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Full Length Research Paper

Evaluating energy balance and energy indices of wheat production in rain-fed farming in northern Iran

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One way to evaluate the sustainable development of agriculture is the use of energy flow method. This method, in an agricultural production system, refers to the energy consumed during production operations and energy saved when crops have been produced. In this article, an evaluation of energy balance and energy indices in rain-fed cultivation of wheat in northern Iran (Guilan province) was carried out. The data were collected in 2011 from 72 farms in Guilan province by using a face to face questionnaire method. By using consumed data as input and total production as output, their respective equivalent energy, energy balance and energy indices were calculated. Energy efficiency (energy output to input energy ratio) for seed and straw in this study were found to be 1.609 and 1.614 respectively, showing the effective usage of energy in agro ecosystems wheat production. Energy balance efficiency (production energy to consumption energy ratio) for seed and straw in this study were found to be 0.92 and 0.79 respectively, showing the effective usage of energy in agro ecosystems wheat production.

Key words: Iran, energy indices, energy balance indices, wheat.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the oldest agricultural crops that are cultivated around the world in order to produce grain for bread, animal feed and industrial uses (Mosatjeran et al., 2005). This plant as a staple food for half of the world's population is very important, therefore shall be considered as a strategic crop (Emam, 2007; Bijanzadeh and Emam, 2010). This plant in terms of acreage and annual production capacity has the first rank among the 8 major cereals and also, in terms of energy production per unit area with 460 kj of energy production per hectare has ranked third (Arasteh, 1991). In the modern world, energy is an essential input to every production, transport, and communication process and is thus a driver for economic as well as social development (Griffin and Steele, 1980; Kofoworola and Gheewala, 2008). In agricultural section, energy is an input which is used for various reasons such as increasing productivity, enhancing food security and contributing to rural economic development (Ghorbani et al., 2011). Energy use in agriculture has been increased in response to increasing population, limited supply of arable lands and a desire for higher standards of living (Rafiee et al., 2010). Agriculture is a producer and on the other hand a consumer of energy. It uses large quantities of locally available noncommercial energy such as seed, manure and animate energy, as well as commercial energies, directly and indirectly, in the form of diesel, electricity, fertilizer, plant protection, chemical, irrigation water, machinery etc (Singh et al., 2002; Jonge, 2004; Dyer and Desjardins, 2006).

On the other hand, dependence of conventional agricultural systems to intensive using of energy is one of the main reasons creating environmental problems such as global warming in the most developing and developed countries. Effective use of energy resources in agriculture is one of the principal requirements for sustainable development; it will minimize environmental problems, prevent destruction of natural resources and promote sustainable agriculture as an economical production

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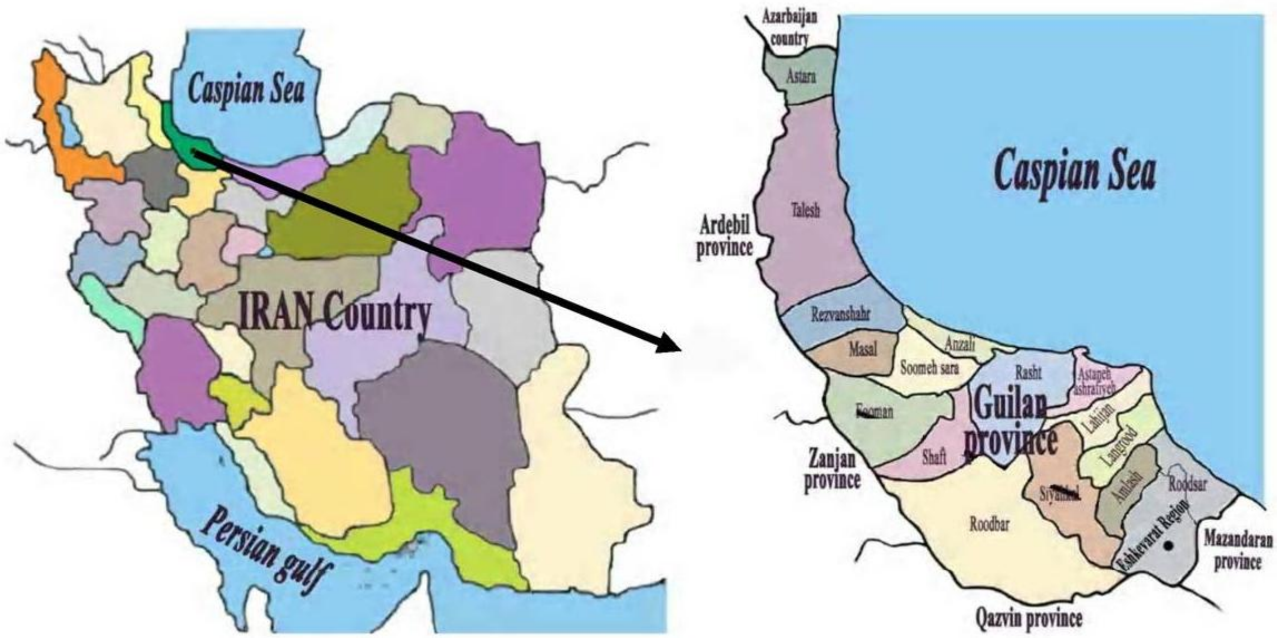

Figure 1. Location of the study area.

system (Jonge, 2004; Rafiee et al., 2010; Ghorbani et al., 2011). To evaluate the sustainability of agriculture, the energy efficiency of the system must be considered (Pervanchon et al., 2002). Calculating energy inputs of agricultural production is more difficult than in the industry sector due to the high number of factors affecting agricultural production (Yaldiz et al., 1993). Considerable studies have been conducted on energy use in agriculture (Kuesters and Lammel, 1999; Sartori et al., 2005; Jianbo, 2006; Uzunoz et al., 2008; Kizilaslan, 2009; Moradi and Azarpour, 2011).

The main aim of this study was to determine energy use in wheat production to investigate the efficiency of energy consumption and to make an energy balance and energy indices analysis of wheat 'under rain fed farming' in Guilan province of Iran.

MATERIALS AND METHODS

Data were collected from 72 farms by using a face to face questionnaire method during 2011 year in Guilan province (north of Iran). The location of studied region in north of Iran was presented in Figure 1. The random sampling of production agro ecosystems was done within whole population and the size of each sample was determined by using the following equation (Kizilaslan, 2009):

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

In the formula, n is the required sample size, s is the standard deviation, t is the t value at95% confidence limit (1.96), N is the number of holding in target population and d is the acceptable error.

In order to calculate input-output ratios and other energy indicators, the data were converted into output and input energy levels using equivalent energy values for each commodity and input (Taheri et al., 2010). Energy equivalents shown in Table 1 was used for estimation (Hulsbergen et al., 2005; Ma et al., 2008; Mandel et al., 2002; Mohammadi and Omid, 2010; Mohammadi et al., 2008; Moradi and Azarpour, 2011; Ozkan et al., 2003a, 2003b; Taheri et al., 2010; Yilmaz et al., 2005). Firstly, the amounts of inputs used in the production of wheat were specified in order to calculate the energy equivalences in the study. Energy input include human labour, machinery, diesel fuel, chemical fertilizers, poison fertilizers, electricity and seed and output yield include grain yield of wheat. The energy use efficiency, energy specific, energy productivity and net energy gain were calculated according to the following equations (Hulsbergen et al., 2005; Ma et al., 2008; Mandel et al., 2002; Mohammadi and Omid, 2010; Mohammadi et al., 2008; Moradi and Azarpour, 2011; Ozkan et al., 2003a, 2003b; Taheri et al., 2010; Yilmaz et al., 2005):

$$\text{Energy use efficiency} = \frac{\text{Output energy (Mj/ha)}}{\text{Input energy (Mj/ha)}}$$

$$\text{Energy production} = \frac{\text{Grain yield (Kg/ha)}}{\text{Input energy (Mj/ha)}}$$

$$\text{Energy specific} = \frac{\text{Input energy (Mj/ha)}}{\text{Grain yield (Kg/ha)}}$$

$$\text{Net energy gain} = \text{Input energy (Mj/ha)} - \text{output energy (Mj/ha)}$$

The input energy was divided into direct, indirect, renewable and non-renewable energies (Kizilaslan, 2009; Samavatean et al., 2010). Direct energy covered human labor and diesel fuel used in the wheat production while indirect energy consists of seed, chemical fertilizers, poison fertilizers and machinery energy. Renewable energy consists of human labor and seed and nonrenewable energy

Table 1. Amounts of inputs and output and their equivalent energy from calculated indicators of energy.

Parameter	Unit	Quantity per hectare	Energy equivalents	Total energy equivalents	Percent (%)
Inputs					
Human labor	h/ha	450	1.96	882	6.03
Machinery	h/ha	12	62.7	752.4	5.14
Diesel fuel	L/ha	133	56.31	7489.23	51.18
Nitrogen	Kg/ha	42	69.5	2918.86	19.95
Phosphorus	Kg/ha	11	12.44	142.14	0.97
Potassium	Kg/ha	2	11.15	24.14	0.16
Poison	L/ha	3	120	360	2.46
Seed	Kg/ha	132	15.7	2064.55	14.11
Output					
Grain yield	Kg/ha	1499	15.7	23538	100
Straw yield	kg/ha	1889	12.5	23613	100

Table 2. Amounts of inputs and their equivalent energy from calculated indicators of energy balance.

Parameter	Unit	Quantity per hectare	Energy equivalents	Total energy equivalents	Percent (%)
Inputs					
Human labor	h/ha	450	500	225000	4.28
Machinery	h/ha	12	90000	1080000	20.56
Diesel fuel	L/ha	133	9237	1228521	23.38
Nitrogen	kg/ha	42	17600	739164.80	14.07
Phosphorus	kg/ha	11	3190	36449.26	0.69
Potassium	kg/ha	2	1600	3464	0.07
Poison	L/ha	3	27170	81510	1.55
Seed	kg/ha	132	6000	789000	15.02
Depreciation for per diesel fuel	L	111.72	9583	1070612.76	20.38

includes, chemical fertilizers, poison fertilizers and machinery energy. In order of indicators of energy balance, basic information on energy inputs were entered into Excel spreadsheets and then energy equivalent were calculated according to Table 2 (Abdollahpour and Zaree, 2009). By using of consumed data as inputs and total production as output, and their concern equivalent energy, indicators of energy balance were calculated. Energy input include human labor, machinery, diesel fuel, chemical fertilizers, poison fertilizers, machinery depreciation for per diesel fuel and seed and output yield include grain yield and straw yield of wheat.

RESULTS AND DISCUSSION

Analysis of input–output energy use in wheat production

The inputs used in wheat production and their energy equivalents and output energy equivalent are illustrated in Table 1. About 132 kg seed, 450 h human labor, 12 h machinery power and 133 L diesel fuel for total operat-ions were used in agro ecosystems wheat production on a hectare basis. The use of nitrogen fertilizer, phosphorus and potassium were 42, 11 and 2 kg per 1 ha respectively. The total energy equivalent of inputs was calculated as 14633 MJ/ha. The highest shares of this amount were reported for diesel fuel (51.14%), nitrogen fertilizer (19.95%) and seed (14.1%) respectively. The energy inputs of potassium chemicals (0.16%), phosphorus chemicals (0.97%) and poison (2.46%) were found to be quite low compared to the other inputs used in production (Table 1). The average seed yield of wheat was found to be 1499 kg/ha and its energy equivalent was calculated to be 23538 MJ/ha (Table 1).

The average straw yield of wheat was found to be 1889 kg/ha and its energy equivalent was calculated to be 23613 MJ/ha (Table 1).

Evaluation indicators of energy in wheat production

The energy use efficiency, energy production, energy specific, energy productivity, net energy gain and intensiveness of wheat seed production were shown in Table 3. Energy efficiency (energy output-input ratio) in this study was calculated as 1.609, showing the affective use of energy in the agro ecosystems wheat production.

Table 3. Analysis of energy indices in wheat production.

Item	Unit	Wheat
Seed		
Yield	Kg/ha	1499
Input energy	Mj/ha	14633
Output energy	Mj/ha	23538
Energy use efficiency	-	1.609
Energy specific	Mj/Kg	9.76
Energy productivity	Kg/Mj	0.10
Net energy gain	Mj/ha	8905
Direct energy	Mj/ha	8371 (57.21%)
Indirect energy	Mj/ha	6362 (42.79%)
Renewable energy	Kg/Mj	2947 (20.14%)
Nonrenewable energy	Mj/ha	11687 (79.86%)
Straw		
Yield	Kg/ha	1889
Input energy	Mj/ha	14633
Output energy	Mj/ha	23613
Energy use efficiency	-	1.614
Energy specific	Mj/Kg	7.75
Energy productivity	Kg/Mj	0.13
Net energy gain	Mj/ha	8979
Direct energy	Mj/ha	8371 (57.21%)
Indirect energy	Mj/ha	6362 (42.79%)
Renewable energy	Kg/Mj	2947 (20.14%)
Nonrenewable energy	Mj/ha	11687 (79.86%)

Energy specific was 9.76 MJ/kg; this means that 9.76 MJ is needed to obtain 1 kg of wheat seed. Energy productivity calculated as 0.10 Kg/MJ in the study area. This means that 0.10 kg of output obtained per unit energy. Net energy gain was 8905 MJ/ha. The energy use efficiency, energy production, energy specific, energy productivity, net energy gain and intensiveness of wheat straw production were shown in Table 3. Energy efficiency (energy output-input ratio) in this study was calculated as 1.614 showing the affective use of energy in the agro ecosystems wheat production. Energy specific was 7.75 MJ/kg; this means that 7.75 MJ is needed to obtain 1 kg of wheat straw. Energy productivity was calculated as 0.13 Kg/MJ in the study area. This means that 0.13 kg of output obtained per unit energy. Net energy gain was 8979 MJ/ha. Houshyar et al. (2010) analyzed the energy indices of wheat production in Iran (Fars province), and found that total input energy for wheat production were 38589.677 and 38817.823 MJ/ha with the averaged weight yield of 6813.996 and 6046.968 kg/ha in regions 1 and 2, respectively. Energy output-input ratio, energy productivity and specific energy were 2.596, 0.178 kg/MJ and 5.603 MJ/kg for region 1, and 2.290, 0.162 kg/MJ and 6.186 MJ/kg for region 2, respectively. The efficiency evaluation disclosed that the number of efficient farmers was more in region 2 (16.2%) and for combined seeder (25.53%).

This means that the amount of output energy is more than input energy and production in this situation is logical. Direct, indirect, renewable and non-renewable energy forms used in wheat production are also investigated in Table 3. The results show that the share of direct input energy was 57.21% (8371 MJ/ha) in the total energy input compared to 42.79% (6262 MJ/ha) for the indirect energy. On the other hand, nonrenewable and renewable energy contributed to 79.86% (11687 MJ/ha) and 20.14% (2947 MJ/ha) of the total energy input, respectively.

Analysis of energy balance in wheat production

The inputs used in wheat production and their energy equivalents and output energy equivalent are illustrated in Table 2. About 132 kg seed, 450 h human labor, 12 h machinery power and 133 L diesel fuel for total operations were used in agro ecosystems wheat production on a hectare basis. The use of nitrogen fertilizer, phosphorus and potassium were 42, 11 and 2 kg per 1 ha respectively. Also, 111.72 L depreciation power in this system

Table 4. Analysis of energy balance indices in wheat production.

Item	Percent of compositions	Energy per gram (kcal)	Amounts (kg/ha)	Production energy (kcal/ha)	Production energy/ consumption energy	Consumption energy/ production energy
				Seed		
Protein	13	4	194.90	779615.20	0.15	6.74
Fat	1.75	9	26.24	236133.45	0.04	22.25
Starch	64	4	959.53	3838105.60	0.73	1.37
Item	Grain yield (kg/ha)	Consumption energy (kcal/ha)	Production energy (kcal/ha)	Energy per unit (kcal)	Production energy/ consumption energy	Consumption energy/ production energy
	1499	5253722	4853854	3238	0.92	30.36
				Straw		
Protein	4.3	4	81.23	324908	0.06	16.17
Fat	3.4	9	64.23	578034	0.11	9.09
Starch	43.3	4	817.94	3271748	0.62	1.61
Item	Grain yield (kg/ha)	Consumption energy (kcal/ha)	Production energy (kcal/ha)	Energy per unit (kcal)	Production energy/ consumption energy	Consumption energy/ production energy
	1889	5253722	4174690	2210	0.79	26.86

system was used. The total energy equivalent of inputs was calculated as 5253722 MJ/ha. The highest shares of this amount were reported for diesel fuel (23.38%), machinery (20.56%) and depreciation for per diesel fuel (20.38%) respectively. The energy inputs of potassium chemicals (0.07%), phosphorus chemicals (0.69%) and poison (1.55%) were found to be quite low compared to the other inputs used in production (Table 1). The highest percent of compositions (64%), amounts (959.53 kg/ha), production energy (3838105.60 kcal/ha) and production energy to consumption energy ratio (0.73) in wheat seed were obtained from starch as compared with protein and fat; the lowest consumption energy to production energy ratio (1.37) in wheat seed was obtained from starch as compared with protein and fat (Table 4).

The highest percent of compositions (43.3%), amounts (817.94 kg/ha), production energy (3271748 kcal/ha) and production energy to consumption energy ratio (0.62) in wheat straw were obtained from starch as compared with protein and fat; the lowest consumption energy to production energy ratio (1.61) in wheat straw was obtained from starch as compared with protein and fat (Table 4).

Evaluation indicators of energy balance in wheat production

The consumption energy (5253722 kcal/ha), production energy (4853854 kcal/ha), energy per unit (3238 kcal), production energy to consumption energy ratio (0.92) and consumption energy to production energy ratio (30.36) of wheat seed production were shown in Table 4. Energy balance efficiency (production energy to consum-ption energy ratio) in this study was calculated as 0.92, showing the affective use of energy in the agro ecosystems wheat seed production. The consumption energy (5253722 kcal/ha), product-ion energy (4174690 kcal/ha), energy per unit (2210 kcal), production energy to consumption energy ratio (0.79) and consumption energy to production energy ratio (26.86) of wheat straw production were shown in Table 4. Energy balance efficiency (production energy to consumption energy ratio) in this study was calculated as 0.79, showing the affective use of energy in the agro ecosystems wheat seed production. Abdollahpour and Zaree (2009) analyzed the energy balance indices of wheat production in Iran (Kermanshah province), and found that energy value of used inputs of this type of cultivation was 6130900 kcal/ha and output (production) energy of value of wheat grain yield and straw were 5018000 and 4316000 kcal/ha, respectively. Also, energy efficiency value was 1.521 and that of grain and straw separately was 0.818 and 0.703, respectively.

Results showed that the highest input energy was due to machinery using, nitrogen fertilizer and fuel; and lowest ones were related to human muscle power and herbicide.

Conclusion

Finally, energy use is one of the key indicators for developing more sustainable agricultural practices; one of the principal requirements of sustainable agriculture, therefore energy management in systems wheat production should be considered an important field in terms of efficient, sustainable and economical use of energy. Using of combination machines, doing timely required repairs and services for tractors and representing a fit crop rotation are suggested to decrease energy consuming for dry farming wheat in Guilan province.

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