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Field Performance Evaluation of Some Sugarcane Combine Harvesters in Kenana area, Sudan

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ABSTRACT

Mechanization application for harvesting and production of sugarcane increases efficiency of field work and improves production quality and costs. The main objective of this study was to evaluate the field performance of two sugarcane combine harvesters Makes in Kenana Sugar Company. Twenty-seven harvesters were used in the study and were grouped as per age in years. The measured parameters were the work rates, machinery productivity, fuel consumption, power requirement and the cost mechanized harvesting operation.

The results showed that generally all measured parameters were increased with age. It was revealed that the average rate of work ranged between 0.61-0.58 ha/hr and the calculated rates of work were found closer to the measured actual rates of work. The average throughout or productivity of the harvesters were 40.9-36.2 ton/hr (67.1-62.4) ton/ha. The average fuel consumption rates of the machinery were 39.7-39.9 lit/hr (65.1-68.8) lit/ha. The calculated power requirements were lower than actual rated ones and the average difference was 5.3%. The average mechanized harvest operation costs were 75.0-79.1 US$/hr (84.9-100.7) US$/ha and (1.85-2.25) US$/ton of production. The average fixed cost was 37% while the variable was 63% of the total cost. Make B was observed to record lower productivity and higher costs of production. It was concluded that although mechanization of sugarcane harvest is important, machine productivity and costs of field operations and production to be well considered through introducing scientific and technological advances.

Keywords

Sugarcane, Performance, Harvester, Productivity, Costs, Kenana.

Introduction

Machinery and equipment represent major capital investments in farm operations. The adoption of large-scale machinery, rapid technological advancements, increasing prices of spare parts and new equipment, as well as rising energy costs, have collectively led to a significant increase in machinery and power-related expenditures. Nevertheless, efficient machinery management practices can help control machinery and power costs per unit area [1]. Farm machinery management deals with the optimization of the equipment used for agricultural production; it is concerned with efficient selection, operation, maintenance, and replacement of machinery [2].

Sugarcane (*Saccharum spp.*) is an important industrial crop, used mainly for sugar production, grown in tropical and subtropical regions. The cultivation of sugar cane crop has spread to over 130 countries; Brazil with 30% of the world's leading producer, followed India (21%), China (7%), Thailand (4%), Pakistan (4%), Mexico (3.5%), Colombia (3%), Australia (3%), United States of America (2%) and Indonesia (2%) [3,4]. Production of sugarcane involves many operations from planting to harvesting [5]. Harvesting represents a major component of total farm expenses, and therefore, managing and improving the economic efficiency of sugarcane harvesting operations is essential for reducing overall production costs [6,7]. Mechanized harvesting systems are central to the production process, as they not only incur substantial operational costs but also influence the quality of the harvested cane [8]. With the advent of the sugarcane harvester, the productivity (acre/hr) has increased substantially, and the cost

has been reduced as compared to manual harvesting [9]. To harvest one hectare of sugarcane requires 3-4.2 machine-h by mechanical harvesting, whereas 850-1000 man-h by manual harvesting [10]. Field performance evaluation of sugarcane harvesters is a fundamental step in assessing the technical and economic efficiency of harvesting machinery, whether whole-stalk or chopper-type harvesters [11,12]. The evaluation aims to measure the actual machinery identifying under real operating conditions and to identify the factors affecting productivity, field efficiency, fuel consumption, and harvesting quality and costs [13]. Such evaluation provides a scientific basis for improving machinery management and reducing operating costs [14,15]. The analysis of productivity and field performance after the implementation of the proposed measures revealed an average of 0.66 ha / h, and an average yield of 45- 65.78 t / h, and fuel consumption of 38.6 – 49.4 L h-1 [16-18]. Some other studies found that sugarcane combine harvester productivity ranges from 0.8 to 1.2 hectares per hour (or roughly 30 to 50+ tons per hour), depending on forward speed, crop yield, and field layout. Operation costs vary based on machine age and field conditions, but generally span from $2.29 to $9.42 per ton, where fuel and machinery depreciation dominate ongoing expenses [19-21]. To increase productivity and reduce production costs of this crop is necessary to introduce scientific and technological advances in all links of the value chain [22,23].

Sugar production in Sudan started for the first time in Gunied in, later followed by New-Halfa, Northwest Sennar, Assalaya and finally Kenana [24]. The Kenana factory, which is in the White Nile state, started producing sugar in 1981. It's designed to provide 300,000 t of sugar per year, while the factory crushing capacity is 17000 t cane per day, the cane production area is around 40,000 ha [25]. For many years, Sudanese sugar companies have been suffering from the high cost of harvesting and high wages of labor in planting and harvesting sugar cane crop and even the labor shortage at the time of the peaks which was due to most workers prefer to work in other crops, therefore the problem of labor shortage leads to the introduction of mechanical processes for the cultivation and production of sugar cane to improve production cost [26]. The Mechanization application in field operations to produce sugar cane in Sudanese sugar companies requires deep study and analysis of mechanization characteristics used from planting to harvesting of the crop for proper decision making and management. Research in the White Nile region of Sudan has shown that while many operations for sugarcane production are well-mechanized, optimizing machine power and operation matching can further reduce costs and environmental impacts [27,28]. Despite the extensive adoption of mechanical sugarcane harvesters in large-scale sugar production schemes in Sudan, particularly in the Kenana area, the performance and management of the harvest machines remain inadequate. Most existing locally developed studies do not sufficiently account for the operational characteristics, complexity, and high capital value of sugarcane harvesters. This gap often limits the ability of machinery managers to make sound economic decisions regarding planning, machinery replacement, budgeting, and optimization of harvesting operations [29]. Therefore, there is a clear need for field evaluation to reflect the actual operating conditions of sugarcane harvesters at the Kenana area of Sudan. The main objective of this study was to evaluate the field performance of some sugarcane combine harvesters for production of sugar cane crop with special reference to Kenana Sugar Company.

The specific objectives are:
* To calculate the work rate of (effective field capacity) of the machine and compare it with the actual rates.
* To estimate the harvesting rate and throughout capacity of the machine
* To calculate the fuel consumption rate and efficiency
* To calculate the total cost of mechanical harvest operation
* To estimate the power requirement of the operation and compare with the used in the field.

Materials and Methods

Study area location

The study was conducted at Kenana Sugar Company, which located on the eastern bank of the White Nile in White Nile State, Sudan, near Rabak town, approximately 250–270 km south of Khartoum, the capital of Sudan. The company operates under a fully mechanized agricultural production system, encompassing land preparation, planting, crop management, harvesting, and transportation operations. Geographically the project is characterized by a flat to gently undulating topography, which enables efficient movement and continuous operation of large agricultural machines. In addition, the availability of a permanent and reliable irrigation supply from the White Nile ensures year-round water availability, supporting continuous cultivation cycles and extended harvesting seasons [29].

Soil and Cropping

The soils of Keanna scheme area are classified as brown montmorillonite clays, which have been deposited by the Blue Nile, forming the central clay plains of the Sudan. The scheme lies within the tropical dry hot semi-arid climatic zone, with a cool dry season during winter (November-February) followed by a hot dry season (April-June). Sunshine hours are high with an average of 9.4 hours/day, which is very important for sugar cane growth and annual rainfall is 400 mm. The major cane varieties grown are co6806, co527, co1001 and co997. The variety 6806 is grown in 60% of the area. The water supply in Kenana is done by lifting water from the White Nile through six pumping stations to an elevation of 45 meters from the White Nile level [30]. The six pumping stations are connected in series to irrigate 35280 ha for the period between Aprils to September.

Machineries Used

The agricultural mechanization system at Kenana Sugar Company encompasses a wide range of machinery and equipment, including agricultural tractors of various horsepower capacities, as well as specialized harvesting equipment. This study relied on sugarcane combine harvesters actively operated at Kenana Sugar Company during the study period. The total number of harvesters included in the study was 27, selected based on the availability of complete

and reliable operating and reliability. The harvesters examined in this study of two Makes, make A (11) and make B (16) harvesters. The general features of the combine harvester is shown in Figure 1. These brands constitute the core of the mechanized sugarcane harvesting system at Kenana Sugar Company. The inclusion of two different harvester types within the study population enabled an objective evaluation of machinery behavior under uniform operational and management conditions. The specifications of the two makes are given in Table 1.

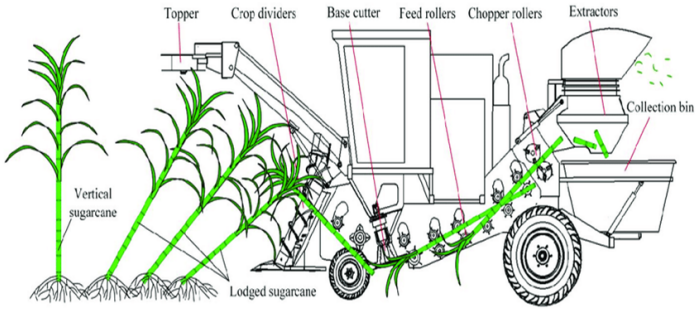


Figure 1: Sugarcane Harvester features.

Table 1: Specifications of the two combine harvesters.

Model	Make A	Make B
Country of make	Brazil	USA
Power Rate	260 kW (358) Hp	251 Kw (337) Hp
Weight	18,100 kg (Empty)	17,500 kg (empty)
Speed	Up to 20 km/h	W. speed: 0 -12 km/h
Fuel Tank Capacity 1-Fuel, 2. Hydraulic	620 Liters (163 Gallons) 400 Liters (105 Gallons)	-605L (160 Gal) -405L (106 Gal)
Wheels Size	14.9-24 23.5-25	-Front tyres: Size 14.9-24 -Rear tyres : Large 23.1-26
Engine Cylinders	6 cylinders in-line	6 in line / 9.0 L
Tracks	457.2 mm (18 in)	457.2 mm (18 in)
Topper	Up to 5.2 m (17.1 feet)	Maximum 5.2 m (17ft)
Chopper	closed-circuit high-pressure hydraulic chopper system.	Eight blade differential chopper system 95 mm
Fuel consumption	32 to 45 Liters per hour	35 to 50 Liters per hour

Types of Data collected

The data was collected from many sources such as mechanics, operators' records, workshops, personal communications, direct observation and from other related departments in the company. The data included information about: Harvesters make, model and age. Initial purchase price, Annual hours of use, Fuel consumption, Labor cost, Rate of work, Machinery weights.

Field operation Calculations:

a. Rate of work (RW):

The rate of work for the field operation was calculated according to [31] as follows:

RW =Area/ used time, or;

$= Wd * S * E$

Where, *Wd*: operational width of equipment, m, *S*: speed of operations, km/h. *E*: field efficiency, %.

b. Harvesting Rate or Throughput Capacity (HR)

The throughput capacity of the harvester was calculated as follows [32]:

HR = Wt./T, HR = Wt./A

Where, Wt = weight of material harvested in tons at the time T or an area A.

c. Fuel Consumption rate (FCR)

Fuel consumption may be expressed in liters per hour, per hectare, or per ton harvested [33]. It was calculated as follows:

FCR = FC/T (lit/hr), or FC/A (lit/ha), or FC/P (lit/ton)

Where, FC= amount of fuel consumption, T= time taken, A= area covered, P= crop harvested

d. Power requirement:

Power requirements (PR) for the operation were calculated according to [2] as follows:

PR = S*Wt*cf

Where, S: speed of operations, km/h, Wt: weight, kN, cf: conservation factor 3.6.

e. Cost calculation of field operations:

Fixed and variable costs were calculated as percentage of initial purchase price and the total cost expressed as cost per hour or cost per area or cost per crop harvested [20].

Results and Discussion

The measured parameters of the combine harvesters

The parameters measured and prices of the types of sugarcane harvesters were grouped with age in years and shown in Table 2. Generally, all parameters were observed to increase with age, but for the same age group, no significant difference was observed. The mean values showed that, for all measured parameters, Make A, recorded higher values and the differences were 10.6%, 14.4%, 10.8% and 18.8% for hours of use, area covered, fuel consumption and the crops harvested respectively. The hours of use recorded in this study is in line with those studies [17] and [20].

Table 2: Parameters measured for the two Makes of sugarcane harvesters.

Makes	Age	Hrs of use	Fuel (lit)	Feddan	Tons
Make A1	(A)1-3 yrs	2330	89,601	3437.5	98920
Make A2	(B) 4-6 yrs	1878	76,778	2677.4	73624.3
Make B1	(A)1-3 yrs	2290	87,559	3403.0	95964.6
Make B2	(B) 4-6 yrs	1970	75,400	2699.3	71034.7
Make B3	(C) 7-10 yrs	1384	59,645	1749.1	43146.9

Hectare = 2.38 feddan.

The harvest rates calculations

The rate of work estimation

The rates of work for the two Makes of harvester were group with age and given in Table 3. Generally, the rates of work were observer to decrease with age which may be due to more wearing and repair and maintenance. Although Make A, recorded higher work rate, the difference is just 5.5% and the average rates of work of the two Makes range between 1.45- 1.37 fed/hr (0.61-0,58 ha/hr). The findings of the present study were in line with those of [17,34,35]. The calculated and actual rates of work of the machines used were compared and it was observed that the actual and calculated rates of work of both Makes were close. The difference between them is 10% for Make A and 15% for Make B.

Table 3: Rates of work and throughput of the two types of harvesters grouped with age.

Makes	Age	Fed/hr	Ton/fed	Ton/hr
Make A1	(A)1-3 yrs	1.47	28.8	42.34
Make A2	(B) 4-6 yrs	1.43	27.5	39.33
Mean		**1.45**	**28.2**	**40.89**
Make B1	(A)1-3 yrs	1.49	28.2	42.02
Make B2	(B) 4-6 yrs	1.37	26.3	36.03
Make B3	(C) 7-10 yrs	1.26	24.7	31.12
Mean		**1.37**	**26.4**	**36.17**

b. Harvesting Rate or Throughput Capacity (HR)

Harvesting rate represents the amount of sugarcane harvested per unit time, commonly expressed in tones per hour. This indicator is widely used to compare different harvesters particularly in large-scale mechanized harvesting systems and it is sometimes expressed in tons/unit area [32,36]. The two Makes of harvesters' productivity in tons/hr and per feddan was presented in Table 3. It can be observed that the mean productivity is higher for Make A than Make B by 11.5% and 6.4% for tons/hr and per feddan respectively. The average finding of this study was about 64ton/ha (41 t/hr) (Figure 2), which was in line with that reported by [17,37] but lower than that of [18].

Fuel consumption rate calculations

Fuel consumption is one of the most important indicators for evaluating the economic performance of the harvester and reflects energy-use efficiency [38]. The results of this study expressed in liters per hour, per hectare and per ton harvested illustrated in Table 4. For the two Makes fuel consumption was observed to increase with age. The average fuel consumption rate in liters/hr of the two makes are similar, while Make B recorded higher values for fuel consumption per feddan and ton by 6.2% and 12.5% respectively. This could be related to the area covered and machine productivity. The average output of this study was in line with the findings of [16,17,18].

The Power requirements estimation

Power requirement was calculated for the two Makes of sugarcane harvesters and compared with the actual rated powers. Generally, the power requirement was observed to increase with the weight of the machine (Table 5). The rated power requirement for both Makes was higher than the calculated, but the average difference was just 5.3%. This is in line with that reported by [20,29]. The harvesting operation was observed to require higher power, as 255.5kW (Table 5). This could be due to the type of crops to be harvested and nature of the operation. This result was in line with [39,40] who reported that the requirement of energy for sugarcane harvesting operation was highest compared to many other crops.

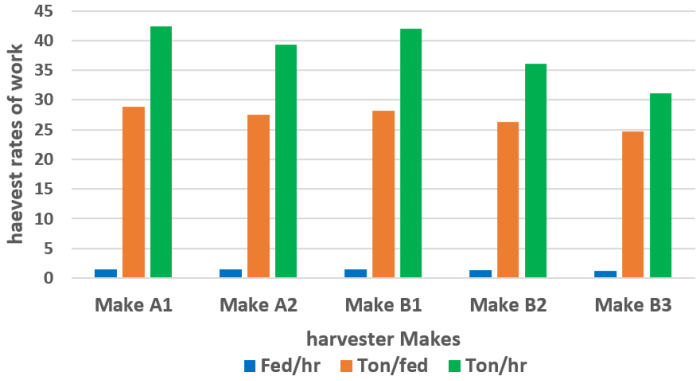


Figure 2: Effect of harvester make type on work rate and through out capacity.

Table 4: Fuel consumption rates for two Makes of sugarcane harvesters grouped by age in years.

Makes	Age	Liter/hr	Liter/Ton	Liter/fed
Make A1	(A)1-3 yrs	38.5	0.91	26.1
Make A2	(B) 4-6 yrs	40.9	1.04	28.7
Mean		**39.7**	**0.98**	**27.4**
Make B1	(A)1-3 yrs	38.2	0.91	25.7
Make B2	(B) 4-6 yrs	38.3	1.06	27.9
Make B3	(C) 7-10 yrs	43.1	1.36	34.1
Mean		**39.9**	**1.12**	**29.2**

Table 5: Power requirements estimation for the two Makes of harvesters.

Make	Speed	Wt. Kg	Wt. kN	Cal. Power req.	Rated Power req.	Diff
Make A	5 m	18100	177.5	246.5	260 kW	5.6%
Make B	5 m	17500	171.6	238.2	251 kW	5.1%
Mean	5m	17800	174.5	242.4	255.5	5.35%

Cost estimation of sugarcane combine harvester

Machinery costs are expressed per unit time, area or per ton of sugarcane harvested. Linking field performance indicators with operating costs provides a sound basis for evaluating the economic feasibility of mechanized harvesting systems [26]. The mechanized harvest operation costs for the two Makes were calculated as variable, fixed and total costs per time, area and productivity. Generally, for both Makes and groups, the variable costs were higher than the fixed costs and presented as 37% and 63% of total costs, respectively (Table 6). Make B observed to record higher values (Figure 3). The values were lower than those obtained by [18,41]. The total costs were observed to increase with age for both Makes as per unit time, unit area and unit of production (Table 7). It was clear that for both types of Make and age groups, the cost per unit time was the highest (Figure 4).

Table 6: Fixed, variable and total costs in US$/hr of the two Makes with age.

Makes	Age	Fixed cost $/hr	Variable cost $/hr	Total cost $/hr
Make A1	(A)1-3 yrs	25.24	42.06	67.30
Make A2	(B) 4-6 yrs	30.99	51.65	82.64
Mean		**28.12**	**46.86**	**74.97**
Make B1	(A)1-3 yrs	25.48	42.47	67.95
Make B2	(B) 4-6 yrs	27.41	45.69	73.10
Make B3	(C) 7-10 yrs	36.09	60.15	96.24
Mean		**29.66**	**49.44**	**79.1**

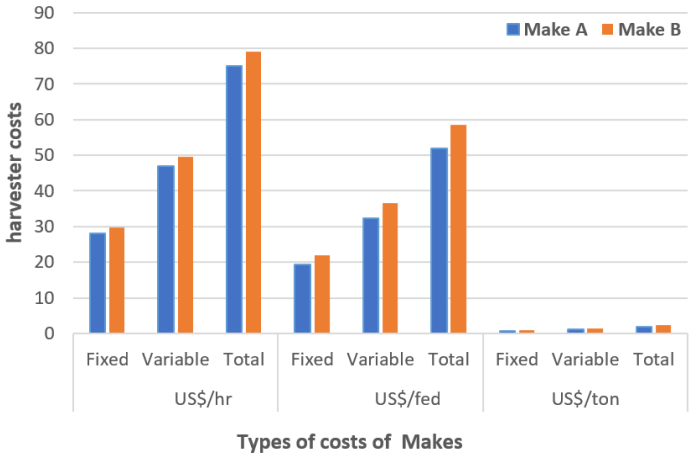


Figure 3: Effect of machine make type on different harvester costs.

Table 7: Total costs for the two Makes grouped with age as per unit time, unit area and unit of productivity.

Makes	Total cost $/hr	Total cost $/fed	Total cost $/ton
Make A1	67.30	45.61	1.58
Make A2	82.64	57.97	2.11
Mean	**74.97**	**51.80**	**1.85**
Make B1	67.95	45.73	1.62
Make B2	73.10	53.35	2.03
Make B3	96.24	76.16	3.09
Mean	**79.1**	**58.42**	**2.25**

The outputs of the present study per unit time were summarized in Table 8. Most of the output values were found to be well compared with some studies e.g., Ramos et al., [16]; Mejias et al., [17] and. Abdelhady et al. [37]; but there were also some differences when comparing with Martins et al. [18] and Rothenfuber et al. [21]. The differences could be due to field and machinery conditions and management.

Table 8: Summary of the study outputs for the two Makes per unit time.

Machine Make	Rate of work ha/hr	Productivity ton/hr	Fuel consumption lit/hr	Total cost US$/hr
Make A	0.61	40.9	39.7	74.9
Make B	0.58	38.2	39.9	79.1

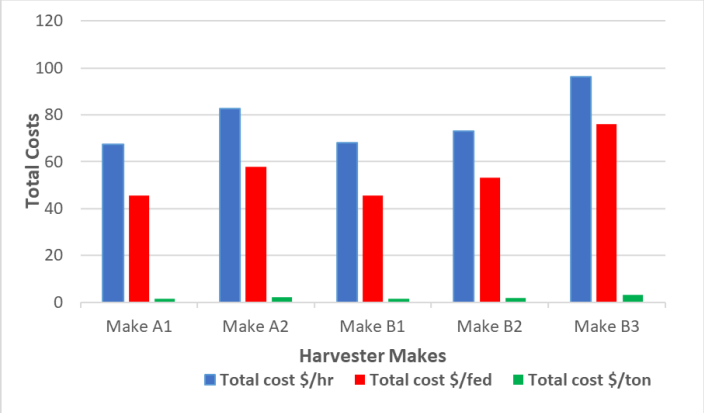


Figure 4: Total costs of the two harvesters make as per unit time, unit area and unit productivity.

Conclusions

The following conclusions may be drawn from the present study:

1. All measured parameters were observed to decrease with age of the machine and Make A, recorded higher values.
2. The average values of work rates obtained of the two Makes were 1.45- 1.37 fed/hr (0.61-0,58 ha/hr), productivity was 40.9 – 38.2 ton/hr, fuel consumption rate was 39.7-39.9 lit/hr (65.1- 68.8 lit/ha) and the total costs of mechanized harvesting operation was 74.9-79.1 US$/hr (1.9-2.3) US$/ton.
3. The power requirements increased with the weight of the machine and the calculated power requirements were observed to be lower than actual ones.

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