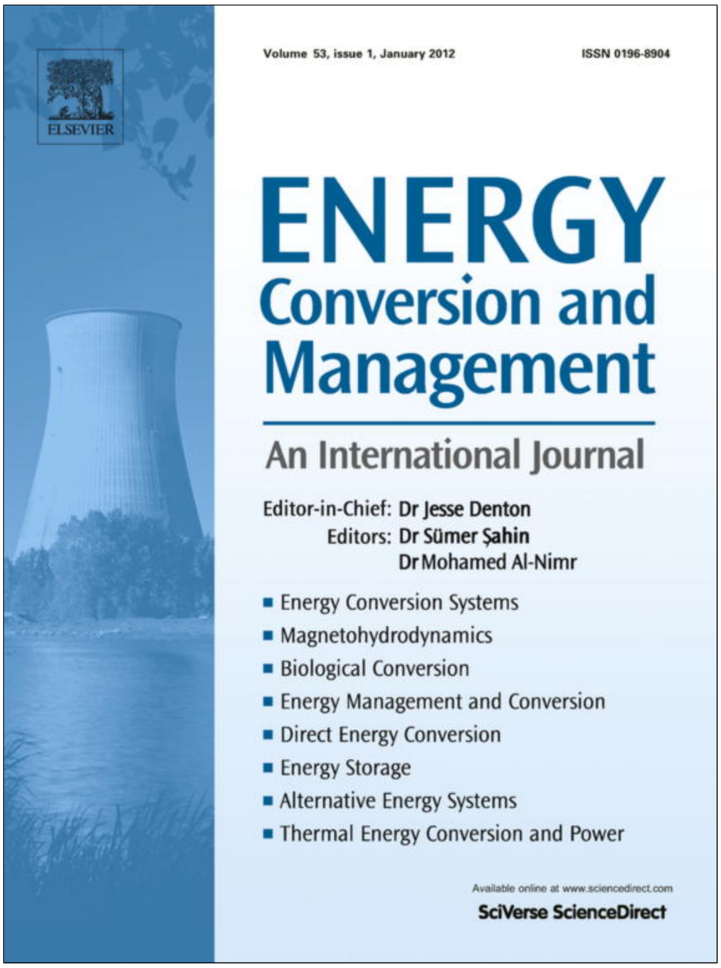
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Energy use pattern in rice production: A case study from Mazandaran province, Iran

M. AghaAlikhani [a,*], H. Kazemi-Poshtmasari [a,b], F. Habibzadeh [a]

[a] Department of Agronomy, Faculty of Agriculture, Tarbiat Modares University, PO Box 14115-336, Tehran, Iran
[b] Department of Agronomy, Faculty of Plant Production, Gorgan University of Agricultural Sciences and Natural Resources, PO Box 49138-15739, Gorgan, Iran

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ABSTRACT

Rice (*Oryza sativa* L.) is grown under both traditional system (TS) and mechanized system (MS) in Iran. In this study the energy consumption for rice is analyzed in Mazandaran, Northern province of Iran. The indicators are: net energy, energy use efficiency, specific energy, energy productivity, direct energy, indirect energy, renewable energy, non-renewable and total energy input. The cultivars of rice commonly grown in Iran are listed in three groups: native, high yield cultivars and hybrid cultivar. Primary data were obtained through field survey and personal interviews using questionnaires from 48 agricultural services center in Mazandaran province. Secondary data and energy equivalents were obtained from available literature using collected data of the production period of 2007–2008. Analysis of date showed that averagely diesel fuel had the highest share within the total energy inputs, followed by chemical fertilizer in rice production in both TS and MS. Energy use efficiency was calculated as 1.72 in TS and 1.63 in MS. Total energy consumption in rice production were 71,092.26 MJ/ha (TS) and 79,460.33 MJ/ha (MS). In general, there were not significant changes regarding the human labor and chemicals in tow systems.

1. Introduction

Energy inputs are critical to agricultural production and the increased use of fossil fuel based energy resources has become increasingly important to both the developed and the developing countries. Agriculture itself is both an energy consumer and energy supplier in the form of bio-energy [2,22,30]. All agricultural operations require energy in one form or another: human labor, animal power, fertilizer, fuels and electricity. The relation between agriculture and energy use is very close [12]. Barton [4] reported that farm power determines the scale and intensity of farm operation. Energy use in agriculture has been rising in response to increasing population, limited supply of arable land, and a desire for an increasing standard of living. In all societies, these factors have encouraged an increase in energy inputs to maximize yields, minimize labor-intensive practices, or both [11]. Warkentin [40] stated that water use efficiency is highly concern of crop management. Effective energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resources preservation and air pollution reduction [39]. Okurut and Odogola [18] reported that besides land, farm power is the second most important input to agricultural production.

Rice (*Oryza sativa* L.) is an important primary crop in the world. It is the staple food for more than two – third of the world's population especially in Asia, where 90% of the world's rice is grown and consumed [16,31], yet before the development and introduction of modern high yielding varieties of rice by International Rice Research Institute (IRRI) in 1960s there was always a shortage of adequate rice in Asia. Large scale growing of modern high yielding varieties of rice in Asia has brought out a sense of plenty and complacency, but the ever growing population in this region of the world demands more and more rice and the latest forecast [13]. Maximum of crop yield per unit of cultivated area for rice and maximization of energy inputs require a careful decision for the interactions involving pre-harvest energy, fertilizer, irrigation and tillage conducted that increased energy consumption in the form of agro-inputs increases the energy efficiency and grain yield [36].

Many researchers have studied energy and economic analysis to determine the energy efficiency of crop production, such as rice in Malaysia [6], wheat, maize, sugar beet, sunflower, barley, oat, soybean and rye in Italy [27,37] tomato, cotton, sugar beet, some field crops and vegetable in Turkey [8,9], wheat in Iran [29], soybean and potato in India [20,41], wheat, maize, sorghum in United States [14] oilseed rape in Germany [25] sunflower in Greece [17] and wheat in New Zealand [26]. Singh [33] stated that growth of crop production depends on the three sources: arable land expansion, increase in cropping intensity and yield growth. According to Baruah and Dutta [5] in six agroclimatic zones of rice in Assam, India the input energy including eight distinct sources, in other words, human, animal, diesel, commercial chemical fertilizer, farm yard manure, seed and pesticide.

Results showed that the use of energy increased the yield increased up to maxima and then declined at higher levels of energy.

* Corresponding author. Tel.: +98 21 48292099; fax: +98 21 48292200.
E-mail address: maghaalikhani@modares.ac.ir (M. AghaAlikhani).

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This was observed in all four categories of farms with variation in yield–energy values. Okurut and Odogola [18] reported that besides land, farm power is the second most important input to agricultural production. In United States of America agricultural sector used an estimated 1.7 quadrillion Btu of energy from both direct (1.1 quadrillion Btu (British thermal unit)) and indirect (0.6 quadrillion Btu) sources in 2002. However, agriculture's total use of energy is low relative to other U.S. producing sectors. Toufiq Iqbal [36] investigated the energy inputs requirement for production of Boro rice in areas of Bangladesh. He showed that the input and output energy for landless, marginal, small, medium and large farmers were 31,936, 30,458, 27,688, 29,394, 27,875 and 115,728, 119,528, 114,616, 115,444, 112,985 MJ/ha respectively. The output–input energy ratio in respective categories was 3.6, 3.9, 4.14, 3.93, and 4.05. The energy ratio was high in PT (Power tiller) farming and it was 4.02 [36]. Sayin et al. [28] reported that although energy consumption in agriculture is much lower than the other sectors in Turkey, energy use as both input and output of agricultural sector is a very important issue due to its large agricultural potential and rural area. Pishgar-Komleh et al. [23] investigated energy and economic analysis of rice production in the farms with different area (small (<0.5 ha) medium (0.5–1 ha) large (>1 ha)) in Guilan province of Iran. They showed that large farms (more than 1 ha) had better management and were more successful in energy use and economic performance. Determination and modelling of energy consumption in wheat production in New Zealand was carried out using neural networks by Safa and Samarasinghe [25]. The final model predicted energy consumption based on farm conditions (size of crop area), farmers' social considerations (level of education), and energy inputs (N and P use and irrigation frequency), with an error margin of +12% (+2900 MJ/ha).

Rice is an important staple food crop in the words. It is vital for the nutrition of much of the population in Asia, as well as in Latin America and Africa. At present, due to the energy crisis in the world, it is necessary to optimize the energy consumption. With regard to the role of rice in the world, understanding the various inputs and energy efficiency, can help to optimize energy consumption in this crop production. The aim of this study was to determine different aspects of energy efficiency of rice production in Mazandaran province, in north of Iran. Also identifies operations where energy savings could be realized by changing applied practices in order to increase the energy ratio, and propose improvements to reduce energy consumption for rice production.

2. Materials and methods

The study was carried out in Mazandaran province, Iran. This province is located between 35°46′ and 36°58′ Lat. N and between 21°50′ and 54°08′ Lon. E, covering a total area of 500,000 ha, and a rice cropping area of 230,000 ha. In this area, rice is grown under both traditional system (TS) and mechanized system (MS). The use of traditional tools and implements might be the reason for under more utilization of the human labor in traditional system. The cultivars of rice commonly grown in Maznandarn province are listed in three groups as follows:

1-Native cultivars: Tarom, Tarom Hashemi, Tarom Langeroodi and Tarom Rashti, 2-high yield cultivars: Shafagh, Fajr, Nehmat, and Nada, and 3-hybrid cultivar: Bahar1.

Data were collected from 48 agricultural service centers of Mazandaran province (with emphasis on fields with area of 1–5 ha) using a face to face questionnaire performed and statistical yearbooks [21] in Feb and Mar 2009. All data detail information of the questionnaire were averaged and arranged in Table 1. First, all inputs and outputs for rice production under both traditional and mechanized system were determined, quantified and entered into excel spreadsheets, and then transformed into energy units and expressed in MJ ha^{-1}.Owing to the fact that data for animal labor and farmyard manure were not available, so data of these inputs were not included in calculations. Actually the collected data belonged to the production period of 2007–2008. The secondary information used in this study was collected from the previous studies and publications by some institutions like IRRI and FAO.

The energetic efficiency of the agricultural system has been evaluated by the energy ratio between output and input. Human labor, machinery, diesel, fertilizer, chemicals and seed amounts and output yield values of rice crops have been used to estimate the energy ratio. Energy equivalents shown in Table 2 were used for estimate the input and output energy. The sources of mechanical energy used on the selected farms included tractor, power tiller and diesel oil. The mechanical energy was computed on the basis of total fuel consumption (L ha^{-1}) in different operations. Based on the total energy equivalents of the inputs and output (Table 3), the energy ratio (energy use efficiency), energy productivity and the specific energy were calculated using following equations [9,29]:

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

$$\text{Energy productivity} = \text{Grain output (kg/ha)}/\text{Energy input (MJ/ha)} \quad (2)$$

$$\text{Specific energy} = \text{Energy input (MJ/ha)}/\text{Grain output (kg/ha)} \quad (3)$$

$$\text{Energy use efficiency} = \text{Energy output (MJ/ha)}/\text{Energy input (MJ/ha)} \quad (4)$$

The direct energy input is the energy consumption of physical energy resources for physical work during field operations. Field operations consume significant amounts of energy in agricultural production, with most being fuel usage [7]. The input energy was divided into direct, indirect, renewable and nonrenewable forms. Indirect energy included energy embodied in seed, fertilizers, chemicals, machinery while direct energy covered human labor and diesel fuel were used in the rice production. Nonrenewable energy includes diesel fuel, chemicals, fertilizers and machinery, and renewable energy consists of human labor, seeds, were considered.

The objective of present study is to assess the energy use pattern and different energy forms for rice production in north of Iran as a means of optimizing energy inputs.

3. Results and discussion

The values of input and output in rice production have been differentiated for three groups of common rice cultivars (Table 1). In addition, energy equivalences are illustrated in Table 2. The results revealed that native, high yield and hybrid rice cultivars required 817.39, 961.69 and 970.33 MJ/ha of human labor in TS (Table 3) and 420.30, 503.26 and 516.59 MJ/ha in MS (Table 4). Among different cultivars, hybrid cultivar showed the highest use of machinery power in both TS and MS of rice production (Tables 3 and 4). Diesel fuel, seed, fertilizer, pesticide chemical and machinery having commercial importance constitute the commercial sources of energy. The total amount of fertilizers estimated as 45,730.09 and 47,166.86 kg/ha in traditional and mechanized systems, respectively. The application of all chemical fertilizers, nitrogen (N), phosphorus (P_2O_5), potassium (K_2O) and Zinc (Zn) were increased when rice grown in TS (Tables 3 and 4).

Table 1
Amount of inputs and outputs in rice production system in Mazandaran province, Iran.

	Cropping systems					
	Traditional system			Mechanized system		
	Rice cultivars					
	Native	High yield	Hybrid	Native	High yield	Hybrid
A. Inputs						
1. Labor (h/ha)	417.04	490.66	495.07	214.44	256.77	263.57
Land preparation	45.23	53.36	51.51	39.65	47.30	46.12
Nursery	37.12	39.48	38.31	31.36	34.69	33.12
Transplanting	91.14	101.23	98.23	17.12	20.30	19.89
Irrigation	75.28	92.69	94.12	71.30	88.56	93.25
Fertilizer application	5.23	8.51	9.51	4.50	7.98	8.91
Spraying	21.12	27.09	29.12	19.56	21.95	24.17
Harvesting	120.78	145.35	151.19	10.50	12.36	13.93
Transporting	21.14	22.95	23.08	20.45	23.63	24.18
2. Machinery (h/ha)	237.24	256.18	268.29	290.4	313.30	332.63
Land preparation	24.89	26.52	25.90	28.12	30.10	31.51
Nursery	5.45	7.09	7.22	6.23	8.19	7.89
Transplanting	0	0	0	12.00	15.96	12.98
Irrigation	180.15	190.56	200.30	210.15	220.36	239.00
Fertilizer application	5.32	6.55	7.58	5.60	6.40	6.96
Spraying	12.11	12.50	13.40	12.23	12.90	13.20
Harvesting	0	0	0	5.55	6.23	6.89
Transporting	9.32	12.96	13.89	10.52	13.16	14.20
3. Diesel (L/ha)	423.06	482.76	538.16	520.36	575.76	591.29
Land preparation	131.58	155.10	171.61	142.23	159.28	165.18
Nursery	19.14	22.23	24.82	22.39	21.98	24.17
Transplanting	0	0	0	22.56	22.96	26.6
Irrigation	213.20	235.63	269.57	260.50	285.11	290.45
Fertilizer application	4.69	5.50	6.08	5.10	6.6	6.31
Spraying	29.78	37.18	38.10	29.13	37.18	36.15
Harvesting	0	0	0	12.25	13.95	13.53
Transporting	24.67	27.12	27.98	26.20	28.7	28.9
4. Fertilizers (kg/ha)						
Nitrogen (N)	130.69	210.36	250.12	140.25	220.15	260.36
Phosphorus (P_2O_5)	81.65	120.41	131.17	85.50	127.63	138.56
Potassium (K_2O)	49.78	70.39	90.76	56.25	64.39	85.59
Zinc (Zn)	3.95	5.50	6.25	4.20	5.39	6.40
5. Chemicals (kg/ha)						
Herbicide	3.67	4.21	4.49	4.00	4.36	4.70
Fungicide	2.38	2.70	2.41	2.36	2.40	2.25
Insecticide	4.57	5.10	5.40	4.90	5.39	5.75
6. Water (m^3/ha)	7287.30	9089.55	9370.30	7120.08	9010.11	9210.51
7. Seeds (kg/ha)	41.25	53.29	25.41	31.25	40.63	20.50
B. Outputs						
1. Paddy rice (kg/ha)	3850.70	6148.23	8447.56	4189.15	6397.20	8780.60
2. Straw (kg/ha)	1878.91	2989.30	2949.78	2047.69	3178.39	3190.20

Table 2
Energy equivalent of inputs and outputs in agricultural production.

Particulars	Unit	Energy equivalent (MJ unit^{-1})	References
A. Inputs			
1. Labor	h	1.96	[19,41]
2. Machinery	h	62.7	[10,28,32]
3. Diesel	L	56.31	[10,28,32]
4. Fertilizers	kg		
4.1. Nitrogen (N)		66.14	[11,41]
4.2. Phosphorus (P_2O_5)		12.44	[11,41]
4.3. Potassium (K_2O)		11.5	[11,41]
4.4. Zinc (Zn)		8.40	[3,21]
5. Chemicals	kg	120	[8,32]
6. Water	m^3	1.02	[1,28]
7. Seed	kg	14.7	[19,28]
B. Outputs			
1. Paddy rice	kg	14.7	[19,28]
2. Straw	kg	12.5	[19,28]

Total energy used for various farm operations during native, high yield and hybrid rice production were 60,187.41, 73,220.42 and 79,908.94 MJ/ha in TS and 69,181.23, 82,005.42 and 87,186.06 MJ/ha in MS, respectively (Tables 3 and 4). Averagely diesel fuel had the highest share within the total energy inputs, followed by chemical fertilizer in rice production in both TS and MS (Tables 3 and 4). Diesel fuel was mainly consumed for land preparation, cultural practices and transportation. Results of Baruah and Dutta [5] showed that rice yield in India could increase further if chemical fertilizer and mechanical power are used. Average annual paddy yield of farms investigated, were 3850.70, 6148.23 and 8447.56 kg/ha in TS and 4189.15, 6397.20 and 8780.60 kg/ha in MS for native, high yield and hybrid respectively. Calculated total energy output were 80,091.66, 127,745.23 and 161,051.382 MJ/ha in TS and, 87,176.625 and 133,748.71, 168,952.32 MJ/ha MS. As Tables 3 and 4 show, seed, human labor and chemicals consumed the least energy inputs for rice production in both TS and MS. As comparison to Turkey, Canakci et al. [8] noted that the rates of other inputs in the total amount of energy such as fertilizers application, seeds, diesel fuel, chemicals, manpower and other inputs in wheat production were 54.1%, 25.2%, 17.4%, 0.6%, 0.1% and 2.6%, respectively.

Results of our investigation for energy input and output, yield, energy use efficiency, specific energy, energy productively and net energy of rice production in the north of Iran are given in Ta-

Table 3
Amounts of inputs and output of rice production in traditional system of Mazandaran province, Iran.

Inputs and outputs	Native cultivar		High yield cultivar		Hybrid cultivar	
	Quantity per ha	Total energy equivalent (MJ/ha)	Quantity per ha	Total energy equivalent (MJ/ha)	Quantity per ha	Total energy equivalent (MJ/ha)
A. Inputs						
1. Labor (h)	417.04	817.39	490.66	961.69	495.07	970.33
2. Machinery (h)	237.24	14,874.94	256.18	16,062.48	268.29	16,687.63
3. Diesel (L)	423.06	23,822.50	482.76	27,184.21	538.16	30,303.78
4. Fertilizers	266.07	10,247.78	406.66	16,242.15	478.3	19,239.16
4.1. Nitrogen (N)	130.69	8643.83	210.36	13,913.21	250.12	16,542.93
4.2. Phosphorus (P_2O_5)	81.65	1015.72	120.41	1497.90	131.17	1631.75
4.3. Potassium (K_2O)	49.78	555.04	70.39	784.84	90.76	1011.97
4.4. Zinc (Zn)	3.95	33.18	5.5	46.2	6.25	52.5
5. Chemicals (kg)	10.62	2385.39	12.16	2741.86	12.3	2776.84
5.1. Herbicide	3.67	982.33	4.36	1167.02	4.49	1201.82
5.2. Fungicide	2.38	490.28	2.7	556.2	2.41	496.46
5.3. Insecticide	4.57	912.77	5.1	1018.63	5.4	1078.55
6. Water (m^3)	7287.3	7433.04	9089.55	9271.34	9370.3	9557.70
7. Seed (kg)	41.25	606.37	53.29	756.71	25.41	373.52
Total energy input (MJ)		60,187.41		73,220.42		79,908.94
B. Outputs						
1. Paddy rice (kg)	3850.7	56,605.29	6148.23	90,378.98	8447.56	124,179.13
2. Straw (kg)	1878.9	23,486.37	2989.3	37,366.25	2949.78	36,872.25
Total energy output (MJ)		80,091.66		127,745.23		161,051.38

Table 4
Amounts of inputs and output of rice production in mechanized system of Mazandaran province, Iran.

Inputs and outputs	Native cultivar		High yield cultivar		Hybrid cultivar	
	Quantity per ha	Total energy equivalent (MJ/ha)	Quantity per ha	Total energy equivalent (MJ/ha)	Quantity per ha	Total energy equivalent (MJ/ha)
A. Inputs						
1. Labor (h)	214.44	420.30	256.77	503.26	263.57	516.59
2. Machinery (h)	290.4	18,208.08	313.3	19,643.91	332.63	20,855.90
3. Diesel (L)	520.36	29,301.47	575.76	32,421.04	591.29	33,295.53
4. Fertilizers	286.2	11,002.22	417.56	16,911.66	490.91	19,951.98
4.1. Nitrogen (N)	140.25	9276.13	220.15	14,560.72	260.36	17,220.21
4.2. Phosphorus (P_2O_5)	85.5	1063.62	127.63	1587.71	138.56	1723.68
4.3. Potassium (K_2O)	56.25	627.18	64.39	717.94	85.59	954.32
4.4. Zinc (Zn)	4.2	35.28	5.39	45.27	6.4	53.76
5. Chemicals (kg)	11.26	2535.51	12.15	2737.98	12.7	2869.99
5.1. Herbicide	4	1070.66	4.36	1167.02	4.7	1258.03
5.2. Fungicide	2.36	486.16	2.4	494.4	2.25	463.5
5.3. Insecticide	4.9	978.69	5.39	1076.56	5.75	1148.46
6. Water (m^3)	7120.08	7262.48	9010.11	9190.31	9210.51	9394.72
7. Seed (kg)	31.25	459.37	40.63	597.26	20.5	301.35
Total energy input (MJ)		69,181.23		82,005.42		87,186.06
B. Outputs						
1. Paddy rice (kg)	4189.15	61,580.505	6397.2	94,038.84	8780.6	129,074.82
2. Straw (kg)	2047.69	25,596.125	3178.39	39,729.875	3190.2	39,877.5
Total energy output (MJ)		87,176.625		133,748.71		168,952.32

ble 5. The ratio of energy output of the production to input energy is termed as energy ratio or energy efficiency. This expression is extensively used to measure the energy efficiency in agricultural and food systems [15]. Energy use efficiency was calculated as 1.72 in TS and 1.63 in MS (Table 5). In Iran, Shahan et al. [29] showed that energy use efficiency was calculated as 1.92 in wheat production. Canakci et al. [8] reported wheat output/input ratio as 2.8. In India, calculated energy output/input ratio for wheat production was 2.9, 4.0, 4.2 and 5.2 at different locations depending on fossil fuel usage and straw drying conditions [35].

Table 5
Energy input–output ratio in rice production of Mazandaran province, Iran.

Items	Unit	Production traditional system	Production mechanized system
Energy input	MJ/ha	71,092.26	79,460.33
Energy output (paddy and straw)	MJ/ha	122,962.76	129,965.88
Paddy rice	Kg/ha	6148.83	6455.65
Energy use efficiency	–	1.72	1.63
Specific energy	MJ/kg	11.56	12.30
Energy productivity	Kg/MJ	0.086	0.081
Net energy	MJ/ha	51,870.49	50,505.56

In this study, the average energy productivity of TS and MS were 0.086 and 0.081 Kg/MJ, respectively. This means that 0.086 and 0.081 Kg of paddy output were obtained per 1 MJ energy (Table 5). Calculation of energy productivity rate is well documented in the literatures such as stake-tomato (1.0) [12], cotton (0.06) [42], sugar beet (1.53) [10]. The specific energy and net energy of rice production were 11.56 MJ/kg and 51,870.49 MJ/ha in TS and 12.30 MJ/kg and 50,505.56 MJ/ha in MS, respectively. Shahan et al. [29] reported that specific energy and net energy of wheat production in Iran were 10.43 MJ/kg and 45,707.06 MJ/ha, respectively. These differences between our findings with the results of Shahan et al. [29] could be mainly attributed to the climatic condition of rice field (Caspian sea shore, hot and humid) and wheat field (Ardabil province, a cold region in north east of the country). Also to better conclusion for these differences the specific agro-technical requirements of two mentioned crops should be considered. Canakci et al. [8] has also reported specific energy for field crops and vegetable production in Turkey, as 5.24 for wheat, 11.24 for cotton, 3.88 for maize, 16.21 for sesame, 1.14 for tomato, 0.98 for melon and 0.97 MJ/kg for water-melon.

Total energy consumption in rice production were 71,092.26 MJ/ha (TS) and 79,460.33 MJ/ha (MS). The rate of direct and indirect input energy in traditional and mechanized system of rice production has revealed the similar pattern, in such a manner about 45.09% and 45.38% of the total energy inputs used in rice production were direct, only 54.91% and 54.62% were indirect in TS and MS, respectively (Table 6).

Approximately 2.39% and 1.32% of total energy input in traditional and mechanized systems of rice production has the renewable source (Table 6). Baruah and Dutta [5] reported that renewable energy dominated the rice cultivation in Assam in India, contributing more than 50% of the total input energy with the exception of mechanical power with commercial fertilizer (MPF) category of farm where share of renewable and nonrenewable were found to be almost equal. Singh et al. [34] indicated 80.90% of total energy input for wheat production resulted from non-renewable and 18.1% from renewable energy and 58.1% from direct energy and 41.9% indirect energy. Several researchers have demonstrated that the ratio in non-renewable energy is higher than renewable energy, in various cropping systems [11,12,19,24,38]. In general, there were not significant changes regarding the human labor and chemicals in both systems. Energy from water used for native, high yield and hybrid cultivars was calculated on average as 7433.04, 9271.341 and 9557.706 MJ/ha in TS and 7262.48, 9190.31 and 9394.72 MJ/ha in MS, respectively (Tables 3 and 4). In addition, the highest seed energy was observed in high yield cultivar in both TS and MS (Tables 3 and 4).

Energy management is an important issue in terms of efficient, sustainable and economic use of energy. Energy use in rice production is not efficient and detrimental to the environment due to mainly excess input use. Therefore, reducing these inputs would provide more efficient fertilizer application and diesel. Furthermore, integrated pest control techniques should be put in practice to improve pesticide use. It can be expected that all these measurements would be useful not only for reducing negative effects to environment, human health, maintaining sustainability and decreasing production costs, but also for providing higher energy use efficiency.

Table 6
Total energy input in the form of direct, indirect, renewable and non-renewable source in traditional and mechanized systems of rice production in Mazandaran province, Iran.

Kind of energy	Traditional system (MJ/ha)	Rate (%)[a]	Mechanized system (MJ/ha)	Rate (%)[a]
Direct[b]	28,019.98	45.09	32,152.74	45.38
Indirect[c]	34,116.12	54.91	38,691.75	54.62
Renewable[d]	1495.34	2.39	932.71	1.32
Non-renewable[e]	60,842.88	97.61	69,911.78	98.68
Total energy input	71,092.26	100.00	79,460.33	100.00

[a] Indicates percentage of total energy input.
[b] Includes human labor, diesel.
[c] Includes seeds, fertilizers, chemical, machinery.
[d] Includes human labor and seeds.
[e] Includes diesel, chemical, fertilizers, machinery.

4. Conclusion

Averagely diesel fuel had the highest share within the total energy inputs, followed by chemical fertilizer in rice production in both TS and MS in north of Iran. It was observed that chemical fertilizer energy consumption per hectare exceeds from the available level. It is showed that seed, human labor and chemicals were the least demanding energy input for rice production in TS and MS. In this study, energy use efficiency was calculated as 1.72 in TS and 1.63 in MS. Also, the specific energy and net energy of rice production were 11.56 MJ/kg and 51,870.49 MJ/ha in TS and 12.30 MJ/kg and 50,505.56 MJ/ha in MS, respectively. About 45.09% and 45.38% of the total energy inputs used in rice production were direct, only 54.91% and 54.62% were indirect in TS and MS, respectively. The results of the present study reflect a clear variation of energy use and yield among the different systems. As the management technique influences the yield–energy input relationship of crop production, the variation observed in the present study might be due to variation in the management techniques adopted in two systems of rice production in Iran.

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