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Contribution of Production Inputs to Energy Consumption in Wheat Production System for Providing a Solution to Improve Energy Consumption

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P A P E R I N F O

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A B S T R A C T

Energy analysis is crucial for improving the energy efficiency of agricultural systems. In this research, the input and output energy of an irrigated wheat production system were determined. For reaching this goal, 110 farmers were asked to complete the questionnaires in which cultivation information such as machinery, diesel fuel, grain produced per hectare, cultivation method, the method and the duration of water supply, workers, chemical materials which were used for plant treatment. The results showed that the total input energy for producing irrigated wheat was 42,481 MJ.ha^{-1}. Energy efficiency was achieved as 1.56, suggesting that the total output energy of the system was more than the input energy. The net output energy, indicating the rate of obtained net energy from the system, was 23,819 MJ.ha^{-1}. Electricity and fertilizer were the inputs consuming the most energy in an irrigated wheat production system, in which 41% and 31% of the total consumed energy were devoted to electricity and fertilizer, respectively. Therefore, the appropriate management of electricity and fertilizer can result in the improvement of the energy efficiency of the system. Reducing seed bed preparing operations (decrease diesel fuel consumption) may also increase the energy efficiency of the wheat production system.

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INTRODUCTION

Increased demand for agricultural products and production resource constraints - especially the limitation of cultivable areas - has made the highest yield per unit area which is the main goal of agricultural producers [1]. Since energy efficiency is a key factor for reaching sustainability [2] and also energy has a direct impact on the efficiency of crop production, a sustainable crop production system needs to be analyzed according to input and output energy to determine the total consumed energy for production per unit area [3].

Green plants, as the starting point of the energy cycle in nature, need specific substances to enable them to transform radiation energy into chemical energy in the form of carbohydrates. Supplying plants with their needs also requires energy. The close relationship between plant growth and energy has turned agriculture into an energy consumption system, in which high levels of energy consumption are inevitable for high-yield production [4].

However, increasing consumption of inputs, including herbicides, diesel fuel, fertilizer, machinery and human labour not only increases the cost of crop production but can also result in environmental pollution. Therefore, the utilization of energy resources must be made as efficient as possible. To achieve this goal, a production system should be analyzed regarding input energy and output energy. However, it should be noted that environmental conditions are also effective in energy efficiency of agronomical systems, where in region with high precipitation, lower irrigation is needed, resulting in lower energy consumption. Under higher precipitation, temperature is also lower, leading to better growth of crops [5].

Shahin et al. [6] reached to this result that machinery and diesel fuel were the inputs consuming the highest amount of energy in wheat production. They also

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observed that greater energy consumption did not result in more wheat production. Yilmaz et al. [7], working with the energy efficiency of cotton fields, concluded that the input exhibiting the greatest energy consumption was diesel fuel, followed by human labour and machinery. Canakci et al [8] observed that more than 60% of the total input energy of a sugar beet production system was devoted to irrigation. They also concluded that omitting consumed energy for irrigation can result in the increased energy efficiency of a sugar beet production system by more than two-fold. It is reported that the energy efficiency of potato production fields depends upon the degree of the mechanization of the production system [9]. Although mechanization of agricultural system improve the production, the increase in mechanization, increased the energy demand in agriculture as well [10]. However, for wheat production in dryland farming, reducing input energy has considered as main factor for improving energy efficiency [11].

The return of energy in a crop production system is related to different factors, including plant species, the kind of tillage system, the type of machinery, the mechanization rate of the production system and the size of farm [12, 13]. Therefore, the current experiment sought to analyze the energy flow of the irrigated wheat production system for the possible improvement of the energy efficiency of the system

MATERIAL AND METHODS

In the current research, input energy of irrigated wheat production system, including seed, machinery, fertilizer, irrigation, electricity, diesel fuel and human labor and, also grain yield as output energy were determined and analyzed. As the first step of the research, the size of the sample was measured according to the following equation [14]:

$$n = [N.t^2.s^2] / [Nd^2+t^2s^2] \quad (1)$$

In which, n was the size of the needed sample, N was the number of farmers who produce wheat, s^2, was the variance of the character, t was the CC (coefficient of the confidence which was considered as 1.96) and d was the observed difference between community and estimation (its value was taken as 0.05)

Regarding the above equation, the sample size was achieved 110 producers. Accordingly, 110 farmers in Ramhormoz region (Southwest Iran, with 46° 36´ N, 31° 16´ E and 150 m above sea level) were asked to complete the questionnaires in which cultivation information such as machinery, fuel, grain produced per hectare, cultivation method, the method and the duration of water supply, workers, chemical materials which were used for plant treatment.

Energy indices of the system were calculated using Table 1 and following equations:

$$\text{Energy ratio} = \text{energy output/ energy input} \quad (2)$$

$$EP = YP / EI \quad (3)$$

In which EP is energy productivuty, YP is yield produced and EI in energy input.

$$\text{Net output energy} = EO - EI \quad (4)$$

In which EO is energy output and EI is energy input.

The data of the research were statistically analyzed, according to t-student test with application of MSTAT-C statistical software.

RESULTS AND DISCUSSION

Calculating the input energy for producing irrigated wheat in terms of human labour, diesel fuel, fertilizer (nitrogen, phosphorous and potassium), seeds, herbicides, machinery and electricity, revealed that electricity (to supply water for irrigating the farm) and fertilizer (providing plants with required nutrient elements) were the inputs which consumed the most energy (Table 1), with 41% and 31% of the total consumed energy devoted to electricity and fertilizer, respectively (Figure 1).

Irrigating water was supplied from subterraneous water resources, resulting in a high consumption of electricity for water pumping. However, the appropriate management of irrigation through the use of advanced methods of irrigation, accurate seedbed levelling, the cultivation of drought-tolerant cultivars would be helpful in reducing electricity consumption and, as a result, increasing the energy efficiency of the system [16]. Fertilizer, with a total energy consumption of 13,287 $MJ.ha^{-1}$, had a significant effect on the total input energy of the system (Table 2 and Figure 1). Furthermore, high

Table 1. Energy equivalent of input and output of irrigated wheat

Input	Energy equivalent	Unit	Reference
Wheat seed	15.7	$MJ.kg^{-1}$	[15]
Machineries	62.5	$MJ.kg^{-1}$	[17]
Diesel fuel	56.3	$MJ.lit^{-1}$	[17]
Nitrogen fertilizer (N)	66.1	$MJ.kg^{-1}$	[18]
Phosphorus fertilizer (P_2O_5)	12.4	$MJ.kg^{-1}$	[18]
Potassium fertilizer (K_2O)	11.2	$MJ.kg^{-1}$	[18]
Herbicides	102.0	$MJ.l^{-1}$	[19]
Human labor	1.96	$MJ.h^{-1}$	[14]
Electricity	11.9	$MJ.kW^{-1}$	[15]

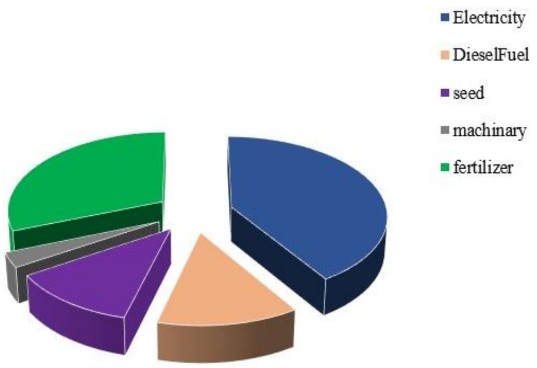

Figure 1. Effect of on different input on total consumed energy of irrigated wheat production system (human labor and herbicide effects on total input energy was less than 0.2% and, thus, were dispensed)

levels of fertilizer can result in destructive environmental effects, especially underground water pollution. Thus, indiscriminate use of fertilizer should be avoided by appropriate agricultural management, such as crop rotation and precision agriculture for the accurate determination of plant nutrient requirements. The proper use of fertilizer has been reported as an effective aspect in improving the energy efficiency of maize production systems [20].

Although electricity and fertilizer exhibited the highest levels of energy consumption for irrigated wheat production, diesel fuel energy consumption was also considerable, whereby 13% of the total input energy was allocated to diesel fuel (Figure 1) in relation to planting and harvesting machinery. Increasing the energy efficiency of irrigated wheat production systems is possible by decreasing diesel fuel through lower machinery use, especially during the seedbed propagation stage. Tabatabaeefar et al [21], working on the effect of the tillage system on the energy output of wheat fields, concluded that the highest energy efficiency was obtained when no-tillage was used as a planting system. They also reported that no-tillage and minimum tillage not only had grain-yield advantages but also that they increased the energy efficiency of the production system through diminishing the application of fuel and machinery.

The input energy of seeds was almost equal to diesel fuel (Table 2 and Figure 1). Certified seeds and appropriate seedbed preparation represent forms of agricultural management which can improve the seed germination percentage and, as a result, decrease the input energy through lower levels of seed sowing. However, in the current research, high-quality seeds with optimum seed germination and seedling emergence were used, suggesting that the energy efficiency of an irrigated wheat production system cannot be improved by seed management

Since most of the irrigated wheat planting and harvesting operations were carried out using machinery, the input energy of human labour was very low (namely 82 kJ.ha^{-1}, which was 0.19% of the total consumed energy) (Table 2). The chemical pesticides used in the cultivation of irrigated wheat were herbicide, the input energy of which was 55 MJ.ha^{-1}, or 0.12% of total input energy. However, this low level of input energy could be decreased by suitable management, such as crop rotation.

According to the results, the total output energy (66,300 kJ.ha^{-1}) of the irrigated wheat production system was more than the input energy (42 484 kJ.ha^{-1}) (Figure 2). In other words, 23,819 kJ.ha^{-1} was recorded as the net output energy (Table 3). The energy efficiency (the ratio of the total output energy to the total input energy of the system) was 1.56 (Table 3), which showed the usefulness of the system in terms of energy. However, lower energy efficiency of the system in comparison with the findings of Sayin et al [22], suggested that more agronomical management is essential for achieving high level of efficiency in energy use under the irrigation condition of wheat production. The results also showed that only 0.12

Table 2. Input and output energy of irrigated wheat

Input	Unit	Energy equivalent	Input energy	Total energy (Mj.ha^{-1})
Human labor	h	1.96	42	82
Diesel fuel	l	56.3	99	5573
Nitrogen fertilizer (N)	kg	66.14	182	12038
Phosphorus fertilizer (P_2O_5)	kg	12.44	92	1145
Potassium fertilizer (K_2O)	kg	11.15	16.5	104
Seed	kg	15.7	330	5181
Herbicide	l	238	1	55
Machinery	h	62.5	18	1125
Electricity	kWh	11.93	1200	17179

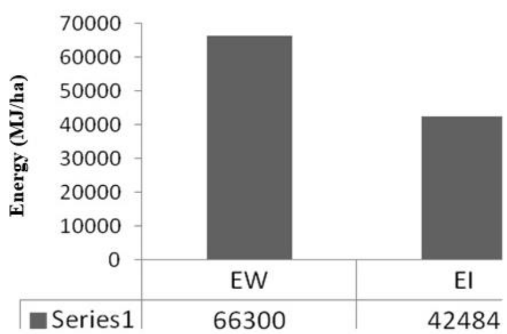

Figure 2. Total energy output (EW) and total energy input (EI) of irrigated wheat production system

Table 3. Energy indices of irrigated wheat production system

Energy indices	Unit	Recorded value
Energy efficiency	---	1.56
Net output energy	$MJ.ha^{-1}$	23819
Energy productivity	$kg.MJ^{-1}$	0.12

kg of grain was produced per kJ of energy (energy productivity) (Table 3). Considering the results, whereby the most energy consumption was observed for electricity and fertilizer, it is necessary to decrease the consumed energy of the entire system by reducing the current inputs. On the other hand, fuel and pesticides are also manageable inputs, such that decreasing the consumed energy in these two inputs can improve the efficiency of the production of irrigated wheat and - in other words – the production of more crops by the consumption of each unit of energy. Findings for barley revealed that reduction in the consumption of diesel fuel and chemical fertilizers (such as nitrogen and phosphorous) offered the greatest possibilities for energy saving [23] which are compatible with the findings of this research. Biomass can be considered as a source for improving soil nutrient and, thus, reducing fertilizers application, because of lower price, renewable and no secondary pollution [24, 25]. However, this issue needs more researches.

CONCLUSION

Electricity, fertilizer, diesel fuel and seeds were the inputs consuming the most energy. The energy efficiency of wheat field can be meliorated by decreasing the consumed energy though the suitable management of electricity, fertilizer and diesel fuel. Water pumping for the supply of irrigating water from subterraneous water resources resulted in high levels of electricity consumption, necessitating the appropriate management of water consumption through the use of advanced methods of irrigation, accurate seedbed levelling, and the cultivation of drought-tolerant cultivars for the reduction of electricity consumption. The strong effect of fertilizer on the energy efficiency of an irrigated wheat production system implicated the exigency of soil fertility maintenance through agricultural management, such as suitable crop rotation and the use of legume plants for their biological nitrogen fixation. Although the highest input energy was observed for electricity and fertilizer, the consumption of diesel fuel was also considerable. Therefore, the management of recent inputs through the decreased use of agricultural machines improves the efficiency of production in terms of energy consumption. Using conservative tillage systems, including no-tillage and minimum tillage, is therefore recommended.

CONFLICT OF INTEREST

The author declares that he has no conflict of interest.

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Persian Abstract

چکیده

تحلیل انرژی برای بهبود کارآیی انرژی در سیستم‌های کشاورزی ضروری است. در این تحقیق، انرژی ورودی و خروجی یک سیستم تولید گندم آبی تعیین شدند. برای این هدف، از ۱۱۰ کشاورز خواسته شد که پرسشنامه‌هایی را تکمیل کنند که در آن اطلاعات مربوط به ماشین‌آلات، سوخت، تولید دانه در هکتار، روش کاشت، روش و طول مدت تامین آب، تعداد کارگرها، مواد شیمیایی مورد استفاده درخواست شده بود. نتایج نشان داد که انرژی ورودی کل برای تولید گندم آبی ۴۲۴۸۱ مگاژول در هکتار بود. کارآیی انرژی ۱/۵۶ بدست آمد که نشان می‌دهد انرژی خروجی کل سیستم بیشتر از انرژی ورودی بود. انرژی خالص خروجی، که مقدار انرژی بدست آمده از سیستم را نشان می‌دهد، ۲۳۸۱۹ مگاژول در هکتار بدست آمد. الکتریسیته و کود شیمیایی ورودی‌هایی بودند که بیشترین انرژی را در سیستم تولید گندم آبی مصرف کردند به طوری که ۴۱ و ۳۱ درصد از کل انرژی مصرفی به ترتیب به الکتریسیته و کود شیمیایی اختصاص داشت. بنابراین، مدیریت مناسب الکتریسیته و کود شیمیایی می‌تواند باعث بهبود کارآیی انرژی سیستم شود. کاهش عملیات تهیه بذر (کاهش مصرف سوخت) نیز می‌تواند کارآیی انرژی سیستم تولید گندم آبی را بهبود ببخشد.