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RESEARCH ARTICLE

Comparison of energy consumption of wheat production in conservation and conventional agriculture using DEA

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Abstract

Energy is one of the essential resources for human life and mainly classified as non-renewable resources. Since huge amounts of energy are consumed in the agriculture sector, an energy audit is an essential strategy in countries. Conservation agriculture as a tool for sustainable development can lead to saving agricultural resources. In the current investigation, energy audit for wheat conservation and conventional production systems was performed. For this purpose, 48 farms were selected randomly in 2016, and their energy performance was evaluated and compared. The data were analyzed to calculate energy parameters. Also, data envelopment analysis technique was used to identify the possible ways to achieve higher efficiency in farms. To this end, current and optimum situations and saving energy in different cultivation systems were determined using Charnes, Cooper, and Rhodes (CCR) model. The research results showed that the average energy ratio, net energy gain, specific energy, and energy productivity for conservation farms were 4.31, 137,656 MJ ha^{-1}, 5.56 MJ kg^{-1}, and 0.18 kg MJ^{-1}, respectively. Corresponded values for conventional farms were measured to be 3.03, 90,101 MJ ha^{-1}, 7.69 MJ kg^{-1}, and 0.13 kg MJ^{-1}, respectively. Data envelopment analysis results revealed that the highest saving energy in conventional system belongs to diesel fuel and irrigation inputs, and the least amount of energy saving was seen in human labor input. While for the conservation system, the highest and the least amount of energy saving belongs to nitrogen and human labor, respectively.

Keywords Energy audit · Data envelopment analysis · Conservation planting · Farm energy efficiency · Benchmarking · Sustainable agriculture · No tillage · Wheat

Introduction

Energy consumption is an important issue for sustainable development that can be evaluated for different productive sectors to identify their deficiencies. In this regard, the sufficient and affordable production of crops, as well as conservation of natural resources, can be obtained by sustainable agriculture (Pervanchon et al. 2002; Bhan and Behera 2014). Investigation and further adjustments in energy consumption could help us to identify reliable methods for saving of the energy, particularly while the common farm inputs such as water for irrigation, fertilizer, machinery processes, and labor consume a large amount of energy (Wang et al. 2006; Rusu 2014).

Wheat is one the most important crops in the world. Wheat can be planted in most region of the world, and about 729 million tons of wheat grains have been harvested from about 220 million ha of farmland (FAO 2014). Crops can be produced in different production systems including conventional and conservation systems (about 125 million ha) (Friedrich et al. 2012). Soil fertility conservation and evaluation of the sustainability of the agricultural system are the important factors which can show the influence of soil tillage systems on soil properties and energy efficiency (Uhlin 1998; Rusu 2001;

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Sarauskis et al. 2009; Vural and Efecan 2012). Conservation systems have several advantages such as energy saving (due to no-tillage system), reducing soil erosion and increasing soil permeability by releasing crop residue. About 30% of energy in the field is consumed by tillage (Borin et al. 1997). In comparison with conventional procedures, fuel consumption decreases up to 77% in conservation tillage (Afzalinia et al. 2009). In other research, this reduction was reported as almost 13 l ha^{-1} (from 25.3 to 12.4 l ha^{-1}) (Rusu 2014).

Many research focused on energy consumption on different tillage systems. Kepner et al. (1978) reported that reducing tillage intensity reduces fuel consumption, increases the energy ratio, controls soil erosion, and decreases time and energy required for seedbed preparation.

Many research calculated the energy consumption in wheat production. Shahan et al. (2008) reported the total energy consumption of 38,360 MJ ha^{-1} in Ardabil province of Iran. The most energy consumer input was chemical fertilizer. Energy ratio and efficiency were reported as 3.13 and 0.16, respectively (Shahan et al. 2008). In another research, the total energy consumption of irrigated and dry-land wheat fields in Canterbury of New Zealand was calculated as 25,600 and 17,458 MJ ha^{-1}, respectively. Average values of energy ratio for irrigated and non-irrigated system were 11.5 and 15.1, respectively (Safa et al. 2011). In a similar research, total energy consumption and energy production for wheat production in Carsamba of Samsun province (in Turkey) were 35,737.13 and 84,427.33 MJ ha^{-1}, respectively. Also, energy efficiency, specific energy, energy productivity, and net energy for wheat production were calculated to be 2.36, 8.96 MJ kg^{-1}, 0.112 kg MJ^{-1} and 48,690.20 MJ ha^{-1} (Yildiz 2016). In Wisconsin, USA, the energy consumption of maize production was 1.7 MJ kg^{-1} that its maximum energy consumption corresponded to urea fertilizer (Kraatz 2008). According to another investigation regarding energy consumption for corn silage production in Tehran, Iran, specific energy, energy ratio, net energy gain, and energy productivity were calculated as 3.76 MJ kg^{-1}, 2.27, 79,452 MJ ha^{-1}, and 0.28 kg MJ^{-1}, respectively (Pishgar-Komleh et al. 2011). Regarding previous research, finding the influence of tillage systems on wheat production needs more general analysis. Therefore, it is important to do an energy input-output analysis. For this purpose, it is essential to calculate the energy parameters such as specific energy, energy ratio, and energy productivity for different wheat production systems.

The parametric and non-parametric techniques are two main approaches to measure the energy efficiency (Thiam et al. 2001; Alen and Zeller 2005; Wadud and White 2000). Also, the data envelopment analysis (DEA) can be defined as a managerial tool combined with a non-parametric method to aid the decision-making units (DMUs) with consideration of the multi-inputs and outputs to evaluate their relative efficiencies. A DMU is a tangible or intangible system, which transforms a set of inputs into outputs. The DEA was introduced by Charnes, Cooper, and Rhodes (CCR) (Charnes et al. 1978) which was the generalization of Farrell's idea (Farrell 1957). Indeed, DEA technique has been used in many studies were carried out in the area of energy efficiency using DEA models (Boubaker 2012; Mardani et al. 2017; Song et al. 2012; Zhou et al. 2008; Komleh et al. 2011). DEA can be used in the agricultural industry to optimize the energy consumption in the farmlands. Optimization of energy consumption is one of the main factors to achieve the sustainable agriculture (Erdal et al. 2007). Some researchers have investigated on the different agricultural production systems to achieve a sustainable production (Aravindakshan et al. 2015; Atici and Podinovski 2015; Baležentis et al. 2014; Blancard and Martin 2014; Mardani and Salarpour 2015; Vlontzos et al. 2014; Pishgar-Komleh et al. 2017).

In the present study, the energy assessments for wheat production by two different planting systems (conventional and conservation) were investigated in the Beyza region of Fars province in Iran. Also, the DEA technique was utilized to analyze the energy efficiency of two production system in different DMUs.

Material and methods

Data collection and energy calculations

This study was carried out in 48 farmlands (selected randomly) of Beyza region of Fars province, Iran in 2016. The sample size was about 30% of the total population of wheat farms in the research area. Beyza is located in the northwest of Shiraz, and its population is about 38,000 people. In order to compare energy aspects of two different planting systems (conventional and conservation), 24 farmlands for each method were selected, and questionnaires for determination of inputs and outputs for farms were prepared to fill by the farmers. Wheat producers were asked about the physical amount inputs and outputs. To compare the energy consumption in different production systems, farms were classified based on the tillage operation into conventional and conservation farms. In the conservation farms, seeds were planted directly by a grain drill whereas in the conventional ones, the tillage operations consist of primary tillage by moldboard plow, secondary tillage by twice disk harrow, and farm leveling were done and afterwards seeds were planted by a broadcast seeder. In the examined regions, wheat is cultivated in rotation with maize. In the no-tillage system, wheat is planted directly in farms with maize residues. Direct wheat planting is done by seed drill and fertilizers are used simultaneously. Wheat production inputs in the research area consist of seed, chemical fertilizer, manure, water for irrigation, fuel, biocide, human labor, and all machineries (tractor, combine, and equipment). Also, the harvested grains and straws were considered outputs. Chemical fertilizer consists of nitrogen (N) and phosphorus (P_2O_5). Phosphate was used as a basic fertilizer before tillage operation, and urea was applied after tillage and before planting operations. Beside chemical fertilizers, manure was applied. Pesticides were applied by a field sprayer. The flooding method was used as an irrigation system in this context; the volumetric flow meter was used to record the consumed water for each farm. However, annual rainfall was 356 mm that was added to the irrigated value to obtain the average amount of received water. To calculate the energy contents of inputs and outputs, the physical quantities were multiplied by their corresponding energy equivalents. The energy equivalents of inputs and outputs are demonstrated in Table 1.

For machinery energy input, Eq. (1) was applied as (Kaltsas et al. 2007):

$$\mathrm{ME} = \frac{E \times M}{N} \tag{1}$$

where ME is machinery energy (MJ h^{-1}), E is energy equivalent per mass of machine (MJ kg^{-1}), M is machine mass (kg), and N was assigned to a useful life of machine (h). The energy equivalent per mass of machine (E) is a constant coefficient which is equal to 142.7 MJ kg^{-1} calculated as total consumed energy for manufacturing of machine used (86.38 MJ kg^{-1}), energy for repair and maintenance (47.5 MJ kg^{-1}), and energy for transportation of machines to the field (8.8 MJ kg^{-1}) (Kaltsas et al. 2007). Data for the useful life of agricultural machinery were obtained from the American Society of Agricultural and Biological Engineers (ASABE) standard (ASAE 2003). All needed information in Eq. (1) can be extracted from Table 2.

To compare different farms and production system, it is essential to apply indices. Many researchers applied different indices such as energy ratio (ER), net energy gain (NEG), energy productivity (EP), and specific energy index (SEI) (Hatirli et al. 2006; Mohammadi et al. 2008; Bayramoglu and Gundogmus 2009) (Eqs. (2)–(5)).

$$ER = \frac{Output\ energy\ \left(MJ\ ha^{-1}\right)}{Input\ energy\ \left(MJ\ ha^{-1}\right)} \tag{2}$$

$$NEG = Output\ energy\ \left(MJ\ ha^{-1}\right) - Input\ energy \left(MJ\ ha^{-1}\right) \tag{3}$$

$$EP = \frac{Grain\ output\ \left(kg\ ha^{-1}\right)}{Input\ energy\ \left(MJ\ ha^{-1}\right)} \tag{4}$$

$$SEI = \frac{Input\ energy\ \left(MJ\ ha^{-1}\right)}{Grain\ output\ \left(kg\ ha^{-1}\right)} \tag{5}$$

Table 1 Energy content of inputs and outputs

Input/ output	Unit	Energy equivalent (MJ $unit^{-1}$)	Reference
Wheat seed	kg	15.7	Tipi et al. (2009)
Labor	h	1.96	Ozkan et al. (2004)
Irrigation	m^3	1.02	Mohammadi and Omid (2010)
Urea	kg	60.6	Akcaoz et al. (2009)
Phosphate	kg	11.1	Akcaoz et al. (2009)
Potassium	kg	6.7	Akcaoz et al. (2009)
Manure	ton	303.1	Esengun et al. (2007)
Herbicide	kg	278	Tzilivakis et al. (2005)
Pesticide	kg	237	Tzilivakis et al. (2005)
Fungicide	kg	99	Strapatsa et al. (2006)
Gasoline	l	46.31	Kitani (1999)
Gas oil	l	56.31	Singh (2002)
Straw	kg	9.25	Tabatabaeefar et al. (2009)

Efficiency measurement

DEA is a powerful and the best known non-parametric technique to measure efficiency. It can be used to evaluate inefficient DMUs and recommend input or output slack values. DEA is a linear programming approach for assessing the efficiency of DMUs. Efficiency can be calculated by three different methods: technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) (Cooper et al. 2006). The CCR (proposed by Charnes et al. 1978) and BCC (introduced by Banker et al. 1984) models are two types of DEA models. CCR model measures the technical efficiency of a DMU relative to other DMUs under the constant return to scale (CRS) conditions. The CCR model was extended to compute the technical efficiencies of DMUs under the variable return to scale (VRS) conditions (Banker et al. 1984).

TE or global efficiency is a tool to measure the relative performance of DMUs (Cooper et al. 2006). TE could be calculated using Eq. (6) (Cooper et al. 2006):

$$TE_j = \frac{\sum_{r=1}^{q} u_r y_{rj}}{\sum_{s=1}^{p} v_s x_{sj}} \tag{6}$$

where TE_j is the technical efficiency of the of j's DMU. The x, y, v, and u are the inputs, outputs, and corresponding weights, respectively. p and q denote the number of inputs and outputs, respectively.

TE provides the ability for a DMU to reach the maximum output by the given inputs and technologies (output-oriented) or, alternatively, to achieve maximum feasible reductions in input quantities by the given outputs (input-oriented) (Farrell

Table 2 Energy content of farm machineries

Machinery type	Unit	Energy content (MJ unit^{-1})	Mass	Useful life (h)
Tractor (75 hp)	h	40.13	2812	10,000
Tractor (184 hp)	h	98.46	6900	10,000
Combine	h	448.08	6280	2000
Moldboard plow	h	23.54	330	2000
Disk plow	h	64.22	900	2000
Leveler	h	35.68	500	2000
Centrifugal broad caster	h	16.5	185	1600
Grain drill	h	190.27	1600	1200
Sprayer	h	11.42	120	1500

1957). Since it is more reasonable to argue that in the agricultural sector a farmer has more control on inputs rather than the outputs, in this study, the input-oriented model was applied. Based on the input-oriented CCR model, Eq. (6) can be converted from the fractional form to a linear programming problem as Eqs. (7) and (8):

$$Min\ \theta = \sum_{s=1}^{p} v_s x_{sj} \tag{7}$$

Subjected to the following conditions:

$$\sum_{r=1}^{q} u_r y_{rj} - \sum_{s=1}^{p} v_s x_{sj} \le 0 \tag{8}$$

$$\begin{array}{ll} \sum_{r=1}^{q} u_r y_{rj} = 1 & j = 1.2.\ldots.k \\ u_r \ge 0 & r = 1.2.\ldots.q \\ v_s \ge 0 & s = 1.2.\ldots.p \end{array}$$

The efficiency has a score between zero and 1 that the value of 1 is associated with efficient DMUs and has no reduction potential. The other values lower than 1 are related to inefficient DMUs.

Pure technical efficiency

Banker et al. (1984) developed a VRS model which is known as BCC. TE scores under VRS are greater than or equal to TE scores under the CRS model. TE with VRS condition is known as PTE or local efficiency. The BCC model is expressed by a dual-linear programming problem as Eq. (9):

$$Maximize\ z = uy_i - u_i \tag{9}$$

Subjected to the following conditions, (Eq. 10)

$$\begin{array}{c} vx_i = 1 \\ -vX + uY - u_0 e \le 0 \\ u \ge 0 \\ v \ge 0 \end{array} \tag{10}$$

Scale efficiency

The effect of DMU size on efficiency is investigated by the SE. It could be computed by the ratio of technical (TE_{CCR}) to the pure technical (TE_{BCC}) efficiencies as Eq. (11) (Masuda 2016; Cooper et al. 2006):

$$SE = \frac{TE_{CCR}}{TE_{BCC}} \tag{11}$$

Eq. (7) can be written as follows:

$$TE_{\text{CCR}} = SE \times TE_{BCC} \tag{12}$$

Eq. (10) indicates the source of inefficiencies, which is arisen from disadvantageous conditions or the inefficient operation. If the level of technical and pure technical efficiencies is the same, SE is equal to 1, and it specifies that the DMU is operating at the most productive scale size. The SE less than 1 implies that DMU is locally efficient (Sarıca and Or 2007).

Inputs in DEA analysis were machinery, fuel, labor, irrigation, nitrogen, biocide, and seed energy content, and output were the sum of wheat grain and straw energy content. To conduct mean comparison test for normal and non-normal parameters, *t* test and Mann-Whitney *U* test (Wilcoxon rank sum test) were applied, respectively.

All energy calculation and DEA analysis were done in Excel and DEA solver software.

Results and discussion

Energy analysis

The average energy content for the farm inputs in conventional and conservation production systems are demonstrated in Table 3. The total input energy for the conventional and conservation farms was about 44,469 and 41,594 MJ ha^{-1}, respectively. As it is seen, the conservation farms consumed lower energy (7%)

Table 3 Average energy values of inputs for traditional and conservation wheat production systems

Input	Traditional system		Conservation system	
	Energy content (MJ ha^{-1})	Percentage	Energy content (MJ ha^{-1})	Percentage
Seed	3885.75	8.74	2773.67	6.67
Human labor	172.06	0.39	132.97	0.32
Irrigation	10,710.95	24.09	10,741.84	25.83
Urea fertilizer	10,150.50	22.83	12,928.00	31.08
Phosphate fertilizer	231.25	0.52	786.25	1.55
Manure	1515.50	3.41	757.75	1.82
Herbicide	245.73	0.55	198.10	0.48
Pesticide	44.44	0.10	127.39	0.31
Fungicide	12.38	0.03	8.25	0.02
Tractor	407.02	0.92	344.77	0.83
Combine	892.80	2.01	967.11	2.33
Moldboard plow	38.59	0.09	0.00	0.00
Disk plow	166.70	0.37	0.00	0.00
Leveler	46.03	0.10	0.00	0.00
Centrifugal broad caster	39.90	0.09	18.89	0.05
Grain drill	0.00	0.00	393.54	0.95
Sprayer	16.42	0.04	19.60	0.05
Gasoline	1923.33	4.33	1339.13	3.22
Gas oil	13,969.57	31.41	10,056.52	24.18
Total	44,468.91	100	41,593.77	100

compared with the conventional ones. Results of the similar research showed that the conservation farms consumed 8% lower input energy than the conventional farms (Saad et al. 2016). Also, our findings demonstrated that diesel fuel, irrigation, and urea fertilizer could be considered the largest energy consumers. In conventional and conservation systems, their energy consumption rates in total energy can be summarized as diesel fuel at 31.4 and 24.18%, irrigation at 24.1 and 25.83%, and urea fertilizer at 22.8 and 31.1%, respectively. Table 4 shows the average energy outputs in wheat production in research area. As it can be seen, about 62% of total output energy belongs to wheat grain, and the rest allocates to the wheat straw. Also, the application of the conservation method in comparison with the conventional system led to an increase in the harvested grain (32.8%) and straw (24.7%).

Table 4 The average equivalent energy of outputs in two different cultivation systems

Output	AEETF[a]	PTOETF[b]	AEECF[c]	PTOECF[d]
Wheat grain	82,442.50	61.26	110,029.50	61.38
Straw	52,127.60	38.74	69,220.83	38.62
Total	134,570.10	100	179,250.33	100

[a] Average equivalent energy for traditional farms

[b] Percentage of total output energy for traditional farms

[c] Average equivalent energy for conservation farms

[d] Percentage of total output energy for conservation farms

Table 5 shows the energy indices and DEA efficiencies of two different wheat production systems. For normal data, mean comparison was done by Student's t test, and since the DEA results were non-normal, Mann-Whitney *U* test (Wilcoxon rank sum test) was applied. The results of mean comparison can be seen in Table 5. Based on the results, a significant difference between two production systems was observed for ER, NEG, SEI, and EP. The ER, NEG, SEI, and EP for the

Table 5 Statistical comparison of two culture methods

Variable	Traditional	Conservation	*P* value *t* student
Energy ratio	3.03[a]	4.31[a]	< 0.01[a]
Net energy gain	90,101[a]	137,656 [a]	< 0.05[a]
Specific energy	7.69 [a]	5.56 [a]	< 0.01[a]
Energy productivity	0.13 [a]	0.18 [a]	< 0.01[a]
Technical efficiency	0.83[b]	0.86 [b]	ns[b]
Pure technical efficiency	0.84 [b]	0.87 [b]	ns[b]
Scale efficiency	0.98[b]	0.99 [b]	ns[b]

[a] Based on *t* student test

[b] Based on Mann-Whitney *U* test

Table 6 Statistics of inputs and output in two different cultivation systems

	Seed (MJ ha^{-1})	Labor (MJ ha^{-1})	Irrigation (MJ ha^{-1})	Fertilizers (MJ ha^{-1})	Biocide (MJ ha^{-1})	Machinery (MJ ha^{-1})	Fuel (MJ ha^{-1})	Output (MJ ha^{-1})
Conservation								
Max	4358	233	19,697	21,582	593	2849	12,985	180,570
Min	1607	64	4576	5826	0	963	4383	177,930
Average	2334	113	9031	12,371	269	1512	9453	179,250
SD	695	42	3629	4211	163	469	2051	1188
Traditional								
Max	11,850	417	22,601	36,539	1481	5024	45,100	148,959
Min	2309	126	9311	0	0	1277	15,677	120,181
Average	6209	236	15,709	17,033	431	2532	24,003	134,570
SD	2583	791	4081	9588	410	957	7344	12,950

conventional farmlands were calculated as 3.03, 137,656 MJ ha^{-1}, 7.69 MJ kg^{-1}, and 0.13 kg MJ^{-1}, respectively. Corresponding values for the conservation farmlands were obtained as 4.31, 90,101 MJ ha^{-1}, 5.56 MJ kg^{-1}, and 0.18 kg MJ^{-1}, respectively. It can be concluded that the energy ratio, net energy, and energy productivity were increased in conservation farms compared with the conventional farms. In other words, more products with the same energy consumption can be obtained in the conservation system. Compared with the conventional, in conservation system, energy ratio, net energy, and energy productivity increased 42.24, 51.67, and 38.46%, respectively. In similar research, energy ratio for conservation was higher than the conventional agriculture (Saad et al. 2016). As it can be seen, the differences between conventional and conservation systems for TE, PTE, and SE were not significant. However, it can be seen that farms with conservation production system had better efficiency values which show the higher levels of inputs and output management in comparison with conventional production systems.

Technical, pure technical, and scale efficiencies

In order to evaluate the productivity of wheat farms, the DEA technique was applied. Table 6 shows some statistic information of inputs and output. Figures 1 and 2 show the frequency distribution of TE, PTE, and SE in two wheat production systems. Results showed that six and eight farms had the TE equal to 1 in conventional and conservation production systems, respectively. Also, these farms had PTE equal to 1. The results showed that the least amount of efficiencies was seen in conventional farms (Fig. 1). As it can be seen in Figs. 1 and 2, in conserved farms, we have more farms with scale efficiency equal to 1.

Considering Table 7 which shows the efficiency of conventional and conserved farms, for all the types of efficiencies, conventional cultivation had the lowest values in comparison with conservation cultivation. Khoshnevisan et al. (2013) found the average values of 0.82, 0.99, and 0.83 for TE, PTE, and SE in wheat farms, respectively. The difference between TE and PTE shows that DMUs have been performed effectively regarding management of the farm because of their inefficiency return to the wrong scale of the

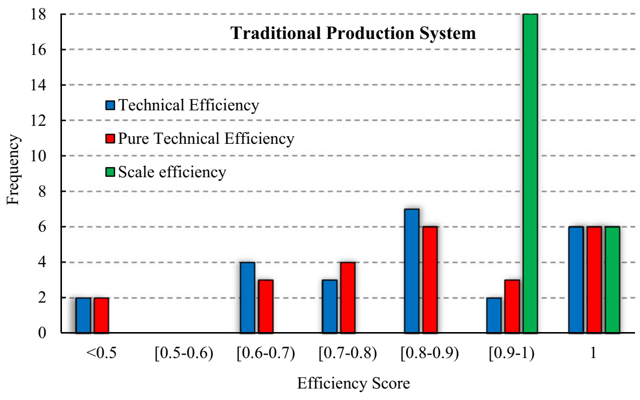

Fig. 1 Technical, pure technical, and scale efficiency distribution of traditional production system

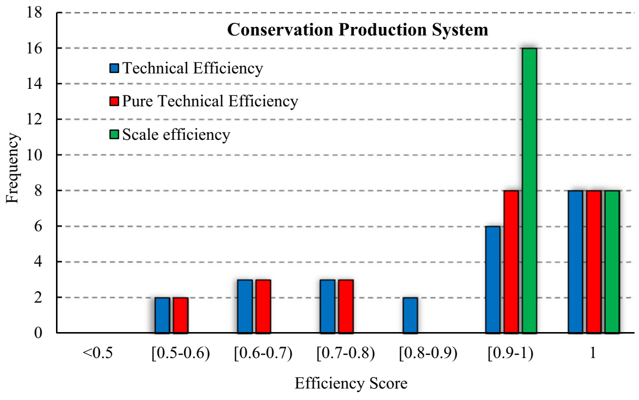

Fig. 2 Technical, pure technical, and scale efficiency distribution of conservation production system

Table 7 Technical, pure technical, and scale efficiency for different wheat cultivation scenarios

Type of efficiency	Max.		Min.		Average		SD	
	Tr.	Con.	Tr.	Con.	Tr.	Con.	Tr.	Con.
TE								
	1	1	0.42	0.56	0.83	0.86	0.17	0.16
Average	1		0.49		0.85		0.16	
PTE								
	1	1	0.46	0.58	0.84	0.87	0.16	0.15
Average	1		0.52		0.86		0.16	
SE								
	1	1	0.92	0.97	0.98	0.99	0.03	0.01
Average	1		0.95		0.98		0.02	

Tr., traditional-based wheat production system; *Con.*, conservation-based wheat production system

farm. Higher TE, PTE, and SE values show higher levels of management in conservation systems. PTE and SE provide an insight into the source of inefficiencies. The PTE measures the technical efficiency without scale efficiency and purely reflects the managerial performance to organize the inputs in the production process. Thus, PTE measurement has been used as an index to capture managerial performance. The SE provides the ability to choose the optimum size of farms. According to Mousavi-Avval et al. (2011), from a total of 94 farmers considered in soybean production, 40 farmers (42.55%) had the PTE score of 1. Moreover, from the PTE farmers, 26 farmers (27.66%) had the technical efficiency score of 1. It was due to their disadvantageous conditions of scale size.

Benchmarking

Table 8 shows the corresponding results for benchmarking as a process of measuring and comparing data to identify the possible ways to achieve higher efficiency (Keehley 1997).

Table 8 Results of benchmarking (technical efficiency analysis) of wheat farms

DMU	Traditional production system			Conservation production system		
	Frequency in reference	TE score	Reference set	Frequency in reference	TE score	Reference set
1	10	1.000		*10*	*1.00*	
2		0.681	1 (0.90); 3 (0.10)		0.95	8 (1)
3	*17*	*1.000*		4	1.00	
4		0.883	1 (0.72); 3 (0.28)	7	1.00	
5		0.484	3 (0.86); 12 (0.14)		0.61	3 (0.12); 8 (0.88)
6		0.899	3 (0.77); 12 (0.23)	5	1.00	
7		0.777	3 (0.83); 12 (0.17)		0.57	1 (0.58); 4 (0.12); 8 (0.29)
8	8	1.000		*10*	*1.00*	
9		0.880	1 (0.96); 3 (0.004)		0.76	3 (0.14); 8 (0.86)
10		0.663	1 (0.01); 3 (0.62); 8 (0.29)	0	1.00	
11		0.828	1 (0.77); 3 (0.23)		0.75	1 (0.29); 6 (0.58); 8 (0.13)
12	3	1.000			0.93	1 (0.72); 4 (0.14); 6 (0.14)
13	0	1.000			0.90	1 (0.95); 4 (0.05)
14		0.659	1 (0.71); 3 (0.16); 8 (0.13)		0.90	8 (1)
15		0.963	1 (0.12); 3 (0.85); 8 (0.003)		0.95	3 (1)
16		0.841	1 (0.79); 3 (0.21)		0.98	1 (6.9E−4); 4 (0.99)
17		0.423	1 (0.92); 8 (0.008)		0.65	3 (0.11); 8 (0.89)
18		0.829	3 (0.97); 8 (0.03)		0.97	1 (0.15); 20 (0.85)
19		0.716	3 (0.90); 8 (0.10)		0.56	1 (0.8); 4 (0.007); 8 (0.65)
20		0.998		1	1.00	
21		0.854	1 (0.98); 3 (0.03)		0.66	1 (0.34); 4 (0.26); 6 (0.15); 8 (0.24)
22		0.647	3 (0.66); 8 (0.34)	0	1.00	
23		0.795	1 (0.82); 3 (0.18)		0.71	1 (0.31); 6 (0.50); 8 (0.19)
24	0	1.000			0.89	1 (0.70); 4 (0.13); 6 (0.16)

According to Table 8, DMUs 3 and 1 appeared in reference set 17 and 10 times for conventional and conservation production systems, respectively

Since we are comparing two production systems, it is important to have different frontier for each system. For this reason, farms with similar production systems were compared with each other. According to Table 8, DMUs 3 and 1 appeared in reference set 17 and 10 times for conventional and conservation production systems, respectively. Frequency in reference set shows the times that a specific DMU was used as the best reference by the other DMUs, to optimize the energy consumption of inputs. This result shows that, e.g., in conventional farms, DMU 3 was used 17 times as the best reference by the other DMUs, to optimize the energy consumption of inputs. Reference set column in Table 8 shows that an efficient DMU could be efficient by following some efficient DMUs. For example, in the conservation production system, DMU 5 with the TE of 0.61 can be efficient by following the DMUs 3 and 8. The values in prentices show the intensity vector λ for the respective units.

Current and optimum situations and saving energy

Table 9 shows the current and optimum scenarios for saving energy in different wheat cultivation systems using CCR model. As it can be concluded, the highest saving energy in conventional system belongs to diesel fuel and irrigation inputs and the least amount of energy saving was correlated to human labor input. So, it is crucial to improve the energy consumption of diesel fuel, irrigation, and nitrogen fertilizer inputs in the conventional system. It has been revealed that some of the farmers in the areas investigated in both conventional and conservation systems are producing the same amount of wheat with less-energy consumption in diesel fuel, irrigation, and nitrogen fertilizer inputs. For a conservation system, the highest and the least amount of energy saving belong to nitrogen and human labor, respectively. As Table 9 shows by applying the CCR model, a saving in total energy of 4155 and 3892 MJ ha^{-1} in conventional and conservation systems was achieved, respectively. Since total saving energy in conservation system is less than the conventional system, it can be concluded that energy consumption in conservation system is in a better situation in comparison with the conventional system. The same results were reported by Malana and Malano (2006), where the overuse of irrigation and fertilizer inputs was reported. In wheat production, the fertilizer rate greatly affects both the yield as the numerator of the efficiency index and the total energy usage as the denominator of efficiency index. Thus, efficient wheat production is attained by obtaining an optimum yield under adequate application of nitrogen fertilizer in accordance with crop demand (Brentrup et al. 2004). According to several reports, DEA can be considered a good tool to find the proper amount of input usage in wheat production (Atici and Podinovski 2015; Malana and Malano 2006; Aravindakshan et al. 2015).

Conclusions

Two different planting methods of wheat, namely conventional and conservation were compared with the aspects of the energy audit. Some energy parameters such as energy ratio, energy productivity, specific energy, and net energy for two different cultivation methods were calculated and compared. Results showed the energy parameters in the conservation method were calculated as more effective compared with the conventional method. Also, DEA as a managerial technique was used to calculate and compare DMU efficiencies for two different cultivation systems. For this purpose, technical, purely technical, and scale efficiency for different wheat cultivation scenarios were calculated, and after that, for efficient and non-efficient DMUs, the increase or decrease of outputs or inputs were suggested. Equivalent energy for different inputs was considered to determine the current and optimum situation of energy consumption for two cultivation methods. According to results, the highest saving energy in conventional system belongs to diesel fuel and irrigation inputs, and the

Table 9 Current and optimum situation and saving energy in different wheat cultivation systems

Inputs	Traditional system			Conservation system		
	Current situation (MJ ha^{-1})	Optimum situation (MJ ha^{-1})	Saving energy (MJ ha^{-1})	Current situation (MJ ha^{-1})	Optimum situation (MJ ha^{-1})	Saving energy (MJ ha^{-1})
Machinery	2532	2295	237	1512	1383	129
Diesel fuel	24,003	22,741	1262	9453	9032	422
Labor	236	229	7	113	97	16
Irrigation	15,709	14,652	1057	9031	8089	942
Nitrogen	17,033	16,174	859	12,371	10,040	2331
Biocide	431	336	95	269	226	43
Seed	6209	5570	639	2334	2324	10
Total	66,152	61,996	4155	35,083	31,190	3892

least amount of energy saving was correlated to human labor input. While for the conservation system, the highest and the least amount of energy saving belongs to nitrogen and human labor, respectively. Based on the attained results of energy index analysis, it was concluded that the wheat farms under conservation system have higher energy productivity compared with the farms under conventional system. The implication of the DEA method showed that managing of inputs use in the conventional system is more critical, i.e., the number of farms with lower TE are more and fewer farms are performing efficiently. To sum it up, it is recommended to policy makers and farmers to apply the optimum amounts found in this study in order to achieve higher efficiency rates. Besides, since the DEA results are realistic, i.e., the optimum results are determined from the farms under study, whereas the mathematical programming methods determine the optimized solutions while the efficient (optimum) farms are not compulsorily among the studied farms. Therefore, to illustrate this discrepancy, future work could be conducted by comparing the results of DEA and optimization algorithms.

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References

Afzalinia S, Dehghanian S, Talati MH (2009) Effect of conservation tillage on soil physical properties fuel consumption and wheat yield. In: 4th Conference on Energy Efficiency and Agricultural Engineering, Rousse, Bulgaria

Akcaoz H, Ozcatalbas O, Kizilay H (2009) Analysis of energy use for pomegranate production in Turkey. J Food Agric Environ 7(2):475–480

Alen AD, Zeller M (2005) Technology adoption and farmer efficiency in multiple crops production in eastern Ethiopia: a comparison of parametric and non-parametric distance functions. Agric Econ Rev 6(1):5–17

Aravindakshan S, Rossi FJ, Krupnik TJ (2015) What does benchmarking of wheat farmers practicing conservation tillage in the eastern Indo-Gangetic Plains tell us about energy use efficiency? An application of slack-based data envelopment analysis. Energy 90(1):483–493

ASAE (2003). Agricultural machinery management data D497.4 FEB03. American Society of Agricultural Engineers. ASAE Standards, pp. 373–380

Atici KB, Podinovski VV (2015) Using data envelopment analysis for the assessment of technical efficiency of units with different specialisations: an application to agriculture. Omega 54:72–83

Baležentis T, Kriščiukaitienė I, Baležentis A (2014) A nonparametric analysis of the determinants of family farm efficiency dynamics in Lithuania. Agric Econ 45(5):589–599

Banker RD, Charnes A, Cooper WW (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manag Sci 30(9):1078–1092

Bayramoglu Z, Gundogmus E (2009) The effect of EurepGAP standards on energy input use: a comparative analysis between certified and uncertified greenhouse tomato producers in Turkey. Energy Convers Manag 50:52–56

Bhan S, Behera UK (2014) Conservation agriculture in India problems prospects and policy issues. International Soil and Water Conservation Research 2(4):1–12

Blancard S, Martin E (2014) Energy efficiency measurement in agriculture with imprecise energy content information. Energy Policy 66:198–208

Borin M, Merini C, Sartori L (1997) Effects of tillage systems on energy and carbon balance in North-Eastern Italy. Soil Tillage Res 40(3):209–226

Boubaker K (2012) A review on renewable energy conceptual perspectives in North Africa using a polynomial optimization scheme. Renew Sust Energ Rev 16(6):4298–4302

Brentrup F, Küsters J, Lammel J, Barraclough P, Kuhlmann H (2004) Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology: II. The application to N fertilizer use in winter wheat production systems. Eur J Agron 20:265–279

Charnes A, Cooper WW, Rhodes E (1978) Measuring the efficiency of decision making units. Eur J Oper Res 2(6):429–444

Cooper WW, Seiford LM, Tone K(2006) Introduction to data envelopment analysis and its uses: with DEA-solver software and references. Springer Science & Business Media

Erdal G, Esengün K, Erdal H, Gündüz O (2007) Energy use and economical analysis of sugar beet production in Tokat province of Turkey. Energy 32(1):35–41

Esengun K, Gunduz O, Erdal G (2007) Input–output energy analysis in dry apricot production of Turkey. Energy Convers Manag 48:592–598

Farrell MJ (1957) The measurement of productive efficiency. Journal of the Royal Statistical Society Series A (General) 120(3):253–290

Food and Agriculture Organization (FAO) (2014) FAOSTAT statistics database

Friedrich T, Derpsch R, Kassam A (2012) Overview of the global spread of conservation agriculture. Field actions science reports [Online]. Special issue 6. Online since 06 November 2012, connection on 30 September 2016. URL: http://factsreports.revues.org/1941

Hatirli AS, Ozkan B, Fert C (2006) Energy inputs and crop yield relationship in greenhouse tomato production. Renew Energy 31(4):427–438

Kaltsas AM, Mamolos AP, Tsatsarelis CA, Nanos GD, Kalburtji KL (2007) Energy budget in organic and conventional olive groves. Agric Ecosyst Environ 122:243–251

Keehley P (1997) Benchmarking for best practices in the public sector: achieving performance breakthroughs in federal, state, and local agencies. Jossey-Bass Inc Pub

Kepner RA, Bainer R, Barger BL (1978) Principles of farm machinery. AVI, Inc., USA

Khoshnevisan B, Rafiee S, Omid M, Mousazadeh H (2013) Applying data envelopment analysis approach to improve energy efficiency and reduce GHG (greenhouse gas) emission of wheat production. Energy 58:588–593

Kitani O (1999) CIGR handbook of agricultural engineering. ASAE Publications, St Joseph

Komleh PSH, Omid M, Keyhani A (2011) Study on energy use pattern and efficiency of corn silage in Iran by using data envelopment analysis (DEA) technique. Int J Environ Sci 1(4):1094–1106

Kraatz S (2008) Energy inputs for corn production in Wisconsin and Germany. ASABE Annual International Meeting, Rhode Island

Malana N, Malano HM (2006) Benchmarking productive efficiency of selected wheat areas in Pakistan and India using data envelopment analysis. Irrig Drain 55:383–394

Mardani M, Salarpour M (2015) Measuring technical efficiency of potato production in Iran using robust data envelopment analysis. Information Processing in Agriculture 2(1):6–14

Mardani A, Zavadskas EK, Streimikiene D, Jusoh A, Khoshnoudi M (2017) A comprehensive review of data envelopment analysis (DEA) approach in energy efficiency. Renew Sust Energ Rev 70: 1298–1322

Masuda K (2016) Measuring eco-efficiency of wheat production in Japan: a combined application of life cycle assessment and data envelopment analysis. J Clean Prod 126:373–431

Mohammadi A, Omid M (2010) Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. Appl Energy 87:191–196

Mohammadi A, Tabatabaeefar A, Shahin S, Rafiee S, Keyhani A (2008) Energy use and economical analysis of potato production in Iran a case study: Ardabil province. Energy Convers Manag 49:3566–3570

Mousavi-Avval SH, Rafiee S, Jafari A, Mohammadi A (2011) Optimization of energy consumption for soybean production using data envelopment analysis (DEA) approach. Appl Energy 88(11): 3765–3772

Ozkan B, Kuklu A, Akcaoz H (2004) An input-output energy analysis in greenhouse vegetable production: a case study for Antalya region of Turkey. Biomass Bioenergy 26:89–95

Pervanchon F, Bockstaller C, Girardin P (2002) Assessment of energy use in arable farming systems by means of an agro-ecological indicator: the energy indicator. Agric Syst 72(2):149–172

Pishgar-Komleh SH, Keyhani A, Rafiee S, Sefeedpary P (2011) Energy use and economic analysis of corn silage production under three cultivated area levels in Tehran province of Iran. Energy 36:3335–3341

Pishgar-Komleh SH, Akram A, Keyhani A, Raei M (2017) Variability in the carbon footprint of open-field tomato production in Iran—a case study of Alborz and East-Azerbaijan provinces. J Clean Prod 142: 1510–1517

Rusu T (2001) The influence of minimum soil tillage upon soil, yield and efficiency. PhD thesis, University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Romania

Rusu T (2014) Energy efficiency and soil conservation in conventional, minimum tillage and no-tillage. International Soil and Water Conservation Research 2(4):42–49

Saad AA, Das TK, Rana DS, Sharma AR, Bhattacharyya R, Krishan L (2016) Energy auditing of a maize–wheat–greengram cropping system under conventional and conservation agriculture in irrigated north-western Indo-Gangetic Plains. Energy 116(1):293–305

Safa M, Samarasinghe S, Mohssen M (2011) A field study of energy consumption in wheat production in Canterbury, New Zealand. Energy Convers Manag 52(7):2526–2532

Sarauskis E, Vaiciukevicius E, Romaneckas K, Sakalauskas A, Baranauskaite R (2009) Economic and energetic evaluation of sustainable tillage and cereal sowing technologies in Lithuania. Rural Development 4(1):280–285

Sarıca K, Or I (2007) Efficiency assessment of Turkish power plants using data envelopment analysis. Energy 32(8):1484–1499

Shahan S, Jafari A, Mobli H, Rafiee S, Karimi M (2008) Energy use and economical analysis of wheat production in Iran: a case study from Ardabil province. Journal of Agricultural Technology 4(1):77–88

Singh JM (2002) On farm energy use pattern in different cropping systems in Haryana, India. M.Sc thesis, International Institute of Management, University of Flensburg, Germany

Song M, An Q, Zhang W, Wang Z, Wu J (2012) Environmental efficiency evaluation based on data envelopment analysis: a review. Renew Sust Energ Rev 16(7):4465–4469

Strapatsa AV, Nanos GD, Tsatsarelis CA (2006) Energy flow for integrated apple production in Greece. Agric Ecosyst Environ 116:176–180

Tabatabaeefar A, Emamzadeh H, Ghasemi Varnamkhasti M, Rahimizadeh R, Karimi M (2009) Comparison of energy of tillage systems in wheat production. Energy 34:41–45

Thiam A, Bravo-Ureta BE, Rivas TE (2001) Technical efficiency in developing country agriculture: a meta-analysis. Agric Econ 25(2–3): 235–243

Tipi T, Cetin B, Vardar A (2009) An analysis of energy use and input costs for wheat production in Turkey. J Food Agric Environ 7(2): 352–356

Tzilivakis J, Warner DJ, May M, Lewis KA, Jaggard K (2005) An assessment of the energy inputs and greenhouse gas emission in sugar beet (Beta vulgaris) production in the UK. Agric Syst 85:101–119

Uhlin HE (1998) Why energy productivity is increasing: an I-O analysis of Swedish agriculture. Agric Syst 56(4):443–465

Vlontzos G, Niavis S, Manos B (2014) A DEA approach for estimating the agricultural energy and environmental efficiency of EU countries. Renew Sust Energ Rev 40:91–96

Vural H, Efecan I (2012) An analysis of energy use and input costs for maize production in Turkey. Journal of Food, Agriculture & Environment 10(2):613–616

Wadud A, White B (2000) Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods. Appl Econ 32(13):1665–1673

Wang XB, Cai DX, Hoogmoed WB, Oenema O, Perdok UD (2006) Potential effect of conservation tillage on sustainable land use: a review of global long-term studies. Pedosphere 16(5):587–595

Yildiz T (2016) An input-output energy analysis of wheat production in Carsamba district of Samsun province. Journal of Agricultural Faculty of Gaziosmanpasa University 33(3):10–20

Zhou P, Ang BW, Poh KL (2008) A survey of data envelopment analysis in energy and environmental studies. Eur J Oper Res 189(1):1–18