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Energy use Pattern and Application a Mathematical Model to Survey Energy Requirement for Wheat Production

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ABSTRACT: The objectives of this study were to determine the energy consumption and evaluation of relationship between inputs and output for wheat production in Karaj region, Iran. For this propose data were collected from 60 wheat farms using a face to face questionnaire. The results revealed that total energy input for wheat production was found to be 31188.25 MJ ha^{-1} that the share of non-renewable energy form (89%) was more than renewable energy form (11%). Electricity has the highest share by 38.25% followed by total fertilizers and diesel fuel. Energy use efficiency, energy productivity, and net energy were 3.03, 0.21 kg MJ^{-1}, and 65012.08 MJ ha^{-1}, respectively. The regression results revealed that the contribution of energy inputs on crop yield (except for diesel fuel energies) was significant. Machinery energy was the most significant input (0.798) which affects the output level. It indicates that a 1% increase in the energy machinery input led to 0.798% increase in yield in these circumstances. The results also showed the impacts of indirect and renewable energy on yield are negative. It was concluded that additional use of machinery, and increasing mechanization level, would result more yield in the area.

Keywords: Energy Use; Energy Efficiency; Cobb-Douglas; wheat

INTRODUCTION

Besides water, food, education, diseases and environmental issues, energy has become one of the main priorities of humankind during the last century. In developing countries, energy is the fundamental factor for population fulfillment and development purposes. Technology advancement and social-economic development are in debt of fossil fuel consumption and this fact that fossil fuel resources run out soon has become one of the main concerns of humankind (Hosseini *et al*., 2013). The need to increase food production has resulted in the increased consumption of energy and natural resources because farmers have little knowledge of or few incentives to use more energy efficient methods (Esengun *et al*., 2007).

It uses large quantities of locally available non-commercial inputs, such as seed, manure and animate energy, and commercial inputs directly and indirectly in the form of fuel, electricity, fertilizer, plant protection, chemicals, irrigation water and machinery. They all can be converted and stated in the form of energy units. Efficient use of energies helps to achieve increased production and productivity and contributes to the economy, profitability and competitiveness of agriculture sustainability in rural living. A significant objective in agricultural production is to decrease costs and increase yield. In this respect, the energy budget is important. Energy input-output analysis is usually used to evaluate the efficiency and environmental impacts of production systems. It is also used to compare the different production systems (Rafiee *et al*., 2010).

Several researches have been conducted on energy use in different agricultural crops (Esengun *et al*., 2007; Mohammadi *et al*., 2008; Rafiee *et al*., 2010; Mohammadshirazi *et al*., 2012).

In a research conducted in Spain, energy use and economic evaluation were considered for winter wheat, winter barley, spring barley and vetch production. The spring barley showed highest energy consumption since a larger number of tillage operations were required and a larger amount of herbicides for weed control (Hernanz *et al*., 1995).

Khan *et al.*, (2009) studied the energy inputs in wheat, rice and barley production for reducing the environmental footprint of food production in Australia. The results showed that barley crop seems more efficient in terms of energy and water use jointly. Heidari and Omid (2011) studied energy use patterns of major greenhouse vegetable productions in Iran and found that impact of human labor for cucumber and chemicals for tomato was significant at 1% levels. Pishgar-Komleh *et al*. (2012) determined energy consumption and CO_2 emissions of potato production in three different sizes of farms in Esfahan province, Iran. The result of this paper revealed total energy consumption and GHG emission in potato production are 47 GJ ha^{-1} and 993 kg CO_2 eq ha^{-1}, respectively. Sonietal. (2013) considered the energy use index and CO_2 emissions in agricultural production systems of North east Thailand. In this study, system efficiency, total energy input and corresponding CO_2 eq. emissions were estimated and compared for different crops. Soltani *et al.* (2013) analyze energy use and greenhouse gases (GHG) emissions in various wheat production scenarios in north eastern Iran. The results indicate that the seed bed preparation, sowing and applications of nitrogen fertilizer are the key factors which are related to energy use and GHG emissions.

Wheat (*Triticum aestivum* L.) is among the oldest and most extensively grown of all crops. It is a main cereal cultivated throughout the world along with rice, barley, maize, rye, sorghum, oats and millet. Nowadays, wheat cultivars have been developed for different qualities in accordance with the development of genetic recombination. Wheat is grown under irrigated as well as rain-fed conditions worldwide. Under rain-fed conditions the developing grains are frequently exposed to mild to severe stress at different stages of grain development (Kizilaslan, 2009). Rahman and Hasan (2014) estimated the productivity and energy efficiency of wheat farming in Bangladesh by applying a stochastic production frontier approach while accounting for the environmental constraints affecting production. Results showed that wheat farming is energy efficient with a net energy balance of 20,596 MJ per ha and energy ratio of 2.34. Environmental constraints such as a combination of unsuitable land, weed and pest attack, bad weather, planting delay and infertile soils significantly reduce wheat production and its energy efficiency. Environmental constraints account for a mean energy efficiency of 3 percentage points. Also results showed that mean technical efficiency is 88% thereby indicating that elimination of inefficiencies can increase wheat energy output by 12%. Farmers' education, access to agricultural information and training in wheat production significantly improves efficiency, whereas events such as a delay in planting and first fertilization significantly reduce it.

The present study investigated the energy consumption in wheat production in Karajregion. Also the relationship between energy inputs and yield was studied using Cobb-Douglas production function. Also in last part of study the relationship between energy form and yield was studied.

MATERIALS AND METHODS

The data were collected from 60wheat farms using a face to face questionnaire. The simple random sampling method was used to determine the survey volume as (Kizilaslan, 2009, Taghavifar and Mardani, 2015):

$$n = \frac{N(s\times t)^2}{(N-1)d^2+(s\times t)^2} \qquad \ldots(1)$$

where n is the required sample size; s, the standard deviation; t, the t value at 95% confidence limit (1.96); N, the number of holding in target population and d, the acceptable error (permissible error 5%), consequently calculated sample size in this study was 60.

The inputs used in the production of wheat were specified in order to calculate the energy equivalences in the study. The input energy was also divided into direct and indirect and renewable and non-renewable forms (Esengun *et al.*, 2007). Direct energy constituted of human labor, diesel fuel and electricity, whereas, indirect energy include chemical fertilizers, biocides, seed and machinery. Renewable energy consists of human labor and seed and non-renewable energy includes machinery, diesel fuel, chemical fertilizers and biocides. Inputs in wheat production were: human labor, machinery, diesel fuel, chemical fertilizers, biocides, seed and electricity and output was wheat. The units in Table 1 were used to calculate the energy equivalent of input.

The input and output were calculated per hectare and then, these input and output data were multiplied by the coefficient of energy equivalent. Following the calculation of energy input and output values, the energy indexes of wheat were calculated (Mandal *et al*., 2002; Mohammadi *et al*., 2008). These indexes are showed in table 2.

Table 1: Energy coefficients of different inputs and outputs used in agriculture production.

Inputs/Output	Units	Energy coefficients (MJ unit^{-1})	Reference
A. Inputs			
1) Human labor	h	1.96	Mohamadi *et al*., 2008; Beheshti Tabar *et al*., 2010
2) Machinery	h	62.7	Beheshti Tabar *et al*., 2010
3) Diesel fuel	L	56.31	Beheshti Tabar *et al*., 2010
4) Electricity	kWh	11.93	Mohammadi *et al*., 2014
5) Chemical fertilizers	kg		
a) Nitrogen (N)		66.14	Esengun *et al*., (2007); Mousavi-Avval *et al*., 2011
b) Phosphate (P_2O_5)		12.44	Esengun *et al*., (2007); Mousavi-Avval *et al*., 2011
c) Potassium (K_2O)		11.15	Esengun *et al*., (2007); Mousavi-Avval *et al*., 2011
6) Biocides	kg	120	Naderloo *et al.*, 2012
7) Seed	kg	14.7	
B. Output			
1) Wheat	kg	14.7	Beheshti Tabar *et al.*, 2010; Mohammadi *et al.*, 2014

Table 2: Indices of energy in Agriculture production (Mandal *et al*., 2002; Mohammadi *et al*., 2008, Amid *et al*, 2016, Kamali and Rasapoor, 2016).

Indicator	Definition	Unit	
Energy use efficiency	$\frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$	ratio	(2)
Energy productivity	$\frac{\text{Yield (kg/ha)}}{\text{Energy input (MJ/ha)}}$	kg/MJ	(3)
Specific energy	$\frac{\text{Energy input (MJ/ha)}}{\text{Yield (kg/ha)}}$	MJ/kg	(4)
Net energy gain	Energy output (MJ/ha) – Energy input (MJ/ha)	MJ/ha	(5)

In order to obtain a relationship between inputs and yield, a mathematical function needs to be specified. For this purpose Cobb-Douglas production function was selected; because it produced better results (yielded better estimates in terms of statistical significance and expected signs of parameters). The Cobb-Douglas production function is frequently used in both energy and economics studies to show the relationship between input factors and the level of production (Mohammadi and Omid, 2010). The Cobb-Douglas production function is expressed as:

$Y = f(x)exp(u)$ (6)

This function has been used by several authors to examine the relation between energy inputs and yield (Singh *et al*., 2004; Hatirli *et al*., 2006; Banaeian *et al*., 2011). The linear form of Eq. (6) can be written as:

$$ln\,Yi = \alpha_0 + \sum_{j=1}^{n} \alpha_j ln(x_{ij}) + e_i \quad _{i=1,2,3,...,n} \quad ...(7)$$

Where *Yi* denotes the yield level of the i'th farmer, *Xij* is the vector inputs used in the production process, α_0 is the constant term, α_j represents coefficients of inputs which are estimated from the model and e_i is the error term.

Using Eq. (7), the effect of energy inputs on wheat yield for each input was studied. On the other hand, wheat yield (endogenous variable) was assumed to be a function of human labor, diesel fuel, machinery, chemical fertilizers, biocides, electricity and seed energy (exogenous variables).

Similarly, the effect of direct, indirect, renewable and non-renewable energies on production was also studied. For this purpose, Cobb-Douglas function was determined as Eqs. (8) and (9):

$$\ln Yi = \beta_0 + \beta_1 \ln DE + \beta_2 \ln IDE + e_i \quad (8)$$

$$\ln Yi = \gamma_0 + \gamma_1 \ln RE + \gamma_1 \ln NRE + e_i \quad (9)$$

Where *Yi* is the *i*th farmer's yield, β_0 and γ_0 are the constant terms, β_i and γ_i are coefficients of exogenous variables and e_i is the error term. DE, IDE, RE and NRE are direct, indirect, renewable and non-renewable energies respectively. Basic information on energy inputs and wheat yield were entered into Excel's spreadsheet and simulated using SPSS 19 software.

RESULT AND DISCUSSION

As it can be seen in the Table 3, 100.86 h of labor, 126.65 l of diesel fuel and 17.67h of machinery per hectare are used for the production of wheat in Karaj region.

The total energy input for various processes in the wheat production was calculated to be 31188.25 MJ ha^{-1}. The average wheat output were found to be 6544.24 kg ha^{-1} in the enterprises that were analyzed. The energy equivalent of this is calculated as 96200.33MJha^{-1}. The highest energy input is provided by electrical (999.96 kWh) followed by chemical fertilizers. Electricity used for irrigation proposes. The shares of nitrogen and phosphorus energy were 85% and 15%, respectively, from the total energy of chemical fertilizer used. Kizilaslan, (2009) concluded that the input energy for wheat production in Kermanshah province of Iran were to be 16762.80 MJ ha^{-1}. Mohammadi *et al.* (2014) reported total energy input for wheat was to be 26.2 GJ ha^{-1} in north Iran. The inputs energy consumption was least for biocides (216.44 MJ ha^{-1}) which accounted for about 0.69% of the total energy consumption.

The share of wheat input can be seen in Fig. 1.With respect to the obtained results, the shares of energy consumption in wheat production consist of 38.25% electricity, 23.60%, fertilizer22.87% diesel fuel, 10.41% seed, 3.55% machinery, 0.69% biocides and 0.63% human labor.

Table 3: Amounts of inputs and output with their equivalent energy.

Inputs (unit)	Quantity per unit area (ha)	Total energy equivalent (MJ ha^{-1})
A. Inputs		
1. Human labor (h)	100.86	197.69
2. Diesel fuel (l)	126.65	7131.44
3. Machinery (kg)	17.67	1107.79
4. Chemical fertilizers (kg)	183.30	7358.80
5. Biocides (kg)	1.80	216.44
6. Electricity (kWh)	999.96	11929.56
7. Seed (m^3)	220.85	3246.53
Total energy input(MJ)	-	**31188.25**
B. Output		
1.Wheat(kg)	6544.24	**96200.33**

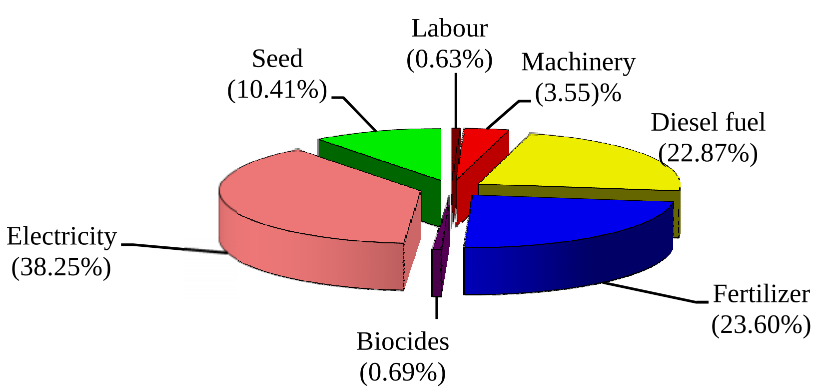

Fig.1. The share of energy inputs for wheat production.

Energy use efficiency, energy productivity, specific energy and net energy gain are listed in Table 4. Energy use efficiency in wheat production was calculated as 3.08, showing the inefficiency use of energy in the greenhouse button mushroom production. It is concluded that the energy use efficiency can be increased by raising the crop yield and or by decreasing energy input consumption. Several authors have been reported the energy use efficiency for different crops such as 1.16 for apple in Iran (Rafiee *et al.*, 2010), 0.32, 0.19, 0.31 and 0.23, for tomato, pepper, cucumber and eggplant greenhouse vegetables, respectively, in Turkey (Canakciand Akinci, 2006).

The average energy productivity of wheat was 0.21 kg MJ^{-1}. This means that 0.21 units output was obtained per unit energy. The specific energy and net energy gain of wheat production are 4.77 MJ kg^{-1} and 65012.08MJ ha^{-1}, respectively. Net energy gain is positive. Therefore, it can be concluded that in wheat production, energy is gain.

Also the distribution of inputs used in the production of wheat according to the direct, indirect, renewable and non-renewable energy groups, are given in Table 4.

It is seen that the ratios of direct energy resources are more than indirect energy (62% and 38%). Also the ratios of non-renewable energy are more than renewable energy (89% and 11%). Therefore, it is clear that wheat production depended on non-renewable energy consumption. Similar results have been reported by other researchers for different crop (Yilmaz *et al.*, 2005; Erdal *et al.*, 2007; Kizilaslan, 2009).

Table 4: Some energy parameters in wheat production.

Items	unit	Quantity
Energy use efficiency	-	3.08
Energy productivity	$kgMJ^{-1}$	0.21
Specific energy	$MJ\ kg^{-1}$	4.77
Net energy gain	$MJ\ ha^{-1}$	65012.08
Direct energy	$MJ\ ha^{-1}$	19258.69 (62%)
Indirect energy	$MJ\ ha^{-1}$	11929.56 (38%)
Renewable energy	$MJ\ ha^{-1}$	3444.22 (11%)
Non-renewable energy	$MJ\ ha^{-1}$	27744.03 (89%)
Total energy input	$MJ\ ha^{-1}$	3246.53 (100%)

In order to estimate the relationship between energy inputs and wheat yield, Cobb-Douglas production function was chosen and assessed using ordinary least square estimation technique. The R2 value was determined as 0.98 for Eq. 7, implying that around 0.98 of the variability in the energy inputs was explained by this model. Regression results for Eq. (7) were estimated and are shown in Table 5. As can be seen from Table 5, all exogenous variables had a positive impact and were found statistically significant on wheat yield (expected biocides and seed energy).

Machinery had the highest impact (0.798) among other inputs and significantly contributed on the productivity at 1% level. It indicates that a 1% increase in the energy machinery input led to 0.798% increase in yield in these circumstances. The second important input was found as electricity with 0.277 elasticity followed by human labor with 0.262 elasticity. Hatirli *et al.* (2006) developed an econometric model for greenhouse tomato production in Antalya province of Turkey and reported that human labor, chemical fertilizers, biocides, machinery and water energy were important inputs significantly contributed to yield. Tabatabaie *et al.* (2013) reported that human labor, gasoline, chemical fertilizers, farmyard manure, electricity and irrigation water had significant influence on prune yield.

Table 5: Econometric estimation results of inputs.

Endogenous variable: yield **Exogenous variables**	**Coefficient**	**t–ratio**
Eq7: $\ln Y_i=\alpha_1\ln X_1+\alpha_2\ln X_2+\alpha_3\ln X_3+\alpha_4\ln X_4+\alpha_5\ln X_5+\alpha_6\ln X_6+\alpha_7\ln X_7+e_i$		
Human labor	0.262	4.18*
Diesel fuel	0.226	1.12
Machinery	0. 798	3.42*
Chemical fertilizers	0.241	2.87**
Biocides	0.137	2.09**
Electricity	0.277	2.46**
Seed	0.308	2.06**
R^2	0.98	

* Indicates significance at 1% level.
** Indicates significance at 5% level.
*** Indicates significance at 10% level.

For the Eqs. (8) and (9) the statistic variables are presented in Table 6. As can be seen, regression coefficients of direct and renewable energies are significant at 1%probability level. The results showed the impacts of indirect and renewable energy on yield are negative. The assessed trends of direct and non-renewable energy were positive, showing the positive impacts on the output level. The R2 value was 0.99 for both these estimated models.

Table 6: Econometric estimation results of direct, indirect, renewable and non-renewable energies.

Endogenous variable: energy output Exogenous variables	Coefficient	t–ratio
Eq8: $\ln Y_i = \beta_1 \ln DE + \beta_2 \ln IDE + e_i$		
Direct energy	2.138	5.61*
Indirect energy	-1.035	-8.50**
R^2	0.99	
Eq9: $\ln Yi = \gamma 1 \ln RE + \gamma 2 \ln NRE + ei$		
Renewable energy	-0.751	-1.9*
Non-renewable energy	1.711	5.42***
R^2	0.99	

*Indicates significance at 1% level.
**Indicates significance at 5% level.
*** Indicates significance at 10% level.

It is concluded that impact of non-renewable energy was higher than that of renewable energy in wheat production. Impact of nonrenewable energy was 1.711 and had positive impact on wheat yield and impact of renewable energy was -0.751 and had negative impact on the wheat yield. Similar results have been reported in the literatures (Mohammadi and Omid, 2010; Unakitan *et al.,* 2010, Sefeedpari *et al*, 2013).

CONCLUSION

The aim of this study was to analyze impact of a particular energy input level on wheat yield in Karaj region, Iran. Based on the results of the investigations, the following conclusions were drawn:

Total energy input for wheat production was found to be 3246.53 MJ ha^{-1} and energy output was calculated as 96200.33 MJ ha^{-1}. Electricity showed as the most energy consuming input followed by chemical fertilizers and diesel fuel.

Energy use efficiency, energy productivity, and net energy were 3.03, 0.21 kg MJ^{-1}, and 65012.08 MJ ha^{-1}, respectively.

The ratios of non-renewable energy are more than renewable energy (89% and 11%). Therefore, it is clear that wheat production depended on non-renewable energy consumption.

The impact of energy inputs could have positive effect on yield (except for diesel fuel energies).

It was concluded that additional use of machinery, and increasing mechanization level, would result more yield in the area.

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