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ESTIMATING PRODUCTION FUNCTION OF WALNUT PRODUCTION IN IRAN USING COBB-DOUGLAS METHOD

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Abstract

Production function is one that specifies the output of a firm, an industry, or an entire economy for all combinations of inputs. The aims of this study were to estimate the production function, to obtain relationship between agricultural inputs and walnut yield in view of energy inputs, and to make an economical analysis in walnut (*Juglans regia*) orchards in Hamedan, Iran. For this purpose, Cobb-Douglas production function method was used. Random sampling technique was used for data collection. Econometric analysis results revealed that human labour, farmyard manure, chemical fertilizers, water for irrigation and transformation contributed significantly to the yield. The results of sensitivity analysis of the energy inputs showed that the Marginal Physical Productivity (MPP) value of human labour was the highest, followed by farmyard manure and water for irrigation energy inputs, respectively. The benefit to cost ratio, mean net return and productivity from walnut production was obtained as 2.1, 2043.7 \$ ha^{-1} and 0.3 kg \$$^{-1}$, respectively. Based on the results, applying mechanization, mechanical harvesting and post harvesting such as shaker, sweeper, pickup machine, cracking and handling unit should be developed. They should be based on the physical characteristics and mechanical properties of walnuts, instead of human labour. Their use in Hamedan walnut orchards can lead to more profit and energy saving which is highly recommended.

Keywords: *Juglans regia;* walnut orchards; production function; sensitivity; economic analysis.

INTRODUCTION

The first aim of the production function is to address attribution efficiency in the use of factor inputs in production and the resulting distribution of income to those factors. Under certain assumptions, the production function can be used to derive a marginal product for each factor, which implies an ideal division of the income generated from output into an income due to each input factor of production (Cobb and Douglas, 1928).

Iran is ranked fourth in the world after USA, China and Turkey in walnut production (Anonymous, 2008). The production of walnuts was about 290,000 tons per year in Iran and the harvested land area was 185,000 ha in 2008. Hamedan province was the first walnut producer per hectare and provided one of the most desirable and high grade walnut of world (Anonymous, 2009). Nutrients such as potassium, magnesium, phosphorus, iron, calcium, zinc, copper, vitamins B9, B6, E, A, and other substances have been found in walnuts (Koyuncu et al., 2004).

The amount of energy used in agricultural production, processing and distribution is extremely high. Sufficient supply of the right amount of energy and its effective and efficient use are necessary for an improved agricultural production. It has been realized that crop yields and food supplies are directly linked to energy (Stout, 1990). In the developed countries, increase in the crop yields has been mainly due to increase in the commercial (but often subsidized) energy inputs in addition to improved crop varieties (Faidley, 1992). Calculating energy inputs into agricultural production is more difficult than in the industry sector due to the high number of factors affecting agricultural production (Yaldiz et al., 1993). The main objective in agricultural production is to increase yield and decrease costs. In this respect, the energy budget is important. Energy budget is the numerical comparison of the relationship between input and output of a system in terms of energy units (Gezer et al., 2003). In general, increases in the agricultural production on a sustainable basis and at a competitive cost are vital to improve the farmer's economic condition (De et al., 2001). Although many experimental works have been conducted on energy use in agriculture, to our knowledge no studies have been done on the energy and economical analysis of walnut production.

Rafiee et al. (2011) studied energy use for apple production in Tehran province and Mohammadi et al. (2010) investigated energy inputs and crop yield relationship to develop and estimate an econometric model for kiwifruit production in Mazandaran province in Iran.

The aims of this research were to determine the production function of walnut production in Iran´s viewpoint of energy and economic subjects, make sensitivity analyses on energy inputs for walnut yield and compare input energy use with input costs. This study also aims to reveal the relationship between energy inputs and yield by developing mathematical models to approximate production technology by fitted Cobb-Douglas production function in walnut orchards in Hamedan province of Iran.

Nomenclature

n	required sample size
N	number of holdings in target population
N_h	number of the population in the h stratification
S^2_h	variance of h stratification
d	precision $(\bar{x} - \bar{X})$
z	reliability coefficient (1.96 in the case of 95% reliability)
D^2	d^2 / z^2
DE	direct energy
IDE	indirect energy
RE	renewable energy
NRE	non-renewable energy
Yi	yield level of the i th farmer
α_0	constant
X_1	human labor energy
X_2	machinery energy
X_3	*diesel fuel energy*
X_4	*transportation energy*
X_5	*farmyard manure energy*
X_6	*chemical fertilizers energy*
X_7	chemicals energy
X_8	electricity energy
X_9	water for irrigation energy
e_i	error term
α_1	coefficient of the variables
β_1	coefficient of variables
γ_1	coefficient of variables
e_j	regression coefficient of jth input
$GM(Y)$	geometric mean of yield
$GM(Y_j)$	geometric mean of jth input energy

MATERIALS AND METHODS

Data were collected from 37 walnut orchards in the Hamedan province of Iran by using a face-to-face questionnaire method performed in July-August 2009. The data used in this study are cross-sectional data collected in one year. In addition to the data obtained by surveys, previous studies of related organizations such as Food and Agricultural Organization (FAO) and Ministry of Jihad-e-Agriculture of Iran (MAJ) were also utilized during this study. The number of operations involved in the walnut production, and their energy requirements influenced the final energy balance. The size of sample of stratifications was determined by Neyman technique (Zangeneh et al., 2010; Yamane, 1967). The size of 37 orchards was considered as adequate sample size.

Energy equivalents showed in Table 1 were used for calculations. In this order the energy equivalents of the inputs and output, the energy ratio (energy use efficiency), energy productivity, net energy gain, energy intensiveness and the specific energy were calculated (Rafiee et al., 2011; Mohammadi et al., 2010; Zangeneh et al., 2010; Tabatabaeefar et al., 2009):

$$\text{Energy use efficiency} = \text{Energyoutput (MJ ha}^{-1}) \; / \; \text{Energyinput (MJh}^{-1}) \quad (1)$$

$$\text{Energyproductivity} = \text{Walnutoutput (kg ha}^{-1}) \; / \; \text{Energyinput (MJh}^{-1}) \quad (2)$$

$$\text{Specificenergy} = \text{Energyinput (MJ ha}^{-1}) \; \text{Walnutoutput (kg ha}^{-1}) \quad (3)$$

$$\text{Netenergygain} = \text{Energyoutput (MJ ha}^{-1}) \; \text{Energyinput (MJ ha}^{-1}) \quad (4)$$

$$\text{Energyintensiveress} = \text{Energyinput (MJ ha}^{-1}) \; / \; \text{Cost of cultivation (\$ ha}^{-1}) \quad (5)$$

What is production function?

In microeconomics and macroeconomics, a production function is one that specifies the output of a firm, an industry, or an entire economy for all combinations of inputs. This function is an assumed technological relationship, based on the current state of engineering knowledge; it does not represent the result of economic choices, but rather is an externally given entity that influences economic decision-making. Almost all economic theories presuppose a production function, either on the firm level or the aggregate level (Daly, 1997; Cohen and Harcourt, 2003).

A meta-production function compares the practice of the existing entities converting inputs into output to determine the most efficient practice production function of the existing entities, whether the most efficient feasible practice production or the most efficient actual practice production. In either case, the maximum output of a technologically-determined production process is a mathematical function of one or more inputs. Put in another way, given the set of all technically feasible combinations of output and inputs, only the combinations encompassing a maximum output for a specified set of inputs would constitute the production

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

Inputs		Unit	Energy equivalent (MJ Unit^{-1})	References
A. Inputs				
1. Human labour	(woman)	h	1.96	Ozkan et al. (2004b)
	(man)	h	1.57	Ozkan et al. (2004b)
2. machinery		h	62.70	Zangeneh et al. (2010)
3. Diesel fuel		L	56.31	Rafiee et al. (2010) and Zangeneh et al. (2010)
4. Transportation		t.km	1.6	Gezer et al. (2003)
5. Farmyard manure		t	303.1	Banaeian et al. (2010)
6. Chemical Fertilizers		kg		
	(a) Nitrogen		66.14	
	(b) Phosphate (P_2O_5)		12.44	Banaeian et al. (2010)
	(c) Potassium (K_2O)		11.15	Banaeian et al. (2010)
	(d) Sulphur (S)		1.12	Banaeian et al. (2010)
	(e) Zinc(Zn)		8.40	Strapatsa et al. (2006)
7. Chemicals		kg		
	(a) Herbicide		238	Zangeneh et al. (2010)
	(b) Insecticide		101.2	Zangeneh et al. (2010)
	(c) Fungicide		216	Banaeian et al. (2010)
8. Electricity		kWh	11.93	Banaeian et al. (2010)
9. Water for irrigation		m^3	1.02	Zangeneh et al. (2010)
B. Output		kg		
1. Walnut			26.15	Singh and Mittal (1992) and Anonymous (2010)
2. Wooden shell			10	Singh and Mittal (1992)
3. Green shell			18	Singh and Mittal (1992)

function. Alternatively, a production function can be defined as the specification of the minimum input requirements needed to produce designated quantities of output, given available technology. It is usually presumed that unique production functions can be constructed for every production technology.

By assuming that the maximum output technologically possible from a given set of inputs is achieved, economists using a production function in analysis are abstracting from the engineering and managerial problems inherently associated with a particular production process.

The first aim of the production function is to address appropriation efficiency in the use of factor inputs in production and the resulting distribution of income to those factors. Under certain assumptions, the production function can be used to derive a marginal product for each factor, which implies an ideal division of the income generated from output into an income due to each input factor of production.

In 1928 Charles Cobb and Paul Douglas published a study in which they modelled the growth of the American economy during the period 1899 - 1922. They considered a simplified view of the economy in which production output is determined by the amount of labour involved and the amount of capital invested. While there are many other factors affecting economic performance, their model proved to be remarkably accurate.

The function they used to model production was of the form:

$$P(L, K) = bL^{\alpha} K^{\beta} \tag{6}$$

Where:

P = total production (the monetary value of all goods produced in a year)

L = labor input (the total number of person-hours worked in a year)

K = capital input (the monetary worth of all machinery, equipment, and buildings)

b = total factor productivity

α and β are the output elasticity of labour and capital, respectively. These values are constants determined by available technology.

Output elasticity measures the responsiveness of output to a change in levels of either labor or capital used in production, ceteris paribus. For example if $\alpha = 0.15$, a 1% increase in labor would lead to approximately a 0.15% increase in output.

Further, if $\alpha + \beta = 1$, the production function has constant returns to scale. That is, if L and K are each increased by 20%, then P increases by 20%.

Returns to scale refers to a technical property of production that examines changes in output subsequent to a proportional change in all inputs (where all inputs increase by a constant factor).

If the production function is denoted by $P = P(L, K)$, then the partial derivative δP/δL is the rate at which production changes with respect to the amount of labour. Economists call it the marginal production with respect to labour or the *marginal productivity of labour*. Likewise, the partial derivative δP/δL is the rate of change of production with respect to capital and is called the *marginal productivity of capital*.

In these terms, the assumptions made by Cobb and Douglas can be stated as follows:

1. If either labour or capital vanishes, then so will production.
2. The marginal productivity of labour is proportional to the amount of production per unit of labor.
3. The marginal productivity of capital is proportional to the amount of production per unit of capital.

Because the production per unit of labour is P/L, assumption 2 says that, $\frac{\partial P}{\partial L} = \alpha \frac{P}{L}$ for some constant α. If we keep K constant ($K = K_0$), then this partial differential equation becomes an ordinary differential equation: $\frac{dP}{dL} = \alpha \frac{P}{L}$. This separable differential equation can be solved by re-arranging the terms and integrating both sides:

$$\int \frac{1}{P}\, dP = \alpha \int \frac{1}{L}\, dL$$

$$\ln(P) = \alpha \ln(cL) \quad (7)$$

$$\ln(P) = \ln(cL^{\alpha})$$

And finally,

$$P(L, K_0) = C_1(K_0)L^{\alpha} \quad (8)$$

Where $C_1(K_0)$ is the constant of integration and we write it as a function of K_0 since it could depend on the value of K_0.

Similarly, assumption 3 says that $\frac{\partial P}{\partial K} = \beta \frac{P}{K}$, keeping L constant (L = L0), this differential equation can be solved to:

$$P(L_0, K) = C_2(L_0)K^{\beta} \quad (9)$$

and finally, combining equations:

$$P(L, K) = bL^{\alpha} K^{\beta} \quad (10)$$

where b is a constant that is independent of both L and K. Assumption 1 shows that $\alpha > 0$ and $\beta > 0$.

Notice from equations (10) that if labour and capital are both increased by a factor m, then

$$P(mL, mK) = b(mL)^{\alpha}(mK)^{\beta}$$

$$= m^{\alpha+\beta} bL^{\alpha}K^{\beta} \quad (11)$$

$$= m^{\alpha+\beta} P(L, K)$$

If $\alpha + \beta = 1$, then $P(mL,mK) = mP(L,K)$, which means that production is also increased by a factor of m, as discussed earlier.

Cobb and Douglas were influenced by statistical evidence that appeared to show that labour and capital shares of total output were constant over time in developed countries; they explained this by statistical fitting least-squares regression of their production function. However, there is now doubt over whether constancy over time exists.

Neither Cobb nor Douglas provided any theoretical reason why the coefficients α and β should be constant over time or be the same between sectors of the economy. Remember that the nature of the machinery and other capital goods (the K) differs between time-periods and according to what is being produced. So do the skills of labour (the L). The Cobb-Douglas production function was not developed on the basis of any knowledge of engineering, technology, or management of the production process. It was instead developed because it had attractive mathematical characteristics, such as diminishing marginal returns to either factor of production. Crucially, there are no micro-foundations for it. In the modern era, economists have insisted that the micro-logic of any larger-scale process should be explained. The C-D production function fails this test.

For example, consider the example of two sectors which have the exactly same Cobb-Douglas technologies:

If, for sector 1,

$$P_1 = b(L_1^{\alpha})(K_1^{\beta}) \quad (12)$$

And, for sector 2,

$$P_2 = b(L_2^{\alpha})(K_2^{\beta}), \quad (13)$$

That, in general, does not imply that

$$P_1 + P_2 = b(L_1 + L_2)^{\alpha}(K_1 + K_2)^{\beta} \quad (14)$$

This holds only if $\frac{L_1}{L_2} = \frac{K_1}{K_2}$ and $\alpha + \beta = 1$, i.e. for constant returns to scale technology.

It is thus a mathematical mistake to assume that just because the Cobb-Douglas function applies at the micro-level, it also applies at the macro-level. Similarly, there is no reason that a macro Cobb-Douglas applies at the disaggregated level (Stewart, 2008).

Overall, Cobb–Douglas production function yielded better estimates in terms of statistical significance and expected signs of parameters. For cost analysis Cobb–Douglas production function yielded better estimates in terms of statistical significance and expected signs of parameters. In economics, the Cobb-Douglas functional form of production functions is widely used to represent the relationship of an output to inputs. It was proposed by Knut Wicksell (1851 - 1926), and tested against statistical evidence by Charles Cobb and Paul Douglas in 1928. The Cobb–Douglas production function is expressed as:

$$Y = f(x)\exp(u) \quad (15)$$

This function has been used by several authors to examine the relationship between input costs and yield (Rafiee et al., 2011; Mohammadi et al., 2010; Hatirli et al., 2006). Eq. (15) can be linearized and be further re-written as:

$$\ln Y_i = a + \sum_{j=1}^{n} \alpha_j \ln (X_{ij}) + e_i \qquad i = 1, 2, \ldots, n \qquad (16)$$

where Y_i denotes the yield of the *i*th farmer, X_{ij} the vector of *j*th input used in *i*th farm in the production process, a the constant term, α_j represent coefficients of inputs which are estimated from the model and e_i is the error term of *i*th farm.

Eq. (16) is expanded in accordance with the assumption that the yield is a function of energy inputs:

$$\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + \alpha_8 \ln X_8 + \alpha_9 \ln X_9 + e_i \qquad (17)$$

Where X_i ($e = 1. 2,..., 9$)) stand for input energies from human labour (X_1), machinery (X_2), diesel fuel (X_3), transportation (X_4), farmyard manure (X_5), chemical fertilizer (X_6), chemicals (X_7), electricity (X_8) and water for irrigation (X_9). With respect to this pattern, by using Eq. (17) the impact of energy inputs on yield was studied. In addition the impacts of DE and IDE items and RE and NRE items on the yield were investigated.

In the last part of this research, the marginal physical productivity (MPP) method, based on the response coefficients of the inputs was utilized to analyze the sensitivity of energy inputs on walnut yield. The MPP of a factor implies the change in the total output with a unit change in the factor input, assuming all other factors are fixed at their geometric mean level. A positive value of MPP of any input variable identifies that the total output is increasing with an increase in input; so, one should not stop increasing the use of variable inputs so long as the fixed resource is not fully utilized. A negative value of MPP of any variable input indicates that every additional unit of input starts to diminish the total output of previous units; therefore, it is better to keep the variable resource in surplus rather than utilizing it as a fixed resource.

The MPP of the various inputs was calculated using the α_j of the various energy inputs as follow (Rafiee et al., 2011; Singh et al., 2004; Mobtaker et al., 2010):

$$MPP_{xj} = \frac{GM(Y)}{GM(X_j)} \times \alpha_j \qquad (18)$$

In this equation MPP_{xj} is marginal physical productivity of *jth* input, α_j regression coefficient of *jth* input, *GM(Y)* geometric mean of yield, and $GM(X_j)$ geometric mean of *jth* input energy on per hectare basis.

There are both financial and environmental reasons to improve energy efficiency in agriculture. From a financial perspective, energy usually costs money. From an environmental perspective, energy use is associated with carbon dioxide emission which has serious implications for global climate change (Wiens et al., 2008). The economic inputs of these systems include fixed and variable costs and outputs include orchards product (walnut). All prices of input and output were market prices (average prices of years 2009 and 2010).

In the last part of the research net and gross return and benefit–cost ratio was calculated (Demircan et al., 2006; Canakci et al., 2005; Mohammadi et al., 2010; Zangeneh et al., 2010). All prices of input and output were market prices (average prices of years 2009–2010). Basic information on energy and energy inputs and walnut output were entered into Excel 2007 spreadsheet and Shazam 9.0 and SPSS 16.0 software.

RESULTS AND DISCUSSION

Socio-economic structures of farms

Socio-economic structures of studied orchards are shown in Table 2. Seldom producers use orchard's tractor for field preparation, most of operations (plow, irrigation, harvesting and post-harvest care) are still accomplished manually in Iran which lead to increased cost and processing time for kernel extraction. Irrigation is necessary in the orchards to be economically feasible, and surface irrigation is frequent. Water was provided by rivers and irrigation was performed 15 times a year between April and September. Field preparation was performed during March.

Table 2. Management practices for walnut production

Practices/ Operations	
Field preparing operation period	March
Distributing fertilizer & farmyard manure	April–June
Irrigation Period	April-September
Average number of irrigation	15 times
Harvesting period	October-November

Analysis of input–output energy use in walnut production

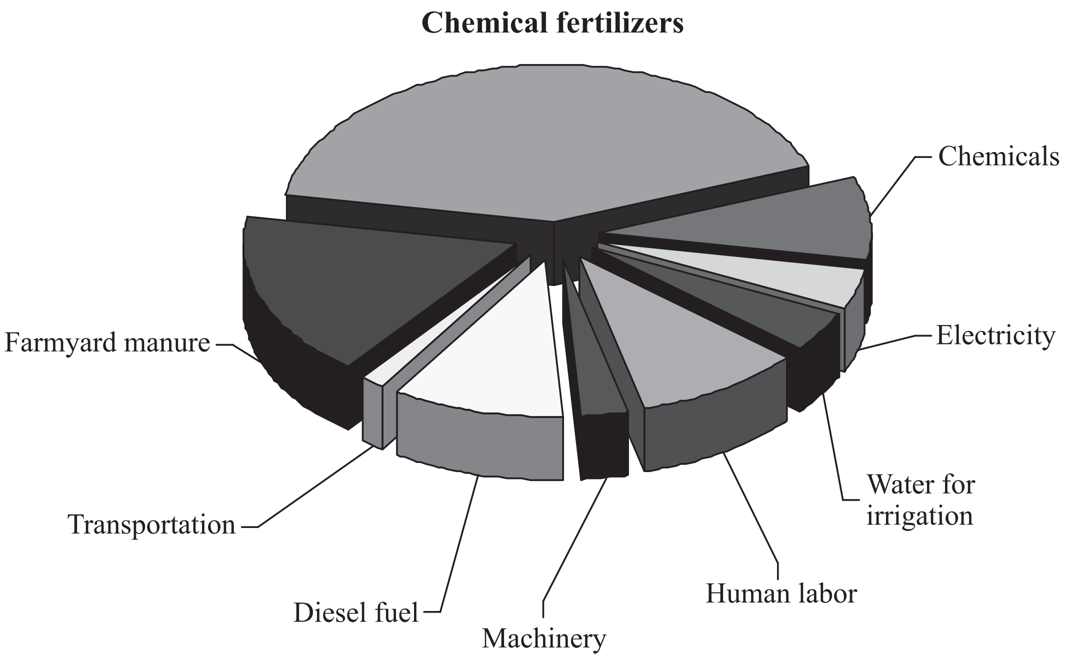
The results in Table 3 revealed that harvesting is the most consumer of human power, 347.4 hours is required per hectare. Therefore, mechanical harvesting and post harvesting such as shaker, sweeper, pickup machine, cracking and handling unit should be developed based on the physical characteristics and mechanical properties of walnuts to reduce the share of human labour cost and energy.

Chemical fertilizer usage in the orchards was found to be 268 kg ha^{-1}; according to the results of Table 3, chemical fertilizers are the superabundant section of energy consumer and consume 41.5% of total energy. Transportation is the smallest energy consumer as you see in Fig. 1. Total energy used in various orchards operations during walnut production was 15196.1MJ ha^{-1}. Average

Table 3. Amounts of inputs and output in walnut production

Inputs (unit)		Quantity per unit area (ha)	Total energy equivalent (MJ ha^{-1})
A. Input			
Human labour (h)			
	Field preparation	233.1	456.9
	Irrigation	162.4	318.3
	Harvest	347.4	653.8
	Post Harvest	62.3	117.2
Machinery (h)		6.3	395
Diesel fuel (L)		31.09	1571
Transportation (t.km)		140.2	224.3
Farmyard manure (tonnes)		8.6	2606.6
Chemical fertilizers (kg)			
	(a) Nitrogen (N)	83.4	5054
	(b) Phosphate (P_2O_5)	52.3	580.5
	(c) Potassium (K_2O)	83.7	560.8
	(d) Sulphur (S)	42.4	47.5
	(e) Zinc (Zn)	6.2	52
Chemicals (kg)			
	Herbicide	0.1	23.8
	Insecticide	7.8	789.3
	Fungicide	2.3	496.8
Electricity (kWh)		168.2	605.5
Water for irrigation (m^3)		630.2	642.8
Total energy input (MJ ha^{-1})			15196.1
B. Output (tonnes)			
Walnut kernel		0.75	19488.6
Wooden shell		1.5	14905
Green shell		2.23	10061
Total energy output (MJ ha^{-1})			44454.6

Figure 1: Share of energy inputs



annual yield of orchards investigated was 4.48 tonnes ha^{-1} and calculated total energy output was 44454.6MJ ha^{-1} which 44% included kernel.

The energy input and output, yield, energy use efficiency, specific energy, energy productivity, net energy gain and energy intensiveness of walnut production in Hamedan province are calculated using Eqs. (1) - (5) and tabulated in Table 4. Energy use efficiency (energy ratio) were calculated as 2.9 and energy intensiveness 8.18 MJ \$$^{-1}$, respectively.

Table 4. Energy input-output in walnut production

Items	Unit	Walnut
Energy use efficiency	-	2.9
Energy productivity	kg MJ^{-1}	0.3
Specific energy	MJ kg^{-1}	3.4
Net energy	MJ ha^{-1}	29258.5
Energy intensiveness	MJ \$$^{-1}$	8.18
Direct energy [a]	MJ ha^{-1}	4589.8
Indirect energy [b]	MJ ha^{-1}	10606.3
Renewable energy [c]	MJ ha^{-1}	4795.6
Non-renewable energy [d]	MJ ha^{-1}	10400.5
Total energy input	MJ ha^{-1}	15196.1

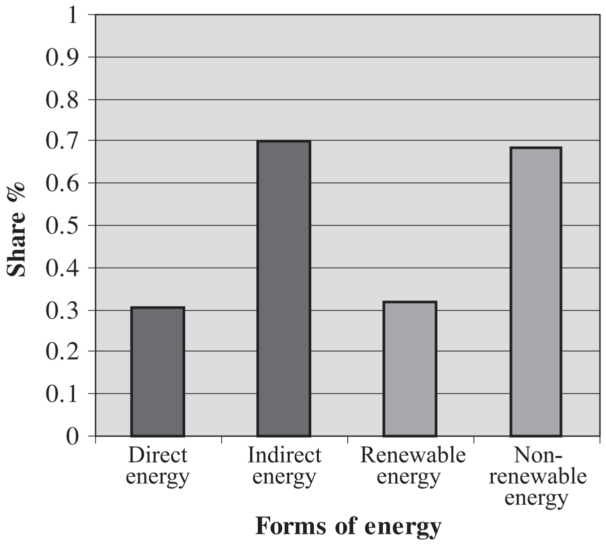
[a] Includes electricity, human labour, diesel fuel, transportation, water for irrigation.

[b] Includes chemical fertilizers, farmyard manure, machinery.

[c] Includes human labour, farmyard manure, water for irrigation.

[d] Includes diesel fuel, electricity, chemical fertilizers, machinery, transportation.

Figure 2: Share of each form of energy



Share of energy forms (Table 4) can be compared with Fig. 2. The share of indirect and non-renewable energy is larger, too, than the direct and renewable energy, respectively. Several researchers have found that the ratio of DE is higher than that of IDE, and the rate of NRE was greater than that of RE consumption in cropping systems (Esengun et al., 2007; Kiziaslan, 2009). The high ratio of NRE in the total used energy inputs causes negative effects on the sustainability in vegetable production of small-scale farms. Therefore, it is important to better utilize the RE sources for making up for the increasing energy deficit. Agriculture has the potential to become an increasingly important source of RE and provides significant economic opportunities for producers. RE production stimulates the agricultural and rural economy, improves the environment and enhances national energy security.

The specific energy and energy productivity of walnut production were 3.4 MJ kg^{-1} and 0.3 kg MJ^{-1} while calculation of energy productivity rate is well documented in the literature such as sweet cherry 0.5 (Demircan et al., 2006), stake-tomato 1.0 (Esengun et al., 2007), cotton 0.06 (Yilmaz et al., 2005), sugar beet 1.53 (Erdal et al., 2007). Canakci et al. (2006) reported specific energy for field crops and vegetable production in Turkey, such as 5.24 for wheat, 11.24 for cotton, 3.88 for maize, 16.21 for sesame, 1.14 for tomato, 0.98 for melon and 0.97 for water- melon.

Net energy gain was 29258.5 MJ ha^{-1}. Also Table 4 shows the distribution of total energy input as direct, indirect (DE vs. IDE), renewable and non-renewable (RE vs. NRE) forms. Several researchers have found that the ratio of DE is higher than that of IDE, and the rate of NRE was greater than that of RE consumption in cropping systems (Esengun et al., 2007; Demircan et al., 2006; Erdal et al., 2007). The high ratio of NRE in the total used energy inputs causes negative effects on the sustainability in agricultural production. Energy use in walnut production is not efficient and detrimental to the environment due to mainly excess input use.

Relation between energy use in walnut orchards and their size

There is a relation between the size of production enterprise and its productivity. To clarify this relation, walnut orchards were categorized in three groups: Small (S, smaller than 2 ha), Medium (M, between 2 and 4 ha) and Large (L, larger than 4 ha) and energy items were compared. In Table 5 energy of human labour in all operations with increasing orchard area has decreased clearly. Because of traditional structure of walnut orchards in Iran, integration is a requirement to decrease human labour usage and increase mechanization percentage in all orchards of Iran. Regarding to fertilizer use in different groups, M has least usage. This could be due to topographic types of gardens and a gardener as well as the

Table 5. Energy items in different groups of orchards based on orchard size (Small, Medium and Large)

Item (Unit)	Group of orchards Small (<2 ha)	 Medium (2 ha< , <4 ha)	 Large (4 ha<)
Human labour (MJ ha^{-1})			
Land Preparation	747.42	299.28	210.45
Irrigation	529.36	188.02	157.76
Harvest	1012.56	476.47	325.46
Post harvest	220.52	55.56	35.96
Transportation	349.54	149.9	125.54
Fertilizer (MJ ha^{-1})			
Farmyard manure	2550.50	2273.43	3043.06
Chemical			
a) Nitrogen	8783.00	2411.73	2626.96
b) Phosphate	954.60	226.84	445.47
c) Potassium	971.00	261.85	303.23
Total energy input (MJ ha^{-1})	16118.50	6342.66	7273.89
Total energy output (MJ ha^{-1})	83374.72	73502.00	73513.44
Yield (tones ha^{-1})	2.49	2.09	2.14
Area (ha)	1.18	3.44	6.85
Number of orchard men studied	15	12	10
Energy use efficiency	5.17	11.5	10.10
Specific energy (MJ kg^{-1})	6473.30	3034.70	3399.00
Energy productivity (kg MJ^{-1})	0.15	0.32	0.29
Net energy gain (MJ ha^{-1})	67256.22	67159.33	66239.55

culture is in how to use fertilizers. M has minimum input energy, while S group has maximum output energy. Also M group has maximum value in energy use efficiency and energy productivity in comparison with others. Thus the M group, i.e. between 2 and 4 ha, is the best size for walnut production in Hamedan province of Iran viewpoint of energy.

Total input and output energy in different orchard sizes are compared in Fig. 3. S group is the largest energy consumer and producer, whereas M is the least. The most Energy use efficiency belongs to M group; we thus conclude that this size (between 2 and 4 ha) is the most efficient alternative to extend and establish new orchards in Hamedan province of Iran.

Figures 1 and 2 show the input and output energy in all 37 studied orchards. Different views were observed showing procedures that need to expand and optimize the production of walnuts, and management of energy resources.

Figure 3: Energy input and output in different orchard sizes

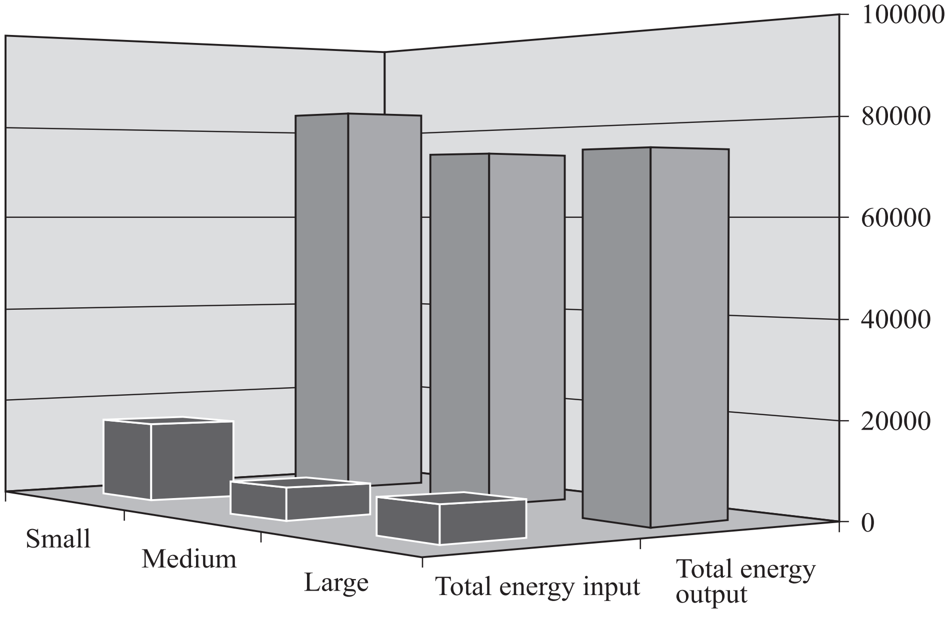


Figure 4: Input energy in studied walnut orchards

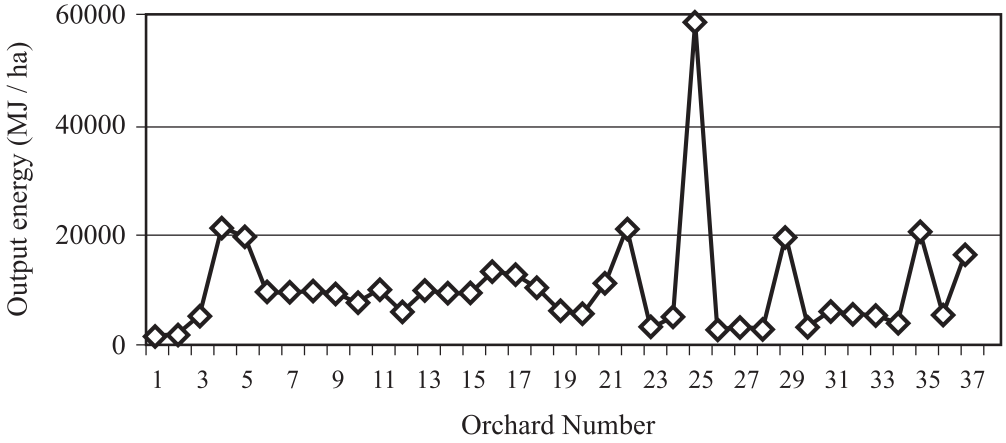
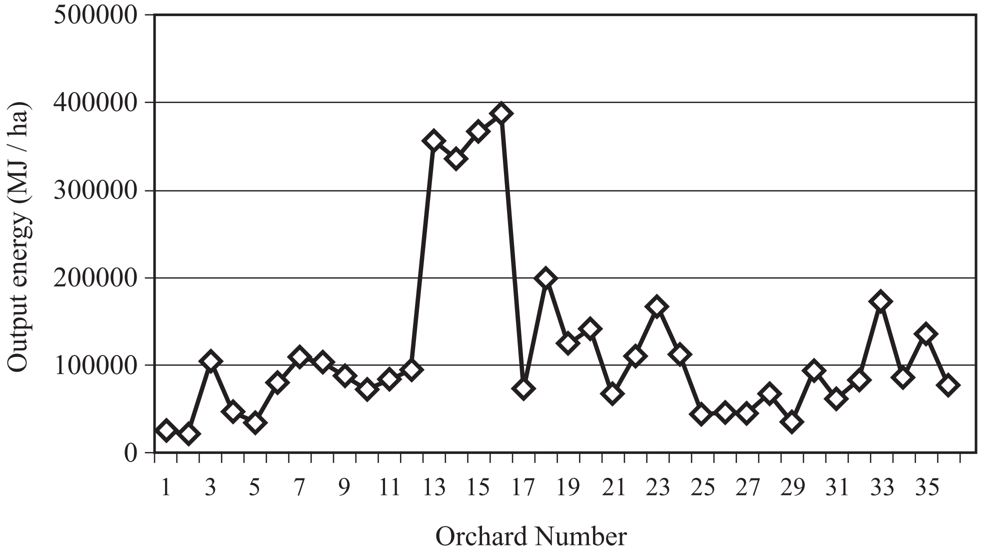


Figure 5: Output energy in studied walnut orchards



Econometric model estimation of walnut production

Relationship between energy inputs and yield was estimated using Cobb–Douglas production function for the walnut crop. Walnut yield (endogenous variable) was assumed to be a function of human labour, machinery, diesel fuel, transportation, FYM, chemical fertilizers, chemicals, electricity and water for irrigation energy (exogenous variables). Durbin-Watson test revealed that Durbin–Watson value was as 1.87 for Model 1 (Eq. (15)), i.e. the variable isn't significant at the 1% significance level in the estimated model. The coefficient of determination (R^2) was 0.98 for this model.

The impact of energy inputs on yield was also investigated by estimating Eq. (15). Regression result for this model is shown in Table 6. The contribution of human labour, FYM and chemical fertilizer energies are significant at the 1% level of confidence. This indicates that with an additional use of 1% for each of these inputs would lead, respectively, to 0.09%, 0.14% and 0.19% increase in yield. The elasticities of transportation, electricity and water energies were estimated as 0.95, 0.12 and 0.20, respectively (all significant at the 5% level). The impact of chemical fertilizers, machinery and diesel fuel energies on yield were estimated statistically non-significant with a negative sign. Rafiee et al. (2011) estimated an econometric model for apple production in Tehran province of Iran. They concluded that among the energy inputs, chemical fertilizer, FYM, water and electricity energies were found as the most important inputs that influences yield. Mohammadi et al. (2010) concluded that in kiwifruit production of Iran, the impact of human labour and water for irrigation energies was significant to the productivity at 1% level.

Estimated coefficients indicate that the impact of energy inputs could be assessed positive on walnut yield. Human labour had the highest impact (0.39) between the other inputs in walnut production indicating that by increase in the energy obtained from human labour input, the amount of yield improves in present condition. With respect to the assessed results, increasing 10% in the energy of human labour led to 3.9% increase in walnut output. The second and third important inputs were found as water for irrigation and farmyard manure with the elasticity of 0.32 and 0.27. Mohammadi et al. (2010) estimated an econometric model for kiwifruit production in Iran. They reported that the parameters of human labour, machinery, total fertilizer and water for irrigation had significant impacts in improving the yield of kiwifruit. The MPP value of model variables is shown in the last column of Table 6. It shows that MPP of human labour, FYM and water for irrigation inputs were found to be 1.83, 1.23 and 1.14, respectively. This indicates that an increase of 1 MJ in each input of human labour, FYM and water for irrigation energy, would lead to an additional increase in yield by 1.83, 1.23 and 1.14 kg ha^{-1}, respectively. The value of return to scale for the model (1) was calculated by gathering the regression coefficients as 1.86. The higher value of return to scale than unity implies increasing return to scale.

The regression coefficients of direct and indirect energies (Model 2) as well as renewable and non-renewable energies (Model 3) on yield were investigated (see Table 7). The regression coefficients of direct, indirect and non-renewable energies were all significant at 1% level, whereas the regression coefficient of renewable energy was found significant at 5% level. The impacts of direct, indirect, renewable and non-renewable energies were estimated as 0.13, 0.24, 0.15 and 0.27, respectively. In the literature, similar results have been reported. For example, the impact of indirect energy was more than the impact of direct energy on yield, and the impact of non-renewable energy was more than renewable energy (Mohammadi and Omid, 2010; Mohammadi et al., 2010; Rafiee et al., 2011). Durbin–Watson values were calculated as 2.18 and 2.08 and corresponding R^2 values for these models were as 0.98 and 0.98, respectively.

Economic analysis of walnut production

Economic analysis process was calculated (see Table 8). The total expenditure was 6986.1 \$ ha^{-1} and the gross production value was found to be 14776.4 \$ ha^{-1}. About 71% of the total expenditure was variable costs, whereas 29% was fixed expenditures. Based on these results, the benefit to cost ratio from walnut production in the orchards was calculated as 2.1. The research results were consistent with finding reported by other authors, such as: 2.53 for sweet cherry (Demircan et al., 2006), 2.37 for orange, 1.89 for lemon and 1.88 for mandarin (Ozkan et al., 2004), 1.03 for stake-tomato (Esengun et al., 2007), 0.86 for cotton (Yilmaz et al., 2005), 1.17 for sugar beet (Erdal et al., 2007), 2.58 for greenhouse cucumber (Mohammadi and Omid, 2010) and 1.94 for kiwifruit (Rafiee et al., 2011). The results of this study indicated that although walnut production is a high energy consumer, it is a profitable agricultural operation and

Table 6. Econometric estimation results of energy inputs on yield

Variables	Coefficient	t-ratio	MPP
Model 1:			
$\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + \alpha_8 \ln X_8 + \alpha_9 \ln X_9 + e_i$			
Endogenous variable			
Yield (kg ha^{-1})	-	-	
Exogenous variables			
Constant (α_0)	9.3	5.44^{*}	
Human labour (α_1)	0.39	6.66^{*}	1.83
Machinery (α_2)	0.11	0.19	0.07
Diesel fuel (α_3)	0.03	0.09	0.26
Transportation (α_4)	0.25	2.68^{**}	0.64
Farmyard manure (α_5)	0.27	4.38^{*}	1.23
Chemical fertilizer (α_6)	0.14	2.83^{*}	0.57
Chemical(α_7)	-0.21	-0.19	0.82
Electricity(α_8)	0.12	1.94^{**}	0.56
Water for irrigation(α_9)	0.32	2.34^{**}	1.14
Durbin-Watson	1.87		
R^2	0.98		
Return to scale	1.86		

* Significant at 1% level

**Significant at 5% level

Table 7. Economic estimation results of direct, indirect, renewable and non-renewable energies

Variables	Coefficient	t-ratio	MPP
Model 2: $\ln Y_i = \beta_0+\beta_1\ln DE+\beta_2\ln IDE+e_i$			
Endogenous variable			
Yield (kg ha^{-1})	7.11	7.02*	
Exogenous variables			
Constant (β_0)	6.01	5.93*	
Direct energy (β_1)	0.13	3.26*	1.72
Indirect energy (β_2)	0.24	4.19*	0.19
Durbin-Watson	2.18		
R^2	0.98		
Return to scale	2.16		
Model 3: $\ln Y_i = \lambda_0+\lambda_1\ln RE+\lambda_2\ln NRE+e_i$			
Constant (γ_0)	6.14	6.03*	
Renewable energy (γ_1)	0.15	3.19**	0.83
Non renewable energy ($\gamma_{2)}$	0.27	4.94*	0.76
Durbin-Watson	2.08		
R^2	0.98		
Return to scale	2.07		

* Significant at 1% level

**Significant at 5% level

net return was +2043.7 \$ ha^{-1}, in year of 2009. Productivity expressed by kg \$$^{-1}$ that means each dollars expending in walnut production how much product is produced. In this study productivity was 0.3 kg \$$^{-1}$.

Table 8. Economic analysis of walnut production

Cost and return components	Unit	Walnut
Yield	kg ha^{-1}	2258.4
Sale price	\$ kg^{-1}	0.5
Gross value of production	\$ ha^{-1}	14776.4
Variable cost of production	\$ ha^{-1}	4942.4
Fixed cost of production	\$ ha^{-1}	2043.7
Total cost of production	\$ ha^{-1}	6986.1
Total cost of production	\$ kg^{-1}	0.36
Gross return	\$ ha^{-1}	-9834
Net return	\$ ha^{-1}	2043.7
Benefit to cost ratio	-	2.1
Productivity	kg \$$^{-1}$	0.3

CONCLUSIONS

Based on the present study the following conclusions are drawn:

1. Walnut production consumed a total energy of 15196.1MJ ha^{-1}. The energy input of chemical fertilizers had the largest share (41% of total energy) which was mainly due to nitrogen. The energy inputs of FYM and diesel fuel have the secondary and tertiary share within the total energy inputs. Energy output was calculated as 44454.6MJ ha^{-1}.
2. Energy use efficiency, energy productivity, specific energy, net energy and energy intensiveness of walnut production were 2.9, 0.3 kg MJ^{-1}, 3.4 MJ kg^{-1}, +29258.5 MJ ha^{-1} and 8.18 MJ \$$^{-1}$, respectively.
3. The impact of human labour, FYM, chemical fertilizers, electricity, water for irrigation and transportation energy inputs was significantly positive on yield. The MPP value of human labour was the highest, followed by FYM and water for irrigation energy inputs, respectively
4. Total mean energy input as direct, indirect, renewable and non-renewable forms were calculated to be 4589.5, 10606.3, 4795.6 and 10400.5 MJ ha^{-1}, respectively. The impacts of direct, indirect and renewable and non-renewable energies on yield were estimated as 0.13, 0.24, 0.15 and 0.27, respectively.
5. The benefit–cost ratio was found to be 2.1 in the result of economical analysis of walnut production. The mean net return and productivity from walnut production was obtained as 2043.7 \$ ha^{-1} and 0.3 kg \$$^{-1}$, respectively.
6. Energy management is an important issue in terms of efficient, sustainable and economic use of energy. Energy use in walnut production is not detrimental to the environment due to mainly excess fertilizers use.
7. Training the farmers to consume optimized inputs, digging well and installing pump for on time irrigation, using machinery for field preparing, harvest and post-harvest processes, applying direct and local marketing improves profitability for growers while reducing the amount of energy used and providing more efficient inputs application. Also cultivation of new cultivars

resulting from a selective breeding program in Iran is leading to standard production of walnuts.

8. It can be expected that all these measurements would be useful not only for reducing negative effects to environment, human health, maintaining sustainability and decreasing production costs, but also for providing higher energy use efficiency.

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