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Energy efficiency for wheat production using data envelopment analysis (DEA) technique

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This study was carried out to assess wheat production efficiency with regard to energy consumption in two regions of Fars province, Iran. For this purpose, the data were collected from 277 wheat growing farmers of which 135 from region 1 and 142 from region 2, using stratified random sampling method. Efficiency evaluation has done using data envelopment analysis (DEA) technique. The results indicated that total input energy for wheat production were 38589.677 and 38817.823 MJ/ha with the averaged weight yield of 6813.996 and 6046.968 kg/ha in region 1 and 2, respectively. Energy output-input ratio, energy productivity and specific energy were 2.596, 0.178 kg/MJ and 5.603 MJ/kg for region 1, and 2.290, 0.162 kg/MJ and 6.186 MJ/kg for region 2, respectively. The efficiency evaluation disclosed that the number of efficient farmers was more in region 2(16.2%) and for combined seeder (25.53%). Also, it expose that a large number of farmers could improve their efficiency in different ranges of efficiency.

Key words: wheat, energy ratio, specific energy

Introduction

Agriculture has become an increasingly energy-intensive sector in the last half-century with much of it attributable to the needed inputs. For example, chemical fertilizers and pesticides require much greater energy to manufacture than to apply on-farm (Dyer and Desjardins, 2006). Agriculture is both a producer and a consumer of energy. Through photosynthesis, crops convert solar energy to biomass, thus providing food, feed and fiber (Stanhill, 1984). Wheat is a worldwide cultivated grass for its highly nutritious and useful grain. It is one of the top three most produced cereals in the world, ranks second after corn and followed by rice. Winter wheat is one of the most major crops has planted in Iran. Iran had been the greatest wheat importer for decades. Due to

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governmental policies and different agricultural programs the nation achieved self-sufficiency in wheat in 2004. But high amount of rain fall besides convenient climate were shown the reasons to this success that should not be neglected. Iran is the sixteenth largest country in the world with an area of more than 1.6 million square Km. planted area was 12.96 million ha in 2005-2006. Cereal planted area was 9.37 (72.28%) million ha, which includes wheat (73.42%), barley (16.73%), paddy (6.73%) and corn (3.12%). Total harvested cereals in 2005-2006 were 22.40 million tons of which wheat recorded of 65.47% followed by barely (13.20%), paddy (11.66%) and corn (9.67%), respectively (Anonym., 2007). At least 40% of Iran's wheat is rain fed with an average yield of only 0.8 tons/ha. Even in irrigated farms the average yield of wheat rarely exceeds 3 tons/ha, which is low by the world standards (Anonym., 2005).

Dramatic increased in crop yields per hectare have been achieved in the developing countries through the use of improved varieties together with commercial energy inputs: particularly mineral fertilizers, farm machinery, pump irrigation and chemical pesticides. Commercial energy inputs are being used increasingly in developing countries and are resulted in a transition from traditional to more energy-oriented agricultural production methods (Richard, 1992). It seems that there is a huge gap between industrialized and developing countries in using energy resources. This problem is even more severe in areas like Iran having almost a large quantity of oil and natural gas resources at hand with a lower price. Energy auditing is a useful tool to characterize farming systems, quantify major inputs and identify promising strategies to improve efficiency and reduce environmental impacts. Data envelopment analysis (DEA) technique is a non-parametric method, supplies a wealth of information in the form of estimates of inefficiencies in both inputs and outputs for every DMU(Decision Making Unit=farmers in this study)-(William *et al*., 2007).

Singh *et al*. (2007) analyzed the energy consumption pattern of wheat production in India, and found that Punjab and UP recorded maximum output-input ratio of 5.2 and 4.2, respectively. Also, Punjab occupied the first place among all states with 3334.8 kg/ha average yield. A study estimated that the amount of energy for corn production in Wisconsin was 1.54 MJ/kg with corn production level of 9398 kg/ha. Energy inputs for drying increased this value to 3.88 MJ/kg. In comparison to Wisconsin, Germany consumed 1.43 MJ/kg with average of 9330 kg/ha corn (Kraatz, 2008). Nassiri and Singh (2009) used DEA technique to determine paddy production efficiency considering energy consumption in India. They study showed that the majority of farmers had technical efficiency less than 80%.

Many researchers have been studied energy consumption pattern for different crops and situations, because the way of the energy consumed and its productivity deserves high attention. Considering the energy scarcity and wheat importance in Iran, this study was carried out to evaluate the use of energy efficiency for wheat production in Iran.

Materials and methods

This study was conducted in order to determine the amount and efficiency of energy consumption for wheat production in two regions of Fars province, Iran. The province is located in the southwest of Iran, within 27° 03' and 31° 40' north latitude and 50° 36' and 55° 35' east longitude. The data were collected from 277 wheat growing farmers of which 135 from region 1 and 142 from region 2. For collecting proper data covering the energy consumption pattern, appropriate questionnaire were designed and completed through face to face interviews.

Since the number of farmers was enormous (about 2700 farmers in two regions) and farms with different sizes were properly distributed, it was decided to classify farmers in two groups according to different planting methods as:

1- Those who used combined seeders (CS).

2- Those who used drill planters or seed applicators (DP-SA).

Sample farms were randomly selected using stratified random sampling method. The sample size was calculated by Neyman technique (Yamane 1967):

$$n = \frac{(\sum N_h S_h)^2}{N^2 D^2 + \sum N_h {S_h}^2} \quad (1)$$

Where n is the required sample size; N is the number of holdings in target population; N_h is the number of the population in h; S_h is the standard deviation of h, ${S_h}^2$ is the variance of h; $D^2 = d^2/z^2$; d is the precision $(\bar{x} - \bar{X})$; z is the reliability coefficient (1.96 which represents the 95% reliability). The permissible error in the sample size was defined to be 5% for 95% confidence. The amount of different inputs were evaluated per hectare and multiplied by their energy equivalents. The energy equivalents of inputs and output used in this study are given in Table 1.

Energy requirements in agriculture are divided into direct and indirect, renewable and non-renewable energies. Direct energy includes fuel, human power and electricity, and indirect energy consists of the energy used in manufacturing, packaging and transporting fertilizers, pesticides and farm machinery. Renewable energies are: human power, seed and manure, and non-renewable energies are: fuel, electricity, fertilizers, pesticides, farm machinery and irrigation (Richard, 1992).

For assessing energy consumption efficiency of each farmer (DMU_S), data envelopment analysis (DEA) technique was used. Technical efficiency and pure technical efficiency were computed using Frontier Analyst Professional.

Table 1. Energy equivalents of inputs and outputs in agricultural production.

Input (unit)	Energy equivalent (MJ/unit)	Reference
Liquid chemical (L)	102	Chaudhary *et al.* (2006)
Granular chemical (kg)	120	Chaudhary *et al.* (2006)
Human power (h)	1.96	Richard (1992)
Machinery (kg)	62.7	Verma (1987)
Nitrogen (kg)	66.14	Shrestha (1998)
Phosphorus (kg)	12.44	Shrestha (1998)
Potassium (kg)	11.15	Shrestha (1998)
Manure (kg)	0.3	Verma (1987)
Zinc sulphate (kg)	20.9	Verma (1987)
Diesel (L)	56.3	Verma (1987)
wheat seed (kg)	14.7	Richard (1992)

Technical efficiency

Technical efficiency is the efficiency in converting inputs to outputs. It exists when it is possible to produce more outputs with the inputs used or to produce the present level of outputs with fewer inputs. In other words, it can be stated as the ratio of sum of weighted outputs to sum of weighted inputs and can be shown as following formula (Cooper *et al.*, 2004):

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \ldots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \ldots + v_m y_{mj}} = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \quad (2)$$

where 'x' and 'y' are input and output and 'v' and 'u' are input and output weights, respectively, 's' is number of inputs (s = 1,2,. . .,m), 'r' is number of outputs (r = 1,2,..,n) and 'j' represents jth DMUs (j = 1,2,. . .,k). For solving Eq. (2) the following linear program (LP) was developed by Charnes *et al.* (1978), which called CCR model:

$$\text{Max:} \quad \theta = u_1 y_{1i} + u_2 y_{2i} + \ldots + u_r y_{ri} \quad (3)$$

$$\text{Subject to:} \quad v_1 x_{1i} + v_2 x_{2i} + \ldots + v_s x_{si} = 1 \quad (4)$$

$$u_1y_{1j} + u2y_{2j} +\ldots+ u_ry_{rj} \leq v_1x_{1j} + v_2x_{2j} +\ldots+ v_sx_{sj} \quad (5)$$

$$u_1, u_2,\ldots, u_r \geq 0 \quad (6)$$

$$v_1, v_2,\ldots, v_s \geq 0, \text{ and } (i \text{ and } j = 1, 2,\ldots, k) \quad (7)$$

Where θ is the technical efficiency and i represents ith DMU.

Pure technical efficiency

In 1984, Banker, Charnes and Cooper introduced a model in DEA, which was called BCC model to draw out the technical efficiency of DMUs (Banker *et al*., 1984). The calculation of efficiency in BBC model is called Pure Technical Efficiency and can be expressed by Dual Linear Program (DLP) as:

Max: $Z = uy_i - u_i$ (8)

Subject to: $vx_i = 1$ (9)

$-vX + uY - u_oe \leq 0$ (10)

$v \geq 0, u \geq 0$ (11)

Generally, the CCR-efficiency does not exceed BCC-efficiency (William *et al*., 2007). The result of BCC model shows that how much percent of energy used has contributed on the output.

Results and discussion

Energy consumption

The outcome of energy assessment for wheat production in Fars province, Iran is given in Table 2. Total energy consumptions were 38589.677 and 38817.823 MJ/ha with the weighted average yield of 6813.996 and 6046.968 kg/ha in region 1 and 2, respectively.

The share of direct and indirect energy consumption was almost equal (about 50%) in both regions. On the other hand, the shares of renewable and non-renewable energy were almost 12.5% and 87.5% in both regions, respectively. The top three energy consumers in the regions were fertilizer, electricity and diesel fuel. These parts consumed about 80% of total input energy in each region. Table 2 shows that there were not significant differences between two regions in most parts of energy consumers. Data analysis revealed that there were no correlation between energy consumption and yield in these regions.

Table 2. Energy used status for wheat production in two regions of Fars province (MJ/ha).

Item	Region 1			Region 2		
	CS	DP-SA	Weighted Average	CS	DP-SA	Weighted Average
1-Machinery	1115.020	1463.259	1335.803(3.45%) [a]	1208.273	1485.704	1419.953(3.66%) [a]
1-1- land preparation	149.480	570.376	416.328[31.17%] [a]	209.750	615.673	519.470[36.58%] [b]
1-2- planting	332.040	202.553	249.945[18.71%] [a]	340.250	198.388	232.009[16.34%] [a]
1-3- fertilizer application + spraying	136.720	158.482	150.517[11.27%] [a]	172.500	156.592	160.362[11.29%] [a]
1-4- harvesting	496.780	531.847	519.013[38.85%] [a]	485.773	515.051	508.112[35.79%] [a]
2- Diesel fuel	6429.136	7669.906	7215.784(18.7%) [a]	7129.805	8157.918	7914.255(20.38%) [a]
2-1- land preparation	1880.300	4007.634	3229.030[44.75%] [a]	2601.145	4474.960	4030.866[50.93%] [a]
2-2- planting	3034.520	2101.148	2442.762[33.85%] [a]	2980.973	2091.341	2302.184[29.1%] [a]
2-3- fertilizer application + spraying	228.190	254.914	245.133[3.4%] [a]	273.959	257.561	261.448[3.3%] [a]
2-4- harvesting	1286.126	1306.209	1298.859[18%] [a]	1273.727	1334.056	1319.758[16.67%] [a]
3- Fertilizer	13978.656	14175.095	14103.199(36.54%) [a]	12383.745	12336.174	12347.448(31.81%) [b]
3-1- Nitrogen	12965.389	12958.585	12961.076[91.9%] [a]	11269.093	11363.154	11340.862[91.85%] [b]
3-2- Phosphorous	392.832	441.148	423.464[3%] [a]	480.218	397.812	417.342[3.38%] [a]
3-3- Potassium	139.365	249.150	208.969[1.48%] [a]	114.023	218.941	194.076[1.57%] [a]
3-4- Manure	432.000	480.000	462.432[3.28%] [a]	490.909	306.122	349.917[2.83%] [a]
3-5- Other (zinc sulphate, iron, etc).	49.070	46.212	47.258[0.34%] [a]	29.502	50.144	45.252[0.37%] [a]
4- Human Power	433.400	440.832	438.112(1.16%) [a]	489.416	469.110	473.922(1.22%) [a]
5- Seed	2087.400	4425.565	3569.796(9.25%) [a]	2652.682	4680.000	4199.526(10.81%) [a]
6- Chemicals	289.906	271.316	278.120(0.72%) [a]	424.357	486.582	471.835(1.22%) [a]
7- Irrigation	1833.144	2004.016	1941.477(5.03%) [a]	1967.636	2008.859	1999.089(5.15%) [a]
8- Electricity	9165.720	10020.082	9707.386(25.16%) [a]	9838.182	10044.296	9995.447(25.75%) [a]
- Total input energy	35332.382	40470.072	38589.677(100%) [a]	36094.095	39663.857	38817.823(100%) [a]
- Direct energy	16028.26	18130.82	17361.282(44.99%)	17457.403	18671.324	18383.62(47.36%)
- Indirect energy	19304.122	22339.252	21228.395(55.01%)	18636.692	20992.533	20434.203(52.64%)
- Renewable energy	2952.800	5346.397	4470.340(11.58%)	3633.007	5455.232	5023.365(12.94%)
- Non-renewable energy	32379.582	35123.675	34119.337(88.42%)	32461.09	34208.625	33794.458(87.06%)
-Total output energy	101248.599	99540.618	100165.739 [a]	92248.043	87847.500	88890.429 [a]
- Energy output-input ratio	2.866	2.460	2.596	2.556	2.215	2.290
- Energy poductivity(kg/MJ)	0.193	0.167	0.178	0.168	0.151	0.162
- Specific energy(MJ/kg)	5.185	5.977	5.603	5.969	6.637	6.186
- Net energy gain(MJ/ha)	65916.217	59070.546	61576.062	56153.948	48183.643	50072.606
- Yield(kg/ha)	6887.660	6771.471	6813.996	6275.377	5976.020	6046.968

*Figures in round brackets are percentage of total energy consumption.
**Figures in square brackets are percentage of energy consumptions in machinery, fuel and fertilizer parts.
***In weighted average columns, any means by the same letters are not statistically different at 1% level of significance.

It was observed that more farmers have used CS in region 1, but most of which have used numerous passes of disking and even land leveling after plowing. This procedure has negated much of the advantages of using combined machines; besides it has some negative effects on soil structure and seed generation like further soil compaction and pulverization and loss of soil moisture. Farmers who have used DP-SA and CS often consumed 250-300 and 140-180 kg/ha seed for planting, respectively. But there was no significant difference between two regions in seed energy consumption, because most of operators could not calibrate the combined seeders properly.

Energy consumption in the form of fertilizer was ranked first in both regions. Fertilizer consumed 36.54% and 31.81% of total input energy in region1 and 2, respectively. Nitrogen consumed almost 92% of total fertilizer energy used. Unfortunately, during the study it was found that there was positive tendency to use more fertilizer, especially nitrogen. Fig.1 shows the increasing trends on fertilizer devouring during 1961-2003. As can be seen from Fig. 1, the increase in fertilizer consumption only during four years (1999-2003) has been almost as much as the increase in each decade. The country could not meet the total demand. And additional supplies were provided by private sector. For instance, total demand fertilizer was 4220 thousand tons in 2004-2005, of which 2222 thousand tons were provided by domestic production, 621 thousand tons through public imports and the remains by private sector. It has predicted that the demand for fertilizer will increase to 6200 thousand tons by 2017-2018 (Anonym., 2006). In such situation most of farmers neither have used any manure nor have kept crops residues. Although farmers are forbidden from burning wheat residue, most of them have burned the wheat residues every year so that they have enough time to planting summer crops.

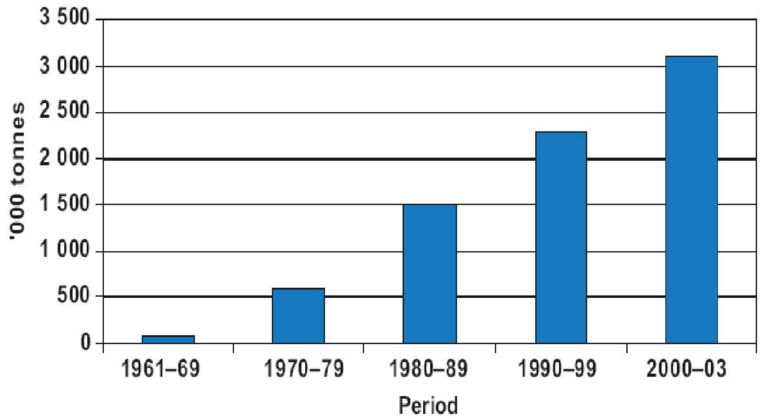

Fig.1. Fertilizer use in Iran since 1961.

Electricity contributed to the total input energy at more than 25% in each region. Energy in the form of electricity was high, because most of farmers have used surface irrigation methods and there were a lot of Water losses in conveyance and use. Surface irrigation techniques are used on 98.8% of the area equipped for irrigation, 1.2% using pressurized irrigation systems.

In this problematic status some factors that can be used to production intensification and agricultural system improvement in Iran are: land leveling, improved irrigation methods, balanced fertilization, treated seeds, using IPM (Integrated Pest Management) practices to control various diseases and pests, and encouraging farmers to plant green manures in fallow farms. Balanced fertilization is an essential factor for achieving yield and quality improvements (Anonym., 2005).

Efficiency analysis

Table 3 shows the frequency of farmers for different planting methods and regions with regard to energy used efficiency. Frequencies in CCR model expose that the number of efficient farmers is more for CS users (25.53%) and region 2 (16.2%). BCC model solution shows that some CCR-inefficient farmers moved toward BCC-efficient frontier in all categories.

Table 3. Frequency distribution of technical and pure technical efficiency of wheat farmers for different planting methods and regions.

CCR model		**Planting method**		**Region**	
		CS	**DP-SA**	**Region1**	**Region2**
Efficient		24	38	19	23
Inefficient	> 90%	13	22	17	18
	81-90%	6	14	25	31
	71-80%	--	6	21	42
	61-70%	31	51	18	--
	< 60%	20	52	35	28
No. of farmers		94	183	135	142
Total		277		277	
BCC model					
Efficient		29	40	28	25
Inefficient	> 90%	11	26	21	16
	81-90%	9	13	18	33
	71-80%	4	10	13	2
	61-70%	33	48	42	39
	< 60%	8	46	13	27
No. of farmers		94	183	135	142
Total		277		277	

The remarkable result is that among DP-SA users 31 and 17 farmers could improve their efficiency by 11-20% and 51-60%, respectively. Also, 13, 16 and 22 farmers in region 2 could improve their efficiency by 81-90%, 41-50% and 21-30%, respectively.

This study was carried on in order to evaluate the efficiency of energy consumption of wheat production in two regions of Fars province, Iran. Total energy inputs were 38589.677 and 38817.823 MJ/ha for region 1 and 2, respectively. Three main energy consumers were fertilizer, electricity and fuel in both regions. These components consumed about 80% of total input energy in each region. Energy output-input ratio, energy productivity and specific energy were 2.596, 0.178 kg/MJ and 5.603 MJ/kg for region 1, and 2.290, 0.162 kg/MJ and 6.186 MJ/kg for region 2, respectively. Efficiency assessment shows that a large number of farmers could improve their efficiency in different ranges of efficiency.

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