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Energy use and economical analysis of seedy watermelon production for different irrigation systems in Iran

Rooholla Moradi [a,*], Parviz Rezvani Moghaddam [b], Hamed Mansoori [b]

[a] Department of Agronomy, Agricultural Faculty of Bardsir, Shahid Bahonar University of Kerman, Iran

[b] Department of Agronomy, Faculty of Agriculture, Ferdowsi University of Mashhad, P.O. Box 91779 48974, Mashhad, Iran

HIGHLIGHTS

- About 85% of used water irrigation in agriculture was supplied from groundwater in Iran.
- Reduced irrigation system improved the IWEUE and energy use efficiency.
- Direct and renewable energies were higher under reduced than full irrigation system.
- Reduced irrigation could be reduced irrigation water use up to 95% than full irrigation.
- Reduced irrigation system led to save the energy resource.

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ABSTRACT

Resource and energy use efficiency is one of the principal requirements of eco-efficient and sustainable agriculture. Seedy watermelon (*Citrullus vulgaris*; Joboni population) is irrigated by two methods including full and reduced irrigation systems in Iran. The objective of the present study was to compare seedy watermelon production in full (high input) and reduced (low input) irrigation systems in terms of irrigation water energy use efficiency (IWEUE), energy budget and economic analysis. Data were collected from 116 full irrigated and 93 reduced irrigated farms in northeast of Iran by using a face-to-face questionnaire in 2011–2012. The results showed that the total energy consumed under high input systems was 25625.94 MJ ha^{-1}, whereas under low input was 3129.3 MJ ha^{-1}. IWEUE and all of the energy indexes were improved in the reduced irrigation system compared to the full condition. The direct and renewable energies in the reduced irrigation system were higher than full irrigation. The economical analysis indicated that higher return was gained by the full irrigation system due to higher yield compared to the reduced irrigation system. Human labor had the highest impact on seedy watermelon among the other inputs based on the Cobb–Douglas production function.

1. Introduction

Irrigation water in many arid and semi-arid areas such as Iran is a vital resource to increase productivity and extend the crop growing season (Esmaeili and Vazirzadeh, 2009). The potential and actual agricultural productivity are closely related to the level of water availability. Agriculture mostly depends on ground water in arid regions of Iran. So, the data show that about 85% of water used for irrigation in 2010 came from non-renewable ground water sources in the country (MAJ, 2012). For example, the ground water level in Mashhad plains (are located in northeast of Iran) was declined about 22 m during 1985–2013 (Fig. 1). Hence, water used for irrigation from ground water sources has to compete with industries and urban demands (Al-Sulaimi et al., 1996). Irrigation water contributes an important share of energy use in agricultural productions (Chizari and Ommani, 2009). Therefore, energy inputs can be reduced by sowing crops that require less water.

Seedy watermelon (*Citrullus vulgaris*; Joboni population) is one of the plants that can be cultivated as a crop with low water needs in Iran. Watermelon seeds generally use in both fresh nuts and/or oil-seed in some part of the world. The seedy watermelon production area was approximately 36,040 ha, which is mainly situated in the central and eastern provinces of Iran (MAJ, 2012). Seedy watermelon is cultivated in many countries such as Iran, Afghanistan, Pakistan, India, Uzbekistan, Turkey and Iraq, and plays a key role in the farmers' incomes (MAJ, 2012). Seedy watermelon irrigation

* Corresponding author. Tel.: +98 9352613381; fax: +98 3413220041.
E-mail addresses: Roholla18@gmail.com, r.moradi@uk.ac.ir (R. Moradi).

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practices are performed by two methods in Iran: (a) full irrigation in which as soon as the seeds were sown, irrigation continued every 10 days, (b) reduced irrigation in which the farm is irrigated once before planting. The shares of full and reduced irrigation seedy watermelon production area are 56% and 44%, respectively. This plant commonly grows in the regions in which other crops do not grow well due to low rainfall or soil salinity.

More than 10.9% of gross domestic product (GDP) belongs to agricultural activities in Iran. More than 25% of the total population of the country was engaged in agriculture (MAJ, 2012). In the last decades, agricultural soils have been an important source of CO_2 and N_2O emissions, following intensive use of chemical fertilizers, pesticides and agricultural machinery in Iran. Therefore, energy consumption in agricultural systems is constantly increasing (Beheshti Tabar et al., 2010). Intensive use of energy causes problems threatening public health and environment (Erdal et al., 2007).

On the other hand, the technologies used by producers, production systems and production levels are essential elements that determine the amount of energy used per unit area (Erdal et al., 2009). The amount of energy used in agricultural production depends on the mechanization level, quantity of active agricultural work and cultivable land (Topak et al., 2010). However, low energy inputs production systems are not yet well accepted by farmers, who are interested in economic benefits rather than in energy productivity. It is realized that crop yields and food supplies are directly linked to energy (Nautiyal et al., 2007; Omid et al., 2011). Energy input–output analysis is usually used to evaluate the energetic and ecological efficiency and environmental impacts of crop productions. The energy analysis is important to ascertain more efficient and environment-friendly production systems (Rathke and Diepenbrock, 2006). Consequently, one main goal for improving the environmental performance of agricultural production has been minimizing energy consumption (Deike et al., 2008). Efficient use of energy in agriculture will prevent destruction of natural resources, and promote sustainable agriculture as an economical production system. Thus, natural resources could be used more efficiently (Erdal et al., 2007).

The objectives of this study were (i) to evaluate the differences in water use efficiency, energy budget and economical use efficiency between full and reduced irrigation production systems and (ii) to study the sensitivity and relationship between energy inputs and seedy watermelon yield in high and low input systems based on the Cobb–Douglas production function.

2. Materials and methods

2.1. Site description and data collection

The study was conducted in four provinces of Iran (main seedy watermelon cultivation areas) that are shown in Fig. 2. Data were collected from growers by using a face to face questionnaire in 2011–2012. In addition to the data obtained by surveys, previous studies of related organizations such as Food and Agricultural Organization (FAO) and Ministry of Agriculture of Iran were also utilized during the study (MAJ, 2012).

2.2. Determination of size sampling

Farm random sampling was done within whole population and the sample size was determined by Eq. (1) (Unakitan et al., 2010),

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

where n is the required sample size, N is the number of holdings in target population, N_h is the number of the population in h stratification, S_h is standard deviation in the h stratification, S_h^2 is variance of h stratification, d is the precision where $(\bar{x} - \bar{X})$, z is the reliability coefficient (1.96 which represents the 95% reliability), and $D^2 = d^2/z^2$. A criterion of 5% deviation from population mean and 95% confidence level were used to calculate sample size. Based on this calculation a size of 116 and 93 was considered as sampling size for full and reduced irrigation seedy watermelon production systems, respectively.

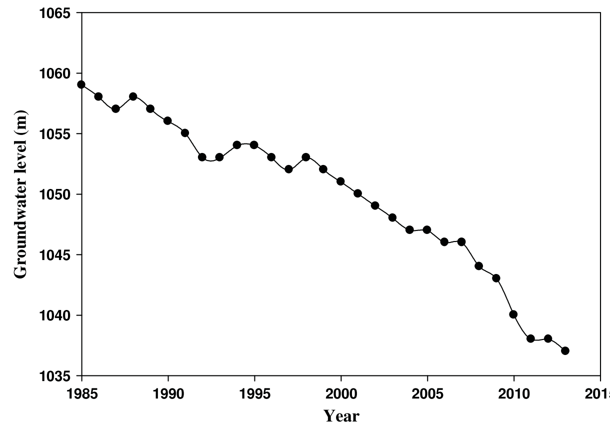

Fig. 1. Change in the groundwater level of Mashhad plain at 1985–2013 (Company of Fundamental Studies of Water Resources, 2014).

2.3. Calculation of energy budget

Human labor, machinery, diesel oil, fertilizer, pesticides, electricity, water of irrigation, seed amounts and output yield values of seedy watermelon have been used to estimate the energy ratio. Energy equivalents for inputs and outputs were shown in Table 1. The mechanical energy used in the seedy watermelon production systems included machinery and diesel fuel. The mechanical energy was computed on the basis of total fuel consumption (L ha^{-1}) in different operations. Therefore, the energy consumed was calculated, using conversion factors (1 L diesel = 56.31 MJ) and expressed in MJ ha^{-1} (Tsatsarelis, 1991).

Basic information on energy inputs and seedy watermelon yields were transferred into Excel spreadsheets, and analyzed by the SPSS program. Based on the energy equivalents of the inputs and output (Table 1), the energy ratio or energy use efficiency, energy productivity, the specific energy and net energy were calculated (Demircan et al., 2006).

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

$$\text{Energy use efficiency} = \frac{\text{Rice output (kg ha}^{-1})}{\text{Energy input (MJ ha}^{-1})} \quad (3)$$

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

$$\text{Net energy} = \text{Energy output}\left(\text{MJ ha}^{-1}\right) - \text{Energy input (MJ ha}^{-1}). \quad (5)$$

Indirect energy included energy embodied in seeds, chemical fertilizers (NPK), herbicide (Basagran), pesticide (Diazinon), fungicide (Metalaxyl) and machinery while direct energy covered human labor, diesel, electricity and water used in the seedy watermelon production. Non-renewable energy includes diesel, electricity, chemical pesticides, chemical fertilizers and machinery, and renewable energy consists of human labor, seeds and water.

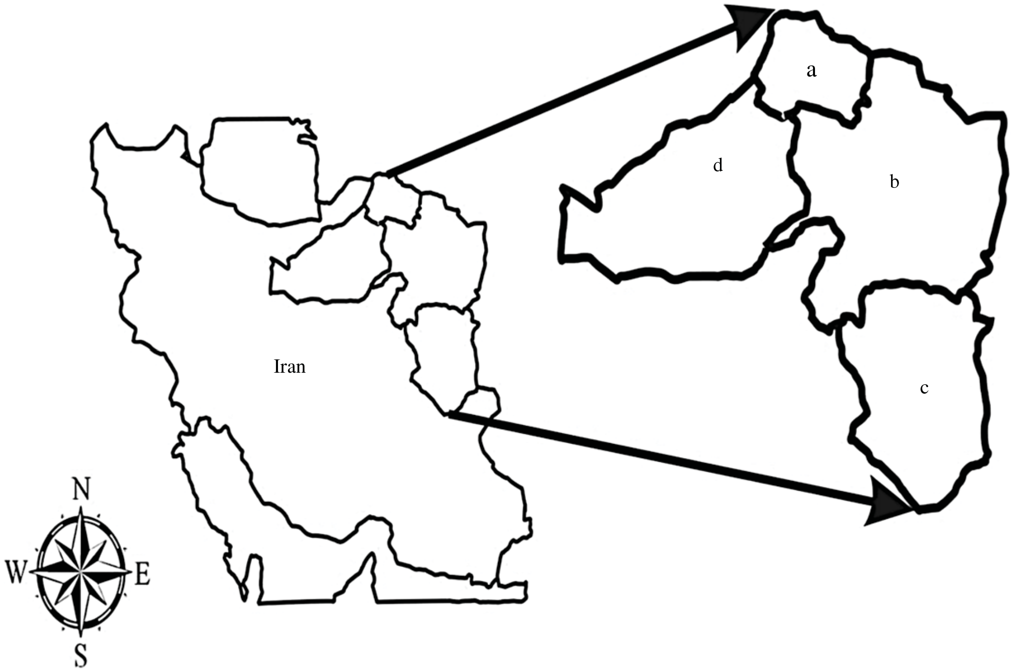

Fig. 2. Location of study sites in Iran; a, b, c and d indicate to North Khorasan, Khorasan Razavi, South Khorasan and Semnan provinces, respectively.

Table 1
Energy equivalent of inputs and outputs in seedy watermelon production.

Particulars	Unit	Energy equivalent ($MJ\ unit^{-1}$)	Ref.
A. Inputs			
1. Human labor	h	1.95	Singh et al. (2002)
2. Machinery	h	62.7	McLaughlin et al. (2000) and Taylor et al. (1993)
3. Diesel fuel	L	50.23	Singh et al. (2002)
4. Chemical fertilizers			
(a) Nitrogen (N)	kg	75.46	Singh et al. (2002)
(b) Phosphate (P2O5)	kg	13.07	Singh et al. (2002)
(c) Potassium (K2O)	kg	11.15	Demircan et al. (2006) and Alam et al. (2005)
5. Chemicals			
(b) Pesticide (Diazinon)	L	101.2	Singh et al. (2002) and Ozkan et al. (2004a)
(c) Fungicide (Metalaxyl)	kg	115.0	Singh et al. (2002) and Ozkan et al. (2004a)
6. Electricity	kW h	3.6	Taylor et al. (1993)
7. Water for irrigation	m^3	1.02	Taylor et al. (1993)
8. Seed	kg	26.2	Kousar et al. (2006) and Kitani (1999)
B. Outputs			
1. Seed yield	kg	26.2	Kousar et al. (2006) and Kitani (1999)
2. Plant residual yield	kg	6.4	Kousar et al. (2006) and Kitani (1999)

2.4. Calculation of Irrigation water energy use efficiency (IWEUE)

Irrigation water use efficiency (IWUE), expressed as the ratio of grain yield ($kg\ ha^{-1}$) to total irrigation water applied ($m^3\ ha^{-1}$) (Tolk and Howell, 2003; Farre and Faci, 2009) and correspondingly, IWEUE was considered as the ratio of energy equivalent of yield to total energy equivalent of irrigation water supplied.

2.5. Economic analysis

The economic output of the reduced and full irrigation seedy watermelon production systems was calculated based on market prices. All prices of inputs and outputs were market prices (average prices of year 2012). One hectare of experimental field was the basic unit for costs analysis. The net and the gross return, the benefit to cost ratio and the productivity were calculated according to the following equations for two systems (Demircan et al., 2006; Ozkan et al., 2004b):

$$\text{Gross value of production} = \text{yield (kg ha}^{-1}) \times \text{price (\$ ha}^{-1}) \tag{6}$$

$$\text{Net return} = \text{gross value of production (\$ ha}^{-1}) - \text{total cost of production (\$ ha}^{-1}) \tag{7}$$

$$\text{Benefit to cost ratio} = \text{gross value of production (\$ ha}^{-1})/\text{total cost of production (\$ ha}^{-1}) \tag{8}$$

$$\text{Productivity} = \text{yield (kg ha}^{-1})/\text{total cost of production(\$ ha}^{-1}). \tag{9}$$

2.6. Function selection

In order to analyze the relationship between energy inputs and seed yield, the Cobb–Douglas function (Singh et al., 2004;

Table 2
Management practices for irrigated and dryland seedy watermelon.

Practices/operations	Full irrigated seedy watermelon	Reduced irrigated seedy watermelon
Names of varieties (population)	Jaboni	Jaboni
Land preparation tractor used: 285 MF 75 hp	Moldboard plow, Land leveler, Ditcher	Moldboard plow, cultivator
Average farm size (ha)	1.3	2.4
Land preparation date	April	June
Average tilling number	2.6	2.0
Planting date	May	June
Farm type	Ridges and furrows	Flat culture
Planting method	Hill planting	Hand spreading
Average number of replantation	1.3	–
Fertilization date (Before planting)	April	–
Fertilization period (Top dressing)	June–July	–
Average number of fertilization	3.8	–
Irrigation period	May–September	June
Average number of irrigation	8.7	1.0
Spraying period	May–August	May
Average number of spraying	2.3	1.0
Harvesting period	August–September	August

Hatrili et al., 2005, 2006) was selected as the function suitable pattern. The Cobb–Douglas function relation is a power function, which is linear in logs (Heady and Dillon, 1961).

The Cobb–Douglas function is expressed as follows:

$$Y = f(x)\exp(u) \quad (10)$$

which can be further written as:

$$\ln Y_i = a + \sum_{i=1}^{n} a_j \ln\left(X_{ij}\right) + e_i \quad (11)$$

where Y_i denotes the seed yield of the ith farmer, X_{ij} is the vector of inputs used in the production process, a is a constant, a_j represents coefficients of inputs which are estimated from the model and e_i is the error term. Eq. (11) can be expressed in the following form for full irrigated seedy watermelon production system:

$$\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \cdots + \alpha_8 \ln X_8 + e_i \quad (12)$$

where human labor energy (X_1), diesel fuel energy (X_2), water for irrigation energy (X_3), machinery energy (X_4), total fertilizer energy (X_5), chemicals energy (X_6), Electricity (X_7) and seed for planting (X_8). In the reduced irrigation seedy watermelon production system Eq. (11) is in the following form:

$$\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \cdots + \alpha_6 \ln X_7 + e_i. \quad (13)$$

The impact of the energy of each input on the seedy watermelon yield was studied based on this pattern. Basic information on energy inputs and seedy watermelon yield in different production systems were entered into Excel's spreadsheet and Shazam 9.0 software program (Mohammadi and Omid, 2010; Asgharipour et al., 2012).

3. Results and discussion

3.1. Socio-economic structures of farms

Socio-economic structures of farms including soil tillage, seedbed preparations, planting methods, planting and harvest period are presented in Table 2. About 55.9% of total land in seedy watermelon production was full irrigated and 44.1% was used as the reduced irrigation system. Average farm size was 1.3 ha for full irrigated and 2.4 for reduced irrigation farms. Cotton, corn, winter wheat, barley, canola and tomato were grown along with seedy watermelon in the farms investigated. All the selected farms were in private possession.

Soil tillage and seedbed preparations are performed during April and June for full and reduced irrigation systems, respectively. The planting date was in May for full and June for reduced irrigation farms. Hill planting and hand spreading methods were used for high and low input systems, respectively. Irrigated operations were performed in average of 8.7 times (starting from May to September) for full irrigation and 1 time before planting (June) for reduced irrigation. Chemicals were sprayed 2.3 times (starting from May to August) in full and once (in May) in reduced irrigation. During the growing season, was applied no fertilizer for low input system whereas fertilizations were done 3.8 times in May–July for the high input system. Land preparation and soil tillage were mostly accomplished by a Massey Ferguson 28,575 hp tractor along with using moldboard plow, land leveler and ditcher (full irrigation) and moldboard plow and cultivator (reduced irrigation). Agronomic practices during the growing season of seedy watermelon along with the periods relevant to these preparations are shown in Table 2.

3.2. Energy input and output

Results showed that 737.3 and 322.01 h of human labor and 12.8 and 5.5 h of machinery power per hectare were needed in high and low input systems, respectively. Cultural practices in low-input systems were 5.6% and in high input farms were 20.1% of total energy input. The total energy used in various production processes for producing full irrigation and reduced systems were 25625.94 and 3129.3 MJ ha^{-1}, respectively (Table 3). Among all the production practices in irrigated seedy watermelon production, nitrogen (35.22%) was the most consumed energy input, followed by irrigation water (21.89%), electricity (15.46%) and diesel fuel (10.89%). In reduced irrigation farms, diesel fuel (31.71%) was the most consumed energy input, followed by human labor (20.06%), seed (18.42%), and machinery (11.02%) (Table 3). The largest share of human labor was used for fruits gathering and separating the seeds from the fruits. Irrigation water energy in high input system was nearly 21 times more than the low input system. Application of deficit irrigation could be one of the suitable strategies for management of limited water resources in semi-arid regions such as Mashhad with considering remarkable declining trend in the groundwater level under the current water management method (Fig. 1). Jackson et al. (2010) based on a comparative analysis of water application and energy consumption at the irrigated field level demonstrated that the total energy consumption was increased by increasing water application in the field. The methods that caused to irrigation saving will also reduce the effect of droughts on energetic parameters by continuing the production (Ghorbani et al., 2011).

Also the energy used in different farming practices such as machinery, electricity and diesel in full irrigated farms was higher

Table 3
Energy consumption and relationship between energy input–output for full and reduced irrigation systems in seedy watermelon.

Energy	Quantity per unit area (ha)		Energy equivalent (MJ unit^{-1})	Total energy equivalent (MJ)		Percentage of total energy input	
	Full	Reduced	Full	Full	Reduced	Full	Reduced
A. Input							
Human labor (h)	737.3	322.0	1.95	1437.7	627.9	5.61	20.06
Machinery (h)	12.80	5.50	62.70	802.7	344.9	3.14	11.02
Diesel fuel (L)	55.60	19.75	50.23	2792.8	992.0	10.89	31.71
Nitrogen (kg)	119.6	–	75.46	9025.0	–	35.22	–
Phosphate (kg)	82.8	–	13.07	1082.2	–	4.22	–
Potassium (kg)	25.00	–	11.15	278.8	–	1.08	–
Pesticide (L)	2.00	–	101.2	202.4	–	0.79	–
Fungicide (kg)	1.50	0.50	115.0	172.5	57.5	0.67	1.84
Electricity (kWh)	1100	74.04	3.60	3960.0	266.4	15.46	8.51
Irrigation Water (m^3)	5500	259	1.02	5610.0	264.2	21.89	8.44
Seed (kg)	10.00	22.11	26.20	262.0	574.4	1.03	18.42
Total energy input (MJ)				25626	3129.3	100.0	100.00
B. Outputs							
Seed yield (kg)	582.4	160.0	26.2	15248	4192.1	50.73	32.83
Plant residual yield (kg)	2314.1	1341.9	6.40	14809	8576.6	49.27	67.17
Total energy output (MJ)				30058	12768.6	100.0	100.00
Energy efficiency				1.17	4.08		
IWEUE[a]				2.72	15.86		
Specific energy (MJ kg^{-1})				44.03	19.55		
Energy productivity (kg MJ^{-1})				0.023	0.051		
Net energy (MJ ha^{-1})				4432.1	9638.7		

[a] Irrigation water energy use efficiency.

than those of reduced irrigation farms. Salami and Ahmadi (2010) stated that the diesel energy contained 37.9% of total energy, followed by chemical fertilizer 29.6% during production period in chickpea in Kurdistan province of Iran. The average yields of high and low systems were 582.4 and 160.0 kg ha^{-1} and chaff yields were calculated as 2314.1 and 1341.9 kg ha^{-1}, respectively (Table 3). Total energy output per hectare was 30058.03 MJ in full irrigation and 12768.62 MJ in the reduced irrigation system.

3.3. Energy balance

Irrigation water energy use efficiency (IWEUE) was found to be better in the reduced irrigation technique than full irrigation. As, the trait was about 82% lower in full irrigation compared to the reduced irrigation system (Table 3). Several studies confirmed that the WUE was greater in the deficit-irrigated system than in the full irrigated (Flenet et al., 1996; Cui et al., 2009, 2008; Webber et al., 2006; Karam et al., 2007). Webber et al. (2006) demonstrated that increasing WUE associated with crop production is a way for arid and semi-arid areas to increase their agricultural production where there is little or no prospect for expansion of water resources. Energy efficiency in the low input system was nearly 3.5 times more than high input due to using low energy input in reduced irrigation seedy watermelon farms. It is concluded that the energy ratio can be increased by raising the crop yield and/or by decreasing energy inputs consumption. In a study in Iran, Ghorbani et al. (2011) evaluated that the total energy requirement under low input systems was 9354.2 MJ ha^{-1}, whereas under high input systems it was 45367.6 MJ ha^{-1} in wheat production and energy ratio in dryland and irrigated systems were 3.38 and 1.44, respectively. They reported that employment of more productive cultivars and more intense crop management will cause higher outputs, and will consequently lead to a higher energy ratio.

The specific energy was 44.03 MJ kg^{-1} and 19.55 MJ kg^{-1} in high and low input systems, respectively (Table 3). Canakci et al. (2005) calculated the specific energy for some field crops and vegetable production in Turkey, such as 16.2 for Sesame, 11.2 for cotton, 5.2 for wheat, 3.9 for maize, 1.1 for tomato, 0.98 for melon and 0.97 for water-melon. The rate of net energy in the full irrigation system (4432.1 MJ ha^{-1}) was lower than reduced irrigation (9638.7 MJ ha^{-1}). Energy productivity generally showed the same trend of net energy (Table 3). So, the seedy watermelon production per unit of energy consumption for the reduced irrigation system (0.05 kg) was higher than full irrigation (0.02 kg). Erdal et al. (2009) evaluated that energy productivity in sugar beet production was 1.53 and also Yilmaz et al. (2005) reported that the energy productivity in cotton farms was 0.06. Improvement of energy use in agriculture is gained by two ways, i.e. an increase in productivity with the existing level of energy inputs or conserved energy without affecting the productivity. Efficient use of these energies can be caused to increase in production and productivity and contribute to economy, profitability and competitiveness of agriculture sustainability (Singh et al., 2002).

3.4. Energetics of producing full and reduced irrigation systems

Total energy input consumed in both full and reduced irrigation systems could be classified as direct (54% *vs.* 69%), indirect (46% *vs.*31%), renewable (29% *vs.* 47%) and non-renewable (71% *vs.* 53%), respectively (Table 4). Result showed that total energy input in high input was 87.8% higher than low input systems. The difference between renewable and non-renewable energies in the reduced irrigation system was lower than full irrigation due to lower application of diesel, electricity, chemical fertilizers and pesticides in reduced irrigation farms (Tables 2–4). It can be inferred that improving irrigation efficiency together with promoting targeted application of fertilizers could have a significant effect on energy efficiency. McLaughlin et al. (2000) demonstrated that production of nitrogen fertilizer represents the largest component of energy consumption for production among all inorganic agricultural fertilizers. Greater energy efficiency can be achieved by reducing the share of non-renewable energies. Reducing diesel fuel and fertilizer (mainly Nitrogen) consumption had a major role on decrease of non-renewable energies in the low input system. Improving energy efficiency would be gain by changing management practices such as tillage or harvest (less diesel consumption). Fuel consumption has risen by 10% in recent years due to the highly mechanized agricultural system in Iran (Beheshti Tabar et al., 2010). Therefore, reduction of fuel consumption in reduced irrigation systems can be caused due to decrease in environmental hazards spatially greenhouse gases emission.

Table 4
Total energy input in the form of direct, indirect, renewable and non-renewable energy for irrigated and dryland seedy watermelon.

Type of energy	Full irrigation system		Reduced irrigation system	
	(MJ ha^{-1})	%[a]	(MJ ha^{-1})	%
Direct energy[b]	13800.52	53.85	2150.52	68.72
Indirect energy[c]	11825.42	46.15	978.75	31.28
Renewable energy[d]	7309.73	28.52	1468.48	46.92
Non-renewable energy[e]	18316.21	71.48	1660.79	53.08
Total energy input	25625.94		3129.27	

[a] Indicate percentage of total energy input.
[b] Indicates human labor, diesel, electricity and water.
[c] Indicates seeds, chemical fertilizers (NPK), pesticide (Diazinon), fungicide (Metalaxyl) and machinery.
[d] Indicates human labor, seeds and water.
[e] Indicates diesel, electricity, chemical fertilizers (NPK), pesticide (Diazinon), fungicide (Metalaxyl) and machinery.

Table 5
Economic analysis for irrigated and dryland seedy watermelon systems.

Cost and return components	Full irrigation system (value)	Reduced irrigation system (value)
Grain yield (kg ha^{-1})	582.00	160.12
Sale price ($ kg^{-1})	4.03	4.03
Plant residual yield (kg ha^{-1})	2314.04	1340.08
Sale price ($ kg^{-1})	0.076	0.076
Total cost of production ($ ha^{-1})	568.77	202.01
Total cost of production ($ kg^{-1})	0.196	0.134
Total cost of production ($ MJ^{-1})	0.018	0.016
Gross return ($ ha^{-1})	2684.65	791.96
Gross return ($ kg^{-1})	0.927	0.528
Gross return ($ MJ^{-1})	0.089	0.062
Net return ($ ha^{-1})	2115.88	589.95
Net return ($ kg^{-1})	0.730	0.393
Net return ($ MJ^{-1})	0.070	0.046
Benefit to cost ratio	4.72	3.92

3.5. Economical analysis of seedy watermelon production systems

Total production cost and gross return values in the full irrigation system were higher than the reduced system (Table 5). The total cost of production as a term of $ kg^{-1} and $ MJ^{-1} in the high input system was higher compared to low input (Table 5). The net return per hectare in high and low input systems was 2115.9$ and 589.9$, respectively. The benefit–cost ratio of seedy watermelon production was calculated by dividing the gross return value into the total production cost in order to determine the economic efficiency. The full irrigation system had higher benefit–cost ratio compared to reduced irrigation condition (Table 5). The study results were consistent with the findings of Ghorbani et al. (2011) that reported the benefit–cost ratio in dryland wheat production systems (2.56) was higher than irrigated systems (1.97). The higher net return in the full irrigation system compared to the reduced system was due to significant higher seed yield in full irrigation system.

3.6. Model estimation of energy inputs for seedy watermelon production

The Cobb–Douglas production function on different categories of farms was used for estimation of relationship between the energy inputs and seedy watermelon yield. Therefore, the yield of seedy watermelon (dependent variable) was supposed to be a function of human labor, diesel fuel, irrigation, machinery, total fertilizer, chemicals, electricity and seed (independent variables) as a multiple regression. For data used in this study, autocorrelation was tested by using the Durbin–Watson test (Hatrili et al., 2005).

Table 6
The coefficients of Cobb–Douglas function and *t*-value.

Source (kg ha^{-1})	Coefficient		*t*-value	
	Dryland	Irrigated	Dryland	Irrigated
Constant				
Human labor	0.16	0.12	2.10**	1.70**
Diesel fuel	0.02	0.03	0.97*	0.58*
Water	0.10	0.12	1.61*	2.07**
Machinery	0.04	0.05	1.84**	0.79**
Fertilizers	–	0.11	–	0.11
Chemicals	−0.01	0.03	0.97*	2.31**
Electricity	0.02	0.09	1.04	1.52*
Seed	−0.04	−0.06	−0.71	−0.56
R^2	0.984**	0.962**		
Durbin–Watson	2.31*	2.24*		

* Significant at 5% level.
** Significant at 1% level.

The values of Durbin–Watson are shown in Table 6. This means that there is no autocorrelation at the 5% significance level in the estimated models for both seedy watermelon production systems. The R^2 values were 0.984 and 0.962 for low and high-input systems, respectively (Table 6). The results of Cobb–Douglass function indicated that the impact of each one of the inputs in seedy watermelon production differ in constitution of production level (Table 6). All inputs had a positive impact on yield of seedy watermelon expect the amount of planted seed in both production systems and chemicals in the reduced irrigation system. Human labor had the highest impact on seedy watermelon among the other inputs in the low input system. This indicates that the amount of output was mainly improved by increasing the energy of human labor input. For example, based on the coefficient of function for human labor (0.16), the 1% increase in the energy of human labor input caused to 0.16% increase in the yield of the reduced irrigation system, whereas human labor and irrigation water inputs had the highest impact on yield in the high-input system in which the coefficient of function for them was 0.12 (Table 6). The second effective input on seedy watermelon was found as fertilizers for high input and irrigation water for the low input system by 0.11 and 0.10 as the Cobb–Douglas function coefficient, respectively (Table 6). Diesel fuel and electricity in the reduced irrigation system and diesel fuel and chemical in full irrigation was calculated as the lowest value of function coefficients that were indicated to have the lowest impact on the yield.

4. Conclusions

The results showed that energy efficiency, energy productivity, net energy and the share of direct and renewable energies in the low input system were extremely higher than the high input system. Nitrogen, irrigation water and diesel fuel energies constituted the major portion of energy inputs used in irrigated farms. The high amount of diesel fuel consumption was because of the intensive use of machinery for operations such as soil preparation, cultural practices, harvest and transportation. The amount of energy used in various agricultural practices such as machinery, electricity, pesticide and labor in the full irrigation production system was higher than those of reduced irrigation. Total energy input used in full irrigation seedy watermelon production was about 25625.9 MJ ha^{-1}, which is 8 times more than of reduced irrigation farms (3129.3 MJ ha^{-1}). The energy output–input ratio in the reduced irrigation system (4.08) was higher than full irrigation (1.17), which was mainly because of the lower use of input energies mainly water and fertilizers.

The reduced irrigation system was contained higher IWEUE compared to full irrigation. In arid and semi-arid areas, energy input through irrigation is the most important energy input (Topak et al., 2010). The groundwater resources are the main source (85%)

of irrigation water in agricultural systems of Iran (MAJ, 2012). Overuse or mismanagement of limited water resources may raise a huge concern on agricultural production quantity and quality in the near future. Therefore, moving towards the reduced irrigation system can be considered as an effective approach to conserve the groundwater resource and decrease the environmental problems. The reduced irrigation system was involved other positive aspects such as reducing erosion by lower operation practices and minimum or no contribution of biocides and chemical synthetic fertilizers which cause lower using energy input and also more environmental friendly production systems.

The results indicated that the reduced irrigation method decreased water used for irrigation by up to 95% in comparison with full irrigation system. In addition, the reduced irrigation method saved 87% of total input energies. Therefore, applying reduced irrigation method in agricultural systems can be led to sustainable agriculture. It can be inferred from the results that reduced irrigation of seedy watermelon in the studied regions is a significant production method which is highly efficient and recommendable strategy on the view of energy-related factors. The farmers can use this pattern for other plants and save water and energy.

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