[1.]Thomas Adedayo AYORINDE, [2.]Oseni Kehinde OWOLARAFE

DEVELOPMENT OF TRACTOR MOUNTED KENAF HARVESTER

[1.]Bioresources Development Centre, National Biotechnology Development Agency, Ogbomoso, NIGERIA
[2.]Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile–Ife, NIGERIA

Abstract: The design, fabrication and evaluation of a tractor mounted kenaf harvester was carried out in this study. The machine comprises of a rotary drive mechanism, which was adapted from a forage harvester. A review of kenaf stem properties was done to ensure accuracy of the design calculation for the machine components. The design of the machine was carried out using standard design procedures. A kenaf experimental field was set up at the Obafemi Awolowo University Teaching and Research Farm for the evaluation of the machine. The machine was evaluated using, crop maturity, crop variety and forward speed of the machine as factors. Effective field capacity and field efficiency of the machine were used as performance output parameters. The data obtained was analysed using 3–level factorial response surface methodology (RSM) of design expert software. The effective field capacity was observed to decrease with increase in plant maturity and increase with increase in forward speed of the machine. The highest effective field capacity recorded was 2.13 ha/day with Ifeken 100 at crop maturity of 10 weeks after planting, and forward speed was 5 km/hr. The field efficiency of the machine was found to decrease with increasing crop maturity and forward speed of the machine. The highest field efficiency of 97% was recorded for Ifeken 100 when the crop maturity was 10 weeks after planting and at 2 km/hr forward speed of machine.
Keywords: kenaf varieties, crop maturity, kenaf harvester, forward speed, field efficiency

INTRODUCTION

Kenaf is a dicotyledonous herbaceous annual plant with a high fibre yield. It has three different morphological fragments, which include the bark (with the bast fibre and the pectin), and the core (which contains the hollow centre that has the pith). The bast represents about 30% of the stalk weight and is the outer part of the plant which can produce high quality pulp, while the inner whiter part of the fibre (the core) is about 70% of the dry weight of the stalk, and produces low quality pulp (Makanjuola *et al.*, 2019; Ayorinde, 2022).

The industrial and economic importance of the entire parts of kenaf plant, i.e. leaves, fibre and seeds is enormous as they provide adequate, readily available and quality raw material that would secure the industrial and economic growth of a producing nation (Alexopoulou and Monti, 2013). Kenaf produces high quality pulp, in the stem. Kenaf fibers can be blended with synthetic fibers for making carpet. The fiber can also be used in making coarse bags, ropes, nets etc. Kenaf industrial applications include automobile, agriculture, construction, chemical process and packaging. Apparel fabrics and plastic/fiber composites from the fiber are its major end–use products. Other end use products include fiber board and particle board, oil and chemical absorbents, animal bedding, horticulture potting mix from the core, and livestock feed from the leaf (Makanjuola *et al.*, 2019).

Kenaf's ability to assimilate carbon dioxide, purify water and grow fast, has stimulated nations to consider kenaf as an alternative source of natural fibre. This discovery coincides with the global drive to mitigate environmental degradation due to the effect of oil spill, deforestation and chemical effluent, which made manufacturer to seek the use of agricultural products, wastes, and derivatives, like kenaf and some other fibrous crop, as raw materials, because of their renewability (Makanjuola *et al.*, 2019; Ayorinde, 2022).

Kenaf grows to maturity and is suitable for practical application in less than 3 months after planting. Manual methods are still used in kenaf harvesting and storage. In addition transportation and post–harvest processes are labour– intensive and time–consuming. Therefore, the development of kenaf harvesting technology continues to be an important aspect to explore (Ghahraei *et al.*, 2011; Dauda *et al.*, 2013). The objective of this study was to develop a tractor–mounted kenaf harvester to enhance the productivity of farmers and processors of kenaf in Nigeria.

MATERIALS AND METHODS

— Design consideration of the kenaf harvester

The following design considerations were followed during the development of the machine:

- The machine is not expected to be operated on a ridged field.
- The machine was designed to harvest the kenaf stem at 0.15 m to the ground level.
- The machine was designed to impact the required cutting power for shearing during operation as estimated with equation (1).
- The tractor was designed to travel outside the crop rows, while the harvester travel in the standing crop rows.

- The design concept is simple, easy to operate and repair by village artisans and farmers with minimum technical knowledge.
- It will be able to do large scale harvesting, save labour engagement and time of harvest.

— Description of the Machine

The machine operates with a mechanism of rotary disc harvester, which was mounted on the 3–point linkage of a tractor, driven by the power take–off (PTO) of the tractor and a bailing system, which bails the severed kenaf stem during harvesting. Circular saw blade was fixed on the rotary discs of the rotary disc harvesting mechanism, and was driven at high speed to achieve the cutting of the stem. The drive from the PTO was transmitted to the chain drive, which drives the bevel gear at the design speed. The bevel gear transmitted the drive at constant velocity ratio to the second chain drive, which drove the first cutting blade at constant velocity. The second cutting blade was designed to rotate concentrically with the first cutting blade, by the spur gear design arrangement on the machine. The machine was designed to accommodate a rack, which will enhance the packing of the stem in bundles. The isomeric and exploded views of the machine are as shown in Figures 1 and 2. Figure 3 shows the harvester mounted on a tractor.

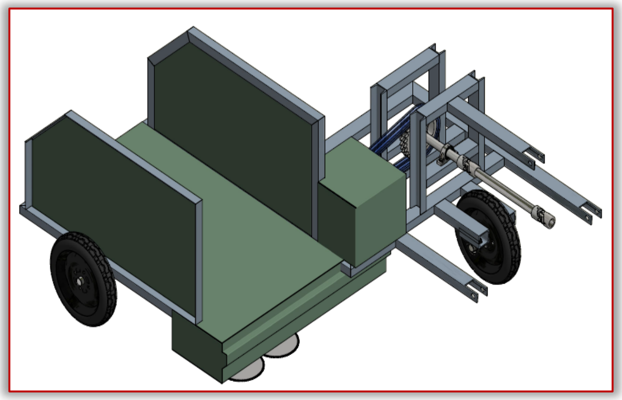

Figure 1: Isometric view of the kenaf harvester

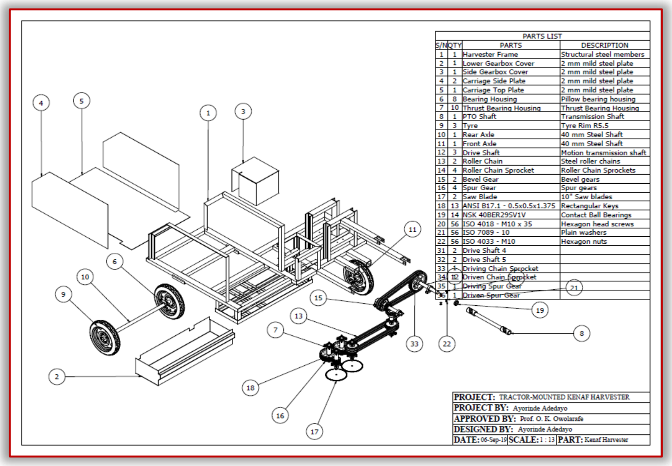

Figure 2: Exploded view of the kenaf harvester

Figure 3: The developed kenaf harvester mounted on a tractor

— Determination of cutting power requirement

The power required to cut kenaf stem was estimated to be 4.88 kW using equation (1), given that the ratio of average to peak cutting force C_f for a typical force–displacement curve is approximately equal to 0.64 (Srivastava *et al.*, 2006). The force required to cut the stem, $F_x$max, was 0.609 kN (Raji and Aremu, 2017), while the depth of material in contact with the blade X_{bu} was 22.98 mm. The cutting frequency, F_{cut} was estimated from the product of speed (647 rpm) by the number of cutting edge per revolution (50). The specifications of the tractor mounted kenaf harvester is shown in Table 1.

$$P = \frac{C_f F_{x\,max} X_{bu} F_{cut}}{60000} \quad (1)$$

where, P = power for cutting, (kW)

Fx_{max} = maximum cutting force, (kN)

Xbu= depth of material at initial contact with knife, mm

fcut = cutting frequency, cuts/min

Cf = ratio of average to peak cutting force (Srivastava *et al.*, 2006)

$$\text{Cutting power required} = \frac{0.64 \times 0.61 \times 22.98 \times (50 \times 647)}{60000} = 4.84\text{kW}$$

Table 1: Specifications of tractor mounted kenaf harvester

Parameter	Specification
Dimension (L × W × H)	2240 x 2192 x 800 mm
Ground clearance	150 (mm)
Total weight	850 (kg)
Power Source	Tractor PTO
Tractor power required	55–70 (hp)
PTO speed	540 rpm
Transmission	PTO, gears, chain drive, shafts, bevel and spur gears
Height adjustment	Hydraulic
Cutting system	Carbonized Circular saw blade
Cutting width	900 mm
Number of tyres	4

— Performance evaluation of the machine

≡ Experimental design for evaluation

Three varieties of kenaf (Cuba 108, Ifeken di 400 and Ifeken 100) were planted at the Teaching and Research Farm Obafemi Awolowo Univeristy, Ile– Ife, Nigeria and monitored till 10th week. The experimetal design for the evaluation is shown in Table 2, with factors arranged in a 3 x 4 x 5 experiment making 60 experimental runs, with 3 replicates, giving 180 runs.

Table 2: Experimental design for the evaluation

S/N	Independent parameters	Indices
1.	Varieties	Cuba 108, Ife ken 100 and Ife ken Di 400
2.	Age of plant (Stem Diameter, mm)	Week 10,12,14 and 16
3.	Forward speed (km/h)	2, 3.5, 5.0, 6.5 and 7.7

≡ Performance evaluation procedure

The machine was mounted on a tractor and evaluated on the field based on the following parameters;

$$\text{Theoretic field capacity, ha/hr} = \frac{W \times S}{10} \quad (2)$$

where, W = Effective harvest width (m)
S = Forward speed (km/h)

$$\text{Effective field capacity, ha/h} = \frac{\text{Acuatal area covered (Ha)}}{\text{Time required to cover the area (h)}} \quad (3)$$

$$\text{Field efficiency (\%)} = = \frac{\text{Effective field capacity}}{\text{Theoretic field capacity}} \quad (4)$$

(Dauda *et al.*, 2013)

The result of the machine field efficiency was subjected to Box–Behnken randomized methodology of the response surface standard design to get the experimental runs presented in Table 3. Data obtain for field efficiency was statistically analyzed.

Table 3: Kenaf harvester machine performance

Std	Run	WAP (weeks)	Variety	Forward Speed (km/hr)
5	1	10	I4	2
10	2	13	I1	2
7	3	10	I4	7.7
15	4	13	I4	5
12	5	13	I1	7.7
4	6	16	I1	5
8	7	16	I4	7.7
1	8	10	C1	5
2	9	16	C1	5
9	10	13	C1	2
3	11	10	I1	5
13	12	13	I4	5
6	13	16	I4	2
11	14	13	C1	7.7
14	15	13	I4	5

Note: C1 = Cuba 108; I4 = Ifeken di 400; I1 = Ifeken 100

RESULT AND DISCUSSION

— Effect of plant maturity on field efficiency of the machine

The field efficiency of the machine decreased with increasing plant maturity, when other factors remain constant. The maximum field efficiency recorded was 97% at week 10 while the minimum was 22% at week 16. The 3D surface graph in Figures 4 to 9 showed similar trend of drop in the machine efficiency at forward speed and crop variety to as low as 22%. Similar result was reported by Falana *et al.* (2020). The analysis of variance using design expert software showed that all machine operational factors had significant effect on the field efficiency (Table 4)

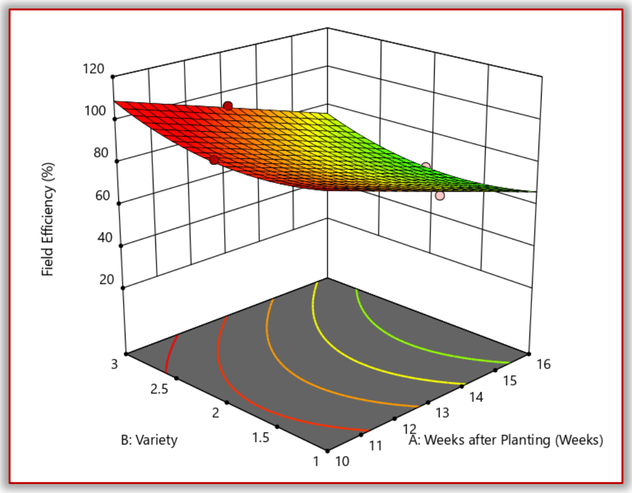

Figure 4: Plot of Effect of variety and weeks after planting on field efficiency when forward speed was 2 km/hr

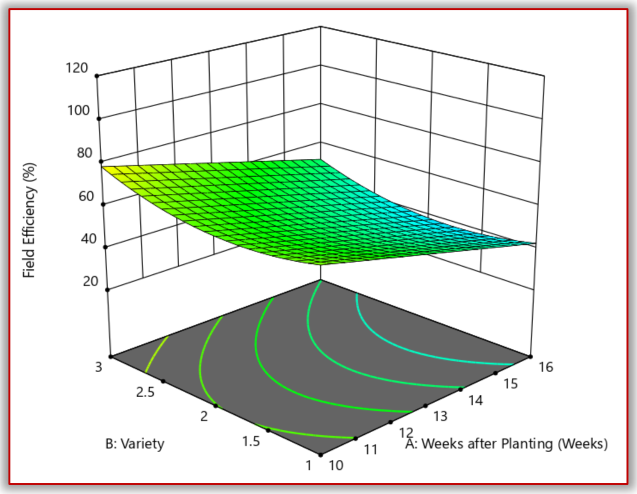

Figure 5: Plot of Effect of variety and weeks after planting on field efficiency when forward speed of tractor was 3.5 km/hr

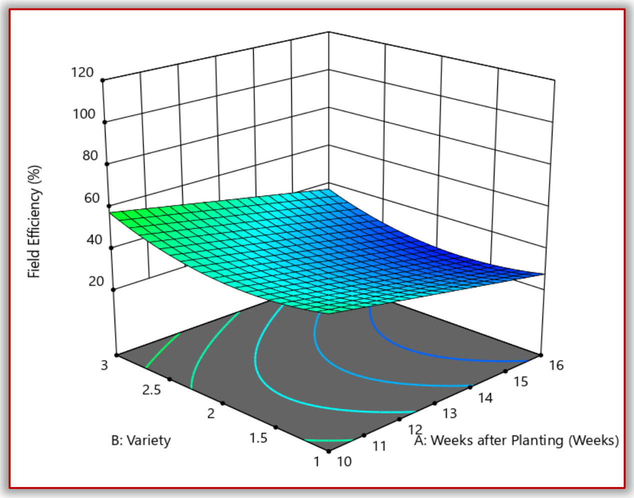

Figure 6: Plot of Effect of variety and weeks after planting on field efficiency when forward speed of tractor was 5 km/hr

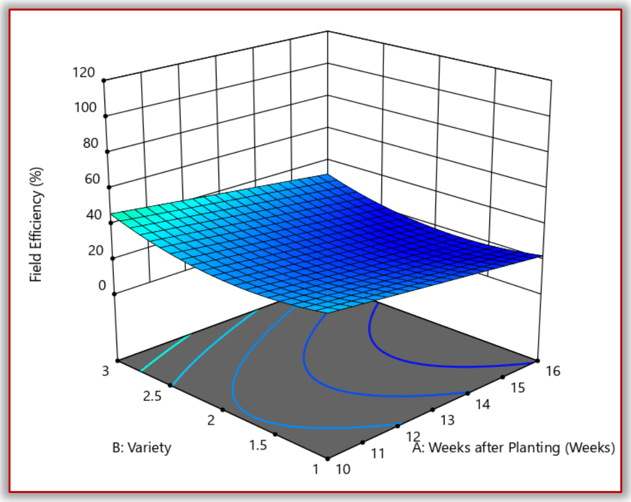

Figure 7: Plot of Effect of variety and weeks after planting on field efficiency when forward speed of tractor was 6.5 km/hr

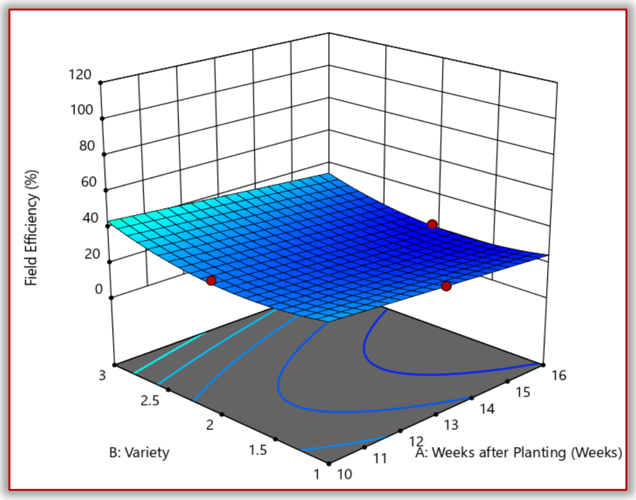

Figure 8: Plot of Effect of variety and weeks after planting on field efficiency when forward speed of tractor was 7.7 km/hr

Table 4: ANOVA of the effect of operation parameters on field efficiency

Source	Sum of squares	DF	Mean Square	F–value	p–value	Remark
Model	8185.65	6	1364.27	357.45	< 0.0001	significant
WAP	913.07	1	913.07	239.23	< 0.0001	significant
V	173.87	1	173.87	45.56	0.0001	significant
FS	5718.38	1	5718.38	1498.27	< 0.0001	significant
WAP*FS	132.41	1	132.41	34.69	0.0004	significant
V^2	261.24	1	261.24	68.45	< 0.0001	significant
FS^2	1055.32	1	1055.32	276.50	< 0.0001	significant
Residual	30.53	8	3.82			
Lack of Fit	30.53	6	5.09			
Pure Error	0.0000	2	0.0000			
Cor Total	8216.18	14				

— Effect of plant variety on field efficiency of the machine

It could be observed from Table 3 that the field efficiency dropped slightly as the variety was changed from Cuba 108 to Ifeken di 400 and increased to the maximum when Ifeken 100 was harvested. The response surface graph in Figures 5 to 9 also confirmed that plant variety had effect on the field efficiency. The highest field efficiency (97%) and the lowest field efficiency (22%) were recorded when Ifeken di 400 was harvested (other machine operation parameters were constant). Similar result was reported by Dauda *et al.* (2013) and Abd–El Mawla and Hameida (2005) in their respective research findings.

— Effect of forward speed of tractor on the field efficiency of the machine

The field efficiency of the machine increased as the forward speed of operation decreased as shown in the response surface graph (Figures 9). The highest and the lowest field efficiencies recorded were 97% and 22%, respectively. The highest field efficiency was recorded when the forward speed of machine was 2.0 km/hr while the lowest field efficiency was at 7.7 km/hr (Table 3). The efficiency of this kenaf harvester is higher than that of the tractor mounted kenaf harvester developed by Dauda *et al.* (2013) which was 76%. The effect of forward speed on the field efficiency was observed to be significant as shown in Table 4.

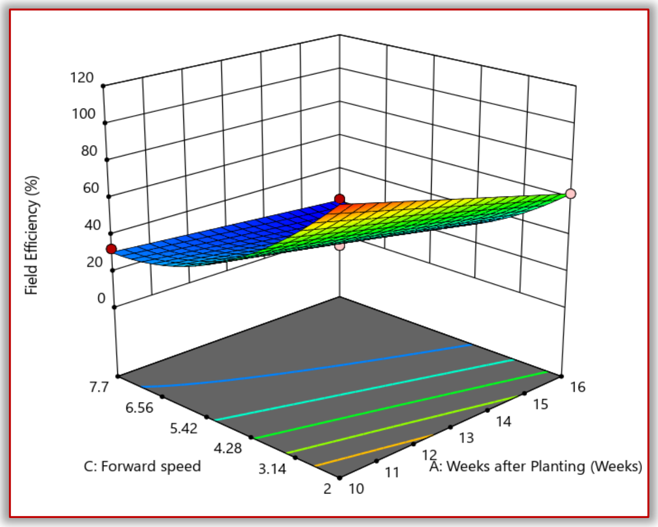

Figure 9: Plot of the effect of forward speed on field efficiency of the machine

CONCLUSIONS

A tractor mounted kenaf havester was developed in this study. The machine harvests the plant stem with a circular blade and it also have a bailing sytem, which make the packing of kenaf stem easy. The result showed that crop maturity, varieties and forward speed during operation have influence on the performance of the harvester. The field efficiency of the machine was found to increase with decreasing crop maturity, and forward speed of the machine. The highest field efficiency was 97% with *Ifeken 100* harvested, when the crop maturity was 10 weeks after planting, and forward speed of machine was 2 km/hr. The result of the performance evaluation indicates that the harvester has the potential for commercialisation for the use of kenaf farmers.

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ISSN: 2067–3809