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Modeling and sensitivity analysis of energy inputs for apple production in Iran

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ABSTRACT

This study was conducted to determine the energy balance between the energy inputs and yield for apple production in Tehran, Iran. For this purpose the data were collected from 56 apple orchards. The following results were obtained from this study: The total energy input of 42819.25 MJ ha^{-1} was required for apple production. The share of diesel fuel by 21.88% of the total energy inputs was the highest energy input. This was followed by farmyard manure (17.66%) and electricity (13.09%), respectively. The energy use efficiency, energy productivity, Specific energy, and net energy were found as 1.16, 0.49 kg MJ^{-1}, 2.06 MJ kg^{-1} and 7038.18 MJ ha^{-1}, respectively. According to the research results, the contribution of direct energy was higher than that of indirect energy; also the share of non-renewable energy was more than that of renewable energy. The results of econometric model estimation revealed that the impact of farmyard manure, water for irrigation, electricity, chemical fertilizer and human labour energy inputs were significantly positive on yield. The results of sensitivity analysis of the energy inputs showed that the MPP value of water for irrigation was the highest, followed by human labour and chemicals energy inputs, respectively.

1. Introduction

Apple is one of the most frequently consumed fruit. Apple constitute an important part of the human diet, as they are a source of monosaccharides, minerals, dietary fibre, and various biologically active compounds, such as vitamin C, and certain phenolic compounds which are known to act as natural antioxidants [1]. The apple is the pomaceous fruit of the apple tree, species *Malus domestica*, belong to the Rosaceae family. The apple tree originated from Central Asia, where its wild ancestor is still found today. Based on the FAO statistics [2], Iran is the 3th largest producer of apple after China and USA, respectively. The production of apple fruit was about 2,660,000 tons/year in Iran and the harvested land area was 202,000 ha in 2008 [2], from which 7% was the share of Tehran province [3].

Agriculture itself is an energy user and energy supplier in the form of bio-energy [4]. Energy has a key role in economic and social development but there is a general lack of rural energy development policies that focus on agriculture [2]. Efficient use of energy is one of the principal requirements of sustainable agriculture. Energy use in agriculture has become more intensive in response to increasing population, limited supply of arable land, and a desire for higher standards of living. Continuous demand in increasing food production resulted in intensive use of chemical fertilizers, pesticides, agricultural machinery, electricity, and other natural resources; however, intensive use of energy causes problems threatening public health and environment. Efficient use of energy in agriculture will minimize environmental problems, prevent destruction of natural resources, and improve sustainable agriculture as an economical production system [5,6]. Wider use of renewable energy sources, increase in energy supply and efficient use of energy can make a valuable contribution to the meeting sustainable energy development targets [7]. The development of energy efficient agricultural systems with low input energy compared to the output of food could help the reduction the emissions of greenhouse gasses in agricultural production systems [8].

The energy input-output analyses are usually made to measure the energy efficiency and environmental aspects. This analysis will determine how efficient the energy is used. Several researches have been conducted on energy use in different agricultural crops [9–19]. Ozkan et al. studied the energy requirements of the input and output in citrus production in the Antalya province of Turkey. Kizilaslan [4] investigated the energy use for cherries production in Turkey. For this purpose he calculated the share of each energy input, output–input energy ratio, energy productivity and shares of energy forms including direct, indirect, renewable and non-renewable. Strapatsa et al. [20] studied energy inputs for integrated apple production, to investigate the most energy consuming operations. Their study was during 1999–2000 period at 26 apple

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Nomenclature

n	required sample size
N	number of holdings in target population
s	standard deviation
D	acceptable error (permissible error was chosen as 5%)
T	confidence limit (1.96 in the case of 95% reliability)
Y_i	yield level of the ith farmer
X_1	labour energy
X_2	machinery energy
X_3	diesel fuel energy
X_4	chemicals energy
X_5	chemical fertilizer energy
X_6	farmyard manure energy
X_7	water for irrigation energy
X_8	electricity energy
e_i	error term
α_i	coefficients of the variables
β_i	coefficients of the variables
γ_i	coefficients of the variables
DE	direct energy
IDE	indirect energy
RE	renewable energy
NRE	non-renewable energy
MPP_{xj}	marginal physical productivity of jth input
α_j	regression coefficient of jth input
GM(Y)	geometric mean of yield
GM(X_j)	geometric mean of jth input energy

orchards in Central Greece. But there is no study about energy sensitivity analysis for apple production in Iran; so the aim of this study was to investigating the input-output energy balance in apple production, specifying a relationship between input energies and yield and sensitivity analysis of the energy inputs on apple yield in Tehran province of Iran.

2. Materials and methods

In this study the data were obtained from 56 apple orchards in 8 villages from Tehran province, Iran. The Tehran province is located within 35°34′ and 35°50′ north latitude and 51°02′ and 51°36′ east longitude. A face-to-face questionnaire was conducted in the production year 2008/2009. For sampling, stratified random sampling method was used. The sample size was calculated using the Neyman method [21,22]:

$$n = \frac{\left(\sum N_h S_h\right)}{N^2 D^2 + \sum N_h S_h^2} \tag{1}$$

where n is the required sample size; N is the number of farmers in the target population; N_h is the number of the farmers in the h stratification; S_h^2 is the variance of the h stratification; d permitted error ratio deviated from average of population $(\bar{x} - \bar{X})$, z is the reliability coefficient (1.96 which represents 95% confidence); $D^2 = d^2/z^2$; the permissible error in the sample population was defined to be 5% within 95% confidence interval. Thus the sample size was calculated to be equals 56, then selection of 56 apple producers from the population were randomly carried out.

In this region the input energy sources for the apple production were human labour, electricity, diesel fuel, machinery, chemicals and farmyard manure; while output energy sources were apple fruit. It must be noted that solar energy, either as radiation or heat, was not taken into account, as it is considered as a free subsidy in the energetic or economic analysis of agricultural systems [23]. The energy equivalent of inputs and output, are shown in Table 1, were used to estimates the energy values.

The input energy in agricultural systems can be divided into direct and indirect or renewable and non-renewable forms. The sources of direct energy include human labour, diesel fuel, electricity and water for irrigation while indirect energy sources include farmyard manure, chemical fertilizer, chemicals and machinery. Renewable energy consists of human labour, farmyard manure and water for irrigation; and nonrenewable energy sources consist of electricity, machinery, diesel fuel, chemicals, and chemical fertilizers. The energy input–output ratio (energy use efficiency), energy productivity, specific energy and net energy were calculated by using the total energy equivalent of inputs and outputs per unit (MJ ha^{-1}) and fruit yield (kg ha^{-1}), using the following equations [27,30]:

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

$$\text{Energy productivity} = \frac{\text{Apple output}\left(\text{kg ha}^{-1}\right)}{\text{Energy input}\left(\text{MJ ha}^{-1}\right)} \tag{3}$$

$$\text{Specific energy} = \frac{\text{Energy input}\left(\text{MJ ha}^{-1}\right)}{\text{Apple output}\left(\text{kg ha}^{-1}\right)} \tag{4}$$

$$\text{Net energy} = \text{Energy output}\left(\text{MJ ha}^{-1}\right) - \text{Energy input}\left(\text{MJ ha}^{-1}\right) \tag{5}$$

In order to specify a relationship between input energies and yield a mathematical function needs to be identified. For this purpose Cobb–Douglass production function was chosen as the best function in terms of statistical significance and expected signs of parameters. The Cobb–Douglass function has been used by several authors to investigate the relationship between input

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

Inputs	Unit	Energy equivalent (MJ unit^{-1})	References
A. Inputs			
1. Human labour	h	1.96	[24,25]
2. Machinery	h	62.70	[26]
3. Diesel fuel	L	56.31	[26,27]
4. Chemicals	kg		
a. Herbicides		238	[5]
b. Insecticides		101.2	[4,5]
c. Fungicides		216	[4,5]
d. Mineral oil		43.2	[17]
5. Chemical fertilizer	kg		
a. Nitrogen		66.14	[4,25]
b. Phosphate (P_2O_5)		12.44	[4,25]
c. Potassium (K_2O)		11.15	[4,25]
d. Sulphur (S)		1.12	[25]
e. Zinc (Zn)		8.40	[20, 28]
6. Farmyard manure	kg	0.3	[4,29]
7. Water for irrigation	m^3	1.02	[25,26]
8. Electricity	kWh	3.6	[4]
B. Output			
1. Apple fruit	kg	2.4	[20]