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Energy use pattern of paddy production systems in khuzestan province, Iran

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ABSTRACT- Energy use patterns and the contribution of energy input vary among farming systems. The optimal use of improved farm machinery coupled with the optimal use of other recommended sources permit an increase in paddy yield up to potential levels. In order to determine the effect of production systems on energy use efficiency focusing on mechanization for paddy production in Khuzestan province, a survey was conducted in the fourth largest rice producing region of Iran. The data were collected by interviewing the farmers using a questionnaire through two-staged cluster sampling of 295 households from these two regions covered farm operations over the period 2009-2010. The surveyed households were grouped into five categories based on the method of crop planting and drainage conditions. The energy input of paddy production systems ranged from 55,000 to 180,000 mega joules per hectare. This high amount of energy applied to paddy production in Khuzestan province is mainly due to the high amount of energy consumed by pumping water. This critical operation led to energy ratios below one for systems recognized as more mechanized. Energy consumption through diesel and electricity which was used for irrigation purposes and machinery operations was the maximum (up to 93%). The second highest energy input source was chemical fertilizer which consumed 4 to 57% of the total energy input. An operation-wise energy use analysis revealed that harvesting and tillage operations are important consumers of energy in paddy production. The rice crop showed a low energy ratio and energy productivity, indicating an energy-expensive crop under the conditions prevailing in the province. .

INTRODUCTION

Energy has been a key input of agriculture since the age of subsistence agriculture. It is an established fact worldwide that agricultural production is positively correlated with energy input (Baruah and Bora, 2008). In fact, energy analysis has several advantages over economic evaluations. First, the problem of spatial and temporal non-uniformity of the economic parameters relating to agricultural inputs–outputs can be effectively handled by expressing them in terms of energy. Secondly, analysis becomes more meaningful with the uniform quantification of agricultural input commodities (which are heterogeneous in nature) into energy values. Thirdly, energy analysis has drawn the attention of all concerned throughout the globe in order to ensure its judicious use amongst all sectors of life such that development does not get adversely affected (Baruah et al., 2004). Energy analysis cannot and should not replace economic analysis, however, but rather should complement it. In recent years, energy input in agriculture, like fuel and electricity, has been highly affected by changes in Iranian energy policy. Due to the elimination of subsidies, farmers have taken on more costs for chemical fertilizers as well as fuel and electricity consumed for irrigation, especially the farmers planting in paddies*.

One of the most important cereal crops in Iran is rice. The annual volume of rice produced in Iran was reported to be more than 2.4 million tons (Mt) in 2013 (FAO, 2013); nonetheless, Iran still stands as a huge rice importing country with more than 2.1 Mt. of rice imports (FAO, 2013). Therefore, to increase the production of rice in the country, efforts are intently required. Moreover, in order to produce crops sustainably, effective energy use is needed, since it causes production costs to reduce, fossil resources to be preserved, and environment distortion to be decreased (Demircan et al., 2006).

*- Paddy is the individual rice kernels that are in their natural, unprocessed state. Sometimes referred to as rough rice, paddy is harvested directly from rice fields or rice paddies and transported to a processing site. As part of the processing, the protective hull is removed, leaving only the actual rice kernel for consumption. Our study investigated paddy production before transportation to the processing site.

Khuzestan province of Iran is commonly known as the fourth largest paddy producer, with about 52,000 hectares devoted to paddy production (MJA, 2010). The mechanization index† ranges from 0.06 to 0.52, showing a high variation in the application of farm machinery for paddy production (Hormozi et al., 2012). Due to variations in climate, culture, and technology adaptation, diverse cropping systems have been developed that vary somewhat distinctly from other provinces in Iran. These diversities render difficulty to decision making and are very attractive to researchers.

Contribution of energy input and energy use patterns change depending on farming conditions, crop seasons, and farming systems. Moreover, optimal use of improved farm machinery coupled with optimal use of other recommended resources permit an increase in paddy yield up to potential levels (Baruah et al., 2004). Thus, the point of this analysis was to determine the impact of the production-system-based seeding method on energy use efficiency per hectare by focusing on mechanization for paddy production. In addition, the purpose was also to study each operation's share of energy consumption.

MATERIALS AND METHODS

A systematic procedure was followed to analyze the effect of energy on paddy production in some selected areas in Khuzestan Province. The description of the study area, procedure of data collection, data type, description of paddy production system, and description of parameters used for energy analysis are discussed below.

Study Area

The province of Khuzestan, which occupies an area of 63,213 km^2 in the southwest of Iran, has about 4.7 million inhabitants. It is located between 48°E and 49.5°E longitudes and between 31°N and 32°N latitudes (Fig. 1). Topographic elevations in the province vary between 0 and 3740m (above MSL). The climate of the study area varies from arid to humid. The northern parts of the province experience cold weather, whereas the southern parts experience tropical weather. Summer is from April to September, and winter is from October to March. Annual mean of maximum summer temperatures in the province is about 50 °C (in July), and annual mean of minimum winter temperature is 9 °C (in March). The annual amounts of rainfall are 150–256 mm in the south and 995–1100 mm in the north, and about 70% of annual rainfall events occur from February to April. The annual evaporation is 2000–4000mm (Zarasvandi et al., 2011).

Data Type and Sampling Procedure

Two climatic regions, mountainous located in the northeast of Khuzestan (M) and the plain region comprising the rest of province (P), were considered for this study. There exists a variation of paddy production amongst the districts (JOKP, 2007) located in both zones. Altogether, eight districts of relatively higher paddy production were considered for the present study. The selected districts are (i) Bagh-e Malek, (ii) Izeh, (iii) Ahvaz, (iv) Shushtar, (v) Shush, (vi) Ramhormoz, (vii) Susangerd, and (viii) Dezful. Out of these eight districts, the first two are located in the mountainous region, and the remaining six are located in the plain region.

The data on energy use were collected by interviewing the farmers on specially designed and pretested questionnaires through two-staged cluster sampling of 295 households from these two regions covered farm operations over the period 2009-2010.

The questionnaires included all kinds of inputs, such as fertilizer, biocide, and fuel, supplied to the crop and use of different power sources, such as human and agricultural machinery as well as output of farm as the yield of main product. The data were analyzed to calculate the operation-wise and source-wise energy consumption on a unit area basis.

Paddy Production Systems

The surveyed households were grouped into five categories based on (i) method of crop planting and (ii) drainage conditions. A brief description of these five categories of rice farming practices is highlighted below.

Transplanting in the mountainous regions (TM) is a farming practice in which rice is grown by transplanting seedling approximately one month old into puddled and continuously flooded land. Dry plowing followed by puddling is usually done in permanent plots and is normally applied by either a puddler or a chisel. The seedlings are transplanted randomly without definite spacing between them. As reported earlier, this practice requires high labor to uproot the nursery seedlings and transplant them (Hormozi et al., 2012). Time and energy input required for transplanting can be significantly decreased if a power transplanter is used to incorporate the seedling into the ground (Freeman, 1980); however, the introduction of this modern technology has not been successful in Khuzestan province. For harvesting, the laborers cut the crops, and threshing is performed either in the field for which machine moves into the farm or at the harvesting floor by means of a tractor-driven paddy thresher, a cereal combine harvester without a reel, or a cereal combine harvester with a specialized header.

†Proportion of machinery costs to operational costs namely machinery, human, and animal costs.

Fig. 1. Map of Khuzestan province in southwest of Iran

The second farming practice is *Transplanting in the plain regions (*TP*)* which resembles TM except in the manner of land preparation. Dry land tillage is used for planting rice in the plain regions (TP) which requires less tillage energy compared to TM. Before transplanting, the bunds are made by a bunder and then laborers compact them to avoid their destruction by water pressure. Plots are leveled to a uniform water height (Hormozi et al., 2012). The harvesting method is mainly two-staged harvesting, like TM. Direct harvesting is done either by a rice harvester or a cereal combine harvester.

There are three other farming conditions in which direct seeding is practiced instead of transplanting. Two of them (WN and WP) employ seeding in wet muddy fields, whereas the third one (DS) employs seeding in dry fields. The first two differ in the provision of drainage in the field. *Wet seeding in the lands with normal drainage (*WN*)* is a common production system in Khuzestan province. In this system, direct seeding on a muddy field, recognized as wet seeding, is applied, where seeds are spread in mud or flooded plots.

The farming condition with inadequate drainage provision is known as *Wet seeding with poor drainage (*WP*)*. This system is unique in the study region because, in spite of the application of heavy equipment in tillage, harvesting is very traditional. Since water logging in the fall occurred, ripping is applied in this production system; moreover, farmers have been forced to cultivate single crops such as paddy in the summer. Tillage in this method is applied using bulldozer equipped by ripper, as in the Ahudasht region of Shush (Hormozi et al., 2012). Harvesting is multistaged, which is considered to be a traditional practice in which laborers not only cut paddy crops, but also clean them. Threshing is done by tractor wheels. It should be noted that the construction of drainage systems has recently begun.

In *Dry seeding (*DS*),* a drill seeder is used to sow seeds in a dry field. It has been reported that this method is one of the aerobic paddy cropping systems that is applied more extensively to reduce human labor, capital input, and water consumption (Singh et al., 2006). Weed control, one of the major challenges toward rice production in the region, is often performed by hand; however, hose-end sprayers are used by dry seeding farmers for weed control. Because this system has extended into the plain regions, tillage and harvesting are similar to the WN and TP except in plot preparation. In DS, land leveling is done after tillage in dry soil by means of a land leveler, and bund making is performed after drill seeding by a bunder.

Methodology of Energy Analysis

Paddy production inputs consisted of human labor, machinery, fertilizers, chemical, biocide, fuel, and seed. Output is paddy (grain) as a product. Energy equivalents of the various inputs and outputs have been presented in Table 1.

Energy use of machinery was estimated by using the following relationship (Mikkola and Ahokas, 2010):

$$E_{ha} = E.M / T.C \quad (1)$$

where E_{ha} is the energy for agricultural machinery in the lifetime allocated to one hectare; E is the energy equivalent, MJ kg^{-1}; M is the mass of the machinery, kg; T is the lifetime, h; and C is field capacity, ha h^{-1}.

Other inputs, like fertilizers, biocide, fuel, and seed, used in the farms were transformed to energy value (MJ ha^{-1}) by multiplying the amount of the inputs applied per hectare by the energy equivalent of each input described in Table 1.

The energy consumption of operations and sources were estimated for the farmers belonging to five different types of paddy production systems. The energy for each of the unit operations was estimated by summing up all components of input energy for that operation. Similarly, source energy consumption was estimated and analyzed.

The energy input was also categorized into (i) direct vs. indirect and (ii) renewable vs. non-renewable energy. The components of direct energy (DE) are diesel, electricity, and human labor. Indirect energy (IDE) includes fertilizer, biocide, machinery, and seed. Renewable energy (RE) consists of human labor and seed, and non-renewable energy (NRE) consists of diesel, electricity, machinery, fertilizer, and biocide. Renewable energy is described as energy sources that are able to be filled naturally on a sufficiently rapid time-scale. Nevertheless, non-renewable energy is utilized to describe energy sources existed in a limited amount on earth (Pishgar-Komleh et al. 2011b).

The amount of output energy (MJ ha^{-1}) is estimated by multiplying the paddy yield (kg ha^{-1}) by paddy energy equivalent (MJ kg^{-1}) as mentioned in Table 1.

The energy ratio (energy use efficiency), energy productivity, and net energy were calculated by the relationships used by earlier researchers (Demircan et al. 2006, Pishgar-Komleh et al. 2011a,Chamsing et al. 2006) as given below.

$$\text{Energy Ratio} = \text{Energy Output (MJ ha}^{-1}\text{)} / \text{Energy Input (MJ ha}^{-1}\text{)} \quad (2)$$

$$\text{Energy Productivity} = \text{Paddy Output (kg ha}^{-1}\text{)} / \text{Energy Input (MJ ha}^{-1} \quad (3)$$

$$\text{Net Energy} = \text{Energy Output (MJ ha}^{-1}\text{)} - \text{Energy Input (MJ ha}^{-1}\text{)} \quad (4)$$

In order to have a better analysis of the energy consumption pattern, the whole energy input, output, and indices were calculated for different paddy production systems.

The ANOVA test and Duncan Compare Mean were utilized to analyze the differences between all values in five different production systems. To calculate the energy values and compare the values of different systems, all data from the paddy farms were entered into Microsoft Office Excel and SPSS software.

Table 1. Energy equivalents of inputs and output in paddy production

Particulars	Unit	Equivalent (MJ)	Reference
Inputs			
1. Machinery			
Tractor and self-propelled	Kg	9-10	Kitani, 1999
Implement and machinery	Kg	6-8	Kitani, 1999
2. Human Labor			
Male	man-h	1.96	Pishgar-Komleh et al., 2011a; Nassiri and Singh, 2009
Female	woman-h	1.57	Pishgar-Komleh et al. 2011a; Nassiri and Singh, 2009
3. Fuel			
Diesel	L	56.31	Nassiri and Singh, 2009
Electricity	kWh	12	Kitani, 1999
4. Fertilizer and manure			
Nitrogen	Kg	78.1	Kitani, 1999
Phosphorus	Kg	17.4	Kitani, 1999
Potash	Kg	13.7	Kitani, 1999
Manure	Kg	0.3	Baruah et al., 2004
5. Biocide			
Insecticide	Kg	185	Bockari-Gevao et al., 2005
Herbicide	Kg	255	Bockari-Gevao et al., 2005
Fungicide	Kg	115	Kitani, 1999
6. Seed	Kg	14.7	Pishgar-Komleh et al., 2011a; Nassiri and Singh, 2009
Output			
Paddy	Kg	14.7	Nassiri and Singh, 2009

RESULTS AND DISCUSSION

Source Energy Consumption Pattern

The pooled data of existing source pattern for five paddy production systems have been presented in Table 2.
Energy input for paddy production was the highest (180057 MJ ha^{-1}) in WN. For TM, TP, and DS, input amounts were 55534, 87465, and 64454 MJ ha^{-1}, respectively. The energy input for the WP production system remained the lowest (22828 MJ ha^{-1}).

Average total energy consumption for paddy production in Khuzestan province is higher than that of other studies (Bockari-Gevao et al., 2005, Pishgar-Komleh et al., 2011a) which is mainly due to high energy consumption in fuel and fertilizer energy input. Although diesel was mainly used for tractors and other machinery, the highest energy use in paddy production belonged to pumping energy, which varied between 76-93% for all systems except WP which showed 21%. This refers to the water supply from the canal, but other systems utilize diesel or electricity for irrigation. Especially in WN and TP, this application of submersible and centrifugal pumps is common. Therefore, with the accompanying irrigation energy, a distinct difference was observed between total energy of WN and other systems.

Although a large amount of water was pumped in paddy production, a high consumption of fuel energy was observed. Moreover, old machinery and equipment could be possible reasons for high fuel energy consumption for paddy production in Iran. Applying new, more energy-efficient machinery and irrigation pumps will decrease the amount of energy used (Pishgar-Komleh et al., 2011a).

There was no significant difference among the systems' machinery energy, but TM and TP had high labor energy consumption because of their identical seeding methods. Data indicated that most energy use was that of human power in TM (2337 MJ/ha) and TP (1551 MJ/ha), which was mainly due to more use of laborers in transplanting and reaping followed by WP (924 MJ/ha), DS (784 MJ/ha), and WN (701 MJ/ha).

Diesel and electrical energy were followed by fertilizer energy with the share of 4-57% of total energy input. It is a common belief that the use of more fertilizer will increase yield. It was surprising to find that inefficient farmers applied more than the necessary amount of fertilizer (Chauhan et al., 2006).

The share of seed energy consumption ranged from 906 MJ ha^{-1} to 2352 MJ ha^{-1} in paddy production systems. The amounts of seed in transplanting systems were the fewest among all the systems (61 kg ha^{-1}). This is because of nursery growing in a limited area of the field and better crop control in primary stages. Seed in wet seeding systems, namely, WN and WP, is applied excessively with 160 and 118 kg/ha, respectively. The required amount of seed will be reduced through the use of higher quality seed and by the introduction of new technologies like drum seeders in Khuzestan province.

Weed control is divided into manual weeding and herbicide application. Insecticide application is common in TM and TP, but because of the mountain climate, fungicide is applied only in TM. In this study, the application of biocide varied between 105-880 MJ ha^{-1}. Due to weed infestation in direct seeding, especially in the dry seeding system, herbicide had the highest consumption (more than three liters per hectare).

Table 2. Source energy consumption pattern for six different paddy production systems

	Paddy production systems				
	TM‡	TP§	WP**	WN††	DS‡‡
Sources (MJ ha^{-1})					
Labour	2337^{c}	1551^{b}	924^{a}	701^{a}	784^{a}
Machinery	850^{a}	846^{a}	876^{a}	836^{a}	933^{a}
Seed	906^{a}	1094^{ab}	2352^{d}	1737^{c}	1429^{bc}
Fertilizer	8575^{b}	6930^{ab}	13122^{c}	8310^{b}	5065^{a}
Manure	394^{b}	5^{a}	0^{a}	16^{a}	0^{a}
Biocide	296^{ab}	105^{a}	767^{c}	601^{bc}	880^{c}
Diesel & Electricity	42172^{ab}	76932^{b}	4784^{a}	167852^{c}	55361^{ab}
Total input energy	55534^{ab}	87465^{b}	22828^{a}	180057^{c}	64454^{ab}
output energy	50714	57335	35970	49415	36423

‡Transplanting in the mountainous regions
§Transplanting in the plain regions
**Wet seeding in the lands with normal drainage
††Wet seeding with poor drainage
‡‡Dry seeding

Furthermore, manure energy in TM ¯is projected at about 394 MJ ha^{-1}. In this system, the rotation of paddy-vegetable and manure applications was common.

Inefficient farmers used higher amounts of energy from all sources; certainly, they should learn from efficient farmers the right method of utilization of these sources. In the study carried out by Chauhan et al. (2006) in paddy production, it was concluded that the total energy input of inefficient farmers was 21% more than that of the most efficient farmers. In contrast, the yields obtained by inefficient farmers were about 18% lower than that of efficient farmers.

Operational Energy Consumption

The operational energy consumption in the paddy production systems was computed for tillage, plot preparation, nursery growing, seeding, weeding, irrigation, fertilization, spraying, and harvesting. Operational energy refers to the energy used for mechanization, i.e. direct energy (diesel, electricity, and human labor).

As can be observed from Table 3, WP had the highest average operational energy consumption of tillage due to intensive tillage (4445 MJ ha^{-1}) by heavy ripper, which accounted for about 68.02% of total operational energy consumption (6535.3 MJ ha^{-1}). In other systems, irrigation caused the highest operational energy consumption (18593-81649 MJ ha^{-1}) which ranged between 69-93% of the total operational energy consumption. These high amounts of irrigation energy are because of the continuous application of electric and diesel pumps, but in WP, farmers use water from a canal for irrigation.

For TM, tillage operation consumes a high value of energy (3887 MJ ha^{-1}). These farmers apply the puddling method after primary tillage to increase tillage energy in the production system. However, application of reduced tillage like twice-disk instead of intensive tillage in TP, WN, and DS systems decreases the energy consumption significantly at the tillage stage.

Plot preparation is an operation that is performed to obtain uniform water level and to avoid the destruction of plot bunds (Hormozi et al., 2012). Energy of land leveling and bund making ranged from 170 to 1768 MJ ha^{-1}. TM system is performed in permanent plots, so it needs the least energy (0.63% of the total operational energy consumption) in this operation. In TP, land leveling is done after machine bund making; in addition, to avoid the destruction of plot bunds, laborers compact wet bunds. Plot preparation in WN and WP is similar to that of TP, but because of the bigger size of the plots, energy values are shown as being lower than TP. The DS system showed the highest energy consumption in plot preparation (1768 MJ ha^{-1}). Because land in this system should be flat for direct seeding by the drill seeder, leveling is done by a land leveler and bunds are made by a bunder.

The seeding operation in transplanting systems shows high amounts of energy consumption because TM and TP with 1132 MJ ha^{-1} and 658 MJ ha^{-1} respectively are labor intensive production systems. The DS system, however, compared to TP, does not show a significant difference, which refers to mechanized seeding in this system.

One of the most important problems of direct seeding systems is weed infestation; thus, as seen in Table 3, weeding is significantly different in transplanting systems, especially in the DS system, because it is an aerobic production system in Khuzestan province. DS is also the only system in which spraying is done by tractor sprayers. This mechanized operation shows the highest energy in spraying (411 MJ ha^{-1}).

Table 3. Operational energy for cultivating paddy

Operations ($MJha^{-1}$)	Paddy production systems				
	TM	TP	WP	WN	DS
Nursery growing	462^{c}	306^{b}	0^{a}	0^{a}	0^{a}
Tillage	3887^{b}	1862^{a}	4445^{c}	2283^{a}	1890^{a}
plot preparation	170^{a}	1170^{c}	325^{a}	856^{b}	1768^{d}
Seeding	1132^{c}	658^{b}	44^{a}	20^{a}	534^{b}
Weeding	53^{a}	51^{a}	122^{b}	68^{a}	138^{b}
Irrigation	18593^{ab}	36240^{b}	285^{a}	81649^{c}	24735^{ab}
Fertilization	66^{ab}	77^{ab}	25^{a}	249^{b}	447^{c}
Spraying	70^{a}	11^{a}	79^{a}	43^{a}	411^{b}
Harvesting	2635^{b}	2913^{b}	1207^{a}	2702^{b}	2629^{b}
Operational energy	27071^{ab}	43292^{b}	6535^{a}	87873^{c}	32556^{ab}

Results show that harvesting energy in the WP system differs significantly from that in other systems. It is only in WP that harvesting is done by traditional methods and is labor intensive. On the contrary, in other systems, machinery is applied, at least for threshing. Although WP has low energy consumption at the harvesting stage (1207 MJ ha^{-1}), because of its low total operational energy, WP reveals 18% of operational energy at highest level among paddy production systems.

Input-Output Energy Analysis

Direct-indirect and renewable-nonrenewable energy forms used in paddy production are indicated in Table 4. The results show that the share of direct input energy for WP was 25% of total energy input compared to 75% for indirect energy. For other systems, direct energy ranged between 80-94%. Referring to diesel and electricity consumption levels, the highest share of direct energy was for WN (168564 MJ ha^{-1}).

Non-renewable and renewable energy for WP contributed 86% and 14% of the total energy input, respectively. Furthermore, non-renewable energy in other systems ranged from 94% to 98%. Clearly, the proportion of non-renewable energy used in the surveyed paddy holdings is very high. This result indicates that paddy production in the research area depends mainly on fossil fuels.

Energy ratio is one essential indicator that provides an understanding of the efficiency of paddy production systems. It is assumed that if the energy ratio is greater than 1, then, the production system is gaining energy; otherwise, it is losing energy. Farmers using WP had better conditions for paddy production with less energy. Moreover, there was a large gap between the energy-ratio in WP and the other systems (1.58 against 0.91, 0.66, 0.57, and 0.27 for TM, TP, DS, and WN, respectively). The highest energy ratios were achieved in those systems which used only human effort and no fossil fuel input (Chamsing et al., 2006).

The results indicated an average energy ratio of 1.49. Because of the high amounts of energy consumed in the irrigation operation, the energy ratio estimate was lower than what other researchers reported; for instance, 2.8 (rain-fed rice), 4 (irrigated rice) (Chamsing et al., 2006), and 1.53 (included cleaning, drying, milling, and sifting) (Pishgar-Komleh et al., 2011a). Because of greater water requirement, however, the energy requirement through irrigation increased; hence, the energy input increased. This results in a low energy ratio for paddy as compared to wheat, even though average paddy yield is more than wheat yield (Singh et al., 1990).

The average grain yield of paddy was 3357 kg/ha; nonetheless, results indicate that, due to low energy input, the highest energy productivity was 0.11 kg/MJ for WP. Other systems reveal extremely low energy

Table 4. Energy forms and indices in Paddy production

Operations ($MJha^{-1}$)		Paddy production systems				
		TM	TP	WP	WN	DS
Energy ratio	–	0.91	0.66	1.58	0.27	0.57
Energy productivity	kg MJ^{-1}	0.06	0.04	0.11	0.02	0.04
Net energy	MJ ha^{-1}	-4819	-30130	13142	-130641	-28030
Yield	kg ha^{-1}	3449^{ab}	3900^{a}	2446^{b}	3361^{ab}	2477^{b}
Direct energy[e]	MJ ha^{-1}	44510^{ab}	78486^{b}	5709^{a}	168564^{c}	56146^{ab}
Indirect energy[f]	MJ ha^{-1}	10629^{a}	8979^{a}	17119^{b}	11492^{a}	8307^{a}
Renewable energy[g]	MJ ha^{-1}	3638^{b}	2651^{a}	3276^{b}	2455^{a}	2213^{a}
Non-Renewable energy[h]	MJ ha^{-1}	51895^{ab}	84814^{b}	19551^{a}	177601^{c}	62240^{ab}
Total energy	MJ ha^{-1}	55534^{ab}	87465^{b}	22828^{a}	180057^{c}	64454^{ab}

Mean in the same column with different letters is significant at 0.05.
[e] Include diesel, electricity, and labor
[f] Include fertilizer, biocide, seed, manure and machinery.
[g] Include labor, seed, and manure.
[h] Include diesel, electricity, machinery, fertilizer, and biocide.

The average grain yield of paddy was 3357 kg/ha; nonetheless, results indicate that, due to low energy input, the highest energy productivity was 0.11 kg/MJ for WP. Other systems reveal extremely low energyproductivity at 0.02, 0.04, 0.04, and 0.06 kg/MJ for WN, DS, TP, and TM respectively. The rice producers who did not use pumps for irrigation were more efficient than others (Hormozi et al., 2013).

CONCLUSIONS

The total energy input from various sources for raising paddy ranges from 55,500 to 180,000 MJ ha^{-1}. The variety of water sources is mainly responsible for these values. In other words, these sources led the farmers to use energy-intensive technologies such as submersible and centrifugal pumps. The system in which irrigation water was supplied from surface water without pumping shows distinct indices. They show the highest energy ratio and a positive net energy. However, in other systems, irrigation consumes the highest amount of direct energy. It could be stated that the most critical operation from the viewpoint of energy is irrigation. A change in water supply or a modification of water pumping systems could considerably increase energy efficiency.

Energy consumption through diesel and electricity which was used for irrigation purposes and machinery operations was the maximum (up to 93%). The second highest energy input source was chemical fertilizer which consumed 4 to 57% of the total energy input.

In terms of operation-wise energy consumption, harvesting and tillage operations were found to be important consumers of energy in rice production. While there has already been some improvement in these operations, there appears to be a distinct possibility to affect further saving in the energy consumption in paddy fields.

The rice crop, in spite of a good yield in most production systems, gives a too low energy ratio and energy productivity, indicating that it is an energy-expensive crop under the conditions prevailing in the province. It is highly recommended that the government of Iran focus on research and the implementation of more efficient water pumping equipment.

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الگوی مصرف انرژی سیستم‌های تولید برنج در استان خوزستان

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چکیده- الگوی مصرف انرژی و سهم نهاده انرژی در میان سامانه‌های کشاورزی به میزان زیادی متغیر است. کاربرد ماشین‌های کشاورزی با استفاده بهینه دیگر نهاده‌ها، می‌تواند عملکرد برنج را افزایش دهد. از این رو این پژوهش برای تعیین اثر سیستم‌های تولید برنج بر کارایی مصرف انرژی با تمرکز بر مکانیزاسیون کشاورزی در استان خوزستان انجام گردید.داده ها از طریق پرسشنامه با بررسی ۲۹۵ از برنجکاران در سال زراعی ۸۹-۸۸ در دو منطقه جغرافیایی دشت و کوهستانی استان به دست آمدند. با بررسی پنج سامانه مختلف تولید، محاسبه و مقایسه نهاده‌های انرژی، انرژی مصرفی در عملیات و شاخص‌های انرژی مشخص گردید که نهاده انرژی از ۵۵۵۰۰ الی ۱۸۰۰۰۰ مگاژول بر هکتار متغیر بود. این میزان بالای انرژی به کار رفته در چهارمین تولید کننده برنج کشور تا حد زیادی ناشی از مصرف بیش از حد انرژی جهت پمپاژ آب در عملیات آبیاری است که معمولاً به صورت پیوسته انجام می‌گردد. این عملیات بحرانی باعث کاهش نسبت انرژی به زیر یک برای سامانه‌های تولید مکانیزه نیز شده است. مصرف انرژی از طریق سوخت دیزل و برق بالاترین میزان را بین نهاده‌ها نشان داده است (تا ۹۳ درصد). دومین منبع نهاده انرژی، کود شیمیایی بوده است که ۴ تا ۵۷ درصد از انرژی ورودی را به خو اختصاص می‌دهد. به علاوه، عملیات برداشت و خاک‌ورزی بعد از آبیاری بیشترین مصرف انرزی را دارا می‌باشند. رویهم رفته، شاخص‌های انرژی این محصول، انرژی‌بر بودن آن را در این استان نمایان می‌کند.