Energy analysis of three rice cultivar using different production methods in Iran: A case study

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Abstract: Beyond 66% of the world population are using rice (*Oryza sativa L.*) as staple food which is considered one of the most popular cereals crop ranked after wheat and corn. Both mechanized and conventional methods are being applied in Iran to grow rice. This study performed an analysis of the energy consumed to produce rice in Mazandaran province, Iran, based on the following indices: energy efficiency, energy productivity, net energy gain, specific energy, direct and indirect energy, renewable and non-renewable energy. The cultivars of rice frequently cultivated in Iran comprise native and high yield cultivars. Face to face interviews and field survey were conducted to collect the initial data. Given the literature and benefiting from the data collected in the 2017-2018 production period, secondary data and energy equivalents were determined. The data analysis revealed that diesel fuel accounted for the highest share among the total energy inputs on average, while machinery energy consumption ranked second in both rice production methods. The values of energy efficiency were obtained of 1.48 and 1.33 in traditional and mechanized methods, respectively. Total energy consumption to produce rice was obtained of 84634.56 MJ ha^{-1} and 95644.80 MJ ha^{-1} in traditional and mechanized methods, respectively. The results showed that the energy consumption of labor, irrigation and seed inputs in the mechanized method were reduced by 53.05%, 2.83% and 18.29%, respectively, compared to the traditional method. The obtained results indicated dramatic changes according to human labor, seed and irrigation inputs in two methods.

Keywords: energy, efficiency, productivity, methods, rice

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1 Introduction

Energy is one of the basic requirements for the economic and social development of a country or area. Analysis and scientific forecasts of energy consumption have major importance for the planning strategies and policies of energy use (Liang et al., 2007). Nowadays, agricultural sector has become more energy intensive in order to supply more food to increase population and provide sufficient and adequate nutrition. However, considering limited natural resources and the impact of using different energy sources on environment and human health, it is substantial to investigate energy use patterns in agriculture (Samavatean et al., 2011).

There is a strong relationship between agriculture and energy consumption. Nowadays, energy consumption in agricultural production systems is one of the most important factors for the security and abundance of food supply chain. On the other hand, agriculture has become increasingly dependent on the application of various inputs, such as chemical fertilizers, pesticides, irrigation systems, farm machineries, etc., which are energy intensive elements

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and are directly or indirectly dependent on fossil fuels. Consequently, high costs of energy directly and strongly affect agricultural production costs. Nevertheless, environmental, economical, and social criteria entail modification of agricultural systems into sustainable production systems (Singh et al., 2013).

Energy requirements in agriculture are divided into two groups being direct and indirect. Direct energy is required to perform various tasks related to crop production processes such as land preparation, irrigation, intercultural, threshing, harvesting and transportation of agricultural inputs and farm produce (Singh, 2002). It is seen that direct energy is directly used at farms and in the fields. Indirect energy, on the other hand, consists of the energy used in the manufacture, packaging and transport of fertilizer, pesticide, seed and farm machinery (Kennedy, 2000). To extend more sustainable agricultural practices, energy consumption needs to be taken into account as a basic index (Acaroglu and Aksoy, 2005). Agricultural production is highly dependent on energy inputs and growing consumption of fossil fuel resources has concerned both developed and developing countries. Speaking of bioenergy, agriculture acts as both energy consumer and supplier (Pimental et al., 1973; Singh and Mittal, 1992; Alam et al, 2005). All operations in the field of agriculture consume energy in various forms, namely human labor, animal power, fertilizer, fuels, and electricity. The agriculture has direct proportion to energy use (Esengun et al., 2007a). Warkentin (1991) posited that the crop management had addressed the efficiency of water consumption as a highly vital concern. Effective agricultural energy consumption is one of the ingredients to facilitate sustainable agricultural production since it deals with financial savings, air pollution reduction, and fossil resources preservation (Uhlin, 1998). In addition to land, farm power is considered the second most critical input to agricultural production (Okurut and Odogola, 1999).

Rice (Oryza sativa L.) is a significantly rich nutrient which includes a diverse range of vitamins and minerals, being considerably good for health. The global rice cultivation, total production, and yield are 167.249×106 ha, 769.657×106 ton and 4.60 ton ha^{-1}, respectively, while they take the values of 0.571×106 ha, 2.639 ×106 ton, 4.61 ton ha^{-1} in Iran, respectively (FAO statistics, 2017).

Many studies have been conducted on energy and economic analysis to obtain the energy efficiency of cereal production, such as rice in Iran, India, China and Malaysia (Kazemi et al., 2015; Alipour et al., 2012; Pishgar-Komleh et al., 2011; Yadav et al., 2013; Nassiri and Singh, 2009; Van den Berg et al., 2007; Bockari-Gevao et al., 2005), wheat, maize, barley, oat, in Italy (Fantin et al., 2017; Triolo et al.,1987; Sartori et al., 2005), wheat in Iran, Turkey and New Zealand (Shahan et al., 2008; Firat and Gokdogan, 2014; Safa et al., 2011), wheat, maize, in United States (Franzluebbers and Francis, 1995). Singh (2002) suggested that enhancement of crop production was dependent on three sources, namely cultivable land growth, escalation in yield growth and cropping intensity.

According to the study carried out by Baruah and Dutta (2007) in six agro-climatic rice regions in Assam, India, the input energy comprised eight clearly different sources, i.e. diesel, human, animal, farm yard manure, commercial chemical fertilizer, seed, and pesticide. Based on the power sources used and application of commercial chemical fertilizer, four categories of farms were delineated: animal power without commercial fertilizer (APNF), animal power with commercial fertilizer (APF), mechanical power without commercial fertilizer (MPNF) and mechanical power with commercial fertilizer (MPF). The best-fit curve of energy versus yield indicated that use of commercial chemical fertilizer and mechanical power resulted in higher rice yield at higher level of input energy. Moreover, as the use of energy increased the yield increased up to maxima and then declined at higher levels of energy. This was observed in all four categories of farms with variation in yield–energy values. The average values of energy input (MJ ha^{-1}) and corresponding yield (kg ha^{-1}) for the APNF, APF, MPNF and MPF type of farms were (5220, 1980); (9050, 3170); (5100, 2360) and (8320, 3800), respectively. However, total agricultural energy consumption is low compared to other production sectors in Turkey and many other developed and developing country. Although agricultural energy consumption is drastically lower than other energy-consuming sectors in Turkey, both input and output energy of agricultural sector is a key issue owing to its immense agricultural potential and being concentrated in rural areas (Sayin et al., 2005).

Energy and economic analyses of rice production were performed in farms of various sizes (small (<0.5 ha), medium (0.5–1 ha), and large (>1 ha)) in Guilan province, Iran (Pishgar-Komleh et al., 2011). They illustrated superior management and effectiveness of large farms in energy consumption and economic performance. Energy use pattern for rice production was analyzed and compared in different geographical regions, Golestan, Mazandaran and Guilan, northern provinces of Iran (Kazemi et al., 2015). They reported that there was a significant difference among the three provinces in respect to input energy and agronomical managements such as crop rotation, transplanting date and land preparation. The energy use efficiency varied from 1.39 for Golestan to 1.67 for Guilan provinces. The results revealed the main difference between energy consumption in three provinces came from diesel fuel, chemical fertilizers and electricity. They showed that net energy for paddy production was approximately higher in Guilan (36,927.58 MJ ha^{-1}) than other provinces. Also, the values of energy productivity for Golestan, Mazandaran and Guilan provinces were found to be 0.064, 0.059 and 0.070 kg MJ^{-1}, respectively. Their results disclosed that average 84.70% of total energy input used in rice production was non-renewable, while the contribution of renewable energy was 15.30. The results showed that the total energy input for rice production in Golestan province was 64,158.78 MJ ha^{-1} which was higher than other provinces, due to high energy consumption in diesel fuel style (46.44%).

Safa and Samarasinghe (2011) benefited from neural networks to determine and model energy consumption to produce wheat in New Zealand. Energy consumption was predicted by the final model based on farm specifications (size of crop area), social status of farmers (level of education), and energy inputs (N and P use and irrigation frequency), with a margin of error equal to +12% (+2900 MJ ha^{-1}).

Shahan et al. (2008) calculated that energy consumption efficiency equal to 1.92 for wheat production in Iran. The wheat output/input ratio was reported by Canakci et al. (2005) equal to 2.8. Based on straw drying conditions and fossil fuel consumption in India, energy output/input ratios were obtained of 2.9, 4.0, 4.2 and 5.2 in different geographical regions (Singh et al., 2007). In Ardabil province (a cold region in northeast of Iran), Shahan et al. (2008) reported the values of net energy gain and specific energy for wheat production equal to 45707.06 MJ kg^{-1} and 10.43 MJ kg^{-1}, respectively.

Above all, it is critically necessary to optimize energy consumption due to energy crises occurring across the world. With regard to the predominant role of rice in food supply in the world, a deep insight into the various inputs and energy efficiency can contribute to optimization of energy consumption to produce rice. This study aims to address various facets of energy using efficiency of rice production in Mazandaran province, Iran. Furthermore, operations leading to energy savings by altering applied practices are identified to augment the energy ratio, followed by reducing energy consumption.

2 Materials and methods

This study was conducted in Mazandaran province, Iran, which is located between 35º 46' and 36º 35' north latitude and between 21º 50' and 54º 08' east longitude, with a total and rice cultivating areas of 500,000 ha and 210,000 ha, respectively. Rice is grown in this region by both mechanized and traditional methods. Using traditional equipment and tools could be the cause of higher levels of human labor embedded in traditional methods. Native and high-yield rice cultivars (Tarom, Shiroodi and Nada, respectively) are typically grown in this region:

Designing a face-to-face questionnaire and benefiting from statistical year books (Ministry of Jihad-e-Agriculture,

2017) from March 2017 to October 2018, data were gathered from 92 agricultural service centers of Mazandaran province (for the fields ranging between 1 and 5 ha in area). All inputs and outputs in traditional and mechanized methods for rice cultivation were specified, quantified, and incorporated into Excel spreadsheets, followed by being transformed into energy units (MJ h^{-1}). Since animal labor and farmyard manure data were unavailable, they were excluded calculations. The secondary data utilized in this study was gathered from the literature presented by some institutions such as IRRI and FAO.

The output/input energy ratio was used as a criterion to assess the energy efficiency of the agricultural method. The Energy use efficiency (energy ratio) was estimated regarding human labor, diesel, machinery, fertilizer, chemicals and seed quantities and output yield values of rice crops (Equation 1).

The mechanical energy was supplied by tractor, power tiller, and diesel oil and was computed according to the total fuel (L ha^{-1}) consumed in various operations. Energy ratio (energy efficiency), energy productivity, net energy gain and the specific energy were calculated on the basis of the total input/output energy equivalents by the equations 1 to 4, respectively (Hosseinzadeh-Bandbafha et al., 2018; Karimi and Moghaddam, 2018; Esmailpour et al., 2018).

$$\text{Energy use efficiency(Energy ratio)} = \text{Energy output (MJ ha}^{-1}\text{)} / \text{Energy input (MJ ha}^{-1}\text{)} \quad (1)$$

$$\text{Energy productivity} = \text{Grain yield (kg ha}^{-1}\text{)} / \text{Energy input (MJ ha}^{-1}\text{)} \quad (2)$$

$$\text{Net energy gain} = \text{Energy output (MJ ha}^{-1}\text{)} - \text{Energy input (MJ ha}^{-1}\text{)} \quad (3)$$

$$\text{Specific energy} = \text{Energy input (MJ ha}^{-1}\text{)} / \text{Grain yield (kg ha}^{-1}\text{)} \quad (4)$$

The direct energy input is defined as the energy consumed by physical work within field operations. Field operations account for a large portion of energy consumption (fuel) in agricultural production (Bowers, 1992). The input energy comprised direct, indirect, renewable and non-renewable forms. Indirect energy consisted of energy embedded in seed, chemicals, fertilizers, and machinery while direct form of energy encompassed diesel fuel and human labor and diesel fuel exploited to produce rice. Non-renewable energy is comprised of chemicals, diesel fuel, machinery, and fertilizers, while human labor and seeds constitute renewable energy.

The objective of this study is to assess the energy use pattern and various energy forms for cultivate rice in north of Iran so as to optimize energy inputs.

3 Results and discussion

Table 1 lists the average of all detailed information of the questionnaire. input/output energy was estimated based on the energy equivalents listed in Table 2.

The total energy consumed to supply different farm operations for Tarom, Shiroodi and Neda cultivation processes were obtained of 86277.51, 97428.50, and 103288.37 MJ ha^{-1} by the Mechanized method and 75597.64, 86819.674, and 91486.41 MJ ha^{-1} by the traditional method, respectively (Tables 3 and 4). Diesel fuel accounted for the highest portion of the total energy inputs (consumed for land preparation, cultural practices, and transportation) on average, followed by machinery energy and then chemical fertilizer in both mechanized and traditional methods (Tables 3 and 4). The results provided by Baruah and Dutta (2007) revealed that rice yield in India could be further augmented provided that mechanical power and chemical fertilizer were applied. Average annual paddy yields of farms for were obtained of 3887.15, 6997.20, 8133.12 kg ha^{-1} by the mechanized method and 3771.70, 7148.23, and 8447.44 kg ha^{-1} by the traditional method, respectively. The total output energy for Tarom, Shiroodi, and Neda rice was obtained of 82267.105, 143116.465, and 160879.364 MJ ha^{-1} by the mechanized method and 79205.365, 140968.981, and 160803.743 MJ ha^{-1} by the traditional method, respectively.

As can be seen in Tables 3 and 4, human labor, seed, and chemicals used the least energy to produce rice in both Traditional and Mechanized methods. As compared to

Turkey, Canakci et al. (2005) determined the rates of other energy inputs to the total energy, including 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.

The investigation results of energy input and output, yield, energy efficiency, specific energy, energy productivity and net energy gain of rice production are listed in Table 5. The ratio of energy output to input energy stands for energy efficiency or energy ratio, which has been widely employed to assess the effectiveness of agricultural and food methods (Hadi, 2006). Energy consumption efficiency was obtained of 1.48 and 1.33 in traditional and mechanized methods, respectively (Table 5).

Table1 Inputs/outputs of rice production method in Mazandaran province

	Cropping methods					
	Traditional method			Mechanized method		
	Tarom	Shiroodi	Neda	Tarom	Shiroodi	Neda
A. Inputs						
1. Labor (h ha^{-1})	518.42	609.84	615.66	238.20	286.14	294.41
Land preparation	52.01	61.36	59.24	43.62	52.03	50.73
Nursery	38.98	41.45	40.23	31.67	35.04	33.45
Transplanting	119.39	132.61	128.68	19.00	22.53	22.08
Irrigation	88.83	109.37	111.06	81.28	100.96	106.31
Fertilizer application	6.80	11.06	12.36	5.85	10.37	11.58
Spraying	22.60	28.99	31.16	20.93	23.49	25.86
Harvesting	160.64	193.32	201.08	13.97	16.44	18.53
Transporting	29.17	31.67	31.85	21.88	25.28	25.87
2. Machinery (h ha^{-1})	265.65	286.68	291.95	333.19	359.25	383.10
Land preparation	27.88	29.70	29.01	37.12	39.73	41.59
Nursery	4.91	6.38	6.50	6.85	9.01	8.68
Transplanting	0.00	0.00	0.00	8.64	11.49	9.35
Irrigation	199.97	211.52	213.45	233.27	244.60	265.29
Fertilizer application	10.59	13.03	15.08	11.14	12.74	13.85
Spraying	13.93	14.38	15.41	14.06	14.84	15.18
Harvesting	0.00	0.00	0.00	6.22	6.98	7.72
Transporting	8.39	11.66	12.50	15.89	19.87	21.44
3. Diesel (L ha^{-1})	453.26	516.87	577.22	569.73	629.49	647.37
Land preparation	144.74	170.61	188.77	125.16	140.17	145.36
Nursery	21.82	25.34	28.29	25.52	25.06	27.55
Transplanting	0.00	0.00	0.00	39.48	40.18	46.55
Irrigation	232.39	256.84	293.83	283.95	310.77	316.59
Fertilizer application	5.07	5.94	6.57	6.27	8.12	7.76
Spraying	26.80	33.46	34.29	36.12	46.10	44.83
Harvesting	0.00	0.00	0.00	18.38	20.93	20.30
Transporting	22.45	24.68	25.46	34.85	38.17	38.44
4. Fertilizers (kg ha^{-1})	287.01	438.54	459.70	308.98	449.67	529.72
Nitrogen (N)	141.28	227.40	232.54	151.61	237.98	281.45
Phosphorus (P2O5)	84.92	125.23	135.38	88.92	132.74	144.10
Potassium (K2O)	56.75	80.24	86.37	64.13	73.40	97.57
Zinc (Zn)	4.07	5.67	5.41	4.33	5.55	6.59
5. Chemicals (kg ha^{-1})	13.11	14.85	15.22	13.92	15.01	15.71
Herbicide	5.14	5.89	6.29	5.60	6.10	6.58

Fungicide	2.90	3.29	2.94	2.88	2.93	2.745
Insecticide	5.07	5.66	5.99	5.44	5.98	6.38
6. Water (m^3 ha^{-1})	17230.43	16462.14	16805.71	16810.08	16187.35	16074.21
7. Seeds (kg ha^{-1})	51.25	54.29	50.41	41.25	45.63	40.50
B. Outputs						
1. Paddy rice (kg ha^{-1})	3771.70	7148.23	8447.44	3887.15	6997.20	8133.12
2. Straw (kg ha^{-1})	1900.91	2871.20	2930.11	2010.08	3220.61	3305.80

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	Ozkan, et al., 2004; Yilmaz et al., 2005
2. Machinery	h	62.7	Erdal et al., 2007;Sayin et al., 2005
3. Diesel	L	56.31	Erdal et al., 2007; Sayin et al., 2005
4. Fertilizers	kg		
4.1. Nitrogen (N)		66.14	Kazemi et al.,2015
4.2. Phosphorus (P2O5)		12.44	Kazemi et al.,2015
4.3.Potassium(K2O)		11.5	Kazemi et al.,2015
4.4. Zinc (Zn)		8.40	Kazemi et al.,2015
5. Chemicals	kg	120	Mandal et al., 2002
6. Water	m3	1.02	Singh and Mittal, 1992
7. Seed	kg	14.7	Ozkan, et al., 2004; Sayin, et al., 2005
B. Outputs			
1. Paddy rice	kg	14.7	Ozkan et al., 2004; Sayin et al., 2005
2. Straw	kg	12.5	Ozkan et al., 2004; Sayin et al., 2005

Table 3 Values of inputs and outputs of rice production by the traditional method

Inputs and outputs	Tarom		Shiroodi		Neda	
	Quantity per ha	Total energy equivalent	Quantity per ha	Total energy equivalent	Quantity per ha	Total energy equivalent
A. Inputs						
1. Labor (h)	518.42	1016.11	609.84	1195.28503	615.66	1206.692
2. Machinery (h)	265.65	16656.23	286.68	17974.742	291.95	18305.27
3. Diesel (L)	453.2625	25523.21	516.87	29104.9553	577.22	32502.99
4. Fertilizers	287.01	11087.13	438.54	17568.40	459.70	18103.23
4.1. Nitrogen (N)	141.28	9343.99	227.40	15040.18	232.54	15380.51
4.2. Phosphorus (P2O5)	84.92	1056.36	125.23	1557.82	135.38	1684.09
4.3. Potassium (K2O)	56.75	652.62	80.24	922.81	86.37	993.21
4.4. Zinc (Zn)	4.07	34.18	5.67	47.59	5.41	45.42
5. Chemicals (kg)	13.11	2986.55	14.85	3386.82	15.22	3485.37
5.1. Herbicide	5.14	1375.24	5.89	1577.59	6.29	1682.51
5.2. Fungicide	2.90	598.14	3.29	678.56	2.94	605.68
5.3. Insecticide	5.07	1013.17	5.66	1130.67	5.99	1197.18
6. Water (m3)	17230.43	17575.04	16462.14	16791.38	16805.71	17141.82
7. Seed (kg)	51.25	753.375	54.29	798.063	50.41	741.027
Total energy input (MJ)		75597.645		86819.647		91486.41
B. Outputs						
1. Paddy rice(kg)	3771.7	55443.99	7148.23	105078.98	8447.44	124177.4
2. Straw (kg)	1900.91	23761.375	2871.2	35890	2930.11	36626.38
Total energy output (MJ)		79205.365		140968.981		160803.743

Table 4 Amounts of inputs and outputs of rice production by the mechanized method

Inputs and outputs	Tarom		Shiroodi		Neda	
	Quantity per ha	Total energy	Quantity per ha	Total energy equivalent	Quantity per ha	Total energy
A. Inputs						
1. Labor (h)	238.20	466.87	286.14	560.83	294.41	577.04

2. Machinery (h)	333.1876	20890.86	359.252	22525.1004	383.097	24020.18
3. Diesel (L)	569.7272	32081.34	629.4907	35446.6213	647.372	36453.52
4. Fertilizers	308.98	11907.44	449.67	18282.15	529.72	21585.14
4.1. Nitrogen (N)	151.61	10027.50	237.98	15740.14	281.45	18615.05
4.2. Phosphorus (P2O5)	88.92	1106.16	132.74	1651.23	144.10	1792.63
4.3. Potassium (K2O)	64.13	737.44	73.40	844.15	97.57	1122.08
4.4. Zinc (Zn)	4.33	36.34	5.55	46.63	6.59	55.37
5. Chemicals (kg)	13.92	3178.34	15.01	3431.93	15.71	3601.45
5.1. Herbicide	5.60	1498.90	6.10	1633.80	6.58	1761.20
5.2. Fungicide	2.88	593.12	2.93	603.17	2.745	565.47
5.3. Insecticide	5.44	1086.33	5.98	1194.96	6.38	1274.78
6. Water (m3)	16810.08	17146.2	16187.35	16511	16074.21	16395.69
7. Seed (kg)	41.25	606.375	45.63	670.761	40.50	595.35
Total energy input (MJ)		86277.514		97428.499		103228.377
B. Outputs						
1. Paddy rice (kg)	3887.15	57141.105	6997.20	102858.84	8133.12	119556.864
2. Straw (kg)	2010.08	25126	3220.61	40257.625	3305.80	41322.5
Total energy output (MJ)		82267.105		143116.465		160879.364

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

Items	Unit	Traditional method			Mechanized method		
		Tarom	Shiroodi	Neda	Tarom	Shiroodi	Neda
Energy input	MJ ha^{-1}	75597.65	86819.65	91486.41	86277.51	97428.50	103228.38
Energy output	MJ ha^{-1}	79205.37	140968.98	160803.74	82267.11	143116.47	160879.36
Paddy yield	Kg ha^{-1}	3771.70	7148.23	8447.44	3887.15	6997.20	8133.12
Energy efficiency	-	1.048	1.624	1.757	0.954	1.469	1.558
Specific energy	MJ kg^{-1}	20.043	12.146	10.830	22.196	13.924	12.692
Energy productivity	Kg MJ^{-1}	0.050	0.082	0.092	0.045	0.072	0.079
Net energy gain	MJ ha^{-1}	3607.72	54149.33	69317.33	-4010.41	45687.97	57650.99

In this study, the average energy productivity of mechanized and traditional methods was obtained of 0.0652 and 0.0748 Kg MJ^{-1}, respectively, i.e. 0.065 and 0.075 Kg of paddy output were reached per MJ produced(Table 5). The rate of energy productivity rate has been properly calculated in the literature such as stake-tomato (1.0) (Esengun et al., 2007b), cotton (0.06) (Yilmaz et al., 2005), sugar beet (1.53) (Erdal et al., 2007).

Net energy gain and specific energy of rice production were obtained of 42358.13 MJ ha^{-1} and 14.34 MJ kg^{-1} by traditional method and 33109.51 MJ ha^{-1} and 16.27 MJ kg^{-1} by mechanized method, respectively. The discrepancy between the findings of the present study with the results reported by Shahan et al. (2008) could be centrally due to the difference between the climatic conditions of wheat and rice fields. Moreover, to better clarify these differences, the specific agro-technical necessities of the two crops should be taken into account. In Turkey, Canakci et al. (2005) obtained the specific energy of wheat, cotton, maize, sesame, tomato, melon, and watermelon equal to5.24, 11.24, 3.88, 16.21, 1.14, 0.98, and 0.97 MJ kg^{-1}, respectively.

Table 6 Total energy input in the form of direct, indirect, renewable and non-renewable source in traditional methods of rice production in Mazandaran

Type of energy	Traditional method (MJ ha^{-1})					
	Tarom	ratio	Shiroodi	ratio	Neda	ratio
Direct	44114.36	58.35	47091.62	54.24	50851.51	55.58
Indirect	31483.29	41.65	39728.02	45.76	40634.90	44.42
Renewable	19344.52	25.59	18784.73	21.64	19089.54	20.87
Non-renewable	56253.12	74.41	68034.92	78.36	72396.86	79.13

Total energy consumed by the traditional and mechanized methods to produce rice was obtained of 84634.56 MJ ha^{-1} and 95644.80 MJ ha^{-1}, respectively. A similar pattern was observed fir the rate of direct and indirect input energy in the rice-production mechanized and traditional methods, i.e. the direct input energy accounted for 56.06% and 54.42% of the total energy inputs while the indirect input energy accounted for only 43.94% and 45.58% in the traditional and mechanized methods, respectively (Table 6 and 7).

Table 7 Total energy input in the form of direct, indirect, renewable and non-renewable source in mechanized methods of rice production in Mazandaran

Type of energy	Mechanized method (MJ ha^{-1})					
	Tarom	ratio	Shiroodi	ratio	Neda	ratio
Direct	49694.49	57.60	52518.56	53.90	53426.26	51.76
Indirect	36583.02	42.40	44909.94	46.10	49802.12	48.24
Renewable	18219.53	21.12	17742.70	18.21	17568.09	17.02
Non-renewable	68057.99	78.88	79685.80	81.79	85660.29	82.98

The renewable resources accounted for approximately 18.78% and 22.70% of total input energy by mechanized and traditional methods to produce rice (Table 6 and 7). Baruah and Dutta (2007) showed in their study that renewable energy supplied a large portion of the energy needed for the rice cultivation in Assam, India, i.e. accounting for more than 50% of the total input energy aside from mechanical power with commercial fertilizer (MPF) (nonrenewable resources as the other half). Singh et al. (2003) showed for wheat production that 80.90% of the total input energy was supplied by nonrenewable resources and from the rest by renewable resources. Also, 58.1% and 41.9% of the total input energy were provided by direct and indirect energy, respectively. Many studies have illustrated higher contribution of non-renewable energy than renewable energy into a diverse range of cropping methods (Tsatsarelis, 1991; Ozkan et al., 2004; Rathke and Diepenbrock, 2006; Esengun et al., 2007a; Esengun et al., 2007b). In general, changes concerning human labor and chemicals were insignificant in both methods. Hydropower used for native, high yield and hybrid cultivars was obtained of 17575.04, 16791.38 and 17141.82 MJ ha^{-1} in traditional method and 17146.28, 16511.1 and 16395.69 MJ ha^{-1} in mechanized methods, respectively (Tables 3 and 4). In addition, in both traditional and mechanized methods, high yield cultivar was observed associating with the highest seed energy (Tables 3 and 4).

Energy management is a key to efficient, sustainable and economic energy consumption. Energy is not being consumed efficiently to produce rice which is harmful to the environment because of excess input usage. Therefore, more efficient fertilizer application and diesel would be achieved by minimizing these inputs. Moreover, one must put integrated pest control techniques in practice to enhance pesticide consumption. All of these measurements would be expected to be beneficial not only to diminishing negative impacts posed on environment, human health, maintaining sustainability, and decrease in production costs, but also to higher efficiency of energy consumption.

The results revealed that the average energy consumed by the labor to produce three rice cultivars in the mechanized and traditional methods were 534.91 and 1139.36 MJ ha^{-1}, respectively, and 53.05% of the energy saved in the mechanized method. The results showed that the average energy consumed by the irrigation to produce three rice cultivars in the mechanized and traditional methods were 16684.29 and 17169.41 MJ ha^{-1}, respectively, and 2.83% of the energy saved in the mechanized method. Average energy consumed by the seed to produce three rice cultivars in the mechanized and traditional methods were 624.36 and 764.15 MJ ha^{-1}, respectively, and 18.29% of the energy saved in the mechanized method.

The results showed that the energy consumption of labor, irrigation and seed inputs in the mechanized method were reduced by 53.05%, 2.83% and 18.29%, respectively, compared to the traditional method.

4 Conclusion

Diesel fuel accounted for the highest portion of the total energy inputs on average, and next ranks were given to machinery and then chemical fertilizer to produce rice in both mechanized and traditional methods in the north of Iran. The energy consumption of chemical fertilizer per hectare was observed to exceed the available level. It has been indicated that seed, human labor, and chemicals demanded the least energy input to produce rice by mechanized and traditional methods. In the present study, the efficiency of energy consumption was obtained of 1.48 and 1.32 by the traditional and mechanized methods, respectively. Furthermore, the net and specific energy of rice production were obtained of 33109.51 MJ ha^{-1} and

16.27 MJ kg^{-1} in the mechanized method and 42358.13 MJ ha^{-1} and 14.34 MJ kg^{-1} in the traditional method, respectively. The direct input energy accounted for 56.06% and 54.42% of the total energy inputs while the indirect input energy accounted for only 43.94% and 45.58% in the traditional and mechanized methods, respectively. The results of the present study revealed a distinct variable energy consumption and crop yield offered by different methods. Since the energy input needed for crop production can be controlled by managerial techniques, the discrepancy observed between the two cultivation methods might attributed to different forms of management adopted. The results showed that the average energy consumed by labor, irrigation and seed inputs for the three rice cultivars in the mechanized method were lower than the traditional method 604.44, 485.12 and 139.79 MJ ha^{-1}, respectively. In order to energy saving in rice production, the minimum tillage method, optimum use of chemical fertilizers based on soil test, use of tractors with proper power, and timely service and maintenance of tractors and equipment are recommended.

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