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Comparison of energy consumption and GHG emissions of open field and greenhouse strawberry production

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A B S T R A C T

The greenhouse areas in Iran have expanded rapidly and the greenhouse holders have shown a great tendency to cultivation of those crops that used to be cultivated in open fields. Although, greenhouses are intensive in terms of yield and whole year production, they are considered being one of the major contributors to greenhouse gases (GHG) emissions in the agricultural sector. In the present study strawberry cultivation in greenhouses (GH) and open fields (OF) was selected as a representative of those crops which can be grown in both systems. Initial data were randomly collected from 70 OFs and 33 GHs in province of Gilan, Iran. Energy consumption and GHG emission of two different strawberry production systems were compared. Moreover, energy use efficiency of GH producers due to more energy consumption was studied, then degrees of technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) were determined using data envelopment analysis (DEA). Additionally, the amount of energy inputs wasted in inefficient greenhouses was assessed and energy saving was computed. Furthermore, the effect of energy optimization on GHG emission was investigated and the total amount of GHG emission was calculated. The total average of energy input and output was estimated at 35,092.4 MJ ha^{-1} and 10,405.9 MJ ha^{-1} for OF production and, similarly, 1,356,932.8 MJ ha^{-1} and 137,772.4 MJ ha^{-1} for GH strawberry production. Total GHG emission was calculated as 803.4 kg CO_{2eq} ha^{-1} and 35083.5 kg CO_{2eq} ha^{-1} for OF and GH production, respectively. Based on the evaluations 20.2% (273,902.8 MJ ha^{-1}) of overall energy sources can be saved if the performance of inefficient farmers is enhanced. Optimizing energy in the greenhouse production can result in a significant reduction in total GHG emission and the present emission of GHG can be reduced to the value of 29309.1 kg CO_{2eq} ha^{-1}.

Contents

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1. Introduction

Intensive agriculture is meant to achieve maximum production with the minimum cropping surface, as in the case of greenhouse cultivation. In recent years, the area covered by intensive cropping systems has been expanded (plastic mulch, plastic tunnels and plastic greenhouses) in response to the demand of developed countries for year-round fresh products [1]. An agricultural greenhouse consists of frames of either metallic or wooden structure covered with a transparent material in which crops are grown under favorable and controlled environmental conditions. Open field agricultural practices have no control on the environment parameters such as sunlight, air composition and temperature that affect the plant growth. Hence, a large number of winter vegetables, flowers and other horticultural crops have to be transported from distant places [2].

In the period of 2002–2007, greenhouse areas of Iran were expanded from 3380 ha to 6630 ha including an increasing rate of 96%. The shares of greenhouse crops production were as follows: vegetables 59.3%, flowers 39.81%, fruits 0.54% and mushroom 0.35% [3]. In recent years, strawberry production has drawn the attention of the most greenhouse holders due to its gross value of production and nutrient value [4]. In Iran, strawberry is widely cultivated in the open fields in some provinces such as Kurdistan and Gilan and also it is grown in greenhouses in some other regions. Some of these areas are appropriate for open field strawberry production, but greenhouse holders of these areas show tendency to grow this crop in their greenhouses. Greenhouses are considered as intensive farming system from productive point of view; however they are the most important energy consumers in the agricultural sector. More energy consumption causes numerous environmental problems of which global warming and greenhouse gases (GHG) are regarded as the most important ones.

Energy is a fundamental component in the process of economic development, as it provides imperative services that maintain economic activities and the quality of human life. Thus, shortages of energy are a serious constraint on the development of low income countries [5]. Increase in the use of energy inputs in agriculture has led to numerous environmental problems like high consumption of non-renewable energy resources, loss of biodiversity, pollution of the aquatic environment by the nutrients nitrogen and phosphorus as well as pesticides [6]. Energy input–output analyses are usually applied to investigate the energy use efficiency and determine the environmental facets of inefficient energy consumption. Several studies have been conducted on energy use in open field and greenhouse production [3,5,7–12], whereas, a few studies have been published on energy analysis and GHG emission of agricultural crops [13].

Therefore, this study was conducted with the following objectives: (a) to estimate energy consumption in open field and greenhouse strawberry production; (b) to compare energy ratio and other energy indices of these two different systems; (c) to assess GHG emission of open field and greenhouse strawberry cultivation and (d) to find some solutions to reduce waste of energy and GHG emission in the inefficient systems.

2. Materials and methods

2.1. Data collection and processing

The present study was carried out in province of Gilan, Iran. Data were collected from rural areas of Rasht (The capital of Gilan province; a province in the north of Iran next to the Caspian Sea) in 2011/2012 production year. The annual average rainfall in above-mentioned area is almost 1100 mm. The soil analysis illustrated that the structure of soil was clay and clay loam. The reason for selecting this area was to investigate whether either of the cultivation systems; open field or greenhouse strawberry production, was reasonable from energy consumption and GHG emission point of views.

The sample size was determined using Cochran technique [5]. Based on this sampling method, 70 open field owners and 33 greenhouse holders were chosen and inquired using face-to-face questionnaire method.

Energy inputs for strawberry production included human labor, chemical fertilizers, farmyard manure (FYM), diesel fuel, electricity, natural gas, biocides, machinery and water for irrigation. In other words, the same energy inputs with different application rates were used in both open-field and greenhouse production except natural gas which is only used in greenhouses by heating system. For both systems, the amount of produced strawberry was considered as output energy. In agricultural production such as greenhouse strawberry production the produced crops are the main outputs of the production process. Produced crops contain protein, carbohydrate, and fat considered as sources of energy for human beings. Therefore, the term output energy is widely used for the outputs of agricultural production. For instance lemon contains 14.1 kJ/g protein, 35 kJ/g fat, and 10.4 kJ/g carbohydrate. Energy equivalents of inputs and outputs were exercised to assess the total energy input and output.

One of the problems of this methodology of energy analysis is unifying criteria for assigning amounts of energy to each input. The lack of reliable data for each country or region forces the researcher, in many cases, to take values from other countries for which circumstances are different. But this problem is not crucial when the comparison is made within the same region and for a specific region they can be merely applied to allow the possibility of comparing different farms from energy consumption point of view. The conversion factor of each input material was estimated based on the amount of energy which was used during manufacturing process. For instance, the production and the repair of farm machinery are important issues in the total energy balance. Accordingly, several steps should be included in calculating this energy. First, the energy used in producing the raw materials (like steel, 22–60 MJ/kg); second, the quantity of energy required in the manufacturing process (mean value of these two first steps, 87 MJ/kg); third, the transportation of the machine to the consumer (estimated, 8.8 MJ/kg); and fourth, the energy sequestered in repairs. Due to the fact that the calculation of these factors is beyond the scope of the present study, these conversion factors were extracted from previous studies and are summarized in Table 1.

The amount of rainfall in the studied region is high, so rainfall can provide some parts of plants' water need in OF production and the rest is provided by agricultural wells. Water for irrigation was extracted from agricultural well by electrical pumps. Energy needed for pumping water was calculated as Eq. (1) [14]:

$$\mathrm{DE} = \frac{\gamma \mathrm{gHQ}}{\varepsilon_{\mathrm{p}} \varepsilon_q} \tag{1}$$

where 'DE' presents direct energy (J/ha), 'g' is acceleration due to gravity (ms^{-2}), 'H' is total dynamic head (m), 'Q' is volume of required water for one cultivating season (m^3 ha^{-1}), 'γ' is density of water (kg m^{-3}), 'ε_p' is electrical pump efficiency (44% calculated) and 'ε_q' is total power conversion efficiency (18–20%) [5,14].

The energy ratio can be used to illustrate the relationship between energy inputs and output. A rise in the energy ratio indicates improvement in energy efficiency with good environmental performance and vice versa [15]. By employing the energy equivalents of inputs and output (Table 1) energy indices – the energy ratio (energy use efficiency), energy productivity, specific