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Energy inputs-yield relationship and sensitivity analysis of pistachio (*Pistacia vera* L.) production in Markazi Region of Iran

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Abstract

Pistachio is considered as an important agricultural commodity in Iran and ranks top amongst all exported agricultural products. Conducting an overall energy audit and economic analysis of pistachio production can provide useful information to help implement management strategies for improving energy efficiency. A study was conducted during 2009 and 2010 to evaluate the overall energy inputs and outputs and to perform an economic analysis of pistachio production in the Iranian province of Markazi. The results revealed that the total energy input for pistachio production was 54305 MJ ha^{-1}. Electricity, followed by diesel fuel and nitrogen fertilizer application were the highest contributors to energy input in pistachio orchards. The contribution of direct energy was higher than indirect energy and share of non-renewable energy was more than renewable energy. Net energy, energy use efficiency, energy productivity and specific energy were 7522 MJ ha^{-1}, 0.86, 0.08 kg MJ^{-1} and 13.69 MJ kg^{-1}, respectively. Econometric model based on Cobb-Douglas function indicated that impacts of electricity, diesel fuel and chemical fertilizer energy inputs on pistachio yield were positive while the impact of machinery was negative. The marginal physical productivity (MPP) value for diesel fuel was the highest among other variables, followed by energy inputs related to the chemicals and irrigation water. The results revealed that production of pistachios in Markazi Province, under current management practices, are not energy efficient and efforts should be made to improve energy use efficiency.

Additional key words: econometric model; energy use efficiency; renewable energy; sustainability.

Introduction

Pistachio (*Pistacia vera* L.) is a widely used nut in Iran and across the globe. Due to its origin (Iran), the pistachio tree is well adapted to the climates of many regions in Iran. Pistachio is considered to be an important agricultural commodity in Iran and ranks top amongst exported agricultural products. As Suppl Fig. 1 [pdf online] shows, Iran is ranked first in the World in terms of production and harvested area of pistachio, followed by USA and Turkey (FAO, 2011).

Today's agricultural production relies heavily on the use of non-renewable fossil fuels (Refsgaard *et al.*, 1998). Elevated prices of fossil fuels and the need to reduce greenhouse gas emissions have created a large demand for improved energy use efficiency. Proper energy consumption regard to optimize energy use efficiency can significantly reduce the negative impact of agricultural activities on environmental quality. Moreover, efficient use of energy in agricultural production enhances farm viability, which in turn promotes the sustainability of agricultural production. Therefore, effective use of energy has been considered as a major component of sustainability across various agricultural systems (Pervanchon *et al.*, 2002). The energy analysis can help minimizing the energy inputs

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Abbreviations used: GM (geometric mean); MPP (marginal physical productivity); OLS (ordinary least square).

and therefore enhancing the energy use efficiency and productivity (Mohammadi *et al*., 2010).

Considerable studies have been conducted to determine the energy usage efficiencies of various agricultural products including kiwifruit (Mohammadi *et al*., 2010), olives (Kaltsas *et al*., 2007), apples (Strapatsa *et al*., 2006) and apricot (Esengun *et al*., 2007). Kaltsas *et al*. (2007) studied the energy budget for organic and conventional olive groves to evaluate present situation and deciding best management strategies. Their findings indicated that energy inputs were not affected by the farming system. Mohammadi *et al*. (2010) determined energy use for kiwifruit production in Mazandaran province of Iran and concluded that human power was the most important variable in kiwifruit production followed by irrigation water. Fertilizer and machinery were amongst the other important energy inputs in kiwifruit production. The authors however, are not aware of any reported document addressing the energy balance and analysis for pistachio production in Iran or in other parts of the world.

The current study was conducted in Markazi Province of Iran. According to Iran's Ministry of Agriculture (Anonymous, 2009), pistachio is the most important horticultural product in Markazi province where 20% of the total orchard area in this province is under cultivation of pistachio. This province ranked fourth among pistachio producers in Iran.

The main goal of the study was to document the current status of energy consumption in pistachio production to identify the opportunities for energy conservation. Specifying a relationship between input energy and yield and sensitivity analysis of the energy inputs on pistachio yield as well as economic analysis of pistachio production in Markazi Province were other notable aims of this study.

Material and methods

Site description

The study was carried out in in Markazi Province (34°00" N, 49°40" E), Iran during 2009-2010. The climate of this area is considered semiarid with hot summers and cold winters with annual precipitation of 213 mm. The average annual air temperature is 18.2°C.

Study details

Data were collected from 132 conventional pistachio orchards located in three different distinguished districts including Saveh, Zarandiye and Delijan through face-to-face interview. Although the most crucial materials to be supplied for agricultural researches are sufficient and reliable data in farm records, data gathered by surveys are also suitable and are a dependable method in cases where these records do not exist. Therefore, the application of the survey forms facilitated providing sufficient information for the aims of the study (Gundogmus, 2006).

The orchards were selected primarily due to their close proximity to each other as well as similarity in size and geographical locations. The size of required sample was estimated using the simple random sampling method derived from Yamane technique (Yamane, 1967):

$$n = \frac{(\sum N_h S_h)}{N^2 D^2 + \sum N_h S_h^2} \qquad [1]$$

where n denotes the required sample size; N is the number of holdings in target population; N_h is the number of the population in the h stratification; S_h represents the standard deviation in the h stratification, S_h^2 is the variance of h stratification; $D^2 = d^2 / z^2$; d is the precision where x-X; z is the reliability coefficient (1.96, which represents the 95% reliability).

Since, samples were located in three distinguished districts of the province (Saveh, Zarandiye and Delijan), therefore each district was considered as strata. A survey was conducted in 2009 and 2010 to collect data. The survey was created based on the authors experience and prior discussion with pistachio specialists. The survey was pre-tested using a group of randomly selected farmers, yet the results were not included in the final data set. Farmers' responses were obtained through farm visits over a two-year period and consisted of several in person interviews with producers. It should be noted that the data used in this study is an average of two consecutive growing year data from the same orchards.

Typical cultivation practices in a pistachio orchard in the targeted area are shown in Suppl. Table 1 [pdf online]. The survey for assessing energy consumption covered information about energy inputs included labor, machinery, fuel, electricity, chemical fertilizers, farmyard manure (cow manure), chemicals, and irriga-

Table 1. Energy equivalents used in energy calculation

Input	Unit	Energy equivalents (MJ unit^{-1})	Reference
Human labor	h	1.96	Singh, 2002
Fertilizers			
Nitrogen (N)	kg	60.60	Singh, 2002
Phosphorous (P_2O_5)	kg	11.10	Singh, 2002
Potassium (K_2O)	kg	6.70	Singh, 2002
Manure	kg	0.30	Singh, 2002
Chemical pesticides			
Insecticide	kg	199.00	Hessel, 1992
Fungicides	kg	92.00	Hessel, 1992
Herbicide	kg	238.00	Hessel, 1992
Diesel fuel	L	56.31	Singh, 2002
Pistachio nut	kg	11.80	Kocheki, 1994
Machinery	h	62.70	Gundogmus, 2006
Irrigation water	m^3	0.63	Gundogmus, 2006
Electricity	kWh	11.93	Gundogmus, 2006

tion, whereas output assessment consisted only of nut yield value. The amounts of input and output were calculated per hectare. Using standard energy coefficients, the collected input and output data were converted into energy units before analysis. The energy equivalents of inputs and outputs in pistachio production used in this study are illustrated in Table 1. Beheshti Tabar *et al*. (2010) stated that due to differences in energy calculation methods in spatial and temporal system boundaries, variations in energy equivalents exist. Energy equivalents are not fixed and must be adapted to local conditions (*e.g.* transport distances) and also to changes in the manufacturing methods.

Input energy is classified further to direct and indirect forms. Direct energy consists of energy embodied in labor force, electricity, diesel fuel and irrigation water, whereas indirect energy sources include chemical fertilizers and pesticides, manure, and machinery used in all steps of production. Energy sources are also classified into renewable and non-renewable sources of energy. Renewable energy includes human power, manure and irrigation water, while non-renewable energy sources include diesel fuel, electricity, chemicals, and machinery.

We used several references to determine the value of various energy equivalents (see Table 1). After energy inputs and outputs were determined by using energy equivalents shown at Table 1, energy efficiency, energy productivity, specific energy and net energy were calculated and are presented in Eqs. [2] to [5] (Singh *et al*., 1997; Yilmaz *et al*., 2005).

$$\text{Energy efficiency} = \text{Total energy output (MJ ha}^{-1}) / \text{Total energy input (MJ ha}^{-1}) \quad [2]$$

$$\text{Energy productivity} = \text{Nut yield (kg ha}^{-1}) / / \text{Total energy input (MJ ha}^{-1}) \quad [3]$$

$$\text{Specific energy} = \text{Total energy input (MJ ha}^{-1}) / \text{Nut yield (kg ha}^{-1}) \quad [4]$$

$$\text{Net energy} = \text{Energy output (MJ ha}^{-1}) - - \text{Energy input (MJ ha}^{-1}) \quad [5]$$

Relationship between energy input and yield of pistachio production

In order to specify a relationship between input energy and yield of pistachio production a mathematical function was needed. For this purpose Cobb-Douglass production function was chosen as the best function in terms of statistical significance and expected signs of parameters. This function relation is a power function, which is linear in logs (Heady & Dillon, 1961) and has been used by several authors to investigate the relationship between input energy and production yield (Mohammadi *et al*., 2010; Rafiee *et al*., 2010). The Cobb-Douglass production function is expressed as follow:

$$Y = f(\text{x}) \exp (u) \quad [6]$$

The Cobb-Douglas relation can be rewritten as a linear relationship (taking log on both sides):

$$LnYi = a + \sum_{j=1}^{n} a_j \ln(X_{ij}) + e_i \quad i = 1, 2, ..., n \qquad [7]$$

where Yi denotes the yield of the ith farmer, X_{ij} is the vector of inputs used in the production process, a is a constant term, a_j represents coefficients of inputs which are estimated from the model and e_i is the error term.

Assuming yield is a function of input energies, for investigating the impact of each input energy on pistachio yield, the Eq. [7] can be further expanded to the following form (Rafiee *et al.*, 2010):

$$\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + e_i \qquad [8]$$

where X_i (i = 1, 2, ..., 7) represents input energies from human labor (X_1), total fertilizer (X_2), chemicals (X_3), water for irrigation (X_4), electricity (X_5), machinery (X_6) and diesel fuel (X_7).

In the present study the return to scale index was determined in order to analyze the proportional changes in output due to a proportional change in all of the inputs (where all inputs increase by a constant factor) (Singh *et al.*, 2004). Return to scale is indicated by the sum of the elasticity ($\Sigma\alpha_i$) derived in the form of regression coefficients in the Cobb-Douglas production function. If the sum is more than, equal to, or less than unity, implies that there are increasing, constant, or decreasing returns to scale, respectively. An increasing, constant and decreasing return to scale indicate that when the energy inputs are increased by X value, the yield of pistachio production increases by more than, exactly and less than X value, respectively.

The marginal physical productivity (MPP) method, based on the response coefficients of the inputs was utilized to analyze the sensitivity of energy inputs on pistachio 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 (Rafiee *et al.*, 2010). The MPP of the various inputs was computed using the α_j of the various energy inputs following Singh *et al.* (2004):

$$MPP_{Xj} = \frac{GM\,(Y)}{GM\,(X_j)} \times \alpha_j \qquad [9]$$

where MPP_{Xj} is marginal physical productivity of j_{th} input; α_j, regression coefficient of j_{th} input; $GM\,(Y)$ geometric mean of yield; and $GM\,(X_j)$, geometric mean of j_{th} input energy on per hectare basis. A positive value of MPP for any input variable identifies that the total output (yield) will be increased with any increase in the input; thus, one should not stop increasing the variable input as long as the fixed resource is not fully utilized. A negative value of MPP for any variable input indicates that every additional unit of input diminishes the total output of previous units; therefore, it would be better to keep the variable resource in surplus rather than utilizing it as a fixed resource (Singh *et al.*, 2004).

Basic information on energy inputs and pistachio yields were entered into MS Excel and SPSS v. 18 spread sheet and all estimations were carried out using these softwares.

Results and discussion

Energy inputs

The total consumed energy in pistachio orchards was 54,305 MJ ha^{-1} (Table 2). The top three energy inputs were related to electricity, diesel fuel and nitrogen fertilizer which consumed 39%, 18% and 17% of the total energy inputs, respectively. Using old and inefficient electric motors for pumping irrigation water makes electricity the highest energy demanding input in pistachio orchards. Similarly, Genitsariotis *et al.* (2000) concluded that electricity and fertilizers were responsible for almost 75% of the total energy inputs in conventional olive orchards. Gundogmus (2006) reported that in conventional apricot production diesel fuel (32%) and fungicides (36%) were among the highest energy demanding inputs. In other crops including apple (Strapatsa *et al.*, 2006) and olive (Kaltsas *et al.*, 2007) fuels (22%-71%) and electricity (42%-44%) were reported as the main components of energy inputs followed by fertilizer application (15%-45%). The human labor energy input employed in pistachio production was 1,213 MJ ha^{-1} (Table 2) which was mainly used for harvesting operation, pruning and land and irrigation channels preparation.

Application of chemical pesticides utilized 1,829 MJ ha^{-1} (Table 2) which accounted for 3.3% of the total energy inputs in pistachio orchards. Weeds usually are a significant factor in economic losses of pistachio production, therefore, the energy input related to herbicides consumption was more than twofold compared with fungicides and insecticide combined. Similar to this finding Uhlin (1998) reported 3%, and Zentner *et al.* (1989) found 4%-11% of the total energy

Table 2. Energy input and output for pistachio production

Inputs and Outputs	Quantity used (ha^{-1})	($MJ\ ha^{-1}$)
Human labor (h)		
Land and irrigation channels preparation	67.8	132.9
Fertilizing (chemical and manure)	47.2	92.5
Agricultural combat	32.5	63.7
Irrigation	32	62.7
Pruning	105.7	207.2
Harvest-classification-package	285.5	559.6
Loading-discharging	26	51.0
Transportation	22.3	43.7
Machinery (h)		
Land preparation	17	1065.9
Fertilizing (chemical and manure)	15.3	959.3
Agricultural combat	14.5	909.2
Irrigation	3.2	200.6
Transportation	3	188.1
Fertilizer (kg)		
Nitrogen fertilizer	150	9090
Phosphorus	50	555
Potassium	55	369
Manure (kg)	3000	900
Chemicals (kg)		
Insecticides	2.3	458
Fungicides	1.2	110
Herbicides	5.3	1261
Diesel fuel (L)	182	10236
Electricity (kWh)	1804	21522
Irrigation water (m^3)	8362	5268
Total energy input ($MJ\ ha^{-1}$)		**54305.4**
Outputs (unit)		
Pistachio nut yield ($kg\ ha^{-1}$)	3965	46783
Total energy output ($MJ\ ha^{-1}$)		**46783**

input were associated with pesticide utilization in Swedish and Canadian agricultural sections, respectively. Indeed, due to specific climate conditions of the area in this study, pests and diseases are not usually considered major limiting factors in pistachio production.

About 19% of total energy input (10,014 MJ ha^{-1}) was related to the use of chemical fertilizers. Out of the total chemical fertilizers, nitrogen possessed the biggest share (Table 2). The average energy input for nitrogen fertilizer accounted for 17% of the total energy input in pistachio orchards. Many other reports have also shown that the application of N fertilizer represented a major component of the total energy input in agricultural systems (*e.g.* Zentner *et al.*, 1989; Hülsbergen *et al.*, 2001; Esengun *et al.*, 2007). On the contrary, energy inputs related to manure application was much lower compared to chemical fertilizers. Manure and other natural nutrient resources play a key role in the success of sustainable farming systems (Deike *et al.*, 2008). However, due to insufficient availability, manure price is relatively high and therefore pistachio growers often rely on chemical fertilizers for fertility management. Use of chemical fertilizers as the main source of nutrient and lack of cover cropping systems has caused a significant reduction in organic matter level in majority of agricultural lands in general and in pistachio orchards in particular which consequently has led lowering soil fertility in the country.

Generally, the rate of N application for growing pistachio trees in the targeted area is considerably lower compared with many other fruit trees and crops (for more details see Yilmaz *et al.*, 2005; Pimentel, 2006; Erdal *et al.*, 2007; Esengun *et al.*, 2007). Over application of chemical fertilizers, especially nitrogen, impose negative impacts on environmental quality and human health, as well as on energy use efficiency. These results bring us to the fact that pistachio production in the targeted area, as compared to other agricultural commodities, such as kiwifruit (Mohammadi *et al*., 2010) which are associated with high pollution rates due to chemical fertilizer especially N, imposes a minimal environmental threat.

Table 2 reveals that the contributions of diesel fuel and machinery in pistachio production were 18% and 6% of the total energy input, respectively. Use of machinery in pistachio orchards is mainly for land preparation, manure application when available, and frequent mechanical weeding and spraying.

Energy input related to irrigation water was 9% of the total energy input. Each pistachio orchard in the area has a "water right" permit which enables growers to purchase water for irrigation purposes. It should be noted that all Iranian pistachio orchards, specifically in the targeted region, are located in arid and semi-arid climates with an average of about 250 mm or less annual precipitation. Thus water availability for irrigation plays a unique role in tree production and successful yield performance.

Energy output

The two-year average yields of pistachio nuts were 3965 kg ha^{-1}, which can be translated to 46,783 MJ ha^{-1} (Table 2). Total energy output for other horticultural crops in Iran has been reported as 49,857 MJ ha^{-1} for apple (Rafiee *et al*., 2010) and 46,640 MJ ha^{-1} for kiwifruit (Mohammadi *et al*., 2010).

Forms of energy

The total energy input and its components, including direct and indirect as well as renewable and non-renewable energy forms, are illustrated in Table 3. As expected, the amount of direct energy consumption was higher than indirect energy. The contribution from direct energy input was 68% of the total energy input in pistachio orchards. Also the contribution of non-renewable energy to the total energy input was 86% in the pistachio farms. Other reports similarly indicated that the ratio of direct to indirect energy and the rate of non-renewable energy were greater than that of renewable energy consumption in production of various agricultural commodities (Erdal *et al*., 2007; Kizilaslan, 2009). In developing countries with low levels of technological knowledge the utilization of non-renewable energy sources, is usually high and imposes a serious threat to environment (Fadai, 2007).

Table 3. Total energy input and related components in the form of direct, indirect, renewable and non-renewable energy for pistachio production

Energy input components (MJ ha^{-1})	Quantity	Percentage of the total energy input
Total energy input (MJ ha^{-1})	54,305	—
Direct energy[a] (MJ ha^{-1})	37,026	68
Indirect energy[b] (MJ ha^{-1})	17,279	32
Renewable energy[c] (MJ ha^{-1})	7,361	14
Non-renewable energy[d] (MJ ha^{-1})	46,944	86

[a] Includes human labour, diesel fuel, electricity and water for irrigation energy sources. [b] Includes fertilizers, manure, chemicals and machinery energy sources. [c] Includes human labour, manure and water for irrigation. [d] Includes diesel fuel, electricity, chemicals, fertilizers and machinery.

Energy balance

When studying energy flow in agricultural systems, use of energy balance indicators seems to be indispensable (Deike *et al*., 2008). Energy productivity, intensity and efficiency are based on the sequestered energy of fuels, fertilizers, machinery, human labor, etc. Solar energy, either in form of radiation or heat, was not taken into account for this study, as it is considered to be a free subsidy in the energy analysis of agricultural systems.

The net energy, specific energy, energy use efficiency and energy productivity of pistachio production are calculated and tabulated in Table 4. The energy use efficiency (output energy/input energy) in pistachio production was 0.86 which shows that energy production was lower than energy utilization. Reported output/input ratio for some other plants include 1.06 for lemon, 1.17 for mandarin and 0.96 for cherries. The comparison clearly indicates that the production of pistachio in Iran is considerably less efficient in terms of energy use compared with production of many other horticultural commodities. Net energy (output energy-input energy) was calculated as –7,522 MJ ha^{-1} for pistachio production. Another approach for evaluating energy utilization in crop production is to calculate the specific energy, *i.e.* the

Table 4. Parameters of energy balance for conventional pistachio production

Parameters	Unit	Conventional
Total energy input	MJ ha^{-1}	54,305
Total energy output	MJ ha^{-1}	46,783
Net energy	MJ ha^{-1}	–7,522
Specific energy	MJ kg^{-1}	13.69
Energy use efficiency	—	0.86
Energy productivity	kg MJ^{-1}	0.08

energy required to produce a unit of the product. As shown in Table 4, specific energy in pistachio orchards was 13.69. The energy productivity (the ratio of pistachio produced to the energy inputs in production) of pistachio orchards was 0.08 (Table 4) which indicates that 0.08 units output was obtained per unit input energy. Energy productivity of 0.49 for apple (Rafiee *et al*., 2010), 0.24 for apricot (Esengun *et al.,* 2007) and 0.07 for olive (Kaltsas *et al*., 2010) has been reported by other researchers.

The results of the current study revealed that pistachio production in Iran, under current management practices, is not energy efficient. Relatively low values for the energy balance indicators obtained in this study can be attributed to several reasons. One important reason could be relatively low price of fossil fuel in Iran which is currently subsidized by the government. Because of the low price, growers do not have strong motivation to increase energy use efficiency in their cultural practices. Other reasons for the negative energy balance are low level of technology including non-efficient tractors and irrigation pumps which consume significant amounts of diesel fuel and electricity. Similar issues with low efficiency energy consumption in production of various crops in developing countries, including Iran, have previously been reported (*e.g.* Canakci & Akinici, 2006; Ozkan *et al*., 2007; Mohammadi & Omid, 2010). However, new policies by the Iranian government aim to gradually eliminate subsidization of fossil fuels which may put pressure on growers to implement more energy efficient practices.

Our results indicate that energy inputs for pistachio production in the area due to high consumption of electricity, diesel fuel as well as over application of chemical fertilizers is relatively high. Therefore, efforts to improve the overall energy efficiency should be focused on consumption of these inputs. Choosing better machinery operation to reduce direct usage of diesel fuel, substituting the old electrical pumps with new and more efficient ones for water pumping and more accurate utilization of fertilizers can significantly improve the energy use efficiency without impairing yield or profitability.

Econometric model estimation of energy inputs for pistachio production and sensitivity analysis

Cobb-Douglas function was employed and assessed using ordinary least square (OLS) estimation technique to estimate the relationship between energy inputs and yield of pistachio. Because of using Cobb-Douglas function in the estimation, the coefficient of variables in log form can be regarded as elasticity (Mohammadi & Omid, 2010). For the data used in this study presence of autocorrelation in the residuals from the regression analysis was tested using the Durbin-Watson statistic test (Singh *et al*., 1997; Pishgar Komleh *et al*., 2011). The test result revealed that Durbin-Watson value was 2.25 for Eq. [8], which indicates that there is no autocorrelation at the 5% significance level in the estimated model. The R^2 (coefficient of determination) was 0.91 for this linear regression model, implying that around 91% of the variability in the energy inputs was explained by the model. With respect to the results of assessment of Cobb- Douglass function the impacts of each input, except machinery energy, could be assessed positive on yield of pistachio (Table 5). The regression results of Eq. [8] (Table 5) revealed that the contribution of total fertilizer and electricity are significant at the 1% level. This indicates that an additional use of 1% for each of these inputs would lead to 0.20%, and 0.35% increase in pistachio yield, respectively. The diesel fuel energy contributed significantly to the yield at 5% level. The impact of machinery energy on pistachio yield was not statistically significant. The sum of the regression coefficients of energy inputs was more than unity (2.08), for Eq. [8]. This implied that 1% increase in the total energy inputs would lead in 2.08% increase in the pistachio yield. Thus, there prevailed an increasing return to scale for estimated models. Mohammadi *et al*. (2010) estimated an econometric model for kiwi fruit production in Iran. They reported that the parameters of human labor, machinery, total fertilizer and irrigation water had significant impacts in improving the yield of kiwi fruit. Rafiee

Table 5. Econometric estimation of inputs.

Energy source	Coefficient	t-ratio	MPP
Model 1: $\ln Yi = \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + e_i$			
1. Human labor	0.06	0.59	0.20
2. Fertilizers	0.20	7.4**	0.07
3. Chemicals	0.14	1.1	0.30
4. Irrigation water	0.36	0.71	0.27
5. Electricity	0.35	14.56**	0.06
6. Machinery	–0.05	–0.45	–0.06
7. Diesel fuel	1.02	2.02*	0.39
Durbin-Watson	2.25		
R^2	0.91		
Return to scale	2.08		

* Significance at 5% level. ** Significance at 1% level.

et al. (2010) also concluded that for apple production in Iran, the impact of farmyard manure, irrigation water, electrical energy and chemical fertilizer were significant to the productivity at 1% level.

The sensitivity of energy input was analyzed using the MPP method. The MPP values of model variables are also shown in Table 5. In this analysis, exogenous parameters (energy inputs) having large sensitivity coefficients will have a strong impact on the endogenous variable (pistachio yield). This method identifies the variables that should be considered most carefully for assessing the state of the environmental system, and those environmental factors that should be managed preferentially (Drechsler, 1998). The MPP for diesel fuel, chemicals, irrigation water and human labor inputs were 0.39, 0.30, 0.27 and 0.20, respectively. The results indicate that an increase of 1 MJ in each input of diesel fuel, chemicals, irrigation water and human labor, would lead to an additional increase in pistachio yield by 0.39, 0.30, 0.27 and 0.20 kg ha^{-1}, respectively. The MPP value of machinery was –0.06. A negative value of MPP for any input implies that additional units of the input will contribute negatively to the commodity production. Although, electricity and nitrogen fertilizer were responsible for 39% and 17% of the total energy input, respectively, the MPP values of these inputs were only 0.06 and 0.07, respectively.

The results of the present study can be used to identify efficient form of input application and to determine wasteful usage of energy inputs for improving energy use efficiency and energy conservation in pistachio production.

Conclusions

This study utilized an energy analysis to evaluate the energy flow in pistachio orchards in Saveh region, in Iran. The results revealed that the total energy input for pistachio production was 54,305 MJ ha^{-1}. The energy input related to electricity followed by diesel fuel and nitrogen fertilizer application contributed the highest share of the total energy inputs. The shares of direct energy and non-renewable energy were 68% and 86% of the total energy input, respectively. The results also indicated that the net energy for pistachio production had negative values. This finding indicated that energy was not used efficiently and portions of energy may have been lost. According to econometric model, there were a positive correlation between electricity, diesel fuel and chemical fertilizer energy inputs and pistachio yield while the correlation for machinery was negative. The MPP value of diesel fuel was the highest among other variables, followed by chemicals and irrigation water energy inputs.

It can be inferred from the results that lesser consumption of electricity, diesel fuel and chemical fertilizers are the important keys for energy saving and decreasing the risk of environmental issues in the area. Employ more efficient machinery management, use of modern electricity pumps for irrigation and more accurate fertilizer use management according to soil test and plant requirement as well as more application of manures and other natural sources for fertilizing the soil are among suggestions to improve the energy use efficiency without impairing yield and profitability. Any positive change in energy consumption will bring us one step closer to the sustainability of agricultural production.

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