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Determination of energy balance, greenhouse gas emissions and global warming potential for sugar beet production

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Key words: Energy, Sugar beet, CO_2, Efficiency Energy Ratio, Energy Productivity.

Abstract

This study aims to estimate and evaluate the energy balance and greenhouse gas emissions in sugar beet production in Naghadeh a northwestern city of Iran. For this reason data was collected by using questionnaires and face to face interviews with 125 farmers. Results showed that total energy inputs and output were 69113.46 and 260429 MJ ha^{-1}, respectively. Efficiency Energy Ratio (ER) was 3.77 and Energy Productivity (EP) was 0.97MJha^{-1}. Maximum CO_2 emission due to N-fertilizer inputs was 938.05 kgha^{-1}, respectively. In sugar beet farms total CO_2 production was 2777.10 kgha^{-1}.The results also showed that the indirect and non-renewable energy sources were 76.28% and 82.36%, respectively. The high rate of non-renewable and indirect energy inputs indicate an intensive use of pesticides, chemical fertilizers, tractor and machinery and irrigation system consumption in these agro-ecosystems. Finally, giving a proper education to farmers about extension services in case of machinery combination, fertilizing, spraying and soil test, in a proper time, can have a great effect in sustainability of the sugar beet production.

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Introduction

Sugar beet is mainly used for human food, livestock, and as a raw material for industry. Sugar content of sugar beet is about 25% higher than found in sugar cane (Erdal *et al.*, 2007). Energy balances that are used for the environmental assessment of agriculture (Castoldi and Bechini, 2010), indicate intensity and environmental effects of production with only a few key figures (Hülsbergen *et al.*, 2001). Low energy input is considered as optimal, since the use of fossil fuel leads to the emission of greenhouse gases (Lal, 2004; Tzilivakis *et al.*, 2005a) and to the consumption of non-renewable resources. High energy output and energy gain are worthwhile, because arable land is limited and the demand for food, feed and renewable raw materials increases (FAO, 2009). Thus, the improvement of energy gain and energy efficiency through optimizing energy input and increasing energy output contributes significantly to sustainable development in agriculture. There is a close relationship between agriculture and energy. Agriculture uses energy, when supplies it in the form of bioenergy. At the present time, the productivity and profitability of agriculture depend upon energy consumption (Tabatabaeefar *et al.*, 2009).

A three year study conducted to investigate energy use pattern in Abyek a town in Ghazvin Province of Iran. The results revealed an increasing trend for energy ratio and energy productivity from 2008 to 2010 (Naderloo *et al.*, 2013)

The effective usage of agricultural products and increasing the amount of production in a unit area are both necessary because the extreme boundaries of agricultural areas in Iran have been reached. Therefore the most suitable method for products such as sugar beet plants must be determined and applied. Sugar, which is obtained from the sugar beet plant, has an important place in the human diet. Moreover the head and the leaves, which are byproducts of sugar beets, are used for producing meals (residues of sugar beet), which are an important nutrient source in animal diet.

Besides the energy consumption, greenhouse gas (GHG) emission and global warming potential (GWP) issues are also critical in the agricultural production systems in recent twenty years (Khoshnevisan *et al.*, 2013a). Gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) produced as a result of agricultural activities, enhance the natural greenhouse effect. Agriculture contributes significantly to atmospheric GHG emissions, with 14% of the global net CO_2 emissions coming from this sector (Parry *et al.*, 2007).

Among the various sectors contributing to greenhouse gas (GHG) emissions, agricultural sector has a significant share. Agriculture is responsible for 10–12% of global GHG emissions (Khoshnevisan *et al.*, 2014a).

In a study, energy consumption and GHG emission of wheat production in Esfahan province of Iran were determined. Electricity, chemical fertilizers and water for irrigation were the most influential factors in energy consumption. Also, electricity, nitrogen and diesel fuel had the highest contribution on total GHG emission (Khoshnevisan *et al.*, 2013b).

Sugar beet is the most widely grown crop in Iran with 3467373 tons in a cropping area of 82516 ha and yield was 42.02 (tonha^{-1}) (Iranian Sugar Factories Syndicate, 2013).

Sugar beet cultivation in tinsel city is 4,500 hectares. For giving the production of 52 tons per hectare, more than 234,000 people and sugar harvesting factories were delivered to the region (Anonymous, 2014).

This study aimed to evaluate the energy balance and greenhouse gas emissions in sugar beet production in Naghadeh, a city in the northwestern of Iran.

Materials and methods

Data Collection: Naghadeh city has an area of 1050087 square kilometers. Its elevation ranges from 1,000 to over 2,000 meters above sea level. Geographically located 36 degrees 57 minutes north latitude and 45 degrees 22 minutes east of the Greenwich meridian (“www.nagadeh-ag.ir,” 2007).

Sample farms were randomly selected from the villages in the study area by using a stratified random sampling technique. The sample size was calculated using the Neyman method as is shown below Eq. (1) (Yamane, 1967):

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

In the above formula n is the required sample size; N is the number of holdings in target population; N_h is the number of the population in the h stratification; S_h is the standard deviation in the h stratification, S_h^2 is the variance of h stratification; d is the precision where $(\bar{x} - \bar{X})$; z is the reliability coefficient (1.96 which represents the 95% reliability); $D^2 = d^2/z^2$.

For the calculation of sample size, criteria of 5% deviation from population mean and 95% confidence level were used. Thus, the number of 125 was considered as sampling size. This study was conducted in October 2014 in Naghade, a city in the northwestern of Iran. For this investigation data was collected from 125. The data used in the study was obtained by using face-to-face interview method.

Calculation

Inputs used in the production of sugar beet were specified in order to calculate the energy equivalences in the study. Inputs in sugar beet production were: human labour, machinery, diesel fuel, chemical fertilizers, farmyard manure, pesticides, fungicides, herbicides as biocides, water for irrigation, and electricity. The output was considered sugar beet yield.

The volumetric fuel consumption for a diesel engine can be calculated as (Eq. 2) :

$$Q = (2.64X + 3.91 - 0.203\sqrt{738X + 173}) \times X \times P_{pto} \quad (2)$$

In the above formula:

Q = diesel fuel consumption at partial load, L/h (gal/h)

X = the ratio of equivalent PTO power (PT) to rated PTO power (Ppto), decimal

Ppto = the rated PTO power, kW (hp) (Grisso *et al.*, 2004).

The production energy of tractors and agricultural machines was calculated by using the following equation (Eq. 3).

$$Mpe = \frac{GMp}{TW} \quad (3)$$

In the above formula , Mpe is the energy of the machine per unit area, MJha^{-1}; G is the mass of machine, kg; Mp is the production energy of machine, MJkg^{-1}; T is the economic life, h; and W is the effective field capacity, ha h^{-1} (Canakci *et al.*, 2005; Gezer, 2003).

Energy production of tractors and agricultural machinery per unit time was calculated using the following formula (Eq. 4):

$$Mpt = \frac{GMp}{T} \quad (4)$$

Where Mpt is the energy of the machine per unit time, MJhr^{-1} (Table 1)

Table 1. Energy equivalent to the production of tractors and agricultural machinery.

Agricultural processes	Energy production (MJ/h)
Tractor	28.5
Moldboard plow	45
Disc harrow	59
Leveler	37.25
Row planter	94.2
Fertilizer	59.1
Mounted sprayer	43
Cultivator	23.8
Topper	67.1
Lifter	18

The energy equivalents given in Table 2, were used to calculate the input amounts. The input and output were calculated per hectare and then, these input and output data were multiplied by the coefficient of energy equivalent. Following the calculation of energy input and output values, the energy ratio (energy use efficiency), energy productivity and net energy were determined (Borin *et al.*, 1997; Mandal *et al.*, 2002; Mohammadi *et al.*, 2008; Zentner *et al.*, 2004) (Eq. 5, 6, 7 and 8):

$$\text{Efficiency Energy Ratio(ER)} = \frac{\text{Energy output (MJ } ha^{-1})}{\text{Energy input (MJ } ha^{-1})} \quad (5)$$

$$\text{Energy productivity(EP)} = \frac{\text{sugar beet output (kg } ha^{-1})}{\text{Energy input (MJ } ha^{-1})} \quad (6)$$

$$\text{Specific energy} = \frac{\text{Energy output (MJ ha}^{-1})}{\text{sugar beet output (kg ha}^{-1})} \quad (7)$$

$$\text{Net Energy Gain}(NEG) = \text{Energy output (MJ } ha^{-1}) - \text{Energy input (MJ } ha^{-1}) \quad (8)$$

Table 2. Energy equivalences of inputs and outputs.

Energy source	Units	Energy equivalences MJ	References
Inputs			
Human labor	h	2.2	(Pimentel and Pimentel, 1979)
Diesel fuel	Lit	47.8	(Kitani, 1999)
fertilizer			
N	Kg	74.2	(Lockeretz, 1980)
P2O5	Kg	13.7	(Lockeretz, 1980)
K2O	Kg	8.8	(Lockeretz, 1980)
Farmyard manure	Kg	0.3	(Singh J. M., 2002)
Ca and Mg	Kg	8.8	(Pimentel and Pimentel, 1979)
Biocides			
Pesticide	Kg	363	(Fluck and Baird, 1982)
Fungicide	Kg	99	(Fluck and Baird, 1982)
Herbicide	Kg	288	(Kitani, 1999)
Irrigation systems	MJ	18% direct energy	(Sloggett, 1992)
Electricity	KWh	12	(Demircan *et al.*, 2006)
Seed	kg	54	(Kitani, 1999)
Output			
Sugar beet	kg	3.89	(Austin *et al.*, 1978)

Production, storage and distribution of agricultural inputs and their application with agricultural machines resulted in combustion of fossil fuel that emits CO2 and other greenhouse gases into atmosphere. Then, an understanding of the emission expressed in kg CO2 equivalent for different agricultural practices is a necessary step toward identifying environmentally efficient alternative such as biofuel and renewable energy sources (Lal, 2004). CO2 equivalent emission coefficients of agricultural inputs were used to determine GHG emission of sugar beet production. GHG emission was calculated by multiplying the application rate of inputs by its corresponding emission coefficient that is presented in table 3.

All data on energy inputs, sugar beet yields and GHG emission were calculated and entered into Excel 2013's spread sheet and SPSS 20 software software programs and analyzed.

Table 3. Greenhouse gas (GWP) emission coefficient of inputs.

Emission source	unit	Emission Kg CO2 eq unit[-1]
Inputs		
Tractor	MJ	0.071
machinery	MJ	0.071
Diesel fuel	Lit	2.762
fertilizer		
N	Kg	3.10
P2O5	Kg	1.00
K2O	Kg	0.70
Farmyard manure	MJ	0.05
Biocides		
Pesticide	MJ	0.06
Fungicide	MJ	0.06
Herbicide	MJ	0.06
Electricity	KWh	0.061
GWP CO_2 equivalence factor	kg	1

(Bonnie, 1987; Green, 1987; Helsel, 1992; Kramer *et al.*, 1999; Lockeretz, 1980; Pimentel, 1980; Snyder *et al.*, 2009; Spugnoli *et al.*, 1993; Terhune, 1980; Tzilivakis *et al.*, 2005b).

Results and discussion

Energy input the different operations from tractor and agricultural equipments for tillage, planting, cultivation and harvesting in sugar beet production systems, their balance of energy equivalents, and percentages in the total energy input showed in the Table 4.

Table 4. Energy inputs operations tractors and agricultural equipment in sugar beet production..

Energy source	Energy equiva-lences (MJ)	Opera-tions (h)	Diesel fuel (Lit)	Energy machinery (MJ/ha)	Energy tractor (MJ/ha)	Energy fuel (MJ/ha)	Total Energy (MJ/ha)	Percentage of total energy (%)
Tractor	45							
Moldboard plow	59.6	3.66	29.31	164.53	164.70	1401.02	1730.25	15.48
Disc harrow	37.25	2.41	17.54	143.54	108.45	838.41	1090.40	9.76
Leveler	94.21	2.33	14.38	86.82	104.85	687.36	879.03	7.87
tillage Energy		8.4	61.23	394.89	378.00	2926.79	3699.68	33.10
Row planter	59.13	2.51	17.35	236.73	112.95	829.33	1179.01	10.55
Fertilizer	43	3.54	22.45	209.01	159.30	1073.11	1441.42	12.90
Mounted sprayer	23.84	3.61	22.77	155.13	162.45	1088.41	1405.99	12.58
cultivator	67.05	1.89	12.89	45.15	85.05	616.14	746.34	6.68
plant and cultivation Energy		11.55	75.46	646.02	519.75	3606.99	4772.76	42.70
Topper	18	2.95	23.9	197.74	132.75	1142.42	1472.91	13.18
lifter	64.4	2.75	22.13	49.45	123.75	1057.81	1231.01	11.01
harvester Energy		5.7	46.03	247.19	256.50	2200.23	2703.92	24.19
total		25.65	182.72	1288.1	1154.25	8734.016	11176.37	100

Input energy for different machine operations was 11176.37 MJ and 16.17% of the total energy production of sugar beet. The most input energy related to the operation of planting, tillage and harvesting, 42.7, 33.10 and 24.19% of the total machinery energy is (Fig.1).

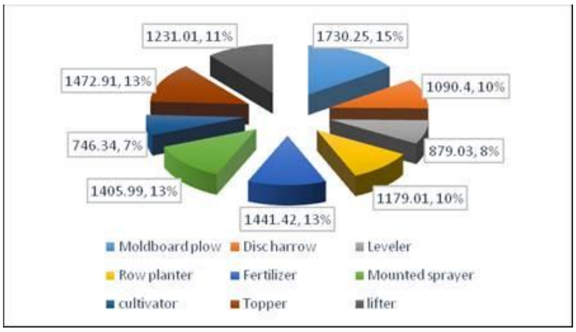

Fig. 1. Energy inputs operations tractors and agricultural equipment in sugar beet production (mjha-1).

Input Energy of planting and cultivation of the stage was higher because of several spraying and fertilizing and the lowest energy input. Harvesting was related to manual operation including collected and topping of sugar beet.

In Naghadeh, different operations including irrigation, weeding, harvesting topping of sugar beet is mainly done manually. Total energy input for these operations was 1221.14 MJ. Human energy inputs for manual operation and the driver is 1277.55MJ which is equal to 1.85 percent of total energy consumption of sugar beet production (Table 5).

Table 5. Energy inputs operations manual in sugar beet production.

Energy source	Energy equiva-lences (MJ/h)	Opera-tions (h)	Energy (MJ/ha)	Percentage of total energy (%)
Human labor				
Weeding and Breaking Crust	2.2	138.27	304.19	23.81
Cumulating	2.2	105.55	232.21	18.18
Topping	2.2	158.65	349.03	27.32
Driver	2.2	25.64	56.41	4.42
Irrigation	2.2	152.60	335.71	26.28
Total Human labor		580.71	1277.55	100.00

In a study of labor input energy at 1932 mg equals to 3.9 percent of total energy input (Yousefi *et al.*, 2014), in another study 385.672MJ obtained (Haciseferogullari *et al.*, 2003).

Energy input of chemical fertilizer and manure, chemical pesticides, irrigation and seed; and output of energy from sugar beet production is showed in Table 6. The results showed that the energy consumed for chemical fertilizers and manure 38138.47MJ was the most amount related to N-fertilizer 22452.62 MJ. The energy used for chemical pesticides was 2150.76MJ among fungicides with 066.56 MJ has the highest amount of energy. In a study conducted in the Kermanshah Province of Iran, the production of sugar beet, the largest share with

27.9% of the nitrogen fertilizer is energy (Yousefi *et al.*, 2014). In another study on an open field strawberry production systems was the maximum with 41% of its energy related to nitrogen and the greatest share of energy-related greenhouse strawberries production systems in natural gas and electricity, respectively, 58.4% and 27.42% (Khoshnevisan *et al.*, 2014b).

Table 6. Energy of fertilizers, pesticides, Irrigation and sugar beet yield in sugar beet production.

Energy source	unite	Energy Equivalences (MJ)	Operations (Kg/ha)	Energy (MJ/ha)
fertilizer				
N	Kg	74.2	306.02	22452.62
P2O5	Kg	13.7	223.30	2940.36
K2O	Kg	9.7	203.20	1910.42
Farmyard manure	Kg	0.3	3867.00	10808.67
Ca and Mg	Kg	8.8	3.00	26.40
Total fertilizer				38138.47
Biocides				
Pesticide	Kg	363	2.63	956.43
Fungicide	Kg	99	1.29	127.77
Herbicide	Kg	288	3.70	1066.56
Total Biocides				2150.76
Irrigation				
Diesel fuel	lit	47.8	78.6	3756.52
Electricity	KWh	12	218.6	2623.10
Irrigation systems	MJ	18% direct energy	6379.63	1148
Total irrigation				7527.62
Seed	kg	54	2.1	108.67
Sugar beet	kg	3.89	67000	260429

The input and output energy used in sugar beet production systems, their energy equivalents, and percentages in the total energy input presented in Table 8. The results revealed that total energy input was 69113.46 $MJha^{-1}$. Chemical fertilizer used in sugar beet production systems had a high share with 39.54% (table7 and fig. 2).

Table 7. Energy inputs, outputs and the ratio in sugar beet production.

Energy source	Energy (MJ/ha)	Percentage of total energy (%)
Inputs		
Tractor and machinery	11176.37	16.17
Human labor	1277.55	1.85
Chemical fertilizer	27329.80	39.54
Farmyard manure	10808.67	15.64
Biocides	2150.76	3.11
Diesel fuel	12490.54	18.07
Electricity	2623.1	3.80
Irrigation system	1148	1.66
Seed	108.67	0.16
Total Inputs	69113.46	100
Output		
Sugar beet	260429	

Diesel fuel energy used in sugar beet production systems ranked in the second place with 18.07% in the total energy input. The lowest share of the total energy input was recorded for seed (0.16%) which is a renewable resource of energy. In this study sugar beet tuber yield was 67000.0 $kgha^{-1}$ and the total energy equivalents was 260429 $MJha^{-1}$.

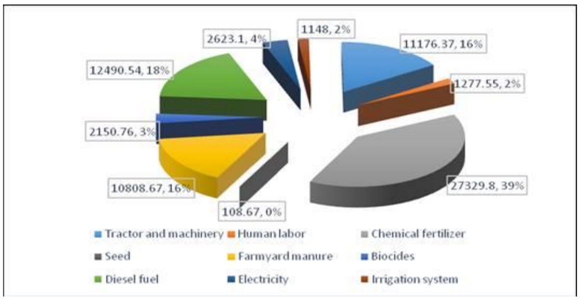

Fig.2. Energy inputs, outputs and the ratio in sugar beet production ($mjha^{-1}$).

In many other studies the energy input ranged between 13 and 30 $GJha^{-1}$ (Hülsbergen *et al.*, 2001; Kuesters and Lammel, 1999; Tzilivakis *et al.*, 2005b). Currently, the total energy input of sugar beet cultivation differs only slightly from the energy input for the cultivation of wheat (16.8–19.3 $GJha^{-1}$), oilseed rape (14.9–18.0) or silage maize (13.9–24.5) (Kränzlein *et al.*, 2007).

Total mean energy input as direct and indirect, renewable and Non-renewable forms for sugar beet farms are given in Table 8. Direct and indirect energy inputs were calculated as 23.72 and 76.28%, respectively. Renewable and non-renewable energy sources were recorded as 17.34 and 82.36%, respectively. Results revealed that indirect energy consumption was higher than direct energy in sugar beet farms; the same was observed for non-renewable versus renewable energy sources. The high rate of non-renewable and indirect energy inputs indicate an intensive use of pesticides, chemical fertilizers, tractor and machinery and irrigation system consumption in these agro-ecosystems.

Results of energy indicators for sugar beet production systems are shown in Table 8. Accordingly, the energy ratio (ER) obtained is 3.77. High energy ratio in sugar beet production systems is due to higher energy output in comparison to energy consumed. Energy use efficiency was reported 13.4 for sugar beet in Iran in Khorasan Razavi Province (Asgharipour *et al.*, 2012), 22.12 and for sugar beet production systems in Kermanshah Province in Iran (Yousefi *et al.*, 2014), 4.83 for all production systems in Iran (Mohammad and Ali, 2011) , 3.51 for rainfed Barley production systems in Iran (Yousefi and Ghazvineh, 2011) and 25.75 for sugar beet production systems in Turkey (Erdal *et al.*, 2007).

Carbon dioxide emissions from the sugar beet production are shown in Table 9 and 10. The Most carbon dioxide emissions related to Chemical fertilizer by 1290.55 kg and 46.47% and diesel fuel with 721.77 kgha^{-1} and 25.99%. Electricity with 13.38 kg ha^{-1} and 0.48% the lowest produced carbon dioxide. In a study of sugar beet production systems Emissions amount of CO2 was 2668.3 kg ha^{-1} (Yousefi *et al.*, 2014). In another study the GHG emissions of 15 truly most efficient and inefficient orange producers were calculated as 755 kg CO_2eq ha^{-1} and 939 kg CO_2eq ha^{-1}, respectively. In terms of CO2 equivalents, 22% of the GWP comes from CO2, 77% from N2O, and 1% from CH4 (Nabavi-Pelesaraei *et al.*, 2014).

Table 8. Energy indices and different form of energy in potato production.

Indicators	Unit	Quantity	Percentage of total energy (%)
Direct energy [a]	MJ/ha	16391.19	23.72
Indirect energy [b]	MJ/ha	52722.27	76.28
Renewable energy [c]	MJ/ha	12194.89	17.64
Non-renewable energy [d]	MJ/ha	56918.57	82.36
Total energy input	MJ/ha	69113.46	100.00
Output energy	MJ/ha	260429	
Sugar beet yield	Kg/ha	67000	
Energy Ratio (ER)	%	3.77	
Energy Productivity (EP)	MJ/ha	0.97	
Net Energy Gain (NEG)	MJ/ha	191315.54	

a Includes human labor, diesel fuel, electricity.

b Includes seeds, chemical fertilizers, manure, pesticides, tractor and machinery, irrigation system.

c Includes human labor, seeds, manure.

d Includes diesel fuel, pesticides, chemical fertilizers, tractor and machinery, electricity, irrigation system.

Table 9. Carbon dioxide emissions from the production of sugar beets.

Emission source	unite	unit/ha	Kg CO2 eq unit-1	CO2 (kg/ha)	GWP	Percentage of total GWP (%)
Tractor	mj	758.87	0.071	53.88	53.88	1.94
machinery	mj	394.89	0.071	28.04	28.04	1.01
Diesel fuel	Lit	261.32	2.762	721.77	721.77	25.99
N	Kg	302.6	3.1	938.05	938.05	33.78
P2O5	Kg	214.625	1	214.63	214.63	7.73
K2O	Kg	196.95	0.7	137.87	137.87	4.96
Farmyard manure	mj	10808.67	0.05	540.43	540.43	19.46
Pesticide	mj	956.43	0.06	57.39	57.39	2.07
Fungicide	mj	127.77	0.06	7.67	7.67	0.28
Herbicide	mj	1066.56	0.06	63.99	63.99	2.30
Electricity	Kwh	218.6	0.061	13.38	13.38	0.48
total					2777.10	100

Table 10. Carbon dioxide emissions from the production of sugar beets.

Emission source	CO_2 (kg/ha)	GWP	Percentage of total GWP (%)
Tractor and machinery	81.92	81.92	2.95
Diesel fuel	721.77	721.77	25.99
Chemical Fertilizer	1290.55	1290.55	46.47
Farmyard manure	540.43	540.43	19.46
Biocides	129.05	129.05	4.65
Electricity	13.38	13.38	0.48
Total	2777.10	2777.10	100.00

Conclusion

The results showed that the maximum energy consumption of chemical fertilizers 27329.80 $MJha^{-1}$ and 39.54% of the total energy input . Carbon dioxide emissions resulting from the use of Chemical fertilizer by 1290.55 kg and 46.47%, with the highest carbon dioxide production. The carbon dioxide emissions from electricity was the lowest 13.38 $kgha^{-1}$ and 0.48%. Indirect and non-renewable energy sources were as 76.28% and 82.36%, respectively. The high rate of non-renewable and indirect energy inputs indicate an intensive use of pesticides, chemical fertilizers, tractor and machinery and irrigation system consumption in these agroecosystems.

Accordingly, the efficiency energy ratio (ER) obtained is 3.77. High energy ratio in sugar beet production systems is due to higher energy output in comparison to energy consumed. Because of semi mechanization in agriculture, most portion of human energy was related to weeding, Breaking Crust, topping and irrigation with 74.1 %.

Labor based production of sugar beet reduces energy consumption and carbon dioxide emissions. Due to the labor consuming and high cultivation area in this region and due to inaccessibility to laborer in the proper time, harvest operation took a long time. This makes the operation not be done in the proper time. So the timeline costs increases because of less quality of sugar beet. So finally the net earn decreases. Tillage and seeding machinery with a high share of energy consumption, cause costs rising of input energy and greenhouse gas emissions. With the extension of machine combination, the input energy and greenhouse gas emissions decreases. Although producers obligated soil trials, farmers disregarded the trials and their misuse of chemical fertilizers, resulted in the increase in energy input and greenhouse gas emissions. Finally, giving a proper education to farmers about extension services in case of machinery combination, fertilizing, spraying and soil test, in a proper time, can have a great effect in sustainability of the sugar beet production.

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