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

Mortaza Zahedi[a], Farzad Mondani[b,*], Hamid Reza Eshghizadeh[a]

[a] Department of Agronomy and Plant Breeding, Faculty of Agriculture, Isfahan University of Technology, Isfahan, Iran
[b] Department of Agronomy and Plant Breeding, Campus of Agriculture and Natural Resources, Razi University, Kermanshah, Iran

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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

* Corresponding author.
E-mail address: f.mondani@razi.ac.ir (F. Mondani).

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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):

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

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

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

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

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

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

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

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

Table 2
Management practices of wheat, barley, rice and corn for grain and silage.

Operations	Wheat	Barely	Seed corn	Seed silage	Rice	Millet
Names of varieties	Rosahan, Kavir, Pishtaz, Native cultivars	Valphajr, Reyhan, Native cultivars	SC704, SC700	SC704, SC700	Native cultivars (Sorkhe, Gerdesefid)	Jam, Kermanshahi, Karaj 12-60-31
Land preparation tractor used: 285 MF 75 hp	Moldboard plow, Disc harrows, Land leveler	Moldboard plow, Disc harrows, Land leveler	Moldboard plow, Disc harrows, Land leveler	Chisel, Disc harrows	Moldboard plow, Disc harrows	Chisel–Disc harrows
Land preparation period	Late October–Mid September	Early October–Early September	Mid May	Late June	Early June	June
Average tilling number	2.2	2.2	2.2	1.2	2.2	1.0
Planting period	Early December–Late September	Mid October–Mid September	Mid June	Early July	Late June	June
Fertilization period (Before planting)	Late October–Mid September	Early October–Early September	Mid May	Late June	Early June	June
Fertilization period (Top dressing)	Mid March–Late March	Mid March–Late March	Late July–Early August	Early August	–	–
Average number of fertilization	2.2	1.2	1.5	1.5	1.2	1.0
Irrigation period	September–Early June	September–Early June	June–Late September	June–Late September	June–Late September	June–September
Average number of irrigation	12.5	11.5	7.2	6	–	3
Spraying period	May–June	May–June	Late July–Early August	–	August	July
Average number of spraying	1	0.6	1.8	0.8	1	1
Harvesting period	Late June	Late June	Late September	Late September	Late September	November

Table 3
Energy consumption and energy input–output relationship of wheat.

Energy	Quantity per unit area (ha)	Energy equivalent (MJ unit^{-1})	Total energy equivalent (MJ)	Percentage of total energy input (%)
Input				
Human labor (h)	495.4	1.95	966.0	1.4
Machinery (h)	52.0	62.70	3260.5	4.8
Diesel fuel (l)	579.3	50.23	29100.8	42.7
Nitrogen (kg)	161.9	75.46	12221.9	17.9
Phosphate (P_2O_5) (kg)	137.4	13.07	1796.4	2.6
Potassium (K_2O) (kg)	106.2	11.15	1184.7	1.7
Manure (kg)	6400	0.30	1920.0	2.8
Micro (kg or l)	4.6	120.0	558.3	0.8
Treflan (l)	3.9	238.32	928.2	1.4
Pesticide (Diazinon) (l)	1.2	101.20	121.4	0.2
Fungicide (Carboxin) (kg)	2.0	216.90	432.0	0.63
Electricity (kWh)	800.0	3.60	2880.0	4.2
Water for irrigation (m^{-3})	6700.0	1.02	6834.0	10.03
Seed (kg)	293.5	20.1	5899.4	8.7
Total energy input (MJ)			68104.1	100.00
Outputs				
Wheat grain yield (kg)	6700.50	14.90	98497.3	90.5
Bean straw yield (kg)	4600.30	2.25	10350.7	9.5
Total energy output (MJ)			108848.0	
Energy efficiency			1.6	

methods, planting and harvest period were determined and presented in Table 2. Our results also indicated that about 84% and 16% of the total planting area in cereal production system was irrigated farms and dryland farms, respectively. All farms were in personal possession. The method and timing of management practices for different crops during the growing season are shown in Table 2.

3.2. Analysis of input–output energy

Total input energy consumed for cereal crops with respect to different input and agronomical practices are shown in Tables 3–7. Most of the input energy for wheat production was related to diesel fuel, nitrogen and water for irrigation by 42.7, 17.9 and 10.03%, respectively. The same trend was observed for barely, grain and silage corn but it was different in rice as inputs of water for irrigation (15.7%) and electricity (10.4%) were higher than nitrogen. So, the share of diesel fuel was the highest energy input for all crops. Similar result have been observed for wheat (Canakci et al., 2005; Ghorbani et al., 2011; Khan et al., 2009), barely (Canakci et al., 2005; Khan et al., 2009), corn (Canakci et al., 2005), rice (Khan et al., 2009) and other irrigated crops such canola and sunflower (Sheikh-Davoodi and Houshyar, 2009) despite the differences in the arrangement in the first second or third category. Given the predominant role of diesel fuel, irrigation and fertilization in accounting for sequestered energy in agricultural systems in this

Table 4
Energy consumption and energy input–output relationship of barely.

Energy	Quantity per unit area (ha)	Energy equivalent (MJ unit^{-1})	Total energy equivalent (MJ)	Percentage of total energy input (%)
Input				
Human labor (h)	350.3	1.95	683.1	1.2
Machinery (h)	47.3	62.70	2965.9	5.1
Diesel fuel (l)	486.9	50.23	24457.7	41.4
Nitrogen (kg)	183.4	75.46	13841.8	23.4
Phosphate (P_2O_5) (kg)	121.3	13.07	1584.8	2.7
Potassium (K_2O) (kg)	91.7	11.15	1022.1	1.7
Manure (kg)	2600.0	0.30	780.0	1.3
Micro (kg or l)	1.4	120.0	162.6	0.3
Treflan (l)	3.1	238.3	737.8	1.3
Pesticide (Diazinon) (l)	1.7	101.20	167.9	01.3
Fungicide (Carboxin) (kg)	2.7	216.00	578.1	0.9
Electricity (kWh)	700	3.60	2520.0	4.3
Water for irrigation (m^{-3})	6000.0	1.02	6120.0	10.4
Seed (kg)	232.7	14.70	3420.7	5.8
Total energy input (MJ)			59042.5	100.00
Outputs				
Barely grain yield (kg)	5081.6	14.07	74699.5	88.5
Barely straw yield (kg)	4300.5	2.25	9676.1	11.5
Total energy output (MJ)			84375.6	
Energy efficiency			1.43	

Table 5
Energy consumption and energy input–output relationship of grain corn.

Energy	Quantity per unit area (ha)	Energy equivalent (MJ unit^{-1})	Total energy equivalent (MJ)	Percentage of total energy input (%)
Input				
Human labor (h)	378.9	1.95	756.6	1.1
Machinery (h)	33.4	62.70	2069.1	3.0
Diesel fuel (l)	641.2	50.23	32205.7	46.1
Nitrogen (kg)	173.1	75.46	13057.7	18.7
Phosphate (P_2O_5) (kg)	90.5	13.07	1182.4	1.7
Potassium (K_2O) (kg)	57.5	11.15	641.4	0.9
Manure (kg)	8125.0	0.30	2437.5	3.5
Micro (kg or l)	7.6	120.0	918.6	1.3
Treflan (l)	5.1	238.32	1213.8	1.7
Pesticide (Diazinon) (l)	1.6	101.20	161.9	0.2
Fungicide (Carboxin) (kg)	3.1	216.90	669.6	1.0
Electricity (kWh)	1330.0	3.60	4788.0	6.8
Water for irrigation (m^{-3})	8870.0	1.02	9047.4	12.9
Seed (kg)	51.7	14.7	759.9	1.1
Total energy input (MJ)			69936.7	100.00
Outputs				
Corn grain yield (kg)	8880.50	14.7	129360.0	100.0
Total energy output (MJ)			129360.0	
Energy efficiency			1.85	

region, it is evident that any attempt to reduce energy input should begin by finding to reduce these inputs. The machinery management and using efficient equipment to reduce direct use of diesel fuel energy, increasing nitrogen use efficiency (due to mainly embodied energy of nitrogen, 75.46 MJ kg^{-1}) with different approaches such as application of nitrogen only base on the soil analysis and using nitrogen in several time as topdressing.

In this region, average of irrigation water that used for successful wheat, barley, rice, grain and silage corn production are around 6700, 6000, 17,500, 8870 and 7821 m^3 per each hectare, respectively. So, reduction of water irrigation may be achieved by reducing the amount of water supplied as effective use of water, deficit irrigation strategy, using, where possible, alternative irrigation systems or improving irrigation and pumping efficiency (Tsatsarelis, 1991).

The total energy input of 140,422 MJ ha^{-1} (W: 68,104 MJ ha^{-1} + SC: 72,318 MJ ha^{-1}), 128,979 MJ ha^{-1} (B: 59,043 MJ ha^{-1} + GC: 69,937 MJ ha^{-1} BSC), 121,360 MJ ha^{-1} (B: 59,043 MJ ha^{-1} + SC: 72,318 MJ ha^{-1}) and 172,962 MJ ha^{-1} (B: 59,043 MJ ha^{-1} + R: 113,920 MJ ha^{-1}) were required for different double cropping systems, respectively (Table 8). In literature, the results showed that total energy input were 51,040 MJ ha^{-1} for full-season wheat and 44,866 for full-season barley (Sahabi et al., 2012), and 72,743 for full-season corn (Safa et al., 2010), respectively.

Grain and straw yield of crops are shown in Tables 3–7. Total energy output per hectare was 108,848, 84,375.6, 129,360, 130,981.5, and 93,690.3 MJ ha^{-1} in wheat, barley, grain corn, silage corn and rice production systems, respectively. The highest output energy (239,829 MJ ha^{-1}) was obtained in W–SC and the lowest (178,066 MJ ha^{-1}) was in the B–R double-cropped system. Energy consumption and energy input–output in different double-cropped cereals are shown in Table 9.

Energy use efficiency in wheat, barley, grain corn, silage corn, and rice was 1.6, 1.43, 1.85, 1.81 and 0.82, respectively. The double-cropped cereals, W–SC had the highest energy efficiency (1.70) and barely–rice had the lowest (1.03). The research results were consistent with finding reported by other authors, such as: 1.70 for wheat and 1.83 for barley in irrigated farming in northeast of Iran (Sahabi et al., 2012) and 2.8 for wheat and 3.8 for maize in Antalya region,

Table 6
Energy consumption and energy input–output relationship of silage corn.

Energy	Quantity per unit area (ha)	Energy equivalent (MJ unit^{-1})	Total energy equivalent (MJ)	Percentage of total energy input (%)
Input				
Human labor (h)	489.5	1.95	954.5	1.3
Machinery (h)	43.1	62.70	2698.1	3.7
Diesel fuel (l)	633.1	50.23	31798.8	44.0
Nitrogen (kg)	214.4	75.46	16181.7	22.4
Phosphate (P_2O_5) (kg)	90.5	13.07	1182.4	1.6
Potassium (K_2O) (kg)	57.5	11.15	641.4	0.9
Manure (kg)	8125.0	0.30	2473.5	3.4
Micro (kg or l)	7.6	120.0	918.6	1.3
Treflan (l)	5.1	238.32	1213.8	1.7
Pesticide (Diazinon) (l)	1.6	101.20	161.9	0.2
Fungicide (Carboxin) (kg)	3.1	216.90	669.6	0.9
Electricity (kWh)	1230.0	3.60	4428.0	6.1
Water for irrigation (m^{-3})	7821.0	1.02	7977.4	11.1
Seed (kg)	71.7	14.7	1054.0	1.5
Total energy input (MJ)			72317.7	100.00
Outputs				
Corn straw yield (kg)	58214.30	2.25	130981.5	100.0
Total energy output (MJ)			130981.5	
Energy efficiency			1.81	

Table 7
Energy consumption and energy input–output relationship of rice.

Energy	Quantity per unit area (ha)	Energy equivalent (MJ unit^{-1})	Total energy equivalent (MJ)	Percentage of total energy input (%)
Input				
Human labor (h)	881.3	1.95	1718.5	1.5
Machinery (h)	58.1	62.70	3642.9	3.2
Diesel fuel (l)	1214.9	50.23	61024.9	53.6
Nitrogen (kg)	116.0	75.46	8750.8	7.7
Phosphate (P_2O_5) (kg)	91.4	13.07	1195.3	1.1
Potassium (K_2O) (kg)	56.2	11.15	627.2	0.5
Manure (kg)	4123.0	0.30	1236.9	1.1
Micro (kg or l)	5.6	120.0	678.6	0.6
Treflan (l)	4.9	238.32	1166.2	1.1
Pesticide (Diazinon) (l)	1.3	101.20	131.6	0.1
Fungicide (Carboxin) (kg)	1.1	216.90	237.6	0.2
Electricity (kWh)	3300.0	3.60	11880.0	10.4
Water for irrigation (m^{-3})	17500.0	1.02	17850.0	15.7
Seed (kg)	257.1	14.7	3779.4	3.3
Total energy input (MJ)			113919.7	100.00
Outputs				
Rice grain yield (kg)	5920.40	14.7	87029.9	92.9
Rice straw yield (kg)	2960.20	2.25	6660.5	7.1
Total energy output (MJ)			93690.3	
Energy efficiency			0.82	

Table 8
Total energy input in the form of direct, indirect, renewable energy for different double cropping systems.

Source	Wheat–Silage corn			Barely–Seed corn			Barely–Silage corn			Barely–Rice		
	W	SC	Total	B	GC	Total	B	SC	Total	B	R	Total
Direct energy[a]	39,780.8	45,158.8	84,939.6	33,780.7	46,797.7	80,578.4	33,780.7	45,158.8	78,939.5	33,780.7	92,473.5	126,254.2
Indirect energy[b]	28,323.2	27,159.0	55,482.2	25,261.7	23,139.0	48,400.7	25,261.7	27,159.0	52,420.7	25,261.7	21,446.3	46,708
Renewable energy[c]	15,619.3	12,423.4	28,042.7	11,003.7	13,001.5	24,005.2	11,003.7	12,423.4	23,427.1	11,003.7	24,584.8	35,588.5
Non-renewable energy[d]	39,780.8	59,894.3	99,675.1	48,038.7	56,935.2	104,973.9	48,038.7	59,894.3	107,933	48,038.7	89,334.9	137,373.6
Total energy input	68,104	72,318	140,422	59,043	69,937	128,979	59,043	72,318	131,360	59,043	113,920	172,962

[a] Indicates human labor, diesel, electricity and water.
[b] Indicates seeds, chemical fertilizers (NPK), herbicide (Treflan and Basagran), pesticide (Diazinon), fungicide (Carboxin) and machinery.
[c] Indicates human labor, seeds and water.
[d] Indicates diesel, electricity, chemical fertilizers (NPK), herbicide (Treflan and Basagran), pesticide (Diazinon), fungicide (Carboxin) and machinery.

Turkey (Canakci et al., 2005) under the conventional farming system, respectively. It seems that suitable condition as climate and soil properties is one of the important reasons for more efficient agriculture systems in Turkey in comparison with Iran in these reports.

In wheat, barley and rice farms overall energy input–output ratio is very low compared to farms at Australia (Khan et al., 2009), where it was 9.21, 8.21 and 6.70, respectively. In case of wheat, energy use efficiency in other parts of the world as well as New Zealand (Barber, 2004), Turkey (Canakci et al., 2005), India

Table 9
Energy input–output ratio in 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).

Source	Unit	Wheat–Silage corn			Barely–Grain corn			Barely–Silage corn			Barely–Rice		
		W	SC	Total	B	GC	Total	B	SC	Total	B	R	Total
Total energy input	MJ ha^{-1}	68,104	72,318	140,422	59,043	69,937	128,979	59,043	72,318	131,360	59,043	113,920	172,962
Total energy output	MJ ha^{-1}	108,848	130,981	239,829	84,376	129,360	213,736	84,376	130,982	215,357	84,376	93,690	178,066
Energy efficiency	–	1.6	1.81	1.70	1.43	1.85	1.66	1.43	1.81	1.64	1.43	0.82	1.03
Energy intensiveness	MJ $\$^{-1}$	36.5	39.5	76	39.3	38.7	78	39.3	39.5	78.8	39.3	35.7	75
Specific energy	MJ kg^{-1}	0.1	1.2	1.3	11.6	7.9	19.5	11.6	1.2	12.8	11.6	0.1	11.7
Energy productivity	kg MJ^{-1}	0.098	0.804	0.46	0.086	0.125	0.107	0.086	0.804	0.481	0.086	0.051	0.063
Net energy	MJ ha^{-1}	40,744.0	58,663.8	99,407.8	25,333.2	59,423.3	84,756.5	25,333.2	58,663.8	83,997	25,333.2	−20,229.4	5103.8

Table 10
Energy consumption (total energy equivalent (MJ ha^{-1})) and energy input–output relationship in different double cropping systems.

Source	Wheat–Silage corn			Barely–Seed corn			Barely–Silage corn			Barely–Rice		
	W	SC	Total	B	GC	Total	B	SC	Total	B	R	Total
Human labor	966	954	1,920	683	757	1,440	683	955	1,638	683	1,719	2,402
Machinery	3,260	2,698	5,959	2,966	2,069	5,035	2,966	2,698	5,664	2,966	3,643	6,609
Diesel fuel	29,101	31,799	60,900	24,458	32,206	56,663	24,458	31,799	56,257	24,458	61,025	85,483
Fertilizers	15,761	18,924	34,685	16,611	15,800	32,411	16,611	18,924	35,535	16,611	11,252	27,863
Chemicals	1,482	2,045	3,527	1,484	2,045	3,529	1,484	2,045	3,529	1,484	1,535	3,019
Manure	1,920	2,473	4,393	780	2,438	3,218	780	2,474	3,254	780	1,237	2,017
Electricity	2,880	4,428	7,308	2,520	4,788	7,308	2,520	4,428	6,948	2,520	11,880	14,400
Water	6,834	7,977	14,811	6,120	9,047	15,167	6,120	7,977	14,097	6,120	17,850	23,970
Seed	5,899	1,054	6,953	3,421	760	4,181	3,421	1,054	4,475	3,421	3,779	7,200
Total energy input	68,104	72,318	140,422	59,043	69,937	128,979	59,043	72,318	131,360	59,043	113,920	172,962
Total energy output	108,848	130,981	239,829	84,376	129,360	213,736	84,376	130,982	215,357	84,376	93,690	178,066
Energy efficiency	1.6	1.81	1.70	1.43	1.85	1.65	1.43	1.81	1.64	1.43	0.82	1.03

(Singh et al., 2002) and Pakistan (Khan et al., 2007), was 2.9, 2.8, 3.2, 2.5 and 3.46, respectively, which is greater than the value obtained in this study. The main reason for this can be the higher consumption of fossil fuels and fertilizer inputs at low cost and low efficiency of the equipment used in this region.

3.3. Energy intensiveness, productivity, specific and net energy

The results showed that acquired amounts of energy intensity had little difference in the various double-cropped systems as is summarized in Table 8. Average of energy productivity of wheat, barley, grain corn, silage corn, and rice was 0.098 kg MJ^{-1}, 0.086 kg MJ^{-1}, 0.125 kg MJ^{-1}, 0.804 kg MJ^{-1} and 0.052 kg MJ^{-1}, respectively. However, the highest energy productivity was observed in the B–SC (0.481 kg MJ^{-1}) and W–SC (0.462 kg MJ^{-1}) double cropping systems and the lowest was achieved in B–R (0.036 kg MJ^{-1}) (Table 8).

The barely–grain corn double-cropped system had the highest specific energy followed by barely–silage corn, barely–rice and winter wheat–silage corn. Net energy was 99,407 MJ ha^{-1}, 84,756 MJ ha^{-1}, 83,997 MJ ha^{-1} and 5103 MJ ha^{-1}in wheat–silage corn, barely–grain corn, barely–silage corn and barely–rice, respectively. The highest net energy was obtained in grain corn by 59,423 MJ ha^{-1}, whereas the lowest (−20,229 MJ ha^{-1}) was related to rice (Table 8). It seems that high level of electricity used was due to electric pumps are old and also high consumption of chemicals and fertilizers could be due to pest invasion and lake of soil analysis which leading to unconscious usage of chemicals. On the other hand, machinery is extensively used for soil preparation, spraying activities and transportation in production process leading to high level of require diesel fuel energy (Rafiee et al., 2010; Singh et al., 2004).

3.4. Energetic of producing cereals and double-cropped systems

The total energy input consumed in wheat, barley, grain corn, silage corn and rice could be classified as direct, indirect, renewable and non-renewable energy. The barely–rice double-cropped systems had the highest direct energy (126,254 MJ) followed by wheat–silage corn (84,939 MJ), barely–grain corn (80,578 MJ) and barely–silage corn (78,939 MJ). The highest (55,482 MJ) indirect energy was related to wheat–silage corn and the lowest (46,708 MJ) was obtained in barely–rice double-cropped systems. Amounts of renewable and non-renewable energy in the double-cropped systems are illustrated in Table 10. The highest records for renewable and non-renewable energy were in the barely–rice. The share of indirect and non-renewable energy input was higher than direct and renewable energy in all crops and double-cropped of cereals. Therefore, it is necessary to increase the share of renewable energy for achieving high energy efficiency and energy productivity in agroecosystems. Saving in diesel fuel by changing tillage method can enhance energy use efficiency. Due to the highly mechanized agricultural system in Iran, fuel consumption has risen by 10% in recent years (BeheshtiTabar et al., 2010). Ghorbani et al. (2011) reported that the share of non-renewable energy (76%) compared to renewable energy (24%) was higher in irrigated and dry-land wheat production systems in Iran.

Change of agricultural systems towards using low inputs of fossil energy would contribute to reduce CO_2 and N_2O emissions (Shahan et al., 2008; Zahid et al., 2010). Our findings indicated that fertilizers especially nitrogen were one of the main input energy that caused to emission of N_2O, so, should be applied by alternative resource such as residual crops, legumes, and manure (McLaughlin et al., 2000). Traditionally, legumes have been viewed as excellent sources of nitrogen in agriculture (Kinzig and Socolow, 1994). Crop rotations with legumes, capable for fixing atmospheric nitrogen, can maintain production levels with reduced reliance on energy intensive mineral fertilizers (Shahan et al., 2008).

4. Conclusions

Based on the present study the following conclusions are drawn:

1. The total energy input of 140,422 MJ ha^{-1} (W: 68,104 MJ ha^{-1} + SC: 72,318 MJ ha^{-1}), 128,979 MJ ha^{-1} (B: 59,043 MJ ha^{-1} + GC: 69,937 MJ ha^{-1} BSC), 121,360 MJ ha^{-1} (B: 59,043 MJ

ha^{-1} + SC: 72,318 MJ ha^{-1}) and 172,962 MJ ha^{-1} (B: 59,043 MJ ha^{-1} + R: 113,920 MJ ha^{-1}) were required for different double cropping systems, respectively.

2. 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.
3. 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.
4. The energy productivity were found as 0.46 for W–SC, 0.11 for B–GC, 0.48 for B–SC and 0.063 for B–R double cropping systems, respectively.

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