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Applying optimization techniques to improve of energy efficiency and GHG (greenhouse gas) emissions of wheat production

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ABSTRACT

In this study a non-parametric method of DEA (Data Envelopment Analysis) and MOGA (Multi-Objective Genetic Algorithm) were used to estimate the energy efficiency and greenhouse gas emissions reduction of wheat farmers in Ahvaz county of Iran. Data were collected using a face-to-face questionnaire method from 39 farmers. The results showed that based on constant returns to scale model, 41.02% of wheat farms were efficient, though based on variable returns to scale model it was 53.23%. The average of technical, pure technical and scale efficiency of wheat farms were 0.94, 0.95 and 0.98, respectively. By following the recommendations of this study, 3640.90 MJ ha^{-1} could be saved (9.13% of total input energy). Moreover, 42 optimal units were found by MOGA. The total energy required and GHG (greenhouse gas) emissions of the best generation of MOGA were about 23105 MJ ha^{-1} and 340 $kgCO_{2eq.}$ ha^{-1}, respectively. The results revealed that the total energy required of MOGA was less than DEA, significantly. Also, the GHG emissions of present, DEA and MOGA farms were about 903, 837 and 340 $kgCO_{2eq.}$ ha^{-1}, respectively.

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the oldest agricultural crops that are cultivated around the world in order to produce grain for bread, animal feed and industrial uses [1] and also wheat has the second rank after maize in the world cereal output [2]. This plant as a staple food for half of the world's population is very important, therefore shall be considered as a strategic crop [3]. The agriculture sector, like other sectors, has become increasingly dependent on energy resources such as electricity, fuels, natural gas and coke. This increase in energy use and its associated increase in capital intensive technology can be partially attributed to low-energy prices in relation to the resource for which it was being substituted [4]. Intensive energy consumption as well as reducing the known energy resources is the key factor to develop the philosophy of optimum energy consumption. Optimum use of energy helps to achieve increased production and contributes to the economy, portability and competitiveness of agricultural sustainability of rural communities [5]. DEA (Data Envelopment Analysis) is a non-parametric technique of frontier estimation which is used extensively in many settings for measuring the efficiency and benchmarking of DMUs (decision making units). The main advantage of non-parametric method of DEA compared to parametric ones is that it assumes neither a preconceived functional relationship imposed between inputs and outputs, nor the prior information about weights of inputs and outputs in contrast to parametric statistical approaches [6]. The enhancement of the greenhouse effect leads to increasing Earth-surface temperatures and global climate change. Global climate change and population growth are placing new pressures on food production systems; demanding increases food security while safeguarding the natural resources by reducing the environmental footprints [7]. The reduction of energy consumption is tantamount to reduction of GHG (greenhouse gas) emissions in agricultural activity; because both items have direct relationship with input usage in agricultural activities. Several investigations had been done on energy use

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optimization and GHG emissions reductions using DEA such as: Khoshnevisan et al. [8] investigated the optimization of energy consumption and GHG emissions reduction for wheat production. Nabavi-Pelesaraei et al. [9] determined and compared the efficient and inefficient orange producers in terms of energy consumption and GHG emissions. They determined the effect of energy optimization on GHG emissions for converting inefficient units to efficient ones. In another study, the DEA method was applied to improve energy efficiency and GHG emissions in rice production [10]. MOGA (Multi-Objective Genetic Algorithm) has been the main method for optimization in recent years. The genetic algorithm is an example of a search procedure that uses random selection for optimization of a function by means of the parameters space coding. The genetic algorithms were developed by Holland [11] and the most popular references are perhaps Goldberg [12] and a more recent one by Bäck [13]. Hematian et al. [14] optimized the energy consumption for wheat production using genetic algorithm. In another study, Nabavi-Pelesaraei et al. [15] applied MOGA for optimization of energy consumption and greenhouse gas emissions of orange production and compare this method with DEA.

With considering lack of any study on optimization of energy use efficiency and GHG emissions together in wheat production by using DEA and MOGA, attempts have been made to determine the technical, pure technical and scale efficiency in DEA and offer suitable model for wheat farms in Iran. Therefore, the present study was undertaken to discriminate efficient farmers from inefficient ones and optimize the energy inputs and GHG emission reduction on wheat production in the Ahvaz county of Iran.

2. Materials and methods

2.1. Sampling design

This study was conducted in December 2012 in the Ahvaz county of Khuzestan province, Iran. This province is located within 29° 58′ and 32° 58′ north latitude and 47° 42′ and 50° 39′ east longitude and the height of 24 m above the sea level [16]. The surveyed region had homogenous conditions with regards to climatic conditions, topography and soil type. The location of studied area is displayed in Fig. 1. The initial data were collected from wheat farmers using face-to-face questionnaire in the production year 2012/2013. A questionnaire form used in this study was designed to collect the required information related to various inputs use (fuel, electricity, fertilizers and pesticides, etc.), the amount of land under cultivation by farmers, crops yield, total working hours of labors, total working hours of machinery and equipment, etc.

According to the report of Ministry of Jihad-e-Agriculture of Iran [16], there were 80 wheat farms in area of study. So, for ease of computation, reduce errors and save time and costs, a simple random sampling method was used to determine sample size and the farms were chosen randomly from study area. This method is expressed as below [17]:

$$n = \frac{N(s \times t)^2}{(N-1)d^2 + (s \times t)^2} \tag{1}$$

Where, n, is the required sample size; s, is the standard deviation; t, is the t value at 95% confidence limit (1.96); N, is the number of holding in target population and d, is the acceptable error (permissible error 5%). So, the sample size was calculated 39 farms.

2.2. Energy equivalents of inputs and output

In this study, gathered data include the quantity of the following eight energy input sources used per hectare: human power, machinery, diesel fuel, chemicals, fertilizer, water, seed and farmyard manure. Wheat yield production and wheat straw data were collected as energy outputs. The data were calculated for 1 ha and

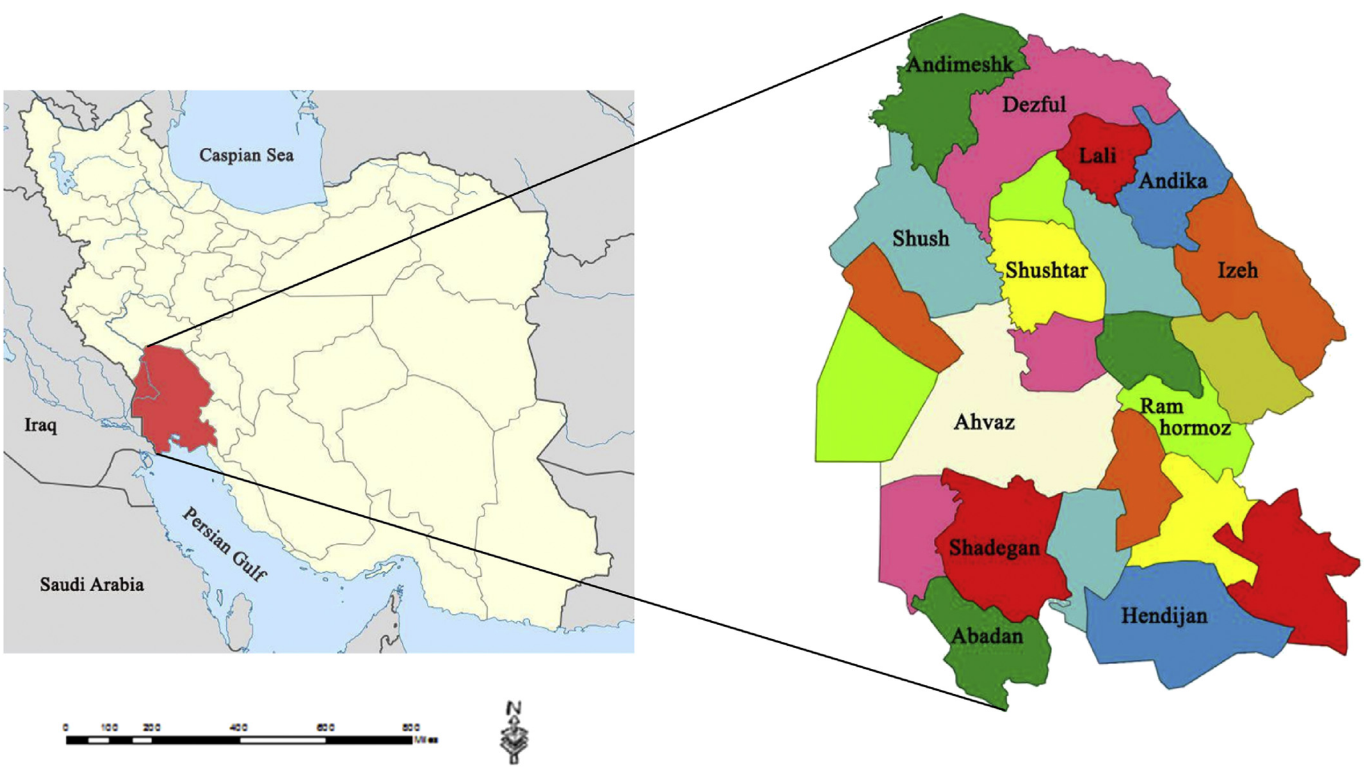

Fig. 1. Location of the studied area in the southwest of Iran.