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ORIGINAL PAPER

A comparative study on energy balance and economical indices in irrigated and dry land barley production systems

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Abstract This study was conducted to determine how energy balances and economical indices of barley production are affected by irrigated and dry land farming systems. Data were collected from 26 irrigated and 68 dry land barley farms. The complimentary data were collected through questionnaires filled by farmers in face-to-face interviews during 2010. The results indicated that total energy input for irrigated barley was 19,308.96 MJ ha^{-1} and for dry land barley was 7,867.82. The non-renewable energy was about 66.83 and 71.02 % in irrigated and dry land systems while the renewable energy was 33.17 and 28.98 %, respectively. Energy use efficiency is energy output MJ ha^{-1} divided by energy input MJ ha^{-1}. Energy use efficiency was 5.3 and 3.96 in dry land and irrigated systems, respectively. Although net return in the irrigated system (266.13$ ha^{-1}) was greater than that in the dry land system (208.64) but the benefit to cost ratio in irrigated system (1.38) was lower than that in the dry land system (1.58). Results showed that human labor as well as machinery energy inputs were the most important inputs influencing the dry land and irrigated barley production systems, respectively. The second important input in the irrigated barley was electricity (with 0.16) which was followed by water for irrigation and diesel fuel (0.14 and 0.13, respectively). In total energy consumption, the ratio of non-renewable energy was greater than that of renewable energy. Since the main non-renewable energy input was diesel, electricity, and chemical fertilizers; therefore, management and improvement in the application of these inputs would increase the proportion of renewable energy.

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Introduction

Energy is a fundamental component of economic development because it provides essential services maintaining the economic activity and enhancing the quality of human life. At the farm level, energy use can be classified into four categories: direct, indirect, renewable, and non-renewable resources (Thankappan et al. 2005). Barley is a major food in several regions of the world and it is generally found in regions where other cereals do not grow well due to the altitude, low precipitation, or soil salinity. This crop remains the most viable option in dry areas (<300 mm of rainfall). The barley grain is either used for backing bread (usually mixed with bread wheat) or for specific recipes (FAO 2009). Total production of barley was about 3 million tons in Iran in a cultivated area of about 1.68 million hectares during 2009 (Safa et al. 2010). The proportion of dry land cultivated barley was 57 % and irrigated barley was 43 % in this year. Lorestan province holds the third place in barley production in Iran. In this province, cultivated areas of barley were about 9,029 and 129,949 ha as irrigated and dry land production systems in 2009, respectively (Anonymous 2010a).

The energy balance is defined as the difference between gross energy of useful products divided by non-renewable energies used to produce them (Risoud 2000). Imposing energy balances could lead to more efficient and environmentally friendly crop production (Moreno et al. 2011). Researchers have performed detailed energy balances for different crops and farm management systems all over the world in attempts to assess the efficiency and environmental impact of crop production systems (Campiglia et al. 2007; Akpinar et al. 2009). Conservation practices, however, balance environmental and energetic effects by production. As a consequence, farmers are now continuously requested to increase crop yields while at the same time preserving the environment by reducing the dependency of agriculture on external, non-renewable fossil energy and reducing the emission of greenhouse gases (Bailey et al. 2003; Bechini and Castoldi 2009).

Efficient energy use is one of the principal requirements to establish sustainable agriculture (Erdal et al. 2007). Because of the preventive role of agriculture in global warming (climate change) and overconsumption of non-renewable resources, it merits a prominent position in global discussions of controlling greenhouse gas emissions and reduction of the dependency on fossil fuels (Ziesemer 2007). The efficiency of energy use can be increased by reducing inputs such as fertilizer and tillage practices or by increasing outputs such as crop yields (Swanton et al. 1996). In some cases, a reduction in energy inputs entails a proportional reduction in crop yields. In such cases, energy efficiency is not significantly affected (Risoud 2000; Bailey et al. 2003). In some modern high-input farming systems, crop yields have been improved continuously as a result of increasing inputs of agrochemicals (inputs of fossil energy) and the growth of more productive cultivars (Hulsbergen et al. 2001). Other studies report reductions in energy efficiency due to increasing energy inputs which are more than energy outputs, this results in growing dependency on inorganic farming and non-renewable energy resources (Gundogmus 2006; Gundogmus and Bayramoglu 2006).

Energy consumption per unit area in agriculture is directly related to the development of farming technology and the production level. Energy use is one of the key indicators for developing more sustainable agricultural practices (Mohammadi et al. 2010). The amount of energy used in agricultural production, processing, and distribution is significantly high. A sufficient supply of the right amount of energy and its effective and efficient use are necessary for an improved agricultural production (Mohammadi and Omid 2010). Energy requirements in different agricultural processes are divided into two groups, including non-renewable and renewable which could be used in forms of direct and indirect energies. Direct energy is required to perform various tasks related to crop production processes such as land preparation, irrigation, inter-culture; threshing, harvesting and transportation of agricultural inputs and farm production (Singh 2000). Indirect energy consists of the energy used in the manufacture, packaging and transportation of fertilizers, biocides and farm machinery (Ozkan et al. 2004a, b). Non-renewable energy includes diesel, chemicals, fertilizers and machinery, and renewable energy consists of human labor, seeds and manure (Mohammadi et al. 2008). The inputs such as the fuel, electricity, machinery, seed, fertilizer and chemical take a significant share of the energy supplies in the production system of modern agriculture (Hatirli et al. 2006).

Efficient use of these inputs helps to attain improved production and productivity and contributes to the economy, profitability and competitiveness of agricultural sustainability of rural communities (Singh et al. 2002). Wider use of renewable energy sources, increase in energy supplies and efficiency of use can make a valuable contribution to meeting sustainable energy development aims (Streimikiene et al. 2007). The size of the population involved in agriculture, the amount of arable land and the level of mechanization are the important factors which energy utilization in the agricultural sector depends on (Ozkan et al. 2004a, b). Energy productivity is an important index for more efficient use of energy although higher energy productivity does not mean more economic feasibility in general (Fluck and Baird 1982).

Energy used in agriculture depends chiefly on fossil fuels which are a rare commodity and need due consideration for their conservation (Khan et al. 2009). The other commodity that needs due concern for its appropriate use is water which is an important element for the growth of crops, but it requires energy for its application. It has been noted that water availability to agriculture is predictable to fall from 72 % in 1995 to 62 % by 2020 globally and 87–73 % in developing countries (Khan et al. 2009). Energy input–output analyses commonly determine energy efficiency based on the impact of energy consumption in any given environment (Gundogmus 2006). Many studies have investigated energy inputs and outputs by the economic analysis to determine the energy efficiency of producing plants such as potatoes, wheat, and barley in Iran (Mohammadi et al. 2008; Ghasemi Mobtaker et al. 2010; Ghorbani et al. 2011), sugar beet in Turkey (Swanton et al. 1996), rice in India (Baruah and Dutta 2007) and maize and sorghum in the United States (Franzluebbers and Francis 1995). Researchers (2009) studied the energy inputs in wheat, rice and barley production for reducing the environmental footprint of food production in Australia (Khan et al. 2009). The results showed that barley crop seems to be more efficient in terms of energy and water use jointly. The researchers (2011) showed that the total energy requirement under dry land wheat production was 9,354.2 MJ ha^{-1}, whereas it was 45,367.6 MJ ha^{-1} under irrigated wheat production system (Ghorbani et al. 2011). Total energy input consumed as direct, indirect, renewable and non-renewable energies in two wheat production systems were 47, 53, 25, 75 %, and 46, 54, 25, 75 %, respectively. Energy ratios of 3.38 in dry land and 1.44 in irrigated systems were achieved. The benefit to cost ratio was 2.56 in dry land and 1.97 in irrigated wheat production systems. Also, the researchers (2010) showed that the maximum energy consumed in corn, wheat and barley for the irrigated farming system and dry land farming system were irrigation and tillage, respectively (Safa et al. 2010). Therefore, the objectives of the present study were (i) to determine the total energy used and the share of each sources of energy in the barley farms, (ii) to evaluate the energy use efficiency and the economical indicators in terms of the cost of energy consumed, and (iii) to assess an economical model to determine the relationship between energies used and yields produced in the barley irrigated and dry land production systems in Lorestan province, Iran.

Materials and methods

Site description

The present study was conducted in Lorestan province, southwestern Iran, which is located between the latitudes 32°30′ and 48°1′ N and longitudes 55°17′ and 61°15′ E. Long-term annual mean precipitation is 580 mm, altitude 1,125 m above the sea level and long-term mean annual temperature is 17.07 °C. Lorestan province has a variation in the weather and climate (a range from warm to cold climates). This province is classified as a region with a semi-arid climatic condition. The total area of the province is 28,064 km^2 and the total cultivated area of barley is about 138,978 ha consisting of 9,029 ha of irrigated and 129,949 ha dry land barley (Anonymous 2010a).

To determine the relationship between the barley yield and its energy consumption, data were collected from growers using a face-to-face questionnaire during 2010. In addition to the survey data, data from previous studies were also used in this study, including those from studies conducted by the Food and Agricultural Organization (FAO) and the Ministry of Agriculture of Iran (FAO 2009). The number of operations involved in the barley production system and their relevant energy requirements clearly influence the final energy balance. A random sampling method was used, and the sample size was calculated using Eq. (1) (Newbold 1994),

$$n = \frac{N \times S^2}{(N-1)S_X^2 + S^2} \quad (1)$$

where n is the required sample size, N is the population size, S is the standard deviation, S_X is the standard deviation of the sample mean. $S_X = d/z$, where d is the permissible error in the sample size, i.e., 10 % of the mean for a 95 % confidence interval, and z is the reliability coefficient (1.96, which represents 95 % reliability). Based on the above calculations, the sample size of 26 and 68 was considered as the sampling size for irrigated and dry land barley, respectively.

Energy analysis

The energy efficiency of the agricultural system was evaluated based on the energy output–input ratio. The human labor, machinery, diesel oil, fertilizers, pesticides, and seed amounts were the inputs and yield values from the barley production system were the outputs used to estimate the energy ratio. Energy equivalents shown in Table 1 were used

Table 1 Energy equivalent of inputs and outputs in agricultural production systems

References	Unit	Energy equivalent (MJ unit^{-1})	Particulars
			A. Inputs
Yilmaz et al. (2005)	h	1.95	1. Human labor
Singh et al. (2002)	h	62.7	2. Machinery
Mohammadi et al. (2008)	l	50.23	3. Diesel fuel
	kg		4. Chemical fertilizers
Mohammadi et al. (2008)		75.46	(a) Nitrogen (N)
Mohammadi et al. (2008)		13.07	(b) Phosphate (P_2O_5)
Mohammadi et al. (2008)		11.15	(c) Potassium (K_2O)
	kg or l		5. Chemicals
Taylor et al. (1993)		238.3	(a) Herbicides
Taylor et al. (1993)		101.2	(b) Pesticides
Taylor et al. (1993)		181.9	(c) Fungicides
Mohammadi et al. (2008)	kWh	3.6	6. Electricity
Acarouglu (1998)	m^3	1.02	7. Water for irrigation
Ozkan et al. (2004a)	kg	14.7	8. Seeds
			B. Outputs
Ozkan et al. (2004b)	kg	14.7	1. Seed (barley)
Kuesters and ammel (1999)	kg	9.25	2. Straw (barley)

for this estimation. The sources of mechanical energy used in selected farms included tractors and diesel oil. Mechanical energy was computed on the basis of total fuel consumption (L ha^{-1}) by different operations. The energy consumed was calculated using conversion factors and expressed in MJ ha^{-1} (Alam et al. 2005). The energy of a tractor and its related equipment indicated the amount of energy needed for unit weights, which provided an insight into the repair and maintenance energy, transport energy, total machine weight, and average economic life. The energy output–input ratio was one of the indices used to describe the energy efficiency of agriculture. This ratio is calculated based on input fossil fuel energy and output food energy, and it is used in developed countries to describe the inefficiency of crop production (Dalgaard et al. 2001). The alterations of energy use efficiency can occur in the short and long periods, and it often reflects changes in technology, government policies, weather patterns, or farm management practices. Therefore, careful assessment of the ratios facilitates the determination of trends in the energy efficiency of agricultural production and explains these trends by attributing each change to various events within the industry (Unakitan et al. 2010). Based on the energy equivalents of the inputs and outputs (Table 1), energy use efficiency, energy productivity, specific energy, energy intensiveness, and net energy were calculated as follows (Tsatsarelis 1991).

$$\text{Energy use efficiency} = \frac{\text{Energy output } (\text{MJ ha}^{-1})}{\text{Energy input } (\text{MJ ha}^{-1})} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{Crops output } (\text{Kg ha}^{-1})}{\text{Energy input } (\text{MJ ha}^{-1})} \quad (3)$$

$$\text{Specific energy} = \frac{\text{Energy input } (\text{MJ ha}^{-1})}{\text{Crops output } (\text{t ha}^{-1})} \quad (4)$$

$$\text{Energy intensiveness} = \frac{\text{Energy input } (\text{MJ ha}^{-1})}{\text{Cost of cultivation } (\$\text{ ha}^{-1})} \quad (5)$$

$$\text{Net energy} = \text{Energy output } (\text{MJ ha}^{-1}) - \text{Energy input } (\text{MJ ha}^{-1}) \quad (6)$$

The indirect energy (IDE) includes energy embodied in seeds, chemical fertilizers, herbicides, pesticides, fungicides, farmyard manure, and machinery, whereas the direct energy (DE) envelopes the diesel fuel, irrigation water, electricity and human labor used in the barley production systems. The renewable energy (RE) includes irrigation water, human labor, farmyard manure, barley wastes and seeds. The non-renewable energy (NRE) resources such as fossil fuels are energy resources that are not replaced or are replaced only very slowly by natural process (Mohammadi et al. 2008). Production functions are essential to ensure the efficient allocation of resources (Mohammadi and Omid 2010). The rate of agricultural wastes in Iran is recently increased. This rise requires a good agricultural waste management. Waste management extension deals with rising the efficiency and productivity of the agricultural industry intellectually and/or economically. By managing the residual of agriculture, energy production from these materials will have a high share of the energy supply in Iran, and consequently there is a need for more research and development on renewable energies. Many developing countries have extensive biomass resources that are becoming more valuable as the demand for biomass and biofuels increases (World energy outlook 2005). It is feasible that corn wastes in Iran can be converted to bioethanol. Bioethanol can practically be used as a 5 % blend with petrol in Iran's vehicles. In Iran, most barley (55 % of total production) is used as animal food. About 5 % of the total production is used for human food while approximately 40 % is lost as waste (Anonymous 2010b). A 0.6×10^{12} g of barley waste can efficiently produce 0.21×10^{9} L of bioethanol (Najafi et al. 2009).

The relationship between energy inputs and yield

To analyze the relationship between energy inputs and outputs in barley production systems, the Cobb–Douglas equation was selected as the most suitable functional pattern (Singh et al. 2004; Mohammadi and Omid 2010; Hatirli et al. 2006). The Cobb–Douglas equation is expressed as follows:

$$Y = f(x)\exp(u) \quad (7)$$

which can be further rewritten as given below:

$$\ln Y_i = a + \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \quad (8)$$

$i = 1, 2\ldots$ n

where Y_i indicates the yield of the ith farmer; X_{ij} is the vector of the inputs used in the production process; a is a constant; a_j represents the coefficients of inputs estimated from the model, and e_i is the error term. Equation (8) is expanded in accordance with the assumption that the yield is a function of energy inputs:

$$\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + \alpha_8 \ln X_8 + \alpha_8 \ln X_9 + e_i \quad (9)$$

where X_i ($i = 1, 2,., 9$) represents human labor (X_1), machinery (X_2), diesel fuel (X_3), total chemical fertilizer (X_4), chemicals (X_5), electricity (X_6), farmyard manure (X_7), water for irrigation (X_8) and seed (X_9). The impact of energy of each input on output energy was studied on the basis of this pattern using Eq. (9). For this Eq. (9), all energy inputs have been considered in the irrigated system, but in the dry land system human labor (X_1), machinery (X_2), diesel fuel (X_3), total chemical fertilizer (X_4), and seed (X_5) have been considered. Thus, we studied the impact of DE, IDE, RE, and

NRE on the output energy. With this aim, the Cobb–Douglas function was determined using the following formula:

$$\ln Y_i = \beta_0 + \beta_1 \ln DE + \beta_2 \ln IDE + e_1 \quad (10)$$

$$\ln Y_i = \gamma_0 + \gamma_1 \ln RE + \gamma_2 \ln NRE + e_1 \quad (11)$$

where Y_i is the ith farm's yield and β_i and γ_i are the coefficients of exogenous variables. Equations (9–11) were estimated using the ordinary least squares technique. Basic information on energy inputs and barley yields were entered into an Excel spreadsheet and the Shazam 9.0 software program (Mohammadi and Omid 2010).

Economical analysis

The input–output analysis was also used to determine economic benefits. This process was similar to that of the energy balance analyses. The basic unit for all analysis was 1 ha of the barley farm. The production cost of barley included both fixed and variable costs. The fixed costs of production included the land value, water value, and properties. The variable costs of production included current costs such as chemicals, fuel, human labor, and electricity. The economic output of barley included the grain and straw yields. All prices of the inputs and outputs were current market prices (average prices over the year 2010) (Anonymous 2010b). The economic benefit analysis focused on the gross and net returns, gross value of production, total cost of production, benefit to cost ratio, and productivity (Ghorbani et al. 2011; Banaeian et al. 2011).

$$\text{Gross return} = \text{gross value of production } (\$\ \text{ha}^{-1}) - \text{variable cost of production } (\$\ \text{ha}^{-1}) \quad (12)$$

$$\text{Gross value of production} = \text{barley yield } (\text{kg ha}^{-1}) \times \text{barley price } (\$\ \text{ha}^{-1}) \quad (13)$$

$$\text{Net return} = \text{gross value of production } (\$\ \text{ha}^{-1}) - \text{total cost of production } (\$\ \text{ha}^{-1}) \quad (14)$$

$$\text{Total cost of production} = \text{variable cost of production } (\$\ \text{ha}^{-1}) + \text{fixed cost of production } (\$\ \text{ha}^{-1}) \quad (15)$$

$$\text{Benefit-to-cost ratio} = \text{gross value of production } (\$\ \text{ha}^{-1}) / \text{total cost of production } (\$\ \text{ha}^{-1}) \quad (16)$$

$$\text{Productivity} = \text{barley yield } (\text{kg ha}^{-1}) / \text{total cost of production } (\$\ \text{ha}^{-1}) \quad (17)$$

Results and discussion

Analysis of input–output energy

Results revealed that 25.11 and 102.55 h of human labor and 10.71 and 7.54 h of machinery power per hectare were needed in irrigated and dry land barley production systems, respectively. The total energy consumed in various production processes for producing irrigated and dry land barley were 19,308.96 and 7,867.82 MJ ha^{-1}, respectively (Table 2). Among all the production practices in irrigated barley, the diesel fuel was the most consumed energy (X) (21.88 %), followed by electricity (20.67) and water for irrigation (20.39 %). On dry land farms, diesel fuel (43.21 %) was the most consumed energy among total inputs followed by seed (26.43 %), and nitrogen fertilizers (18.75 %) (Table 2). Nitrogen and diesel energies were mainly utilized for fertilizing and machinery in irrigated and dry land barley. Researchers (2010) reported that the total energy consumed in irrigated wheat, barley and maize was estimated at 51,587, 53,529, and 72,743 MJ ha^{-1}, respectively (Safa et al. 2010).

On the other hand, the mean grain yields in irrigated and dry land barley were measured as 3,710 and 2,195 kg ha^{-1}, and straw yields were measured as 2,375 and 1,020 kg ha^{-1}, respectively. Therefore, the total energy output was 76,505.75 MJ ha^{-1}in irrigated and 41,701.5 MJ ha^{-1} in dry land systems. The share of the energy output embodied in the grain yield of the total energy output was higher than the energy output embodied in the straw yield in two investigated systems (Table 3).

Energy use efficiency was 5.30 and 3.96 for dry land and irrigated barley, respectively. Energy efficiency in dry land barley was nearly 1.34 times better than irrigated barley. Thus, the dry land barley production system was more efficient in energy utilization compared to the irrigated barley production system. The total energy input used in irrigated barley was 2.45 times more than that of dry land fields. The main factor resulting in excessive energy utilization in the irrigated barley was because of more diesel fuel consumption. Also, the amounts of energy used in the irrigation water supply including irrigation water and electricity in irrigated barley were higher than those of dry land ones. In fact, in the dry land system, water for crop irrigation is provided from annual precipitation, thus it does not need from water supply. However, the share of energy use of the total energy for the diesel fuel, seed, machinery and human labor was higher in dry land production systems. Researchers (2011) reported that the total energy requirement under the dry land wheat production system was 9,354.2 MJ ha^{-1} (Ghorbani et al. 2011), whereas

Table 2 Energy consumption and energy input–output relationship in irrigated and dry land barley farms

Energy	Quantity per unit area (ha) irrigated	Quantity per unit area (ha) dry land	Total energy equivalent (MJ) irrigated	Total energy equivalent (MJ) dry land	Percentage of total energy input (%) irrigated	Percentage of total energy input (%) dry land
Input						
1. Human labor (h)	25.11	102.55	48.97	199.97	0.25	2.54
2. Machinery (h)	10.71	7.54	671.61	472.76	3.48	6.01
3. Diesel fuel (l)	84.12	67.68	4,225.46	3,399.32	21.88	43.21
4. Total chemical fertilizers (kg)	104.27	37.95	3,563.71	1,715.73	18.47	21.81
(a) Nitrogen	36.16	19.55	2,728.33	1,475.24	14.13	18.75
(b) Phosphate	39.56	18.4	517.05	240.49	2.68	3.06
(c) Potassium	28.55	–	318.33	–	1.66	–
5. Chemicals (kg)	3.23		562.79		2.9	
(a) Herbicides	1.75	–	416.51	–	2.15	–
(b) Pesticides	1.1	–	111.32	–	0.57	–
(c) Fungicide	0.38	–	34.96	–	0.18	–
6. Electricity (kWh)	1,109	–	3,992.4	–	20.67	–
7. Water for irrigation (m^3)	3,860	141.5	3,937.2	2,080.05	20.39	26.43
8. Seed (kg)	164.5		2,418.15	7,867.82	12.53	100.00
Total energy input (MJ)			19,308.96		100.00	
Outputs						
Seed yield (kg)	3,710	2,195	54,537	32,266.5	71.28	77.37
Straw yield (kg)	2,375	1,020	21,968	9,437	28.72	22.63
Total energy output (MJ)			76,505.75	41,701.5		

under irrigated wheat it was 45,367.6 MJ ha^{-1}. They demonstrated that energy use efficiency in dry land wheat was 3.38 kg MJ^{-1}, and in the irrigated system it was 1.44 kg MJ^{-1}. Reduction in the diesel fuel and fertilizer (mainly nitrogen) consumption had a major role in energy use efficiency. Researchers (2010) reported that because of the highly mechanized agricultural system, fuel utilization has risen by 10 % in recent years in Iran (Beheshti Tabar et al. 2010). They also stated that with higher yields and improved agricultural practices in the irrigated wheat systems, the unit of land used per unit of the output, reduced by 32 % in 2006 compared to 1990. It can be inferred that improvements in the crop irrigation efficiency together with the promotion of targeted application of fertilizers can have a significant effect on the energy efficiency of agriculture in Iran. Advances in irrigation systems will also lighten the effect of droughts on energetic parameters. Employment of more productive cultivars and more intense crop management will cause more efficient consumption of resources and will consequently lead to higher energy use efficiency.

Energetics of producing

The total energy input consumed in irrigated and dry land barley farms could be classified as direct (63.2 and 47.75 %), indirect (36.8 and 54.25 %), renewable (33.17 and 28.98 %), and non-renewable (66.83 and 71.02 %) energies (Table 4). The share of the indirect energy input was higher than direct energy in irrigated and dry land production systems. Also, the share of renewable energy utilization from the total energy input was 33.17 % in irrigated barley and 28.98 % in dry land barley systems (Table 4). Of the total energy input used in barley fields, 2,280 MJ ha^{-1} was renewable energy, which was 4,124 MJ ha^{-1} lower than that of the irrigated barley system. Consequently, production of barley as the dry land system in view of energy conservation was more energy efficient compared to the irrigated system. Researchers (2010) revealed that the total energy input used in irrigated barley production was non-renewable 66 % and renewable 34 % energy (Ghasemi Mobtaker et al. 2010).

Our results showed that the specific energy was 5.2 MJ kg^{-1} in irrigated barley and 3.58 MJ kg^{-1}in dry land barley. Energy productivity achieved in barley production was 0.19 and 0.28 kg MJ^{-1} in irrigated and dry land barley, respectively. Energy productivity is well recognized in the literature such as 1.0 for stake-tomato (Esengun et al. 2007), 0.06 for cotton (Yilmaz et al. 2005), and 1.53 for sugar beet (Erdal et al. 2007). In another study (2005), achieved specific energy for different field crops and vegetable production in Turkey were 16.21 for sesame, 11.24 for cotton, 5.24 for wheat, 3.88 for maize, 1.14 for tomato, 0.98 for melon and 0.97 for water-melon (Canakci et al. 2005). The application

Table 3 Total energy input in the form of direct, indirect, renewable energy for irrigated and dry land barley farms

Type of energy	Irrigated		Dry land	
	(MJ ha^{-1})	%[a]	(MJ ha^{-1})	%
Direct energy[b]	12,204.03	63.20	3,599.29	45.75
Indirect energy[c]	7,104.93	36.80	4,268.54	54.25
Renewable energy[d]	6,404.32	33.17	2,280.02	28.98
Non-renewable energy[e]	12,904.64	66.83	5,587.80	71.02
Total energy input	19,308.96	100	7,867.82	100

[a] Indicates the percentage of total energy input

[b] Indicates direct energy includes: diesel fuel, irrigation water, electricity and human labor

[c] Indicates indirect energy includes: energy embodied in seeds, chemical fertilizers, herbicides, pesticides, fungicides, farmyard manure, and machinery

[d] Indicates renewable energy includes: irrigation water, human labor, farmyard manure, barley wastes and seeds

[e] Indicates non-renewable energy includes: diesel fuel, electricity, chemical fertilizers, herbicides, pesticides, fungicides and machinery

Table 4 Energy input–output ratio in irrigated and barley farms

Items	Unit	Irrigated	Dry land
Energy input	MJ ha^{-1}	19,308.96	7,867.82
Energy output	MJ ha^{-1}	76,505.75	41,701.5
Energy use efficiency	–	3.96	5.30
Energy intensiveness	MJ $\$^{-1}$	28.87	21.93
Specific energy	MJ kg^{-1}	5.20	3.58
Energy productivity	kg MJ^{-1}	0.19	0.28
Net energy	MJ ha^{-1}	57,196.79	33,833.67

of non-renewable energy in irrigated production systems was great, indicating the fact that these systems are relying extremely on fossil fuels. In irrigated barley, high consumption of fossil fuel resources is considered to achieve higher yields. The utilization of fossil fuel resources in agriculture threatens fertility of the soil and weakens the economic independence of farmers. Consumption of optimal energy in agriculture is reflected in two ways: (a) increase to productivity with the existing level of energy inputs or (b) conserve to energy without affecting the productivity. In practice, a barley farmer could not take advantage of the conserved energy due to the high miss-consumption of energy. We believe that input energies (especially diesel fuel, chemical fertilizers, and water for irrigation) in dry land barley production systems are lower than those in irrigated system.

Economic indices

The economic indices of both studied systems are shown in Table 5. The gross value of production per hectare in irrigated systems (952.02 \$ ha^{-1}) was higher than that of the dry land production system (567.4 \$ ha^{-1}). Since both of the variable and fixed costs were lower in dry land system compared to the irrigated system, as a result, the total cost of production in the dry land system was 48.2 % lower than that of the irrigated barley system. The gross return and net return per hectare in the irrigated production system (692.17, 266.13 \$ ha^{-1}, respectively) were higher than those in the dry land production systems (380.97, 208.64 \$ ha^{-1}, respectively). Results of our study also indicated that the benefit to cost ratios in dry land barley (1.58) was higher than those in irrigated barley (1.38). The returns based on the land area (ha) were 81.7 % (gross) and 27.6 % (net) greater in irrigated barley; however, the benefit to cost ratios were higher in dry land barley compared to that in irrigated systems. This condition is considerably the result of the low cost of the input in dry land systems. Researchers (2010) reported that the benefit to cost ratios was the highest on rice farms (3.33) as compared to wheat (2.82) and barley farms (2.50). Productivity of the irrigated and dry land production systems was 5.35 kg $\$^{-1}$ and 6.12 kg $\$^{-1}$, respectively (Khan et al. 2010). This means that 5.35 and 6.12 outputs were obtained per cost unit (1 \$) in the irrigated and dry land production systems. Researchers (2011) indicated that the benefit to cost ratios were 2.56 in dry land and 1.97 in irrigated wheat production systems (Ghorbani et al. 2011).

The relationship between energy inputs and yields

The Cobb–Douglas production equation was used to assess the energy inputs and barley yield relationships. Therefore, the yield of barley (dependent variable) was supposed to be

Table 5 Economic analysis of barley production in irrigated and dry land farms

Cost and return components	Irrigated (value)	Dry land (value)
Gross value of production (\$ ha^{-1})	952.02	567.40
Variable cost of production (\$ ha^{-1})	266.85	186.43
Fixed cost of production (\$ ha^{-1})	426.04	172.33
Total cost of production (\$ ha^{-1})	692.89	358.77
Total cost of production (\$ kg^{-1})	0.11	0.11
Total cost production (\$ MJ^{-1})	0.01	0.01
Gross return (\$ ha^{-1})	692.17	380.97
Gross return (\$ kg^{-1})	0.11	0.12
Gross return (\$ MJ^{-1})	0.01	0.01
Net return (\$ ha^{-1})	266.13	208.64
Net return (\$ kg^{-1})	0.04	0.06
Net return (\$ MJ^{-1})	0.003	0.005
Benefit to cost ratio	1.38	1.58
Productivity (kg $\$^{-1}$)	5.35	6.12

a function of the human labor, diesel fuel, irrigation, machinery, total fertilizer, chemicals, electricity and seed (independent variables) in the irrigated system while in the dry land system it was supposed to be a function of human labor, diesel fuel, machinery, total fertilizer, electricity and seed. The data in this study were tested by the Durbin–Watson test (Ozkan et al. 2004a, b). The values of Durbin–Watson are shown in (Table 6). This means that there is no autocorrelation at the 5 % significance level for the evaluated modeling irrigated and dry land barley production systems. The R^2 values were 0.96 and 0.93 for irrigated and dry land barley, respectively. The results of the Cobb–Douglas equation explaining the impact of each one of the energy inputs on barley yields were different (Table 6). The results indicated that the impact of energy inputs could be evaluated positive on barely yields of irrigated (except seed energy) and dry land systems (except chemical fertilizers and seed energy). The human labor and machinery had the highest impact on the other inputs in dry land and irrigated barley systems, respectively (Table 6). This indicates that by increasing the energy attained from the human labor and machinery inputs, the amount of the output level improved in the present condition. For example, with respect to the coefficient of the equation for human labor (0.22) and machinery (0.19), a 1 % increase in these energy inputs led to 0.22 and 19 % increase in dry land and irrigated barley, respectively. The second important input was found to be the electricity with 0.16 for irrigated barley and machinery inputs with 0.18 for dry land barley (Table 6). In both investigated systems, the seed had a negative impact on yields. It seems that increasing the amount of seeds in the farms at the sowing time leads to increasing plant density and because of the optimum plant density in most of the crops, this process does not have any positive effect on crop yields. The negative impact of seeds was more in the dry land barley compared to irrigated barley (Table 6). Researchers (2010) reported that machinery and human labor energy inputs were the essential inputs significantly contributing to the barley yield in Iran (Ghasemi Mobtaker et al. 2010). Other researchers (2010) also reported that the contribution of human labor and machinery energy inputs were important at the 1 % level on the greenhouse cucumber yields in Iran (Mohammadi and Omid 2010). In another study (2010), it was demonstrated that human labor, irrigation water, fertilizer, and machinery energy inputs were important inputs considerably contributing in kiwifruit yields in Iran (Mohammadi et al. 2010).

Table 6 Relationship between energy inputs and yield in irrigated and dry land fields

Endogenous variable: yield	Irrigated system		Dry land system	
Exogenous variables	Coefficient	t-ratio	Coefficient	t-ratio
Human labor	0.10	2.36[a]	0.22	4.97[b]
Machinery	0.19	5.07[b]	0.18	3.16[a]
Diesel fuel	0.13	2.98[b]	0.15	5.36[b]
Total chemical fertilizer	0.09	1.89[ns]	−0.06	−0.35[ns]
Chemicals	0.04	2.10[a]	–	–
Electricity	0.16	4.87[b]	–	–
Water for irrigation	0.14	4.23[a]	–	4.23[a]
Seed	−0.05	−0.43[ns]	−0.08	−0.43[ns]
Durbin-Watson	2.09		2.12	
R^2	0.96		0.93	

[a] Significance at 1 % level

[b] Significance at 5 % level

[ns] Not significant

Conclusions

Based on the results of this study, the following conclusions were drawn:

1. The diesel fuel was found as the most consumed energy which was followed by electricity and water for irrigation in irrigated barley production.
2. In dry land barley production, the diesel fuel was found as the most consumed energy input followed by the seed.
3. In total energy consumption, the ratio of non-renewable energy was greater than that of renewable energy. Since the main non-renewable energy input was diesel, electricity, and chemical fertilizers, management and improvement in application of these inputs would increase the proportion of renewable energy.
4. The energy use efficiency, energy productivity, specific energy, net energy, and energy intensiveness of irrigated barley production were 3 96, 0.19 kg MJ^{-1}, 1.23 MJ kg^{-1}, 57,196.79 MJ ha^{-1} and 28.87 MJ $\$^{-1}$, respectively.
5. The energy use efficiency, energy productivity, specific energy, net energy, and energy intensiveness of dry land barley production were 5.3, 0.28 kg MJ^{-1}, 3.58 MJ kg^{-1}, 33,833.67 MJ ha^{-1} and 21.93 MJ $\$^{-1}$, respectively.
6. The benefit to cost ratio was 1.38 for irrigated barley and 1.58 for dry land barley. The mean net return and productivity of irrigated barley were 266.13$ ha^{-1} and 5.35 kg $\$^{-1}$ and in dry land barley were 208.64$ ha^{-1} and −6.12 kg $\$^{-1}$, respectively.
7. Results of this study showed that human labor as well as machinery energy inputs were the most important

inputs influencing the dry land and irrigated barley production systems, respectively. The second important input in the irrigated barley was electricity (with 0.16) which was followed by water for irrigation and diesel fuel (0.14 and 0.13, respectively).

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