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Energy use efficiency and economic analysis of sugar beet fields in Miandoab city, West Azerbaijan province

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ABSTRACT

The objectives of this study were to determine the energy use efficiency and economic potential of sugar beet production in Miandoab, West Azerbaijan province in 2011-12. Fields were classified into three groups as group I (less than 1 ha), group II (1-2 ha), and group III (more than 2 ha). Input and output data were collected from growers using questionnaire and interview methods. Results showed that the total energy input for the groups I, II and III was 40700, 46868, and 48646 MJ ha^{-1}, respectively and the total energy output was 565488, 857657, and 1081920 MJ ha^{-1}, respectively. Energy use efficiency for the groups I, II and III was 13.89, 18.30 and 22.24%, respectively. The total cost of sugar beet production for the groups I, II and III was 40570, 42315 and 47996 thousand IRR ha^{-1}, respectively. The benefit-to-cost ratio for the groups I, II and III was 1.02, 1.42 and 1.56, respectively. Results of this study showed that larger farms had better energy use efficiency and economic performance.

Keywords: benefit-to-cost ratio, energy use efficiency, sugar beet.

INTRODUCTION

Sugar beet is a strategic crop which is a major source of sugar production beside sugarcane. The sugar content of sugar beet (almost 25%) is higher than sugarcane, and about a quarter of global sugar production comes from sugar beet. In addition to sugar production, the crop has some byproducts such as pulp and molasses that are used for animal feeding and in industries, respectively. The process of sugar production from sugar beet is much more complicated than that of sugarcane, however its planting area is growing in most countries because of the financial benefit for the sugar industry, some social benefits as well as its usage for bioethanol production (Erdal et al., 2007).

The increasing rate of population growth and demand for food supply has led to boomed attempts for crop production. Given the limitations of natural resources and suitable condition for agriculture, attention has been directed to improve the productivity of the agricultural sector (Zanganeh et al., 2010). Crop production systems have undergone extensive changes in recent decades owing to the increased level of mechanization, more chemical fertilizers and pesticides application,, and improved seed quality. An area of changes has been in the rate and manner of energy use in the agricultural sector. These changes have tended to increase the dependence of this sector to energy (Hatirli et al., 2005). According to Beheshti Tabar et al. (2010), the average energy consumption in the agricultural sector of Iran has increased from 32.40 GJ ha^{-1} in 1990 to 37.20 GJ ha^{-1} in 2006.

Energy usage of the agricultural sector is classified into different categories including direct energy, indirect energy, renewable energy, and non-

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renewable energy. Direct energy is mainly used in the farms including labor, fuel, and electricity used by machinery and equipment, and energy used for irrigation water. Indirect energy, which is used off-farm, includes energy consumed during the application of chemical fertilizers and pesticides, seed preparation, and the fabrication of agricultural implements and machinery. Renewable energy encompasses labor, water, manure, and seed, whereas non-renewable energy includes fuel, energy used during pesticide and chemical fertilizer usage, energy used for machinery fabrication, and electricity.

Presently, energy is one of the most important and valuable inputs of agriculture, and the rate of crop production is directly related to it. On the other hand, excessive energy usage increase costs and entails environmental impacts such as soil structure degradation, ground tables contamination, boom in greenhouse gas emission, and increase in public health risk due to the loss of food quality and toxicity risk (Ghasemi Mobtaker et al., 2010). Therefore, it is imperative to optimize energy usage of the agricultural sector to increase crop yield per unit area and to minimize its adverse impacts so that energy optimization is regarded as a basic need for sustainable agriculture (Mohammadi et al., 2008).

The analysis of input and output energy of crop production is usually based on determining energy use efficiency and the environmental impacts of production systems. These analyses are employed to find out how to use energy optimally and to compare different crop production systems (Rafiee et al., 2010). Many researchers have studied different crop production systems from energy use and economic perspectives.

Rajabi Hamedani et al. (2011) addressed energy use rate and the relationship of energy inputs and crop yield of potato in Hamedan Province, Iran. They reported that the rate of energy use for potato production was 92296.3 MJ ha^{-1} and that the nitrogen fertilizer and diesel fuel had the highest shares in energy use accounting for 39 and 21% of energy, respectively. Further, they estimated energy ratio, specific energy, and energy productivity indices at 1.1, 3.2 MJ kg^{-1}, and 0.3 kg MJ^{-1}, respectively.

Erdal et al. (2007) studied sugar beet production in Tokat province of Turkey. They estimated total energy usage for sugar beet production at 39685.5 MJ ha^{-1} and found that chemical fertilizers and diesel fuel were the most important inputs for the crop production accounting for 49.33 and 24.16% of total energy usage, respectively. They, also, reported the indices of energy productivity, energy ratio and profit-cost ratio at 1.57, 25.75 kg MJ^{-1}, and 1.17, respectively.

Asgharipour et al. (2012) reported that about 57% of the energy input of sugar beet production in Khorasan Razavi province of Iran was direct energy and about 43% was of the indirect type. Total energy input was calculated to be 42231.9 MJ ha^{-1}, and the most important inputs were reported to be chemical fertilizers and irrigation water. Also, their economic assessments showed that sugar beet production cost per ha was 2896 USD and energy efficiency and benefit-cost ratio were 13.4 and 1.3, respectively.

Tabatabaie et al. (2012) investigated energy input to produce two plum cultivars of ‘Ghatreh Tala’ and ‘Shablon’. They reported total energy usage for these two cultivars at 192652.55 and 168783.94 MJ ha^{-1}, respectively. Further, they asserted that electricity accounted for nearly 80% of total energy usage so that it was the most important component of energy use for plum production.

The rate and manner of energy use, as well as the economic performance of crop production, are dictated by multiple factors. One of the critical factors is land size. In a study on the impact of farm size on the energy use efficiency and economic performance of paddy farms in Guilan Province, Pishgar-Komleh et al. (2011) divided the farms into three size groups: small-sized (<0.5 ha), medium-sized (0.5-1 ha), and large-sized (>1 ha). They revealed that the large-sized farms had higher energy use efficiency and economic performance than the other two groups.

Külekçi and Aksoy (2013) focused on pistachio farms in Turkey. They divided the pistachio farms into small-sized (0.1-10 ha) and large-sized (>10 ha) groups and reported that their energy use was 23454.33 and 20473.06 MJ ha^{-1}, respectively. It was revealed that energy use efficiency of these farms was 0.4 and 0.43, respectively, but both farm sizes had the same energy productivity of 0.02 kg MJ^{-1}. According to their economic analysis, the profit of small-sized and large-sized farms were 1429.10 and 1595.11 USD ha^{-1}, respectively.

Accordingly, we can see that land size is an important parameter underpinning energy use efficiency and economic performance of crop farms. The present study focused on estimating total inputs and output and energy indices and performing an economic analysis of sugar beet production in Miandoab County of Western Azerbaijan Province, Iran. The farms were considered in three size groups of <1 ha (Group I), 1-2 ha (Group II), and >2 ha (Group III).

MATERIALS AND METHODS

Sugar beet acreage in Iran has been estimated at about 110,000 ha in the 2010-2011 growing season. Eastern Azerbaijan Province is ranked the first accounting for 34.7% of this acreage followed by Razavi Khorasan and Fars provinces in the second and third ranks. Total sugar beet production was estimated to be 4.7 million tons in this growing year and again Eastern Azerbaijan Province was the leading producer accounting for 42.9% of total production. The second and third leading producing provinces were Razavi Khorasan (18.5%) and Fars (10.9%, Iranian Ministry of Agriculture, 2011). Therefore, we selected Miandoab County in Eastern Azerbaijan province as the leading sugar beet producer in Iran to study sugar beet production from the economic and energy use efficiency perspectives. Miandoab County is the first region in Iran where sugar beet was cultivated, so it has a special niche in sugar beet production and processing in Eastern Azerbaijan province. The county (46°06' E., 36°46' N.) covers an area of 223,300 ha in the south of the province, accounting for about 4.18% of the province area. According to the data derived from Ministry of Jihad-e-Agriculture and Sugar Factory of the county, sugar beet farms were divided into large-sized (>2 ha), medium-sized (1-2 ha), and small-sized (<1 ha) farms.

We performed one-on-one interviews with individual growers. Also, Neyman's method was applied to determine the minimum number of fields from each field size group to administer the questionnaire (Yamane 1967; Mohammadi and Omid 2010).

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

in which n is the minimum number of fields, N is the total number of fields in the region, N_h is the number of fields in the desired group, S_h^2 is the variance of field area in the specific group, S_h is the standard deviation of the specific group, z is the coefficient of confidence at the 95% level (1.96), $d = \bar{x} - \bar{X}$ is the precision, and $D^2 = \frac{d^2}{z^2}$.

According to Equation (1), the minimum sample size in the first, second and third groups was estimated at 20, 27 and 23 fields, respectively. Then, sample fields were randomly selected from each group, and data were collected by interviewing growers about their input usage and crop yield. Data were entered into the MS-Excel and SPSS19 software packages, and the energy equivalents of the individual input and output (sugar beet crop) per ha were calculated. Also, the energy usage of agricultural machinery was calculated by Equation 2 (Mousavi-Avval et al. 2011):

$$ME = \frac{GM_p t}{T} \tag{2}$$

in which ME denotes machinery energy ratio (MJ ha^{-1}), G denotes machinery weight (kg), M_p denotes energy used to manufacture machinery (MJ kg^{-1}), t is the extent of machinery use per unit area (hr ha^{-1}), and T is the economic life of machinery (hr).

Then, we used Equations (3)-(6) to calculate energy use efficiency, energy productivity, specific energy, and energy benefit (Ramedani et al., 2011).

$$\text{Energy use efficiency} = \frac{\text{Output energy (MJ ha}^{-1}\text{)}}{\text{Input energy (MJ ha}^{-1}\text{)}} \tag{3}$$

$$\text{Energy productivity} = \frac{\text{Sugar beet yield (kg ha}^{-1}\text{)}}{\text{Input energy (MJ ha}^{-1}\text{)}} \tag{4}$$

$$\text{Specific energy} = \frac{\text{Input energy (MJ ha}^{-1}\text{)}}{\text{Sugar beet yield (kg ha}^{-1}\text{)}} \tag{5}$$

$$\text{Energy benefit} = \text{Total energy output (MJ ha}^{-1}\text{)} - \text{Total energy inputs (MJ ha}^{-1}\text{)} \tag{6}$$

Also, to perform an economic analysis of sugar beet production in three field size groups in Miandoab, we estimated economic indices of profit, gross income, benefit-cost ratio, and productivity by Equations (7-10), respectively.

$$\text{Gross income} = \text{Total production value (000 IRR ha}^{-1}\text{)} - \text{Variable cost of production (000 IRR ha}^{-1}\text{)} \tag{7}$$

$$\text{Profit} = \text{Total production value (000 IRR ha}^{-1}\text{)} - \text{Total cost of production (000 IRR ha}^{-1}\text{)} \tag{8}$$

$$\text{Benefit - cost ratio} = \frac{\text{Total production value (000 IRR ha}^{-1}\text{)}}{\text{Total production cost (000 IRR ha}^{-1}\text{)}} \tag{9}$$

$$\text{Productivity} = \frac{\text{Crop yield (kg ha}^{-1}\text{)}}{\text{Total production cost (000 IRR ha}^{-1}\text{)}} \tag{10}$$

RESULTS AND DISCUSSION

Table 2 shows the amount and energy equivalent of individual input and output of sugar beet production in the studied area for the three studied field size groups. It, also, presents the

Table 1. Energy equivalent of input and output for sugar beet production

	Unit	Energy equivalent (MJ unit^{-1})	Source
Input			
1. Labor	hr person^{-1}		
Male	hr person^{-1}	1.96	Erdal et al. (2007)
Female	hr person^{-1}	1.57	Pishgar-Komleh et al. (2011)
2. Tractor	kg	138	Kitani (1999)
3. Machinery	kg	62.7	Ozkan et al. (2004)
4. Fuel	L	40.68	Topak et al. (2010)
5. Chemical fertilizer	kg		
N		47.1	Topak et al. (2010)
P		13.7	Tsatsarelis (1993)
K		11.15	Erdal et al. (2007)
6. Pesticide	kg		
Herbicide		238	Erdal et al. (2007)
Fungicide		216	Erdal et al. (2007)
Insecticide		101.2	Erdal et al. (2007)
7. Seed	kg	50	Haciseferogullari et al. (2003)
8. Irrigation	m^3	1.02	Mohammadshirazi et al. (2012)
Output			
1. Sugar beet	kg	16.8	Erdal et al. (2007)

Table 2. Input and output (sugar crop) and their energy equivalent per ha for three field sizes in 2011-12

Input/output	Field size groups								
	Small-sized fields			Medium-sized fields			Large-sized fields		
	Rate	Energy equivalent (MJ)	% of total	Rate	Energy equivalent (MJ)	% of total	Rate	Energy equivalent (MJ)	% of total
(i) Input									
(1) Labor (hr)									
Female	473.0	743	1.83	410.0	644	1.37	371.0	582	1.20
Male	615.0	1205	2.96	468.0	917	1.96	385.0	755	1.55
Total labor	1088.0	1948	4.79	878.0	1561	3.33	756.0	1337	2.75
(2) Machinery (kg)									
Tractor	5.5	759	1.86	7.4	1017	2.17	9.0	1242	2.55
Implements	22.4	1404	3.45	27.4	1718	3.68	40.0	2508	5.16
Total machinery	27.9	2163	5.31	34.8	2735	5.84	49.0	3750	7.71
(3) Fuel (L)	408.7	16626	40.85	503.3	20474	43.68	527.4	21455	44.10
(4) Chemical fertilizer (kg)									
N	119.3	5617	13.80	143.0	6735	14.37	158.3	7456	15.33
P	25.8	353	0.87	38.0	521	1.11	55.8	764	1.57
K	11.3	125	0.31	15.0	167	0.36	18.3	204	0.42
Total fertilizers	156.2	6095	14.98	196.0	7423	15.84	232.4	8424	17.32
(5) Pesticide (kg)									
Herbicide	1.0	238	0.58	1.2	274	0.58	1.5	345	0.71
Fungicide	1.3	281	0.70	1.6	337	0.72	2.0	432	0.89
Insecticide	2.6	263	0.65	3.3	329	0.70	2.5	257	0.53
Total pesticide	4.9	782	1.92	6.1	940	2.00	6.0	1034	2.13
(6) Seed (kg)	2.9	145	0.36	1.9	95	0.20	1.9	97	0.20
(7) Water (m^3)	12687.5	12941	31.80	13373.0	13640	29.10	12303.0	12549	25.80
Total input energy		40700	100		46868	100		48646	100
(ii) Output									
Sugar beet (kg)	33660.0	565488		51051.0	857657		64400.0	1081920	
Total output energy		565488	100		857657	100		1081920	100

contribution of each individual input to the total energy consumption. As the results reveal, all field size groups use labor, machinery (tractor, implements), diesel, different chemical fertilizers (nitrogen, phosphate, and potassium), pesticides (herbicides, fungicides, and insecticides), seeds, and water, but none of them consume electrical energy or manure. The average total energy use for sugar beet production was 40700, 46868, and 48646 MJ ha^{-1} in three studied field size groups, respectively. Total energy use for sugar beet production has been estimated at 42232 MJ ha^{-1} in Khorasan Razavi province, Iran (Asgharipour et al. 2012) and at 39686 MJ ha^{-1} in Tokat province,Turkey (Erdal et al. 2007). It can be inferred from Table 2 that more energy is consumed in

Table 3. Energy indices of sugar beet production in three field size groups in 2011-12

	Unit	Farm size groups		
		Small-sized farms	Medium-sized farms	Large-sized farms
Total energy input	MJ ha^{-1}	40700	46868	48646
Total energy output	MJ ha^{-1}	565488	857657	1081920
Energy use efficiency	-	13.89	18.30	22.24
Energy productivity	kg MJ^{-1}	0.83	1.09	1.32
Specific energy	MJ kg^{-1}	1.20	0.92	0.76
Energy profit	MJ ha^{-1}	524788	810789	1033274

larger fields and the main reason being the use of inputs such as machinery, diesel, chemical fertilizer, and pesticide. The energy equivalent of labor in three field sizes was 1948, 1561, and 1337 MJ ha^{-1} and that of machinery was 2136, 2735 and 3750 MJ ha^{-1}, respectively. In the studied area, men are mostly used to operate agricultural machines and perform irrigation operations, and women are used for weeding, thinning and harvesting operations in some fields. As the acreage increased, labor (both men and women) was used to a lesser extent because of more machinery application.

We observed that in the groups of small, medium and large-sized fields, diesel, irrigation, and chemical fertilizer accounted for about 40, 30, and 16% of total energy input, respectively. The lowest rate was for seed accounting for less than 0.4% of total energy input. Asgharipour et al. (2012) reported that the highest contributions to energy use were related to chemical fertilizers (about 28.5%), irrigation (about 22.1%), electrical power (about 15.6%), and diesel (about 15.2%) with the lowest contribution related to seed (0.3%).

According to Table 2, crop yield increased with field size so that crop yield per ha in the three studied field sizes was found to be 33660, 51051, and 64400 kg ha^{-1}, respectively. Average crop yield in Iran and in Western Azerbaijan province was 42943 and 503060 kg ha^{-1} in 2011-2012, respectively (Iranian Ministry of Agriculture, 2011).

Energy use efficiency, energy productivity, specific energy, and net energy benefit are presented in Table 3. Energy use efficiency in three field size groups was estimated at 13.89, 18.30 and 22.24; in other words, 13.89, 18.30 and 22.24 units of energy were produced in these fields per consumption of one unit of energy. Asgharipour et al. (2012) reported energy use efficiency of sugar beet production in Khorasan Razavi province to be 13.4%. It is evident in Table 3 that as sugar beet fields get larger, although energy input per unit area increases, the increase in energy output is much greater so that energy benefit of small, medium and large-sized fields was estimated to be 524788, 810789, and 1033274 MJ ha^{-1}, respectively. Also, the energy productivity in the first, second, and third group was 0.83, 0.92, and 1.32 and the specific energy was 1.20, 0.92, and 0.76, respectively. This implies that in larger fields, energy use per one unit of sugar beet crop production is lower. More efficient use of energy in larger fields than in smaller fields has been reported by Pishgar-Komleh et al. (2011) for paddy fields in Guilan province of Iran and by Yilmaz et al. (2005) for cotton fields in Turkey, too.

Table 4 displays the amount and percentage of different forms of energy which were used for sugar beet production in three field size groups. It can be observed that in all field groups, the rate of direct energy was greater than that of indirect energy and the rate of non-renewable energy was greater than that of renewable energy. As mentioned previously, one of the key requirements to accomplish sustainable farming is to use more renewable. Therefore, it is vital to make decisions and investments to extend the use of renewable energy resources and to reduce the contribution of non-renewable energy forms in the agricultural sector. For example, in this study since the highest energy consumption rate (about 40% of total energy input) is related to diesel which is used to pump water at cultivation stage, the replacement of diesel engines with electrical engines can contribute to the reduction of fossil fuels usage remarkably. Also, electrical power can be generated by renewable resources, e.g. water, wind, or sunlight. As such, a remarkable step can be taken to reduce the dependence on fossil fuels and environmental pollution.

Production costs, production value, and economic indices for three field size groups are presented in Table 5. As it can be seen, the total production cost of the three field size groups is 40570, 42315, and 47996 thousand IRR ha^{-1}. Results in Table 5 shows that as field size increased, except seed and labor, all the input cost increased. The main reason for the higher total production cost of large fields is their fixed costs which raised to 43% (4710 thousand IRR ha^{-1}) and 110% (8260 thousand IRR ha^{-1}) higher than medium- and small-sized fields, respectively.

According to the results, all economic indicators were enhanced with an increase in field size. It can be seen that the benefit to cost ratio was 1.02, 1.42 and 1.56 for small, medium and large-sized fields, respectively. This is consistent with

Table 4. The amount and percentage of different energy forms used for sugar beet production in three field groups in 2011-12

Energy form	Unit	Field size groups					
		Small-sized fields		Medium-sized fields		Large-sized fields	
		Amount	% of total	Amount	% of total	Amount	% of total
Direct energy	MJ ha^{-1}	31515	77	35675	76	35341	73
Indirect energy	MJ ha^{-1}	9185	23	11193	24	13305	28
Renewable energy	MJ ha^{-1}	15034	37	15296	33	13983	29
Non-renewable energy	MJ ha^{-1}	25666	63	31572	67	34663	71
Total energy input	MJ ha^{-1}	40700		46868		48646	

Table 5. Economic analysis of sugar beet production in three field size groups in 2011-12

	Unit	Farm size groups		
		Small-sized farms	Medium-sized farms	Large-sized farms
Crop yield	kg ha^{-1}	33660	51050	64400
Selling price	IRR kg^{-1}	1090	1090	1090
Land lease profit	000 IRR ha^{-1}	4500	4500	4500
Crop sale value	000 IRR ha^{-1}	36689	55645	70196
Total production value	000 IRR ha^{-1}	41189	60145	74696
Variable costs	000 IRR ha^{-1}			
Seed		4800	3155	3026
Chemical fertilizer		1700	2130	2650
Pesticide		730	1080	1080
Machinery		6170	8360	10630
Irrigation		2570	2840	3650
Labor		17100	13700	11200
Total variable costs	000 IRR ha^{-1}	33070	31265	32236
Fixed costs	000 IRR ha^{-1}	7500	11050	15760
Total production cost	000 IRR ha^{-1}	40570	42315	47996
Total production cost	IRR kg^{-1}	1205	829	745
Gross income	000 IRR ha^{-1}	8119	28880	42460
Margin	000 IRR ha^{-1}	619	17830	26700
Benefit-cost ratio	-	1.02	1.42	1.56
Productivity	kg 000 IRR^{-1}	0.83	1.21	1.34

other studies. For example, Asgharipour et al. (2012) and Erdal et al. (2007) estimated benefit to cost ratio for sugar beet production to 1.3 and 1.17, respectively.

Table 5 shows that the profit of sugar beet production in the studied area was 619, 17830, and 26700 thousand IRR ha^{-1} for small, medium and large-sized fields, respectively. A higher profit of large-sized fields can be attributed to the optimal use of inputs and more crop production. In fact, the productivity of these three field sizes was found to be 0.83, 1.21, and 1.23 kg thousand IRR^{-1}, respectively. Higher productivity, gross income, and profit of large-sized fields have been reported by other researchers for different agricultural crops. For example, Pishgar Komleh et al. (2011) reported that the profit from rice production was 807.43, 922.85, and 1088.87 US dollars ha^{-1} in small- (<0.5 ha), medium- (0.5-1 ha) and large-sized (>1 ha) fields in Guilan province, respectively. They, also reported 1.08, 1.12, and 1.18 kg US dollars productivity of these fields, respectively.

Figure 1 shows the contribution of different inputs to crop production in small, medium and large-sized fields. According to this figure, the most important input in terms of cost in small and medium-sized fields was labor accounting for 42.15 and 32.38% of total production cost, respectively. The second rank was belonged to fixed costs accounting for 18.49 and 26.11% of total costs, respectively. In large-sized fields, fixed costs accounted for the highest rate of total production costs (32.84%) followed by labor accounting for 23.33% of total costs. In addition, Figure 1 depicts that pesticides and chemical fertilizers account for the smallest rate of total production costs in all three field groups.

Figure 2 displays the product costs for different operational phases including land preparation and sowing, plant husbandry, harvest, and crop transportation for different field size groups. It can be observed that large-sized fields had the highest costs and small-sized fields had the lowest costs of land preparation and sowing operation. For plant husbandry operation, the highest cost is incurred by small-sized fields and the lowest by large-sized fields. This can be attributed to the more extensive use of labor for weeding and thinning in small-sized fields. The highest harvest cost was related to small-sized fields and the lowest to

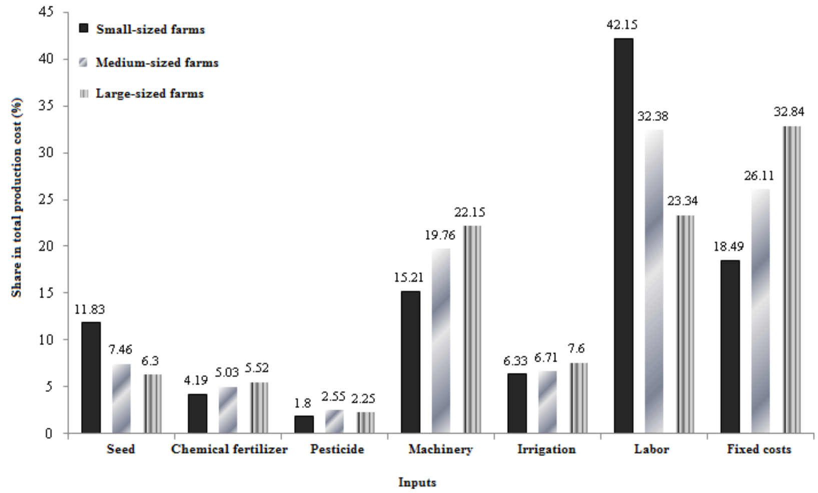

Figure 1. Comparison of the rate of input in total production costs in different field size groups in 2011-12

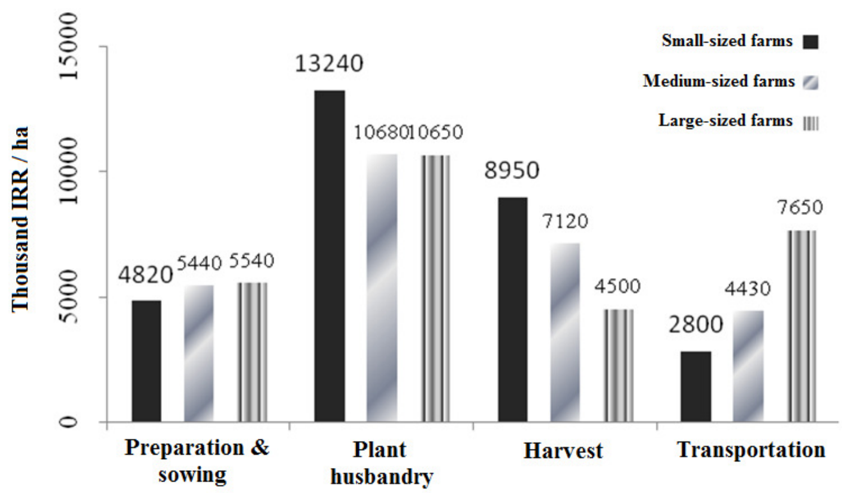

Figure 2. Comparison of production costs among field size groups in terms of different crop production phases in 2011-12

large-sized fields since the former use labor to harvest beets while the latter employ combines and other harvest machinery. Large-sized fields had the highest transportation cost and small-sized fields had the lowest because of the higher crop yield per unit area in large-sized fields.

According to our findings, we can reduce the cost of weeding and as a result, the cost of crop production considerably by applying scientific methods of land preparation and drip irrigation which reduces the growth of weeds throughout the field. Furthermore, given high costs of harvest, we can partially cut these costs in small-sized fields by using tractor-mounted harvester.

Conclusion

The present study investigated the sugar beet production in Miandoab in terms of both economic and energy use perspectives. To explore the effect of field size on energy use efficiency and economic performance of the production system, fields were divided up into three groups of small-sized (<1 ha), medium-sized (1-2 ha) and large-sized (>2 ha). Data were collected by one-on-one interviews with farmers. Results showed that energy use per unit area increased with an increase in field size so that the energy use of large-sized fields was 1778 and 7946 MJ ha^{-1} higher than medium and small-sized fields, respectively. consumption higher rate of chemical fertilizers, agricultural machinery, and fuel usage is the main reason for high energy usage in large fields. Also, crop yield per unit area increased with field size so that crop yield in the three studied field sizes was found to be 33660, 51051, and 64400 kg ha^{-1}, respectively. In total, energy use efficiency was higher in large fields than smaller ones as data showed that energy profit in small, medium, and large fields was 524788, 810789, and 1033274 MJ ha^{-1}, respectively.

We found that diesel was the most energy-intensive input accounting for about 40% of the total energy input in sugar beet fields. Half of this fuel is used to operate diesel engines of water pumps. The second most energy-intensive input was irrigation and chemical fertilizer accounted for 30 and 16% of total energy input, respectively. Given the adverse environmental impacts as well as high cost of fossil fuels and chemical fertilizer, it is recommended to replace diesel engines with electrical ones to reduce diesel consumption. Also, it is recommended to apply chemical fertilizer to the minimum level with respect to soil nutritional status and plant nutrient requirements to avoid environmental damages in addition to reducing total energy use. Furthermore, application of pressurized irrigation methods can contribute to decrease irrigation frequency and contribute to water resource management. It can also contribute to the reduction of water pump usage and as a result economic saving.

According to the results, growers do not apply manure in sugar beet fields. Since most arable lands of Iran are suffering from organic matter deficiency, application of organic matter such as manure can be a good strategy to improve soil structure and its physicochemical characteristics. This will eventually increase crop yield. Thus, it is recommended to apply manures in sugar beet fields.

It was shown that labor accounted for a significant portion of production costs so that it was the most energy-intensive input of the small and medium-sized farms accounting for 42 and 33% of total production costs in the above-mentioned fields, respectively. Even in large-sized fields, it was the second most energy-intensive input with a rate of 23% after fixed costs with a rate of 33%. Therefore, the reduction of production costs and improvement of profit requires accurate management practices and effective approaches such as optimal use of machinery in order to reduce labor use.

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