

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 sugar and other products for local consumption and export. The purpose of the present study was to investigate and determine 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 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 the values 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 operations require energy in one form or another, human labour, fertilizer, machinery, chemicals, fuel and electricity. To meet the growing demand of the increasing population and raw materials, the productivity of land to be increased, this would substantially require higher energy input and better management of production system [2]. Therefore, effective energy use of inputs is required to sustain agricultural production, since it provides ultimate financial saving, preservation of fossil resources 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]. Many researchers have studied energy use in agriculture and economic analysis to determine the energy use efficiency for crop production in many countries and for some crops e.g. [5,6,7,8,9,10, 11 and 12]. Energy utilization in farm level usually varies with farm size, crop growing, production practices and physical environmental [13]. However, availability of mechanical power for high rate of application in specific time permitted farmers to use different production strategies and thus resulted in increased food and crop production. By the

increase need for higher productivity per unit area and bringing additional areas under high yielding crops, it is inevitable that the share of agriculture in the national energy consumption would increase [14].

Sugar-cane of the genus *Saccharum*, belonging to the family *Gramineae*, is grown in more than a hundred different countries located between latitudes of about 40 degrees North and South of the equator and well adapted to dry subtropical savannahs [15]. The major producers of cane sugar include Brazil, India, Cuba, China, Mexico, the Philippines, South Africa, Australia and the USA, as well as many smaller nations in the Caribbean, Latin America, Africa, the Pacific and even in Europe [16]. Climatic differences, soil types and variations in farming practice result in crops with widely differing yields grown for anything from 9 months to almost 2 years between harvests. Yields, of green cane per hectare vary from as low as 20 t to over 200 tons with an annual current national average of all developed countries at about 80 green 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% from sugar cane [18].

The energy consumption in the 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 availability of labour for sugarcane production, it has been experienced that the use of modern machinery is inevitable. Use of machinery helps in labour saving and timeliness of operations, reduces drudgery, helps in 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 contributes directly to the Gross Domestic Product (GDP) by 36.8 percent and indirectly by influencing other sectors activities. The plant 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. Sugar cane is reflected as one of the major strategic crops in the country and sugar production started for the first time in Gunied in area (1962-1963) and there are five sugar producing companies, four of them are governmental which are successively Elguneid, New Halfa, North East Sinnar and Assalaya, which are established from 1962 to 1980. The fifth one is 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 derived from human, chemical and mechanical power [26, 27]. It is mainly used for land preparation, planting, weeding, spraying, fertilizer application, harvesting and transportation. Although most of energy input resources are used for crop production in Sudan, but still the contribution of the different elements and the output of these crops is not well identified. This study was intended to assess the energy inputs during field activities of different farm operations and the energy outputs for production of sugar cane crop.

2. MATERIALS and METHODS

2.1 The study area:

This study was conducted at Kenana Sugar Company, 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 classified as aridisol, low in organic matter, total nitrogen ($< 0.05\%$), and low in available P (< 10 ppm). The mechanical analysis classified the soil 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 heavyripper 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 urea fertilizer recommended was 476 Kg per hectare and was applied in two doses, the first 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 were used to control weeds at a rate of (5.0 l/ha+6.7 kg/ha). The number and duration of operations, technical systems used, fuel consumption and amount of human labour were investigated. Data for the study was collected and obtained from field visits, agricultural engineers and other people working in the company and 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 due to differences in the calculation methods and in the spatial and temporal system boundaries.

2.3 Input energy calculations:

The data collected for the crop included energy input resources for different farm operations, from land preparation up to crop harvesting. The total energy inputs in (MJ/ha) was calculated as total of labour, mechanical, and agrochemical energy. Human energy input was calculated as hrs of work 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 was converted to MJ/ha by energy equivalent of diesel fuel. Machinery energy

input was determined from the weight of the machine (kg) and annual area covered by the machines during the season. Other production energy inputs were computed from rates of application and energy equivalents of the inputs (Table 1). In this study it was assumed the harvested sugar cane stalks as the only output product of the plant. 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 stem, 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 coefficient for various sources of energy used for energy calculations

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 these data of sugar cane production, specific energy input, energy output–input ratio, energy productivity and net energy gain were estimated as follows:

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

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

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

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

Where; SpEn is the specific energy in (MJ/kg), InEn is the energy input in the production (MJ/ha), 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). The energy inputs were calculated by multiplying the material inputs by the referent energy equivalent [9,32].

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 seen, average total energy consumption for sugar cane production was 85496 MJha^{-1} . This is closer to those reported by [30]. Most of the input energy in production, $31606.4 \text{ MJha}^{-1}$, was used through the urea fertilizer application (Fig. 1), having a share of 37.0% in the total energy flow. 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). This pattern can be explained by the production technology since sugar cane is a very intensive crop in terms of fertilizer use [33]. The average sugar cane production in this study was 94010 kgha^{-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 similar to the findings of this study. In other investigations, [34] reported sugar cane total energy input and output, and output/input ratio as 49240 MJha^{-1} , 261530 MJha^{-1} and 5.3, respectively. The total energy input as direct, indirect, renewable and non-renewable forms are given in Table 3. As it can be seen 76.6% of total energy input resulted from non-renewable and 23.4% from renewable energy and 42.6% from direct energy and 57.4% indirect energy. Intensity of non-renewable energy consumption resulted from fertilizer and diesel fuel in production. A similar energy use pattern was reported by [3] in Turkey, where the share of fertilizer was ranked first followed by diesel fuel and irrigation. Similar, results were also reported by [7, 20] for sugar cane production.

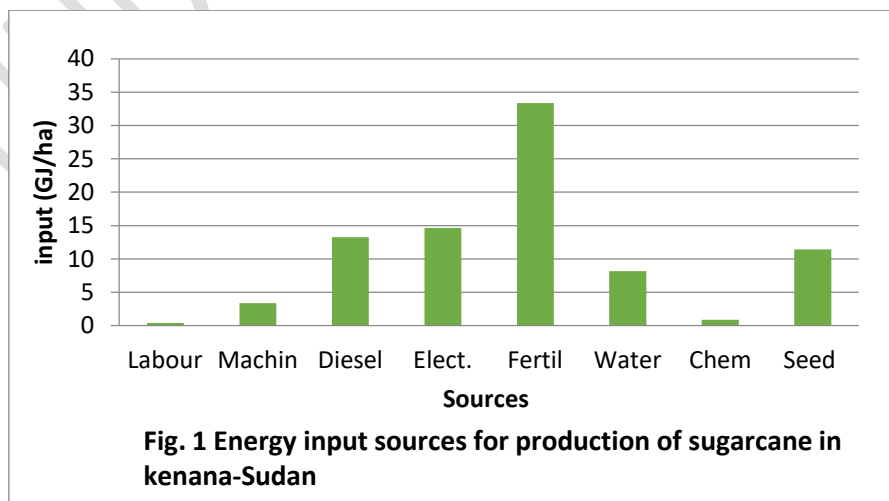
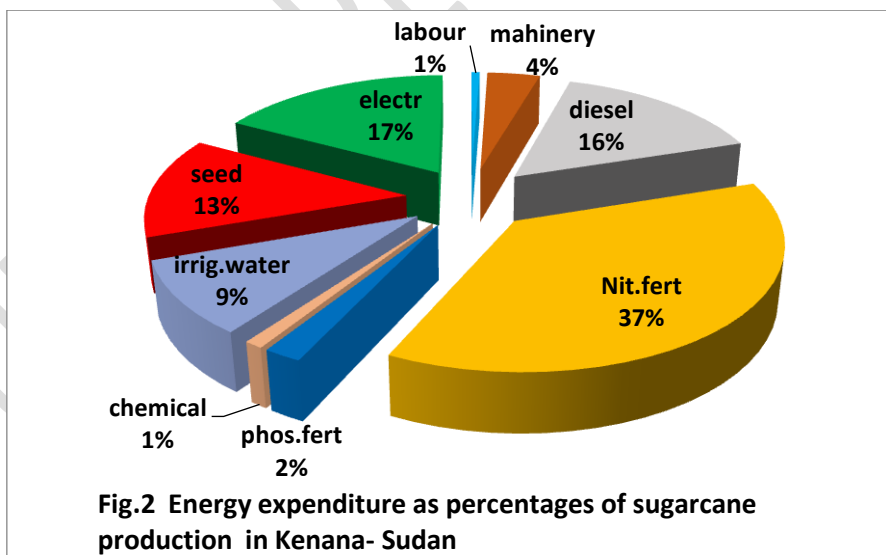


Table 2: Energy equivalents of different inputs and output for sugar beet

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 efficiency of sugarcane production:

The energy efficiency of sugar cane production was defined by some energy terminologies, i.e., specific energy input, energy ratio, energy productivity, and

net energy gain. The specific energy input gives the data about how much energy is spent on the yield obtained. Concerning the sugar cane yields, it was expected to have a lower overall specific energy input. The specific energy input, energy ratio, energy productivity, and net energy gain of sugar cane production of this study were 0.91 MJkg^{-1} , 1.31, 1.10 kgMJ^{-1} and 26980 MJha^{-1} (Table 3). [30] stated that, 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 $26666.2 \text{ MJha}^{-1}$, 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, but when the obtained yield was considered, it was observed that more energy feasible to grow intensive crops like sugar cane. As for the energy ratio, it is stated [35] that if it is higher than one, the system will earn energy, whereas if it is less than one, the system will lose energy. The energy ratio in sugar cane production shows the values higher than one, so the system earned energy. EnPd gives a fair idea about how much product is produced per unit of input energy. EnPd and EnRatio are in direct relation. The energy productivity can be used for evaluation of how efficiently energy is utilized in different production systems. To improve EnPd in a process, it is possible either to reduce the energy expended in the inputs or to increase the yield of the product. In Iran, the average value of the energy productivity in sugar cane production was 0.63 kgMJ^{-1} and the energy ratio 0.76, while in India they were 0.81 kgMJ^{-1} and 0.97, respectively [7, 20]. The values of net energy gain were -35.8 GJha^{-1} in Iran [7] and in Pakistan they reported the value of 212080 MJha^{-1} [26].

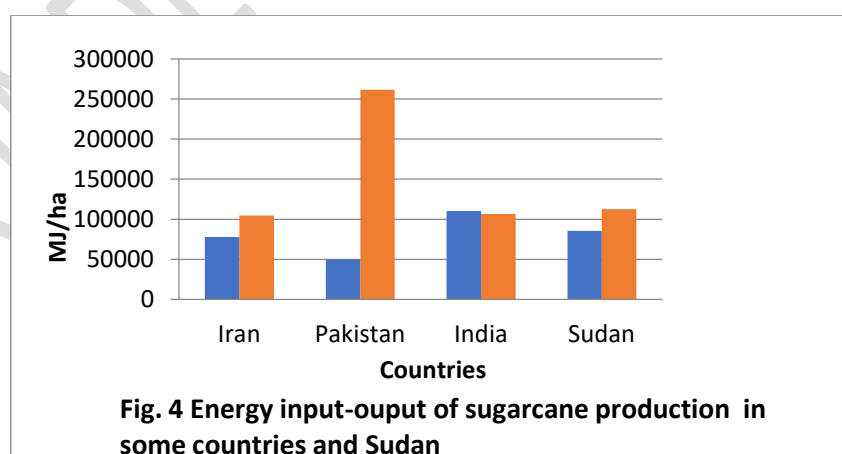
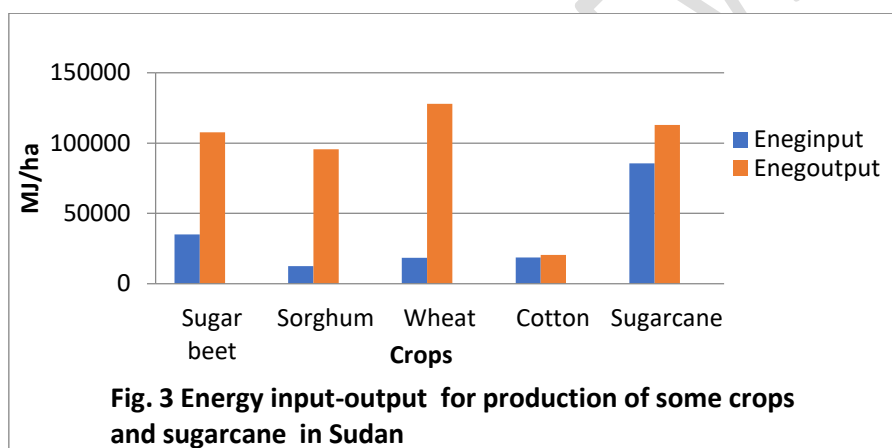
Table 3. Total energy input in the form of direct, indirect, renewable and non-renewable for sugar cane production (MJ ha^{-1})

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 =including human labour, diesel, electricity and water, ^b = Including seed, fertilizers, chemicals and machinery, ^c = Including human labour, water and seed, ^d = Including diesel, chemicals, fertilizers, electricity and machinery,

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. 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.



4. CONCLUSION

- Analysis of energy inputs for the sugar cane crop showed that energy input from fertilizer, electricity and diesel was the highest and the share of labour energy was very low.
- Energy savings may be possible by using lower recommended doses of fertilizers and proper timing of field operations and matching the size and power of tractor with machinery for field operations.
- Since the energy inputs for production of crops is looking high, it is important to suggest methods and policies that may reduce the negative effect of high energy inputs such as pollution, global warming and to develop more efficient, and environment friendly agricultural production systems 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

REFERENCES

1. Rosegrant, M.W.; Agcaolli-Sombilla, A.; Perez, N. 1995. Global Food Projections to 2020: Implications for Investment; International Food Policy Research Institute: Washington, DC, USA.
2. Chambsing,A., V.M. Salokhe and G. Singh. 2006. "Energy Consumption analysis for selected crops in different regions of Thailand". Agric. Engineering International: The CIGR Ejournal, vol. 8, pp.1-18.
3. Ozkan B, Akcaoz H, Fert C. 2004. Energy input/output analysis in Turkish agriculture. Renewable Energy. 2(9):39-51.
4. Esengun, K., O. Gunduz and G. Erdal, 2007. Input-output energy analysis in dry apricot Industry farms. production of Turkey. Energy Convers Manage., 48: 592-598.
5. Khan M.A.and G. Singh. 1997. Energy inputs and potential for agricultural production in Western Pakistan. Agricultural systems, 54, 341-356.

6. Alam, MS., MR. Alam and KK. Islam, 2005. Energy Sugarcane production in Debelkhazai Agro-Industry Flow in Agriculture: Bangladesh. *American J. Environ. Sci.*, 1(3): 213-220.
7. Karimi, M., P.A. Rajabi and A. Borghei.2008. "Energy analysis of sugarcane production in plant farms: A case study in DebelKhazai Agro-Industry in Iran". *American – Eurasian J. Agric. and Environ. Sci.*, 4, 165-171.
8. Abdalla N. O. Kheiry, Mohamed H. Dahab 2016. Energy Input-Output Analysis for Production of Selected Crops in the Central Clay Vertisols of Gezira Agricultural Scheme (Sudan). *International Journal of Science and Research (IJSR)*,.5, 1215-1220
9. Erdal, G.; Esengün, K.; Erdal, H.; Gündüz, O. Energy use and economical analysis of sugar beet production in Tokat province of Turkey. *Energy* **2007**, 1, 35–41.
10. Aleksandra Dimitrijević ,MarijaGavrilović, SanjinIvanović, Zoran Mileusnić, RajkoMiodragović and SašaTodorović. 2020. Energy Use and Economic Analysis of Fertilizer Use in Wheat and Sugar Beet Production in Serbia. *Energies*, 13, 1-12
11. Naeem MK, Bashir MK, Hussain B, AbbasM. Assessment of profitability of sugarcane crop in Faisalabad District. *Pak. J. LifeSoc. Sci.* 2007;5(1-2):30-33.
12. Mrini, M., F. Senhaji and D. Pimentel, 2001. Energy analysis of sugarcane production in Morocco. *Environ. Develop. Sustainability.*, 3: 109-126.
13. Sarker. R.L. 2000. Energy use pattern in small farm systems of Bangladesh". *J. Agric. and Mech.* Vol, 4, pp. 20-44,
14. Singh, J.M., 2002. On farm energy use pattern in different cropping systems in Haryana, India. Master of Science. Germany: International Institute of Management, University of Flensburg
15. Coombs, J. 2013. Biotechnology and Genetic Engineering Reviews Sugarcane as an Energy Crop. (Online) Journal homepage: <https://www.tandfonline.com/loi/tbgr20>
16. Abda, A. E. and Osman M. M. 2011. The Competitiveness of Sugar Cane Production: A Study of Kenana Sugar Company, Sudan. *Journal of Agricultural Science*,(3) 3, 202 – 210
17. FAO. 2020. Statistics of sugar production. Available online: <http://www.fao.org/faostat/en/#data>.
18. Mohamed O. A, (2014). Sugarcane growing and processing with special reference to the Sudan. Ph.D thesis, University of Sudan for Science and Technology, Sudan
19. Canakci, M., M. Topakci., I. Akinci and A. Ozmerz. 2005. Energy use pattern of some field crops and vegetable production: case study for Antalya region, Turkey. *Energy Convers Manage.*, 46: 655-666.
20. Kumar, A., Atul Kumar S. and Aaradhana P. 2018. Energy Analysis for Cultivation of Sugarcane: A Case Study in Narsinghpur (M. P.), India. *Current Journal of Applied Science and Technology*, 28(2): 1-10

21. Yilmaz, I., Akcaoz, H., Ozkan, B. 2005. An analysis of energy use and input–output costs for cotton production in Turkey. *Renew. Energy* 30: 145–155.
22. Abdalla N. O. Kheiry, Mohamed H. Dahab. 2016. Energy Input-Output Analysis for Production of Selected Crops in the Central Clay Vertisols of Gezira Agricultural Scheme (Sudan). *International Journal of Science and Research (IJSR)*, 5: 1215-1220.
23. Yusuf, D.D. and Asota, C.N., (1999). Design, Development and performance Evaluation of a once cover tillage machinery utilized single axle tractor. *AMA*, 29(3): 20-24.
24. Abdalla, A.A. and H.O. Abdel Nour.2004. The agricultural potentials of Sudan. *Exclusive Intelligence Review*, 34-42.
25. Bank of Sudan. 2014. Annual report, Khartoum, Sudan
26. Hussain M.F., Anwar S, Hussain Z.2011. Economics of sugarcane production in Pakistan: A price risk analysis. *Journal of Risk and Diversification*.1(1):33-39.
27. Baiyegunhi L.J.S, Arnold C.A. 2011. Economics of sugarcane production on large scale farms in the Eshowe/Entumeni areas of Kwazulu-Natal, South Africa. *African Journal of Agricultural Research*.6(21):4960-4967.
28. Kizilaslan H. 2009."Input–output energy analysis of cherries production in Tokat Province of Turkey". *Applied Energy.*, 86: 1354–1358.
29. Tabar, B.I., A. Keyhani and S. Rafiee, 2010. Energy balance in Iran's agronomy 1990-2006. *Renewable and Sustainable Energy Reviews*,(14): 849-55.
30. Ebrahim, Z. S., Mohammad A. A., Afshin M. and Abbas A. 2013. Energy use and economical analysis of Sugarcane production in Iran a case study: Debel Khazaei agro-industry. *Intl J Agri Crop Sci.*, 5 (3): 249-252.
31. Dahab, M. H., Elwaleed M. H. B. and Omer A. A. 2020. Energy use Efficiency and Cost-Benefit Analysis of Sugar Beet (*Beta vulgaris*) Production in the Irrigated Central Clay Plain of Guneid Area – Sudan. *Journal of Energy Research and Reviews*6(2): 49-57.
32. Aggarwal, G.C. 1995. Fertilizer and irrigation management for energy conservation in crop production. *Energy*, 20: 771–776.
33. Reineke, H.; Stockfisch, N.; Märlander, B. 2013. Analyzing the energy balances of sugar beet cultivation in commercial farms in Germany. *Eur. J. Agron.* 45: 27–38.
34. Khan MA, Zafar J, Bakhsh A. 2008. Energy requirement and economic analysis of sugarcane production in Dera Islamic Khan district of Pakistan. *Gomal University Journal of Research* 24: 72-82.
35. Conforti, P. and Giampietro, M. 1997. Fossil energy use in agriculture: An international comparison. *Agric. Ecosyst. Environ.*, 65: 231–243.