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Evaluation of Sugar Cane Harvester and Cutter

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Abstract: Sugarcane is widely cultivated in sub-Saharan Africa (SSA), particularly in Ethiopia. According to Central Statistics Agency (CSA) of Ethiopia, 1,090,575 households cultivated sugarcane in about 29,536.49 hectares of land and 13,470,350.06 productions in quintals and in Oromia region 324,526.00 households grew sugarcane and 3,162,239.03 productions in quintals. Sugarcane harvesting is a process of cutting and detaching of matured sugarcane from the field. Manual harvesting causes fatigue due to excessive stress on the joints and muscles and are exposed to harmful pests from plantations, creating safety concerns. Harvesting by machine makes green sugarcane harvesting possible, which reduces Green House Gas emissions from pre-harvest burning necessitated by manual harvesting. Result analysis indicate that the cutting capacity of sugar cane cuter machine was significantly affected by engine motor speed, sugarcane feed rate. The thoroughgoing cutting capacity of 1200.7 (stoke/h) was noted when the machine motor speed was 400 rpm and the feed amount of 3 (stoke/min). The thoroughgoing cutting effectiveness of 99.48% was recorded when the machine was worked at speed of 400 rpm and at feed amount of 2 (stoke/min). Gas ingesting of the cutting machine amplified with in increment of machine speeds and surge with increments of feed rates (from 100.33 to 124.33 ml/stoke with engine speed of 300 and 400 rpm and the feeding rate of 1, 2 and 3 stoke/min). Rise in the engine swiftness resulted in declined cutting efficiency. This could be due to the very fact that at higher engine speed the energy imparted to the sugarcane was high and hence causing disturbance for harmonic motion which leads to decline cutting uniformity. Thoroughgoing cutting uniformity 99.99% was observed when the machine was operated at engine speed of 300 rpm and at feed rate of 1 (stoke/min). The average cut height (mm) remains on ground, Forward speed (km/hr), Actual width of cut (mm), Theoretical field capacity (ha/hr), Actual field capacity (ha/hr) and Field efficiency (%) were 50.75, 2.18, 600,1.31, 0.69 and 52.67 respectively.

Keywords: Harvesting, Sugar Cane, Development, Evaluation

1. Introduction

According to FAO [2], world sugarcane growing area increased from 6.3 - 25.4 million hectares starting from 1950 to 2011 respectively in more than 90 countries, with a worldwide harvest of 1.69 billion tons. Sugarcane is an important crop widely cultivated for multiple purposes by smallholder farmers in sub-Saharan Africa (SSA), including Ethiopia. A report by the Central Statistics Agency of Ethiopia showed that 1,090,575 households grew sugarcane in about 29,536.49 hectares of land and 13,470,350.06 productions in quintals and in Oromia region 324,526.00 households grew sugarcane and 3,162,239.03 productions in quintals [1].

Sugarcane harvesting is a process of cutting and detaching of matured sugarcane from the field. Manual harvesting causes fatigue due to excessive stress on the joints and muscles and are exposed to harmful pests from plantations, creating safety concerns [3]. Labors can't cut sugarcane properly at ground level. This conventional harvesting operation still continues in a large scale in developing and underdeveloped countries around the world. Manual sugarcane harvesting is a very labor-intensive and laborious activity.

Manual harvesting causes fatigue due to excessive stress on the joints and muscles [4]. In manually operated harvesting method 16 - 17 labors/ha are required and they take three days to cut one hector and involves harvesting of 70 - 80 ton/hector with labors being paid 7.33 - 8.06 dollar/ton of harvest hence total cost of harvesting per hector comes up to 439.62 - 586.17 dollar. In mechanization now by using large scale harvesting machine takes about 6 - 7 hours for harvesting one hector averaging about 70 - 80 tons with labor costing around 51.29 - 58.58 dollar per hour hence the total cost of harvesting per hector comes up to 293.08-366.35 dollar [6].

Studies by Zenebe Mengiste et al. [8] have found that replacing land for sugarcane cultivation has not jeopardized the income and food security status of households. In contrast, studies by these authors [9-12, 16] reported that land diversion for sugar-cane expansion has had detrimental effects on the income and livelihood of households.

The advent of mechanical harvesting systems frees harvest laborers from the drudgery of field operations. To harvest one hectare of sugarcane, it requires 3.3 - 4.2 machine/hour by mechanical harvesting whereas 850 - 1000 man/hour by manual harvesting [7]. Mechanical harvesting also makes green cane harvesting possible, which reduces Green House Gas emissions from pre-harvest burning necessitated by manual harvesting.

The chopping is a mechanism to reduce sugar cane stalks into uniform-sized pieces. Chopping mechanism is used to simplify sugarcane handling operation [5]. Cutting quality on stalks and stools is critically important to reduce cane (juice) loss and to avoid the possibility of reduction in ratoon (the shoot of new sugarcane plant). Therefore, a good cane cutter should produce a smooth cut surface with minimal splits or cracks in addition to minimizing cutting force and cutting energy consumption. Rotating Cutting System is used to cut thick stalks having greater resistance to cutting (maize, sorghum, sugarcane, elephant grass, bamboo, etc.).

Objective: To develop and evaluate performance of sugar cane harvester and cutter.

2. Research Methodology

2.1. Study Area

Research was conducted at West Shoa BakoTibe Woreda based on sugarcane production potential on farmers farm field for trail in 2022 cropping season.

2.2. Materials Used

The following basic manufacturing machines, tools and instruments will be used:

1) Sheet metal
2) Engine
3) Weighing balance
4) Vernier caliper
5) Lathe machine
6) Fixed grinder
7) Welding machines
8) Drilling machine
9) Milling machine

Determination of height of cut above the ground

Height of cut above ground determined according to [6] the four unlike research plot of sugarcane after harvesting procedure were reviewed for defining height of cut. Ten cuts of stalks left after harvest in mechanical harvested was selected arbitrarily in unlike rows. Height of cuts was noted by placing the scale along the left over cut stalks in both mechanical and manual harvested fields. These heights of cuts of machine harvested fields were calculated to evaluate its performance.

Determination of time taken to harvest

Determination of time taken to harvest was estimated according to the research [6]. The gathering action was made to start in both mechanical and manual harvested fields and the time of start of harvest was noted using a stopwatch. Furthermore, the machine operational time of single row was noted for about five rows and also the total time taken to harvest one hector is noted by using a stopwatch. The noted mechanical and manual time reading was compared to evaluate the harvester performance [17].

Determination of field capacity

Machine field capacity was the total area covered in an operation to the total time taken to complete the operation according to Terry, A. and Ryder, M. [13] research finds. The total area covered in each of the field trials was taken as one hector to make a standard. The total time taken to harvest is noted already during both mechanical and manual harvesting trials. The field capacity was obtained by dividing area covered in harvesting operation with the total time taken to harvest in both mechanical and manual trials [15].

Actual performance rate (Pr)

$$Pr = Ha / Tc$$

Where:
Ha = total harvested area,
Tc = total consumed time, h
Field efficiency (ηt):

$$\eta t = \{(Th - Tu)/ Th \}* 100$$

Where:
Th = total time for harvesting, h;
Tu = total un-productive time during harvesting, h.

Cutting efficiency: Average lengths of 100 plants from different 10 locations in the field during and after harvesting were measured to calculate cutting efficiency.

$$\eta c = (hh / ht)* 100$$

Where:
hh = average height of plant after cutting, cm;
ht = average height of plant before cutting, cm.

Percentage breakage: Estimated by Counting from random locations.

$$Pb = \{(Gy - Wg) \div Gy\} * 100$$

Where:
Gy = total harvested
Wg= Number of breakage

Data management and statistical analysis

After the machine was developed primary was conducted at BAERC and necessary data was collected on the field. The parameters to be considered during the test were speed of operation, actual performance rate, field efficiency, cutting efficiency, percentage breakage, fuel consumption, time taken to harvest, suitability to operate, feedback of operators, capacity to finish work within a given time. Collected data was subjected to the statistical analysis according to the techniques of analysis of variance for split plot block design and then combined analysis was done by means of Gen-stat computer software package.

3. Performance Evaluation of the Prototype Machine

During the field test; speed of operation, actual performance rate and field efficiency were recorded as mentioned in table 1.

Table 1. *Mean results of field test on theoretical field capacity (TFC, ha/hr), actual field capacity (AFC, ha/hr) and field efficiency (FE, %).*

Plot	Average cut height remain (mm)	Forward speed (km/hr)	Actual width of cut (mm)	TFC (ha/hr)	AFC (ha/hr)	FE (%)
A	50.74	1.90	600	1.14	0.54	47.37
B	50.49	2.20	600	1.32	0.68	51.52
C	60.01	2.45	600	1.47	0.85	57.78
Aver.	50.75	2.18	600	1.31	0.69	52.67

The average cut height (mm) remains on ground, Forward speed (km/hr), Actual width of cut (mm), TFC (ha/hr), AFC (ha/hr) and FE (%) were 50.75, 2.18, 600, 1.31, 0.69 and 52.67 respectively.

To determine the effect of cutter bar of machine; machine speeds and sugar cane feed stoke on the routine data of the machine; fuel consumption, cutting efficiency, and cutting capacity and uniformity of cut were calculated respectively.

3.1. Cutting Capacity

The average cutting measurements and investigation of variance were offered in (Table 2). The results clearly shown that the cutting measurements of the machine of sugar cane cuter was significantly affected by machine speed, sugarcane feed rate. The maximum cutting capacity of 1200.7 (stoke/h) was documented when the machine speed was 400 rpm and the feed rate 3 (stoke/min).

Generally, cutting magnitude increased by increasing the machine speed and feed rate. The associations between machine swiftness and machine productivity (ton/h) at different feed rates, increasing the machine speed increased the product with increasing the treatments with direct relationships [12].

Table 2. *Cutting capacity (Cc in (stoke/hr)) of sugarcane cutter at various engine speeds, feed rates.*

Rpm	Fs (stoke/min)	Cc (stoke/hr)	Lower bound	Difference	Upper bound	Grand mean
	1	400.0	-807.2	-800.7*	0.0	
300	2	798.7	-408.5	-402.0*	0.0	
	3	1199.3	-8.2	-1.3	5.5	799.83
	1	400.7	-806.8	-800.0*	0.0	
400	2	799.7	-407.8	-401.0*	0.0	
	3	1200.7	-5.5	1.3	8.2	
Cv 0.38						

3.2. Cutting Efficiency

The average percent cutting efficiency of the machine and investigation of variance are given in (Table 3). Investigation of variance revealed that machine speeds and feed stoke had significant effect on cutting efficiency. As can be seen from (Table 3), increase in the machine speed give rise to enlarged cutting efficiency. This could be due to the very fact that at higher engine speed the energy imparted to the sugarcane was high and hence causing high cutting efficiency. The maximum cutting efficiency 99.48% was detected when the machine was operated at velocity of 400 rpm and at feed rate of 2 (stoke/min); whereas the minimum cutting efficiency of 98.6% was detected when the machine speed was 400 rpm and feed rate 3 (stoke/min) as can be seen from Table 3.

Table 3. *Cutting efficiency (%) of sugarcane cutter at several engine speeds, feed rates.*

Rpm	Fs	Ee (%)	Lower bound	Difference	Upper bound	Grand mean
	1	99.330	-0.828	-0.153	0.522	
300	2	99.280	-0.878	-0.203	0.472	
	3	98.610	-1.548	-0.873*	0.000	99.118
	1	99.407	-0.338	-0.077	0.185	
400	2	99.483	-0.185	0.077	0.338	
	3	98.600	-1.145	-0.883*	0.000	
CV(%) 0.12						

3.3. Fuel Consumption

The investigation of variance on fuel consumption of the cutting machine revealed that machine speed and feed rate had highly significant effects on the fuel consumption of the prototype machine. The average fuel consumption ranged from 100.33 to 124.33 ml/stoke with machine speed of 300 and 400 rpm and the feeding rate of 1, 2 and 3 stoke/min. It could be observed that the lowest values of fuel consumption were found at engine speed (V) 300 rpm and feed rate (Fr) of 1 stoke/min, however the highest values of fuel consumption were found at machine speed (V) 400 rpm and feed rate (Fs) 3 stoke/min.

Table 4. *Fuel consumption (ml/stoke) of sugarcane cutter at ifferent engine speeds, feed rates.*

Rpm	Fs	Fc (ml/stoke)	Lower bound	Difference	Upper bound	Grand mean
	1	100.33	-31.51	-24.00*	0.00	
300	2	102.00	-29.84	-22.33*	0.00	
	3	103.67	-28.17	-20.67*	0.00	111.28
	1	117.33	-8.49	-7.00*	0.00	
400	2	120.00	-5.82	-4.33*	0.00	
	3	124.33	0.00	4.33	5.82	
CV(%) 0.62						

3.4. Cutting Uniformity

The average percent cutting uniformity of the machine and investigation of variance are given in (Table 5). As can be seen from (Table 4), rise in the machine speed resulted in declined cutting efficiency. This could be due to the very fact that at higher engine speed the energy conveyed to the sugarcane was high and hence causing disturbance for harmonic motion which leads to decline cutting uniformity. The maximum cutting uniformity 99.99% was observed when the machine was worked at velocity of 300 rpm and at feed rate of 1 (stoke/min); whereas the minimum cutting efficiency of 98.59% was detected when the machine speed was 400 rpm and feed rate 3 (stoke/min) as can be seen from Table 4.

Table 5. *Cutting uniformity (%) of sugarcane cutter at different engine speeds, feed rates.*

Rpm	Fs	Cu (%)	Lower bound	Difference	Upper bound	Grand mean
	1	99.993	-0.936	0.047	1.030	
300	2	99.647	-0.987	-0.347	0.294	
	3	98.520	-2.114	-1.473*	0.000	99.382
	1	99.947	-1.030	-0.047	0.936	
400	2	99.593	-1.383	-0.400	0.583	
	3	98.593	-2.383	-1.400*	0.000	
CV(%) 0.30						

4. Conclusion and Recommendations

4.1. Conclusion

Sugarcane is widely cultivated for numerous purposes by smallholder farmers in sub-Saharan Africa (SSA), including Ethiopia. Even if many households grew sugarcane in about 29,536.49 hectares of land in Oromia region it's harvested by conventional method. Manual harvesting causes tiredness due to excessive stress on the joints and muscles and are exposed to injurious pests from plantations. The use of mechanical harvesting systems frees harvest laborers from the drudgery of field operations. Mechanical harvesting also makes green cane harvesting possible, which reduces Green House Gas emissions from pre-harvest burning necessitated by manual harvesting. The maximum cutting measurements of 1200.7 (stoke/h) was documented when the machine swiftness was 400 rpm and the feed amount 3 (stoke/min). Rise in the machine speed resulted in amplified cutting efficiency. The maximum cutting efficiency 99.48% was detected when the machine was operated at swiftness of 400 rpm and at feed amount of 2 (stoke/min); whereas the minimum cutting efficiency of 98.6% was detected when the machine speed was 400 rpm and feed amount 3 (stoke/min). Fuel ingesting of the cutting machine augmented with in increasing of engine speeds and rise with increasing of feed amount (from 100.33 to 124.33 ml/stoke with machine speed of 300 and 400 rpm and the feeding rate of 1, 2 and 3 stoke/min). Rise in the engine swiftness resulted in declined cutting efficiency. This could be due to the very fact that at higher machine speed the energy conveyed to the sugarcane was high and hence causing disturbance for harmonic motion which leads to decline cutting uniformity. Maximum cutting uniformity 99.99% was detected when the machine was operated at engine of 300 rpm and at feed rate of 1 (stoke/min); whereas the minimum cutting efficiency of 98.59% was detected when the machine swiftness was 400 rpm and feed rate 3 (stoke/min). The mean cut height (mm) remains on ground, Forward speed (km/hr), Actual width of cut (mm), TFC (ha/hr), AFC (ha/hr) and FE (%) were 50.75, 2.18, 600, 1.31, 0.69 and 52.67 respectively. Regarding to those, it can be concluded that the machine can be used and solve the problems of the farmers.

4.2. Recommendation

From obtained result the machine has a very good performance for cutting of sugarcane similar to performance outcome mentioned above. But, it can be more efficient if re-evaluated and extra work is done on it, particularly in harvesting of sugarcane.

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