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Energy Requirements and Economic Analysis for Wheat Production in Iran

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ABSTRACT: The aims of this study were to estimate the amount of input and output energy per unit area and to make an economic analysis of wheat production in Shahreza, located in Esfahan province, Iran. A survey was conducted using a face to face questionnaire with 70 wheat producers. Results showed that the rate of water pumping energy input was higher than other inputs; this is due to deep wells of water resources and also high rate of water consumption for wheat production. Also, because of high total energy input, this study indicated that equivalent energy inputs, net energy gain, and energy ratio of wheat grain were 125.6 GJ/ha, -35.57 GJ/ha and 0.7 respectively. By referring to obtained coefficients from this research, the appropriate energy production function found to be a transcendental function.

Keywords: Energy efficiency, energy production function, transcendental function

INTRODUCTION

In modern world, food production for inhabitants, from first stage up to final consumption, relies on abundant energy. Tillage operations, crop planting, care and harvesting, processing, packaging and transportation need a lot of energy. Population growth rate in one hand and changes in consumption pattern on the other hand, especially in industrialized and developing countries increase per capita energy consumption. Increase in net production of agro ecosystems is contribution of high energy input which is being introduced to the system by human. Hence in most parts of the world, the ratio for output and input of total energy has been calculated for different agricultural ecosystems. In the future, man will be forced to produce more food while using less energy. Therefore promotion of new practices and optimal use of farm lands are some approaches for human food production in the future. So a method which can produce more while using lower quantity of energy will assume sustainable production and will be a success. Also energy productivity, which means unit quantity of crop production per unit amount of energy input, is one of the most important arguments towards development of sustainable agriculture. Higher the productivity ratio the faster would be the development of sustainable agriculture, conversely, the lower the ratio, results in faster destruction of environment and ecological instability (Mansourian, 2005). Energy consumptions in agriculture are categorized within two groups: direct, and indirect (Burhan *et al,* 2004). Direct energy include energies which are directly used in farm, such as electricity, gasoline, diesel fuel, and gas for irrigation water pumps, tractors, agricultural machines, heating of installations, and crop cooling. Indirect energies are those which are used out of farm to produce farm machinery and equipment, pesticides, chemical fertilizers, etc. which have to be used on farm or crop processing plants. Energy analysis is necessary for proper management of scarce resources to improve agricultural production, and it is through this analysis that the efficient and economic production activities can be distinguished (Chaudhary *et al,* 2006).

An approach to evaluate productivity of production factors, is devising a production function. The function is a mathematical relationship between inputs and outputs which can be expressed as follows:

$$y = f(x_1, x_2, x_3 ..., x_n) \qquad \text{C (1)}$$

Where y, is crop yield, and x_n is net input among production factors.

Production functions in agriculture can be determined through experiments and analysis of statistical data on agricultural units (Arsalanbod, 1987). Production functions can be expressed in different forms. One of the first attempts pursued by agricultural scientists to conform production function to farm data was published by Heady and Dillon (1988). Other production functions such as Cobb-Douglas, polynomial, transcendental and Trans-Log can be cited. In practice, generally three function forms of Cobb-Douglas, transcendental, and cubic polynomial are more frequently applied (Anonymous, 2008). Singh *et al* (2005) declared that wheat production yield is a function of variety type, mechanization level, amount of chemical fertilizers used, and other energy inputs, and they suggested the following quadratic equation:

$$y = \beta_1 + \beta_2 x^2 \qquad (2)$$

Values of coefficients, β_1 and β_2 can be obtained by least squares method. Singh *et al* (2004) aiming to study energy condition and to improve energy consumption in Punjab, showed relationships between wheat production and energy inputs were using Cobb-Douglas function. This function which is applicable to establish most appropriate relation between production, various energy inputs, and also area size of cropping, is as follows:

$$Ln(P_i) = a \sum_{i=1}^{i=k} \beta_j Ln(E_{ji}) + U_i \qquad (3)$$

Where α, P_i, E_{ji}, U_i, and β_j denote; intercept coefficient, total production of i^{th} farmer, j^{th} inputs of energies by i^{th} farmer to produce one unit of crop, error term, and regression coefficient of jth input respectively (Arsalanbod, 1987).

Pashaii *et al* (2001) reported the energy intensity of 0.8 MJ/kg for production of greenhouse tomatoes in Kermanshah, Iran. Mohammdian Sabour (2007) assessed net energy gain and energy efficiency for canola in Mashhad, Iran to be 1812 MJ ha^{-1}, and 1.03 respectively. Faraji (2007) reported the energy intensity of mechanized wheat production in Dasht-Abbas plain to be 0.206 MJ kg^{-1}.

Cetin and Vardar (2008) studied on differentiation of direct and indirect energy inputs in agro industrial production of tomatoes. Erdal *et al* (2007) have studied on energy consumption and economical analysis of sugar beet production. Damirjan *et al* (2006) studied the energy and economic analysis of sweet cherry production. Alam *et al* (2005) studied the energy flow in agriculture of Bangladesh for a period of 20 years. Satori *et al* (2005) studied the comparison of energy consumption on two farming system of conservation and organic in Italy.

In present research the energy analysis between output and inputs have been considered to drive a production function for wheat production in Shahreza.

MATERIALS AND METODS

This research was conducted in Shahreza township of Esfahan province, Iran. Information was collected through questionnaires completed by 70 randomly selected farmers, and also via interviews with experts and officials of agricultural services, cooperatives and agricultural authorities. Collected samples were divided into four cultivation size groups.

To compare the variables under discussion among the four groups, Duncan method was employed for comparison to the average. Data analysis was preformed, using SPSS 16 software. Also to estimate the production function of energy, Ln of variables values were calculated using the EXCEL software, and were entered to EVIEWS 5 software as primary data.

To show relationship between input and output values, regression analysis was used. Basis for this method is to develop a mathematical equation to describe the production as a function of production factors. Hence, this was done through estimation of energy production function.

RESULTS AND DISCUSION

A. Determination of energy consumption and production rates

To estimate the amount of energy used to produce field crops, it is necessary to determine energy equivalents for machinery manufacturing, depreciation, fuel consumption for operations, irrigation, labor, fertilizer, agricultural pesticides and seed, and their shares should be specified in total energy inputs. As matter of fact, the condition of field operations in different stages from tillage up to harvesting should be specified. Singh (2002) proposed the following relationship to calculate equivalent energy for machinery manufacture and depreciation:

$$ME = \frac{Mm.T.EE}{L} \qquad (4)$$

Where, ME, Mm, T, EE, L, denote; equivalent energy for construction and depreciation of machine in MJ ha^{-1}, machine mass in kg, hours of machine operation per hectare, equivalent energy for manufacturing each kg of machine, and estimated machine life in hours, respectively. Table 1 shows estimated life of some machinery.

Table 1: Useful life of some agricultural machinery.

Machinery and Tractor	Useful life (hr)
Tractor	12000
Moldboard plow	2000
Disc harrow	2000
Fertilizer distributor	1200
Planter	1500
Leveler	2000
Sprayer	1500
Combine harvester	1500

Considering the unit equivalent energy for different inputs weighted average of equivalent energy for construction and depreciation of machinery in the plain was calculated using the following equation and its results are presented in Table 2.

Weighted average of equivalent energy for construction and depreciation of machinery (MJ. ha^{-1}). Average fuel consumption of different operations per hectare of wheat production using the relevant equations and considering equivalent energy of 47.8 MJ lit-1for diesel fuel are given in table 3.

$$= \sum_{i=1}^{70} \frac{ith\ \ field\ \ area\,(\,ha\,)\times Equivalent\ \ energy\ \ of\ \ constructi\ \ on\ and\ \ depreciati\ \ on\ of\ \ ith\ \ field\,(\,MJ\ \ ha^{\ 1}\,)}{Area\ \ of\ \ whole\ \ samples\ \ (\,ha\,)} \quad (5)$$

Table 2: Average equivalent energy of manufacturing and depreciation per hectare.

Machines and tractor	Energy equivalent (MJ kg^{-1})	Energy (MJ ha^{-1})
Tractor	93.61	433.3
Combine harvester	87.63	519.4
Moldboard plow	62.7	68
Disc harrow	62.7	181
Leveler	62.7	26
Disk border	62.7	16.5
Fertilizer distributor	62.7	21.5
Sprayer	62.7	26.3
Planting by combined	62.7	41
Total	-	1333

Table 3: Calculated average fuel consumption per hectare of different operations.

Operations	Fuel consumption (lit ha^{-1})	Energy (MJ ha^{-1})
Tillage	62	2963.6
Disking	35	1673
Leveling	15	717
Bordering (ridging)	15	717
Seeding and Fertilizer distributing	14.6	697.9
Spraying	16	764.8
Planting by combined drill	8.4	401.5
Harvesting	42.85	2048.2
Total	208.85	9983

For irrigation of farms, pumping water from deep and semi-deep wells is being used. Direct energy of pumping is obtained using the following equation (Kitani, 1999):

$$I_{DE} = \frac{\rho gHQ}{\varepsilon_1 \varepsilon_2} \quad (6)$$

In the above relation, I_{DE}, ρ, g, H, Q, ε_1, ε_2 are; direct energy of irrigation (J/ha), water density (1000kg/m^3), acceleration of gravity (9.81 m/s^2), total head (m), water consumption rate (m^3/ha), pump efficiency and total efficiency of energy and power conversion respectively. The value of latter efficiency on prime-movers is considered to be 0.18 to 0.22 for electric motors and 0.25 up to 0.30 for diesel engines.

Indirect energy of irrigation includes raw materials, manufacturing, and transportation of all equipments which involve in irrigation. Since determination of its value is difficult, usually a percentage of direct energy, e.g. 18% of direct energy for pressurized irrigation system, and 37% for surface irrigation can be considered.

Considering the irrigation frequency (about 9 times), period of each irrigation time (about 12 hours), average depth of wells (187 meters), and average discharge of pumps (25 liters per second), total direct plus indirect energy of irrigation is estimated to be 154 GJ ha^{-1}.

But since some farmers use the irrigation water of canals network, so mean irrigation energy over the plain calculated to be 97GJha^{-1}. Equivalent energy of human power considering the hours spend from tillage stage to crop harvesting for driving machinery, irrigation, etc., based on man-hour rate of 1.96 MJ hr^{-1}. Recorded to be 387 MJha-1. Energy for seed, pesticides, and chemical fertilizers obtained by using their unit energy which are listed in table 4. Energy contribution of each input is mentioned in table 5.

Table 4: Mean equivalent energy of seed, toxins, and chemical fertilizers used per hectare.

Input		Unit energy (MJkg^{-1})	Mean quantity (kg)	Energy equivalent (MJha^{-1})
Seed	Improved breed of previous crop	25	277.8	5595.2
Chemical fertilizer	Nitrogen (N)	47.1	183	8619.3
	Phosphate	15.8	108.3	1632.14
	Potassium (K_2O)	9.28	25.9	240.35
Toxins (Chemical)	Pesticide	101.2	2.29	231.75
	Herbicide	238	0.52	123.76

Table 5: Contribution of energy inputs per hectare of wheat cultivation.

Input	Equivalent energy (MJha^{-1})	Percent of total
Machinery manufacture and depreciation	1332.9	1.06
Fuel consumption	9983	7.9
Irrigation	96885.5	77.1
Human power	378	0.31
Seed, fertilizer, and chemicals	16442.5	13.1
Transportation	643.77	0.51
Total	125674.8	100

Average crop yield of wheat grain (disregarding of straw) in the farm studied was 6129 kg ha-1. Considering equivalent energy of 14.7MJ kg-1 for wheat grain, output energy of wheat crop is 90.1GJ ha-1. According to foregone explanation, utilization of energy is as follows:

$$\text{Energy ratio (ER)} = \frac{\textit{Output energy}}{\textit{Input energy}} = \frac{90.1}{125.67} = 0.717 \quad (7)$$

$$\text{Energy productivity (EP)} = \frac{\textit{Crop yield per hectare}}{\textit{Input energy}} = \frac{6129}{125674.8} = 0.048 \, {}^{kg}\!/_{MJ} \quad (8)$$

Net energy gain (NEG) = (Output energy- Input energy) = -35.57 (9)

To estimate production function of energy, equivalent energies of used inputs are considered to be independent and energy of crop (wheat grain) as dependent variables. Area under cultivation, energy of water quantity used, seed, chemical fertilizers (nitrogen, phosphate, and potash), human power, equivalent energy of fuel used by tractor and by combine-harvester for wheat production are included in the model. Because of high co linearity with other inputs, seed energy omitted from the model.

Inputs of human, and pesticide energies, because of application similarities in different farms, did not show significant effect on production and therefore excluded from the model. Hence empirical pattern of Cobb-Douglas production function for energy with the remaining inputs was written in the equation 10.

After removal of data which were not significant in the model, the form of transcendental function of energy is as in Eqn. 11.

$$Ln\ y = Ln\ \alpha + \beta_A\ LnA + \beta_{Fer}\ LnFer + \beta_F\ LnF + \beta_W\ LnW \qquad (10)$$

$$\begin{aligned} Ln\ y = {} & \mathrm{Ln}\ \alpha + \beta_A\ LnA + \beta_{Fer}\ LnFer + \beta_F\ LnF \\ & + \alpha_w\ LnW + \alpha_A\ A + \alpha_{Fer}\ Fer + \alpha_F\ F + \alpha_W\ W \end{aligned} \qquad (11)$$

In the above functions; y (MJ), α, A(ha), Fer (MJ), F(MJ), and W(MJ) denote for; output energy, intercept coefficient, area cultivated, chemical fertilizer energy, consumed fuel energy, and energy of water pumping respectively. Other α and β signs represent parameters of function pattern (Arsalanbod, 1987).

To select the appropriate one, from the two functions of Cobb-Douglas or the transcendental, the estimated functions were compared for significance of parameters, total coefficients, likelihood ratio based on coefficient of determination (R2) and also Durbin-Watson statistic.

The estimated coefficients of models for functions No. (10, 11) in relation to energy consumption pattern in wheat crop production is given in table 6.

Table 6: Estimated coefficients of energy production functions.

Parameters	Cobb-Douglas	Transcendental
α	5.31^{**} (0.85)	2.98^{**} (1.53)
βA	0.33^{**} (0.09)	0.076^{ns} (0.16)
βF	0.2^{*} (0.077)	0.39^{**} (0.14)
βFer	0.26^{**} (0.073)	0.262^{*} (0.125)
βW	0.14^{*} (0.059)	0.209^{*} (0.0049)
αA		0.01^{*} (0.0047)
αF		$-1.11\times10^{-6}(6.99\times10^{-7})$
αFer		$2.75\times10^{-7}(6.99\times10^{-7})$
αW		$-6.53\times10^{-8}(4.76\times10^{-8})$
	D.W=2.07 $F=135^{**}$	D.W=1.95 $F=214^{**}$

** Significant at 1% probability level. * Significant at 5% probability level.
Ns not significant. Figures in parentheses are standard deviation of coefficients.

As table 6 shows, the output energy Y (MJ) is a function of cultivation are A (ha), energy quantity of fuel consumed (F), chemical fertilizer energy (Fer), and pumping energy of water (W) (all in MJ). Revilement of estimated coefficients in table 6 shows that the functional forms with regard to determination of pattern based on R2 and W.D statistics are appropriate. Considering contents of table 7, the transcendental function determined to be superior.

It is apparent from table 5 that the highest share of total energy used, belongs to irrigation (77.1%). This is due to high depth of water wells because of underground water resource depletion. Hence, because of decrease in rainfall and also inefficient use of water through inferior irrigation methods, proper management of water use both in selection of appropriate irrigation methods, and also in irrigation rates and periods is a necessity. Obviously the figure in table 5 is an average energy of water use from wells and of canal network. However, had the water to be provided by wells only, then the energy rate of irrigation over the plain would be 154 GJ ha^{-1}.

Energy utilization which is calculated through equation 7 shows that the ER over the plain is so low, even net energy gain, which is subtraction of input from output energy, is negative.

Table 7: Comparison of energy production functions based on statistics R2, and JB of goodness of fit, and also likelihood test.

Energy production function	No. of total coefficients	No. of significant coefficients	Adjusted R^2	JB	Likelihood estimator	LR
Cobb-Douglas	5	4	0.939	2.32^{ns}	19.94	-
Transcendental	9	5	0.953	2.79^{ns}	24.93	6.77

*Ns not significant

This, which means that the input energy is higher than output energy, is not rational in any way. Taki *et al.* (2012) reported the ER to be 0.56 and 0.92 for cucumber and tomato production in Esfahan province of Iran. Hassanzadeh and Mazaheri (1996) reported the ER, for wheat production in Falavarjan region of Esfahan province, as 2.41. A study done by Singh (2002) showed the highest energy input for wheat production in India as17.78 GJ ha $^{-1}$. In transcendental function an elasticity of between 0 and 1 indicates the use of input to be in acceptance region of economical production. Considering contents of table 8, the cultivation area, energy of chemical fertilizer, energy of consumed fuel by machines, and pumping energy have high effects on energy production of wheat crop. Negative value of input elasticity for pumping energy reveals that, use of this input has entered into third economic region (region of rejection), and has been unjustifiably overused.

Table 8: Input elasticity in transcendental function of energy in relation to wheat production.

Function	Cultivation area A	Chemical fertilizer Fer	Fuel F	Water consumption W
Transcendental function	0.39	0.35	0.055	-0.05

CONCLUSION

In this study, relationship between energy inputs and yield for wheat production were investigated in Esfahan province of Iran. Results showed that wheat production consumed a total energy of 125674.8MJha^{-1}, which was mainly due to Irrigation (77% of total energy). Energy ratio, energy productivity and net energy for wheat production were 0.717, 0.048 and -35.57 GJha^{-1}, respectively. Results show that the cultivation area, energy of chemical fertilizer, energy of consumed fuel by machines, and pumping energy have high effects on energy production of wheat production.

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