ISSN: 2073-9524
eISSN: 2310-8746

Energy use analysis for sunflower (*Helianthus annuus* L.) production in the mechanized rain fed schemes eastern Sudan

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Article history:

Received: 21 July 2022
Accepted : 7 September 2022
Published: 30 December 2022

Keywords: *direct and indirect energy; energy ratio; renewable and non-renewable energy; rain fed sunflower.*

Abstract

The objectives of this study were to analyze energy input-output and to identify the energy use patterns for sunflower production in the mechanized rain fed agricultural schemes eastern Sudan. The results revealed that the total energy input used to produce sunflower was 1671.33 MJ ha^{-1} and the total energy output was 11882.83 MJ ha-1. Sunflower production was efficient in energy consumption. The result showed that the energy ratio of output to input was greater than seven. The results indicated that the average net energy, the energy productivity and the specific energy was 10211.5 MJ ha^{-1}, 0.28 kg. MJ-1 and 3.52 MJ kg^{-1}, respectively. Fuel energy input was the highest among the energy input items while hand labor energy input was lower. These results indicate the dependence of sunflower production in rain fed agricultural schemes eastern Sudan on machinery. This necessitated the availability and readiness of the relevant and appropriate machineries as well as sufficient amount of fuel. The results also revealed that the energy profitability was 6.11 and human energy profitability was 1165.83 MJ h^{-1}.The direct energy input was greater than the indirect energy input. Similarly, non-renewable energy was much greater than renewable energy. The established information is useful to manage and to sustain the productivity of sunflower crop in the mechanized rain fed schemes eastern Sudan.

https://dx.doi.org/10.52951/dasj.22140205

Introduction

Sunflower (*Helianthus annuus* L.) is one of the most important world annual crops that are grown for edible oil. It is an excellent alternative in the production of oil crops besides sesame, groundnut and cottonseed (Mohamed *et al.*, 2014). Moreover, it provides a high value animal feed. In Sudan, the climate and soil conditions are suitable for its production. It is grown as a summer and winter crop under irrigated sector and as a summer crop under rain fed sector. The rain fed (rain fed) areas of Gedarif, Sinnar, Blue Nile, White Nile and Kordofan States are the most favorable conditions for growing sunflower in Sudan. In the mechanized rain fed schemes of Sudan, especially where annual rainfall is 500 mm and more, sunflower has potential in cropped area expansion. It is an easy crop to cultivate because it is fully mechanized; meanwhile the same fleet of implements used for crop production in the rain fed areas could be used for sunflower production too. Moreover, the introduction of pre-emergence herbicides for weed control convinced farmers to increase the cropped areas. In these areas the commercial production of sunflower crop started during the late eighties and early nineties. However, during the last two decades (2000 to 2020), the cultivated areas fluctuated from season to season due to dependence on imported seed. Despite the high cost of hybrid seeds and agro-chemicals, some farmers continue to grow the crop. If these problems are solved, the huge expansion of sunflower in cropped areas will take place (Dawelbeit, 2012). On the other hand, the researchers have considered sunflower in their research work; and their efforts had been culminated in releasing improved varieties and hybrids (Mohamed, 2018) in addition to other management practices.

Agricultural production represents both consumed and produced energy. The production activities that consume energy are hand labor, fuel, machinery, agrochemicals and seed. Yield is the main energy producer in agricultural production. The use of energy in agricultural production has been increased in response to the growing demand for food production to meet the rapid growth of the population. The share of energy in agricultural production differs according to crops grown, production practices and sector (Erdal *et al.*, 2007). Understanding the use of energy in agricultural production will promote sustainable agriculture and decrease environmental harms. In addition, efficient use of the energy resources is vital for improving the productivity and competitiveness (Hatirli *et al.*, 2005). In opposition, excessive use of energy causes problems threatening public health and the environment (Rafiee *et al.,* 2010). Energy requirements in agricultural production can be divided into direct and indirect energy, either of these divisions could also be categorized as renewable or non-renewable. Direct energy includes fuel and hand labors (Uzunoz *et al.,* 2008; Canakci *et al.,* 2005; Yilmaz *et al.,* 2005; Zahedi *et al.,* 2014). The indirect energy includes seeds, agrochemical and machinery (Ozkan *et al*. 2004). Renewable energy includes hand labors and seeds while non-renewable energy consists of fuel, agrochemicals and machinery (Uzunoz *et al.,* 2008).

The energy input-output analysis is usually made to evaluate the efficiency of the production system. Several indicators are frequently used in energy analysis, which include; total energy input, total energy output and energy use efficiency.

In addition to that, energy productivity, specific energy and net energy are also common indicators. Numerous studies on the subject of energy use, energy input–output analysis and their relationships have been conducted on agricultural production elsewhere (Canakci *et al.,* 2005;Yilmaz *et al.,* 2005;Safa *et al.,* 2010**;** Zahedi *et al.,* 2014**;** Kheiry and Dahab, 2016). However, investigations related to energy use in crop production in Sudan are a few. The objectives of this study were to analyze energy input-output and to identify the energy use patterns for sunflower production in the mechanized rain fed agricultural schemes eastern Sudan.

Materials and Methods

Study area

The mechanized rain fed agricultural schemes in eastern Sudan are located in Gedarif State eastern Sudan lies between latitudes 12.67º and 15.75º N and longitudes 33.57 º and 37.0º E, covering 71000 km2. The State extends through three-climate zones from arid zone in the North to the dry monsoon zone in the South (Adam, 2008). The total area suitable for cultivation is about 3.4 million hectares. The soil is heavy clay (Vertisols). Effective rainfall occurs during June - July and is extended to September-October. There is a single growing season a year. Sunflower is one of the crops grown in the area. The crops production in the study area has been practiced by private farmers.

Sunflower production practices

The majority of the farmers in the mechanized rain fed schemes have been used wide level disk harrow implement for seedbed preparation and sowing of the sunflower crop. Tractors of 56 to 60 kW have used to power the used implements. Farmers sow hybrid seeds of sunflower, which was expensive. The Sowing date starts during the second week of July and extends up to mid-August. The average seed rate is4.61 kg ha^{-1} and the crop grow without the addition of fertilizer. Farmers applied pre-emergence herbicide for weed control. However, manual weeding is also a common practice. The crop depends mainly on rainfall and no supplementary irrigation. The crop is ready for harvest in about 120 to 140 days from emergence. Harvesting is normally carried out in the late of October and extends until early December. Farmers have used direct combine harvester to harvest the crop. This crop is an easy crop to produce as most if not all of its operations are fully mechanized and few labor are involved in its production process.

Data collection

The required data was collected through structured questionnaire from 54 large-scale farmers in the mechanized rain fed areas in eastern Sudan. The respondent farmers were randomly selected and interviewed. The number of respondent farmers considered sufficient for the purposes of this study, as the farmers using similar implements, adopting similar operations and farming system besides that face similar constrains. The questionnaires considered details about the inputs used and operations done for sunflower production from seedbed preparation to harvesting. In addition, the questionnaire focused on hand labor, the area cultivated, diesel fuel and tractor power as well as sunflower grain yield. Human labor, machinery, diesel fuel, agrochemicals, seed rate and output yield of sunflower crop were considered as energy analysis components.

The equivalent of the energy inputs used in sunflower production is depicted in Table 1. All these values have been attained from those studies that have addressed energy analysis in agricultural production in general and sunflower as specific. The collected data was prepared in an excel worksheet. Based on energy equivalent, some energy indicators were determined.

Table 1. Energy content for inputs and outputs of sunflower crop production

Item	Unit	Energy content (MJ/unit)	Source number
Labor	Hour.	1.96	1
Machinery	Hour.	62.7	2
Fuel	litter	47.8	3
Herbicides	kg	288	4
Sunflower seeds	kg	3.6	5
Sunflower yield	kg	25	6

Source:
Heidari *et al.* (2012); Gokdogani and Sevim (2016)
Singh *et al.,* (2003); Zahedi, *et al.,* (2014)
Elhami *et al.,* (2016) ; Abbas *et al.,* (2017)
Uzunoz *et al.,* (2008); Hulsbergen *et al.,* (2001)
Ozkan *et al.,* (2004); Uzunoz *et al.,* (2008)
Hatirli *et al.,* (2005); Uzunoz *et al.,* (2008)

Energy analysis

The amounts of inputs used were determined a per hectare base. Energy values were calculated by multiplying the amounts of inputs and outputs by their energy equivalents with the use of related conversion factors (Kizilaslan, 2009). The total energy input was considered as the sum of the input components multiplied by the relevant energy conversion coefficient for each component. The energy indicators such as energy ratio (energy use efficiency), energy productivity, specific energy (energy intensity) and net energy were calculated according to the procedure described by (Rafiee *et al.*, 2010; Ghorbani *et al.*, 2011; Zahedi *et al.*, 2014) as follows:

Energy efficiency = Total energy output (MJ/ha)/Total energy input (MJ/ha)…... (1)

Energy productivity = Grain yield (kg/ha) / Total energy input (MJ/ha) …………… (2)

Specific energy = Total energy input (MJ/ha) / Grain yield (kg/ha) …………. (3)

Net energy = Energy output (MJ/ha) – Energy input (MJ/ha) …………………. (4)

Moreover, energy parameters and their definitions are shown in Table 2 were computed according to the procedure described by Uzunoz *et al.,* (2008).

Table 2. Energy parameters and their definitions

Energy parameters	Unit	Definition
Direct energy inputs (Ed)	MJ ha^{-1}	Diesel fuel + human labor
Indirect energy inputs (Ei)	MJ ha^{-1}	Machinery + fertilizers + pesticides, seeds
Renewable energy inputs	MJ ha^{-1}	Human labor + seed
Non-renewable energy inputs	MJ ha^{-1}	Diesel fuel + fertilizers + pesticides + machinery
Total energy input (ET)	MJ ha^{-1}	ET = Ed + Ei
Energy output (EO)	MJ ha^{-1}	Energy in the harvested grain

Furthermore, equations 5 and 6 calculate energy profitability and human energy profitability for sunflower production as suggested by Tabatabaeefar *al.,* (2009) and Ali *et al.,* (2018).

Energy profitability = net energy (MJ ha^{-1})/ Energy input (MJ ha^{-1}) …………………. (5)

Human energy profitability = Energy output (MJ ha^{-1})/ human labor (h ha^{-1})..............… (6)

Results and Discussion

Table 3 shows the number of the surveyed farmers and their holding size. A total number of 54 farmers who practiced crop production in the mechanized rain fed schemes eastern Sudan were interviewed. The total area owned by the surveyed farmers was 120042 ha. Of whom 15 farmers (28%) grew sunflower crop. The total area owned by the surveyed sunflower growers was 66176 hectares. Sunflower crop was grown in an area of 13025 hectares, which represented 20% of the total area owned by the surveyed farmers and 11% of the total area owned by surveyed sunflower farmers. The average farm size grown by sunflower crop was 868 ha. Other crops such as millet, sesame, sunflower and cotton were grown in the remaining area.

Table 3. The number of the surveyed farmers and the holding size of sunflower farms in the mechanized rain fed schemes in eastern Sudan

Items	Value
Total number of surveyed farmers	54
Total area owned by the surveyed farmers, ha	120042
Number of the surveyed sunflower growers	15
Percentage of sunflower growers from total surveyed farmers, %	28
Total area owned by surveyed sunflower growers, ha	66176
Area grown by sunflower crop, ha	13025
Average sunflower farm size for surveyed sunflower growers, ha	868
% of sunflower cropped area from total area owned by the surveyed farmers	20
% of sunflower cropped area from area owned by surveyed sunflower farmers	11

The quantities of input and output for sunflower production and their energy equivalents were shown in Table 4. The results showed that the labor hours used in sunflower was about 10.19man-hour per hectare and its respective energy equivalents was 19.98MJ ha^{-1}. The used hours per hectare by machinery were about 1.85 hrs.

And its respective energy equivalent was 116.26 MJ ha^{-1}. The results also showed that the total fuel consumption was 20.98 l ha^{-1}which equivalent to 1002.94 MJ ha^{-1}.On the other hand, 4.62 kg.ha^{-1} seed and 1.79 kg a. i. ha-1of herbicide were used for sunflower production.

The energy equivalent for sunflower seeds and the used herbicide was 16.63 and 515.52 MJ ha^{-1}, respectively. The total energy input for sunflower production in the studied mechanized rain fed schemes was 1671.33 MJ ha-1(Table 4). In addition, the total energy output for sunflower production in the mechanized rainfed schemes was 11882.831MJ ha^{-1}(Table 4). The obtained values of inputs and outputs energy in this study were much lower than the input energy used to produce sunflower in Turkey which were 18931.09 MJ ha^{-1} and 55750 MJ ha^{-1} as reported by (Uzunoz *et al.*, 2008). These variations in the total energy input and output for sunflower production between this study and other studies may be due to the variation in the amount of the used inputs, cultivars and management practices.

It is first time to establish such information in the mechanized rain fed schemes eastern Sudan; therefore it hard to judge on the values on energy input and output. It is thought that the furnished information will help researchers and engineers as well as farmers to understand the relationship between energy input and production techniques; and this will help in allocating inputs to optimize and sustain productivity.

Table 4. Amount of inputs, outputs and their energy equivalent for sunflower production in the mechanized rain fed schemes e in astern Sudan

Inputs	Quantity per hectare	Total energy equivalent (MJ ha^{-1})
Labor (h)	10.19	19.98
Machinery (h)	1.85	116.26
Diesel fuel (l)	20.98	1002.94
Seeds (kg)	4.62	16.63
Herbicides (kg)*	1.79	515.52
Total inputs	-	1671.33
Outputs		
Sunflower seed (kg)	475.31	11882.83

*Active ingredient

Energy input-output relationships were presented in Table 5. The results showed that the energy ratio (energy use efficiency) was 7.11%. This result indicates that sunflower production in the mechanized rain fed schemes was efficient in term of energy consumption. As Safa et al.,(2010) mentioned that if the energy input-output ratio is higher than one, the system is earning energy, whereas if it is less than one, the system is losing energy. However, Uzunoz et *al.* (2008) found that the energy ratio for sunflower production in Turkey was 2.95. The results showed that the energy productivity was 0.28 kg MJ^{-1}(Table 5). This means that one Mega Joule energy input was used to produce 280 grams of sunflower on average. The specific energy for sunflower production in the mechanized rain fed schemes in eastern Sudan was 3.52 MJ kg^{-1}.This means that every 3.52 MJ of energy was used to produce one kilogram of sunflower. In addition, the results showed that the net energy was 10211.5 MJ ha^{-1}(Table 5).

Table 5. Some energy indices for sunflower production in the mechanized rainfed schemes in eastern Sudan

Inputs	**Unit**	**Quantity**
Energy use efficiency	**-**	**7.11**
Energy productivity	**kg MJ^{-1}**	**0.28**
Specific energy	**MJ kg^{-1}**	**3.52**
Net energy	**MJ ha^{-1}**	**10211.50**

On the other hand, Table 6 describes the quantity distribution of the total energy input into the forms of direct, indirect, renewable and nonrenewable energies used in production of sunflower. The direct energy input was 1022.92 MJ ha^{-1}.The indirect input energy was 648.41MJ ha^{-1}.This revealed that the direct energy input was about 1.5 greater than indirect energy. Furthermore, the renewable energy for sunflower production in the mechanized rain fed schemes was fewer (36.61 MJ ha-1) than the non-renewable energy (1634.72 MJ ha-1). On the other hand, results showed that the energy productivity was 6.11 human energy productivity were equal to1165.83 MJ h^{-1}.

It is the first time to establish such information in the mechanized rain fed schemes eastern Sudan; therefore it is hard to judge on the obtained values on energy parameters. The study goal is to help the researchers and engineers as well as farmers to understand sustainable productivity.

Table 6. Energy parameters for sunflower production in the mechanized schemes eastern Sudan

Inputs	Unit	Quantity
Direct energy	MJ ha^{-1}	1022.92
Indirect energy	MJ ha^{-1}	648.41
Renewable energy	MJ ha^{-1}	36.61
Non-renewable energy	MJ ha^{-1}	1634.72
Energy profitability	-	6.11
Human energy profitability	MJ h^{-1}	1165.83

The share of energy input sources in sunflower production is illustrated in Figure 1. Out of the total energy input, the share of fuel energy was found to be the highest (60.0%). Similarly, several authors had reported that fuel energy was the highest energy consumed for crop production (Canakci *et al.*, 2005; Umar and Ibrahim, 2012).The highest share of fuel energy implies that sunflower production in the studied areas depends greatly on machinery. This high dependence on machinery necessitated the availability and readiness of the machineries such as tractors, planters, harvesters etc. The share of herbicide energy input ranked second after fuel and it was 30.84%. The results also showed that the energy excreted by machinery to the total energy input was 6.96%. Whereas hand labor and seeds represented a lower share of energy input 1.2% and 1.0%, respectively. The lower share of hand labor energy indicated the ease of sunflower production if a suitable set of machinery and sufficient amount of fuel are available.

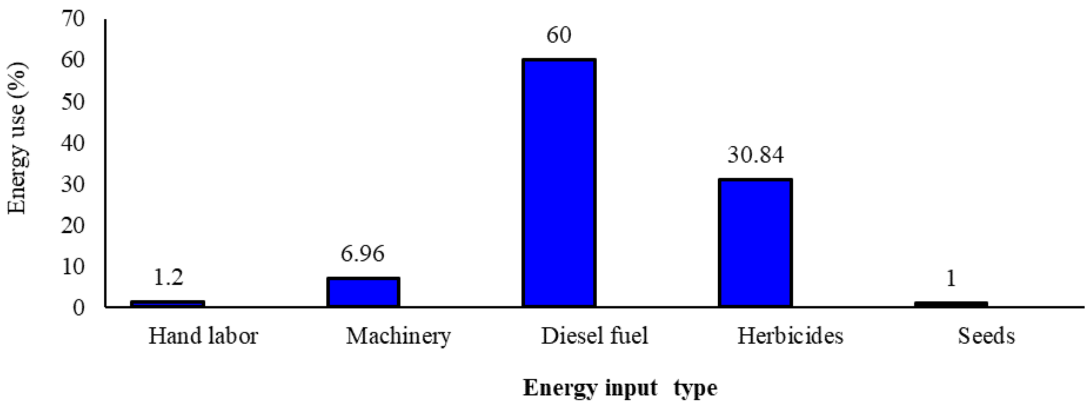

Fig. 1. The shares of energy inputs for sunflower production

Results showed that the direct energy (hand labor and diesel fuel) was 61.2% and the indirect energy (machinery, herbicides and seeds) was 38.8% of the total energy input (Fig. 2). The obtained result indicated that the direct energy for sunflower production was higher than the indirect energy. This result disagrees with others studies that showed the direct input energy was lower than the indirect input energy in other crops produced elsewhere (Yilmaz *et al.,* 2005; Uzunoz *et al.,* 2008; Dagistan*et al.,* 2009). They also revealed that the non-renewable energy was much greater than the renewable energy used for sunflower production. Similarly, some authors found that the share of non-renewable energy used in crop production elsewhere was greater than the share of renewable energy (Yilmaz *et al.,* 2005; Dagistan*et al.,* 2009; Zahedi *et al.,* 2014).

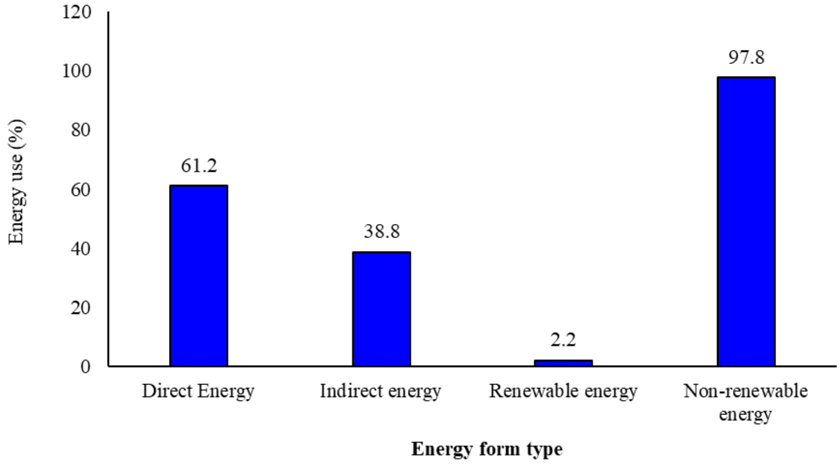

Fig. 2. Distribution of energy forms in sunflower production

Therefore, researchers need to investigate more on balanced utilization of energy sources for sunflower production in the mechanized rain fed schemes eastern Sudan. This could be achieved by examining different management practices.

Conclusion

Depending on the research results, and taking into account the research circumstances, the following can be concluded:

- The average energy input used to produce sunflower in the mechanized rain fed schemes in rain fed areas was 1671.33 MJ ha^{-1} and the total energy output was 11882.83 MJ ha-1.
- Sunflower production was efficient in energy consumption; the energy use efficiency was higher than seven. The average net energy, the energy productivity and the specific energy was 10211.50 MJ ha^{-1}, 0.28kg MJ^{-1} and 3.52 MJ kg $^{-1}$, respectively. Fuel energy input was the highest among the energy input items.
- The energy profitability was 6.11 and human energy profitability was 1165.83 MJ h^{-1}.
- The direct energy was greater than the indirect energy. Similarly, non-renewable energy was much greater than the renewable energy. The established information is useful to manage and to sustain the productivity of the sunflower crop in the mechanized rain fed schemes in eastern Sudan.

Conflict of interests

The authors declare that they have no competing.

Acknowledgments

The authors thank mechanized rain fed schemes staff at eastern Sudan, for their assistance.

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