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Determining efficiency of energy input for silage corn production: An econometric approach

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ABSTRACT

This study was undertaken to analyze the energy consumption patterns of silage corn production, the corresponding GHG emissions, the relationships between energy inputs and outputs, and the sensitivity of yield-to-energy inputs, using the Cobb–Douglass econometric model and MPP (Marginal Physical Productivity) in the Fars province of southwest Iran. Although the average amount of inputs and outputs were analyzed, 20% of the maximum and minimum values were also reported as cluster 1 (C1) and cluster 2 (C2) farmers. The results showed that around 45–68 GJ/ha energy was needed to produce 67–85 ton ha^{-1} of silage corn. According to the MPP, the most effective inputs on the yield were human power, chemicals and seed energy inputs, since the yield had the highest sensitivity to these three inputs. Three energy input scenarios were proposed based on the average, minimum and maximum energy consumptions; i.e. *LEI* (Low Energy Input), *MEI* (Medium Energy Input) and *HEI* (High Energy Input) scenarios. The lowest energy and yield were consumed and produced in the *LEI*, respectively. The output–input energy ratio, energy productivity and kg yield per kg CO_2 were highest in the *LEI*, although higher energy and yield were used and produced in the *MEI* and *HEI*, respectively.

1. Introduction

Different sources of energy are used in agriculture to produce food for the increasing population [1,2]. Energy is applied directly, mainly through diesel engines in farm operations and for pumping water. The indirect energy, which is not applied within the farm gate, are consumed in the formulation, storage and distribution of farm inputs, such as fertilizers and chemicals [3,4]. Agriculture can be regarded as both an energy consumer and producer. Higher yields per unit area are obtained in modern agriculture largely through the external supply of energy, especially fossil fuels [5,6]. In the coming decades, the world will face the challenge of increasing energy efficiency and saving fossil fuels to reduce the negative impact of burning fossil fuels on the environment [7–9]. The gradual reduction of the availability of fossil fuels, and their increasing costs, will inevitably create problems for global agriculture. It is possible to reduce the amount of fossil fuels used in agriculture by various methods that aim to conserve resources as well as use more effective cultivation techniques [10]. Renewable sources of energy such as solar, wind, geothermal and biofuels have a high potential of reducing dependency on fossil fuels and emitting lower GHGs [11–14]. In addition to economic benefits, there are social and environmental advantages to reducing energy consumption, such as preserving fossil fuel supply and minimizing global warming. The limited availability of energy, particularly from fossil fuels, has led researchers to assess the energy-use-efficiency of different crops in different regions [15–21]. Energy-use analysis is an important step in making appropriate energy policies [22,23]. A more efficient use of energy inputs will result in lower GHG emissions and environmental footprints [24,25].

It is essential to determine how different inputs affect crop growth, especially in agronomy. Finding the relationships between energy input and yield is necessary in order to focus on the most effective inputs to use and, consequently, to reduce waste. Furthermore, the sensitivity of crop output to each energy input can be determined by suitable econometric models [1,26].

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Corn (for grain and silage) is a strategic crop in Iran as a main source of feed in poultry production and animal husbandry. The Fars province in southwest Iran is the top corn producer in the country [27]. Accordingly, two main objectives of this study were: 1) to evaluate the energy efficiency of silage corn production, and 2) to determine a suitable econometric model to estimate the appropriate energy input for silage corn production. To meet these objectives, the efficiency of energy use and related equivalent carbon emission were investigated by energy and environmental indices (See Section 2.1. for the methodology and Sections 3.1 and 3.2 for the results).

Next, the suitable econometric model was estimated based on the energy inputs and output (see Section 2.2) by applying different statistical analyses (see Section 2.3). In the econometric analysis, the well-known Cobb–Douglas production function was used to determine the relationships between energy inputs and silage corn yield. Afterwards, the MPP (Marginal Physical Productivity) measure was employed to determine the sensitivity of yield to each energy input, which in turn is helpful for determining which energy inputs are most effectively increased or decreased (see Section 2.2 for the methodology and Sections 3.3 and 3.4 for the results). Finally, three scenarios for using energy were proposed according to current energy inputs and outputs in Section 3.5.

2. Methodology

This study was carried out to assess appropriate energy inputs in silage corn production and the sensitivity of yield to energy inputs in the Fars province. The province is located within 27° 03′ and 31° 40′ north latitude and 50° 36′ and 55° 35′ east longitude.

The farmers were selected through a simple random sampling without replacement. The desired sample size of farms was calculated by Eq. (1) [28]:

$$n = (N \times Z^2 \times p \times q)/(N \times d^2 + Z^2 \times p \times q) \quad (1)$$

where:

- n is the required sample size;
- N is the number of holdings in target population;
- Z is the reliability coefficient (1.96 which represents the 95% reliability);
- p is equal to 0.5;
- q is equal to 0.5;
- d is the precision ($\bar{x}-\bar{X}$) which is equal to 0.07 in this study.

Accordingly, 194 farmers were chosen from a total of 2780.

2.1. Analyses of energy use and related CO_2 emissions

An eight-page questionnaire was designed to gather data related to silage corn production. The amount of each input, including fertilizers, chemicals, human power, diesel fuel for farm operations and water pumping, water and seed was calculated per hectare and multiplied by its energy equivalent (Table 1) to account for the total energy use in MJ/ha.

The amount of indirect energy input in the manufacturing of farm machines was estimated by Eq. (2) [33]:

$$ME = \frac{EG}{T\,W}\left(\text{MJ ha}^{-1}\right) \quad (2)$$

where:

- ME is the indirect energy used in the farm machinery manufacturing, MJ ha^{-1};
- E is the cumulative energy demand for machinery, MJ kg^{-1};
- G is the total weight of the specific machine, kg;
- T is the life time of machinery until replacement is required, h.
- W is the Effective field capacity in ha h^{-1}.

Common energy indices were employed to assess efficiency of energy inputs [30]:

$$\text{Energy ratio} = \frac{\text{energy output (MJ/ha)}}{\text{energy input(MJ/ha)}}\ \text{(dimensionless)} \quad (3)$$

$$\text{Specific energy} = \frac{\text{energy input (MJ/ha)}}{\text{yield output (kg/ha)}}\ \text{(MJ/kg)} \quad (4)$$

$$\text{Energy productivity} = \frac{\text{yield output (kg/ha)}}{\text{energy input (MJ/ha)}}\ \text{(kg/MJ)} \quad (5)$$

$$\text{Net energy gain} = \text{energy output} - \text{energy input (MJ/ha)} \quad (6)$$

These indices express the efficiency of energy used in a system. However, they cannot reveal the environmental risks of energy inputs.

The equivalent CO_2 from each energy input was calculated using available data given in Table 1. The amount of yield per kg emitted CO_2 was determined as follows:

$$(I_{GHG}) = \frac{Y}{\sum_{j=1}^{n} CI}\ \text{(dimensionless)} \quad (7)$$

where:

- $(I_{GHG})_A$ is the index of average kg yield per kg CO_2;
- Y is the yield, kg ha^{-1};
- $\sum_{j=1}^{n}CI$ is the total CO_2 from energy inputs, kg ha^{-1};
- j = 1, 2,..., n is the number of energy inputs.

Since the index shows kg yield per kg CO_2, different groups of farmers or systems can be easily compared with regard to environmental risks of energy inputs. This index can be considered as corresponding to the energy productivity index, but also contains the environmental risk of production.

2.2. Econometric model of silage corn production

The relationship between energy inputs and silage corn yield was investigated using the Cobb–Douglass production function. The Cobb–Douglas and Translog are two common econometric models used to estimate the relationships between inputs and output [37]. The Cobb–Douglas model in the power form is [26]:

$$Y_i = a\prod_{j=1}^{n} x_{ij}^{\propto_j} e_i^u \quad (8)$$

where:

- y_i is the yield of i^{th} farmer;
- a is the constant term;
- x_{ij} is the vector of inputs;
- $\propto_j$ is the coefficients of inputs;
- e_i^u is the error term;
- i = 1, 2,..., K is the number of farmers;
- j = 1, 2,..., n is the number of inputs.