\ energy\ input\ (MJ\ ha^{-1})} \quad (11)$$

The water-energy productivity is defined as the grain yield per unit of energy and water inputs. It combines both the effect of water and energy inputs on yield. Lower values may indicate higher environmental footprint. Water energy ratio focuses specifically on the both direct and indirect energy from irrigation water as a contribution of total energy input. These

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can be useful for formulating recommendations for rationalizing water consumption and help to achieve optimal environmental outcomes (Khan et al., 2009).

3. Results and discussions

3.1 Operation wise energy consumption under different irrigation systems

The conversion factors given in Table 1 were used to determine energy inputs and outputs for soybean production in the region. Table 2 shows the amounts of average operation wise energy inputs and outputs energy in soybean production. Also energy consumption in the pump and canal irrigation systems are tabulated.

Table 2: Amounts of operational inputs and output energies in soybean production.

Item	Energy equivalent (MJ ha^{-1})		
	Weighted average	Pump irrigated	Canal irrigated
A. Inputs			
1. Tillage	1565.5	1621.53	1216.4
2. Sowing	449.79	449.71	450.28
3. Irrigation	19568.77	22282.46	2660.4
4. Weeding	96.79	97.15	94.56
5. Application	1217.82	1250.13	1016.5
6. Harvesting	1811.24	1759.43	2134.02
7. Transportation	893.61	968.13	350.01
8. Seed	247.68	249.56	236.08
9. Chemical fertilizers	7014.73	6955.18	7386.7
10. Farmyard manure	1604.36	1718.79	891.35
11. Chemicals	901.92	914.64	819.65
Total energy input	35372.23	38266.71	17255.96
B. Output			
1. Grain yield (kg)	3233.15	3282.15	3185.58
Total energy output	80828.75	82053.69	79639.42

The results revealed that the total energy input and output energy for soybean production in the region were averagely as 35372.23 and 80828.75 MJ ha^{-1}, respectively. Also it is evident that soybean production under pump irrigation conditions (38266.71 MJ ha^{-1}) had higher total energy input than that of canal irrigation systems (17255.96 MJ ha^{-1}). On the other hand the production yield and consequently output energy for pump irrigation system were greater than that of canal irrigation systems. Also, energy consumption by irrigation operation including energy sequestered in electricity, diesel fuel, human labour and indirect energy of irrigation was 19568.77 MJ ha^{-1}, averagely; from which the share of electricity energy by 81.44% was the highest. Also it was found to be 22282.46 and 2660.40 MJ ha^{-1} for pump and canal irrigation system, respectively; which was about 8 times higher under pump irrigation conditions.

The energy consumption in different operations under pump and canal irrigated systems comparatively illustrated in Fig. 1. From the results it is clear that, in the case of pump

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irrigation system the major component of total energy input was the irrigation operation (58.23%), indicating that significant energy savings may be possible through better irrigation management. Apart from irrigation operation energy, fertilizer and chemical application (28.32%) and harvesting operations (4.60%) were the major energy users. On the other hand, under canal irrigation conditions the main energy consumers were fertilizer and chemical applications (58.61%), irrigation (15.42%) and harvesting (12.37%) operations, respectively. However, the shares of weeding and sowing operational energy inputs from total energy input for soybean production under both irrigation systems were relatively low. Sheikh Davoodi and Houshyar (2009) investigated the energy consumption for canola and sunflower Production in Iran. They reported that total energy requirement for canola and sunflower were as 30889.098 and 22945.3 MJ ha^{-1}, respectively. Also the three main energy consuming inputs were fertilizer, electricity and diesel fuel for both crops. These inputs contribute to the total energy consumption at more than 80%.

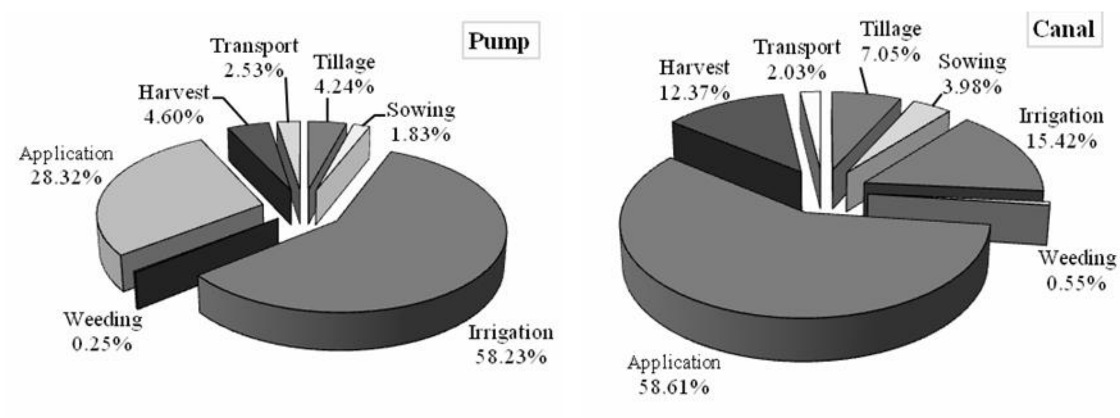

Figure1: Contributions of operation wise energy inputs in pump and canal irrigated systems

3.2 Source wise energy consumption under different irrigated systems

The estimates of source wise energy inputs for soybean production under different irrigation systems are given in Fig. 2. Clearly the main energy consumer input under pump irrigation system is electricity energy input, consumed as 18.50 GJ per hectare of soybean production. This is because that, in surveyed region the farmers under pump irrigation conditions extensively use electricity to pump water from wells for irrigation of crops. Also fertilizer energy (8.67 GJ ha^{-1}) and diesel fuel energy (5.08 GJ ha^{-1}) inputs were the second and third energy consumers by priority. The results revealed that under canal irrigation systems the electricity energy usage was found to be zero. So, the fertilizer energy input (8.28 GJ ha^{-1}) was the major component of total energy input, followed by diesel fuel energy (4.13 GJ ha^{-1}) and water energy input (indirect energy of irrigation) by 4.13 GJ ha^{-1}, respectively. On the other hand utilization of all of the energy inputs under canal irrigation system were lower than that of pump irrigation system; however, use of machinery, chemicals, seed and human labour energy inputs for soybean production under two irrigation systems had not considerable differences. From these results it is suggested that, employing canal irrigation systems, improving efficiency for converting energy to lifted water, using renewable energy

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such as manure instead of chemical fertilizer could be a pathway to make the use of aforementioned inputs more environmental friendly and thus reduce its environmental risks.

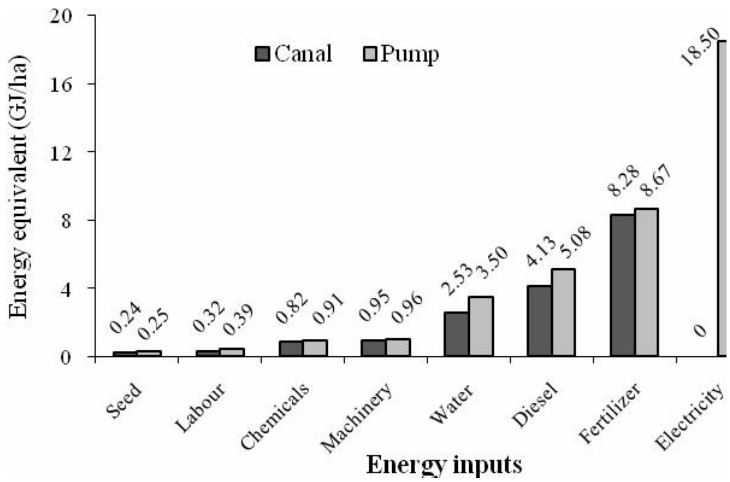

Figure2: Comparison of the source wise energy inputs under canal and pump irrigation systems

3.3 Investigating the water and energy indicators

In this section the water and energy indices for soybean production had presented; also these indicators had compared for crop production under two irrigation systems. Table 3 shows the indices of energy and water on average. The results indicate that the contribution of direct energy was more than that of indirect energy; also it was found to be greater for non-renewable energy with respect to that of renewable energy.

Table 3: Analysis of energy and water indicators in soybean production

Items	Unit	Quantity
Direct energy	MJ ha^{-1}	21035.73 (60.01%)
Indirect energy	MJ ha^{-1}	14017.61 (39.99%)
Renewable energy	MJ ha^{-1}	5366.61 (15.31%)
Non-renewable energy	MJ ha^{-1}	29686.72 (84.69%)
Energy use efficiency	-	2.29
Energy productivity	kg MJ^{-1}	0.09
Energy intensity	MJ kg^{-1}	10.94
Net energy return	MJ ha^{-1}	45456.52
Water energy use efficiency	-	4.13
Water productivity	kg m^{-3}	0.98
Water intensity	m^3 kg^{-1}	1.02
Water-energy productivity	g m^{-3} MJ^{-1}	0.03
Water energy ratio	%	55.32
Water direct energy ratio	%	45.80
Water indirect energy ratio	%	9.52

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On the other hand, water energy use efficiency was 4.13. This indicates that on average an increase of 1 MJ in both irrigation direct or indirect energy inputs, would lead to an additional increase in output energy by 4.13 MJ ha^{-1}. Also the water productivity and water intensity were calculated as 0.98 kg m^{-3} and 1.02 m^3 kg^{-1}, respectively. Water energy ratio was found to be 55.32%, from witch 45.80% consumed in direct form and the reminder of 9.52% was the contribution of irrigation indirect energy.

Table 4 present the water and energy indicators for two different irrigation systems. It is evident that in pump irrigation system the share of direct energy is more than that of indirect energy but in the case of canal irrigation the contribution of indirect energy is higher. Also use of non-renewable energy inputs in pump irrigation condition is more than canal irrigation, while in renewable energy sources it is inverted. On the other hand energy use efficiency and energy productivity in canal irrigated were found to be about 2 times greater than that of pump irrigation condition. Also water energy use efficiency in pump and canal irrigation system was found to be 3.68 and 29.94, respectively. Water energy ratio in pump irrigation system was found to be 58.23%, from which the hares of direct and indirect were 49.08% and 9.15%, respectively; while in canal irrigation system it was 15.42% and the contribution of water direct energy compared to that of water direct energy was relatively low.

Table 4: Analysis of energy and water indicators for pump and canal irrigated systems

Items	Unit	Pump irrigated	Canal irrigated
Direct energy	MJ ha^{-1}	23970.68 (62.63%)[a]	4452.17 (25.78%)
Indirect energy	MJ ha^{-1}	14303.20 (37.37%)	12814.64 (74.22%)
Renewable energy	MJ ha^{-1}	5862.52 (15.32%)	3980.19 (23.05%)
Non-renewable energy	MJ ha^{-1}	32411.36 (84.68%)	13286.62 (76.95%)
Energy use efficiency	-	2.14	4.62
Energy productivity	kg MJ^{-1}	0.09	0.18
Energy intensity	MJ kg^{-1}	11.66	5.42
Net energy return	MJ ha^{-1}	43786.99	62383.46
Water energy use efficiency	-	3.68	29.94
Water productivity	kg m^{-3}	0.96	1.28
Water intensity	m^3 kg^{-1}	1.05	0.78
Water-energy productivity	g m^{-3} MJ^{-1}	0.02 000	0.07
Water energy ratio	%	58.23	15.42
Water direct energy ratio	%	49.08	0.73
Water indirect energy ratio	%	9.15	14.69

[a] Figures in parenthesis indicate percentage from total energy input.

4. Conclusions

This research presents a case study of energy and water inputs for soybean production under canal and pump irrigation system conditions in Golestan province of Iran. Also energy and water indicators were analyzed. The comparisons thus showed that in pump irrigation

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condition the three major energy consumer inputs were electricity, fertilizers and diesel fuel. Also, in canal irrigation condition fertilizers, diesel fuel and indirect energy of irrigation were the main energy users. Furthermore, total energy consumption for soybean production under pump irrigation condition was higher than that of canal irrigation, suggesting that significant energy savings may be possible through employing canal irrigation system. Canal irrigation system showed higher energy use efficiency and water productivity; so it is suggested to shift the pump irrigation systems to canal irrigation system for soybean production in the region. Also in the pump irrigation conditions, improving efficiency for converting energy to lifted water, using renewable energy such as solar and wind energy instead of electricity or diesel fuel, using hybrid fuels and improving timing, amount, and reliability of water applications could be a pathway to improve energy use efficiency and to make the use of inputs more efficiently and environmental friendly and thus reduce their environmental risks problems.

5. Acknowledgement

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