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Research paper

Applying data envelopment analysis approach to improve energy efficiency and reduce greenhouse gas emission of rice production

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ABSTRACT

The main purpose of this study is to apply non-parametric method of data envelopment analysis (DEA) for optimization of energy inputs and reduction of greenhouse gas (GHG) emission for rice production in Guilan province of Iran. For these aims, 120 rice producers were selected for data collection in Astaneh Ashrafiyeh city of Guilan province. In this paper, seven energy inputs and rice yield as output were considered for DEA method. The technical, pure technical and scale efficiency were determined based on Charnes-Cooper-Rhodes (CCR) and Banker-Charnes-Cooper (BCC) models. The average of technical, pure technical and scale efficiency were calculated as 0.79, 0.98 and 0.81, respectively. The results revealed 35 (29.17% of total units) and 72 (60% of total units) rice producers were efficient in technical and pure technical efficiency, respectively. The total energy saving was estimated about 19.80%. Also, the highest share of contribution to the total savings energy was calculated as 43.41% for diesel fuel. The energy use efficiency was improved about 25% by converting present farms to target units. Furthermore, the GHG emission of each input was investigated for present and optimum units. The results indicated that the total GHG emission of present and optimum farms was calculated as 1847.26 and 1483.52 $kgCO_{2eq.}\ ha^{-1}$, respectively. Moreover, the effect of energy optimization in reduction of GHG emission was found to be as 363.74 $kgCO_{2eq.}\ ha^{-1}$. With respect to DEA method, the diesel fuel consumption of efficient units had the highest effect to helping for GHG reduction.

1. Introduction

Rice (*Oryza sativa*) is the hugely important food crop for the world's population, especially in East, South, Southeast Asia, the Middle East, Latin America, and the West Indies. It is the grain with the second highest worldwide production, after maize (Zea mays) (FAO, 2011). Food security, which is the condition of having enough food to provide adequate nutrition for a healthy life, is a critical issue in the developing world. About 3 billion people, nearly half of the world's population, depend on rice for survival. In Asia as a whole, most of the population consume rice in every meal. In many countries, rice accounts for more than 70% of human caloric intake. In Asia in total, just over 30% of all calories come from rice (Pishgar-Komleh et al., 2011). Rice is one of the most important grain crops cultivated in Iran. Also, Iran is one of the major rice producers in the Middle East. In Iran, the share of rice production is very high (about 33%) in Guilan province (Ministry of Jihad-e-Agriculture of Iran, 2014). Energy use is of great concern within agricultural productions, due to both associated environmental effects and the cost of inputs. Efficient use of energy within farming systems is critical for reducing the environmental footprints of energy inputs in food production, and so, providing sustainable agricultural production. Improving energy use efficiency is becoming increasingly important for combating rising energy costs, depletion of natural resources and environmental deterioration (Dovì et al., 2009). Data envelopment analysis (DEA) is a non-parametric technique of frontier estimation which has been used and continues to be used extensively in many settings for measuring the efficiency and benchmarking of decision making units (DMUs) (Adler et al., 2002). Big advantage of DEA is that it does not need any prior assumptions on the underlying functional relationships between inputs and outputs (Seiford and Thrall, 1990). One of the most important issues in recent century is the global warming, and greenhouse gas (GHG)

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emission is the main factor of this happening (Sefeedpari et al., 2013). Use of fossil energy has some harmful effects on environment such as global warming. Nowadays, global warming and exhaustion of fossil resources are also the major concern which is related to energy consumption. The carbon cycle in nature is basically balanced, but the artificial emission of CO_2 by the combustion or disintegration of fossil resources and other organic matters is the cause of the increase in CO_2 in the air (Pishgar-Komleh et al., 2012). In similar study, Chauhan et al. (2006) studied to determine the efficiencies of farmers with regard to energy consumption using non-parametric method DEA approach in rice production activities in the alluvial zone in the state of West Bengal in India. Their results revealed about 11.6% of the total input energy could be saved if the farmers follow the input package recommended by the study. Nassiri and Singh (2009) determined energy use efficiency by paddy crop DEA technique in India. Their results disclosed that small farmers had high energy-ratio and low specific energy requirement as compared to larger ones at paddy farms. In another study, Khai and Yabe (2011) estimated technical efficiency of rice production in Vietnam country. Their results illustrated the average of technical efficiency was calculated as 0.816. Mousavi-Avval et al. (2011a) applied DEA method to estimate the energy efficiencies of soybean producers based on eight energy inputs including human labor, diesel fuel, machinery, fertilizers, chemicals, water for irrigation, electricity and seed energy and single output of grain yield. In another research, Sefeedpari et al. (2012) applied DEA to determine the technical efficiency in industrial dairy farms in Tehran province of Iran. Their results revealed the efficiency of farmers were calculated as 0.88 and 0.93 for constant and variable returns to scale models, respectively. However in recent years, many authors applied DEA in agriculture but few of them investigated the amount of GHG emission. Khoshnevisan et al. (2013a) examined energy use efficiency and reduction of CO_2 in greenhouse cucumber production using a non-parametric production function. Nabavi-Pelesaraei et al. (2014) optimized the energy required by DEA method and determined the effect of energy optimization on GHG emission for orange production. In another study, Khoshnevisan et al. (2014) utilized DEA method to comparison of energy consumption and GHG emission for open field and greenhouse strawberry production.

The main objectives of this study were to determine the energy use efficiency, wasteful uses and target energy requirement and to identify the effect of energy optimization on GHG emission for rice production in Guilan province of Iran.

2. Materials and methods

2.1. Sampling design

Initial data used in the DEA analysis comprised information on rice producers in the Astaneh Ashrafiyeh city of Guilan province, Iran. The data for the study were taken from 120 farmers growing rice by using A face-to-face questionnaire method in the production year 2012/2013. Several villages were selected for collecting data with homogenous condition (climatic conditions, topography, soil type, etc). The main drawbacks of deterministic frontier models-both non-parametric and parametric models are that they are very sensitive to outliers and extreme values, and that noisy data are not allowed (Pahlavan et al., 2011). The data of questionnaires covered the input energy recourses encompassed in rice production from different sources such as human labor, machinery, diesel fuel, chemical fertilizer, farmyard manure, biocide, electricity and seeds, rice yield weight as an output, age, level of knowledge, and the experience of farmers. 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 (Nabavi-Pelesaraei et al., 2014). The average size of the studied farms has been found to be 2.5 ha. For sampling, stratified random sampling method was used. In this paper, the Neyman method was applied to calculate sample size (Yamane, 1967). So, the research sample size was found to be 111 but it was considered to be 120 to ensure the accuracy.

2.2. Energy equivalents of inputs and output

The quantity of inputs used per hectare is demonstrated in Table 1. Then, these input data were multiplied by the coefficient of energy equivalent, which were taken from other related researches (Pishgar-Komleh et al., 2012). Accordingly, In last column of Table 1, the total energy equivalent of each input is illustrated. The results revealed total energy inputs was calculated about 51,430 MJ ha^{-1} (with the standard deviation of 18103.86). With respect to rice yield, the total energy outputs estimated about 66,387 MJ ha^{-1} (with the standard deviation of 17533.98).

2.3. Data envelopment analysis (DEA)

DEA is a method to estimate non-parametric efficiency frontiers in multi-product and multi-input systems. DEA involves the use of linear programming to build a non-parametric surface over the data; thus, efficiency measures are calculated relative to this surface or frontier (Alzamora and Apiolaza, 2013). In DEA application, a unit can be made efficient either by reducing the input levels and getting the same output (input orientation), or symmetrically, by increasing the output level with the same input level (output orientation). The input-oriented analysis is becoming more common in DEA applications because profitability depends on the efficiency of the operations. In this paper, we adopt an input-oriented DEA approach for efficiency estimation. This approach was deemed to be more appropriate because there is only one output while multiple inputs are used; also as a recommendation in agricultural production, input conservation for given outputs seems to be a more reasonable logic (Zhou et al., 2008); so, rice production yield is hold fixed and the quantity of source wise energy inputs can be reduced.

Comparison of DEA approach and parametric approach (Regression Analysis) showed in Fig. 1 where the case of seven DMUs with single inputs and single outputs is considered. The

Table 1
Energy coefficients and energy inputs/output in various operations of rice 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., 2012a)	740.67	1451.71
2. Machinery (h)	62.70 (Rafiee et al., 2010)	15.15	949.75
3. Diesel fuel (l)	56.31 (Barber, 2003)	407.41	22941.36
4. Chemical fertilizers (kg)			
(a) Nitrogen	66.14 (Mobtaker et al., 2012a)	113.91	7534.12
(b) Phosphate (P_2O_5)	12.44 (Unakitan et al., 2010)	402.57	5007.94
(c) Potassium (K_2O)	11.15 (Pahlavan et al., 2011)	210.89	2351.48
5. Biocides (kg)			
(a) Herbicides	85 (Pishgar-Komleh et al., 2012)	10.84	921.22
(b) Insecticides	199 (Ozkan et al., 2004)	7.85	1562.33
(c) Fungicides	92 (Ozkan et al., 2004)	2.72	250.44
6. Electricity (kWh)	11.93 (Mobtaker et al., 2010)	436.95	5212.78
7. Seed (kg)	14.7 (Kitani, 1999)	220.87	3246.83
The total energy input (MJ)			51429.95
B. Output			
1. Rice (kg)	17 (Kitani, 1999)	3905.13	66387.22