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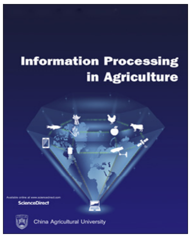

Energy-use pattern and carbon footprint of rain-fed watermelon production in Iran

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The analysis of energy-use patterns and carbon footprint is useful in achieving sustainable development in agriculture. Energy-use indices and carbon footprint for rain-fed watermelon production were studied in the Kiashahr region of Northern Iran. Data were collected from 58 farmers using a self-structured questionnaire during the growing season of 2013. The Cobb–Douglas model and sensitivity analysis were used to evaluate the effects of energy input on rain-fed watermelon yield. The findings demonstrated that chemical fertilizers consumed the highest percentage of total energy input (75.2%), followed by diesel fuel (12.9%). The total energy input was 16594.74 MJ ha^{-1} and total energy output was 36275.24 MJ ha^{-1}. The results showed that the energy-use ratio was 2.19, energy productivity was 1.15 kg MJ^{-1}, energy intensity was 0.87 MJ kg^{-1}, and net energy gain was 19680.60 MJ ha^{-1}. Direct and indirect energy for watermelon production were calculated as 2374.4 MJ ha^{-1} (14.3%) and 14220.3 MJ ha^{-1} (85.7%), respectively. The share of renewable energy was 1.4%. This highlights the need to reduce the share of non-renewable energy and improve the sustainability of rain-fed watermelon production in Northern Iran. The study of carbon footprint showed that the chemical fertilizer caused the highest percentage of greenhouse gas emissions (GHG) followed by machinery with 52.6% and 23.8% of total GHG emissions, respectively. The results of the Cobb–Douglas model and sensitivity analysis revealed that increasing one MJ of energy input of human labor, machinery, diesel fuel, chemical fertilizers, biocides, and seed changed the yield by 1.03, 0.96, 0.19, −0.97, 0.16, and 0.22 kg, respectively, in the Kiashahr region of Northern Iran. Providing some of the nitrogen required for crop growth through biological alternatives, renewing old power tillers, and using conservation tillage machinery may enhance energy efficiency and mitigate GHG emissions for rain-fed watermelon production in Northern Iran.

1. Introduction

Watermelon (*Citrullus lanatus*) is a popular melon mainly grown in warmer regions of the world. Its fruit, juice, and seeds are used for human nutrition. The therapeutic properties of watermelon, attributed to its antioxidant compounds, have been reported previously [1,2].

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Due to increased food demands for the world's growing population, energy use in the agricultural sector has increased [3]. The main drawbacks to increased energy consumption are inadequate energy sources, high production costs, incorrect supply allocation, and increased national and international competition in agricultural trade [4]. Therefore, the study of energy patterns in the agricultural sector helps evaluate the efficiency and environmental impact of production systems [5]. Iran is among the 10 countries that emit the greatest amount of CO_2 in the world [6]. The agricultural sector in this country emits approximately 36.5% of the total N_2O emission and 2% of CO_2 and CH_4 [6,7]. Therefore, along with attention to energy-use efficiency in agriculture, the environmental impact of agricultural activities should be more carefully considered. Previous works have examined energy-use patterns and carbon footprint. Pishgar-Komleh et al. [8] analyzed the energy consumption and GHG emission of cotton production in Iran and found that the total GHG emission was 1195 kg CO_2 eq ha^{-1}, with machinery input and diesel being the most important inputs. Khoshnevisan et al. [9] studied the energy audit and carbon footprint of wheat production in the Isfahan province of Iran. The electricity and chemical fertilizers contributed most to energy consumption for wheat production in the Isfahan province of Iran. Electricity contributed most to the carbon footprint of wheat production (74%), followed by chemical fertilizers (14%). Soltani et al. [10] studied the energy use and GHG emissions resulting from wheat production in the Gorgan province of Iran, reporting a total energy input of 15.58 GJ ha^{-1}. They suggested that conservation tillage and improved nitrogen management would reduce energy use and GHG emissions. Sefeedpari et al. [11] demonstrated that sugarcane production in the Haft-Tappeh sugarcane agro-industrial company in Iran used a total energy input of 198 GJ ha^{-1} and the energy ratio was 1.18. The greatest share of energy consumption was from electricity (39%). The GHG emissions of diesel fuel consumption could be reduced by alternative tillage systems, such as reduced and minimum tillage practices. Bartzas et al. [12] compared the energy consumption and environmental impacts of lettuce and barely production in Italy and Spain in both open field and greenhouse cultivations. They used life cycle assessment (LCA) and cumulative energy demand (CED) methodology to assess the environmental impacts and energy consumption, respectively. The impacts of open-field cultivations were reported to be higher than those of greenhouse cultivations.

Moradi et al. [13] compared energy-use indices of full and reduced irrigated systems for seedy watermelon production in northeast Iran. The reduced irrigation system was more energy efficient than the full irrigation system (4.08 and 1.17, respectively), attributable to lower energy input, particularly of water and chemicals. Nabavi-Pelesaraei et al. [14] investigated the energy-use and GHG emissions of irrigated watermelon production at different farm levels in the Chaf region, Guilan province, Iran. No significant differences between energy efficiency and GHG emissions among different farm sizes (small (<1 ha), medium (1–3 ha), and large (>3 ha)) were observed. Nitrogen fertilizer has been identified as the most important input in terms of the output–input energy ratio and GHG emissions, followed by diesel fuel for applying farm machinery and electricity for pumping irrigation water. Khoshnevisan et al. [15] also evaluated the environmental impacts of watermelon production using life cycle assessment (LCA) and multi-objective genetic algorithm (MOGA) in Kerman province of Iran. They reported that the use of LCA + MOGA revealed that a reduction of 27% in respiratory inorganics and 35% in global warming and non-renewable energy use can take place if a proper combination of resources is used in the cultivation.

Until today, to the best of our knowledge, there has been no research on energy-use patterns and GHG emissions for watermelon production under rain-fed agro-systems. The aim of the current study is to analyze the energy-use pattern and carbon footprint of watermelon production by the dry farming system in the Kiashahr region of Northern Iran.

2. Materials and methods

2.1. *Case study and sample selection*

Kiashahr is located at Northern Iran (37°25′ N and 49°56′ E; Fig. 1). Its annual rainfall was reported as 1496 mm in 2013. Peanut, rice, bean, and melons constitute the main agricultural products of this region. Watermelon is the most important melon cultivated by the rain-fed production system in this agricultural region. The data for rain-fed watermelon production inputs were collected from regional watermelon producers using a questionnaire structured to measure prevalent cultivation practices and common inputs. General inputs in watermelon production include human labor, machinery, diesel fuel, chemical fertilizers, biocide, and watermelon seed. Tillage operations are performed by moldboard plow, disc harrow, and tractor operated rotovator. Planting and harvesting operations are conducted manually; weeding is performed by power tiller operated comb harrow.

A sample of 58 farmers was selected using stratified random sampling. The Cochran method was used to determine sample size [16]:

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

where n = required sample size; s = standard deviation, t = reliability coefficient (1.96 that indicates the 95% reliability); N = number of holdings in target population; d = permissible error (5% for a 95% confidence interval) which was calculated from Eq. (2):

$$d = \frac{t \times s}{\sqrt{n}} \quad (2)$$

2.2. *Energy analysis*

The energy equivalent of different inputs and output (Table 1) was used to estimate the energy values. The human energy as an energy input was calculated by multiplying the number of man-hours (h ha^{-1}) by estimated power rating of human labor (MJ h^{-1}) from Table 1. Energy used for machinery was calculated by multiplying the time of using the machinery by its corresponding energy equivalent. Other inputs, including the diesel fuel, watermelon seed, and chemicals were converted to equivalent energy values (MJ ha^{-1}) by multiplying