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Investigation of CO_2 emission reduction and improving energy use efficiency of button mushroom production using Data Envelopment Analysis

Rahim Ebrahimi*, Marzie Salehi

Department of Agriculture Machine Mechanics, Shahrekord University, P.O. Box 115, Shahrekord, Iran

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ABSTRACT

Data Envelopment Analysis (DEA) is a linear programming based frontier estimation technique for measuring the relative efficiencies of a homogenous set of Decision Making Units. This approach has two models including constant returns to scale and variable returns to scale model. In this study energy use pattern and CO_2 emission of button mushroom production in Isfahan province of Iran was studied and the degrees of technical and scale efficiency of producers were analyzed using DEA technique. Technical, pure technical, scale and cross efficiencies were calculated using CCR and BCC models for producers. The results revealed that, the total amount of CO_2 emission was 23.84 and 32.86 kg CO_{2eq} m^{-2} in efficient and inefficient farmers, respectively. Total optimum energy requirement was found to be 812.75 MJ m^2; showing that 88.07 MJ m^{-2} of input energy could be saved if the producers follow the results recommended by this study. Optimization of energy use improved the energy use efficiency, specific energy and net energy by 13.3%, 9.38% and 10.06%, respectively.

1. Introduction

Energy is used in almost all facets of living and in all countries, and makes possible the existence of ecosystems, human civilizations and life itself. Agriculture is one of the most important sectors, which consumes and supplies energy in the form of bio-energy (Ozkan et al., 2004). Energy use in agriculture has developed in response to increasing populations, limited supply of arable land and desire for an increasing standard of living. In all societies, these factors have encouraged an increase in energy inputs to maximize yields, minimize labor-intensive practices, or both (Esengun et al., 2007). Efficient use of energy in agriculture is one of the principal requirements of sustainable development; it will minimize environmental problems, prevent destruction of natural resources, and promote sustainable agriculture as an economical production system (Rafiee et al., 2010). There are several parametric and non-parametric approaches to measure the efficiency in agricultural productions; based on the literature, the indicators of energy ratio and specific energy in crop production systems have been used to evaluate the efficiency and performance of farms (Kuesters and Lammel, 1999; Esengun et al., 2007; Cetin and Vardar, 2008; Mohammadi and Omid, 2010; Mousavi-Avval et al., 2011a,b; Tabatabaie et al., 2013).

In production efficiency is defined as the ratio of the sum of weighted outputs to the sum of weighted inputs or as the ratio of the actual output to the optimal output. The weights for inputs and outputs are estimated to the best advantage for each unit so as to maximize its relative efficiency (Mukherjee, 2008). Efficiency measurement has been a subject of tremendous interest as organizations have struggled to improve productivity.

Data envelopment analysis (DEA) is a non-parametric method in operations research and economics for the estimation of production frontiers (Charnes et al., 1994). It is a data-oriented method for measuring and benchmarking the relative efficiency of peer decision making units (DMUs) with multiple inputs and multiple outputs (Zhu, 2002). One of the advantages of the DEA method is that it requires neither a priori weights nor explicit specification of functional relationships among the multiple outputs and inputs (Huang and X.Li, 1996). In addition, DEA is a data-driven frontier analysis technique that floats a piecewise linear surface to rest on top of the empirical observations (Cooper and Seiford, 2006). Due to the high advantages of DEA, it has been used in different issues (Athanassopoulos and Shale, 1997; Sheldon, 2003; Galanopoulos et al., 2006; Onut and Soner, 2006; Wei et al., 2007; Bozoglu and Ceyhan, 2009; Lygnerud, 2010; Assaf et al., 2011). In recent years, many authors have applied DEA in agricultural researches: Bames

* Corresponding author. Tel./fax: +98 3814424428.
E-mail address: Rahim.Ebrahimi@gmail.com (R. Ebrahimi).

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Nomenclature

ACE	Average cross efficiency
BCC	Bankere Charnese Cooper (DEA model)
CCR	Charnese Coopere Rhodes (DEA model)
CRS	constant returns to scale
DEA	data envelopment analysis
DMU	decision making unit
ESTR	energy saving target ratio
GHG	greenhouse gas
PTE	pure technical efficiency
SE	scale efficiency
TE	technical efficiency
VRS	variable returns to scale

(2006), identified the technical efficiency scores of Scottish dairy farms by applying the non-parametric method of DEA. In another study, DEA was employed to evaluate the efficiency of individual producers and to identify the efficient units for citrus production in Spain (Reig-Martínez and Picazo-Tadeo, 2004). Also, Chauhan et al. (2006) applied DEA approach to determine the efficiency scores of paddy producers with regard to six input parameters of human labor, diesel, seed, farmyard manure, fertilizers and machinery energy inputs and the paddy yield as output parameter. Mohammadi et al. (2011) used DEA approach to improve the energy efficiency of producers and to identify the wasteful uses of energy in kiwifruit production in Iran. In this study the average values of technical, pure technical and scale efficiencies of producers were 0.942, 0.993 and 0.948, respectively. Also the results revealed that 12.2% of input energy could be saved if the producers follow the results recommended by this study. Pahlavan et al. (2012) applied DEA approach to Optimize of energy consumption for rose production. The results revealed that about 43.59% of the total input energy could be saved without reducing the rose yield. Mobtaker et al. (2012) employed the DEA technique to analyze the efficiency of producers and discriminate efficient producers from inefficient ones for alfalfa production in Hamedan province, Iran. In this study it was found that, from the total of 80 producers, considered for the analysis, 46% and 69% were found to be technically and pure technically efficient, respectively. Button mushroom (Agaricus bisporus) contains high levels of dietary fibers and antioxidants including vitamin C, D, and B_{12}; folates; and polyphenols (Fukushima et al., 2000). It is produced on a composted substrate consisting of various raw materials including wheat straw, chicken manure, nitrogen and gypsum. In Iran from 2001 to 2012, button mushroom production increased from 6997 tonnes to 57,932 tonnes from which about 10% is produced in Isfahan province (Anonymous, 2012).

In this study, the energy use pattern for button mushroom production in Isfahan province of Iran was investigated and the DEA technique was applied to analyze the technical and scale efficiencies of producers, discriminate efficient producers from inefficient ones, recognize target energy requirement and wasteful uses of energy in order to optimize the energy inputs (human labor, diesel fuel, machinery, electricity, chemicals, compost and water) for button mushroom production.

2. Materials and methods

The study was done in Isfahan province which covers an area of approximately 1 million hectare and is situated in the center of Iran; within 30°04′ and 34°27′ north latitude and 49°36′ and 55°31′ east longitude. The data used in the study were collected from 22 greenhouses using a face–to–face questionnaire during November–December 2012 period in Isfahan province of Iran and the Cronbach method was applied to estimate of reliability of a psychometric test for samples (Cronbach, 1951). The face-to-face interview, also called an in-person interview, is probably the most popular and oldest form of survey data collection. It has continued to be the best form of data collection when one wants to minimize non response and maximize the quality of the data collected. In a face-to-face survey, an interviewer is physically present to ask the survey questions and to assist the respondent in answering them. The questionnaires included total energy inputs from different sources and yield weight. The inputs used in the production of button mushroom were specified in order to calculate the energy equivalences in the study. Inputs in button mushroom production were in the form of human labor, diesel fuel, compost, machinery, chemicals, electricity and water; while the button mushroom yield was the single output. The sample size was calculated using the Cochran method (Snedecor and Cochran, 1989). Also each producer was called a Decision Making Unit (DMU).

The results of study in the field of modeling of energy and assessment of input costs have been published by the author previously and the summarized results of the study are presented in Table 1 (Salehi et al., 2014). In the last column of Table 1, the standard deviation values for the inputs and output used in Button mushroom are presented. As can be seen from the this table, there was wide variation in the quantity of energy inputs and output for button mushroom production, indicating that there is a great scope for optimization of energy usage and improving the efficiency of energy consumption for button mushroom production in the region.

Demand in increasing food production resulted in intensive use of chemical fertilizers, diesel fuel, agricultural machinery, and other natural resources. Global Warming is the increase temperature of Earth's atmosphere due to effect of greenhouse gases, such as carbon dioxide emissions from burning fossil fuels or from deforestation, which trap heat that would otherwise escape from Earth. One of the world's greatest fears is that warming will endanger global agricultural and food production. The amounts of greenhouse gas (GHG) emission from inputs in button mushroom production per square meter were calculated by using CO_2 emission coefficient of agricultural inputs in the literature (Table 2). These coefficients were used in several studies (Pishgar-Komleh et al., 2012; Mobtake et al., 2013). The amount of produced CO_2 was calculated by multiplying the input application rate (machinery, diesel fuel, chemicals and electricity) by its corresponding emission coefficient that is given in Table 2.

Table 1
Amounts of inputs, output and energy equivalents used for button mushroom production.

Inputs (unit)	Quantity per unit area (m^2)	Total energy equivalent (MJ m^{-2})	SD[a]
A. Inputs			
1. Human labor (h)	2	3.57	0.79
2.Diesel fuel (l)	7.27	409.66	202.32
3.Compost (kg)	87.5	444.29	85.68
4.Machinery (kg)	0.76	4.36	2.17
5.Chemicals (kg)	0.01	1.49	0.93
6.Electricity (kWh)	10.32	37.19	16.3
7.Water (m^3)	0.21	0.22	0.06
Total energy input (MJ)		900.8	
B.Output			
1. Button mushroom (kg)	15.7	25.45	2.57

[a] Indicates standard deviation of energy inputs (MJ m^{-2}) and button mushroom yield (kg m^2).

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