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# Efficient use of energy through organic rice–duck mutualism system

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**Abstract** Industrial agriculture is not efficient anymore due in particular to the use of nonrenewable energy such as fossil fuels. Organic agriculture is an alternative system that aims to reduce the consumption of fossil fuels, pesticides, and mineral fertilizers. Animal–crop systems present potential mutual benefits, but such systems have been rarely studied quantitatively. Here, we compare energy inputs and outputs of organic rice–duck farming with conventional rice production in Mazandaran province, Iran. Our results show that the global energy input of organic rice–duck, 79,307 MJ ha<sup>-1</sup>, is lower than that of conventional rice, 94,377 MJ ha<sup>-1</sup>. On the contrary, the energy output of organic rice–duck, 117,325 MJ ha<sup>-1</sup>, is higher than that of conventional rice, 111,914 MJ ha<sup>-1</sup>. The most used energy was fuel, amounting to 40 % of total energy for organic rice–duck and 33 % for conventional rice. Then, machinery consumed 25 % of total

energy for organic rice–duck and 20 % for conventional rice. Then, fertilizers consumed 20 % of total energy in the form of organic fertilizers for organic rice–duck versus 16 % in the form of mineral fertilizers for conventional rice. Overall, our findings show that organic rice–duck farming has more energy efficiency than conventional rice farming.

**Keywords** Renewable energy · Rice · Rice–duck · Sustainable agriculture · Mutualism

## 1 Introduction

Population growth is believed to be one of the main challenges for the future of human civilization (Kibirige 1997; Swaminathan 2010). Although extensive population control programs have been successfully performed in many countries, the world's population has doubled since 1960 and is still increasing (Gilland 2002). One of the main challenges of population growth is food shortage caused by limited resources and the limitations of traditional agriculture, which was a main concern of the classical Malthusian approach. Fortunately, modern agriculture has successfully attacked the problem by developing more efficient techniques, such as using more efficient plant and animal varieties, increasing the use of fertilizers, extending irrigation, effectively controlling insects and diseases, and so on (Guangyong et al. 2011; Mosher and Corscadden 2012; Sarkar et al. 2012). It seems that modern agriculture is able to solve this problem and feed the increasing population, and it is hoped that equilibrium will be reached in the current century. The employment of these modern agricultural policies, however, demands higher amounts of energy. It is well known that modern farming is very energy intensive (Singh et al. 2000). The future of human civilization still faces the challenge of energy, and it seems that

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modern agriculture has exacerbated this challenge by widely using nonrenewable energy sources such as fossil fuels, especially for operating farm and irrigation machinery, producing chemical fertilizers, pesticides, and herbicides and using electrical inputs which may be produced by fuel consumption in power plants.

Modern agriculture has also to face the paradoxical problem of eco-efficient and sustainable production. Some researchers have reported the substantial share held by modern agriculture of the emission of trace greenhouse gases (Isermann 1994; Yuksel and Kaygusuz 2011). Therefore, methods of decreasing the energy needs of modern, energy-intensive agriculture must be found. Some researchers claim that the use of renewable energy may reduce the consumption of fossil fuels (Panwar et al. 2011; Ong et al. 2011; Hasan et al. 2012; Bardi et al. 2013). Efficiency in energy use has also been reported to minimize many of these problems by saving natural resources and leading to sustainable agriculture (Kizilaslan 2009; Ozkan et al. 2011a, b). Organic agriculture, which has been widely studied in recent years, is believed to lower energy consumption and balance long-term productivity with ecological sustainability (Lund and Algers 2003; Mingl and Sauerborn 2006). According to International Federation of Organic Agriculture Movements (IFOAM) definition, organic farming is free of agricultural chemicals, such as synthetic chemical fertilizers and pesticides, with the exception of certain permitted chemicals including lime sulfur and low-synthetic minerals (<http://www.ifoam.bio/>, Hokazono and Hayashi 2012).

Rice (*Oryza sativa* L.) is cultivated in many parts of the world and is the second most-produced grain in the world. Since this grain requires plenty of water and labor, it is believed that it consumes much energy. Areas which have high rainfall and low labor costs, such as East, South, and Southeast Asia and certain regions of the Middle East, are considered most suitable for rice production. Rice is cultivated under different soil, water, and temperature conditions (Pishgar-Komleh et al. 2011; Chauhan et al. 2006).

In Iran, the agriculture sector contributed significantly to the GDP (11.9 %) in 2011, and rice was considered one of the country's most important and strategic crops (<http://www.imna.ir>). Iran's arable area is 17,541,000 ha, of which 574,000 ha (3.27 %) were rice fields in 2011. In 2011, rice produced in Iran equaled more than 2.7 Mt of the 728.7 Mt produced worldwide. The 2011 worldwide average yield of rice was 4300 kg ha<sup>-1</sup>; however, the average rice yield in Iran was almost 4478.2 kg ha<sup>-1</sup>. That year, Mazandaran province ranked first in total rice crop production share in Iran (46.3 %) (Food and Agriculture Organization FAO of the United Nation Statistics 2013; Annual agricultural statistics. Available from: Ministry of Jihad-e- Agriculture of Iran 2013). According to FAO (2012) reports, among the main countries now expected to cut imports from the previous year are China, Indonesia, the Islamic Rep. of Iran, Nigeria, the Philippines, Senegal, and

Thailand. Iran has many reasons to cut imports, e.g., independent political property, increased energy costs, unemployment problems, etc. Thus, efforts are immediately required not only to improve rice crop production but also to decrease the associated direct and indirect costs by lessening pollution and preventing environmental problems such as nitrate leaching and eutrophication. Based on these important reasons, one of Iran's main agriculture strategies is to implement organic and sustainable agriculture. Today, Iran has begun spatially converting conventional rice monocropping patterns to different multiple cropping rice-based systems, like the rice/green manure or rice-duck organic farming systems. According to FAO (2012) reports, Iran with 43,332 ha was the sixth country with the most organic agricultural land in 2011 behind China, India, Kazakhstan, the Philippines, and Indonesia.

Rice-duck farming, a form of organic agriculture, has many economic, environmental, and ecological benefits (Li et al. 2012). Since the harmful effects of the intensive employment of agrochemicals and chemical fertilizers in commercial agricultural systems were highlighted by numerous researches worldwide, the integrated rice-duck system has been recommended into cultivation practices in many Asian countries, particularly Japan, China, Indonesia, Vietnam, Korea, and the Philippines. This system creates a yield-increasing model of integrated utilization of paddy resources for rice production and, more importantly, duck breeding. Thus, a mutually beneficial situation is established for both rice growing and duck breeding in this system rather than a simple combination (Xi and Qin 2009; Pin et al. 2012). A number of studies have compared the rice-duck mutualism organic farming as an organic farming system to conventional cultivation methods with respect to environmental and ecological issues. Their findings attribute high advantages to this system because of the reduction in expenses of herbicides, insecticides, fungicides, and chemical fertilizers which are replaced with duck manure and the foraging behavior and frequent movements of ducks, which effectively control weeds and insects (Takayama et al. 2004; Li et al. 2008; Zhan et al. 2011). Huang et al. (2005, 2008) investigated the effects of a rice-duck complex ecosystem on methane emission. They found that the rice-duck ecological planting and breeding model significantly decreased methane emissions from paddy fields compared with conventional rice fields. Li et al. (2012) reported the efficacy of the rice-duck mutualism organic farming in depleting weed seed banks and as a weed management approach without the use of herbicides.

Factors which influence the economy of conventional crops are directly related to energy. Quantitative relations show how the system's benefits and costs are affected by energy consumptions. Determining energy efficiency has been the main subject of the majority of previous studies (e.g., Singh et al. 2000; Karkacier and Goktolga 2005; Rafiee et al. 2010; Zangeneh et al. 2010; Pahlavan et al. 2011; Bojacá et al. 2012; Tabatabaie et al. 2013). Some studies have published energy and economic analyses of rice crop alone (Pishgar-Komleh et al. 2011).

Many studies compare the different aspects of organic and conventional rice production methods. This work aimed to investigate the energy and economic aspects which are usually ignored. Factors such as energy productivity, different energy ratios, and so on are studied, and economic values are related to environmental issues.

## 2 Materials and methods

### 2.1 Site description and climatic data

The current study was conducted in the Mazandaran province of northern Iran, along the southern coast of the Caspian Sea (Fig. 1), which has an altitude of 16 m above sea level. This province is located between 35° 46' and 36° 58' lat. N and 21° 50' and 54° 08' long. E. The climate of the area (data relating to the years 2001–2012) is characterized by an annual average rainfall of 1315.5 mm, distributed mostly in autumn and winter. Annual average temperatures are 7–32 °C, with a monthly maximum ranging between 23 and 35 °C in July and a minimum of 3–20 °C in January. During the study period, annual precipitation measured 877.20 mm in 2011 and 1706.4 mm in 2012. Soil analysis showed soil texture to be clay and clay loam. Mazandaran province was selected for this research because it is the number one rice cultivating area in Iran (46.3 % of the country's area).

### 2.2 Experimental details and sampling procedure

Experimental data for the 2011–2012 period was gathered from different rice-producing plants regarding 112 cases in 23 different villages of Mazandaran province. The average

area of the studied cases was 0.8 ha, and both single rice and rice–duck farming cases were considered.

The survey volume was determined by the simple random sampling method (Yates et al 2008; Ghasemi Mobtaker et al. 2010):

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

where  $n$  is the required sample size,  $s$  is the standard deviation,  $t$  is the  $t$  value at a 95 % confidence level (1.96),  $N$  is the number of holding in target population, and  $d$  is the acceptable error (permissible error 5 %).

### 2.3 Data mining

The inputs considered for these two modes were human labor, machinery, diesel fuel, chemical fertilizers, pesticides, fungicides, and herbicides as biocides, water for irrigation, seed, rice bran, and duckling. The outputs considered were grain, straw, and duck as a product. The input and output amounts utilized in two rice production systems are presented in Table 1.

Human energy as an energy input was calculated by multiplying the number of man-hours ( $\text{hha}^{-1}$ ) based on the estimated power rating of human labor ( $\text{MJh}^{-1}$ ) from Table 1. The energy used by machinery was estimated as follows (Kitani et al. 1999):

$$\text{ME} = E \times G \times T \quad (2)$$

where ME is the machinery energy (MJ),  $E$  is the production energy of the machine (Table 1),  $G$  is the mass of the machine



Fig. 1 Map of Iran showing the location of Mazandaran province



**Table 1** Energy equivalent of inputs and output in two different rice production systems

Input	Unit	Energy equivalent (MJunit <sup>-1</sup> )	References
<b>A. Inputs</b>			
1. Machinery	h	62.70	Royan et al.(2012), Agha Alikhani et al.(2013)
2. Human labor			
Male	h	1.96	Sing et al.(1994), Agha Alikhani et al.(2013),
Female	h	1.54	Sing et al.(1994)
3. Diesel	L	56.31	Agha Alikhani et al.(2013)
4. Chemical fertilizer			
Nitrogen (N)	kg	66.14	Kitani (1999)
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	kg	12.44	Kitani (1999)
Potassium (K <sub>2</sub> O)	kg	11.50	Kitani (1999)
Zinc (Zn)	kg	8.40	Agha Alikhani et al.(2013)
5. Organic fertilizer	ton	303.10	Rai Jadidi et al.(2010)
6. Biocide			
Insecticide	kg	229.00	Kitani (1999)
Herbicide	kg	85.00	Kitani (1999)
Fungicide	kg	115.00	Kitani (1999)
7. Seed	kg	14.70	Kitani (1999)
8. Rice bran	kg	12.55	Sayin et al.(2005)
9. Water	m <sup>3</sup>	1.02	Agha Alikhani et al.(2013)
10. Duckling	kg	14.10	William (2008)
<b>B. Outputs</b>			
1. Paddy rice	kg	14.70	Agha Alikhani et al.(2013)
2. Straw	kg	12.50	Agha Alikhani et al.(2013)
3. Duck	kg	14.10	William (2008)

(kg), and  $T$  is the economic life of the machine (years). Other inputs such as fuel, seed, biocides, and chemical fertilizers used in rice production were transformed to energy value (MJha<sup>-1</sup>) by multiplying the quantity of the material used on the farms by the energy equivalent of each material. For example, the energy consumed to produce chemical fertilizer (potassium) was calculated by multiplying the amount of potassium usage (kg ha<sup>-1</sup>) by the energy coefficient of potassium fertilizer production (12.44 MJkg<sup>-1</sup> from Table 1); the result is the energy consumption of potassium fertilizer (MJha<sup>-1</sup>) in rice production. Other energy inputs can be similarly estimated. Since gasoline pumps are used to prepare irrigation water, irrigation energy was displayed as diesel energy. The amount of output energy (MJ ha<sup>-1</sup>) was estimated by multiplying the rice paddy yield (kg ha<sup>-1</sup>) by the rice energy equivalent

(MJ kg<sup>-1</sup>). The total input equivalent can be calculated by adding up the energy equivalences of all inputs in mega joules (MJ). Based on the energy equivalents of the inputs and output (Table 2), the energy ratio (energy use efficiency) and energy productivity were calculated as follows (Hülsbergen et al. 2001; Yilmaz et al. 2005; Demircan et al. 2006; Shahan et al. 2008):

$$\text{Energy use efficiency} = \frac{\text{Energy Output (MJ ha}^{-1}\text{)}}{\text{Energy Input (MJ ha}^{-1}\text{)}} \quad (3)$$

$$\text{Energy productivity} = \frac{\text{Production (kg ha}^{-1}\text{)}}{\text{Energy Input (MJ ha}^{-1}\text{)}} \quad (4)$$

$$\text{Specific energy} = \frac{\text{Energy Input (MJ ha}^{-1}\text{)}}{\text{Production (kg ha}^{-1}\text{)}} \quad (5)$$

$$\text{Net Energy} = \text{Energy Output (MJ ha}^{-1}\text{)} - \text{Energy Input (MJ ha}^{-1}\text{)} \quad (6)$$

In the last part of the study, total energy input was also classified into either direct and indirect or renewable and non-renewable forms. Direct energy (DE) included human labor and diesel fuel energy used in the production process, and indirect energy (IDE) consisted of machinery, seed, chemical fertilizer, biocide, organic fertilizer, rice bran, water, and duckling and duck energy. Renewable energy (RE) consisted of seed and human labor, organic fertilizer, rice bran, water, duckling and duck; nonrenewable energy (NRE) included machinery, diesel fuel, biocides, and chemical fertilizers. The term ‘renewable energy’ refers to energy sources that are replenished by natural processes on a sufficiently rapid time-scale; they can be used by humans more or less indefinitely, provided the quantity taken per unit of time is not too great. The term ‘nonrenewable energy’ is used to describe energy sources that exist in limited amounts on earth (Singh et al. 2003; Tabatabaie et al. 2013). The data were subjected to SPSS, version 18, and  $t$  test was used to compare two systems ( $P < 0.05$  was considered statistically significant).

### 3 Results and discussion

All inputs and outputs for the rice–duck mutualism organic farming and the conventional rice cultivation are shown in Table 2. Human labor for the rice–duck mutualism farming system was determined to be about 267.9 h, which 155.4 h for male and 112.5 h for female, while for conventional rice cultivation system was determined to be about 240.1 h (180.0 h for male and 60.06 h for female). The human labor for the rice–duck mutualism farming system was greater than conventional rice cultivation system. One of the main reason

**Table 2** Amounts of used inputs and outputs and their energy equivalences in two rice production systems

Input	Rice–duck mutualism organic farming			Conventional rice cultivation			T test significance
	Quantity per unit area (ha)	Energy equivalent (MJ unit <sup>-1</sup> )	Percentage	Quantity per unit area (ha)	Energy equivalent (MJ unit <sup>-1</sup> )	Percentage	
<b>A. Inputs</b>							
1. Machinery (h)	313.3±7.40	19,643±464	24.77	302.1±7.64	18,941±479	20.07	0.955
2. Human Labor (h)	267.9±28.7	478±44	0.6	240.1±6.17	445±11	0.47	0.000
Male (h)	155.4±8.09	305±16	0.38	180.0±5.07	352±10	0.37	0.013
Female (h)	112.5±30.9	173±31	0.22	60.06±3.70	93±4	0.10	0.015
3. Diesel (L)	561.5±6.2	31,616±351	39.87	554.5±6.9	31,168±387	33.02	0.837
4. Chemical fertilizer (kg)	0.00	0	0.00	359.90±20.7	15,042±1352	15.94	0.008
Nitrogen (N)	0.00	0	0.00	198.17±20.2	13,107±1340	13.89	0.008
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	0.00	0	0.00	96.50±2.1	1200±26	1.27	0.000
Potassium (K <sub>2</sub> O)	0.00	0	0.00	60.12±1.83	691±21	0.73	0.000
Zinc (Zn)	0.00	0	0.00	5.11±1.05	43±8	0.05	0.000
5. Organic fertilizer (ton)	3.00±0.92	909±280	1.15	0.00	0	0.00	0.000
6. Biocide (kg)	0.00	0	0.00	12.02±0.93	1842±196	1.95	0.000
Insecticide	0.00	0	0.00	5.22±0.83	1195±190	1.27	0.000
Herbicide	0.00	0	0.00	4.50±0.27	383±23	0.41	0.000
Fungicide	0.00	0	0.00	2.30±0.27	265±31	0.28	0.000
7. Seed (kg)	36.20±2.3	532±34	0.67	36.20±2.07	532±30	0.56	0.961
8. Rice bran (kg)	1250.00±28.6	15,688±358	19.78	0.00	0	0.00	0.000
9. Water (m <sup>3</sup> )	7585.60±18.4	8900±18.8	11.22	7737.31±516.5	9078±527	9.62	0.422
10. Duckling (kg)	75.42±4.40	1063±62	1.34	0.00	0	0.00	0.000
Total energy input	–	<i>79,307</i>	<i>100.00</i>	–	<i>94,377</i>	<i>100.00</i>	
<b>B. Outputs</b>							
1. Grain (kg)	5500.65±156.17	80,860±825	68.92	5435.42±146.2	79,901±727	71.39	0.000
2. Straw (kg)	2559.12±124.5	29,377±306	25.04	2561.03±122.8	32,013±105	28.60	0.020
3. Duck (kg)	502.69±14.9	7088±210	6.04	0.00	0.00	0.00	0.000
Total energy output	<i>8562.46</i>	<i>117,325</i>	<i>100.00</i>	<i>7996.45</i>	<i>111,914</i>	<i>100.00</i>	

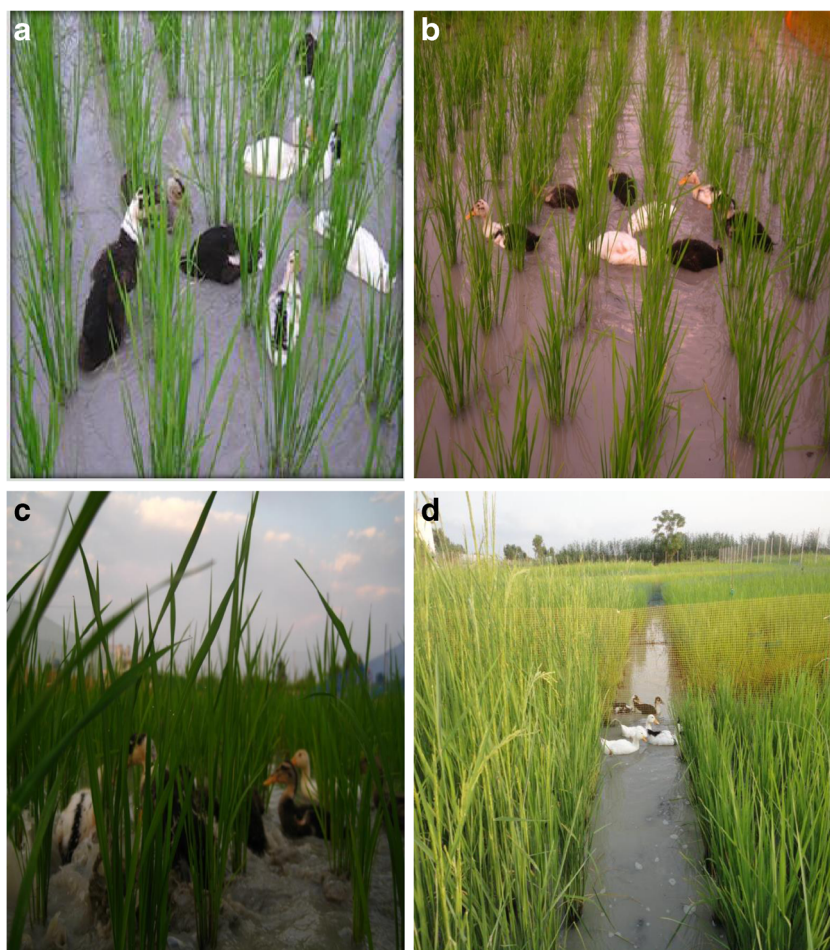
Value in *italic* indicate total energy input and output of two production systems

was duck farming is labor-intensive. Also, the ratio of female to male workers in the rice–duck mutualism organic farming was bigger than the conventional rice cultivation. Duck farming was held by female labor. It will be a positive note that women are more active in the social economy. Machinery power was estimated to be around 313.3 and 302.1 h ha<sup>-1</sup> for the rice–duck mutualism organic farming and the conventional rice cultivation system, respectively. The amount of diesel fuel required for the conventional rice cultivation or the rice–duck mutualism organic farming production was about 561.5 and 554.5 L, respectively. The total amounts of fertilizers and biocides used for the conventional rice cultivation and rice production were 359.90 and 12.02 kg ha<sup>-1</sup>, respectively. Ducks tend to move about as they forage, and the rice–duck mutualism organic farming takes advantage of this habit to control plant diseases, insect pests, and weeds and to

increase both rice production and income (Fig. 2 a, b, c, d). The long-term adverse health and environmental effects of insecticides, herbicides, and chemical fertilizer use were also substantially reduced, thus making the system beneficial to the environment. Only 3 tons of organic fertilizer was used in the rice–duck mutualism organic farming areas; no fertilizers or biocides were used. Moreover, healthier duck meat was produced. Huang et al. (2013) similarly observed that the organic rice–prawn farming yields 20 % higher revenues.

It can be concluded that the rice–duck mutualism organic farming producer may obtain dual benefits from the simultaneous production of rice and duck meat. Hong et al. (2009) compared the quality of meat produced by rice–duck mutualism and conventional duck production. They found the rice–duck mutualism system could significantly improve the quality of both duck meat and duck carcass. The total averages for energy

**Fig. 2** **a** Duckling, **b** weed and pest control, **c** soil fertility, and **d** ready-for-sale or marketable duck in the rice–duck mutualism system



input and output in the rice–duck mutualism organic farming and the conventional rice cultivation were calculated as 79,307 and 117,325 MJ ha<sup>-1</sup> and 94,377 and 111,914 MJ ha<sup>-1</sup>, respectively. The results showed that the rice–duck mutualism organic farming produced greater energy outputs and used less energy inputs than the conventional rice cultivation.

Fuel consumption comprised the highest energy input in the both systems, being 39.87 % for the rice–duck mutualism organic farming and 33.02 % for the conventional rice cultivation and used mainly to irrigate and operate tractors and other machinery. The low price of hydrocarbon fuels in Iran usually leads to overconsumption of energy due to oversupplying water to rice plantations.

Other researchers have also reported that fuel inputs comprise an important section of energy consumption in rice production and that machine power has replaced human and animal labor (Eskandari Cherati et al. 2011; Pin et al. 2012). The age of the machinery and equipment used may be one reason for poor energy efficiency in rice production in Iran, and this may be improved by applying more efficient machinery and equipment. Table 2 shows that machinery (24.77 % for the rice–duck mutualism organic farming and 20.07 % for the conventional rice cultivation) constituted the second highest energy

consumption item, which included tractors and stationary equipment. The third item is rice bran, accounting for 19.78 % in the rice–duck mutualism organic farming and chemical fertilizers was determined 15.94 % in the conventional rice cultivation. The shares of nitrogen, phosphorus, potassium, and zinc were around 13.89, 1.27, 0.73, and 0.05 %, respectively. The total amount of biocide energy consumed in the rice–duck mutualism organic farming production was found to be 1.95 %, which included 1.27 % for insecticide, 0.41 % for herbicide, and 0.28 % for fungicide. Such efficiency in reducing of chemical fertilizer (up to 52 % N fertilizer replaced by biofertilizer) has been previously reported by Huang et al. (2013) in the organic rice–prawn farming system.

Table 3 shows the energy consumption, productivity, and energy gain of various processes in rice production. The energy efficiency of the rice–duck mutualism organic farming (1.48 %) was somewhat higher than that of the conventional rice cultivation (1.19 %). Some researchers have used the energy ratio as a measure for energy efficiency in crop production (Kuesters and Lammel 1999). Pishgar-Komleh et al. (2012) reported a ratio of 1.30 for rice production, while Agha Alikhani et al. (2013) reported ratios of 1.72 for traditional and 1.63 for mechanized rice production. The energy productivity

**Table 3** Energy forms and indices in two rice production systems

Item	Unit	Rice–duck mutualism organic farming	Percentage (%)	Conventional rice cultivation	Percentage (%)	<i>T</i> test significance
Energy use efficiency	–	1.48±0.02	–	1.19±.003	–	0.000
Energy productivity	(kgMJ <sup>-1</sup> )	0.11	–	0.08	–	–
Specific energy	(MJkg <sup>-1</sup> )	9.10	–	12.50	–	–
Net energy	(MJha <sup>-1</sup> )	38,018±1112	–	17,537±1072	–	0.000
Direct energy	(MJha)	32,094±961.64	40.47	31,613±1238.95	33.50	0.000
Indirect energy	(MJha <sup>-1</sup> )	46,735±1333.56	58.93	45,435±1488.24	48.14	0.000
Renewable energy	(MJha)	27,570±811.16	34.76	10,055±250.08	10.65	0.000
Nonrenewable energy	(MJha)	51,259±1574.03	64.63	66,993±1715.05	70.98	0.000
Total energy input	(MJha)	<i>79,307</i>	<i>100.00</i>	<i>94,377</i>	<i>100.00</i>	–

Values in *italic* indicate total energy inputs of two production systems

values of the rice–duck mutualism organic farming and the conventional rice cultivation were found to be 0.11 and 0.08 kg MJ<sup>-1</sup>, respectively. The net energy values of the two systems were also calculated to be 38,018 and 17,537 MJ ha<sup>-1</sup>, respectively. This fact indicates that energy is gained in both of these rice production systems. Table 3 shows the different energy parameters in the rice–duck mutualism organic farming and the conventional rice cultivation rice production systems.

This study clearly shows that direct and indirect energy resources are nearly equally utilized. These figures are 40.47 and 58.93 % for the rice–duck mutualism organic farming and 33.50 and 48.14 % for the conventional rice cultivation. The percentages of renewable and nonrenewable energies for the rice–duck mutualism organic farming are 34.76 and 64.63 %, respectively. These percentages are quite different for the conventional rice cultivation (10.65 and 70.98 %, respectively). This fact shows that a much higher percentage of nonrenewable energy is utilized for the conventional rice cultivation, but these two items are nearly the same for the rice–duck mutualism organic farming.

## 4 Conclusion

Energy analysis was used to evaluate and compare sustainability along with ecological and economic benefits of the rice–duck mutualism organic farming versus the conventional rice cultivation and to optimize the rice cultivation-based rice–duck mutualism system. The rice–duck mutualism organic farming, a form of organic agriculture, has many economic, environmental, and ecological benefits. According to the results of the current study, the ratio of renewable energy to nonrenewable energy utilized in the rice–duck mutualism organic farming was greater than that in the conventional rice cultivation where the main nonrenewable inputs were chemical fertilizers and biocides. The rice–duck mutualism organic

farming can improve the physical structure of paddy soils and suppress weeds using renewable energy resources. This organic farming method has more benefits such as increased or at least maintained soil fertility over the long term, maximized animal welfare, control of air pollution, and restricted stocking densities. Women would have a good opportunity to participate in this activity. Furthermore, it produces healthier and higher quality duck meat and rice than the conventional rice cultivation. This could lead to the development of established sustainability, efficient energy utilization, and environmentally friendly agricultural production systems in the studied area. The results of this research can provide theoretical and practical bases for further optimizing the animal–plant symbiosis pattern and increase the economic benefits for farmers through the effective use of energy and conservation of the ecosystem. Consequently, further assessments on economic and environmental issues are needed to support such a conclusion.

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