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Optimization of energy required and greenhouse gas emissions analysis for orange producers using data envelopment analysis approach

Ashkan Nabavi-Pelesaraei [a,*], Reza Abdi [a], Shahin Rafiee [b], Hassan Ghasemi Mobtaker [a]

[a] Department of Agricultural Machinery Engineering, Faculty of Agriculture, University of Tabriz, Tabriz, Iran
[b] Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj, Iran

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ABSTRACT

Data envelopment analysis is a non-parametric method for multi-criteria decision and performance measurement. This approach has two models including constant returns to scale and variable returns to scale model. The main objective of this study was to analyze the efficiency of orchardists, discriminate efficient orchardists from inefficient ones and identify wasteful uses of energy using Data envelopment analysis for orange production in Guilan province of Iran. Also, another purpose of this paper was to determine greenhouse gas emissions for efficient and inefficient orange producers. This method was used based on single output of orange yield and seven energy inputs including human labor, machinery, diesel fuel, chemical fertilizers, farmyard manure, chemical and electricity. The technical, pure technical, scale and cross efficiencies were calculated for orange orchardists using CCR and BCC models. The results indicated that out of the total number of orchardists the share of efficient and inefficient units were 73.3% and 26.7% based on BCC model, respectively. Also, the results revealed the average of technical, pure technical and scale efficiencies of orchardists were 0.894, 0.965 and 0.922, respectively. Energy saving for target ratio was calculated about 13% for orange production in Guilan province of Iran. The energy use efficiency, energy productivity and net energy were improved by 14.7%, 14.4% and 15.4% using optimization of energy. The results illustrated the difference of greenhouse gas emissions between efficient and inefficient units. It was calculated about 19.6%. Also, the electricity has the highest difference of greenhouse gas emissions between efficient and inefficient orchardists for orange production. Generally, the application of data envelopment analysis method can improve energy efficiency and GHG emissions in orange production, significantly.

1. Introduction

Orange production is very important for Iran in terms of both exports and domestic consumption (Ministry of Jihad-e-Agriculture of Iran, 2012). Brazil, United States, China, India and Mexico are the main orange producers. Also, Iran has the thirteenth place of orange production in the world (FAO, 2011). Guilan province of Iran with horticultural crops area of 87533 ha was one of the most important orange producers in 2011 (Ministry of Jihad-e-Agriculture of Iran, 2012). Historically, the efficient use of energy in agriculture did not have a high priority but recently the use of energy resources has increased markedly with advancement in the technology and general agricultural developments (Chaudhary et al., 2009). Effective energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resources preservation and air pollution reduction. Data envelopment analysis (DEA) is a nonparametric method in operations research and economics for the estimation of production frontiers. It is used to empirically measure productive efficiency of decision making units. DEA allows the decision makers to simultaneously consider multiple inputs and outputs, when efficiency of each Decision Making Unit (DMU) is compared to that of an ideal operating unit rather than to the average performance (Zhang et al., 2009). Due to the high advantages of DEA, it has been demonstrated to be effective for benchmarking in different systems involving complex input–output relationships (Zhu, 2003). Moreover in recent years, many authors have applied DEA in agricultural enterprises: Fraser and Cordina (1999) used DEA to evaluate the

* Corresponding author. Tel: +98 4113392776; fax: +98 4113356007.
E-mail addresses: ashkan.nabavi@yahoo.com, ashkan.nabavi91@ms.tabrizu.ac.ir (A. Nabavi-Pelesaraei).

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technical efficiency of irrigated dairy farms in Australia. Mohammadi et al. (2011) applied DEA to determine the efficiencies of orchardists with regard to energy use and saving cost in kiwifruit production activities in Iran. Mousavi-Avval et al. (2011c) did a DEA on a non-parametric method to analyze the efficiency of farmers, to differentiate efficient farmers from inefficient ones and to identify wasteful uses of energy in order to optimize the energy inputs for apple production in Tehran province, Iran. Global warming is the rise in the average temperature of Earth's atmosphere and oceans since the late 19th century and its projected continuation since the early 20th century. A greenhouse gas (sometimes abbreviated GHG) is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. GHG emissions greatly affect the temperature of the Earth (Le Treut et al., 2007). The GHG emissions are increasing in agriculture sector recently. So research on GHG emissions of agricultural production is very important. Pishgar-Komleh et al. (2012) determined energy consumption and CO_2 emissions of potato production in three different sizes of farms in Esfahan province, Iran. The result of this paper revealed total energy consumption and GHG emission of 47 GJ ha^{-1} and 993 kg CO_{2eq}. ha^{-1}, respectively. Also, Soni et al. (2013) presents the energy input–output analyses of different agricultural activities and fresh pond culture (polyculture). Results reveal noticeable variations in energy consumption and CO_2 emissions from various agricultural production activities. The study reveals that the maximum energy consumer is cassava (32.4 GJ ha^{-1}). Transplanted rice provides the highest CO_2 emission (1112 kg CO_{2eq}. ha^{-1}) among crops, in which more than 50% is contributed by methane (CH_4).

This study focuses on the application of DEA to benchmark and rank the productivity performance of orange fruit growers based on the amount of various energy inputs use, and output yield values of orange. A further aim of the study is to determine the GHG emissions for efficient and inefficient orchardists for orange production in Guilan province of Iran.

2. Materials and methods

2.1. Sampling design

Data used in this study were collected from 60 orange orchardist from Langroud city in Guilan province, Iran. This province is located in the North of Iran, within 36° 34′ and 38° 27′ north latitude and 48° 53′ and 50° 34′ east longitude (Ministry of Jihad-e-Agriculture of Iran, 2012). A face-to-face questionnaire was conducted in the production year 2012/2013. The Cronbach method was applied to estimate of reliability of a psychometric test for samples (Cronbach, 1951). The Cronbach's alpha of questionnaire was calculated as 92%. Also, before and after data collection, we consulted regional experts about quality of questionnaire and responses of orchardists, respectively. The simple random sampling method used for estimating the size of required (Kizilaslan, 2009). Thus, the sample size was found to be 52 but it was considered to be 60 to ensure the accuracy.

2.2. Energy analysis

A standard procedure was used to convert each agricultural input and output into energy equivalent (Mousavi-Avval et al., 2012). The selection of Guilan region as the case study was basically due to its major contribution to the orange production in Iran. It also allows more validity to the assumptions of DEA that all units should operate in a relatively homogenous region and, hence, technical efficiency of orchardists will not be adversely affected by climatic and bio-physical constraints (Mohammadi et al., 2011). The data included the quantity of various energy inputs used per hectare of orange production including: human labor, machinery, diesel fuel, farmyard manure, chemical fertilizers, chemical, and electricity; while the orange yield was the single output. The energy equivalents of these inputs and outputs were calculated using the energy equivalent coefficients as presented in Table 1. The energy equivalent of human labor is the muscle power used in field operations of crop production. It should be noted, muscle power is the ability to exert an average energy in one hour of agricultural activities. Chemical and chemical fertilizers energy equivalents means the energy consumption for producing, packing and distributing the materials and they are given on an active ingredient basis. Farmyard manure is regarded as a source of nutrients and no chemicals used in the production process. The energy equivalent of farmyard manure equates with that sum of mineral components energy is released from manure per kilograms. Also, the energy sequestered in diesel fuel and electricity means their heating value (enthalpy) and the energy needed to make their energy available directly to the orchardists (Kitani, 1999; Nagy, 1999; Mousavi-Avval et al., 2011b). Also, descriptive statistics for energy inputs and output in orange production are presented in Table 1. The total energy inputs and production yield were

Table 1
Energy coefficients and energy inputs/output in various operations of orange production.

Inputs (unit)	Energy equivalent (MJ $unit^{-1}$)	Quantity per unit area (ha)	Total energy equivalent (MJ ha^{-1})
A. Inputs			
1. Human labor (h)	1.96 (Mobtaker et al., 2012b)	434	851
2. Machinery (h)	62.7 (Rafiee et al., 2010)	34.2	2150
3. Diesel fuel (L)	56.3 (Barber, 2003)	104	5851
4. Chemical fertilizers (kg)			
(a) Nitrogen	66.1 (Mousavi-Avval et al., 2011b)	142	9425
(b) Phosphate (P_2O_5)	12.4 (Unakitan et al., 2010)	105	1309
(c) Potassium (K_2O)	11.1 (Pahlavan et al., 2011)	284	1309
(d) Sulphur (S)	1.1 (Mousavi-Avval et al., 2011a)	125	140
(e) Ferrum (Fe^{2+})	6.3 (Akbarpour, 2013)	1.63	10.3
5. Farmyard manure (kg)	0.3 (Demircan et al., 2006)	1735	520
6. Chemical (kg)			
(a) Pesticides	199 (Ozkan et al., 2004)	1.25	249
(b) Fungicides	92 (Ozkan et al., 2004)	3.8	350
7. Electricity (kWh)	11.9 (Mobtaker et al., 2010)	131	1559
The total energy input (MJ)			25582
B. Output			
1. Orange (kg)	1.9 (Ozkan et al., 2004)	24750	47025
Total energy output (MJ)			43922