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Energy use Efficiency and Cost-Benefit Analysis of Sugar Beet (*Beta vulgaris*) Production in the Irrigated Central Clay Plain of Guneid Area - Sudan

Mohamed Hassan Dahab[1*], Elwaleed M. H. Basheeir[2] and Omer Ahmed Abdallah[1]

[1]*Faculty of Agriculture, University of Khartoum, Shambat, Sudan.*
[2]*Faculty of Agricultural Sciences, University of Gezira, Sudan.*

Authors' contributions

This work was carried out in collaboration among all authors. Author MHD designed the study, performed the statistical analysis, wrote the protocol and the first draft of the manuscript. Author EMHB performed the field work and managed the analyses of the study. Author OAA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The main objectives of this study were to determine and analyze energy use efficiency in sugar beet production, and to make cost-benefit analysis in Guneid area - Sudan. An experiment was carried out using three tillage implements (disc plough, disc harrow and ridger) for land preparation, seven days irrigation interval and mechanical planter. The treatments were replicated four times in a completely randomized block design. The results showed that total energy consumption in sugar beet production was 35099.20MJha^{-1}, out of which 52.33% of fertilizer energy, 18.0% water energy and 9.0% of diesel energy. The energy use ratio was 28.71 and energy productivity was 1.71kgMJha^{-1}. The results also showed that 73.6% of total energy input was in non-renewable energy form, and only 26.4% was in renewable form, while 34.1% was in from of direct energy and 65.9% indirect energy. Cost-Benefit analyses showed that the total return, net return, benefit–cost ratio and productivity of crop were 2689.6 US$ha^{-1}, 990.8 US$ha^{-1}, 1.58. and 35.3kgUSD^{-1} respectively. Although large amounts of energy consumption for sugar beet production increased

**Corresponding author: E-mail: mhdahabahmed55@yahoo.com;*

the yield, it also caused in problems related to environmental pollution, land degradation, nutrient loading and pesticide toxicity. Therefore, it is important to look for methods and systems that can reduce the negative effect of high energy inputs and to develop more efficient, economical and environmentally friendly agricultural production systems that increase energy use efficiency and crop yield.

Keywords: Energy; input – output; energy use efficiency; cost-benefit analysis; Guneid; sugar beet.

1. INTRODUCTION

Agriculture is the primary source of employment, food and raw material for the majority of the world countries and population. It is known that agricultural operations are taking progressing manner regarding new inputs, food storage and new farming techniques and therefore, more energy required in one form or another, human labour, animal power, fertilizer, machinery, chemicals, fuel and electricity. To meet the growing demand of the increasing population and economy, the productivity of land to be increased, this would substantially require higher energy input and better management of production system [1]. Therefore, in order to sustain agricultural production, effective energy use is required, which provides ultimate financial saving, preservation of energy resources and reduction of environmental hazards [2]. The energy used in agricultural can be divided into direct energy and indirect energy, which is not directly used on the fields for crop production such as fertilizer, seed and chemicals. Also, the energy may be classified into physical, chemical and biological energy or renewable and non-renewable energy [3]. Many research outputs have showed energy use in agriculture and economic analysis to determine the energy use ratios for crop production in many countries e.g. [4,5,6,7,8,9,10]. Energy utilization in field level usually varies with farm size, crop growing, production practices and physical environmental [11]. However, availability of farm mechanization for high rate of application in specific time helps farmers to use different production strategies which resulted in increased food and crop production. Higher productivity per unit area and putting more areas under high yielding crops, this could increase the share of agriculture in the national energy consumption [12].

Sugar beet products are used for many objectives, as sugar human and as fodder for livestock nutrition and also for industrial needs. Sugar production from sugar beet is about 25% of the world's sugar production [13]. On the other hand, sugar beet is also used for biofuel land alcohol production. The total production of the world from sugar beets estimated to be 271.6 million metric tons [14].The two main sources of sucrose for human consumption are sugar cane and sugar beet. About one fourth of the world's sugar production comes from sugar beet (about 40 million tons in 1999), and sugar content of sugar beet is about 25% higher than that found in sugar cane [15].

Sudan is one of the world largest potential areas for agricultural production and the estimated arable land for agriculture is more than 8.4 million hectares, which is equivalent to about 32% of total arable land in Africa [16]. Out of this great area only 25% is currently under cultivation. Sugar beet is not widely grown in Sudan, but recently introduced. Several variety adaptability trials were carried out at Guneid and Sennar 1998/1999, Kenana 2000/2001[17]. They all reported encouraging results of root and sugar yields, with 15.6% sugar content was reported in season 2002/2003 in experiments conducted at Dongola Research Station. Recently some intensive work is being carried out at Guneid Sugarcane Research Center and Gezira Scheme to test the adaptability of several varieties and to determine the suitable cultural practices such as sowing/harvesting dates, fertilizer rates, irrigation and weed control. Although most of energy inputs are used for crop production in Sudan from different resources, but still not well estimated and the component energy items are not well identified since it is recently introduced for sugar production. The output of the crop is low. The main objective of the study is to evaluate the energy inputs during field different operations and the energy outputs for production of sugar beet crop. Together with the energy efficiency and the cost –benefit analysis of the sugar beet production.

2. MATERIALS AND METHODS

This study was conducted at Guneid Sugar Cane Research Center which lies on the eastern bank of the Blue Nile, Gezira State, for two successive growing seasons, April 2014 and 2015. The soil is classified as aridisol, low in organic matter, total nitrogen (< 0.05%), organic carbon 0.41%, and low in available P (< 10 ppm). The mechanical analysis classified the soil as clay-loam, with the average bulk density 1.75 gm/cm^3. Guneid Sugarcane Scheme falls within the aridic climatic zone. The land was prepared by the tillage implement disc plough before three weeks from planting for every replication, then the land was harrowed by the disc harrow before one week from planting and also furrowed by ridger at the same time of planting. A pneumatic planter with four units was calibrated and used for planting the seed at 75 cm between rows and 15 cm between plants. Lenard, monogerm seed type was used for planting the experiment field. The irrigation water was applied after planting every 7 days during the growing season according to Crop Watt program version- 8. Two types of fertilizers were applied, superphosphate and urea. The recommended dose from superphosphate was 119 Kg per hectare and was added at seeding. The urea fertilizer recommended was 238 Kg per hectare and was applied in two doses, the first at seeding and the second after 45 days from germination. Attakan 350sc insecticide was used to control the termites in sugar beet. The total quantity of the insecticide used was 2.2 kg/ha. Two weeding's were carried out using a hand tool (Naggama), the first after one month from planting and the second was after two months. The thinning was done during the second weeding. The number and periods of operations, fuel consumption, irrigation water, fertilizer, weeding, sowing rate and amount of human labour, were investigated. Data for energy input resources and energy outputs were obtained from the available information in literatures and other resources (Table 1). There are a lot of variations in energy equivalents reported in literature. These variations may be the result of differences in the calculation methods and in the spatial and temporary system limits.

Energy input resources data for different farm operations of the crop was collected, from land preparation until crop harvesting. The total energy inputs in (MJ/ha) was calculated as ∑(physical + chemical + biological).Human energy input was calculated as man-days hrs/ha for field operations, multiplied by energy equivalent of human labour (Tables 2, 3). Fuel energy (diesel) in (MJ/ha) was calculated fuel consumed by the machines and energy equivalent of diesel fuel (Table 3). Machinery energy input was determined from the weight of the machine (kg) and annual area covered by the machine as follows:

$$\text{Machinery energy (MJ/ha)} = EEm \times [MW/Aa] \quad (1)$$

Where; MW = machinery weight (kg), EEm = machinery energy equivalent in (MJ/kg), Aa = annual planted area (ha).

Table 1. Energy equivalents of different inputs and output in sugar beet production

Inputs	Units	Equiv. Energy ($MJunit^{-1}$)
1. Seed	Kg	50.0
2. Agrochemicals		
i) Nitrogen	Kg	75.4
ii) Phosphorus	Kg	17.4
iii) Pesticides	Kg	120.0
3. Mechanical power		
i) Diesel	L	56.3
ii) Tractor	Kg	92.6
iii) Machinery	Kg	86.8
4. Human labour	hr	1.96
5. Water	m^3	1.02
6. Output	Kg	16.8

Source: [4,7,1]

Other production energy inputs were computed from rates of application and energy equivalents of the inputs (Table 3). In this study it was assumed the harvested sugar beet root as the only output product of the plant. The total energy inputs were grouped into direct and indirect, as well as renewable and non-renewable forms and also as physical, chemical and biological energy. Direct energy included labour, diesel and water. While indirect energy covers machinery, seeds, chemicals and fertilizers. On the other hand, renewable energy included labour and seed. Non-renewable energy included machinery, diesel, chemicals and fertilizers [18,19].

According to the energy data in (Table 1) for sugar beet production, the following were estimated:

$$SpEn = EnIP/Yd, \quad (2)$$

$$EnR = EnOP/EnIP, \quad (3)$$

$$EnPd = Yd/EnIP, \quad (4)$$

$$NtEG = EnOP - EnIP \quad (5)$$

Where: SpEn is the specific energy input (MJ/kg), EnIP is the energy input in the production (MJ/ha), Yd is crop yield (kg/ha), EnR is energy ratio, EnOP is the energy output of the production (MJ/ha), EnPd is energy productivity(kg/MJ), and NtEG is net energy gain (MJ/ha).The energy inputs were calculated by multiplying the material input by the referent energy equivalent [9,20]. Human labour and diesel used were classified as direct energy inputs while seeds, fertilizers, pesticides, and water were grouped as indirect energy [9]. In other classification, non-renewable energy includes diesel, chemical, and fertilizers and renewable energy consists of human labour and seeds [9]. Cost – benefit analysis was used to determine the economic energy benefits of sugar beet production. The production cost of sugar beet in this study was calculated based on hiring rates of operations at the time of research study especially labour and machinery. The variable costs of production included costs such as seed, fertilizers, pesticides, fuel, and all other costs that varied depending on a farm production volume. Variable and fixed costs comprised the total cost. The crop output used for cost-benefit analysis included only the major product for sugar beet which included the root yield. All prices of the input and output were average prices over the experiment period. The analysis of total and net returns, benefit-to-cost ratio and productivity [21] as follows:

$$NtRn = TPV - TPC, \quad (6)$$

$$BtCR = TPV / TPC, \quad (7)$$

$$Pd = Yd/TPC, \quad (8)$$

Where: TPV is the total production value (USDha^{-1}), NtRn is the net return (USD_ha^{-1}), TPC stands for the total production cost (USDha^{-1}), BtCR is the benefit-to-cost ratio and Pd is productivity kg/USDha^{-1}. The economic efficiency of energy [22] was based on NtRn and it is in accordance with the methodology given by [22].

3. RESULTS AND DISCUSSION

The human energy calculation was based on man-days required to carry out the different operations for crop production. The man-days requirement for production of sugar beet after conversion into hours of work per feddan is given in Table 2. The total human labour energy consumed to carry out the different types of operations in this study was 2489.61 MJha^{-1} as shown in Table 3.

3.1 Energy Use Analysis in Sugar Beet Production

Energy inputs and output amounts for all items used for sugar beet production, energy equivalences and percentages output are given in Table 4. It can be observed that, total energy consumption in sugar beet production was 35099 MJha^{-1}. More than half of the total energy (51.1%), was used through the urea fertilizer application having a share of 17,945.20 MJha^{-1} in the total energy consumption (Table 4). This is in line with the findings of [9,23]. The second intensive energy source in sugar beet production of this study was irrigation water, with a share of 18.0%, then followed by the fuel energy with a share of 9.0%. The contribution percentages of different input item are shown in Fig. 1.

The average sugar beet yield of this study was 59.98 t ha^{-1} with the energy output of 1007596.8 MJha^{-1} and energy use efficiency of 28.71 (Table 4). This is closer to that reported by [9] as an average annual yield of 60.82tons ha^{-1} and energy ratio of 25.75. It is also similar to the previous decades both in Europe and in the

Table 2. Total man power used (man-h/feddan) for different farm operations

Items	No of labor	Time (hour)	Area (feddan)	T. man power (man-h/feddan)
Disc plow	2	0.3	0.34	4.0
Disc harrow	2	0.13	0.34	2.06
Ridger	2	1.3	1.37	2.32
planter	2	0.45	1.37	2.63
Field preparation	3	3.5	1.37	7.83
Weeding	36	6	1.37	157.66
Thinning	4	2	0.685	11.68
Insecticide application	1	3.6	1.37	2.63
Fertilization application	2	5.4	1.37	7.88
Irrigation	20×2	2.5	0.456	219.45
Harvesting and collecting	20	1.04	0.18	115.56

Table 3. Energy equivalents MJ/ha of labor inputs different operations for sugar beet production

Item	Total hrs /ha	Equiv. Engy MJ/unit	MJ/ha
Machine Labour /hr	26.20 hr.ha	1.96	51.35
Field preparation	18.63 hr/ha	1.96	36.51
Weeding	375.24 hr/ha	1.96	731.06
Thinning	27.80 hr/ha	1.96	54.49
Insecticide application	6.26 hr/ha	1.96	12.27
Fertilization application	18.76 hr/ha	1.96	36.77
Irrigation water application	522.29 hr/ha	1.96	1023.69
Harvesting	275.03 hr/ha	1.96	438.63
Total	1270.21		2489.61

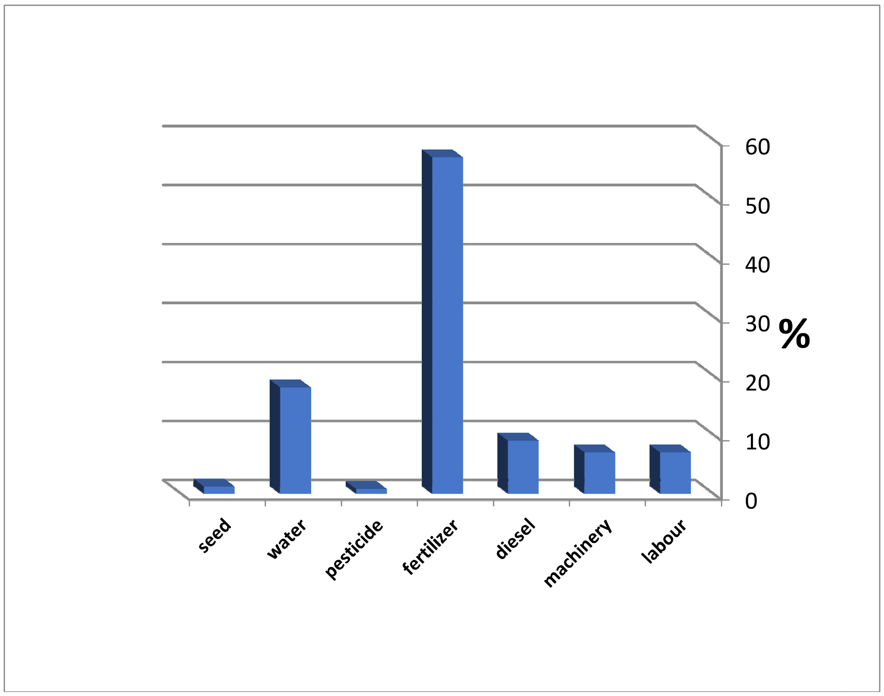

Fig. 1. Energy input percentages for sugar beet production

world outputs which was around 59.6 tha^{-1}[14]. Other studies, [24] reported sugar beet yield, total energy input and output, and output/input ratio as 44.6 tons ha^{-1}, 20 567MJha^{-1}, 103 862MJ ha^{-1}and 5.04, respectively. It was also reported that total energy input used in sugar beet production was 32900MJ ha^{-1} and the calculated energy output/input ratio was 19.15 [25].Total energy input used was reported as 50630 MJha^{-1} [3], In another study, sugar beet yield, total energy input and output were found 48,157.40 kgha^{-1}, 27,848.92MJha^{-1} and 809,044.00MJha^{-1}respectively[10]. As for the energy ratio, it was stated by [26] that if it is higher than one, the system earns energy, but if it is less than one, the system will lose energy.

3.2 Total Energy Input Resources Investigation

The direct, indirect, renewable and non-renewable forms of total energies are given in Table 5. It can be observed that 73.6% of total energy input resulted from non-renewable and 26.4% from renewable energy and 34.1% from direct energy and 65.9% indirect energy. Intensity of non-renewable energy consumption resulted from the chemical fertilizer and water used in production. A similar energy use pattern was reported by [27] for the Kirklareli province in Turkey, where the share of fertilizer was with 41.97%, followed by diesel fuel (21.16%) and irrigation (11.97%), while in the Tokat province, it was reported by [9] as the highest share of the fertilizer in the energy input as (49.33%). The total energy input for sugar beet production system in Iran, the Khorasan Razavi province was 42,231.9 $MJha^{-1}$ and the direct energy input had its share of 56.9% [19]. It was reported that in sugar beet production, 82.43% of total energy input resulted from non-renewable and 12.82% from renewable energy [9]. They also reported 29.62% of energy input as from direct energy and 65.64%was indirect energy. Similar results were observed in a study carried out in Serbia where the non-renewable energy share was 96.93%, mainly due to fertilizers [10]. The energy efficiency of sugar beet production may be evaluated by energy parameters such as specific energy input, energy productivity, and net energy gain).The specific energy input gives an idea about how much energy is spent on the yield obtained. The average specific energy input of sugar beet production in this study was 0.59 $MJkg^{-1}$ of energy was needed to produce one kilogram of the product, where as the energy productivity was 1.71 $kgMJ^{-1}$and the net energy gain in this study was 972497 $MJha^{-1}$ (Table 5). In case of sugar beet production in Turkey the reported net energy gain were 982,090.5 $MJha^{-1}$ [9] and 251,398.25 $MJha^{-1}$ [27] while in Serbia it was 781,195.40 $MJha^{-1}$ [29].

Generally, more energy was needed for sugar beet production on the unit area and higher sugar beet yields of around 60 tha^{-1} were reported by many studies [30, 13, 28], but lower value of specific energy output, 0.5 $MJkg^{-1}$, was reported for the Kirklareli province in Turkey [27]. Energy productivity gives an idea about how much product is produced per unit of input energy. Energy productivity and energy ratio are in direct relation, Energy productivity is specific for each farm product, location, and affected by time [28]. It can be used as an evaluator of how efficiently energy is used in different production systems. Energy productivity in a process may be improved either by reducing the energy consumed in inputs or by increasing the yield of the crop. It was reported that the energy productivity in sugar beet production in Serbia, was1.57 $kgMJ^{-1}$ with the sugar beet yield of 48.16 tha^{-1} while the energy productivity recorded in this study was 1.71$kgMJ^{-1}$ with crop yield of 59.98 tha^{-1} and in the case of the Turkish province of Kirklareli, [27] the energy productivity was 1.98 $kgMJ^{-1}$ and sugar beet yield was 68 tha^{-1}. These results confirmed that energy productivity increases as the yield increases.

The amount of physical energy in the total input energy was 14368.8$MJha^{-1}$ (40.9%), and the share of human labour in the physical energy for production of sugar beet was 17.3%. Material energy inputs which included chemical energy and biological energy from seeds. was the highest energy component compared to other energy sources (59.1%). This is in line with the findings that reported by [8].

3.3 Economic Analysis of Sugar Beet Production

The results of the calculated cost-benefit analysis show that sugar beet production with a net return of 990.8 $USDha^{-1}$, 0.02 $USDkg^{-1}$ and 0.001$USDMJ^{-1}$ (Table 6). It is important to note that the total return and net return per MJ which reflects the economic efficiency of energy used were 0.003 and 0.001 respectively. The benefit-to-cost ratio for the sugar beet production in the study was 1.58, while the productivity was 35.3 kg USD^{-1} which indicates the amount in kg of

Table 4. Energy equivalents of different inputs and output for sugar beet

Item	Total units /ha	Equiv. Energy MJ/unit	MJ/ha	%
Labour /hr	1270.21	1.96	2489.61	7.0
Tractor/ kg	14.8 /ha	91.6	1355.68	3.9
Machinery /kg	12.13 /ha	86.8	1052.90	3.0
Diesel /l	56.06 /ha	56.3	3156.18	9.0
Nitrogen fert/kg	238kg/ha	75.4	17945.20	51.1
Phosphorus /kg	119kg/ha	17.4	2070.6	5.9
Pesticide /kg	2.19kg/ha	120.0	262.8	0.75
Water /m^3	6190.4m^3	1.02	6314.16	18.0
Seed /kg	9.04 kg/ha	50.0	452.0	1.29
Total input			35099.13	100.0
Output /kg	59976 kg/ha	16.8	1007596.8	
Energy use efficiency	--	-	28.71	

Table 5. Total energy input in the form of direct, indirect, renewable and non-renewablefor sugar beet production (MJ ha^{-1})

Item	Unit	Energy relations
Specific energy	MJkg^{-1}	0.59
Energy productivity	kgMJ^{-1}	1.71
Net energy gain	MJha^{-1}	972497
Direct energy[a]	MJha^{-1}	11960 (34.1%)
Indirect energy[b]	MJha^{-1}	23139.2 (65.9%)
Renewable energy[c]	MJha^{-1}	9255.8 (26.4%)
Non-renewable energy[d]	MJha^{-1}	25843.4 (73.6%)
Physical energy [e]	MJha^{-1}	14368.8 (40.9%)
Material energy (chemical +biological)[f]	MJha^{-1}	20730.6 (59.1%)

[a] = human labour, diesel and water, [b] = seed, fertilizers, chemicals and machinery,
[c] = human labour and seed, [d] = diesel, chemicals, fertilizers and machinery, water
[e] = human labour, machinery, diesel and water, [f] = chemicals, fertilizers and seed

Table 6. Cost /benefit analysis and productivity of the sugar beet production

Item	USDha^{-1}	USDkg^{-1}	USDMJ^{-1}
Total cost	1698.8	--	--
Total return	2689.6	0.04	0.003
Net return	990.8	0.02	0.001
Benefit/cost ratio	1.58	--	--
Productivity	35.3kgUSD^{-1}	0.03	--

US$ = 6.7 SDG

crop product per dollar spent on the production of sugar beet. It was only 0.03 dollar was spent to produce one kg of the sugar beet production. It was reported the total production cost of sugar beet was 3569.83 $ ha^{-1}, and the total production value was 4 183.30 $ ha^{-1} and the net return was 613,5 $ha^{-1} whereas benefit–cost ratio 1.17 [9]. In another study it was reported that the total and net returns from sugar beet production in Serbia were 905.5 and 513.53 USDha^{-1} respectively, while the benefit to cost ratio and productivity were 1.33 and 31.19 respectively [10]. These findings are in agreement with outputs of the present study.

4. CONCLUSION

- Energy inputs analysis for the sugar beet crop production showed that energy input from fertilizer and irrigation water was the highest and the share of machinery and labour energy was low.
- Indirect energy, nonrenewable energy and the material energy were the main sources of energy inputs for production of sugar beet.
- Energy consumption may be reduced by using lower recommended doses of urea fertilizers and proper timing of field operations.
- It is important to suggest methods and practices that may reduce the negative effect of high energy inputs such as pollution, global warming and to develop more efficient, economical and environment friendly production systems and increase energy use efficiency.
- High energy input use to increase yields may not lead maximum profits due to increasing production costs. In addition, increased input use may result in excessive use of natural resources.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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