academicJournals

Vol. 8(46), pp. 5776-5784, 27 November, 2013
DOI: 10.5897/AJAR10.847
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Energy saving of field operations in soybean production using data envelopment analysis approach

Seyed Hashem Mousavi-Avval*, Shahin Rafiee, Ali Jafari and Ali Mohammadi

Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj, Iran.

Accepted 19 November, 2010

In this study, a data envelopment analysis approach was used to determine the efficiency of farmers, rank the efficient and inefficient ones and to identify the wasteful uses of energy by inefficient farmers with respect to energy use in different operations of soybean production in Golestan province, Iran. Data used in this study were obtained from 94 randomly selected soybean farms using a survey method. From this study, the following results were obtained: From total operational energy consumption in soybean production (22235 MJ ha^{-1}), the greatest part was used in irrigation operation (73%); also, harvesting and tillage were the other main energy consumer operations. The technical, pure technical and scale efficiency scores of farmers were found to be 0.88, 0.91 and 0.96, respectively. Total energy requirement in target condition was calculated as 17937.7 MJ ha^{-1}; accordingly, about 19.3% from the total input energy in present condition could be saved if the farmers follow the input package recommended by the study. Energy saving from irrigation (81.8%) had the highest share from total saving energy (4296.8 MJ ha^{-1}). Also, the contributions of tillage, transportation and harvesting operations were found to be 4.7, 4.2 and 3.9%, respectively.

Key words: Operational energy, irrigation operation, energy efficiency, soybean production.

INTRODUCTION

Soybean [*Glycine max* (L.) *Merrill*] is a warm-season oilseed crop originated in Asia and was first introduced to Europe and North America (Caldwell, 1973). Nowadays, it is produced in the largest amounts in the world and is an important staple food for the Orient. It is an annual legume that is primarily produced to be used as food or as a source of edible oil for human consumption (FAO, 2010). On the other hand, its residual meal is used as a supplemental protein source for feeding livestock (Caldwell, 1973). The world's production of soybean was about 99 million tons in 2009. The USA, Brazil and Argentina are the largest soybean producers in the world. Iran produced about 207,000 tons of soybeans from 84,000 ha harvested land area, in 2009 (FAO, 2010). The majority (about 75%) of soybean production in Iran is provided from Golestan province (Anonymous, 2010). Agriculture itself serves a dual role as an energy user, but also energy supplier in the form of bio-energy (FAO, 2010). The size of the population engaged in agricultural sector, the amount of arable land and the level of mechanization are the most important factors on the energy consumption in the agricultural sector (Alam et al., 2005). In current years, considerable studies have been the cash flow generated by the investment. To evaluate

*Corresponding author. E-mail: sh.mousavi@ut.ac.ir. Tel: (+98) 2612801011.

suitable investment possibilities, an investor-farmer needs to take into account the value of keeping options conducted on energy use in agricultural production (Kallivroussis et al., 2002; Karkacier and Goktolga, 2005; Pokharel, 2007). On the other hand, Data Envelopment Analysis (DEA) is a nonparametric technique used to treat problems of multiple inputs and outputs associated with multiple decision making units (DMUs). This technique was introduced in 1978 by Charnes et al. (1978), developing Farrell (1957) idea of estimating technical efficiency relation to production frontier.

In current years, the most popular approach employs non-parametric techniques such as DEA; the main advantages of non-parametric method of DEA compared to parametric ones is that it does not require any prior assumptions on the underlying functional relationships between inputs and outputs. Moreover, in DEA analysis, the results are presented clearly (efficiency scores as a percentage of the maximum sample efficiency); so it is possible to simply compare efficient DMUs with inefficient ones (Zhou et al., 2008; Lygnerud and Peltola-Ojala, 2010). Several authors have employed DEA method for evaluating the performances of DMUs in different issues (Barnes, 2006; Zhou et al., 2008; Bozoglu and Ceyhan, 2009; Kilic et al., 2009). Also in recent years, many authors applied DEA in agricultural enterprises. In an earlier study, Fraser and Cordina (1999) applied DEA to evaluate the technical efficiency of input use for irrigated dairy farms in Australia. They reported that DEA was a useful tool in helping to benchmark the dairy industry, which is continually striving to improve the productive efficiency of farms. Subsequently, Reig-Martínez and Picazo-Tadeo (2004) used DEA to investigate the efficiency of individual farmers and to identify the efficient units in citrus production in Spain. In another study, the technique was applied to benchmark the productive efficiency of irrigated wheat area in Pakistan and India, based on three inputs: irrigation (m^3 ha^{-1}), seed (kg ha^{-1}) and fertilizer use (kg ha^{-1}) (Malana and Malano, 2006).

Nassiri and Singh (2009) applied the DEA technique to the data of energy use for paddy production in India. They used human, diesel, seed, chemicals, fertilizers and machinery energy as inputs and the paddy yield as output. The energy usage analysis in terms of crop production operations provides a closer insight into the pathways to reduce energy inputs by targeting improvements in specific production operations for agricultural crops (Khan et al., 2009). Energy input in various operations can be considered separately for a DEA type study. Such a study will help to pinpoint more precisely the agricultural practices at the operation level that make a farmer efficient (Chauhan et al., 2006). With considering the literature, there was no study on saving energy of farming practices for soybean production in Iran. Therefore, the purpose of this research is to analyze the efficiency of farmers, discriminate efficient farmers from inefficient ones and to identify wasteful uses of energy in different operations for soybean production.

MATERIALS AND METHODS

Golestan province is situated in the north-east of Iran, within 36° 30' and 38° 08' north latitude and 53° 57' and 56° 22' east longitude. The data for this study were taken from 94 soybean producers in Golestan province. A survey approach was used to collect quantitative information about soybean production in the region. The simple random sampling method was used to determine the survey volume. The formula is as follows (Mobtaker et al., 2010):

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

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

The selected farmers were predominantly soybean producing and have a similar topography, soil type and irrigation environment. The data were included the amount of all direct and indirect energy inputs used in different operations and soybean yield as well as socio-economic structures of farms. The inputs were machinery, diesel fuel, electricity, human labour and land; while, the output was considered as the soybean grain yield. The energy equivalent of operation wise human labour, electricity and diesel fuel inputs were estimated by multiplying the quantity of each input by its coefficient of energy equivalent. The energy coefficient of human labour was considered as 1.96 (MJ h^{-1}), as used by several authors (Mohammadi et al., 2008; Rafiee et al., 2010). For calculating the energy equivalents of agricultural machinery, the coefficient of 93.61 (MJ kg^{-1}) for tractors (Hetz, 1992), 87.63 (MJ kg^{-1}) for self propelled combines (Hetz, 1992) and 62.70 (MJ kg^{-1}) for other agricultural machinery (Canakci and Akinci, 2006) were used. Also, the coefficients of 47.80 (MJ L^{-1}) and 11.93 (MJ kWh^{-1}) were used to calculate the energy equivalent of diesel fuel and electricity, respectively; the energy equivalent of soybean yield was considered as 25 MJ ha^{-1} (Hatirli et al., 2005). This study analyzes the efficiency of soybean producers using DEA approach. So, the energy inputs for different practices, including tillage, sowing, irrigation, weeding, fertilizer and chemical application (that is, spraying and fertilizer spreading), harvesting and transportation (MJ per farm) and the land area (ha) were defined as input variables, and the soybean grain obtained (kg) was defined as output; also each farmer called a DMU.

In order to analyze the efficiency of farmers, a non-parametric method of DEA was used. In DEA method, an inefficient unit can be made efficient either by reducing the input level while the output is fixed (input oriented), or by reducing the output level while input is fixed (output oriented). In this study, the input oriented approach was deemed to be more appropriate because there was only one output while multiple inputs were used; also as a recommendation, input conservation for the given outputs seems to be a reasonable logic (Zhou et al., 2008). Therefore, the production yield is fixed and the quantity of source wise energy inputs can be optimized. In order to separate efficient farmers from inefficient ones, arrange them, and to specify the efficiency score of individual farmers, the technical, pure technical and scale efficiency indices were investigated (Nassiri and Singh, 2009).

Technical efficiency

Technical efficiency is basically a measure by which DMUs are evaluated for their performance relative to other DMUs in a sample; it is also called global efficiency which can be expressed as follows (Cooper et al., 2004):

$$TE_j = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \quad (2)$$

Where TE_j is the technical efficiency of the DMU under consideration, x and y denote 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 j^{th} DMUs (j = 1, 2, . . ., k).

Equation 2 is a fractional problem, so it can be translated into a linear programming problem which is introduced by Charnes et al. (1978):

Maximize $\theta = \sum_{r=1}^{n} u_r y_{ri}$

Subjected to

(i) $\sum_{s=1}^{m} v_s x_{si} = 1$, i = 1, 2, . . ., k (3)

(ii) $\sum_{r=1}^{n} u_r y_{rj} - \sum_{s=1}^{m} v_s x_{sj} \leq 0$

(iii) $u_r \geq 0$, r = 1, 2, . . ., n

(iiii) $v_s \geq 0$, s= 1, 2, . . ., m

Where θ is the technical efficiency.

Model 3 is known as the input-oriented CCR DEA modal which attempts to proportionally contract DMUs inputs as possible while not decreasing its current level of outputs. So, the value of technical efficiency approaches to the maximum level.

Pure technical efficiency

The CCR model comprehends both technical and scale efficiencies. So in 1984, Banker, Charnes and Cooper developed a model in DEA, which was called BCC model to calculate the technical efficiency of DMUs, called pure technical efficiency or local efficiency. In an input-oriented framework, the BCC model can be discribed by a dual linear programming problem as follows (Banker et al., 1984):

Maximize $z = uy_i - u_i$

Subjected to

(i) $vx_i = 1$ (4)

(ii) $-vX + uY - u_o e \leq 0$

(iii) $v \geq 0$, $u \geq 0$ and u_o is unconstrained in sign.

Where z and u_0 are scalar and free in sign, u and v are output and inputs weight matrixes, and Y and X are corresponding output and input matrixes, respectively. The letters x_i and y_i refer to the inputs and output of i^{th} DMU.

Scale efficiency

Pure technical efficiency is the technical efficiency that the effect of scale efficiency has been removed. So the scale efficiency can be calculated by the relation between efficiencies derived from the aforrementioned as (Nassiri and Singh, 2009):

Technical efficiency = scale efficiency × pure technical efficiency (5)

Scale efficiency gives quantitative information of scale characteristics. It is the potential productivity gained from achieving optimum size of a DMU. However, scale inefficiency can be due to the existence of either increasing or decreasing returns to scale. The conventional DEA results separate the DMUs into two sets of those that are efficient and locate on the frontier line and those that are inefficient and locate below the frontier line; so many units are specified as efficient and can not to be ranked. In order to rank all the DMUs, discrimination among the efficient farmers is necessary, because in DEA, it is possible that some of the efficient units be better overall performers than the other efficient ones. This is because of the unrestricted weight flexibility problem in DEA. A number of methods are in use to enhance the discriminating capacity of DEA (Adler et al., 2002). In this study, the benchmarking method was applied to overcome this problem. In this method, an efficient unit which is chosen as a useful target for many inefficient DMUs, and so appears frequently in the referent sets, is highly ranked. Each set is formed by the efficient DMUs that are similar to the input and output levels of inefficient DMUs (Lygnerud and Peltola-Ojala, 2010). This approach was also used by Malana and Malano (2006) in a study for ranking the efficient and inefficient wheat producers in selected areas of Pakistan and India.

In the analysis of efficient and inefficient DMUs, the energy saving target ratio (ESTR) index can be used which represents the inefficiency level for each DMUs with respect to energy use. The formula is as follows (Hu and Kao, 2007):

$$ESTR_j = \frac{(\text{Energy saving target})_j}{(\text{Actual energy input})_i} \quad (6)$$

Where energy saving target is the total reducing amount of input that could be saved without decreasing output level and j represents j^{th} DMU.

Since the actual operation can be improved to the best operation, the actual energy input is always larger than or equal to the optimum energy input. The minimal value of energy saving target is zero, so the value of ESTR will be between zero and unity. A zero ESTR value indicates the DMU on the frontier such as efficient ones. On the other hand, for inefficient DMUs, the value of ESTR is larger than zero, indicating that energy can be saved. A higher ESTR value implies higher energy inefficiency and a higher energy saving amount (Hu and Kao, 2007).

RESULTS AND DISCUSSION

Average farm size of selected soybean producers was calculated as 5.17 ha. In general, the farmers grow more than one crop in a growing season. Wheat, paddy, canola and sunflower were other crops grown besides soybean.

Table 1. Amounts of operational energy inputs, outputs and their energy equivalents in soybean production.

Item (unit)	Quantity per unit area (ha)	Total energy equivalent (MJ ha^{-1})
Inputs		
Tillage		1565.5
Human labour (h)	11.3	22.2
Machinery (h)	3.6	148.1
Diesel fuel (L)	29.2	1395.2
Sowing		449.8
Human labour (h)	1.2	2.4
Machinery (h)	1.2	74.2
Diesel fuel (L)	7.8	373.2
Irrigation		16200.0
Human labour (h)	54.2	106.2
Diesel fuel (L)	3.3	155.8
Electricity (kWh)	1335.9	15938.0
Weeding		96.8
Human labour (h)	49.4	96.8
Fertilizer and chemical application		1217.8
Human labour (h)	31.9	62.5
Machinery (h)	4.3	207.7
Diesel fuel (L)	19.8	947.6
Harvesting		1811.3
Human labour (h)	31.6	62.0
Machinery (h)	1.5	388.1
Diesel fuel (L)	28.5	1361.2
Transportation		893.8
Human labour (h)	10.9	21.5
Machinery (h)	3.8	152.8
Diesel fuel (L)	15.0	719.5
Total		22235.0
Output		
Grain yield (kg)	3233.1	

100% of total land in each farm was irrigated. Land and machinery, with respect, in the 94 and 56% of selected farms were owned; while, in 6 and 44% of farms they were rental. The farmers mainly used trailer and tractor to transport the inputs to/from the farms. Table 1 shows the inputs used for different field operations, the output and their energy equivalents for soybean production in the area of survey. The results revealed that, energy consumption in irrigation operation (16200 MJ ha^{-1}) was the highest; from which the electricity energy input had the greatest share, followed by diesel fuel and human labour, respectively. Singh et al. (1990) investigated the energy consumption for paddy-wheat rotation in Punjab; they reported that irrigation consumed the maximum share of energy in all the farm operations for both paddy (81.9%) and wheat (38.1%) productions. The energy consumption for harvesting and tillage practices was found to be 1811.3 and 1565.5 MJ ha^{-1}. The fertilizer and chemical application operation in soybean production consumed 1217.8 MJ ha^{-1}. It was mainly used in spraying practice. Energy consumption for weeding operation was found to be the lowest; it was due to the lack in use of machinery and diesel fuel in these practices. Table 2 presents the descriptive statistics of the variables used in the analysis.

A wide variation in both the input use and the output is noticeable. Such a variation in the levels of inputs being used is mainly due to the variation in the land area; moreover, it represents a mismanagement of resource usage between the farmers, indicating that there is a

Table 2. Descriptive statistics of input and output variables for soybean production in Golestan, Iran.

Variable (MJ)	Average	SD	Maximum	Minimum
Inputs				
Tillage	8087.3	5680.3	57683.4	375.3
Sowing	2323.6	1275.6	9593.2	132.6
Irrigation	83687.2	52280.0	204372.8	117.7
Weeding	500.0	373.1	3511.9	24.7
Fertilizer and chemical application	6291.2	3995.4	72340.2	28.6
Harvesting	9356.8	6060.7	55404.5	300.4
Transportation	4616.4	3465.5	20664.7	141.2
Land area (ha)	5.17	6.12	30.24	0.52
Output				
Yield (kg)	182731.4	19201.2	99000.0	1800.0

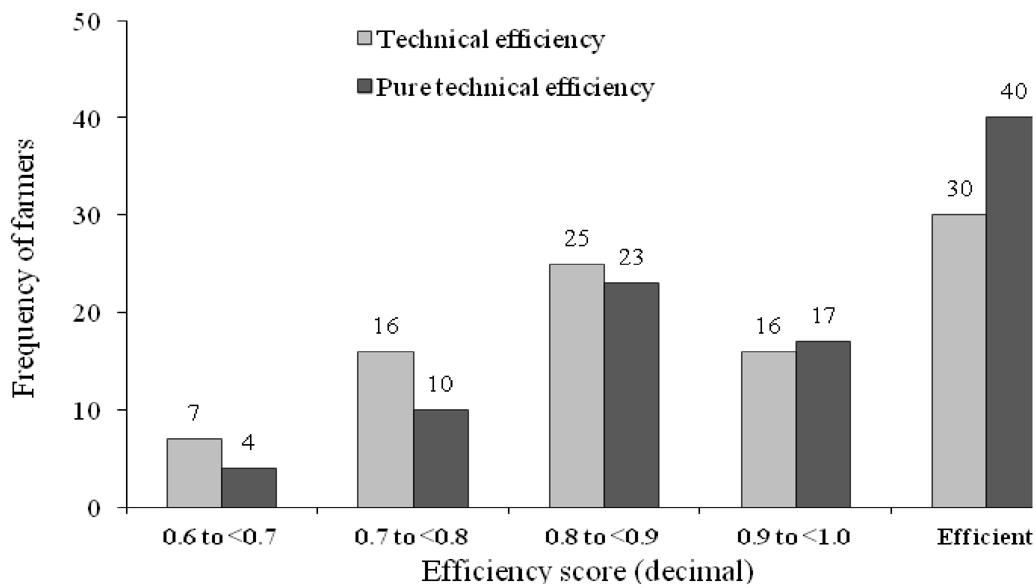

Figure 1. Efficiency scores distribution of farmers.

great scope for improving the efficiency of energy consumption in farming practices for soybean production. For investigating the efficiency scores of farmers, both the constant and variable returns to scale models were estimated for the inputs and output. As can be seen in Figure 1, the results revealed that from the total of 94 farmers considered for the analysis, 30 ones (32%) and 40 ones (43%) were recognized as technically and pure technically efficient farmers, respectively; so, they have no reduction potential on operational energy use. From these efficient farmers, 30 ones were the fully efficient farmers in both the technical and pure technical efficiency scores, indicating that they were globally efficient and operated at the most productive scale size of farm but the reminder of 10 efficient farmers were only locally not globally efficient; implying that, they confront with disadvantagiouse conditions of scale size of the farms; however, they moved toward the BCC efficient frontier when the effect of scale size was omited.

On the other hand, from inefficient farmers 16 and 17 ones, with respect, had their technical and pure technical efficiency scores in the 0.9 to 0.99 range. This means that the farmers should be able to produce the same level of output using the efficiency score of their current level of energy input when compared to their benchmark which are constructed from the best performers with similar characteristics. Moreover, 25 farmers and 23 ones had their technical and pure technical efficiency scores at 0.8 to 0.9 ranges, respectively; which was the major contribution from inefficient farmers in both the results of

Table 3. Average efficiencies of the farmers

Technical efficiency	0.88	0.11	0.62	1
Pure technical efficiency	0.91	0.10	0.64	1
Scale efficiency	0.96	0.06	0.69	1

Table 4. Ranking 10 truly most efficient farmers based on the results of BCC model.

Benchmark ranking	Farmer no.	Times references
1	84	36
2	41	27
3	25	24
4	7	20
5	22	17
6	31	16
7	32	15
8	6	13
9	47	12
10	83	9

CCR and BCC models. The summarized statistics for the three estimated measures of efficiency based on the results of the models (3), (4) and Equation 5 are presented in Table 3. The results revealed that technical, pure technical and scale efficiency scores were found to be 0.88, 0.91 and 0.96, respectively. Also, the technical efficiency varied from 0.62 to 1, with the standard deviation of 0.11, which was greater than that of pure technical and scale efficiencies. The high variation in the technical efficiency of farmers indicated that all the farmers were not fully aware of the right production techniques or did not apply them at the proper time in the optimum quantity.

Chauhan et al. (2006) investigated the optimization of energy input for paddy production in India. They reported that the technical, pure technical and scale efficiency scores were 0.92, 0.83 and 0.77, respectively. In order to provide an overall assessment of the performances of all farmers, the efficient farmers were ranked on the basis of counting the number of times they appear in the referent sets. Considering the results obtained by the study, DMUs 84, 41, 25, 7 and 22 appear 36, 27, 24, 20 and 17 times in the referent set, respectively (Table 4). Those efficient DMUs that appear more frequently in the referent set of inefficient DMUs, are considered superior because they are not only efficient but are also close to input–output levels of inefficient DMUs in the sample. The results for 10 most truly efficient farmers are shown in Table 4. By considering these farmers as the benchmarks, inefficient farmers are capable to determine which changes in resource usage are necessary in order to establish the best practice management and improve their performance, from an energy use efficiency point of view. The energy use pattern in different practices, land area and yield obtained by truly efficient farmers and inefficient farmers is compared in Table 5. It is clear that, the use of human labour by efficient farmers in tillage, irrigation and fertilizer and chemical application was higher than that of inefficient ones; however, the inefficient farmers used higher amounts of machinery, diesel fuel and electricity. The higher use of electricity was mainly due to the excessive use of water in irrigation operation. The mean land area was calculated as 5.5 and 6.3 ha for the most efficient and inefficient farmers, respectively. On the other hand, the soybean yield obtained by inefficient farmers was found to be 23.5% lower than that of the most efficient farmers. To sum up, the results clearly indicate that inefficient farmers did not use the resources efficiently.

The improper use of machinery and groundwater in agricultural practices may result in land quality degradation such as soil erosion, compaction, salinization and reduction of organic matter. The high water input in soybean farms may exacerbate the problem of soil drainage and excessive leaching of water to shallow groundwater aquifers which may impact groundwater table and soil salinity dynamics (Khan et al., 2009). Also, soil compaction may be caused by the repetitive and cumulative effect of heavy machinery, resulting in reduction of soil porosity and root penetration and alters the biological activity on the farm scale. On the watershed scale, soil compaction increases surface

Table 5. Quantities of inputs and output per hectare and land area for efficient and inefficient farmers.

Item (unit)	10 truly most efficient farmers (A)	Inefficient farmers (B)	Difference (B-A)*100/B
Inputs			
Tillage			
Human labour (h)	12.2	10.5	-16.2
Machinery (h)	3.4	3.7	8.1
Diesel fuel (L)	26.5	31.3	15.3
Sowing			
Human labour (h)	1.1	1.3	15.4
Machinery (h)	1.1	1.3	15.4
Diesel fuel (L)	6.6	8.6	23.3
Irrigation			
Human labour (h)	70.6	50.2	-40.6
Diesel fuel (L)	3.4	3.5	2.9
Electricity (kWh)	1132.0	1503.0	24.7
Weeding			
Human labour (h)	42.2	52.3	19.3
Fertilizer and chemical application			
Human labour (h)	34.8	32.5	-7.1
Machinery (h)	3.7	4.8	22.9
Diesel fuel (L)	17.6	21.9	19.6
Harvesting			
Human labour (h)	21.5	31.8	32.4
Machinery (h)	1.0	1.6	37.5
Diesel fuel (L)	23.3	30.1	22.6
Transportation			
Human labour (h)	11.0	12.2	9.8
Machinery (h)	3.2	4.7	31.9
Diesel fuel (L)	12.4	18.8	34.0
Land area (ha)	7.3	5.1	-43.1
Total			
Human labour (h)	193.0	191.0	-1.0
Machinery (h)	12.4	16.3	23.9
Diesel fuel (L)	89.8	114.0	21.2
Electricity (kWh)	1132.0	1503.0	24.7
Land area (ha)	5.5	6.3	12.7
Output			
Grain yield (kg)	3940.0	3190.0	-23.5

runoff and water erosion, loss of topsoil and nutrients, and non-point source pollution of water resources (Zalidis et al., 2002). Introduction of conservation agriculture technologies, also, effective use of machinery and irrigation water in crop production operations may be the pathways to enhance the food security and reduce their environmental footprints. The results of optimization of energy input for different practices are tabulated in Table 6. In this table the present energy use, target energy requirement, saving energy and ESTR percentage are presented. The results revealed that from different practices, a total energy of 22234.5 MJ ha^{-1} was consumed for soybean production in present condition; while total energy requirement in target condition was found to be 17937.7 MJ ha^{-1}; from which the major contribution was required for irrigation practices (12678.8

Table 6. Present, target and savings of operational energy for soybean production in Golestan, Iran.

Input	Present quantity (MJ ha^{-1})	Target quantity (MJ ha^{-1})	Saving (MJ ha^{-1})	ESTR (%)
Tillage	1565.5	1364.7	200.8	12.8
Sowing	449.8	394.0	55.8	12.4
Irrigation	16199.8	12678.8	3521.0	21.7
Weeding	96.8	82.1	14.7	15.2
Fertilizer and chemical application	1217.8	1060.3	157.5	12.9
Harvesting	1811.2	1645.0	166.2	9.2
Transportation	893.6	712.9	180.7	20.2
Total	22234.5	17937.7	4296.8	19.3

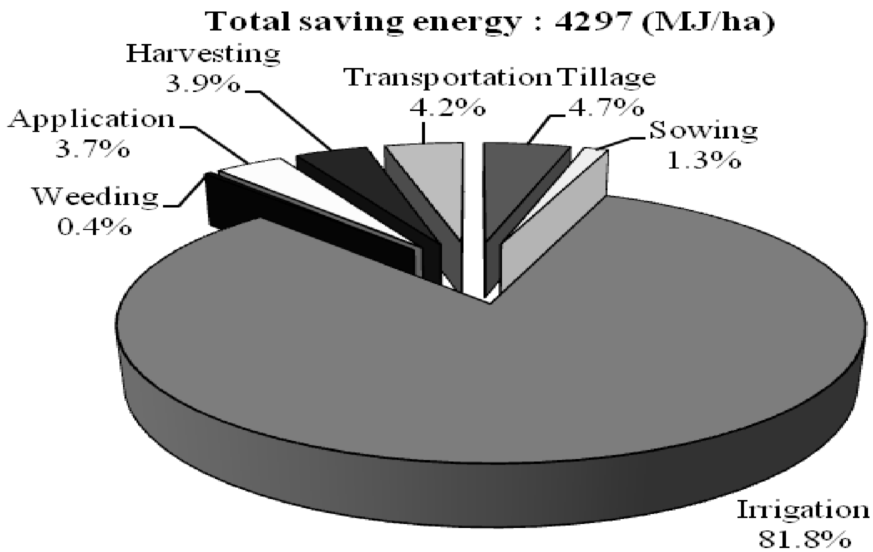

Figure 2. Distribution of saving energy for each operation.

MJ ha^{-1}), followed by harvesting (1645 MJ ha^{-1}).

Utilization of new irrigation systems, increasing the water pumping systems efficiency or technological upgrade to reduce fossil-fuel inputs by substitution with renewable energy such as biogas and solar energy or using machines running on hybrid fuels could be a pathway to make machinery use more environmental friendly and thus reduce its environmental footprints. Also, good maintenance of combine harvesters and introducing of suitable headers for combines in the area may help to save more energy in the region. Apart from irrigation and harvesting operations, the operational energy in tillage, fertilizer and chemical application, transportation and sowing operations was required as 1364.7, 1060.3, 712.9 and 394 MJ ha^{-1}, respectively; while, the target energy requirement for weeding practices was the lowest. Moreover, the average land area in optimum condition was found to be 5.16 ha. The total saving energy was calculated as 4296.8 MJ ha^{-1}; which consisted of 19.3% from actual energy use for soybean production operations (Table 6). Furthermore, the results revealed that, the energy consumption for transportation, irrigation, weeding, fertilizer and chemical application and tillage practices can be saved as 20.2, 21.7, 15.2, 12.9 and 12.8%, respectively. Figure 2 shows the potential improvement of energy consumption from different operations. The results revealed that from the total saving energy, the share of irrigation energy (81.8%) was the highest; indicating that there is a great scope for saving energy by improving the energy use in irrigation operation. It followed by tillage (4.7%), transportation (4.2%) and harvesting practices (3.9%), respectively. On the other hand, the contribution of weeding saved energy was found to be the lowest.

Conclusions

In this study, the performance of 94 farmers with respect to energy consumption in field practices for soybean production in Golestan province of Iran was investigated. For this purpose, an input-oriented DEA model has been applied. Based on the results of the study, the following conclusions may be drawn:

(1) The methodology presented in this paper demonstrates how farmers may benefit from applying operational management tools to assess their performance. Given that inefficiency variation among the studied farms was large, we investigated whether efficient soybean farms share certain common characteristics in terms of management practices.
(2) Total target energy requirement was obtained about 17938 MJ ha^{-1}; on average, the total input energy could be reduced by 19.3% without reducing the grain yield from its present level by adopting the recommendations based on the present study.
(3) Irrigation and harvesting were the operations with the highest energy demands in target conditions. More energy saving may be achieved by increasing the water pumping systems efficiency or replacing with alternative sources of energy such as biogas and solar energy, and also, good maintenance of harvester combines and introducing of suitable headers for combines in the area.
4) The use of machinery, diesel fuel and electricity energy was found to be higher for inefficient farmers for all the practices, resulting in soil quality degradation and risk on the environment and human health. Therefore, investments are needed in new technologies and farming practices that would boost energy and water use efficiency without impacting the environment.

REFERENCES

Adler N, Friedman L, Sinuany-Stern Z (2002). Review of ranking methods in the data envelopment analysis context. Eur. J. Oper. Res. 140:249-265.

Alam MS, Alam MR, Islam KK (2005). Energy Flow in Agriculture: Bangladesh. Am. J. Environ. Sci. 1:213-220.

Anonymous (2010). Annual agricultural statistics. Ministry of Jihad-e-Agriculture of Iran. www.maj.ir.

Banker R, Charnes A, Cooper W (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manag. Sci. 30:1078-1092.

Barnes AP (2006). Does multi-functionality affect technical efficiency? A non-parametric analysis of the Scottish dairy industry. J. Environ. Manag. 80:287-294.

Bozoglu M, Ceyhan V (2009). Energy conversion efficiency of trout and sea bass production in the Black Sea, Turkey. Energy 34:199-204.

Caldwell BE (1973). Soybeans: Improvement, production, and uses. Agronomy Monograph16. ASA, CSSA, SSSA, Madison, WI.

Canakci A, Akinci I (2006). Energy use pattern analyses of greenhouse vegetable production. Energy 31:1243-1256.

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

Chauhan NS, Mohapatra PKJ, Pandey KP (2006). Improving energy productivity in paddy production through benchmarking--An application of data envelopment analysis. Energy Convers. Manag. 47:1063-1085.

Cooper W, Seiford LM, Tone K (2004). Data Envelopment Analysis, A comprehensive text with models, applications, references and DEA-solver software. Massachusetts, USA: Kluwer Academic Publishers.

FAO (2010). Food and Agricultural Organization. www.fao.org.

Farrell MJ (1957). The measurement of productive efficiency. J. Royal Stat. Soc. 120:253-281.

Fraser I, Cordina D (1999). An application of data envelopment analysis to irrigated dairy farms in Northern Victoria, Australia. Agric. Syst. 59:267-282.

Hatirli SA, Ozkan B, Fert C (2005). An econometric analysis of energy input-output in Turkish agriculture. Renewable and Sustain. Energy Rev. 9:608-623.

Hetz E (1992). Energy utilization in Chilean agriculture. Agric. Mech. Asia Afr. Latin Am. (AMA) 23:52-56.

Hu JL, Kao CH (2007). Efficient energy-saving targets for APEC economies Energy Policy 35:373-382.

Kallivroussis L, Natsis A, Papadakis G (2002). The energy balance of sunflower production for biodiesel in Greece. Biosyst. Eng. 81:347-354.

Karkacier O, Goktolga ZG (2005). Input-output analysis of energy use in agriculture. Energy Convers. Manag. 46:1513-1521.

Khan S, Khan MA, Hanjra MA, Mu J (2009). Pathways to reduce the environmental footprints of water and energy inputs in food production. Food Policy 34:141-149.

Kilic O, Binici T, Zulauf CR (2009). Assessing the efficiency of hazelnut production. Afr. J. Agric. Res. 4:695-700.

Lygnerud K, Peltola-Ojala P (2010). Factors impacting district heating companies' decision to provide small house customers with heat. Appl. Energy 87:185-190.

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

Mobtaker HG, Keyhani A, Mohammadi A, Rafiee S, Akram A (2010). Sensitivity analysis of energy inputs for barley production in Hamedan Province of Iran. Agric. Ecosyst. Environ. 137:367-372.

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.

Nassiri SM, Singh S (2009). Study on energy use efficiency for paddy crop using data envelopment analysis (DEA) technique. Appl. Energy 86:1320-1325.

Pokharel S (2007). An econometric analysis of energy consumption in Nepal. Energy Policy 35:350-361.

Rafiee S, Mousavi Avval SH, Mohammadi A (2010). Modeling and sensitivity analysis of energy inputs for apple production in Iran. Energy 35:3301-3306.

Reig-Martínez E, Picazo-Tadeo AJ (2004). Analysing farming systems with Data Envelopment Analysis: citrus farming in Spain. Agric. Syst. 82:17-30.

Singh S, Singh MP, Bakhshi R (1990). Unit energy consumption for paddy-wheat rotation. Energy Convers. Manag. 30:121-125.

Zalidis G, Stamatiadis S, Takavakoglou V, Eskridge K, Misopolinos N (2002). Impacts of agricultural practices on soil and water quality in the Mediterranean region and proposed assessment methodology. Agric. Ecosyst. Environ. 88:137-146.

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