



Analysis of cotton production by energy indicators in two different climatic regions

Hossein Kazemi^{*}, Mohsen Shokrgozar, Behnam Kamkar, Afshin Soltani

Department of Agronomy, Faculty of Plant Production, Gorgan University of Agricultural Sciences and Natural Resources (GUASNR), PO Box 49189-43464, Gorgan, Iran

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ABSTRACT

In this study, the energy pattern of cotton production was analyzed and compared by energy indicators in the Darab (with arid climate) and Gorgan (with sub-humid climate) regions, in Iran. For this purpose, different climatic conditions, agronomic managements, energy inputs and cotton varieties were considered. The data were collected from a survey of 30 cotton fields in each region during 2013–2014. All agricultural managements in the studied fields were monitored and recorded. Then, some energy related indicators, including renewable and non-renewable energies, energy use efficiency, direct and indirect energies, net energy, energy productivity and specific energy were calculated. On the base of obtained results, total energy consumption of cotton production was estimated as 36,189.03 in Darab and 31,860.6 MJ ha⁻¹ in Gorgan. The factors relating to energy consumption were diesel fuel (Darab 39.09% and Gorgan 59.94%), and fertilizers (Darab 16.9% and Gorgan 15.25%). The cotton output energy was being as 34,076.04 MJ ha⁻¹ for Darab and 35,231.26 MJ ha⁻¹ for Gorgan. Also, energy use efficiency was calculated as 0.942 in Darab (as an arid climate) and 1.106 in Gorgan (as a sub-humid climate). The indirect energy and non-renewable energy were relatively high in Gorgan compared to Darab. It was concluded that energy productivity index implies that lower units of output was obtained per unit energy in Darab region. Also, the high ratio of non-renewable energy in total used energy inputs causes negative effects on the sustainability of cotton production systems.

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1. Introduction

Global food security relies mainly on the productivity of agriculture section, environmental resources use efficiency, year-to-year stability, and long-term sustainability (Denison and McGuire, 2015). The indiscriminate use of environmental resources to achieve greater production, leads to depletion of environmental resources, increasing environmental pollution and the increasing concentration of (GHGs) emissions (Esengun et al., 2007).

Evidence suggests that excessive use of inputs (such as fossil fuels, agrochemicals, machinery and electricity) with the goal of a significant increase in food and fiber production and improving nutrition has led to agricultural intensification. However, greater

use (more intensive energy use) of energy threatens human health and the environment, therefore, this makes more efficient use of energy to become a major issue in sustainable agriculture (Yilmaz et al., 2005). Efficient use of farming techniques and the intelligent use of inputs reduces adverse effects of external inputs on the environment and leads us to sustainable intensification (Erdal et al., 2007). To that end, today integrated systems of farming, conservation agriculture and practices, low-input agriculture, organic farming and etc. have been proposed as a solution (Dumanski et al., 2006). For example, Arunrat et al. (2016) investigated the five alternative crop rotations of ten alternative cropping systems in Phichit province of Thailand. Results showed that alternative cropping systems with selecting crop rotation not only reduce GHGs emissions of the rice fields, but also increase the benefits of farmers.

The energy analysis done with two objectives: evaluation of agroecosystems efficiency and assessment of related adverse effects on the environment. Many researchers have studied the energy balance of different crops and agroecosystems. All of these studies have focused on the energy use efficiency and impact on

^{*} Corresponding author. Department of Agronomy, Faculty of Plant Production, Gorgan University of Agricultural Sciences and Natural Resources (GUASNR), PO Box 49189-43464, Gorgan, Iran.

E-mail addresses: hkazemi@guau.ac.ir (H. Kazemi), shokrgozar.d@gmail.com (M. Shokrgozar), kamkar@guau.ac.ir (B. Kamkar), afshin.soltani@gmail.com (A. Soltani).

energy consumption of the production systems on the environment (Akpınar et al., 2009). In the study of Yilmaz et al. (2005) in cotton production systems in Turkey, 49.73 GJ ha⁻¹ energy was consumed totally, while the energy input to energy output ratio was equal to 0.74. In this regard, fossil fuels, fertilizers and machinery were the most important components of energy consumption. In a study with the aim of optimizing the energy inputs in Punjab province, Pakistan, the energy input for cotton production systems was investigated (Singh et al., 2000). The results showed that 70% of the total energy consumed for seedbed preparation, irrigation operation and weeding. The researchers also concluded that with one to three percent more energy, especially for plowing, irrigation and spraying, cotton yield can be increased by as much as 6–8 percent (Singh et al., 2000). In a study in Turkey, the maximum energy required for cultivating and crops was reported as 45,596.5 MJ ha⁻¹ for tomato and 34,891.2 MJ ha⁻¹ for potato (Canakci et al., 2005). In another study, Ullah et al. (2016) investigated eco-efficiency of cotton cropping systems in Pakistan using life cycle assessment (LCA) and data envelopment analysis (DEA). Results showed that pesticides and fertilizer use, irrigation, field operations, and field emissions were the main sources of environmental impacts. They concluded that high economic performance and low environmental impacts cannot be combined in the most cotton farms of Pakistan. Yadav et al. (2017) identified sustainable and environmentally safer cropping systems with low global warming potential and low energy requirement for rainfed rice fallow lands in India. Their results showed that the relative amounts of energy input in all cropping systems involved 44–55% for chemical fertilizers, 13–17% for land preparation, 12–15% for diesel and 11–14% for labor. Also, the highest energy productivity was obtained from the rice–garden pea system.

Tsatsarelis (1991) reported that the total amount of sequestered energy for cotton production in central Greece with the with the highest share for irrigation and synthetic fertilizers was about 82,600 MJ ha⁻¹. Yaldiz et al. (1993) showed that the highest share of energy consumption of cotton production systems of Turkey belongs to fertilizers and irrigation. In one study to compare sweet sorghum, cotton and maize in terms of energy productivity in China, the results showed that the energy input of sweet sorghum production systems was less than cotton and maize (Ren et al., 2012). The results of this study demonstrated a significantly positive impact of the diesel fuel and nitrogen fertilizer energy inputs on the sweet sorghum energy output.

Energy indicators have been investigated in different regions of Iran for different field crops, including wheat (Ghorbani et al., 2011), barley (Ghasemi-Mobtaker et al., 2010), potato (Rajabi-Hamedani and Shabani, 2011), canola (Sheikh-Davoodi and Houshyar, 2009), sugarcane (Karimi et al., 2008), rice (AghaAlikhani et al., 2013) and soybean (Alimaghani et al., 2017). For example, Zahedi and Eshghizadeh (2014) reported that the total energy of cotton production systems in Isfahan, central province of Iran, is equal to 52,507.8 MJ ha⁻¹. Energy use efficiency, specific energy, energy productivity, energy intensiveness, and net energy indicator values were reported as 0.7, 19.2 MJ kg⁻¹, 0.10 kg MJ⁻¹, 27.2 MJ \$⁻¹, and –15,625.2 MJ ha⁻¹, respectively.

In the viewpoint of the energy analysis, the total input energy of a system can be separated into two forms: renewable/non-renewable and direct/indirect inputs (Singh et al., 1994). In general, in advanced cotton production systems, non-renewable energy resources accounted for the major share of the energy. In this regard, fertilizers, pesticides and fossil fuels are the largest share. Many researchers have pointed out a higher share of non-renewable sources of energy compared to other sources (Esengun et al., 2007). For instance, in Turkey, Erdal et al. (2009) reported

that the share of direct, indirect, renewable and non-renewable energy of total energy input (19,558 MJ ha⁻¹) of cotton production systems was equal to 4384 MJ ha⁻¹ (28.87%), 10,800 MJ ha⁻¹ (71.13%), 1867 MJ ha⁻¹ (12.30%) and 13,316 MJ ha⁻¹ (87.70%), respectively.

Cotton is an important economic fiber crop, also it is considered as an important feed source (as an oil crop), and the cottonseed meal also is used for animal feed (Agarwal et al., 2003). Cotton is a high value crop in the world trade of agricultural products and can also play an important role in agricultural employment. International traders are China, India, the USA, the EU and central Asian and African states are the major producers and international traders of this crop all over the world (FAO, 2016). The area under cotton cultivation in Iran in 2015 was 72,000 ha (with total production of 175,000 t). In the same year the share of Golestan province was 13.39 percent and the share of the Fars province was 17.79 percent (Ministry of Jihad-e-Agriculture, 2015). Energy analysis for agroecosystems has been considered since the 1970s. In the process of energy analysis, agroecosystems are considered as user and producer of energies (Pimentel et al., 1973). Given the importance and role of cotton as a strategic crop in the world, determining the energy inputs and energy-related can help to optimize cotton production systems. Therefore, this study aimed to determine the energy related indicators and energy consumption patterns in cotton production systems in Iran. In this research, it compared cotton production by energy indicators in two important cotton production regions for the point of view different climatic conditions (sub-humid and arid), agronomic management, energy inputs and used cotton varieties. Also, for the first time, the state of electrical energy consumption was analyzed in cotton production systems in Iran.

2. Material and methods

2.1. Description of the regions

This study aimed to evaluate and compare the energy indicators in cotton production systems of two different climates. For this, the study was performed in two different regions. Darab township is located almost in the south of Iran, between 28°46' and 28°76' north latitude and 54°32' and 54°54' east longitude with arid climate and an average annual rainfall of 270 mm. Darab is one of the major agricultural zones in Fars province, which its arable lands are mostly irrigated by groundwater resources. In terms of topography, the agricultural areas of Darab, are located between the plains and mountains. One of the challenges in this area is the low chemical quality of the water along with the drop in groundwater levels. The chemical quality of groundwater in this flat is influenced by the salt domes, evaporation rate and the direction of groundwater, which are the main factors affecting the water quality of the plains.

Gorgan township (Golestan province), is located in the northern strip of Iran, has a sum-humid climate and average annual precipitation of 533.9 mm. The township is geographically located in 36°30.6' and 36°58.8' north latitude and 54°12.9' and 54°44.9' east longitude. Golestan province in Iran is an ancient land of cotton cultivation and over the years has been known as the land of white gold. That's why Golestan province is introduced as Iran's capital of cotton (Mehregan et al., 2013). Due to history of cotton cultivation in the province and favorable climatic conditions for cotton cultivation, National Cotton Research Center of Iran is located in this province. Some values of climate variables (such as temperature, evaporation, sunshine hours and relativity humidity) are presented in Table 1 for two townships in 2013.

Table 1
Climatic variables in Darab and Gorgan townships, Iran.

Variables	Average temperature (°C)		Evaporation (mm)		Sunshine hours (hours)		Average relative humidity (%)	
Month/Region	Gorgan	Darab	Gorgan	Darab	Gorgan	Darab	Gorgan	Darab
June	24.7	30.6	199.1	325.0	253.7	272.3	63.0	25.5
July	27.4	33.8	206.4	360.5	228.5	362.4	65.0	27.5
August	28.3	32.8	208.8	311.5	245.7	325.6	66.0	36.0
September	26.1	29.9	160.2	263.9	219.4	297.1	69.0	35.0
October	21.2	24.4	109.0	172.9	207.4	307.6	69.0	34.5
November	14.1	13.5	50.8	74.6	185.1	272.0	58.0	54.5
December	08.0	08.4	32.2	53.2	147.4	224.6	68.0	55.0

2.2. Management practices

List of agricultural practices used in the fields of study is presented in Table 2. According to data recorded in the farms, the average size of fields is 1.5 ha (varies from one to 5 ha). Land preparation and plowing were done by a Massey Ferguson 285,75 hp tractor. To do this, the plow and disc harrows were used as needed. In Darab, the land is plowed once between May–June and thinning is done twice on the ground. Cotton seed is sown in June. The seeding rate is approximately 42.0 kg ha⁻¹ and the common variety is Bakhtagan. Irrigation is done 10 times from June to September with needed intervals. Chemical fertilizers also to be consumed three times from June–August. Pesticides and herbicides are used as needed (began in June and ended in August). On average, the cotton crop is hoed two times by hand. In Darab region, the cotton is generally hand-harvested in three times from November to mid-December.

Based on the recorded data, the cotton fields of the Gorgan (as the second township) are disked four times from April–May, and sowing is done from May–June (common variety is Golestan (Dej-59)). Seeding rate is approximately 43.7 kg ha⁻¹. Usually, cotton is irrigated about four or five times from June to September using the furrow irrigation method. Chemical fertilizers are applied 3–4 times within the April–August period. On average, the cotton crop is hoed three to four times by hand during the period of June–July and usually, harvested by hand during October and November (Table 2).

2.3. Data collection and analysis

Data were collected from 60 cotton-grown fields from 75 main farms (1–5 ha) and from 2253 farmers in the two regions by face to face interviews. Sample fields were randomly selected from the 12 villages by a stratified random sampling technique (equation (1)) during the 2013–2014 (Singh et al., 1997).

$$n = \left(\sum N_h \cdot S_h \right)^2 / \left(N^2 \cdot D^2 + \sum N_h \cdot S_h^2 \right) \quad (1)$$

where n , N , N_h , S_h^2 , D^2 , d and z are the required sample size; the

number of total holdings in each given population; the number of the population in h ; the variance of h stratification, d^2/z^2 , the precision where $(\bar{x} - \bar{X})$; and the reliability coefficient, respectively (Singh et al., 1997). The permissible error was defined as 5% for 95% confidence in the sample size and the sample size was calculated as farms number. Human labor, machinery, diesel fuels, chemical fertilizers, agrochemicals, seed rate and output yield values of cotton crop were considered as energy analysis components. Information on the inputs of the cotton fields is presented in Table 3. SPSS software Ver.16. be involved in needed analysis and means comparison of all the data sets. To detect significant mean difference in two separate studied areas, the independent-samples t -test was involved ($p \leq 0.01$).

The equivalent of the energy inputs used in the cotton production systems is presented in Table 4. All these values have been obtained from those studies that have addressed energy analysis in agricultural production systems. The amount of energy consumed for each input was calculated by the amount of the input and the output amount multiplied by corresponding energy equivalents. The total energy input (E) was considered as the sum of the input factors (A_i) multiplied by the relevant energy conversion coefficient for each factor (C_i) as the following equation (Safa et al., 2011).

$$E = \sum (A_i \cdot C_i) \quad (2)$$

The energy equivalent of machinery input also was calculated using equation (3):

$$ME = E \cdot (G/T) \quad (3)$$

where ME , E , T and G , denote the machinery energy (MJ h⁻¹), the production energy of the machine (62.7 MJ kg⁻¹), the economic life of the machine (h), and the weight of the machine (kg), respectively (Rafiee et al., 2010).

2.4. Energy indicators

Based on the energy equivalents, eight energy indicators (including renewable and non-renewable energies, energy use efficiency, direct and indirect energies, specific energy, net energy

Table 2
Common agricultural practices for cotton production in Darab and Gorgan regions, Iran.

Practices/Operations	Gorgan	Darab
Tractor type	285 MF 75 hp	285 MF 75 hp
Varieties	Golestan (Dej-59)	Bakhtagan
Amounts of seed	43.7 kg	42.0 kg
Land preparation period	May	May–June
Tilling number	6	4
Irrigation times	4–5	10
Number of spraying	4	3
Harvesting time	October and November	November to mid-December

Table 3

Amounts of inputs and output (per hectare) in cotton fields of Darab and Gorgan regions, Iran.

Region/Input	Water m ³	Fertilizers kg	Seed kg	Electricity kWh	Diesel fuel L	Chemicals kg	Machinery h	Labor h	Cotton yield kg
Darab	7257.67	164.613	42.000	835.000	241.167	9.223	23.217	503.717	2887.670
SE ^a	63.711	2.308	1.189	94.681	74.353	0.159	0.640	3.475	59.808
Gorgan	800.00 ^b	120.800	43.667	259.400	339.167	10.800	24.467	445.000	2985.680
SE	21.571	1.249	1.416	67.646	48.414	0.161	0.602	3.586	74.113

^a Standard Error.^b As supplemental irrigation.**Table 4**

Energy equivalent of inputs and outputs in agricultural production.

Particulars	Unit	Energy equivalent (MJ unit ⁻¹)	References
A. Inputs			
1. Human labor	h	1.95	(Yilmaz et al., 2005)
2. Machinery	h	62.70	(Singh, 2002)
3. Diesel fuel	L	56.31	(Ozkanet al., 2007)
4. Chemical fertilizers			
(a) Nitrogen (N)	kg	58.106	(Erdal et al., 2007)
(b) Phosphate (P ₂ O ₅)	kg	13.971	(Erdal et al., 2007)
(c) Potassium (K ₂ O)	kg	7.947	(Erdal et al., 2007)
5. Chemicals			
(a) Herbicides	kg	238.30	(Hülsbergen et al., 2002)
(b) Pesticides	L	101.20	(Meul et al., 2007)
(c) Fungicides	kg	216.00	(Meul et al., 2007)
7. Electricity	kWh	3.60	(Zahedi and Eshghizadeh, 2014)
8. Water for irrigation	m ³	1.02	(Zahedi and Eshghizadeh, 2014)
9. Seed	kg	11.80	(Singh et al., 2000)
B. Outputs			
1. Cotton grain yield	kg	11.80	(Erdal et al., 2007)

and energy productivity) were calculated by following equations (4)–(7) (Ghorbani et al., 2011).

$$\text{Net energy (NE)} = \text{Energy output (EO)} \left(\text{MJ ha}^{-1} \right) - \text{Energy input (EI)} \left(\text{MJ ha}^{-1} \right) \quad (4)$$

$$\text{Energy productivity (EP)} = \text{Yield output (YO)} \left(\text{kg ha}^{-1} \right) \times \frac{1}{\text{Energy input (EI)} \left(\text{MJ ha}^{-1} \right)} \quad (5)$$

$$\text{Specific energy (SE)} = \text{Energy input (EI)} \left(\text{MJ ha}^{-1} \right) \times \frac{1}{\text{Yield output (YO)} \left(\text{kg ha}^{-1} \right)} \quad (6)$$

$$\text{Energy use efficiency (EUE)} = \text{Energy output (EO)} \left(\text{MJ ha}^{-1} \right) \times \frac{1}{\text{Energy input (EI)} \left(\text{MJ ha}^{-1} \right)} \quad (7)$$

Indirect energy refers to chemical fertilizers, cotton seed, pesticides, and machinery related energies, while direct energy covers human labor, electricity, diesel fuels, and irrigation water in the cotton production process. Also, diesel fuels, pesticides, chemical fertilizers, machinery and electricity were considered as non-renewable inputs, while cotton seed, human labor and water for irrigation as renewable energy sources (AghaAlikhani et al., 2013).

3. Results and discussion

3.1. Energy input and output analysis

Table 5 displays the related average of energy consumption as inputs and outputs for cotton production in two different climatic regions. The results showed that the total energy input in Darab (as arid climate) was 36,189.03 MJ ha⁻¹, which was more than Gorgan (as sub-humid climate) (31,860.6 MJ ha⁻¹), this is while the total energy output was significantly higher in Gorgan than Darab ($P < 5\%$). Also, results showed that the low energy consumption in Gorgan was related to less inputs of labor, chemical fertilizers, irrigation water, and electricity and more precipitation amounts along with low evaporation in growth period of cotton. However, the other inputs such as diesel fuels, machinery, chemicals, and seed rate were more in the cotton fields of Gorgan (Table 5). The differences in climatic condition and cultivar type between Darab and Gorgan cause to make distinctions on their input consumption. In this regard, Singh (2002) indicated that cotton consumed maximum energy compared to wheat, mustard, maize and cluster bean. In the Antalya region (Turkey), the maximum energy requirements was related to cotton (34,891.2 MJ ha⁻¹) (Canakci et al., 2005). In another study, Yilmaz et al. (2005) concluded that with the management of energy at the farm level, a more efficient and economical use of energy could be achieved.

The percentage of energy inputs showed in Figs. 1 and 2. The results showed that diesel fuels by 39.01% in Darab and 59.94% in Gorgan have the highest share of total energy input. In Gorgan region, the consumption rate of diesel fuels was more than Darab, but the electricity consumption was lower than Darab. It seems that the main reason for the high consumption of fuels is the temporal depreciation of machinery in Iran. It has also been reported that energy input of fuels has the biggest share of the total energy inputs in crop production (Chauhan et al., 2006). In contrast, in Darab

Table 5
Energy equivalent of input and output for cotton production in Gorgan and Darab regions, Iran.

Inputs and outputs/Region	Gorgan	Darab	Pr> t
	Total energy equivalent (MJ ha ⁻¹)	Total energy equivalent (MJ ha ⁻¹)	
A. Input			
1.Human labor	867.70	982.26	*
2.Diesel for irrigation pump	10738.31	7016.23	ns
3.Diesel fuel for machinery	8361.64	7128.85	*
4.Machinery	1534.27	1455.90	*
5.Irrigation water	816.00	7402.85	*
6.Fertilizers	4860.47	6116.82	*
7.Chemicals	3237.80	2584.52	ns
8.Electricity	928.80	3006.00	*
9.Seed	515.66	495.60	*
Total input	31860.6	36189.03	*
B. Output			
Cotton yield	35231.26	34076.04	*

ns:Non –significant

*: Significant at 5% probability level.

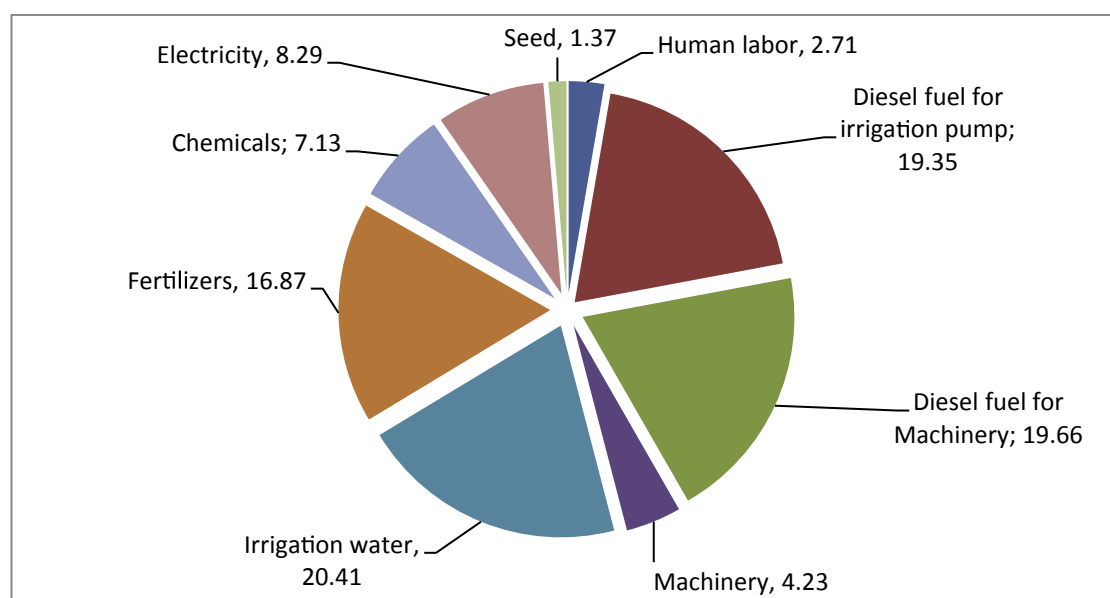


Fig. 1. Share of inputs in energy consumption for cotton cropping in Darab region, Iran.

region, the highest energy use belonged to water energy, followed by diesel fuel with a share of 20.14% of the total energy consumed (Fig. 2). A high percent of the energy in the studied regions could be attributed to use of inefficient irrigation pumps and low cost of electricity in Iran. Also, the amount of annual rainfall in this area was less than Gorgan (Table 1). In confirmation of these results, Ghasemi-Mobtaker et al. (2012) reported the electricity used in pumping system was the highest energy inputs for alfalfa production (75.79%) in Iran.

In Iran, the amount of cotton produced is a direct function of energy inputs. Cotton is produced using energy sources ranging from fuels, human labor and the power of heavy machinery. Particularly on the remarkable findings was a strong and significant increase in electricity usage in the cotton fields of Darab comparing Gorgan region. This increase is mainly due to electrified wells and increase in the wells depth. In general, in Iran, electrical energy used in agriculture is produced mainly from non-renewable sources, especially fossil fuels. Also, the non-renewable sources are still the main fuel source of power plants. In similar study on wheat farms of New Zealand, Safa et al. (2011) reported that electricity

use depends on several factors such as irrigation system, depth of well, and soil type and it may even change into different years with different precipitation amounts.

In this study, the amount of chemical fertilizers used for cotton growing were as 4860.47 MJ ha⁻¹ in Gorgan and 2584.52 MJ ha⁻¹ in Darab (Table 5). According to the data collected from all surveyed cotton fields, energy input of nitrogen fertilizer has the largest share among other chemical fertilizers. It indicates that the average chemical fertilizers rates is 72.8 kg N ha⁻¹ in Darab and 87.6 kg N ha⁻¹ in Gorgan. Related values for phosphorus fertilizer were as 43.7 kg P₂O₅ ha⁻¹ for Darab and 46 kg P₂O₅ ha⁻¹ for Gorgan. The high amount of energy needed for the manufacture of fertilizers, in particular nitrogen. In this regard, Yaldiz et al. (1993) pointed out that fertilizers and irrigation energies dominate the energy consumption in Turkish cotton production systems. Canakci et al. (2005) noted that the share of energy consumption of fertilizers was 54.1% in the studied fields. In these studied fields, reduction of some inputs such as fuels, chemical fertilizers and irrigation water are promising managerial options to improve energy consumption in cotton production systems. In the other hands, the cotton

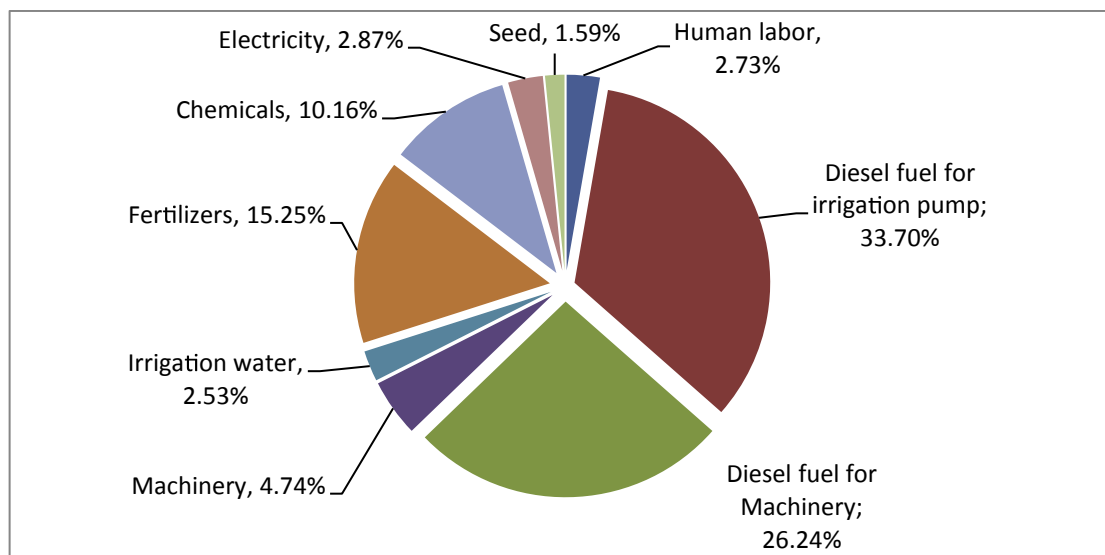


Fig. 2. Share of inputs in energy consumption for cotton cropping in Gorgan region, Iran.

production will be more efficient in two studied regions by increasing the yield or decreasing the afore mentioned inputs.

Table 5 also demonstrates that seed input has a little share of total energy inputs. There is a significant difference between two regions with respect to seed input energy. These amounts were calculated on average as $515.66 \text{ MJ ha}^{-1}$ in Gorgan and $495.60 \text{ MJ ha}^{-1}$ in Darab. Principally, the qualified cotton seed will help to reduce the eventuality of pests and weed infestation, the energy consumption of weeding and chemical inputs and increase the crop yield (Pishgar-Komleh et al., 2011).

Results of surveyed cotton fields indicated that 867.70 h (in Gorgan) and 982.26 h (in Darab) of human labor (from family members of farmers or seasonal labors sources) required per hectare in the cotton fields (Table 3). The majority of human labor in the cotton farms was used for harvesting, weeding, and planting operations. Similar results have been reported in the literature implying that the energy input of human labor has a little share of total energy input in agricultural production (Zahedi and Eshghizadeh, 2014).

Also, based on the evaluation of collected data, the average machinery required in cotton production of Gorgan was $1534.27 \text{ MJ ha}^{-1}$. Total machinery power was involved in seedbed preparation (plowing, disking and land leveling). Results of Singh et al. (2000) revealed that seedbed preparation, irrigation and weeding consumed about 70% of the total energy input for the cotton production in Punjab. Canakci et al. (2005) reported that from all field operations for wheat production, seedbed preparation required the maximum energy followed by harvesting. Alhajj-Ali et al. (2013) indicated that the conservation tillage of durum wheat fields in southern Italy can be used to maintain or increase productivity with only a minimum energy input. In general, there was no significant change regarding the chemicals in two regions. Weed and insect control consume relatively high amounts of energy due mainly to the embodied energy of pesticides (Table 5).

In the cotton fields of Darab, after fossil fuels, irrigation and fertilizers played the most important role in sequestered energy (Table 5). It is evident that any attempt to reduce energy inputs should begin by seeking to reduce these inputs by pre-season or within season managements. Irrigation input reduction may be achieved by reducing the amounts of irrigation water, using alternative irrigation systems or improving irrigation efficiency and

pumping efficiency. Cotton yield depends not only on the water supplied, but also on many other factors such as planting date, variety, soil fertility and climatic conditions during spring and summer, in the way that there was a strong correlation between all these factors. Irrigation is an important issue of intensive cotton production in Iran. Cotton was irrigated by furrow method and average of 10.8 times per season in Darab. The share of irrigation water energy from the total energy inputs in Gorgan and Darab was 20.41% and 2.53%, respectively. Also, the energy of irrigation water from total input energy constituted 20.41% in Gorgan and 2.53% in Darab (Figs. 1 and 2). In these regions, furrow irrigation is not efficient method, instead of, it is recommended that modern irrigation systems used in these fields.

The cotton yield from this sequestered energy was as $2887.8 \text{ kg ha}^{-1}$ ($34,076.04 \text{ MJ ha}^{-1}$) in Darab and $2985.7 \text{ kg ha}^{-1}$ ($35,231.26 \text{ MJ ha}^{-1}$) in Gorgan (Table 5). In the cotton fields of Gorgan, the average of the yield was higher than Darab, may be due to variety or more organic matter in soil or more favorable weather conditions such as more precipitation rate. A total energy input of 52,507.8 (Zahedi et al., 2015), 49,736 (Yilmaz et al., 2005) and 34,891.2 (Canakci et al., 2005) were also reported for cotton production in different regions.

3.2. Energy indicators

The ratio of energy of output of the production to input energy is termed as energy ratio or energy use efficiency (Hadi, 2006). Energy use efficiency was calculated as 0.942 in Darab and 1.106 in Gorgan (Table 6). The value of this index for both regions indicated that cotton fields are not efficient in the use of energy in cotton production and this indicator can be improved by increasing cotton

Table 6
Energy indicators in cotton production in Darab and Gorgan regions, Iran.

Index	Township	Gorgan
	Darab	
Energy use efficiency	0.942	1.106
Energy productivity (kg MJ^{-1})	0.079	0.0937
Specific energy (MJ kg^{-1})	12.530	10.670
Net energy (MJ ha^{-1})	−2112.990	3370.660

and or by decreasing the inputs consumption. Dagistan et al. (2009) reported that the energy use efficiency of cotton farms in Turkey is 2.36, but Yilmaz et al. (2005) reported that the energy use efficiency in cotton farms was 0.74. Zahedi and Eshghizadeh (2014) reported that energy ratio of cotton production in Isfahan, central province of Iran with an arid climate, was 0.7. These differences between the findings of this study and the results of Zahedi et al. (2015) could be mainly attributed to the climatic condition of fields and site-specific nature of this index. In an arid region, the energy use efficiency was found as 1.70 in wheat–silage corn, 1.65 for barley-grain corn, and 1.03 for barley-rice double cropping systems (Zahedi et al., 2015). Principally, environmental constraints such as unsuitable climate and infertile soils can significantly reduce yield and its related indicators, especially energy use efficiency (Rahman and Hasan, 2014).

The specific energy was 12.53 MJ kg⁻¹ for Darab, while 10.67 MJ kg⁻¹ for Gorgan fields. In Turkey, this indicator was estimated as 11.24 for cotton, 5.24 for wheat, and 3.88 for maize (Canakci et al., 2005). The rate of net energy in the Darab (–2112.99 MJ ha⁻¹) was less than Gorgan (3370.66 MJ ha⁻¹). Also, this energy index was negative (less than zero) in Darab. Improving energy use efficiency and using new technologies can enhance energy conservation on these fields. Net energy increases as long as the energy output per unit energy input increases. It should be maximum when the availability of arable land is the limiting factor of plant production or when the land is used to produce renewable energy (Kazemi et al., 2015; Hulsbergen et al., 2001). The average energy productivity of cotton was as 0.0798 kg MJ⁻¹ in Darab and 0.0937 kg MJ⁻¹ in Gorgan. This means that 0.0798 (in Darab) and 0.0937 (in Gorgan) units of output were obtained per unit energy. Zahedi and Eshghizadeh (2014) reported that the energy productivity was reported as 0.10 kg MJ⁻¹ for cotton production systems in Isfahan, central province of Iran.

Total mean energy input as direct, indirect, renewable and non-renewable types is given in Table 7. Results showed that cotton consumed more indirect energy (68.08% and 70.56%) than direct energy (31.92% and 29.44%) and more non-renewable energy (93.11% and 75.45%) than renewable energy (6.89% and 24.54%) at both regions. The total energy input in faba bean fields of Golestan province was beclassified as direct energy (18.77%), indirect energy (81.23%) and renewable energy (25.28%) and non-renewable energy (74.72%) (Kazemi et al., 2015). Principally, the high consumption of non-renewable energies decreases the energy use efficiency in production systems, since production of chemicals and using of machinery as the major indices of common systems need high amounts of energy (Pimentel et al., 2005). In another study, the shares of indirect and non-renewable energies were higher than other indices (Zahedi et al., 2015). In Turkey, as one of the major cotton producing countries, the ratio of indirect energy was higher than that of direct energy and the rate of non-renewable energy was greater than that of renewable energy consumption (Yilmaz et al., 2005). In contrast to these results, Moore (2010) believes that to achieve a sustainable system, the indicators of energy use efficiency and renewable energy should be increased. This issue is crucially significant from the ecological viewpoint, because the

source of non-renewable with the surveyed region and the results of long-term studies in Iran show that agriculture section is very much dependent on non-renewable energies (Taheri-Garavand et al., 2010). For instance, about 0.2% of total electricity in Iran was supplied from renewable sources (Kazemi et al., 2015).

4. Conclusions

Today, the modern farming has become very energy intensive. There is a great need for a balance between the use and availability of energy, especially in the agricultural sector. An important aspect of this investigation was the comparison of energy use efficiency of cotton production in different regions of Iran. In this research, cotton production compared by energy indicators and based on different climatic condition, agronomic managements, energy inputs and cotton varieties. The results of the present study reveal a clear variation of energy consumption pattern between Darab (as arid region) and Gorgan (as sub-humid region) cotton fields. There is a significant difference between the two regions in respect to input energy, climatic conditions, and agronomic managements. The results of this study revealed that cotton production depends mainly on diesel fuel input. Therefore, it is necessary to focus more on diesel fuel consumption than other factors to effectively reduce energy consumption in cotton cropping systems. In this study, energy use efficiency was calculated as 0.942 in Darab and 1.106 in Gorgan. Also, energy productivity index implies that lower units of output was obtained per unit energy in Darab region. Temporal depreciation of machinery, use of irrigation pumps with low efficiency and low cost of electricity, use of electrified wells and increase in the wells depth and high consumption of diesel fuels are the most important reasons for low values of this indicator in Iran. These results revealed that there was a huge potential for improving energy efficiency of cotton production in the studied regions, including consumption of non-renewable energies in cotton fields. It is shown that seed, human labor and agrochemicals were the least demanding energy inputs for cotton production in Darab and Gorgan. In this study, the shares of direct, indirect, renewable and non-renewable energies were the same in two sites. The difference between the RE and NRE forms was related to more consumption of chemicals and machinery energies in Gorgan cotton fields than Darab region. These results are related to the higher relative humidity and precipitation in Gorgan. Accordingly, the pests and pathogens have high presence and their control requires to more consumption of chemicals. Also, in this condition, higher energy consumption is needed for tillage operations. The high amounts of fuel consumption could be affected on the share of indirect and non-renewable energy forms. To approach to sustainable development, our viewpoint on the assessment of cropping patterns should have a tendency to those inputs which will not affect future generation's welfare and income. It is undeniable that lack of renewable inputs will force us to find alternative energy inputs. This is not the case pending when we could be achieved and provided these sources throughout the world. Inputs use optimization, especially in the agricultural systems could be considered as a positive case to direct world in a safe and healthy atmosphere.

Table 7

Total energy input in the form of direct, indirect, renewable and non-renewable energy source for cotton production in Darab and Gorgan regions, Iran.

Item	Percentage from total energy	Consumed energy (MJ ha ⁻¹)	
		(Gorgan)	(Darab)
Direct energy	68.08	21712.4	25536.19
Indirect energy	31.92	10178.2	12312.09
Renewable energy	6.89	2199.36	8880.71
Non-renewable energy	93.11	29691.24	28967.57

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