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Analyzing the energy balances of double-cropped cereals in an arid region

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ABSTRACT

Efficient use of energy in agroecosystems will reduce environmental problems, prevent destruction of natural resources and serve to promote sustainable agriculture as an economical production system. The aim of this study was to investigate the energy use efficiency in four double cropping systems including: wheat–silage corn (W–SC), barely–silage corn (B–SC), barely–grain corn (B–GC) and barely–rice (B–R) in the arid regions of Isfahan province, Iran. Data used in this study were collected from 73, 45, 38, 18, 18 wheat, barley, silage corn, grain corn and rice farms, respectively, personal interview using semi-structured questionnaire during 2010. The results indicated that the total energy consumed were 140,422, 128,979, 121,360 and 172,962 MJ ha^{-1} for the W–SC, the B–GC, the B–SC and the B–R cropping systems, respectively. The share of diesel fuel by 43.36% (W–SC), 43.93% (B–GC), 42.82% (B–SC) and 49.40 % (B–R) was the highest input. This was followed by fertilizer (W–SC: 24.70%, B–GC: 25.12%, B–SC: 27.05 and B–R: 16.11) and water (W–SC: 10.54%, B–GC: 11.76%, B–SC: 10.73 and B–R: 13.85), respectively. The energy use efficiency was found as 1.70 for W–SC, 1.65 for B–GC, 1.64 for B–SC and 1.03 for B–R double cropping systems, respectively. According to the research results the W–SC, B–SC, B–GC and B–R double cropping systems were more efficient in terms of energy, respectively.

1. Introduction

Energy is a critical input in agricultural production systems. The energy used in agriculture was directly related to environmental factors such as soil and climatic conditions, amount of inputs and techniques employed in production (Esengun et al., 2007). The link between agriculture and energy is very close. Agriculture itself uses energy and is also a supplier of energy in the form of bio-energy (Alam et al., 2005). Energy used in agriculture has developed in response to increasing populations, the limited supply of arable land and a desire for increasing standards of living (Shahan et al., 2008). All inputs and outputs of a cropping system can be expressed in terms of energy. Hence, energy input and output are essential factors for determining energy efficiency and the environmental impact of crop production. However, energy utilization and output differs widely among crops, production systems and management intensity (Rathke et al., 2007).

Changes in farm technology over time have increased the amount of energy used in crop production (Rathke and Diepenbrock, 2006). The predominant feature for increasing crop production is the use of a large amount of energy either directly or indirectly in the form of fuel, electricity and fertilizers (Haj-SeyedHadi et al., 2009). Environmental problems such as those associated with soil, water pollution and CO_2 and N_2O emissions that contribute to global warming are related to intensive use of energy. Energy analysis of agricultural ecosystems seems to be a promising approach to investigate and assess efficiency, environmental problems and their relations to sustainability (Khan et al., 2007). It is also used to compare different production systems (Ghasemi-Mobtaker et al., 2010). Efficient use of energy in agriculture will minimize environmental problems, prevent destruction of natural resources and serve to promote sustainable agriculture as an economical production system (Esengun et al., 2007; Erdal et al., 2007). The relation of energy input and energy output in the agroecosystems have been investigated by many researchers for many crops such as sugar beet (Asgharipour et al., 2012; Yousefi et al., 2014), tomato (Rezvani Moghaddam et al., 2011), pulses (Koocheki et al., 2011) and cotton (Zahedi et al., 2014).

In the Mediterranean regions such as Isfahan province when irrigation water is available, the double cropping systems can be

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improved income of farmers and might be helped to sustainability of agricultural activities. Double cereal systems differences in management practices such as farm technology, tillage and intensity, have considerable effects on energy input and efficiency of crop production systems. Browning (Browning, 2011) indicated that soybean double-cropped after barley has the potential to yield equal to or greater than full-season soybean or double-cropped soybean following wheat, but its relative yield is very dependent on growing conditions in Virginia and the Mid-Atlantic, USA. Therefore, aims of this study were (i) to determine the total amount of input–output energy used in four double cropping systems (wheat–silage corn, barely–silage corn, barely–grain corn and barely–rice), (ii) to determine energy use efficiency, (iii) to determine the best double-cropped cereals based on energy efficiency, in Isfahan province of Iran as a Mediterranean region.

2. Material and methods

The present study was conducted in Isfahan province located in central Iran (geographical coordinates 30°43′ and 34°27′N and 49°36′ and 55°31′E). The total area of the province is 105,937 km^2 and the total farming area is 360,181 km^2, of that the share of cereal (wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), rice (*Oryza sativa*) and corn (*Zea mays*)) is about 57% (206,172 ha). Four double cropping systems consist: wheat–silage corn (W–SC), barely–silage corn (B–SC), barely–grain corn (B–GC) and barely–rice (B–R) were determining energy use, to investigate the energy use efficiency, and to make an economical analysis. Information was collected from cereal farmers using a face-to-face questionnaire during 2010. In addition to the data obtained by surveys, previous studies of related organizations such as the Ministry of Agriculture of Iran (MAJ) (Browning, 2011) were also used for this research. The number of operations involved in cereal rotation production systems and their energy requirements influence the final energy balance. The sample size was calculated using the Neyman method (Newbold, 1994):

$$n = \frac{N \times S^2}{(N-1)S_X^2 + S^2} \tag{1}$$

where: n, is the required sample size; N, is number of farmers in the target population; S is standard deviation, S_X, is standard deviation of sample mean ($S_X = d/z$), d, is the permissible error in the sample size, and was determined as 10% of the mean for a 95% confidence interval and z is the reliability coefficient (1.96, which represents 95% reliability). Based on this calculation the size of 73 for wheat, 45 for barley, 38 for silage corn, 18 for grain corn, and 18 for rice farms were considered as sampling sizes.

Energy efficiency of the agricultural system has been evaluated by the energy ratio between output and input. Human labor, machinery, diesel oil, fertilizer, pesticides and seed amounts and output yield values of cereal production systems have been used to estimate energy ratios (Alam et al., 2005). Energy equivalents shown in Table 1 were used for estimations (Haj-SeyedHadi et al., 2009; Khan et al., 2007; Erdal et al., 2007). The sources of mechanical energy used on the selected farms included tractors and diesel fuel. Mechanical energy was computed on the basis of total fuel consumption (l ha^{-1}) in different operations. Therefore, the energy consumed was calculated using conversion factors and expressed in MJ ha^1 (Tsatsarelis, 1991). The energy of a tractor and its equipment reveals the amount of energy needed for unit weights and calculates repair and care energy, transport energy, total machine weight and average economic life. Based on energy equivalents of inputs and outputs (Table 1), energy use efficiency, energy productivity, specific energy, energy intensiveness and net energy were calculated by the following equations (Demircan et al., 2006):

Table 1
Energy equivalent of inputs and outputs in agricultural production.

Particulars	Unit	Energy equivalent (MJ unit^{-1})
A. Inputs		
1. Human labor	h	1.95
2. Machinery	h	62.7
3. Diesel fuel	l	50.23
4. Chemical fertilizers		
(a) Nitrogen (N)	kg	75.46
(b) Phosphate (P_2O_5)	kg	13.07
(c) Potassium (K_2O)	kg	11.15
(d) Micro	kg	120.00
5. Manure	kg	0.30
6. Chemicals		
(a) Herbicides	kg or l	238.3
(b) Pesticide	l	101.2
(c) Fungicide	kg	181.9
7. Electricity	kWh	3.6
8. Water for irrigation	m^3	1.02
9. Seeds (wheat)	kg	20.10
10. Seeds (barely)	kg	14.7
11. Seeds (corn)	kg	14.7
12. Seeds (rice)	kg	14.7
B. Outputs		
1. Wheat grain yield	kg	14.7
2. Wheat straw yield	kg	2.25
3. Barely grain yield	kg	14.7
4. Barely straw yield	kg	2.25
5. Corn grain yield	kg	14.7
6. Corn straw yield	kg	2.25
7. Rice grain yield	kg	14.7
8. Rice straw yield	kg	2.25

$$\text{Energy use efficiency} = \frac{\textit{Energy output}\ (\text{MJ ha}^{-1})}{\textit{Energy input}\ (\text{MJ ha}^{-1})} \tag{2}$$

$$\text{Energy productivity} = \frac{\textit{crops output}\ (\text{Kg ha}^{-1})}{\textit{Energy input}\ (\text{MJ ha}^{-1})} \tag{3}$$

$$\text{Specific energy} = \frac{\textit{Energy input}\ (\text{MJ ha}^{-1})}{\textit{crops output}\ (\text{Kg ha}^{-1})} \tag{4}$$

$$\text{Energy intensiveness} = \frac{\textit{Energy input}\ (\text{MJ ha}^{-1})}{\textit{cost of cultivation}\ (\$\ \text{ha}^{-1})} \tag{5}$$

$$\text{Net energy} = \text{Energy output (MJ ha}^{-1}) - \text{Energy input (MJ ha}^{-1}). \tag{6}$$

Indirect energy included energy embodied in seeds, chemical fertilizers, herbicide, pesticide, fungicide, farmyard manure and machinery; while direct energy was evaluated in terms of human labor, diesel, electricity and water for irrigation used in the cereal rotation production systems. Non-renewable energy included diesel, electricity, chemical fertilizers, herbicides; pesticides, fungicides and machinery; and renewable energy consisted of human labor, farmyard, seeds and water for irrigation, farmyard manure.

3. Results and discussion

3.1. Structures of farms

The average field size was about 20.2 ha for wheat, 14.4 ha for barley, 5.5 ha for silage corn, 2.6 ha grain corn, and 0.5 ha for rice in according to information provided by the survey. Planting areas for wheat, barley, rice and grain corn were 139,426, 47,288, 17,452 and 2006 ha, and the production of these crops was 561,652, 177,893, 99,407 and 13,838 tons, respectively. All necessary cultural practices such as soil tillage, seedbed preparation, planting