

Original Research Article

Energy use efficiency of Sugar cane production in the central clay plain of Kenana area

ABSTRACT: Sugarcane is one of the strategic cash crops in Sudan for production of sugar and other products for local consumption and export. The objective of this research study was to investigate and calculate the amounts of energy used in sugarcane production, to evaluate the energy use efficiency at Kenana Sugarcane Company. Data were collected from this company and literature to compute the required energy parameters. The results indicated that total energy input was 85496.6 MJha⁻¹ and total energy output was 112812 MJha⁻¹ and urea fertilizer energy used in sugarcane production systems had the highest share with 37.0 percent, followed by electricity for irrigation pumps, diesel fuel and seed cuttings used, as 17.1, 15.5 and 13.4 percent energy respectively. The energy use efficiency, energy productivity, specific energy, renewable energy and non-renewable energy of sugarcane production were 1.31, 1.10 KgMJ⁻¹, 0.91 MJkg⁻¹, 19989.2 MJha⁻¹, 65507.4 MJha⁻¹ and 26980 MJha⁻¹ respectively. The energy use efficiency of sugarcane production shows value higher than one, so the system earned energy for sugarcane production in Kenana-Sudan.

Key words: Input energy, output energy, Energy use efficiency, sugarcane, Sudan.

1. INTRODUCTION

Agriculture is the primary source of employment for the majority of the world population. It is known that agricultural operations are taking progressing manner regarding new inputs, food storage and new farming techniques [1]. All agricultural field operations require many types of energy, human labour, fertilizer, machinery, chemicals, fuel and electricity. Higher energy input and better management of production system may be required to increase land productivity to meet the increasing world population demand and raw materials [2]. Therefore, effective energy use of inputs is required to sustain agricultural production, since it provides cost saving, preservation of chemicals use and reduction of environmental distortion [3]. Energy required in agriculture may be divided into direct energy and indirect energy, such as fertilizer, seed and chemicals. Also, it may be grouped into physical, chemical and biological energy or renewable and non-renewable energy [4]. There are many research studies have been carried out in some countries to investigate energy use in agriculture to determine the energy use efficiency for crop production and economic analysis e.g. [5, 6, 7, 8, 9, 10,11and 12]. The amounts of energy use in farms usually vary with farm size, the crop grown, the practices used in production and environmental effects [13]. Mechanical power may help farmers to increase the areas under production and yield per unit area and consequently may increase food and crop production by consuming more energy [14].

Sugar-cane of the genus *Saccharum*, belonging to the family *Gramineae*, is grown in many different countries worldwide and well adapted to dry subtropical savannahs [15]. The main sugar cane producers include Brazil, India, Cuba, China, Mexico, the Philippines, South Africa, Australia and the USA, and some smaller nations in the Caribbean, Latin America, Africa, and even in Europe [16]. Variations in climate, soil types and in farming practice caused in crops with widely differing yields grown for from 9 months to almost 2 years between harvests. Yields of cane per hectare vary from 20 ton to over 200 tons with an annual present national average of most developed countries at about 80 cane tons per hectare and developing countries averaging about 54 tons per hectare [17]. By 2013 total world production of sugar from sugarcane and sugar beet was 160 million tons out of which 75% was from sugar cane [18].

The energy consumption for production of sugarcane was observed the highest as compared to many other crops such as cotton, sesame, wheat, sorghum etc [19, 20, 21]. Considering the present trend of labour availability for sugarcane production, it has been experienced that the use of advanced machinery is very important. Which will help in saving of labour, timeliness of operations, reduces drudgery, improving quality of work, reduces cost of operation and ensures effective utilization of resources [7, 22, 23].

The total cultivable area in the Sudan is about 200 million feddan of which only 41 million feddans are under crop production [24]. Agriculture (crops + animals) contributes directly to the Gross Domestic Product (GDP) of the country by 36.8 percent and indirectly by influencing other sectors activities. The crops sector contributes with 56.5 percent of total agricultural sector [25]. There are number of cash crops grown in this sector, such as cotton, sesame, sunflower, groundnuts, gum Arabic and sugar cane as one of the major strategic crops in the country. Sugar production in the country started for the first time in Gunied area (1962-1963) and there are five sugar producing companies established from 1962 to 1980, four of them are governmental which are successively Elguneid, New Halfa, North East Sinnar and Assalaya, which are. The fifth one is share with private sector which is Kenana Sugar Company that started its production in March 1981, and recently the White Nile sugar company [16].

The energy used for carrying out the field operations for production of sugar cane is mostly came from human, chemical and mechanical power [26, 27]. It is mainly used for land preparation, planting, weeding, spraying, fertilizer application, harvesting and transportation. Although many energy input resources are used for sugar cane and other crops production in Sudan, but still the contribution of the different types of energy and the output of these crops is not well identified. The main objective of this study was to evaluate the energy inputs required for the different field operations and the energy outputs for production of sugar cane crop in Kenana Sugar Company.

2. MATERIALS AND METHODS

2.1 The study area:

This study was conducted at Kenana Sugar Company, Sudan, which located on the eastern bank of the White Nile near Rabak town about 300 Km south of Khartoum. The scheme extended in a plain clay soil which slopes towards the White Nile. The soil is of the scheme classified as aridisol, with organic matter, total nitrogen and available Phosphor. The soil was classified as heavy clay with clay content 65% (dominant motimorillonite element), silt 11% and sand 24%. The soil is non-saline, non-sodic with pH range of 7.5-8.0. Kenana Sugarcane Scheme falls within the aridic climatic zone with maximum rainfall in August about 340mm. The total area of the scheme is about 67000 ha, while the area planted annually is about 40000ha.

2.2 Field operations:

The land preparation started by uprooting of the previous crop using heavy ripper and disc harrow of 20-disc units. After 2-4 weeks then the land was re-harrowed also by the heavy breaker implement. The land was leveled using large tractor drawn scrapers or by motor graders. Big ridgers were used to make large furrows spaced 150-155cm. Planting carried out manually or mechanically by a planting machine at a seed rate of 6-8 ton/ha. The irrigation water was applied after planting every 7- 10 days during the growing season by pumping the water from the White Nile and using long furrows. 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 recommended amount of urea fertilizer was 476 Kg per hectare and was applied in two doses, the first dose at seeding and the second after 45 days from germination. Recently DAP fertilizer is used which includes the potassium element. Growth regulators were used at a rate of 1.4 l/ha. There are some herbicides which were used to control weeds at a rate of (5.0 l/ha+6.7 kg/ha). The number and duration of different operations carried out, fuel consumption and amounts of human labour and machinery were also investigated. Data for the study was collected and obtained from field visits, agricultural engineers and other people working in the company and also from the available information in literatures and other resources (Table 1). There are many differences in energy equivalents reported in literature. These variations may be due to differences in the calculation methods and in the locality and timeliness of system boundaries.

2.3 Input and output energy calculations:

The data collected included energy inputs for different farm operations, from land preparation up to crop harvesting as output energy. The total energy inputs in mega-jule per hectare (MJ/ha) was calculated as total of labour, mechanical, and agrochemical energy. Labour energy input was calculated as hours of work of labour for field operations, multiplied by energy coefficient of human labour (Table 1). Fuel consumed by the machinery and tractors to carry out the field operations per hour was converted into energy as MJ/ha by using energy equivalent of diesel fuel. Machinery energy input was

determined from the weight of the machine (kg) and annual area covered by the machinery during the season and energy coefficients. Other production energy inputs, as agrochemicals, electricity and irrigation water were computed from rates of application and energy equivalents of these inputs (Table 1). The harvested sugar cane stalks was assumed as the only output product of the plant and multiplied by energy equivalent. Sometimes and for comparison, the total energy input was classified into direct and indirect, as well as renewable and non-renewable forms. Direct energy included labour, diesel and water. While indirect energy covers machinery, sugar cane stems, chemicals and fertilizers [28]. On the other hand, renewable energy included labour, irrigation water and sugar cane stem. Non-renewable energy included machinery, diesel, chemicals and fertilizers [3, 29].

Table 1. Equivalent coefficients for various sources of energy used.

Inputs	Units	Equiv. Energy(MJunit ⁻¹)
Human labour	Man-hr	1.96
Diesel	lit	56.3
Machinery	kg	62.7
Electricity	kwh	3.6
irrigation	m ³	1.02
Tractor	kg	91.6
Nitrogen	kg	75.4
phosphorus	kg	12.44
Potash	kg	6.7
Chemicals		
Needing dilution	lit	120
Not needing dilution	kg	10
Sugar cane stem cuttings	kg	1.2

Source ;[2, 5,7,30, 31]

Based on the data of sugar cane crop production and energy coefficients, specific energy input, energy output–input ratio, energy productivity and net energy gain were estimated as follows:

$$SpEn = InEn/Yld, \quad (1)$$

$$EnRatio = OtEn /InEn, \quad (2)$$

$$EnPd = Yld/InEn, \quad (3)$$

$$NtEnGn = OtEn -InEn \quad (4)$$

Where; SpEn is the specific energy in (MJ/kg), InEn is the energy input in the production system (MJ/ha), Yld is yield in (kg/ha), EnRatio is energy ratio, OtEn is the energy output of the production (MJ/ha), EnPd is energy productivity (kg/MJ), and NtEnGn is net energy gain (MJ/ha). These relations are similar to that reported by [32].

3. RESULTS AND DISCUSSION

3.1. Energy input, output analysis of sugarcane production

Amounts of inputs used and output for sugar cane production and energy equivalences and percentages of different inputs are illustrated in Table 2. As it can be observed, the average total energy consumption for sugar cane production was 85496 MJha^{-1} . This is closer to those reported by [30]. More than 30% of the input energy used in production, $31606.4 \text{ MJha}^{-1}$, was consumed through the urea fertilizer application (Fig. 1). This can be explained since sugar cane is a very intensive crop in terms of fertilizer use [33]. The second intensive energy source in sugar cane production was water pump electricity followed by fuel energy, with a share of 17.1% and 15.5% respectively. The input seed energy ranked fourth with a share of 13.4% (Fig.2). The average sugar cane production in this study was 94010 kg ha^{-1} with energy output of $112812.0 \text{ MJha}^{-1}$ and energy use efficiency of 1.32. [7] reported an average annual yield of $93.5 \text{ tons ha}^{-1}$, output energy of 112220 MJha^{-1} , and energy output/input ratio of 0.76, which are very close to the findings of this study. In other studies, [34] reported sugar cane total energy input and output, and energy use efficiency as 49240 MJha^{-1} , 261530 MJha^{-1} and 5.3, respectively. The direct, indirect, renewable and non-renewable forms energy input are shown in Table 3. As it can be observed 42.6% from direct energy and 57.4% indirect energy, therefore the indirect source was higher. The non-renewable share of total energy input was 76.6%, while 23.4% from renewable energy. The percentage of non-renewable energy consumption resulted from fertilizer and diesel fuel in production. Similar results was reported by [3] in Turkey, and also by [7, 20] for sugar cane production.

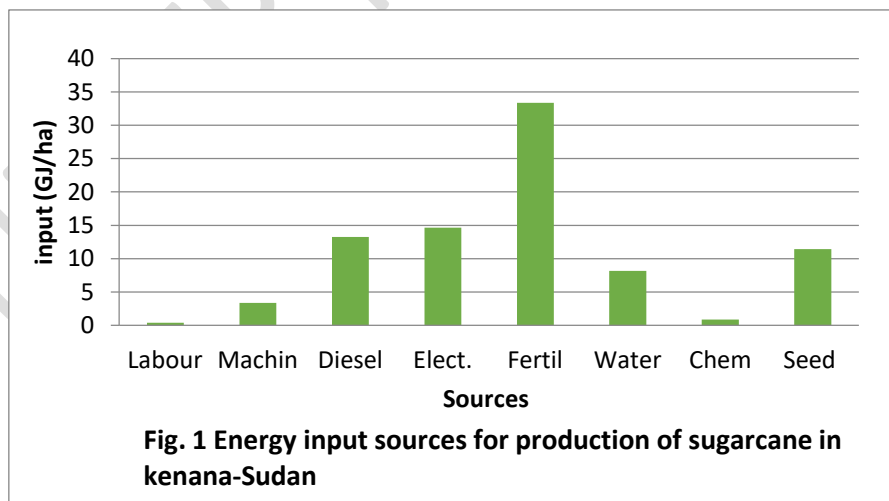
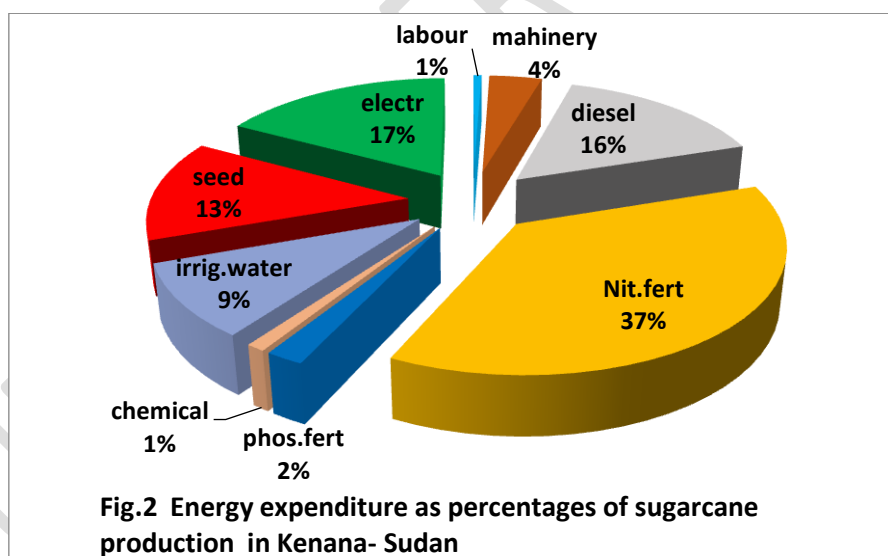


Table 2: Total energy equivalents of different inputs and output for sugarcane production

Item	Total units /ha	MJ/ha	%
Labour /hr	204.3	400.4	0.6
Tractor/ kg	2.2 /ha	1145	1.3
Machinery /kg	23.6 /ha	2582.8	3.0
Diesel /lit	235.2 /ha	13241.8	15.4
Electricity /kWhr	4070	14652.0	17.1
Nitrogen fert/kg	476 kg/ha	31,606.4	36.8
Phosphorus /kg	143 kg/ha	1746.8	2.0
Pesticide /kg	6.7 kg/ha	868.0	1.0
Water /m ³	8000 m ³	8160	9.5
Seed cuttings /kg	9524 kg/ha	11428.8	13.3
Total input		85832.0	100.0
Output /kg	94010 kg/ha	112812.0	



3.2 Energy use efficiency of sugarcane production:

The energy efficiency of sugarcane production may be expressed by some energy terminologies, i.e., specific energy input, energy ratio, energy productivity, and net energy gain. The specific energy input gives the information about how much energy is spent on the yield obtained. The specific energy input, energy ratio, energy productivity, and net energy gain of the present study were 0.91 MJkg⁻¹, 1.31, 1.10 kg MJ⁻¹ and 26980 MJha⁻¹

(Table 3). [30] stated that, in their study, the output to input energy ratio, Energy productivity, Specific energy and Net energy gain were calculated as, 1.34, 1.12 kgMJ⁻¹, 0.90 MJ kg⁻¹ and 26666.2MJha⁻¹, respectively. It can be observed that the findings of this study are very close to the present study results. Generally, more energy was needed for sugar cane production as per unit area. As for the energy ratio, it was stated [35] that if it is higher than one, the production system is earning energy, whereas if it is less than one, that system is losing energy. The energy ratio of sugar cane production of this study shows a value higher than one, therefore, the crop production system earned energy. EnPd gives an idea about how much product is produced per unit of input energy. EnPd and EnRatio are in direct relation. The EnPd can be used for evaluation of how efficiently energy is used in the production systems. It is possible to improve EnPd in a crop production process, by either reducing the total energy used in the inputs or through increasing the yield of the product. It was observed that, the average energy productivity of sugar cane production in Iran, was 0.63 kgMJ⁻¹ and the energy ratio was 0.76, while in India they were 0.81 kgMJ⁻¹ and 0.97, respectively [7, 20]. The values of net energy gain were -35.8GJha⁻¹ in Iran [7] and in Pakistan they reported the value of 212080 MJha⁻¹ [26].

Table 3. Some energy terminologies for evaluation of sugar cane production (MJ ha⁻¹)

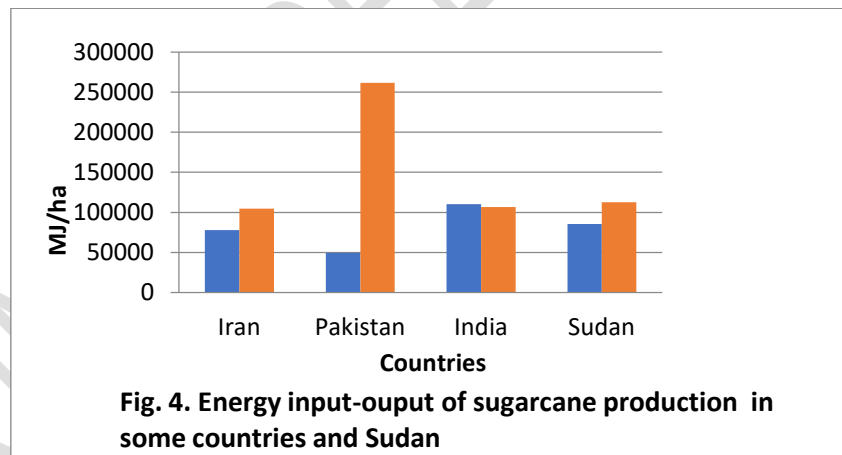
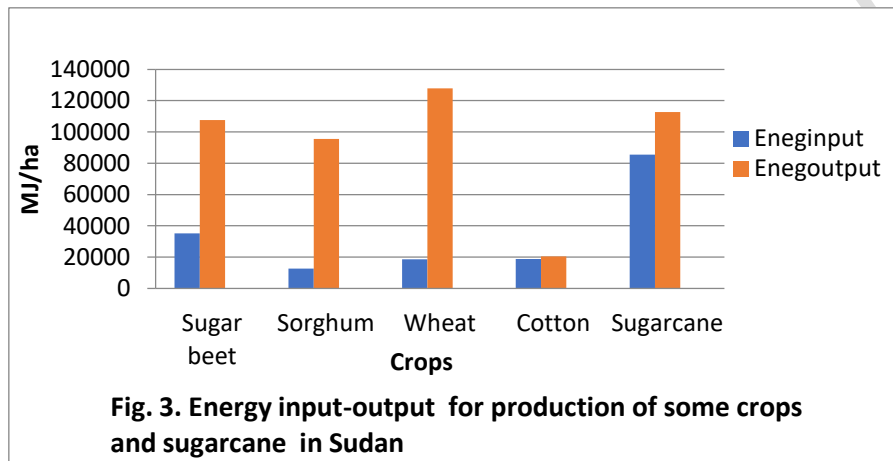
Item	Unit	Energy relations
Specific energy	MJkg ⁻¹	0.91
Energy productivity	kgMJ ⁻¹	1.10
Net energy gain	MJha ⁻¹	26980
Energy use efficiency	--	1.31
Direct energy ^a	MJha ⁻¹	36454.2 (42.5%)
Indirect energy ^b	MJha ⁻¹	49042.4(57.5%)
Renewable energy ^c	MJha ⁻¹	19989.2 (23.3%)
Non-renewable energy ^d	MJha ⁻¹	65507.4(76.7%)

^a = human labour+ diesel+ electricity + water energy, ^b = seed+ fertilizers+ chemicals + machinery energy, ^c = human labour+ water + seed energy, ^d = diesel+ chemicals+ fertilizers+ electricity + machinery energy,

3.3 Comparison of energy input-output of sugarcane production with some crops in Sudan and with other developing countries

It was observed the input energy expenditure of sugarcane production was the highest compared to some crops produced in Sudan while, wheat recorded the highest output energy (Fig. 3). The energy use efficiency was, 3.1, 7.7, 6.9, 1.1 and 1.3 for sugar beet, sorghum, wheat, cotton and

sugarcane, respectively. The energy ratio of sugarcane compared to other crops except cotton was lower mainly due to higher input energy, with the mean and standard deviation of 4.0 ± 3.1 . The energy input- output of sugarcane production in Kenana-Sudan was also compared with that in some developing countries. India recorded the highest average input energy as 110200 MJ/ha, while Pakistan recorded the highest output energy as 261530 MJ/ha (Fig. 4). Iran and Sudan recorded similar energy use efficiency as 1.3 since their input-output energies were very close, whereas Pakistan recorded the highest as 5.3 with mean and standard deviation of 2.2 ± 2.1 .



4. CONCLUSION

- Energy inputs analysis of sugar cane crop production in Kenana Sugar company showed that, the crop production is energy intensive and the highest energy consumers are fertilizers, electricity and fuel whereas the energy share of labour was very low.

- Using of new planting and mechanization techniques in sugarcane cultivation and timely care of operations may reduce energy costs and improve the efficiency of sugarcane production.
- High energy inputs may cause pollution, global warming and therefore, it's important to enhance more efficient, and environment friendly agricultural production systems such as organic cropping that increase energy use efficiency.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors

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