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Energy Use Efficiency and Economical Analysis in Cotton Production System in an Arid Region: A Case Study for Isfahan Province, Iran

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ABSTRACT: The objective of this survey was to evaluate the energy consumption and the economic analysis of cotton production in Esfahan province of Iran. For this purpose, data were selected from 47 cotton growers using a face-to-face questionnaire. The results indicate that cotton production consumed a total energy of 52507.8 MJ ha^{-1}. Among sources of input energy, the contribution of energy related to diesel fuel (47%) was highest, followed by chemical fertilizers (20%) and water for irrigation (12%). The shares of direct and non renewable energy were 68.3% and 77.7%, respectively. The impacts of indirect and non-renewable energy on cotton yield were higher than those of direct and renewable energy. Energy use efficiency, specific energy, energy productivity, energy intensiveness, and net energy were 0.7, 19.2 MJ^{-1} kg, 0.10 kg MJ^{-1}, 27.2 MJ^{-1} \$ $^{-1}$, -15625.2 MJ^{-1}ha^{-1}, respectively. Total cost of cotton production was 1927.9 \$ ha^{-1}. About 67% of the cost of production was variable costs, while 33% was fixed costs. The benefit to cost ratio was estimated 1.22. It is suggested that efforts to increase energy efficiency of cotton production in the investigated area should primarily focus on proper use of fertilizers and irrigation systems and also on saving diesel fuel by improving machinery operating performance.

Keywords: economical assessment; energy consumption; energy intensiveness; energy productivity
JEL Classifications: O13; Q12; Q43

1. Introduction

Cotton is a valuable product traded globally as well as an important employment creator. World widely, more than 100 million farming units are directly involved in cotton production, with many more in its complementary activities (FAO, 2005). Major cotton producers and its international traders are China, India, the USA, the EU and central Asian and African states. Cotton production in Iran is about 300000 t, and the cultivated area was about 122000 ha in 2009, from which 4% is produced in Esfahan Province (Ministry of Agriculture of Iran, 2010). Cotton production in this province is a source of income and employment for many rural families especially in the areas where saline soils restrict the production of some other crops.

Population growth and enhancing food demands accompanied with limited supply of arable lands has led to a significant increase of energy use in agriculture. Intensive use of support energy inputs due to rising food production has caused considerable environment problems such as water and air pollution and growing atmospheric carbon dioxide concentrations. Effective application of agricultural techniques and efficient use of support inputs can minimize environmental problems and in consequence promote sustainable agricultural intensification (Erdal et al., 2007). Energy input and output are two main factors for determining the energy efficiency and environmental impact of crop production (Stout, 1990). Energy utilization and output differs among crops, production systems and intensity of management. Energy productivity, as the quality of a given agricultural product per unit of energy required for its production, is a critical indicator for more efficient use of energy. The analysis of energy is therefore necessary to decide on methods for minimizing the energy inputs and enhancing the energy productivity (Fluck and Baird, 1982).

Energy requirements in a farm unit can be separated into direct and indirect energy, either of these sections could also be classified as renewable or non-renewable. Direct energy is mainly used for land preparation, planting, irrigation, applying chemicals, harvesting and transporting products to and from market (Singh, 2004). Indirect energy is used for producing pesticides and fertilizers (Ozkan et al. 2004). Renewable energy includes human labor, irrigation water, seeds and non-chemical fertilizers while non-renewable energy is consist of fossil fuels, pesticides, chemical fertilizers and machinery (Mohammadi et al., 2008).

Although numerous investigations have been conducted on energy use of different crop production systems (Erdal et al., 2007; Mohammadi et al., 2008; Ozkan et al., 2004; Mohammadi and Omid, 2010; Unakitan et al. 2010), only a few studies have focused on the energy and economical analysis of cotton production (Tsatsarelis, 1991; Canakci et al., 2005; Yilmaz et al., 2005). In the study of Yilmaz et al. (2005) in Turkey, the cotton production consumed a total energy of 49.73 $GJha^{-1}$ and the output-input energy ratio and energy productivity were 0.74 and 0.06 kg of cotton MJ^{-1} respectively. The most important items in terms of energy consumption were diesel, fertilizer and machinery. Tsatsarelis (1991) reported that the total amount of sequestrated energy for cotton production in central Greece was about 82600 MJ/ha with irrigation and fertilizers as major inputs. In Iran, energy inputs and crop yield relationship has been investigated for wheat (Ghorbani et al., 2011), barley (Ghasemi Mobtaker et al., 2010), potato (Rajabi Hamedani et al., 2011), sugarcane (Karimi et al 2008), cucumber (Mohammadi and Omid 2010), canola (Sheikh Davoodi and Houshyar 2009; Taheri-Garavand et al., 2010) and sunflower (Sheikh Davoodi and Houshyar 2009), apple (Rafiee et al. 2010), However, no information is available on the energy analysis of cotton production under the agricultural situation of Iran.

The aims of this study were (i) to determine the total amount of input-output energy used in cotton production, (ii) to investigate energy use efficiency and economical analysis, and (iii) to evaluate the relationship between inputs and output to develop an econometric model for cotton production in Esfahan province of Iran.

2. Material and Methods

Data were collected from 47 cotton growers in Esfahan province located almost in the center of Iran, within $30^{0}43'$ and $34^{0}27'$ north latitude and $49^{0}36'$ and $55^{0}31'$ east longitude, using a face-to-face questionnaire in October 2010. In addition to data provided by the survey, the data from earlier studies of related organizations, Food and Agricultural Organization (FAO) and Iranian Ministry of Agriculture, were also used in this study. A random sampling of farms was done and the sample size was calculated using following Equation (Unakitan et al., 2010):

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

where n is the required sample size, N is population volume, S is standard deviation, S_X is standard deviation of sample mean ($S_X = d/z$) , d, the permissible error in the sample size, was defined to be 10% of the mean for a 95% confidence interval and z is the reliability coefficient (1.96, which represents the 95% reliability).

Energy use efficiency of the cropping system was evaluated by the energy ratio between output and input. The energy input values for human labor, machinery, diesel fuel, fertilizers, pesticides and seed and the energy output value of cotton yield were used to estimate the energy ratio (Alam et al., 2005). Energy equivalents of the inputs used in cotton production are shown in Table 1. The sources of mechanical energy, included tractors and diesel fuel, was computed on the basis of total fuel consumption ($l\ ha^{-1}$) in different operations. The energy consumption was calculated by using conversion factors (1l diesel=56.3 MJ ha^{-1}) and was expressed in MJ ha^{-1} (Tsatsarelis, 1991; Erdal 2007).

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

Particulars	Unit	Energy equivalent (MJ $unit^{-1}$)	Ref.
A. Inputs			
1. Human labor	h	1.95	(22)
2. Machinery	h	62.70	(21,23,24)
3. Diesel fuel	l	56.31	(22)
4. Total Chemical fertilizers			
(a) Nitrogen (N)	kg	75.46	(22)
(b) Phosphate (P2O5)	kg	13.07	(22)
(c) Potassium (K2O)	kg	11.15	(25,26,27)
(d) Micro elements	kg	120.00	
5. Chemicals			
(a) Herbicides	kg	238.30	(22,28)
(b) Pesticides	l	101.20	(22,28)
(c) Fungicides	kg	216.00	(22)
6. Farmyard manure	kg	0.30	
7. Electricity	kWh	3.6	(22)
8. Water for irrigation	m^3	1.02	(18,29)
9. Seed	kg	11.8	(22)
B. Outputs			
1. Cotton grain yield	kg	11.8	(28)
2. Cotton straw yield	kg	2.25	(28)

Based on the energy equivalents of inputs and output (Table 1), energy use efficiency, energy productivity, specific energy, energy intensiveness and net energy were calculated for cotton production by following equations (Banaeian et al. 2010; Ghorbani et al. 2011):

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

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

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

$$\text{Energy intesiveness} = \frac{Energy\ \text{input}\ (MJ\ ha^{-1})}{\text{cost of cultivation}\ (\$\ ha^{-1})} \qquad (5)$$

Net energy = Energy output (MJ ha^{-1}) - Energy Input (MJ ha^{-1}) (6)

Indirect energy included energy embodied in seeds, chemical fertilizers, herbicides, pesticides, fungicides, farmyard manure and machinery while direct energy covered human labor, diesel, electricity and water for irrigation that were used in cotton production. Non-renewable energy included diesel, electricity, chemical fertilizers, herbicides; pesticides, fungicides and machinery, and renewable energy consisted of human labor, farmyard manure, seed and water for irrigation.

Output-input analysis was also applied for economic benefits analysis. The process was similar to the energy balance analysis. One hectare of experimental field was the basic unit for analysis. The cost of cotton production was consisting of fixed and variable costs. The fixed costs included land value, water value and fundamentals and the variable costs comprised current costs such as chemicals, fuel, human labor and electricity. The economic output of cotton included fiber and seed yield. All prices of inputs and outputs were market prices (2010 average price). The economic analysis of cotton production focused on gross and net return, gross value of production, total cost of production, benefit to cost ratio and productivity that were calculated by following equations (Banaeian et al., 2010; Ghorbani et al., 2011):

Gross return = gross value of production ($ ha^{-1}) - variable cost of production ($ ha^{-1}) (7)

Gross value of production = cotton yield (kg ha^{-1}) × cotton price ($ ha^{-1}) (8)

Net return = gross value of production ($ ha^{-1}) - total cost of production ($ ha^{-1}) (9)

Total cost of production = variable cost of production ($ ha^{-1}) + fixed cost of production ($ ha^{-1}) (10)

Benefit to cost ratio = gross value of production ($ ha^{-1}) / total cost of production ($ ha^{-1}) (11)

Productivity = cotton yield (kg ha^{-1}) / total cost of production ($ ha^{-1}) (12)

In order to analyze the relationship between energy inputs and energy output a production function was applied which is suggested by Cobb-Douglas. The function has also been used by other investigators (Singh et al. 2004; Hatirli et al. 2006; Mohammadi and Omid 2010). Cobb-Douglas function is expressed as follows:

$$Y = f(x)\exp(u) \quad (13)$$

which can be further written as:

$$\ln Y_i = a + \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \quad i = 1, 2, \ldots, n \quad (14)$$

where Y_i indicates the yield of the i'th farmer, X_{ij} is the vector of inputs used in the production process, a is a constant, α_j represents coefficients of inputs which are estimated from the model and e_i is the error term. Eq. (14) is expanded in accordance with the assumption that the yield is a function of energy inputs:

$$lnY_i = \alpha_0 + \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \alpha_8 lnX_8 + \alpha_9 lnX_9 + e_i$$
(15)

Where X_i (I = 1, 2, …, 9) stand for human labour (X_1), machinery (X_2), diesel fuel (X_3), total chemical fertilizer (X_4), chemicals (X_5), farmyard manure (X_6), electricity (X_7), water for irrigation (X_8) and seed (X_9).

With respect to this pattern, by using (15), we evaluated the impact of the energy of each input as well as the impact of direct (DE) and indirect (IDE), renewable (RE) and nonrenewable (NRE) energies on output energy. For this aim, Cobb-Douglas function was determined in the following forms:

$$lnY_i = \beta_0 + \beta_1 ln\, DE + \beta_2 ln\, IDE + e_i \quad (16)$$

$$lnY_i = \gamma_0 + \gamma_1 ln\, RE + \gamma_2 ln\, NRE + e_i \quad (17)$$

where Y_i is the i'th farm's yield, β_i and γ_i are the coefficient of exogenous variables. Eqs. (15)-(17) were estimated using ordinary least square technique. Basic information on energy inputs and cotton yields were entered into Excel's spreadsheet and Shazam 9.0 software program (Mohammadi and Omid, 2010).

3. Results and Discussion

3.1. Management practices

Agronomic practices which were used in the investigated farms are shown in Table 2. According to the results, average farm size was 1.4 ha ranged from 5 to 0.5 ha. All cotton farms in the area were irrigated. Land preparation and soil tillage, performed in May or early June, were generally done by a Massey Ferguson 28,575 hp tractor with using moldboard plow and disc harrows. The planting period was June. Irrigation operations were done 10.2 times during period from June to October. Pumped irrigation was mostly done by using diesel engine to utilize underground water. Average number of spraying and harvesting were 1.5 and 2.7 times, respectively. Harvesting period was from mid October to late November. Cotton was hand harvested either by family members or by local workers. Other crops grown in the farms besides cotton, depending on water availability and growing conditions, were wheat, maize, barley, alfalfa, clover, safflower, sunflower, sugar beet, potato and tomato.

Table 2. Management practices in cotton production system.

Practices/operations	**Cotton**
Names of varieties	Native Cultivars
Land preparation tractor used: 285 MF 75 hp	Moldboard plow, Disc harrows, Land leveller
Land preparation period	May-June
Average tilling number	2.2±0.5
Planting period	June
Fertilization period (Before planting)	May
Fertilization period (Top dressing)	___
Average number of fertilization	1.2±0.9
Irrigation period	June-October
Average number of irrigation	10.2±1.3
Spraying period	August
Average number of spraying	1.5±0.8
Harvesting period	November
Average number of harvesting	2.7±0.3

3.2. Analysis of input-output energy

The input and output energy of cotton production and their energy equivalents are presented in Table 3. The results show that about 863 h human labor, 25 h machinery, 495 L diesel fuel, 237 kg chemical fertilizers (including 115 kg nitrogen, 69 kg phosphorus and 50 kg potassium) and 5200 kg farmyard manure were used per hectare cotton production. Yilmaz et al. (2005) reported that about 740 h of human labor, 29 h of machinery, 275 l of diesel fuel, and 340 kg chemical fertilizers were used for cotton production in Hatay province of Turkey.

Total energy used in the investigated farms was 52507.8 MJ ha^{-1} most of which was related to diesel fuel (47.4%), followed by chemical fertilizers (19.8%) particularly nitrogen (16.5%), and irrigation water (12.4%). The contribution of energy from electricity, seed, human labor, farmyard manure and chemicals were 5.3%, 3.7%, 3.2%, 3.0% and 2.3%, respectively. Total energy input of 82600 (Tsatsarelis, 1991), 49736.9 (Yilmaz et al. 2005), and 34891.2 (Canakci et al., 2005) were also reported for cotton production. In the study of Canakci et al. (2005) chemical fertilizers (50.7%) and diesel fuel (33.9%) were also the main contributors of input energy in cotton production. The results of this study indicate that efforts to improve energy use of cotton production in the surveyed area should primarily be focused on diesel fuel, chemical fertilizers and irrigation water. Choosing suitable methods for fertilizer application as well as employment of new irrigation systems may decrease energy consumption in these portions. It is also suggested to save diesel fuel through using electricity for water extraction and improving machinery operating performance (Mohammadi and Omid, 2010).

The average straw and grain yield were 2033 and 2738.2 kg ha^{-1}, respectively, containing a total energy of 36882.6 MJ ha^{-1}. Total energy output was reported to be 36729.9 by Yilmaz et al. (2005) and 46221 MJ ha^{-1} by Erdal et al. (2007) for per hectare cotton production.

Energy input-output relationships are shown in Table 4. The calculated energy use efficiency of 0.70 shows that cotton production in this area is not fairly efficient in terms of energy consumption. Energy ratio of 0.74 (Yilmaz et al. 2005), 2.36 (Dagistan et al. 2009) and 4.8 (Canakci et al. 2005) were also reported for cotton production. In comparison, energy ratio has been reported to be 1.25 for potato (Mohammadi et al. 2008), 2.86 for barley (Ghasemi Mobtaker et al., 2010), 3.38 for dryland wheat, 1.44 for irrigated wheat (Ghorbani et al., 2011), 3.8 for maize and 1.5 for sesame (Canakci et al. 2005). In this study the energy intensiveness, specific energy, energy productivity and net energy were 27.2 MJ \$$^{-1}$, 19.2 MJ kg^{-1}, 0.1 kg MJ^{-1} and -15625.2 MJ ha^{-1}, respectively. These values in the study of Dagistan et al. (2009) were 8.71 MJ \$$^{-1}$, 4.99 MJ kg^{-1}, 0.20 kg MJ^{-1} and 26663 MJ ha^{-1}, respectively. Energy productivity of 0.06 kg MJ^{-1} (Yilmaz et al. 2005) and specific energy of 11.24 MJ kg^{-1} (Canakci et al., 2005) were also reported for cotton production. Energy input-output relationships have been reported for canola (Unakitan et al., 2010; Mousavi-Avval et al., 2011a), potato (Rajabi Hamedani et al. 2011; Mohammadi et al., 2008), sunflower (Sheikh Davoodi and Hushyar, 2009), Wheat and maize (Canakci et al., 2005), alfalfa (Ghasemi Mobtaker et al., 2011), and Sugar beet (Dagistan et al., 2009).

Total average energy inputs in the forms of direct, indirect, renewable and nonrenewable are presented in Table 4. Most of input energy was in the form of direct (68.3%) and non-renewable (77.7%) energy. Similar results were obtained for cotton (Yilmaz et al. 2007), canola (Unakitan et al. 2010), irrigated and dryland wheat (Ghorbani et al., 2011), and potato (Mohammadi et al., 2008).

Table 3. Energy consumption and energy input-output relationship in cotton production system

Energy	**Quantity per unit area (ha)**	**Total energy equivalent (MJ)**	**Percentage of total energy input (%)**
Input			
1. Human labor (h)	863.4	1683.7	3.2
2. Machinery (h)	25.2	1565.4	3.0
3. Diesel fuel (l)	495.1	24863.0	47.4
4. Total chemical fertilizers (kg)	236.8	10401.2	19.8
(a) Nitrogen	115.2	8677.9	16.5
(b) Phosphate (P2O5)	69.1	901.8	1.7
(c) Potassium (K2O)	50.3	557.5	1.1
(d) Micro elements	2.2	264.0	0.5
5. Chemicals (kg)	5.9	1174.8	2.3
(a) Herbicides	3.3	785.4	1.5
(b) Pesticides	1.5	151.8	0.3
(c) Fungicides	1.1	237.6	0.5
6. Farmyard manure (kg)	5200.4	1560.0	3.0
6. Electricity (KWH)	778.0	2800.8	5.3
7. Irrigation water (m3)	6390.0	6517.8	12.4
Seed (kg)	164.5	1941.1	3.7
Total energy input (MJ)		52507.8	100.00
Outputs			
Cotton grain yield (kg)	2738.2	32308.4	87.6
Cotton straw yield (kg)	2033.1	4574.2	12.4
Total energy output (MJ)		36882.6	

Table 4. Energy input-output ratio in cotton production system.

Items	**Unit**	**Cotton**
Energy use efficiency	-	0.7
Energy intensiveness	MJ $-1	27.2
Specific energy	MJ kg-1	19.2
Energy productivity	kg MJ-1	0.1
Net energy	MJ ha-1	-15625.2
Direct energy[b]	MJ ha-1	35865.3 (68.3)[a]
Indirect energy[c]	MJ ha-1	16642.5 (31.7)
Renewable energy[d]	MJ ha-1	11702.6 (22.3)
Non-renewable energy[e]	MJ ha-1	40805.3 (77.7)
Total energy input	MJ ha-1	52507.8 (100%)

a: Indicate percentage of total energy input.
b: Indicates human labor, diesel, electricity and water.
c: Indicates seeds, farmyard manure, chemical fertilizers, herbicides, pesticides, fungicides and machinery.
d: Indicates human labor, seeds and water, farmyard manure.
e: Indicates diesel, electricity, chemical fertilizers, herbicides, pesticides, fungicides and machinery.

3.3. Economic analysis of cotton production

The total cost of cotton production, the gross value of production and the main economic indicators are presented in Table 5. Total cost and gross values were 1927.93 and 2359.21 \$ ha^{-1}, respectively. About 67% of the total cost was variable cost and the remaining was fixed cost. The benefit to cost ratio was 1.22 and the net return was 431.29 \$ ha^{-1}, indicating that cotton production in this area not only consumes a considerable amount of energy but also is a low-profitable agricultural operation. In comparison, the benefit to cost ratio has been reported to be 0.86 (Yilmaz et al. 2007) and 1.24 (Dagistan et al. 2009) for cotton, 2.09 for canola (Unakitan et al. 2010), 1.17 for sugar beet (Erdal et al. 2007), 1.88 for potato (Mohammadi et al., 2008), 1.97 for wheat (Ghorbani et al., 2011), and 1.27 for barley (Ghasemi Mobtaker et al., 2010).

Table 5. Economic analysis in cotton production system.

Cost and return components	Cotton (value)
Yield (kg ha^{-1})	2738.00
Sale price (\$ kg^{-1})	0.86
Gross value of production (\$ ha^{-1})	2359.21
Variable cost of production (\$ ha^{-1})	1291.26
Fixed cost of production (\$ ha^{-1})	636.67
Total cost of production (\$ ha^{-1})	1927.93
Total cost of production (\$ kg^{-1})	0.40
Total cost production (\$ MJ^{-1})	0.05
Gross return (\$ ha^{-1})	1067.96
Gross return (\$ kg^{-1})	0.22
Gross return (\$ MJ^{-1})	0.03
Net return (\$ ha^{-1})	431.29
Net return (\$ kg^{-1})	0.09
Net return (\$ MJ^{-1})	0.01
Benefit to cost ratio	1.22
Productivity (kg \$$^{-1}$)	1.42

3.4. Econometric model estimation of energy inputs for cotton production

The Cobb-Douglas production function was used to evaluate the relationship between energy inputs and yield. Cotton yield (endogenous variable) was assumed to be a function of human labor, machinery, diesel fuel, total chemical fertilizers, chemicals, farmyard manure, electricity, irrigation water and seed (exogenous variables). Autocorrelation was tested by using Durbin-Watson test (Hatirli et al., 2005). This test indicated that Durbin-Watson value was 1.98 for Eq. (15). It means that there was no autocorrelation in this model, implying that inputs were contributed to yield independently. The R^2 value was 0.94 for this Eq. Regression results for Eq. (15) are shown in Table 6.

With respect to Cobb-Douglass production function, it could be seen that the impacts of each one of the inputs differ in constitution production level. The results indicated that the impact of energy inputs can be assessed positive on yield except for seed energy. Human labor had the highest impact (0.29) on yield which was significant at 1% level of confidence. This indicates that each 1% increase in the energy from human labour would lead to 0.29% improve in cotton yield. Electricity was the second important input with 0.20 elasticity, followed by machinery and farmyard manure with elasticities of 0.17 and 0.15, respectively. Mohammadi and Omid (2010) found that human labour, irrigation water, fertilizer and machinery had the most significant impact on kiwifruit yield. In the study of Mohammadi and Omid (2010) the contribution of human labour and machinery was significant at 1% level on the greenhouse cucumber yield.

The regression coefficients for direct, indirect, renewable, and non-renewable energy, estimated by Eqs. (16) and (17), were statistically significant at 1% level of confidence (Table 7). The impacts of indirect and non-renewable energy on cotton yield were higher than those of direct and renewable energy. According to the analysis, with each 1% raise in the amount of direct, indirect, renewable and non-renewable energy, there would be 0.29, 0.53, 0.14 and 0.83 improve in cotton yield, respectively. In the study of Mohammadi and Omid, (2010) the impacts of indirect and non-renewable energy were also highest on cucumber yield. Durbin-Watson values were calculated as 1.96 and 1.87 for Eqs. (16) and (17). The corresponding R^2 values for these models were as 0.97 and 0.94, respectively.

Table 6. Econometric estimation results of Inputs.

Endogenous variable: yield Exogenous variables	Coefficient	t-ratio
Model 1: $LnY1 = \alpha 0 + a1LnX1 + a2LnX2 + a3LnX3 + a4LnX4 + a5LnX5 + a6LnX6 + a7LnX7 + a8LnX8 + a9LnX9 + ei$		
Constant	6.22	0.59^{ns}
Human labour	0.29	5.97**
Machinery	0.17	4.16*
Diesel fuel	0.05	0.56^{ns}
Total chemical fertilizer	0.11	1.35**
Chemicals	0.07	0.23^{ns}
Farmyard manure	0.15	3.19**
Electricity	0.20	2.58**
Water for irrigation	0.12	2.27*
Seed	-0.01	-0.39^{ns}
Durbin-Watson	1.98	
R2	0.94	
** Indicates significance at 1% level. * Indicates significance at 5% level.		

Table 7. Econometric estimation results of direct, indirect, renewable and non-renewable energy.

Endogenous variable: yield Exogenous variables	Coefficient	t-ratio
Model 2: $LnYi = \beta 0 + \beta 1Ln\ DE + \beta 2Ln\ IDE + ei$		
Constant	5.82	5.85*
Direct energy	0.29	4.12**
Indirect energy	0.53	6.87**
Durbin-Watson	1.96	
R2	0.97	
Model 3: $LnYi = \gamma 0 + \gamma 1Ln\ RE + \gamma 2Ln\ NRE + ei$		
Constant	6.22	6.18*
Renewable energy	0.14	3.22**
Non-renewable energy	0.83	7.16**
Durbin-Watson	1.87	
R2	0.94	
** Indicates significance at 1% level. * Indicates significance at 5% level.		

4. Conclusions

Cotton production in Esfahan province of Iran consumed a total energy of 52507.8 MJ ha^{-1}, which was mainly related to diesel fuel (47%), followed by chemical fertilizers (20%) and irrigation water (12%). Total energy output was 36882.6 MJ ha^{-1}. The energy use efficiency, energy intensiveness, specific energy, energy productivity, net energy and of cotton production system were 0.7, 27.2 MJ $\$^{-1}$, 19.2 MJ kg^{-1}, -15625.2 MJ ha^{-1} and 0.1 kg MJ^{-1}, respectively. The results indicate that cotton production in this area is not efficient enough in terms of energy consumption. Appropriate energy management should therefore be considered to avoid excess energy input consumption. This aim can be primarily achieved by reducing the use of diesel fuel, proper application of fertilizers and by employment of new irrigation systems. A saving in diesel fuel may be possible through using electricity for extraction of irrigation water and improving machine's operating performance. The benefit to cost ratio of 1.22 and net return of 431.29 \$ ha^{-1} indicated that cotton production was a low-profitable operation. However, the production of cotton in this area is one of major sources of income and employment for family members. Moreover, cotton accompanies with a few numbers of salt tolerant crops such as barley and sugar beet is cultivated in some of the agricultural areas of this province where saline soils restrict the production of many other profitable crops.

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