Gezira J. of Engineering and applied Sciences
ISSN Linking: 1858-5698
http://journals.uofg.edu.sd/index.php/gjeas/

Energy use for millet (*Pennisetum glaucum* (L) *R. Br.*) production in the large-scale rain fed schemes in eastern Sudan

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INFORMATIONs
Submission: 20/09/2021
Accepted: 22/12/2022
Publication: 30/03/2023

ABSTRACT

Energy in agricultural production is used in different forms and ways to meet the increasing demand for food. The share of energy in agricultural production differs according to crops grown, production practices and sector. This study aimed at analyzing energy input-output and to identify the energy use patterns for millet production in the large–scale rain fed agricultural schemes in eastern Sudan. The required data was collect from 54 farmers through well-designed questionnaire. The results showed that 30% of the surveyed farmers grew millet crop. The average millet grown area by one farmer was 205 ha. The results showed that the total energy input used to produce millet was 1358.24 MJ ha^{-1} and the total energy output was 8557.90 MJ ha^{-1}. The results revealed that millet production was efficient in energy consumption; the output-input energy ratio was higher than 5 :1. The average net energy, the productivity energy and the specific energy were 8699.66 MJ ha^{-1}, 0.43 kg MJ^{-1} and 2.35 MJ kg^{-1}, respectively. The results showed that the energy input for fuel was the highest among the other items of input energy. The use of stationary threshing in harvesting saved the direct energy by 219.63 MJ ha^{-1} compared to direct combine harvesting, but the former required additional 100.83 MJ ha^{-1} of manual energy. The results showed that, the more machinery is used in harvesting the more amount of the renewable energy is saved. The result indicated that the direct energy that used to produce the crop was greater compared to the indirect energy. Likewise, the non-renewable energy that used to produce the crop was greater than the renewable energy. The study concluded that more investigations are needed to balance utilization of energy sources for millet production in the large-scale schemes in rain fed areas in eastern Sudan.

KEYWORDS: ***Energy ratio; Renewable and non-renewable energy; Direct and indirect energy; Rain fed millet; Sudan***

1. INTRODUCTION

Millet (*Pennisetum glaucum* (L) R. Br.) is one of the cereal crops grown in Sudan. Its grain has been used as food because it is rich with protein, energy, vitamins and minerals. It is a major contributor to food security for poor inhabitants in rural communities. Moreover, its stalks are used as a fodder and building material in local areas. In Sudan, Millet crop has been mainly grown in rain fed areas, which extends from Darfur in the West to Gedarif in the East. In these areas, millet has been produced under small size farms and large-scale mechanized schemes.

The large-scale mechanized schemes in Gedarif rain fed areas are the most important agricultural production areas as they have significant contribution to economy of the country. These schemes have been cultivated and managed by private farmers. The farmers have owned sets of machinery to execute seedbed preparation, seeding, weed control and harvesting operations. On the other hand, hand labors have been also employed to carry out weeding and harvesting operations

Agricultural production is energy consumer and at the same time is energy producer. The production activities that consume energy are hand labor, fuel, machinery, agrochemicals and seed. Yield is the one of the main energy producer in agricultural production. The use of energy in agricultural production has been intensified in response to the increasing demand for food to meet the continued growth of population. The share of energy in agricultural production differs according to crops grown, production practices and sector [1]. Understanding the use of energy in agricultural production will promote sustainable agriculture and minimize environmental harms. In addition, efficient use of the energy resources is vital for improving the productivity and competitiveness [2]. In opposition, excessive use of energy causes problems threatening public health and environment [3]. 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. The direct energy includes fuel and hand labors [4, 5, 6, 7]. The indirect energy includes seeds, agrochemical and machinery [8]. The Renewable energy includes hand labors and seeds while non-renewable energy consists of fuel, agrochemicals and machinery [4].

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 [5, 6, 9, 7, 10]. However, investigations related to energy use in crop production in Sudan are rare. This study aimed at analyzing energy input-output and to identify the energy use patterns for millet production in the large–scale rain fed agricultural schemes in eastern Sudan.

2. MATERIALS AND METHODS

a. *Description of the study area*

The large-scale rain fed agricultural schemes in eastern Sudan are mainly located in Gedarif State. Gedarif State lies between latitudes 12.67º and 15.75º N and longitudes 33.57 º and 37.0º E, covering 71000 km^2. The State encompasses three-climate zones arid zone in the North to dry monsoon zone in the South [11]. 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 extended to September - October and accordingly there is a single growing season a year. Millet is one of the crops grown in the area. The crops production in the study area have been practiced by private farmers.

b. *Crop management practices*

The farmers in the large-scale rain fed schemes have been used wide level disk (WLD) harrow for seedbed preparation and sowing the millet crop. Tractors of 75 to 80 hp have been used for powering the necessary implements. The sowing date starts during the second week of July and extends up to early August. The average seed rate of 3.62 kg/ha is applied and no fertilizer is used. Manual weeding is a common practice; however, the farmers recently adopted chemical herbicide to control weeds. The crop is ready for harvest in about 120 days from emergence. Harvesting normally carried out in late October and extends until early December. Stationary threshing is the main harvesting method while recently some farmers have practiced direct combine harvesting. The stationary threshing occurs in two steps. The first step is to cut the crop heads and heap the cut heads. This step is completely manual, which is labor intensive, time consuming and costly. The second step is threshing. The tractor-operated thresher is the main threshing implement, in this step feeding the plant heads to the threshing unit and sacks tying have been carried out manually. On the other hand, direct combine harvesting is recently introduced, in which sacks filling and tying were carried out manually too.

c. *Data collection*

The required data was collect through structured questionnaire from 54 large-scale farmers. The respondent farmers were randomly selected and interviewed. The number of the respondent farmers considered sufficient for the purposes of this study, as the farmers being use similar implements, adopting similar operations and farming system besides that they face similar constrains. The questionnaire considered details about the inputs used and operations done for millet production from seedbed preparation to harvest. In addition, the questionnaire included data on hand labor, area cultivated, diesel fuel and tractor power as well as millet grain yield. Human labor, machinery, diesel fuel, agrochemicals, seed rate and grain yield were considered as energy analysis components.

The equivalent of the energy inputs used in the millet production is depicted in Table 1. All these values have been attained from those studies that have addressed energy analysis in agricultural production. The collected data was prepared in an excel worksheet and some energy indicators were calculated

d. *Analysis of energy indicators*

The amounts of the used inputs were calculated on per hectare base and these input data were converted into energy equivalent, they multiplied by the relevant coefficient of energy equivalent [12]. 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 as follow [3, 13, 7].

$$ER = \frac{TEO}{TEI} \dots\dots. (1)$$

Where:
ER= Energy ratio
TEO = Total energy output (MJ/ha)
TEI = Total energy input (MJ/ha)

$$EP = \frac{Y}{TEI} \dots\dots\dots. (2)$$

Where:
EP = Energy productivity (kg/MJ)
Y=Yield (kg/ha)

$$SE = \frac{TEI}{Y} \dots\dots\dots (3)$$

Where:
SE= Specific energy (kg/MJ)

$$NE = TEO - TEI \dots. (4)$$

Where:
NE = Net energy (MJ/ha)

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

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

Item	Unit	Energy content (MJ/unit)	Source
Labor	h	1.96	[7, 14]
Machinery	h	62.7	[1, 15]
Fuel	l	47.8	[16, 17]
Herbicides	kg	85.0	[18, 19]
Millet Seeds	kg	14.7	[20, 21]
Millet yield	kg	14.7	[20, 21]

Table 2. Energy parameters and their definitions

Energy parameters	Unit	Definition
Direct energy (DE)	MJ ha^{-1}	Fuel, human labor
Indirect energy (IE)	MJ ha^{-1}	Machinery, agrochemicals, seeds
Renewable energy (RE)	MJ ha^{-1}	Human labor, seed
Non-renewable energy (NE)	MJ ha^{-1}	Fuel, agrochemicals, machinery
Total energy input (ET)	MJ ha^{-1}	ET = (DE + IE) = (RE + NE)
Energy output (EO)	MJ ha^{-1}	Energy in the harvested sesame seeds

3. RESULTS AND DISCUSSION

The number of the surveyed farmers and their holding size were depicted in Table 3. A total number of 54 farmers practiced crop production in the large-scale rainfed schemes (120042 ha) in eastern Sudan were interviewed. Of whom 16 farmers grew millet crop. The total area owned by the surveyed millet growers was 21092 hectares. Millet crop was grown in an area of 3288 hectares, which represented 3% of the total area owned by the surveyed farmers and 16% of the total area owned by surveyed millet farmers. The average farm size grown by millet crop was 205 ha. Other crops such as sorghum, sesame, sunflower and cotton was grown in the remaining of the total area.

Table 3. Number of the surveyed farmers and the holding size of millet farms

Items	Value
Total number of surveyed farmers	54
Total area owned by the surveyed farmers, ha	120042
Number of millet growers	16
Percentage of millet growers from total surveyed farmers, %	30
Total area owned by surveyed millet growers, ha	21092
Area grown by millet crop, ha	3288
Average millet farm size for surveyed millet growers, ha	205
% of millet cropped area from total area owned by the surveyed farmers	3
% of millet cropped area from area owned by surveyed millet farmers	16

The quantities of input and output for millet production and their energy equivalents were shown in Table 4. The results showed that about 82.29 and 30.85 man-hour per hectare were used in millet production for stationary threshing and direct combining harvesting methods, respectively. Their respective energy equivalents were 161.30 and 60.47 MJ ha^{-1}, indicated that the direct combine harvesting methods saved 100.83 MJ ha^{-1} in manual energy. This result revealed that the use of combine harvester for direct combine harvesting of millet crop saved about 63% of man-hour and their equivalent energy compared to the stationary threshing. The used hours per hectare by machinery were about 2.14 and 2.24 for stationary threshing and direct combining harvesting methods, respectively. Their respective energy equivalent were 134.19 and 140.33 MJ ha^{-1}. This revealed that the difference between the direct combine harvesting and the stationary threshing in machinery energy was only 6.14 MJ ha^{-1}. The results also showed that the total fuel consumption in the direct combine harvesting exceeded that of the stationary threshing by 6.71 lha^{-1}. The stationary threshing consumed 17.38 l ha^{-1} which equivalent to 830.85 MJ ha^{-1}, while the direct combine harvesting consumed 24.09 l ha^{-1} which equivalent to 1151.30 MJ ha^{-1}. On the other hand, the same quantities of seeds (3.62 kg ha^{-1}) and herbicide (0.76 kg a. i. ha^{-1}) were used for millet production in the two harvesting methods. The energy equivalent for millet seeds and herbicide was 53.21 and 64.60 MJ ha^{-1}, respectively. Total energy input for millet production in the studied large-scale rainfed schemes was 1245.35 and 1471.12 MJ ha^{-1} for stationary threshing and direct combining harvesting methods, respectively (Table 4). The overall average total energy input was 1358.24 MJ ha^{-1}. The obtained total energy input was lower compared to that computed by other authors in the semi-arid zone of Nigeria. Abubakar (2012) [22] found that the total input energy used in millet production was in the range between 3945 and 6090 MJ ha^{-1}. These variations in the total energy input and output for millet production between this study and other studies may be due to the variation in the amount of the used inputs, cultivars and management practices.

Table 4. Amount of inputs, outputs and their energy equivalent for millet production

	Stationary threshing		Direct combine harvesting	
Inputs	Quantity /ha	Energy, MJ ha^{-1}	Quantity/ ha	Energy, MJ ha^{-1}
Labor, h	82.29	161.30	30.85	60.47
Machinery, h	2.14	134.19	2.24	140.33
Fuel, l	17.38	830.85	24.09	1151.30
Agrochemicals, kg	0.76	64.60	0.76	64.60
Seeds, kg	3.62	53.21	3.62	53.21
Total energy input, MJ ha^{-1}	-	1245.35	-	1471.12
Outputs				
Grain yield, kg	497.97	7320.16	666.37	9795.64

Energy input-output relationships were displayed in Table 5. The results revealed that the energy ratio (energy use efficiency) was between 5.88 and 6.66% for stationary threshing and direct combining harvesting methods, respectively. This result indicates that millet production in the large-scale rainfed schemes was efficient in term of energy consumption. As mentioned by Safa *et al.*, (2010) 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, [22] found that the energy ratio for millet production in semi-arid zone of Nigeria was between 0.8 and 2.6. The results showed that there was slight variation in energy productivity between the two harvesting options (Table 5) which ranged between 0.40 and 0.45 kg MJ^{-1}. This means that one Mega Joule energy input used to produce 400 and 450 grams of millet seeds. The specific energy for millet production in the large-scale rainfed schemes eastern Sudan was almost similar in the two harvesting options with an overall average of 2.23 MJ kg $^{-1}$. This means that every 2.23 MJ energy was used to produce one kilogram of millet seeds. The use of direct combine harvesting gave higher net energy (8324.52 MJ ha^{-1}) compared to stationary threshing (6074.81 MJ ha^{-1}). The results revealed that the average net energy was 7199.67 MJ ha^{-1} (Table 5). Moreover, Table 5 shows the total energy input in form of direct, indirect, renewable and nonrenewable used in production of millet using the two harvesting methods. The direct energy varied among the millet harvesting methods. The direct energy input was higher for the direct combine harvesting (1211.77 MJ ha^{-1}) compared to stationary threshing (992.14 MJ ha^{-1}). The use of stationary threshing saved direct energy by 219.63 MJ ha^{-1} compared to the direct combine harvesting. This variation in direct energy was mainly due to higher quantity of fuel used in the direct combine harvesting. The indirect input energy was 253.21 and 259.35 MJ ha^{-1} for stationary threshing and direct combine harvesting of millet crop, respectively. Furthermore, the renewable energy for millet production in the large-scale rainfed schemes was 214.51 and 113.69 MJ ha^{-1} for the stationary threshing and for direct combine harvesting (Table 5). This result indicated that the more machinery used in millet harvesting the more amount of the renewable energy is saved. The reverse was true for non-renewable energy, where the non-renewable energy for stationary threshing was1030.84 MJ ha^{-1} and for direct combine harvesting was 1357.43 MJ ha^{-1}.

Figure 1 illustrates the share of energy input sources for millet production under the two the harvesting methods. Out of the total energy input, the share of fuel energy was found to be the highest (66.72 - 78.26%). The highest share of fuel energy implies that millet production in the large-scale rainfed schemes depend heavily on fuel especially for performing seedbed preparation, seeding operations and harvesting. Several authors had found that fuel energy was the highest energy consumed for crop production [5, 23]

Table 5. Some energy indicators for millet production in the large-scale schemes in rainfed areas

Inputs	Unit	Stationary threshing	Direct combine harvesting
Energy ratio	-	5.88	6.66
Energy productivity	kg MJ^{-1}	0.40	0.45
Specific energy	MJ kg^{-1}	2.50	2.21
Net energy	MJ ha^{-1}	6074.81	8324.52
Direct energy	MJ ha^{-1}	992.14	1211.77
Indirect energy	MJ ha^{-1}	253.21	259.35
Renewable energy	MJ ha^{-1}	214.51	113.69
Non-renewable energy	MJ ha^{-1}	1030.84	1357.43
Total energy input	MJ ha^{-1}	1245.35	1471.12

The share of energy excreted by hand labor to the total energy input was higher in the stationary threshing (12.95%) compared to in direct combining harvesting method (4.11%). The share of machinery consumed energy from the total input energy was (10.87 - 9.54%), whereas herbicides and seeds represented lower energy sources (5.19 – 4.39%) and (4.27 - 3.62%) for the stationary threshing and the direct combine harvesting, respectively. Efforts should be focused on fuel consumption, hand labor and machinery to improve energy use of millet production in the study area.

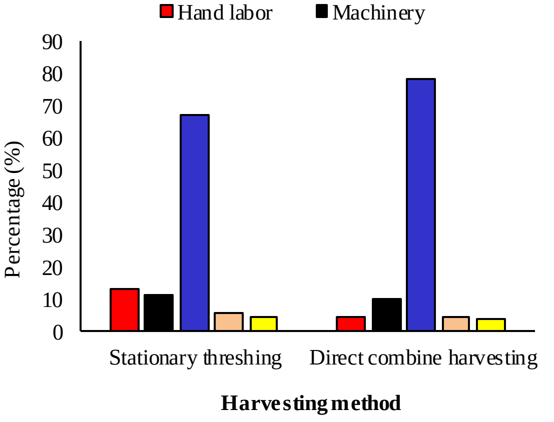

Fig. 1. The shares of energy inputs for millet production under two harvesting methods

Regardless to millet harvesting method, the direct energy was about four folds compared to the indirect energy (Fig. 2). The results showed that the percentage of the direct energy consumed for millet production using stationary threshing and direct combine harvesting was 79.7 and 82.4%, respectively. This results indicated that the direct and indirect energy for millet production were in semi-balanced consumption. The non-renewable energy was greater than the renewable energy that used for millet production in the two harvesting methods. Therefore, researchers need to investigate more on balanced utilization of energy sources for millet production in the large-scale schemes in rainfed areas eastern Sudan. This could be achieved by examine different management practices.

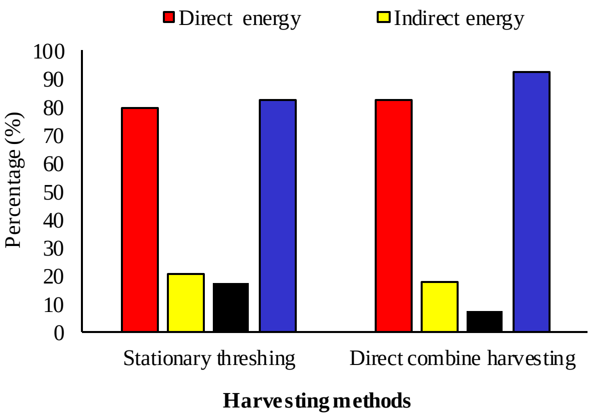

Fig. 2. Distribution of energy forms in millet production under two harvesting methods

4. CONCLUSION

- The average energy input consumed to produce millet in the large-scale schemes in rainfed areas was 1358.24 MJ ha^{-1} and the total energy output was 8557.90 MJ ha^{-1}.
- Millet production is efficient in energy consumption, the energy ratio of output-input was high (greater than 5). The average net energy, the energy productivity and the specific energy were 8699.66 MJ ha^{-1}, 0.43 kg MJ^{-1} and 2.35 MJ kg $^{-1}$, respectively. Fuel energy input dominated the total energy input.
- The use of stationary threshing saved the direct energy by 219.63 MJ ha^{-1} compared to the direct combine harvesting, but it required additional 100.83 MJ ha^{-1} in manual energy. The more machinery used in millet harvesting the more amount of the renewable energy is saved.
- The direct energy was greater compared to the indirect energy. Likewise, the non-renewable energy was greater than the renewable energy.

5. RECOMMENDATION

- Investigations on balanced utilization of energy sources for millet production in the large-scale schemes in rain fed areas in eastern Sudan are necessary.

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