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Energy consumption in production of grains prevalent in Saveh, Iran

M. Safa, S. S. Mohtasebi, M. Behroozi Lar and M. Ghasemi-Varnamkhasti*

Department of Agricultural Machinery Engineering, University of Tehran, Karaj, Iran.

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This paper examines the energy consumption of wheat, barley and maize production in Iran (Saveh area). This study was conducted over 28,400 ha of irrigated wheat, barley and maize fields and 19,300 ha of dry land wheat and barley fields in Saveh, a central city, Iran, in the harvest year of 2003 - 2004. The data was collected from three different sources: questionnaire, literature review and field measurement. Total energy consumption for irrigated wheat, barley and maize were estimated as 51587, 53529 and 72743 MJ/ha, respectively. Also energy consumption for wheat and barley in dry land system were estimated as 12543 and 11935 MJ/ha, respectively. The average operational energy consumption for cultivation of wheat (irrigated), wheat (dry land), barley (irrigated) , barley (dry land) and maize were 36107, 6067, 40498, 6250 and 48632 MJ/ha, respectively. The maximum energy consumed in these productions, for irrigated farming systems and dry land farming system were irrigation and tillage, respectively. Fuel consumption is one of the important input elements, which must be taken under close managerial supervision in order to optimize the amount of energy consumed.

Key words: Energy consumption, production, agricultural machinery, wheat, barley, maize.

INTRODUCTION

Saveh has a population of 238,000 over an area of 10,279 km^2. The annual rainfall is from 100 to 400 mm; the temperature varies from -20 to 40°C (Anonymous, 2008). Crop yields and food supplies to consumers are directly linked to energy; that is, sufficient energy is needed in the right form at the right time for this purpose (Karkacier et al., 2006). Agricultural production includes all farming operations that occur after the land is cleared and developed, such as tillage, planting, fertilizing, pest control, harvesting and transportation. Energy needed for agricultural production is about 3% of the national energy consumption in developed countries and about 5 to 6% in developing countries (Stout, 1989). The entire food system (processing, storage, transportation and final operation) may require 15 to 20% or even more as compared to developing nation's energy (Stout, 1989). In agriculture and other economic activities, energy consumption in crop production increased in developed countries more than developing countries as a result of population growth, migration from rural areas to urban areas and design and improvement of new production techniques (Kitani, 1999). Total energy consumption increased by 500% and the petroleum and natural gas consumption increased by about 900%, while the world population growth increased by 200% between 1945 and 1985 (Haldenbilen, 2003).

Fossil fuel energy can either be replaced with new sources of energy, or it can be optimized in an applied manner. One way to optimize energy consumption is to determine the efficiency of methods and techniques used (Kitani, 1998). There should be a plan for energy consumption, otherwise, with the current population growth; the world would come to a dead end. Energy consumption has been reduced in developed industrial countries from 4.9 to 1.3% within, 14 year period (Singh and Mittal, 1992). Use of diesel in tractors and diesel engines for various operations contributed 27.2% of the total energy input under irrigated conditions and electricity, which was used in irrigation only, supplied 12.7% energy (Singh and Mittal, 1992). However, the percentage has not drastically changed in Iran.

*Corresponding author. E-mail: mohtaseb@ut.ac.ir. Tel. 0098-912-1066902. Fax. 0098261-280-1011.

Therefore, one should recognize the input elements and recommend a method in order to control them. Since there are different methods to estimate the energy consumption; comparison and evaluation of results are difficult. For example, some researches consider human labor as an energy input in their calculation; however, many others do not (Fluck, 1992; Sartori et al., 2005; Hulsbergen and Kalk, 2001). Furthermore, it is difficult to have general international agreement on how to estimate input energy. The lack of reliable data for each country and region often forces researchers to take values from other countries for which circumstances are usually different (Conforti and Giampietro, 1997). At the present time, the productivity and profitability of agriculture depend upon energy consumption (Tabatabaeefaret et al., 2009). Agricultural energy used can be classified as either direct or indirect. The primary means of direct energy used on-farm involves the consumption of fuels such as diesel, furnace oil, gasoline, other petroleum products, electricity and wood. Indirect energy is the energy used to create and transport farm inputs such as pesticides, feed, machinery, seeds and fertilizers. Indirect energy accounts for 70% of total energy use on farms and about 50% on arable farms walls (Meul et al., 2007). To meet the basic food needs of our expanding human population, a productive, sustainable agricultural system must become a major priority. From analyses of various agricultural systems, we can understand the use of all forms of energy and learn how to preserve essential land, water and biological resources for future generations.

In this regard, a research was aimed to determine the energy consumption in grains (wheat, barley and maize) production, based on field operations, in irrigated and dry land farming systems. Field size and its effects on energy and fuel consumption were also studied in details on the farms.

MATERIALS AND METHODS

The survey was conducted to identify farmers' attitudes and opinions towards energy consumption. There were two demographic variables: farm type and size. Farmers were asked to introduce all sources of energy used in their farms.

The inputs for energy analysis in grain production include operational energy consumption (field machinery, human labor, irrigation pumps (electrical or fuel) and irrigation), and also indirect energy: fertilizer, pesticides and seed. Therefore, the two major parts of this study, operations and energy sources should be identified.

Operations

Energy consumption in grain production operation such as tillage machinery, planters, fertilizer broadcasters, sprayers, irrigation, transportation and harvesting were determined in both farming systems, except for irrigation in dry land farming system. The number and duration of operations, the rate of seed, pesticide, fertilizer and amount of human labor were investigated using questionnaire and making personal interviews with farmers.

Randomly selected farm owners completed the questionnaire. For each operation, fuel consumption was measured in the field by filling the tractor tank twice, before and after each operation and then the difference was recorded. From the literature review and ASAE standards, equivalent energy inputs were determined for all input and output parameters for wheat, barley and maize. For comparison of energy consumption in different field sizes, irrigated farm land was surveyed based on three different size categories: less than 2 ha, between 2 - 10 ha and more than 10 ha. However, dry land was not divided into different categories due to extensive variations and having more fields of large sizes than irrigated land. Irrigation energy consumption was included with water pumping from water surface to land surface (water well depths varies from 40 - 156 m in vast area of Saveh) and energy used for surface irrigation.

Energy sources

Human

Human labor is being used for almost every task on the farm, from driving machinery, maintenance, repair, irrigation, spraying and fertilizer to farm management. In the future, human labor will be reduced in the fully mechanized farm to almost nil. However, the energy output for a male worker is 1.96 and 0.8 MJ/hr for a female. In children, it is about 0.98 MJ/hr, half of a man's output energy (Singh and Mittal, 1992). One must recognize that human energy is the most expensive form of energy in field operations.

Fuel

Diesel fuel is the main source of fuel in agricultural machinery as well as motor pumps and water pumps, except in air spraying and portable sprayers. Fuel consumption was determined before and after any operation by filling the tractor fuel tank and recording the difference. MF 285 tractors were used in most operations. This test was repeated six times for each operation. The energy output for analysis was determined from fuel consumption per operation of 1 ha of land times the fuel equivalent energy per liter as shown in equation 1.

$$\text{Energy (input)/ hectare} = \text{Operation fuel consumption (L/ha)} \times \text{Fuel energy (MJ/L)} \quad (1)$$

For self-propelled combines and chopper, the fuel was measured separately and the values were 27 and 36 l/ha, respectively. Fuel consumption for air spraying was determined by fuel used in one year divided by the land areas, hectare, which was approximately 2 l/ha. Equation 1 was applied for determining energy consumption per hectare.

Fertilizer

Mineral fertilizer is the fastest growing form of energy consumption in agricultural production. Nitrogen fertilizer is by far the most important mineral fertilizer in world agriculture, both in the amount of plant nutrient used and in energy requirements. The most popular fertilizers are nitrate ammonium, phosphate ammonium and supper phosphate. Nitrogen (N) fertilizer is very energy intensive and on the other hand, phosphate (P_2O_5) and potash (K_2O) do not require high feedstock energy. The energy output for one kilogram of N and supper phosphate (P_2O_5) is 78.1 and 17.4 MJ/kg respectively (Kitani, 1999). Unfortunately, most farmers believed that the yield would increase only with a higher rate of ammonium. However; only a few amount of the nitrogen applied to crops is

Table 1. Nitrate (N) consumption (kg) for different grain production.

Acreage category(ha)	Wheat (Irrigated)	Wheat (Dry land)	Barley (Irrigated)	Barley (Dry land)	Maize
N	236	100	208	98	396
P	182	98	199	92	296

Table 2. Seed consumption (kg) for different grain production.

Acreage category(ha)	Wheat (Irrigated)	wheat(Dry land)	Barley (Irrigated)	Barley (Dry land)	Maize
Less than 2	260.4	0.0	176.0	0.0	46.3
2 to 10	240.3	111.5	246.6	111.9	42.3
Greater than 10	224.5	127.8	207.7	110.1	27.7
Average	229.4	126.5	215.5	110.2	33.1

Table 3. Energy consumption (MJ/ha) based on operations for wheat production.

Acreage category(ha)	Tillage	Planting	Spraying	Fertilizer distributor	Harvesting	Irrigation	Transportation
Irrigation farming (MJ/ha)							
Less than 2	5446	679	58	281	1290	29836	358
2 to 10	5785	992	89	294	1107	27900	726
Greater than 10	4826	911	86	313	997	28360	265
Dry land farming (MJ/ha)							
2 to 10	3919	853	232	384	1290	--	73
Greater than 10	3552	836	109	1112	1290	--	106

absorbed by the plant itself, which is a function of soil type, temperature and rainfall (Witney, 1988). Table 1 shows the average amount of nitrate consumption in different products.

Biochemical

Three different methods of pest control that is, chemical, mechanical and biological are usually applied to control or eliminate fungi, insects and weeds in a farm. Most farmers choose the chemical method. The most common chemicals which are used in farms in order to fight against diseases, insects and weeds on a wheat farm, are 2-4-D, Linden, Para coat and Mali tune, in order. In Saveh, airplane spraying (air spraying) and tractor-mounted spraying are used to apply chemicals to fight against crop farm diseases. The energy output for one liter of 2-4-D and Linden were 2.4 and 85 MJ/kg, respectively (Kitani, 1999).

Seed

Clean and proper seeds were provided in package from Agricultural Research Center. However, some farmers used their own seeds. On the average, 229 and 126 kg/ha seeds were planted for wheat production in irrigated and dry land farms, respectively. Normally, a range of 100 to 350 kg/ha seeds is applied on the irrigated farm (wheat). For dry land farm (wheat) with a range of 90 - 150 kg/ha was planted. Different factors such as planting system, variety of seeds and germination rate have influence on the amount of seed in different grain. Table 2 shows the average of seed for wheat, barley and maize production. The average energy outputs per one kg of seeds are 13 MJ/kg for wheat, 14 MJ/kg for barley and 100 MJ/kg for maize production (Kitani, 1999). The input energy for manufacturing machinery, fertilizer and pesticide was not considered in this study.

RESULTS AND DISCUSSION

Energy consumption in wheat production for one hectare of land

Energy consumption in wheat production for one hectare of land has two main components; operations and energy sources.

Operations

Energy consumption in wheat production operation includes: tillage, planting, fertilizer broadcasting, spraying, irrigation, transportation and harvesting; they were determined in irrigated farming systems as shown in Table 3. Except for irrigation, all other operations were considered for energy consumption of dry land farming system as shown in Table 3. The energy consumption in

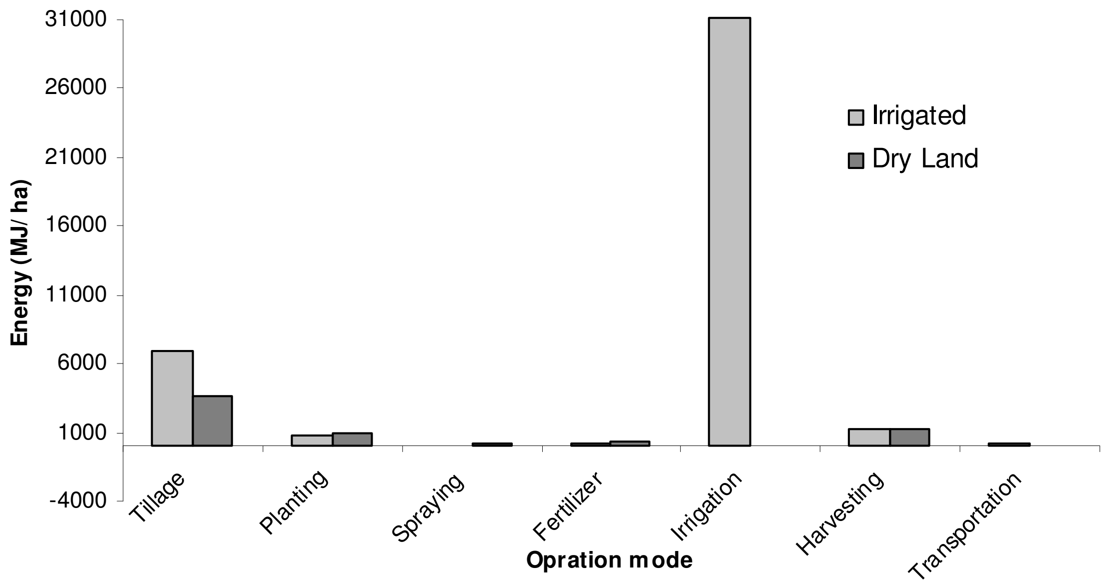

Figure 1. Operational energy consumption for wheat production.

Table 4. Energy consumption for wheat production, MJ/ha based on sources.

Acreage category(ha)	Direct energy MJ/ha			Indirect energy MJ/ha		
	Human	Electricity	Fuel	Fertilizer	Pesticide	Seed
			Irrigation farming MJ/ha			
Less than 2	124	871	37,986	9,934	128	3,385
2 to 10	126	656	37,158	1,0627	153	3,124
Greater than 10	148	621	36,183	1,1420	165	2,917
			Dry land farming MJ/ha			
2 to 10	10	--	6,751	4,515	106	1,449
Greater than 10	12	--	6008	4,753	83	1,661

wheat production per hectare was much higher in irrigated farming land system than in dry land system. It was around 51,587 and 12,543 MJ for irrigated farming and dry land farming system, respectively. The operational energy consumption was much higher in irrigated land due to tillage, fertilizer and irrigation operations; however, the major difference is due to irrigation operation with 78.4% of total operational energy consumption. Operational energy consumptions in both systems are shown in Figure 1.

Tillage is ranked high in both systems. Tillage, operational energy consumption, ranked first with 59% in dry land farming. Fertilizer consumption was not under any control by the farmers. They believed that more fertilizer broadcasted, higher yield would result. Operational energy consumption was greater for the small-scale farming system than other categories. Energy consumption was 37,951 MJ/ha for less than two hectares field and 36,897 MJ/ha for farming between two to ten hectares, with 26,172 MJ/ha for greater than ten hectares. Therefore larger field sizes should be practiced.

Energy sources

The direct and indirect energy sources for irrigation and dry land farming system were determined as shown in Table 4. The main source of energy was fuel consumption with 36,472 MJ/ha for irrigated farming system and 6,067 MJ/ha for dry land farming system as shown in Figure 2. By far, fuel is the most important source of energy. Fertilizer is second most important source of energy in wheat production. Pesticide consumption was lower for dry land area than irrigation farming system due to larger field sizes and air spraying pesticide. Fuel consumption is one of the important input elements in energy consumption; therefore, a detailed study on tractors service and maintenance should be

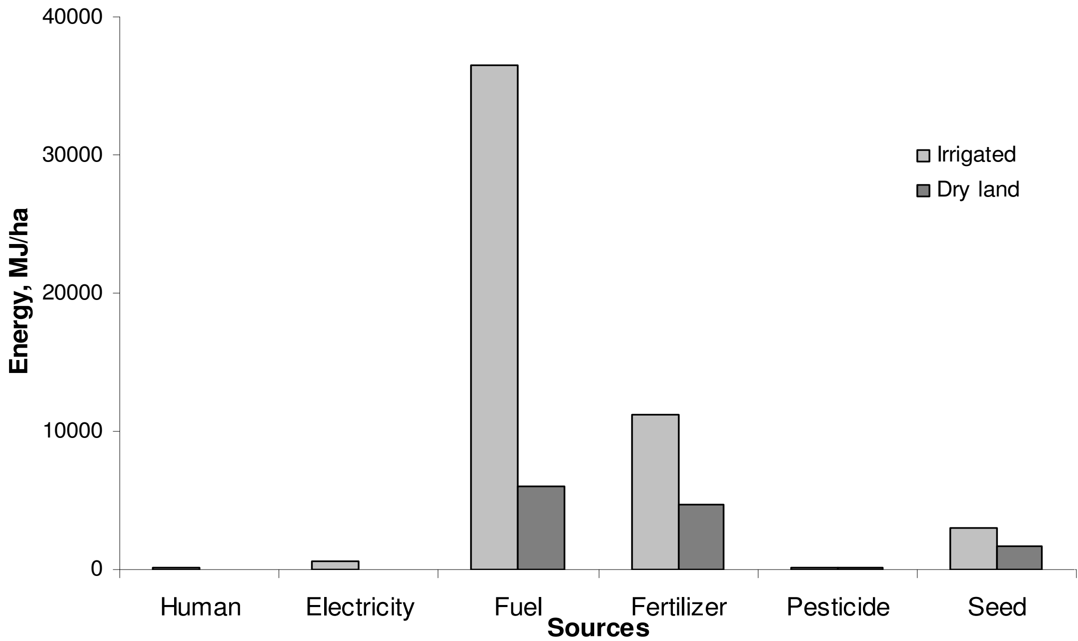

Figure 2. Energy source consumption for irrigated and dry land-farming systems for wheat production.

Table 5. Energy consumption (MJ/ha) based on operations for barely production.

Acreage category(ha)	Tillage	Planting	Spraying	Fertilizer distributor	Harvesting	Irrigation	Transportation
Irrigation farming(MJ/ha)							
Less than 2	5408	356	7	86	848	25207	118
2 to 10	6640	820	36	226	1291	24693	431
Greater than 10	6989	788	22	233	1192	33568	194
Dry land farming(MJ/ha)							
2 to 10	3681	554	34	183	1290	_	10
Greater than 10	3580	979	140	301	1290	_	12

done and operation must be conducted in order to address a managerial supervision method for decreasing the amount of energy consumed.

Shahin et al. (2008) conducted a research to study and examine direct and indirect input energy per hectare in wheat production in Ardabil province of Iran. Based on their report, wheat production consumed a total of 38.36 GJ ha-1 that from which fertilizer energy consumption was 38.45% followed by diesel and machinery energy. Then, they concluded that fertilizer and fuel were the highest values. This result is in close agreement with what was found in the current study as seen in Figure 2.

Also, they pointed out that output–input energy ratio and energy productivity values were 3.13 and 0.16, respectively and large farms were more successful in energy use and energy ratio. It was concluded that energy use management at farm level could be improved to give more efficient use of energy.

Energy consumption for barley production

In Saveh, barley is produced for animal feeding; especially farmers who have small farms produce barley for their own animals. The energy consumption in barley production per hectare was much higher in irrigated farming land than in dry land. It was around 54,529 and 11,935 MJ for irrigated farming and dry land farming system, respectively.

Operation

It seems that energy consumption operation for wheat and barley has similar circumstances as shown in Tables 3 and 5 and Figures 1 and 3. However, the operational energy consumption in irrigated land for barley production was around 4,000 MJ/ha higher than operational energy

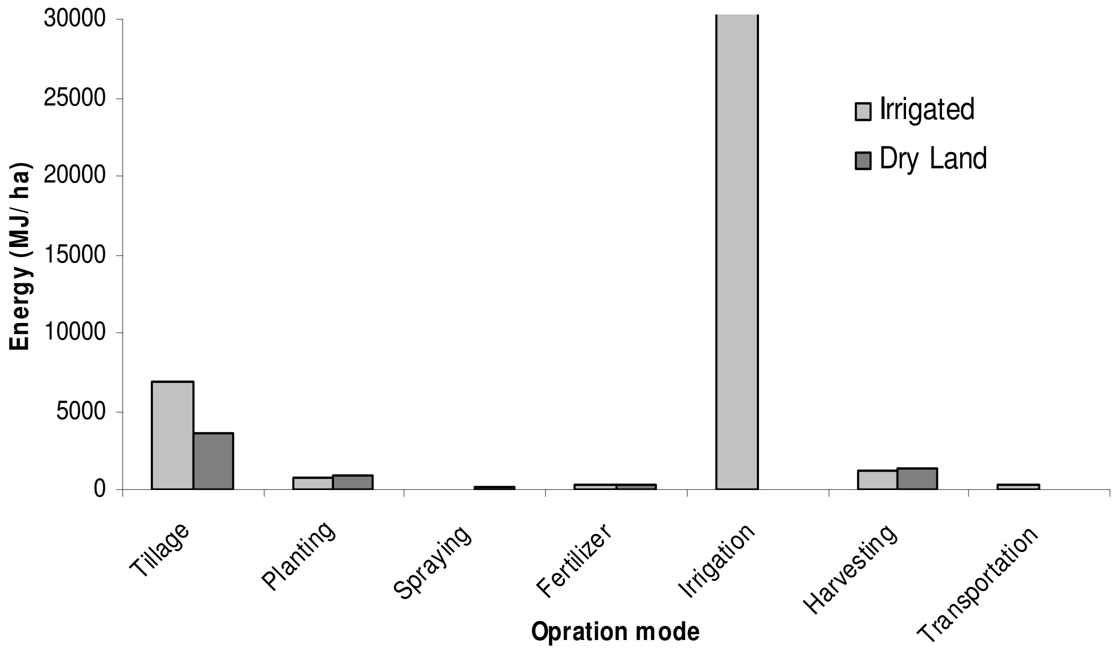

Figure 3. Operational energy consumption for barley production.

Table 6. Energy consumption for barley production, MJ/ha based on sources.

	Direct energy MJ/ha			Indirect energy MJ/ha		
Acreage category(ha)	**Human**	**Electricity**	**Fuel**	**Fertilizer**	**Pesticide**	**Seed**
			Irrigation farming MJ/ha			
Less than 2	118	717	31,313	9,394	2	2,288
2 to 10	104	992	33,144	11,671	63	3,205
Greater than 10	90	748	42,876	9,722	49	2,700
			Dry land farming MJ/ha			
2 to 10	10	--	5,753	5,933	114	1,455
Greater than 10	5	--	6,304	3,931	121	1,431

consumption for wheat production and major differences come from harvesting and irrigation.

Operational energy consumption in irrigated land for barley was greater for the large-scale farming system than other categories (against the wheat production), energy consumption was 32,030 MJ/ha for less than two hectares field and 34,136 MJ/ha for farming between two to ten hectares, with 26,172 MJ/ha for greater than ten hectares. Moreover, in dry land system, there is similar situation and operational energy consumption was 5,753 for farming between two to ten hectares and 6,303 MJ/ha for greater than ten hectares. For barley production in larger farms, it seems efficiency reduced or farmers consumed more energy for their production or farmers who have bigger farms consume more inputs. Also, in bigger farms, machinery energy is consumed more than human energy and it increases total energy consumption significantly.

Energy sources

Table 6 shows the direct and indirect energy sources for irrigation and dry land farming system. The main source of energy was fuel consumption with 40,159 MJ/ha for irrigated farming system and 6,250 MJ/ha for dry land farming system as shown in Figure 4. Fertilizer is second most important source of energy in barley production. One of the interesting results is pesticide consumption. Pesticide consumption was lower for irrigation farming system due to larger field sizes than dry land farming system. It is necessary to investigate more to find why in dry land farming system farmers consumed pesticides more than irrigated farming systems.

Energy consumption for maize production

Maize is new in agricultural production in Saveh area. It

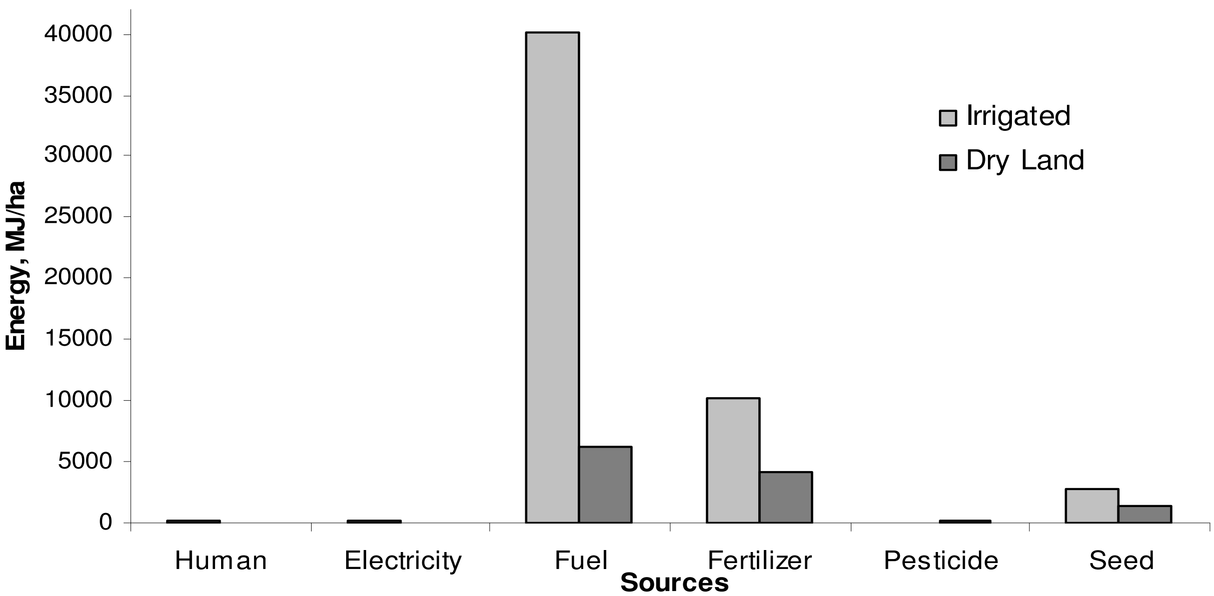

Figure 4. Energy source consumption for irrigated and dry land-farming systems for barley production.

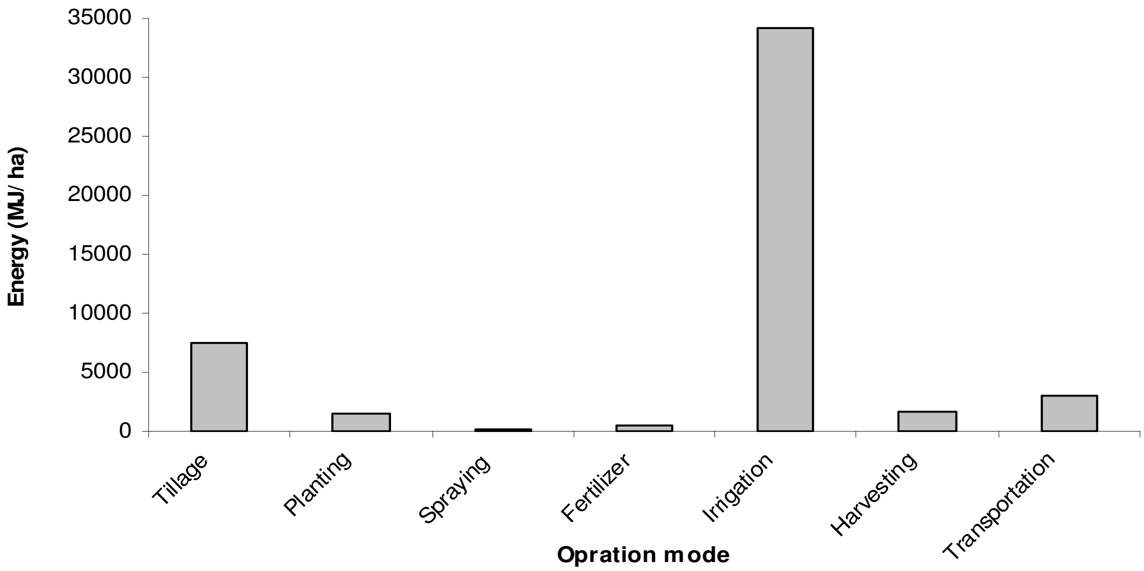

Figure 5. Operational energy consumption for maize production.

has been produced from 15 years ago and in recent years it has been produced as third production after wheat and barley. Most Maize is consumed domestically in poetry and livestock industries.

Operation

As shown in Figure 5 and Table 7, out of all the farm operations, irrigation consumed the maximum energy, 34199 MJ/ha (70.3%), followed by seedbed preparation 7225 MJ/ha(15.5%). Total operational energy consumption was 32,030 MJ/ha for less than two hectares field and 34,136 MJ/ha for farming between two to ten hectares, with 26,172 MJ/ha for greater than ten hectares.

Energy sources

Table 8 shows the direct and indirect energy sources for maize production. The source of energy input for the

Table 7. Energy consumption (MJ/ha) based on operations for maize production.

Acreage category(ha)	Tillage	Planting	Spraying	Fertilizer distributor	Harvesting	Irrigation	Transportation
Irrigation farming MJ/ha)							
Less than 2	8837	1434	149	460	1721	38622	2254
2 to 10	6620	1434	193	319	1721	25442	1210
Greater than 10	7972	1434	202	529	1721	38522	4076

Table 8. Energy consumption for Maze production, MJ/ha based on sources.

Acreage category(ha)	Direct energy MJ/ha			Indirect energy MJ/ha		
	Human	Electricity	Fuel	Fertilizer	Pesticide	Seed
Less than 2	94	721	53,478	15,469	200	4,625
2 to 10	103	3547	33,392	19,936	254	4,229
Greater than 10	113	1038	53,418	20,926	274	2,770

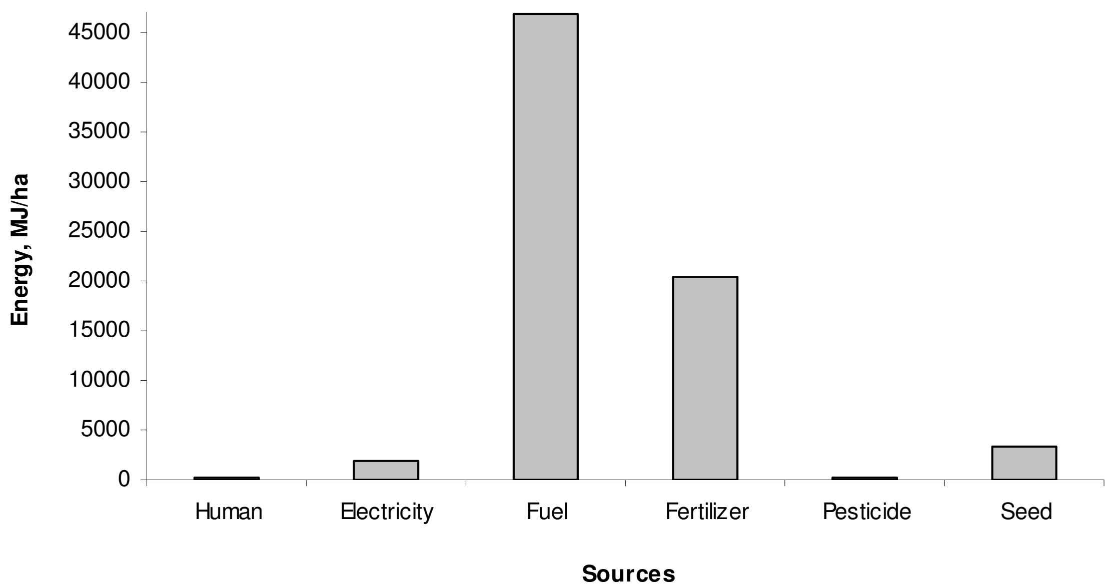

Figure 6. Energy source consumption for maize production.

wheat was 72,743 MJ/ha. More than half (64%) of the total energy input was found as Fuel, followed by fertilizer (28%), seeds (4.6%), Electricity (2.5%) and Biochemical (0.4%), as shown in Figure 6. It seems the amount of fuel and fertilizer consumption in maize production is more than barley and wheat production because in Maize production amount of agricultural operation, especially disc and leveler are more than other crops.

Energy ratio and net gain

Energy ratio was determined from output energy to input energy (Kitani, 1998). Fluck (1992) analyzed this concept and stated that "the energy ratio can be applied to the use of energy in isolated societies, in which it is important that the output energy is greater than the input energy in order to assure their subsistence". Conforti and Giampietro (1997) by using energy ratio separated 75 countries into five clusters. They explained that land constraints, with respect to the total population size, rather than labor constraints, tend to be associated with comparatively higher energy requirements in agricultural production. Also, they suggested that the output/input ratio may depend mostly on the average output/farmer and on overall population density. If the ratio is higher than one, the system is earning energy, whereas if it is less than one, the system is losing energy as shown in Table 9. Practically, the energy gain shows that most farmers earn what they put in to fail in the long run.

Table 9. Energy ratio and net energy gain for different production

Acreage category(ha)	Yield, ton/ha	Output energy, MJ/ha	Input Energy ,MJ/ha	ER	NEG(MJ/kg)
Wheat (Irrigation system)	4.0	98,321	51,587	1.9	46,733
Wheat (Dry Land system)	1.2	31,811	12,543	2.5	19,268
Barley (Irrigation system)	3.9	94,583	53,529	1.8	41,054
Barley (Dry Land system)	1.2	29,515	11,935	2.5	17,581
Maize	32.5	521,156	72,743	7.2	448,412

Table 10. Yield and some of inputs in different clusters.

	Less than 2 Ha	Between 2 and 10 Ha	Greater than 10 Ha	Total
Farmer Age	50.29	50.74	50.87	50.65
Age of Tractor	8.94	13.18	14.27	12.33
Number of Paddocks	2.12	1.82	1.47	1.79
Distance from city	48.38	76.68	76.42	68.54

Energy ratio for wheat production in India was 1.69 (Stout, 1989), which is 27.5% higher than the best ratio found in this study. A system of precision farming or precision management must be in place for Iranian farmers.

The average values of estimated energy ratio for wheat (irrigated), wheat (Dry Land), barley (irrigated), barley (Dry Land) and maize were 1.9, 2.5, 1.5, 2.5 and 7.2, respectively. This suggests that the maize crop is more rewarding to the farmers in Saveh as compared to wheat and barley. Furthermore, it seems that wheat and barley in irrigated system have similar circumstances.

Other results

For better comparison, different inputs were classified into three different clusters; Table 10 compares average of some inputs and yields in different clusters. It shows, there are no significant differences between the farmers' age in different groups. Furthermore, the average age of farmers (50 years) is more than the average age of society (24 years); therefore, their ability to new practice is reduced.

Furthermore farmers in first group sell their production to nearest markets but farmer who have bigger farm have better opportunities to sell their production. This table shows that increasing the size of farms reduces the number of paddocks, it means that small farms, which are separated to another sections, can reduce efficiency more and more. On the other hand, the farmers who have bigger farms use older tractors because they have better facilities and abilities for maintenance and repair. Overall, contrary to expectation in some factors and operations, by increasing the size of farms the efficiency did not increase but farm size as a factor influencing on energy consumption was reported by Shahin et al. (2008) may be due to field management. They suggested that better energy efficiency and productivity was found on the large farms. According to these criteria large farms were more successful in energy use. It is worth mentioning that different factors such as management abilities of farmers can influence energy consumption. It means that some farmers have not enough ability to manage the big farms or the old farmers could not arrange their traditional experience with new technologies.

Application of integrated production methods are recently considered as a means to reduce production costs, to efficiently use human labor and other inputs and to protect the environmental (often in conjunction with high numbers of tourists present in the area). Energy budgets for agricultural production can be used as building blocks for life-cycle assessment that include agricultural products and can also serve as a first step towards identifying crop production process that benefit most from increased efficiency.

Conclusion

Energy input in grain production was similar for both wheat and barley in both systems, except the sources of energy consumption varied strongly in different systems. Also, graphs of energy sources and operational energy consumption illustrate most of fuel consumption is consumed in irrigation. It means conversion of old diesel pumps to electric pumps can reduce energy (fuel) consumption significantly. By far, in the crop production, fuel is the most important source of energy and fertilizer comes second; therefore, it is necessary to focus on fuel and fertilizer consumption more than other factors. Fossil fuel energy has enabled a nation's economy to feed an increasing number of humans and improve the general quality of life for people in many ways, including reducing numerous diseases in humans (Pimentel and Pimentel, 1996). But continued heavy reliance on fossil fuels for food production systems will adversely affect the sustainability of food production. A detail study of the amount and methods of fuel and fertilizer must take place in order to reduce the energy consumptions. Given the findings of this research the most significant areas for improving overall energy efficiency on arable farms in Saveh area are as follows:

(1) Fertilizer management, particularly in relation to the use of urea, to reduce indirect energy requirements for fertilizer manufacture ;(A serious educational workshop must be held about fertilizer consumption and method for the farmer. The method of fertilizer broadcasting and amount of the fertilizer used must be taken under study and guidance to managerial staff).

(2) Water management on irrigated farms, particularly using electric pumps instead diesel pumps and also; with high pressure spray irrigation, to reduce direct use of electricity.

(3) Tractor and vehicle selection and operation to reduce direct use of diesel and petrol; better equipments and reduction of tractors passes in farms can reduce fuel consumption significantly, also some educational workshop must be held about operation, service and maintenance of different machinery for the farmers. These results will be helpful in developing a comprehensive database on the power and energy requirements in crop production for Iranian agricultural machinery management.

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