Optimization of energy consumption for sunflower production using data envelopment analysis approach

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Abstract

Aim: To determine the energy efficiency of farmers, to find efficient and inefficient ones and to identify the wasteful use of energy in sunflower production. Moreover, the degrees of technical and scale efficiency of producers were investigated.

Methodology: Data used in this study were collected using face-to-face surveys from 113 sunflower farms in Aksaray in Central Anatolian Region, one of the most important center of sunflower production in Turkey. Data Envelopment Analysis approach was used to analyze the energy efficiency of farmers

Results: The average yield and energy consumption for sunflower production was 2124.4 kg ha⁻¹ and 13517.45 MJ ha⁻¹, respectively. In addition, the results of DEA application showed that the technical, pure technical and scale efficiencies of farmers were 0.82, 0.97 and 0.84, respectively.

Interpretation: Energy saving target ratio for sunflower production was calculated as 4.18%, indicating that by following the recommendations resulted from this study, about 564.54 MJ ha⁻¹ of total input energy could be saved while holding the constant level of sunflower yield. Also, the highest contribution to total energy saving was made by chemical fertilizers with 42.58% of total saving, followed by diesel fuel (20.13%), machinery (19.33%) and chemicals (13.74%).

Key words: Data envelopment analysis, Energy efficiency, Scale efficiency, Sunflower production

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Introduction

Sunflower (*Helianthus annuus L.*) is mainly grown for oil production, confectionery industry, other human consumptions and animal feed because of its rich protein and oil content. Central Anatolia and Thrace regions are the most important regions of sunflower production in Turkey. Over 76.4% of sunflower production in the country is provided from these regions (TSI, 2013).

One of the most basic requirements to achieve the economic and social development of a country or region is energy. Energy usage policies and planning strategies need analysis and scientific forecasts of energy consumption (Liang *et al.*, 2007). With increase in the world population, agriculture consumes more energy in order to supply more food and provide balanced and enough nutrition (Samavatean *et al.*, 2011). Therefore, analysis of energy consumption in agriculture as well as other sectors is important. On the other hand, high energy consumption in agriculture and decrease of current energy resources have shown up the importance of energy consumption at optimum level. Latter leads to an increase in the production, reduces the environmental impacts of excessive input usage and contributes towards the economy, profitability, developing of agricultural sustainability in the rural areas (FAO, 2008). In view of this, determination of optimum energy consumption together with energy analyses are needed. Providing optimum energy usage in the agricultural production is a way to achieve the energy efficiency. Efficiency is defined as capability of producing the current production with minimum quantity of resource. Improving energy efficiency also contributes in overcoming climate change impacts and the emissions (Varone and Aebischer, 2001). Therefore, effective use of energy in agriculture is good for a sustainable production, by decreasing use of fossil resources, financial savings, reduction in air pollution (Uhlir, 1998).

Improvement in the energy productivity is a key to sustainable energy management. For enhanced of energy efficiency attempt should be made to increase the production yield or to conserve the energy input without affecting the output (Singh *et al.*, 2004; Shahi *et al.*, 2019). Therefore, energy saving has been a crucial issue for sustainable development in agricultural systems.

There are several parametric and non-parametric techniques to measure the efficiency in agricultural productions. In some studies, the econometric approach has been used to identify the relationship between energy consumption from different inputs and yield values of crop production (Mobtaker *et al.*, 2010; Rafiee *et al.*, 2010). On the other hand, Data Envelopment Analysis (DEA) a non-parametric technique based linear programming to estimate the production frontier, has been used in several studies to improve energy efficiency.

In recent decades, many studies have been carried out to improve the energy use efficiency in agricultural production. Singh *et al.* (2004) investigated improved energy usage efficiency for wheat production in Punjab. They found that total energy consumption could be saved ranging from 7.1 to 22.3% in different zones. Chauhan *et al.* (2006) applied DEA approach to improve the energy consumption efficiencies of paddy farms in India. Their results have revealed that about 11.6% of the total input energy could be saved. Mousavi Avval *et al.* (2011) and Mousavi-Avval *et al.* (2011a, 2011b, 2011c;) employed DEA technique to perform and rank the productivity performance of sunflower, canola, soybean and apple based on the amount of various energy inputs and output values. Results of previous studies on sunflower, canola, soybean and apple products have revealed that 10.8, 9.5, 20.1 and 11.3% of total input energy can be saved. In another study carried out by Mousavi-Avval *et al.* (2012), DEA technique was subjected to the data of energy use for different barberry production systems; the technical efficiency of farmers in different farm sizes was also analyzed. Mobtaker *et al.* (2012) have investigated optimization of alfalfa production in India. Similarly, Gündüz (2015) applied fuzzy DEA technique to determine the efficiency of farms producing dry apricot in Turkey. The results have revealed that the boundaries of efficiency scores of farms change from 0.899 to 0.909. Further, studies on optimization of energy consumption for sunflower production in Turkey in meagre. Therefore, this study was carried out to specify energy use pattern for sunflower production, analyze technical, pure technical and scale efficiency of farmers, discriminate efficient farmers from inefficient ones and to identify the wasteful use of energy, in order to optimize the energy inputs for sunflower production in Aksaray province of Turkey.

Materials and Methods

Data collection : The data used in this study were collected through semi-structured questionnaires/interviewes (Bargali *et al.*, 2007; Parihaar *et al.*, 2015; Padalia *et al.*, 2017) from 113 sample sunflower farms in Aksaray Province of Central Anatolian Region. The sample size was determined by Simple Random Sampling method (Çiçek and Erkan, 1996):

$$n = \frac{N \cdot S^2}{(N - 1) S^2 + S^2} \quad (1)$$

where, n= Required sample size; N= Total number of sunflower farms in the population; S=Standard deviation; $S_x = (d/z)$; d= Acceptable error in sample size; z= z table value.

Energy balance analysis : Energy equivalents of inputs used in sunflower production as well as outputs are shown in Table 1. Data for these equivalents were obtained from several published results. Mechanical energy utilized by sampled farms was calculated by using total fuel (diesel) consumption by tractors

Table 1 : Energy equivalents of inputs and output in sunflower production

Input/output	Unit	Energy equivalent (MJ unit ⁻¹)	References
A. Inputs			
1. Human labour	h	2.28	(Kallivroussis <i>et al.</i> , 2002)
2. Machinery	h		
a. Tractor		93.61	(Canakci <i>et al.</i> , 2005)
b. Self propelled combine		87.63	(Canakci <i>et al.</i> , 2005)
c. Others		62.7	(Canakci <i>et al.</i> , 2005)
3. Diesel fuel	L	55.6	(Canakci <i>et al.</i> , 2005)
4. Chemicals	kg		
a. Herbicides		171.4	(Kallivroussis <i>et al.</i> , 2002)
5. Fertilizers	kg		
a. Nitrogen		74.2	(Kallivroussis <i>et al.</i> , 2002)
b. Phosphate (P ₂ O ₅)		14.3	(Kallivroussis <i>et al.</i> , 2002)
c. Potassium (K ₂ O ₅)		11.15	(Rafiee <i>et al.</i> , 2010)
6. Water for irrigation	m ³	1.02	(Rafiee <i>et al.</i> , 2010)
7. Seed	kg	26.3	(Kallivroussis <i>et al.</i> , 2002)
B. Output			
1. Sunflower	kg	26.3	(Kallivroussis <i>et al.</i> , 2002)

used in different tasks in farms and then by converting this use with the conversion factor (1 diesel=55.6 MJ ha⁻¹) as provided in Table 1.

Energy ratio (energy use efficiency) and energy productivity were calculated as per the following formula, based on energy equivalents of inputs and outputs (Singh *et al.*, 1997; Mandal *et al.*, 2002):

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

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

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

$$\text{Labor Productivity} = \text{Output Energy (MJ/ha)} / \text{Labor Utilization (hours ha}^{-1}\text{)} \quad (5)$$

Input energy is divided into four parts as direct, indirect, renewable and non-renewable energy (Yilmaz *et al.*, 2005). Direct energy consists of diesel and labor used in sunflower production while indirect energy comprised of energy inherent in seeds, fertilizers and pesticides. Non-renewable energy, on the other hand, composed of diesel, chemical agricultural medications (chemicals) and fertilizers while renewable energy included labour.

Data envelopment analysis : Data Envelopment Analysis (DEA), a non-parametric method, was used in this study to determine technical, pure technical and scale efficiencies of agricultural farms that produce same product (sunflower) using

same inputs and operate in a relatively homogeneous (topographically, by soil type, by climatic conditions, etc.) region. While sunflower yield is the only output variable, input variables are energy consumption of labour, machinery, diesel fuel, chemicals, chemical fertilizers, farm manure, irrigation water, electric and seed inputs. Inefficient decision units may become more efficient in DEA symmetrically either by achieving the same output level by minimum inputs (input-oriented) or by maximizing the level of output using constant amount of inputs (output-oriented). Sunflower production is carried out with scarce and insufficient resources. Therefore, decreasing inputs by applying input-oriented DEA is more preferable.

Energy inputs of sunflower (MJ ha⁻¹) and yield values (kg ha⁻¹) were used to calculate technical, pure technical and scale efficiencies of farms in order to define efficient and inefficient farms.

Technical Efficiency (TE) can be defined as the ability of a decision making unit (DMU) to obtain maximum output from a given input set under available technology. In case of existence of multiple input and output factors, TE score (θ) can be calculated (Cooper *et al.*, 2004):

$$\theta = \frac{u_1 y_{1j} + u_2 y_{2j} + u_3 y_{3j} + \dots + u_s y_{sj}}{v_1 x_{1j} + v_2 x_{2j} + v_3 x_{3j} + \dots + v_m x_{mj}} = \frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \quad (6)$$

In Eq. 6, m represents the number of compared DMU; s is the number of outputs; m represents the number of inputs; u_r ($r=1,2,3,\dots,s$) is the weighing of compared outputs; v_i ($i=1,2,3,\dots,m$) is the weighing of inputs and y_{rj} ; x_{ij} are the values of inputs and outputs, respectively, for the DMU.

The model for measuring relative efficiency of a DMU, depending on n number of DMU, is constructed as a simple programming process (Cooper *et al.*, 2006):

$$\text{Max} : \theta = \frac{\sum_{r=1}^s u_r y_{r0}}{\sum_{i=1}^m v_i x_{i0}} \quad (7)$$

$$\frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \leq 1, j=1, 2, \dots, n \quad u_i \geq 0, v_i \geq 0$$

Eq. 8 can be written as a linear programming process as follows:

$$\text{Max} : \theta = \sum_{r=1}^s u_r y_{r0} \quad (8)$$

$$\sum_{r=1}^s u_r y_{rj} - \sum_{i=1}^m v_i x_{ij} \leq 0, j = 1, 2, \dots, n$$

$$\sum_{i=1}^m v_i x_{i0} = 1$$

$$u_i \geq 0, v_i \geq 0$$

In fact, solution of a dual linear programming problem is simpler than solving Eq. 8 which has fewer limitations. Mathematically, dual linear programming problem is written as (Cooper *et al.*, 2006):

$$\text{Min} = \theta \quad (9)$$

$$Y\lambda \geq y_0$$

$$X\lambda - \theta x_0 \leq 0$$

$$\lambda \geq 0$$

where, y_0 represents $s \times 1$ vector of produced original product value, x_0 is $m \times 1$ vector of original input value used by 0th DMU; Y is the $s \times n$ matrix of the outputs; X is the $m \times n$ matrix of the inputs of n number of DMU included in the sample; λ represents $n \times 1$ vector and θ is a scale between 0 and 1 that defines technical efficiency scores of each DMU. Model 9 is known as input-based CCR DEA model. This model represents constant returns to scale assumption which postulates that a certain amount of increase in input brings about a same amount of increase in the output.

Pure Technical Efficiency (PTE) is obtained from the CCR model which includes both technical and scale efficiency. Hence, Banker *et al.* (1984) developed a DEA model to determine pure technical efficiency of DMU which is known as Banker-Charnes-Cooper (BCC) model. BCC model was constructed by adding a limitation on λ in Model 9 ($\lambda=1$). This model assumes variable returns to scale which means a different proportion of change in output in response to one unit of change in inputs.

Scale Efficiency (SE) is related to the most efficient scales

of farms which operate with the sensitivity of maximizing average yield. It can be calculated as follows:

$$SE = TE/PTE \quad (10)$$

SE gives information on the amount of scale characteristics. It is the potential productivity achieving gained by optimum scale by a DMU. However, scale inefficiency may either stem from the existence of increasing returns to scale (IRS) or decreasing returns to scale (DRS). IRS and DRS can be detected by comparing efficiency scores obtained by BCC models. Therefore, if any two of the efficiency score are equal then DRS is applied; otherwise, IRS preponderates (Chauhan *et al.*, 2006). The information on whether a farmer is at IRS, CRS or DRS status is important since it reflects potential redistribution of resources among farmers and, thus, facilitates production of higher amount of outputs by farmers.

Results and Discussion

Energy balance in sunflower production : Energy equivalents of input and output in sunflower production are given in Table 2. As apparent from Table 2, total energy input for sunflower is 13517.45 MJ ha⁻¹. The highest ratio of contribution to this amount was from chemical fertilizers with 45.29% (6122.43 MJ ha⁻¹), followed by diesel fuel with 34.84% and machine inputs with 6.43%. Chemical fertilizer inputs energy distribution were determined as 82.0% N, 16.7% P and 1.3% K. It was reported that the highest input energy consumption is by N fertilizer (42.4%) followed by diesel fuel (33.9%) in a study conducted by Kallivroussis *et al.* (2002) in Greece on sunflower production. In another study conducted by Mousavi-Avval *et al.* (2011a) in Iran, the highest input energy consumption in sunflower production are reported to be by diesel fuel (42.3%) and chemical fertilizer (24.9%), respectively. Pimentel and Patzek (2005) have also reported similar results. Chemical fertilizers and diesel fuel have been reported as the most intensive energy inputs in studies conducted on other agricultural products (Erdal *et al.*, 2007; Mobtaker *et al.*, 2010). Total output energy in the studied farms was found to be 55872.37 MJ ha⁻¹. This value is similar to the findings of other studies conducted on sunflower production.

Energy balance analysis showed that total energy consumption during sunflower production period was 13517.45 MJ ha⁻¹. Similarly, total input energy for sunflower was determined as 10491 MJ ha⁻¹ in Greece (Kallivroussis *et al.*, 2002) and 9468.5 MJ ha⁻¹ in Iran (Mousavi-Avval *et al.*, 2011a). Total input energy was 14348.9 MJ ha⁻¹ for cotton, 11366.2 MJ ha⁻¹ for corn, 9436.8 MJ ha⁻¹ for rice and 35372.23 MJ ha⁻¹ for soybean production (Canakci *et al.*, 2005; Chauhan *et al.*, 2006; Mousavi-Avval *et al.*, 2011c).

Energy indicators are shown in Table 2. Energy ratio in sunflower was calculated as 4.13. This result was close to the

Table 2 : Amount of inputs, output and their equivalents for sunflower production

Input / Output	Quantity (Unit ha ⁻¹)	Energy equivalent (MJ ha ⁻¹)	Percentage (%)
(A) Inputs			
1. Human labour (h)	127.26	290.16	2.15
2. Machinery (h)	10.25	869.88	6.43
3. Diesel fuel (L)	84.71	4709.66	34.84
4. Fertilizers (kg)	146.40	6122.43	45.29
5. Chemicals (kg)	2.80	480.22	3.55
6. Water for irrigation (m ³)	628.94	641.52	4.75
7. Seed (kg)	15.35	403.58	2.99
Total Energy input		13517.45	100.00
(B) Output			
1. Sunflower (kg)	2124.42		
Total energy output		55872.37	
Energy ratio	4.13		
Energy productivity (kg MJ ⁻¹)		0.16	
Specific energy (MJ kg ⁻¹)		6.36	
Net energy (MJ ha ⁻¹)		42354.92	

Table 3 : Average efficiencies of sunflower producers in Aksaray, Turkey

Efficiency type	Average	SD	Minimum	Maximum
Technical efficiency	0.82	0.16	0.44	1
Pure technical efficiency	0.97	0.04	0.80	1
Scale efficiency	0.84	0.44	0.44	1

studies carried out on other countries like; Greece (4.5), USA (5.0) and Iran (4.5) (Kallivroussis *et al.*, 2002; Pimentel and Patzek, 2005; Mousavi-Avval *et al.*, 2011a). In the studies using other agricultural products; energy ratio was reported as 4.8 for cotton, 4.68 for canola, 0.64 for pepper and 2.28 for soybean (Canakci *et al.*, 2005; Unakitan *et al.*, 2010; Mousavi-Avval *et al.*, 2011c; Omid *et al.*, 2011). The average energy productivity and net energy for sunflower production was 0.16 kg MJ⁻¹ and 42354.92 MJ ha⁻¹, respectively. However, average energy productivity ratio and net energy was 0.17 kg MJ⁻¹ and 33309 MJ ha⁻¹, respectively in the study conducted on sunflower production (Mousavi-Avval *et al.*, 2011a). The energy productivity ratios calculated for other oil seeds was 0.17 kg MJ⁻¹ for canola and 0.18 kg MJ⁻¹ for soybean (Unakitan *et al.*, 2010; Mousavi-Avval *et al.*, 2011c).

Efficiency of farmers : Efficiency estimates of farms were obtained using input-oriented CCR and BCC DEA application (Fig. 1). According to DEA results, 18.54% (CRS) and 54.87% (VRS) of farms were efficient. The ratio of farms which had technical and pure technical efficiency scores as 0.9 and 1 were 20.35% and 36.28%, respectively. There were no farms with efficiency score lower than 0.7 under BCC assumption while efficiency scores of 22.12% of the farms were lower than 0.7 under CCR assumption.

Estimated returns-to-scale results showed that 18.58% of the studied farms (technically-efficient farms) were operating at

CRS indicating the optimal scale. On the other hand, 79.65% of the farms operated at IRS while 1.77% operated at DRS. These findings imply that most of the sunflower- producing farms in the research area operated below the optimal scale. Therefore, a proportional increase in all inputs would increase output at a proportion that is higher than the proportional increase in inputs.

Statistics of efficiency measurements for three different efficiency types is given in Table 3. According to the findings, the average technical and pure technical efficiency scores were 0.82 and 0.97, respectively. This implies that the studied farms have a great potential for improving technical efficiency by saving. The technical efficiency scores vary between 0.44 and 1 among farms. This broad variation in technical efficiency is an indicator of the fact that farmers do not have the knowledge of appropriate production techniques or, if they have such knowledge, they do not apply it properly.

The technical and pure technical efficiency scores for sunflower was 0.87 and 0.96 (Mousavi-Avval *et al.* 2011a), 0.85 and 0.92 for soybean (Mousavi-Avval *et al.*, 2011c), 0.77 and 0.92 for rice (Chauhan *et al.*, 2006) and 0.74 and 0.88 for canola (Mousavi-Avval *et al.*, 2011b). Relatively low average scale efficiency (0.84) of sunflower-producing farms in the region implies that these farms work under disadvantaged scale conditions, meaning that if all inefficient farms operate at productive scale size, they can produce same amount with 16%

Fig. 1 : Efficiency score distribution of sunflower producers in Aksaray, Turkey.

of energy saving.

Comparing input use pattern of efficient and inefficient farmers : Benchmarking method was applied to order efficient farms hierarchically. Observation numbers and ranks of efficient farms according to their reference frequencies are shown in Table 4. This table depicts that farms coded 17 and 26 are detected in the set of inefficient farms, 25 and 15 times, respectively. On the other hand, farms coded 12 and 16 came up in the same set 13 times each. The efficient farms are observed frequently in the set of inefficient farms, which are thought to be superior farms. Superior-efficient farms are not only efficient but also have input-output levels that are close to those of inefficient farms in the sample. Such farms are taken as benchmarks and input energy usage levels of inefficient farms are determined by comparing

them with superior farms and their performances improved.

Energy equivalents of output and inputs for efficient and inefficient farmers are presented in Table 5. Table shows that inefficient farms use 4.94%, 22.08% and 9.12% more labor, machine and diesel fuel energy, respectively, than efficient ones. Use of all other types of input energy is at low levels in inefficient farms. As against this, total input energy of inefficient farms ($13468.05 \text{ MJ ha}^{-1}$) was 2.97% more than that of efficient farms ($13079.57 \text{ MJ ha}^{-1}$). 79.65% of inefficient farms operating under

Table 4 : Ranking of ten superior efficient farmers in sunflower production in Aksaray, Turkey

Rank	Farmer number	Frequency in reference set
1	17	25
2	26	15
3	12	13
4	16	13
5	37	11
6	86	11
7	64	5
8	113	3
9	8	3
10	112	2

Fig. 2 : Distribution of energy saving from different inputs for sunflower production.

the optimum scale, implies that these farms must proportionally increase their use of input energy in order to achieve efficiency. The situation that some farms remain inefficient despite using more input energy than the efficient farms is a result of disproportionate distribution of excess input energy among energy sources. Moreover, production value obtained by inefficient farmers was 26.42% lower than that of efficient farmers. All these results indicate that inefficient farms use more input energy to obtain higher amounts of output. However, the increase in the output of such farms is relatively less, which is also an outcome of disproportionate distribution of excess input energy among energy sources.

Setting realistic input levels for inefficient farmers : Pure Technical Efficiency score less than 1 means that the particular enterprise in question consumes more than required amount of

input energy. In order to prevent energy wastage, real energy levels must be used according to each input resource as given in Table 6.

This table shows that total input energy can be decreased to 12494.94 MJ ha⁻¹ to obtain existing level of output, assuming other constraining factors are non-existent. The highest saving rates were observed in machinery and chemicals with 12.54 and 16.15%, respectively. These sources of input energy are followed by labor and fertilizers. These inputs are, thus the most effective sources of inefficiency among the farmers. On the other hand, saving rates for irrigation water, seed and diesel fuel were found as 0.32 , 2.27 and 2.41 % respectively. These inputs are utilized efficiently. The existing level of production could be achieved with 4.18% (564.54 MJ ha⁻¹) saving in total input energy by improving technical efficiency of farms through adapting the recommendations made within the framework of the findings of

Table 5 : Energy inputs and output (MJha⁻¹) for efficient and inefficient farmers

Input/output (unit)	Ten superior efficient farmers (A)	Inefficient farmers (B)	Difference (%) (B-A)/A x 100
A. Inputs			
1. Human labour	279.16	292.96	4.94
2. Machinery	732.01	893.67	22.08
3. Diesel fuel	4350.70	4747.58	9.12
4. Fertilizers	6104.81	6005.71	-1.62
5. Chemicals	505.63	493.52	-2.39
6. Irrigation water	686.46	626.97	-8.67
7. Seed	420.80	407.65	-3.13
Total energy input	13079.57	13468.05	2.97
B. Output			
1. Sunflower (kg ha ⁻¹)	2706.67	1991.52	-26.42
Total energy output	71185.33	52377.02	-26.42

Table 6 : Optimum energy requirements and energy savings for sunflower production in Aksaray, Turkey

Inputs	Target use (MJ ha ⁻¹)	Energy saving (MJ ha ⁻¹)	Saving (%)
Human labor	267.55	12.65	4.36
Machinery	724.69	109.13	12.54
Diesel fuel	4441.64	113.62	2.41
Fertilizers	5673.03	240.37	3.93
Chemicals	387.46	77.55	16.15
Irrigation water	618.93	2.06	0.32
Seed	381.65	9.16	2.27
Total input energy	12494.94	564.54	4.18

Table 7 : Improvement of energy indices for sunflower production in Aksaray, Turkey

Items	Unit	Quantity of optimum use	Improvement (%)
Energy ratio	-	4.48	61.25
Energy productivity	Kg MJ ⁻¹	0.17	54.57
Specific energy	MJ kg ⁻¹	5.88	-37.89
Net energy	MJ ha ⁻¹	43516.61	21.72
Total input energy	MJ ha ⁻¹	12494.94	7.56

this study. Mousavi-Avval *et al.* (2011a) have also reported that 10.8% (1020.3 MJ ha⁻¹) of total energy input can be saved in sunflower production in Iran's Galastian region. For other agricultural products, Mousavi-Avval *et al.* (2011b, 2011c) have reported that 9.5% (16090 MJ ha⁻¹) and 20.12% (7116.84 MJ ha⁻¹) for canola and soybean, 12.17% (3687.62 MJ ha⁻¹) can be saved in kiwi production as reported by Mohammadi *et al.* (2011). Chauhan *et al.* (2006) reported that 1093.8 MJ ha⁻¹ could be saved in rice production. Fig. 2 shows the shares of various resources in total input energy saving. The highest contribution to total energy saving was made by chemical fertilizers with 42.58%, followed by diesel fuel (20.13%), machinery (19.33%) and chemicals (13.74 %). It can be concluded that labor, seed and irrigation water energy usages of the studied farms were relatively efficient.

Improvement of energy indices : Optimum use and improvement ratios of sunflower production energy indicators are presented in Table 7. Table shows that optimization of energy consumption can be achieved by improving energy ratio, energy productivity and net energy, respectively, by 61.25 , 54.57 and 21.72%. These results indicate that there is a great potential for improving energy efficiency of sunflower production in the region, in case input energy is used at optimum level.

Analyses has shown that energy use of chemical fertilizers, diesel fuel, machinery and chemicals have the highest energy-saving potential. Therefore, such measures as applying a better machinery management technique, including legume fodder crops in field rotation and soil-improving applications like applying organic fertilizers can be recommended to prevent energy wastage and decrease in negative effects of chemicals on environment. Farmers should be provided with trainings and extension programs on optimum use of energy and use of advanced technologies in farming.

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