Energy requirements for sugar beet cultivated in Iran: A case study in Qazvin province

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Abstract: Estimating the energy required to produce a crop is an important indicator in analyzing and evaluating agricultural sustainability. This study aimed to investigate the energy use of strategic sugar beet crop in Qazvin provinces of Iran. In this study, data were collected from growers using a face-to-face questionnaire to calculate the consumption inputs (such as water for irrigation, fuel consumption, seeds, human labor, electricity, machinery, fertilizers and pesticides) for different seedbed preparation, planting and harvesting operations. The results showed that the average input energy of sugar beet was 52055 MJ ha^{-1} and the average output energy was 532135 MJ ha^{-1}. In sugar beet cultivation, the highest and lowest energy inputs belonged to chemical fertilizer with 27.7% and seed with 0.2% of total input energy, respectively. The energy ratio of sugar beet was 10.5. Also energy productivity of sugar beet was calculated 0.61 kg MJ^{-1}, net energy gain of sugar beet was 480080 MJ ha^{-1} and the energy rate of sugar beet was 1.64 MJ kg^{-1}.

Keywords: energy requirements, energy ratio, productivity, sustainability, sugar beet

Citation: Younesi A. M., A. vahedi, M. Sedaghathoseyni. 2024. Energy requirements for sugar beet cultivated in Iran: A case study in Qazvin province. Agricultural Engineering International: CIGR Journal, 26 (1):140-147.

1 Introduction

Energy is one of the important inputs for the economic and social development of a country or an area. Analysis and scientific forecasts of energy consumption have major importance for the planning strategies and policies of energy use (Erdal et al., 2007). Nowadays, the agricultural sector has become more energy intensive to supply more food to increase population and provide sufficient nutrition. However, considering limited natural resources and the impact of using different energy sources on environment and human health, it is important to investigate energy use patterns in agriculture (Samavatean et al., 2011, Alamouti et al., 2015).

There is a strong relationship between agriculture and energy consumption (Younesi and Hedayatipoor, 2019; Hedayatipoor and Younesi, 2020). Energy consumption in agricultural production systems is one of the most important factors for the security and abundance of food supply chain. On the other hand, agriculture has become increasingly dependent on the application of various inputs, such as chemical fertilizers, pesticides, irrigation systems, farm machinery, etc., which are energy intensive elements and are directly or indirectly dependent on fossil fuels. Consequently, high costs of energy directly and strongly affect agricultural cultivation costs. Nevertheless, environmental, economical, and social criteria entail modification of agricultural systems

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Received date: 2023-07-11 **Accepted date:** 2023-12-30

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into sustainable production systems. Energy on farm can be used in two types: direct and indirect.

Direct energy consists of fuel and animal energy and indirect energy consists of used energy to product and transportation of farm inputs such as chemical fertilizers, seeds, machinery and pesticides (Sedaghat et al., 2014). Direct energy is required to perform various tasks related to crop production operations such as land preparation, irrigation, intercultural, threshing, harvesting and transportation of agricultural inputs and crops (Singh, 2002). It is seen that direct energy is directly used at farms and in the fields. Indirect energy, on the other hand, consists of the energy used in the manufacture, packaging and transport of fertilizer, pesticide, seed and farm machinery (Kennedy, 2000). To extend more sustainable agricultural operations, energy consumption needs to be taken into account as a basic index (Acaroglu and Aksoy, 2005). Agricultural production is highly dependent on energy inputs and growing consumption of fossil fuel resources has concerned both developed and developing countries. Speaking of bioenergy, agriculture acts as both energy consumer and supplier (Singh and Mittal, 1992; Alam et al., 2005).

All operations in the field of agriculture consume energy in various forms, namely human labor, animal power, fertilizer, fuels, and electricity. The agriculture has direct proportion to energy use (Esengun et al., 2007). Warkentin (1991) posited that the crop management had addressed the efficiency of water consumption as a highly vital concern. Effective agricultural energy consumption is one of the ingredients to facilitate sustainable agricultural production since it deals with financial savings, air pollution reduction, and fossil resources preservation (Uhlin, 1998).

In addition to land, farm power is considered the second most critical input to agricultural production (Okurut and Odogola, 1999). Efficient use of energy in agriculture will minimize environmental problems, prevent destruction of natural resources and serve to promote sustainable agriculture as an economical production system (Esengun et al., 2007; Erdal et al., 2007). The relation of energy input and energy output in the agroecosystems have been investigated by many researchers for many crops such as sugar beet (Asgharipour et al., 2012; Yousefi et al., 2014), tomato (Moghaddam et al., 2011), pulses (Koocheki et al., 2011) and cotton (Zahedi et al., 2014). Also, many researchers have studied energy and economic analysis to determine the energy efficiency of plant production, such as sugarcane in Morocco (Mrini et al., 2001).

This study aimed to investigate the energy consumption and output in the cultivation of sugar beet in Qazvin province.

2 Materials and methods

This study was conducted in Qazvin province, with an area of 15,623 square kilometers, is located in the central part of Iran and located between the latitudes 35°24′ N and 36°48′ N and longitudes 48°44′ E and 50°51′ E. Qazvin province, with only 1% of Iran area, is close to 5% in Iran's economy and production. To determine the relationship between sugar beet yield and its energy consumption, data were collected from growers using a face-to-face questionnaire. In addition to the survey data, data from previous studies were also used in this study, including those from studies conducted by the Food and Agricultural Organization (FAO) and the Ministry of Agriculture of Iran.

In order to determine the used energy for sugar beet cultivation, the equivalent energy of inputs (such as electricity, fuel, seeds, machines, manpower, fertilizer, poison, etc.) and their contribution to the total energy was calculated. Energy equivalent indicates the amount of energy content that enters or exits in the production process. For example, the equivalent energy considered for each hour of human work for farm work conditions is 1.96 MJ for male workers and 1.57 MJ for female workers, which is equivalent to the amount of energy consumed by them (Singh and Mittal, 1992). To calculate the energy equivalent of input and output, the coefficients and equivalents mentioned in the available sources were used (Table 1).

2.1 Energy calculation

To determine the energy consumption, the amounts of inputs consumed in the cultivation of sugar beet were measured. Then, by placing the amount of energy equivalent to each of the inputs, used energy was calculated. The energy content of each of the inputs and output was determined from Table 1.

Table 1 Energy equivalent of agricultural inputs and outputs

energy input	Type of energy	Unit	Energy content (MJ unit^{-1})	Reference
	worker (male)	hour	1.96	(Sedaghat et al., 2014)
	Tractor	Kg	138	(Kitani, 1999)
	Combine harvester	Kg	116	(Kitani, 1999)
	Farm machinery	hour	62.7	(Royan et al, 2012) (Singh and Mittal, 1992)
	Fuel (Diesel)	litr	47.8	(Kitani, 1999)
	Farmyard manure	Kg	0.3	(Ozkan et al, 2004)
	Nitrogen fertilizer	Kg	78.1	(Kitani, 1999)
	Phosphate fertilizer	Kg	17.4	(Kitani, 1999)
	potash fertilizer	Kg	13.7	(Kitani, 1999)
	Fungicides	Lit	216	(Rafiee et al., 2010)
	herbicide	Lit	238	(Rafiee et al., 2010)
	insecticide	Lit	101.2	(Rafiee et al., 2010)
	Electricity	Kw hr	11.92	(Ozkan et al., 2004)
Energy output				
	Sugar beet tuber	Kg	54	(Kitani, 1999)

2.2 Fuel energy

In the study, the fuel consumption in each sugar beet cultivation operation was obtained from the questionnaires. The total fuel consumption for sugar beet cultivation was calculated. Then, fuel consumption energy was calculated by Equation 1 (Kitani, 1999).

$$E_{fuel} = Q_{fuel} \times EI_{fuel} \quad (1)$$

That: E_{fuel} is fuel energy (MJ ha^{-1}), Q_{fuel} is fuel use rate (Lit hr^{-1}) and EI_{fuel} is energy content per liter of fuel (MJ Lit^{-1}).

2.3 Human labor energy

Human labor (worker) energy consists of used energy by machine operators and farm labors. The required number of labors (person-hours) was determined from the completed questionnaires. The number of labors and the time required to perform farm operations (such as tilling, fertilizing, spraying, weeding in two stages, harvesting, transportation, etc.) were determined. Then, the used labor energy was calculated by Equation 2 (Kitani, 1999).

$$E_{lab} = EI_{lab} \times t \quad (2)$$

That: E_{lab} is used worker (labor) energy (MJ ha^{-1}), EI_{lab} is worker energy equivalent (MJ hr^{-1}) and t is working time required to do farm operations (hr ha^{-1}).

2.4 Machinery energy

Machinery information (including machine weight, machinery life and annual work area) used in sugar beet cultivation was calculated by completing questionnaire information. Machinery energy was calculated by Equation 3 (Singh et al., 2002).

$$E_{Mach} = \frac{G \times I}{L \times A} \quad (3)$$

That: E_{mach} is Energy used to produce machinery (MJ ha^{-1}), I is machinery energy equivalent (MJ Kg^{-1}), G is machinery weight (Kg), L is machinery life (years) and A is annual work area (ha yr^{-1}). Determining the exact life of a machine is very complicated. The life of tractors and agricultural machinery depends on several factors, such as the quality of parts, the way the machine application, climatic conditions, crop and soil conditions, regular periodic services, etc.

The life of some agricultural machinery was determined from Table 2.

Table 2 Working life of some agricultural machines (ASAE, 2005)

Machine	Working life (hours)
Tractor	12000
Plow	2000
Disk harrow	2000
Cultivator	2000
Ditcher	2000
Ridger	2000
Land leveler	2000
Fertilizer distributor	1200
sSeeder	1200
Sprayer	1500
Combine harvester	3000

The weight of some agricultural machines was determined from Table 3.

Table 3 weight of some agricultural machines (Vahedi et al., 2017)

Machine	Weight (Kg)
Tractor MF285	2800
Tractor MF399	3300
Moldboard plow	400
Disk harrow (tandom)	1800
Fertilizer distributor	350
Seed distributor	350
Land leveler	750
Ditcher	250
Sprayer	300
Combine harvester	6800

The energy equivalent of some agricultural machines was determined from Table 4.

Table 4 Energy equivalent of some agricultural machines (Kitani, 1999)

Machine	energy equivalent (MJ Kg^{-1})
Tractor	138
Plow	180
Disk harrow	149
Seeder	133
Fertilizer distributor	129
Combine harvester	116
Annual average of agricultural implements	6-8
Annual average of agricultural machines	8-10

2.5 Seed energy

The seed energy consumption was calculated from Equation 4 (Kitani, 1999).

$$E_s = W_s \times EI_s \tag{4}$$

That: *Es* is used seed energy (MJ ha^{-1}), *Ws* is used seed (Kg ha^{-1}) and *EIs* is equivalent energy per unit of seeds (MJ Kg^{-1}).

Equivalent energy per unit of seeds was determined from Table 5.

Table 5 Equivalent energy per unit of some seeds (Kitani, 1999)

Seed	energy equivalent (MJ Kg^{-1})
Corn hybrid	110
Potato	93
wheat	13
Rice	17
Sugar beet	54
soybeans	34
cotton	44
Alfalfa	230
Oil seeds	200

2.6 Fertilizer energy

The average weight and type of used fertilizers were determined from the completed questionnaires. According to the number of elements in each type of fertilizer, the weight of the four main elements (nitrogen, phosphorus, potassium and sulfur) was determined. Fertilizer energy consumption was calculated using Equation 5 (Kitani, 1999).

$$E_f = W_f \times EI_f \tag{5}$$

That: E_f is fertilizer energy (MJ ha^{-1}), EI_f is equivalent energy per unit of fertilizer (MJ Kg^{-1}) and W_f is used fertilizer (Kg ha^{-1}).

Table 6 Equivalent energy per unit of some pesticides (Kitani, 1999)

	type	energy equivalent (MJ Kg^{-1})
Herbicides	McpA	130
	2-4D	85
	2-4D-T	135
	Ametrvn	250
	Atrazine	190
	Linuron	290
	Metribuzine	250
	Paraquate	460
	Dicdmba	295
	Alachlor	278
	Glvpnosate	454
	Fluazilop b.	518
Fungicides	Cuptan	115
	Maneb	99
	Ferbam	61
	Bcnomvle	397
Insecticides	Carbofuran	454
	Lindanc	58
	Malathion	229
	Metnvle	160
	Cypermethrin	280

2.7 Energy of pesticides

The pesticides were divided into three groups: fungicides, herbicides and insecticides. The equivalent energy of each type of pesticide was determined from Table 6.

Pesticide energy consumption was calculated using Equation 6 (Kitani, 1999).

$$E_p = W_p \times EI_p \tag{6}$$

That: E_p is pesticide energy (MJ ha^{-1}), Wp is used pesticide (Kg ha^{-1}) and EI_p is equivalent energy per unit of pesticide (MJ Kg^{-1}).

2.8 Irrigation energy

Irrigation energy in crops production is divided into two parts: direct and indirect energy. Direct energy includes the energy needed to pump water. Water pumping energy is calculated by Equation 7 (Ercolia et al., 1999).

$$DE_{iTT} = \frac{\gamma g H Q}{\varepsilon_q} \tag{7}$$

That: DE_{irr} is direct irrigation energy (J ha^{-1}), γ is water density (1000 Kg m^{-3}), g is acceleration of gravity (9.81 m s^{-2}), Q is water requirement of the crop in a season (m3.ha-1), H is the total dynamic head, including friction losses (in meters), and ε_q is the overall efficiency of the electric motor and pump (0.18 to 0.8). Indirect energy includes the energy needed to extract raw materials, manufacture and transport all factors involved in irrigation (such as drilling, pumps and piping, facilities, etc.) according to their work lifes. Because calculating indirect energy is very difficult, usually 15%-20% of direct energy is considered (Kitani, 1999).

2.9 Transportation energy

The energy required to transport the product is 1.6-4.5 (MJ ton^{-1} Km^{-1}). In this study, this was considered 3 (MJ ton^{-1} Km^{-1}).

2.10 Output energy

The output energy includes the energy content of the produced crops. The output energy is calculated from the yeilds of crops multiplied by its energy content (Hatirli et al., 2006).

2.11 Energy indices

To study the energy situation in a region or a system and compare it with other regions or systems, standard energy indices are needed.

2.12 Energy ratio

It is the ratio of output (MJ ha^{-1}) to input (MJ ha^{-1}) energy. Energy Ratio was calculated by Equation 8 (Sedaghat et al., 2014).

$$E_R = \frac{Energy_{output}(MJ\ ha^{-1})}{Energy_{input}(MJ\ ha^{-1})} \tag{8}$$

2.13 Energy productivity

It is the amount of produced crops (Kg.ha^{-1}) per unit of energy input (MJ.ha^{-1}). Energy Productivity was calculated by Equation 9 (Sedagha et al., 2014).

$$E_P(Kg\ ha^{-1}) = \frac{Yield(kg\ ha^{-1})}{Energy_{output}(MJ\ ha^{-1})} \tag{9}$$

2.14 Energy rate

This index is the inverse of the energy productivity. It is the energy required to produce one unit (kg) of the crop.

3 Results and discussion

3.1 Energy balance in sugar beet cultivation

Inputs and energy consumption and output energy in sugar beet cultivation are shown in Table 7. The energy consumption in sugar beet cultivation is related to diesel fuel, fertilizer, water for irrigation, electricity, farmyard manure, machinery, human labor and seed, with 12394.5, 12264, 10030.5, 7119, 2557.5, 1780.7, 1684.6 and 120 MJ ha^{-1}, respectively. The total energy input in sugar beet cultivation was calculated as 48723.9 MJ ha^{-1}.

The average yield of sugar beet in this province was 30590.2 kg ha^{-1} and the total energy output in the cultivation of sugar beet was calculated as 513915.37 MJ ha^{-1} (Table 7).

Figure 1 shows the input energy used in sugar beet cultivation in Qazvin province. Chemical fertilizers, fuel, water forirrigation, electricity, and farmyard manure account for the largest share of the total input energy in sugar beet cultivation with 25%, 25%, 21%, 15%, and 5%, respectively. The energy consumption of machinery and labor inputs were ranked next with 4% and 3%, respectively.

The lowest share in the energy consumption of sugar beet cultivation inputs in Qazvin province was determined as 2% and 0.2%, respectively, in the energy consumption of pesticides and seeds.

Table 7 Energy inputs and output in sugar beet cultivation

inputs		units	Amount of input consumed (U)	Energy input ($MJ.ha^{-1}$)	Energy input (%)
Energy inputs					
Human labor		hr ha^{-1}	859.5	1684.6	3.5
Machinery		hr ha^{-1}	28.4	1780.7	3.7
Fuel (Diesel)		Lit ha^{-1}	259.3	12394.5	25.4
Fertilizer		Kg ha^{-1}			
	Nitrogen		143.4	11199.5	23.0
	Phosphate		11.3	154.8	0.3
	Potash		81.5	908.7	1.9
Farmyard manure		Kg ha^{-1}	8525.1	2557.5	5.2
Electricity		Kw hr	198.3	7119.0	14.6
Pesticides					
herbicide		Lit ha^{-1}	1.1	261.8	0.5
Fungicides		Kg ha^{-1}	1.2	259.2	0.5
Insecticides		Kg ha^{-1}	2.5	253.0	0.5
Water for irrigation		m^3 ha^{-1}	9833.8	10030.5	20.6
Seed		Kg ha^{-1}	2.4	120.0	0.2
Total energy input				48723.9	100.0
Energy output					
Sugar beet tuber		Kg ha^{-1}	30590.2	513915.36	

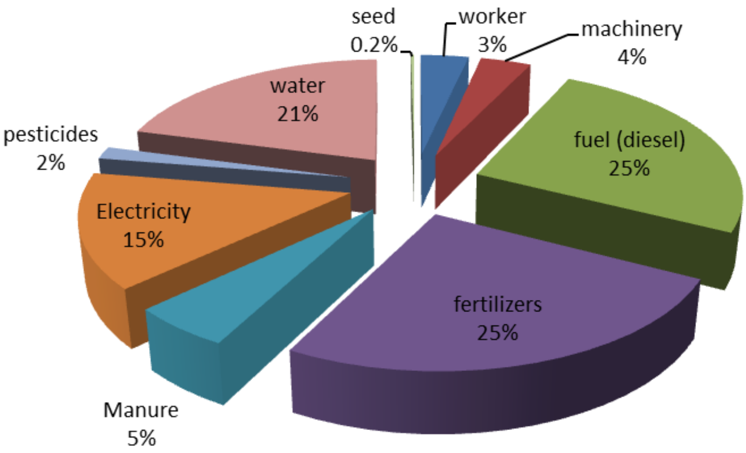

Figure 1 Energy contribution of inputs in sugar beet cultivation

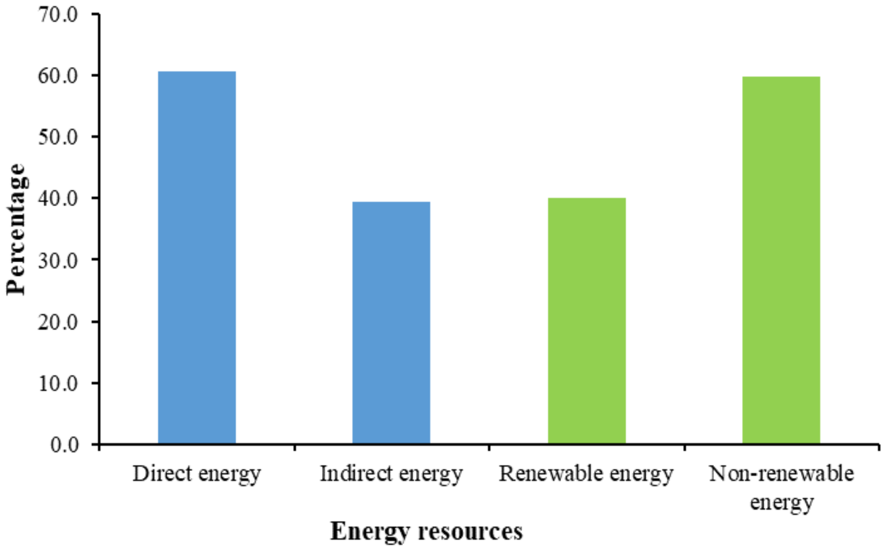

Figure 2 Types of energy input in sugar beet cultivation

60.6% of the total energy input in sugar beet cultivation is direct energy and 39.4% is indirect energy (Figure 2). Also, 40.1% of the input energy was determined as renewable energy and 59.9% as non-renewable energy.

3.2 Energy indices

Energy indices in sugar beet cultivation in Qazvin province are determined in Table 8. As Table 8 shows, the energy ratio of sugar beet cultivation is 10.5. Energy productivity, which is an important index in energy studies, was found to be 0.63 Kg MJ^{-1} in this study. In other words, for every MJ of energy consumed, sugar beet cultivation systems in Qazvin province produce 0.63 kg of sugar beet.

The energy net gain index in sugar beet cultivation in this province states that the total energy output from sugar beet cultivation systems is on average 465191.5 MJ ha^{-1} more than the total input energy. The energy rate index calculated in Table 8 shows that 1.59 MJ of energy was consumed per kg of sugar beet produced in Qazvin province.

Table 8 Energy indices in sugar beet cultivation

Energy ratio	Energy productivity (Kg ha^{-1})	Energy net gain (MJ ha^{-1})	Energy rate (MJ Kg^{-1})
10.5	0.63	465191.5	1.59

4 Conclusion

- The total input energy in sugar beet cultivation in Qazvin province was 48723.9 MJ ha^{-1}. The average yield of sugar beet in Qazvin province was 30590.2 Kg ha^{-1} and the total energy output in the cultivation of sugar beet in these three provinces was calculated as 513915.36 MJ ha^{-1}.

- The average indices of energy ratio, energy productivity, energy net gain and energy rate in sugar beet cultivation in Qazvin province were obtained as 10.5, 0.63 (Kg MJ^{-1}), 465191.5 (MJ ha^{-1}) and 1.59 (MJ Kg^{-1}) respectively.

Recommendations

- In order to optimize fuel consumption and increase efficiency and energy productivity, it is suggested to use compound machines in land preparation and planting operations, and also to replace new machines with old and worn-out machines.

- Due to the high consumption of fossil fuels to carry out field preparation operations by tools, as well as the high energy of fossil fuel compared to other inputs, it is suggested to train farmers and especially the operators of agricultural machines. In order to use the tractor correctly and choose the appropriate implement, as well as achieve the best combination of land preparation machines, it reduced the consumption of fossil fuels.

- Applying crop rotation appropriate to the studied areas, which requires conducting studies in this field; can reduce the consumption of inputs and subsequently reduce the environmental effects caused by the consumption of inputs, including the effects caused by the excessive use of nitrogen fertilizers.

- Carrying out the necessary measures and teaching methods to prevent the burning of straw and stubble left over after harvest; In addition to reducing the environmental impact, preventing the burning of the remaining residues can create conditions for reducing the use of chemical fertilizers and increasing yield.

- The equivalent energy of chemical fertilizers, especially nitrogen fertilizer, is very high. Therefore, a lot of energy is used to produce this type of fertilizer. Using farmyard manure can be a good alternative to chemical fertilizers, which can both reduce the energy consumption of chemical fertilizers and prevent the destruction of soil structure.

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