Determining the efficiency of a modified brush cutter for kenaf (*Hibiscus cannabinus*) harvesting

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Abstract: The adaptation of some existing technologies such as sugarcane-type harvester, jute/reed-type harvesters and forage harvesters for kenaf harvesting have not been successful. These machines apart from being expensive cut kenaf stems into too short fragments. Information regarding machines for kenaf harvesting is rarely found in the literature. In this work, an existing 1.65 kW brush cutter was modified and adapted for kenaf harvesting with the view to developing a low-cost machine for kenaf harvesting. The modifications made include incorporating a suitable metal guard based on the physical properties of kenaf stem and selection of an appropriate serrated blade cutting mechanism. The machine was tested on an experimental field of 3 and 4 months old kenaf plantation, and its performance was evaluated considering the effective field capacity, theoretical field capacity, field efficiency and fuel consumption. The results showed that the field efficiency of the machine ranged from 69.15% – 81.21%. The theoretical field capacity and fuel consumption were 0.14 ha h^{-1}, and 46.91 L ha^{-1}, respectively. Furthermore, it was found that kenaf variety had a significant effect ($p<0.05$) on the theoretical field capacity. The field efficiency was significantly affected ($p<0.05$), by the maturity of the kenaf plant and harvester blade type. However, blade type and kenaf varieties do not have a significant effect on fuel consumed by the harvester. The kenaf harvesting machine was able to harvest the two kenaf varieties considered in this study when fitted with the 3-tooth and 40-tooth brush cutter blades. A machine of this nature is a positive development in kenaf harvesting, which hitherto has been an arduous task for kenaf farmers.

Keywords: kenaf harvesting, modified brush cutter, performance evaluation.

Citation: Falana, O. B., O. B. Aluko, D. A. Adetan, and J. A. Osunbitan. 2020. Determining the efficiency of a modified brush cutter for kenaf (*Hibiscus cannabinus*) harvesting. Agricultural Engineering International: CIGR Journal, 22(2): 59-67.

1 Introduction

Kenaf (*Hibiscus cannabinus*) is a warm-season annual fibre crop that grows very well in Nigeria (Amusat and Ademola, 2014). It matures in three to four months (Webber et al., 2002a). Kenaf has been known as a fibre crop which has much economic importance. Kenaf fibres can be used for making many agricultural and industrial products like thermoplastics, composites, geotextiles, potting mixes, agricultural mulches and films, fabrics and industrial absorbents (Webber et al., 2002b). The fibre is also used for making fishing nets, ropes and doormats while fabric can be woven into carpets, cloth and clotheslining (Hittersay, 2005). Fibres from the stem can be used as an animal litter. The leaves may be edible to both animals and humans and can be used as a herb in some dishes (Webber et al., 2002a). Oil produced from the seeds is used for cooking oil and margarine production (Kayembe, 2015). Kenaf seeds can be used in the manufacture of soap and paints. Kenaf contains many potentially useful compounds for medicines to ease problems such as bruising, cuts and aches. However, the most important use of kenaf is for the production of sacks and paper pulp. (Hittersay, 2005). Despite the numerous uses of kenaf, the cultivation processes such as harvesting

Received date: 2019-01-06 **Accepted date:** 2020-02-05

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and post-harvest are still labour intensive and take up a lot of time (Ghahraei et al., 2011). Over many years, kenaf has consistently been hand-harvested for use. Recently, forage harvesters are generally used for the harvesting of kenaf, because of their high efficiency (Dauda et al., 2013).

Kenaf is usually harvested for fibre in its vegetative or dry state, with the aid of herbicides, when it is still growing. Once dried, the kenaf can be chopped, baled with bailing equipment (Broadway, 1990), or transported as full-length stems (Webber et al., 2002b). Crane and Acuna (1945) reported that the percentage of fibre in the stem increased until the time of flowering and then remained approximately the same. However, the highest quality fibre was obtained when kenaf was harvested at the onset of flowering (Crane and Acuna, 1945; Webber et al., 2002a; Kayembe, 2015). If harvested before or after flowering, lower fibre quality was obtained (Webber et al., 2002a).

Forage harvesters can be used for harvesting kenaf either as forage or fibre crop (Webber and Bledsoe, 1993). According to Webber et al. (2002b), when harvesting kenaf for use as fibre, moisture content consideration was vital. The best practice was to harvest at three months after planting for quality fibre and four months after planting for quality seeds. In regions where cottons are grown, cotton modules have been used for field-side storage of chopped kenaf (Fuller and Doler, 1994).

Mechanical harvesting of kenaf has called for the adaptation of some existing technologies such as sugarcane-type harvester, jute/reed-type harvesters and forage harvesters. These machines, apart from being expensive cut kenaf stems into undesirably too short fragments (Kobayashi et al., 2003). Information regarding the adaptation of a brush cutter for this purpose is rarely found in the literature. Therefore, in this work, the brush cutter was modified and adapted for harvesting/cutting kenaf as a whole stalk.

2 Materials and method

Seeds of two kenaf varieties (Ifeken 100 and Tianung 1) obtained from the Institute of Agricultural Research and Training (I.A.R&T), Ibadan were planted on a plot measuring 1244.16 m^2 at the Teaching and Research Farms, Obafemi Awolowo University, Ile-Ife. The experimental factors are kenaf variety, kenaf maturity and harvester blade type. There are two levels of kenaf variety: Ifeken 100 and Tianung 1; two levels of kenaf maturity: three months and four months old; two levels of harvester blade type: 40-tooth and 3-tooth brush cutter blades. The factors were arranged in a completely randomized design in a 2 by 2 by 2 factorial experiment, giving eight experimental plots (Table 1).

Table 1 Designation of the kenaf experimental plots

S. no.	Plot label	Description
1	I 3(40T)	Ifeken 100 harvested 3 months after planting with a 40-tooth brush cutter blade
2	I 3(3T)	Ifeken 100 harvested 3 months after planting with a 3-tooth brush cutter blade
3	T 3(40T)	Tianung 1 harvested 3 months after planting with a 40-tooth brush cutter blade
4	T 3(3T)	Tianung 1 harvested 3 months after planting with a 3-tooth brush cutter blade
5	I 4(40T)	Ifeken 100 harvested 4 months after planting with a 40-tooth brush cutter blade
6	I 4(3T)	Ifeken 100 harvested 4 months after planting with a 3-tooth brush cutter blade
7	T 4(40T)	Tianung 1 harvested 4 months after planting with a 40-tooth brush cutter blade
8	T 4(3T)	Tianung 1 harvested 4 months after planting with a 3-tooth brush cutter blade

First planting commenced on 16th August 2017 and second planting commenced on 16th September 2017. Seedlings were sown at a spacing of 0.3 by 0.7 m on each experimental plot which has a dimension of 0.90 by 86.4 m with two replicates. Stems of the planted kenaf were harvested at 3 and 4 months after planting, using the modified brush cutter. The moisture content of the stems was determined by oven drying (ASABE, 2012).

2.1 The description of a brush cutter

Brush cutters are implements that are readily available and easily serviced. It usually consists of two or four-stroke petrol engine driving an attachment/blade via a shaft. It is portable, manoeuvrable and can be harnessed to the operator (Langton, 2007). It has a lightweight aluminium body (7 – 8 kg), hence, the operator never feels its heavyweight,

vibration is less, hence, exerting less strains on the operator. It consumes 600 – 900 mL lubricating oil mixed with gasoline per hour depending on the work used for. It can be operated over any terrain for 800 h. Figure 1 shows the schematic drawing of a typical brush cutter.

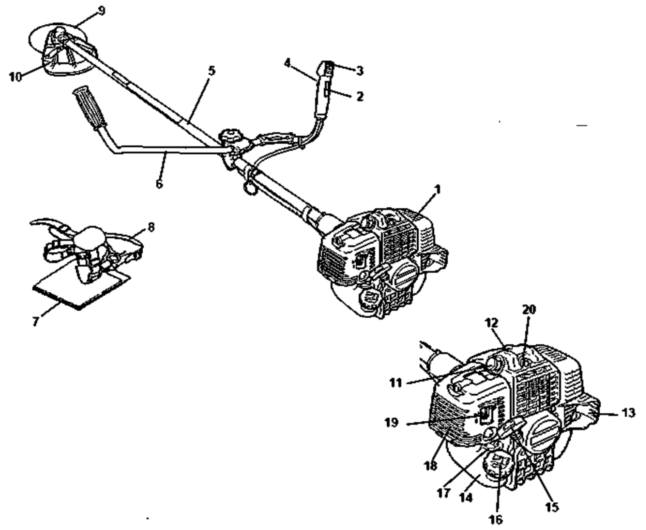


Figure 1 A Schematic drawing of a typical brush cutter
1. Power head 2. Throttle trigger lockout 3. Stop switch 4. Throttle trigger 5. Drive shaft assembly 6. U-handle 7. Hip pad 8. Shoulder harness 9. Blade 10. Metal blade shield 11. Spark plug 12. Arm rest 13. Spark arrestor muffler 14. fuel tank 15. Recoil starter handle 16. Fuel tank cap 17. Purge bulb 18. Air cleaner 19. Choke 20. Decompression button

A typical brush cutter has five sub-assemblies which include:

Engine subassembly

Brush cutter uses a light-weight, low emission, 2 or 4-stroke single-cylinder spark-ignition engine. This sub-assembly has a recoil starter for starting the engine. It also has a muffler that is connected at the end of the exhaust box, which minimize noise during operation.

Driveshaft subassembly

It is made of a central steel drive spindle which is 5 mm in diameter and 153 cm long surrounded by a bushed outer aluminium hollow sleeve. One end of the drive spindle is connected to the engine shaft while the other end is attached to a bevel gear unit at the gear head. The lubricated hollow sleeve which is 149 cm long has an internal recess to hold the spindle firmly. There are bushings inside the hollow sleeve holding the internal spindle for proper gripping with the outer sleeve.

Gear drive subassembly

This is a cast-in subassembly having two bevel gears. One bevel gear is attached to the end of the driveshaft, while other is fixed to the shaft carrying the trimming head. Both drive and cutter shafts are laid at some angle such that the cutting mechanism is in a plane parallel to the ground. According to Reddy et al. (2010) the gear ratio of a typical brush cutter was 1:1.46.

Trimming head subassembly

The trimming head has a small shaft projecting out of the gear head. It drives any cutting mechanism. It is majorly used with a nylon thread holder. It can also be used with blades with different designs depending on the purposes of use.

Handle subassembly

The handle of the brush cutter comprises of a clamp mounted centrally about the aluminium that house the driveshaft. The handle holds the throttle trigger, stop switch and clutch/throttle trigger lockout of the brush cutter. The direction and height of the handle can be adjusted with respect to the ergonomics of the operator.

2.2 Selection of brush cutter

To select an adequate brush cutter, the power required to cut kenaf stem was estimated using Equation 1 from Srivastava et al. (2006). In calculating rotational power, it was necessary to convert the velocity from rpm to rad s^{-1}.

$$P = \frac{C_f\,F_{xmax}\,X_{bu}\,f_{cut}}{60000} \tag{1}$$

where,

P = power (kW)

C_f = ratio of average to peak cutting force

$F_{x\,max}$ = maximum cutting force (kN)

X_{bu} = depth of material in contact with blade (mm)

f_{cut} = cutting frequency (cuts min^{-1})

A C_f value of 0.64 was obtained from a typical force-displacement curve according to Srivastava et al. (2006). Based on some determined properties of kenaf stem, the force required to cut the stem was 0.192 kN and the X_{bu} value was 14.26 mm. Hence,

$$P = \frac{0.64 \times 0.192 \times 14.59 \times 700 \times 40}{60000} = 0.837\ \text{kW}$$

The wide variety of brush cutter available allows the choice of an appropriate brush cutter well suited to cutting kenaf. The choice of brush cutter was also facilitated by reports of previous experiments with brush cutters cutting sugarcane (Srivastava et al., 2006; Langton, 2007). A Maxmech XY-CG520M rated 1.65 kW was chosen (see specifications in Table 2).

Table 2 Detailed specification of maxmech 520M

Properties	Specifications
Power rating	1.65 kW
Power transmission method	Automatic centrifugal clutch, spiral gear
Size (L × W × H)	1830 × 610 × 420 mm
Weight	8.4 kg
Fuel tank capacity	1 L
Idle speed	7500 rpm
Maximum speed	10000 rpm
Fuel used (mixing rate)	Lubricating oil mixed gasoline (1:25)

2.3 Modifications made: Introduction of a metal guard

The design of a suitable metal guard was based on the average height of kenaf stem determined on the field. The main purpose of the metal guard is to prevent the cut stem from falling on the operator of the harvester. The guard required a number of design constraints which were as follows:

i The guard is required to be attached to a standard commercial brush cutter,

ii The guard must be able to withstand the weight of the plant,

iii The guard must be able to resist corrosion, and

iv The guard must be lightweight.

The material selected for the metal guard is mild steel bar which is 5 mm thick and 25 mm wide. It has a tensile strength (yield) of 370 MPa which is greater than the strength of the kenaf stem (44.86 MPa) which was determined using Instron Universal Testing Machine (UTM, Instron 3369K1781, 50 KN, USA). This implies that it can bear the load of the kenaf stem without deforming. The metal is a curved component with a radius of curvature 305 mm. The metal guard was able to guide the stem to the cutting zone especially for stands with more than one kenaf stems. A detailed drawing of the guard is shown in Figure 2. It was fabricated afterwards and attached to the brush cutter gear head using bolts and nuts. The total weight of the metal guard after fabrication was 1.4 kg.

2.4 Selection of brush cutter blades

To enable the brush cutter function as a kenaf harvester, selection of appropriate recommended cutting mechanism (serrated blade) which replaced the conventional trimmer line with a metal blade was a major consideration. The blade selection was constrained by the following requirements:

i The blade was required to be attached to a standard commercial brush cutter;

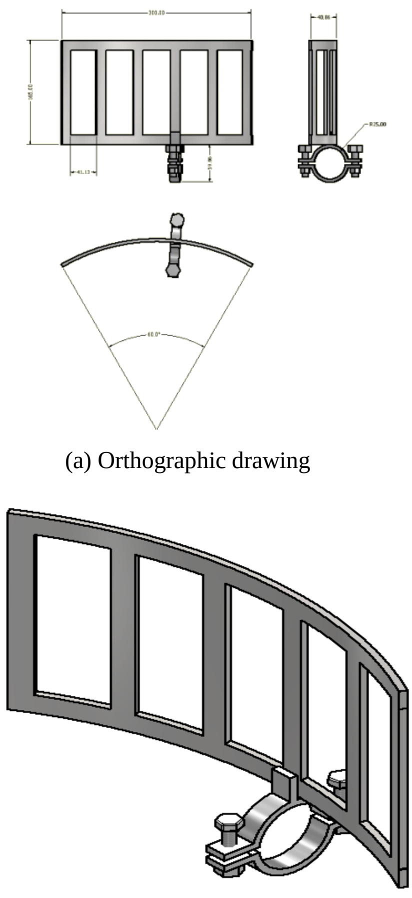
ii The blade must be able to operate at high speeds (6000 - 9000 rpm);

iii The blade weight must not exceed 1.5 kg;

iv The blade must cut the kenaf stem as close to the ground as possible;

v The blade must cut the kenaf stem cleanly without fibre damage; and

vi The blade must be safe to use and be economically viable.

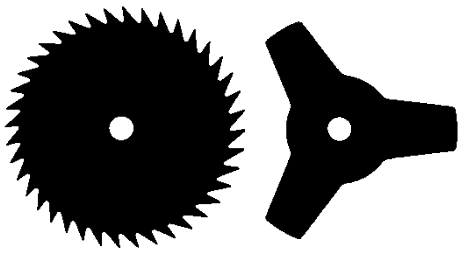


(a) Orthographic drawing

(b) Isometric drawing

Figure 2 Metal guard

The brush cutter selected for this study can accommodate a blade of 2.54 cm inner diameter and 24 cm outer diameter. The system requires a tolerance between the blade and the metal guard because any deflection of the blade that leads to contact with the metal guard can be catastrophic. Therefore, the rigidity of the blade was considered as the highest priority in the blade selection. A 40-tooth brush cutter blade was chosen based on the report of Ghahraei et al. (2011) and Dauda et al. (2015) while a 3-tooth brush cutter blade was chosen to compare the quality of cut of both blades on two varieties of kenaf at different maturity stages and to see if there were any significant difference in the efficiency of the harvesting machine. The two brush cutter blades are made from High Carbon Steel metal. The 40-tooth brush cutter blade has a weight of 499 g and a knife-edge angle of 30°, while the 3-tooth brush cutter blade has a weight of 397 g and a knife-edge angle of 30°. The blades are readily obtainable for use by any operator. These blades were not modified because they conform with the recommendation by earlier researchers (Ghahraei et al., 2011; Dauda et al., 2015). Both brush cutter blades (Figure 3) meet the design constraints stated earlier and can, therefore, be adopted for the cutting mechanism of the kenaf harvesting machine.



(a) 40-tooth brush cutter blade (b) 3-tooth brush cutter blade

Figure 3 Brush cutter blades

Table 3 The bill of quantity and evaluation for modified brush cutter machine

S/No	Description	Length	Quantity	Unit Cost (₦)	Total Cost (₦)
1	Brush Cutter	1.8 m	1	70000	70000
2	Brush Cutter Blades	Ø 24 cm	2	4000	8000
3	Flat bar	4 m	1	2000	2000
4	Electrodes		1	1000	1000
5	Bolts and Nuts		4	25	100
6	Transport				2000
7	Workmanship				3000
	TOTAL				86,100

2.5 Performance evaluation of the harvester

The machine components were assembled and tested on an experimental field of 3 and 4 months old kenaf plantation. The net weight of the kenaf harvesting machine was 10.3 kg. However, the weight was supported by a shoulder strap, which eases operation and manoeuvrability of the harvester. The performance evaluation of the kenaf harvesting machine (Plate 1) was based on the following parameters:

i. Effective field capacity (EFC) measured in ha h^{-1} (Oyelade and Oni, 2011) could be expressed as:

$$D = \frac{E\,(3600)}{F} \quad (2)$$

where,

D = effective field capacity (ha h^{-1})

E = area of the field (ha)

F = total time taken in completing the whole harvesting operation (s)

ii. Theoretical field capacity (TFC) measured in ha h^{-1} (Oyelade and Oni, 2011) could be expressed as:

$$G = \frac{E\,(3600)}{T} \quad (3)$$

where,

G = theoretical field capacity (ha h^{-1})

E = area of the field (ha)

T = actual time taken in doing the main harvesting work (s)

iii. Field efficiency (FE) measured in (%) (Oyelade and Oni, 2011) can be expressed as:

$$H = \frac{D\,(3600)}{G} \quad (4)$$

where,

H = field efficiency (%)

D = effective field capacity (ha h^{-1})

G = theoretical field capacity (ha h^{-1})

iv. Fuel consumption (FU) measured in L ha^{-1} (Oyelade and Oni, 2011) can be expressed as:

$$I = \frac{J}{E} \quad (5)$$

where,

I = fuel consumption (L ha^{-1})

J = volume of fuel consumed (L)

E = area of the plot (ha)

Data obtained were subjected to regression analysis to determine the effects of kenaf maturity (M), kenaf variety (V) and blade type (B) on theoretical field capacity, field efficiency and fuel consumption of the kenaf harvesting machine.

(a) modified brush cutter (b) Metal guard attached to the gear head

Figure 4 Kenaf harvesting machine

3 Results and discussion

The yield of Ifeken 100 at three and four months after planting was 247.56 and 271.67 kg ha^{-1} with a corresponding moisture content of 57.55% and 30.73% (wb), respectively. Similarly, Tianung 1 yielded 535.30 and 597.99 kg ha^{-1} with a corresponding average moisture content of 61.48% and 32.55%, respectively. It was observed that the moisture content of the stem reduced with maturity for the two kenaf varieties used for this study.

3.1 Effect of kenaf variety, maturity and blade type on the field efficiency

Figure 5 shows the effects of kenaf variety, maturity and blade type on the field efficiency of the kenaf harvesting machine. The field efficiency ranged from 69.15% to 81.21%. This variation was as a result of the maturity and blade type attached to the kenaf harvesting machine. Tables 4 and 5 shows the Analysis of Variance (ANOVA) table and the interaction effect of the factors with respect to their response on the field efficiency of the kenaf harvesting machine. The maturity of the kenaf had a significant effect on the field efficiency of the machine. This implies that harvesting at four months rather than three months reduces the efficiency of the machine by 3.52 units. This is because the stem gets tougher as the moisture content level of the stem reduced with maturity hence, more energy was required to shear the kenaf stem. All the factors were significant ($P < 0.05$) in their effect except for the kenaf variety. This shows that the machine performed equally well on the two kenaf varieties used for this study. Dauda et al. (2013) reported a field efficiency of 76% for a tractor-mounted kenaf harvester and Abd-El Mawla and Hemeida (2015) reported 71% for a sugarcane harvester.

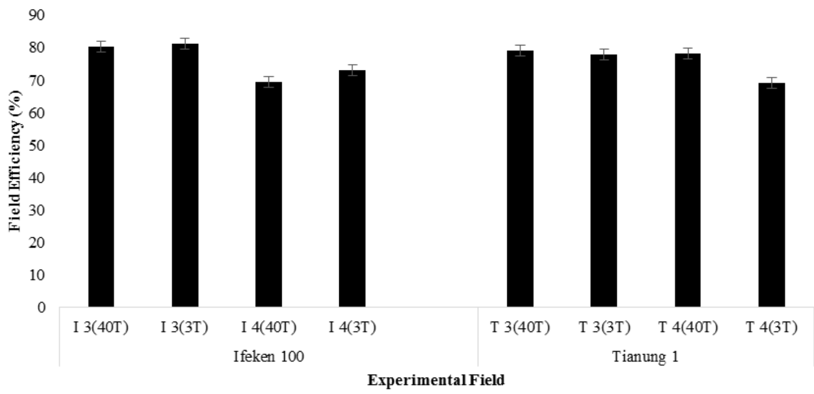


Figure 5 Effect of kenaf variety, maturity and blade type on the field efficiency

Table 4 Analysis of variance for field efficiency of the kenaf harvesting machine

Source of variation	DF	SS	MS	F-stat	P-value
V	1	0.09923	0.09923	0.07078	0.79694
M	1	197.684	197.684	141.007	0.00000*
B	1	9.27202	9.27202	6.61372	0.03304*
VM	1	21.2521	21.2521	15.1591	0.00459*
VB	1	54.686	54.686	39.0075	0.00025*
MB	1	7.7284	7.7284	5.51266	0.04683*
VMB	1	26.3169	26.3169	18.7718	0.00250*
Error	8	11.2155	1.40194		
Total	15	328.254			

Note: * significant in its effect ($p < 0.05$)

Table 5 Interaction effects on the field efficiency of the harvesting machine

Factor	Coefficients	Standard Error	P-value
Intercept	75.99	0.29601	0.00000
V	0.08	0.29601	0.79694
M	-3.52	0.29601	0.00000*
B	0.76	0.29601	0.03304*
VM	1.15	0.29601	0.00459*
VB	1.85	0.29601	0.00025*
MB	0.69	0.29601	0.04683*
VMB	1.28	0.29601	0.00250*

Note: * significant in its effect ($p < 0.05$)

3.2 Effect of kenaf variety, maturity and blade type on the theoretical field capacity

Figure 6 shows the effects of kenaf variety, maturity and blade type on the theoretical field capacity. The theoretical field capacity of the kenaf harvesting machine ranged from 0.1210 to 0.1410 for Ifeken 100 and 0.0579 to 0.0726 for Tianung 1. The theoretical field capacity varied significantly between the kenaf varieties (Table 6). Tianung 1 gave higher yield than Ifeken 100. Hence, more time was required to harvest Tianung 1 kenaf variety. This might be as a result of the low viability of the Ifeken 100 seeds obtained at IAR&T. However, kenaf maturity and harvester blade type do not have a significant effect on the theoretical field capacity of the kenaf harvesting machine.

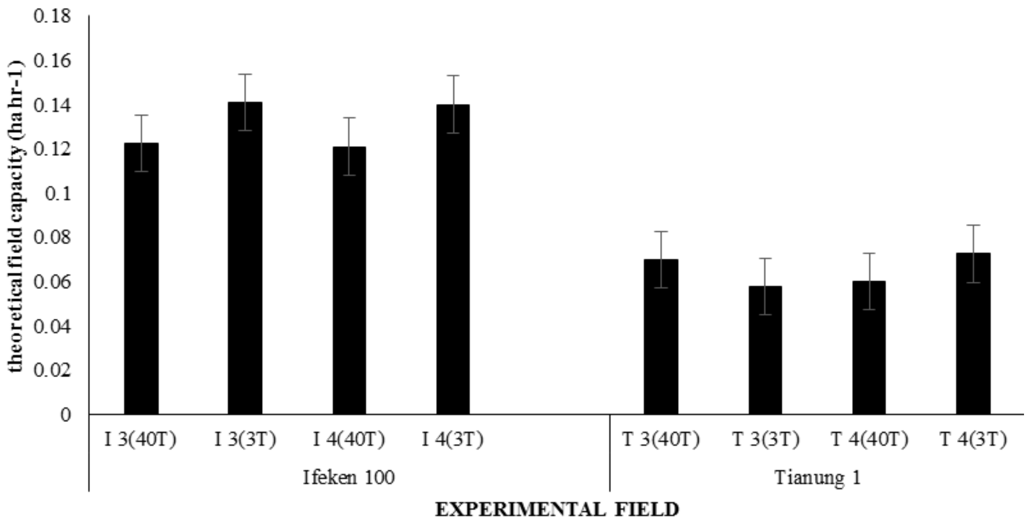


Figure 6 Theoretical field capacity of the kenaf harvesting machine

Table 6 ANOVA for theoretical field efficiency of the kenaf harvesting machine

Source of Variation	DF	SS	MS	F-stat	P-value
V	1	0.0174	0.0174	33.2535	0.00042*
M	1	1.5E-06	1.5E-06	0.00291	0.95827
B	1	0.00036	0.00036	0.69224	0.42954
VM	1	1.4E-05	1.4E-05	0.02602	0.87585
VB	1	0.00035	0.00035	0.65999	0.44007
MB	1	0.00015	0.00015	0.29444	0.60217
VMB	1	0.00014	0.00014	0.27173	0.61629
Error	8	0.00419	0.00052		
Total	15	0.0226			

Note: * significant in its effect ($p < 0.05$)

3.3 Effects of kenaf variety, maturity and blade type on the fuel consumption

Figure 7 shows the effects of kenaf variety, maturity and blade type on the fuel consumption of the kenaf harvesting machine. The fuel consumed by the harvester ranged from 21.28 to 46.91 L ha^{-1}. The kenaf maturity has a significant effect ($p<0.05$) on the fuel consumption of the kenaf harvesting machine (Table 7). This was as a result of the higher energy demand to cut the kenaf stem as the kenaf plant matured from 3 months to 4 months old.

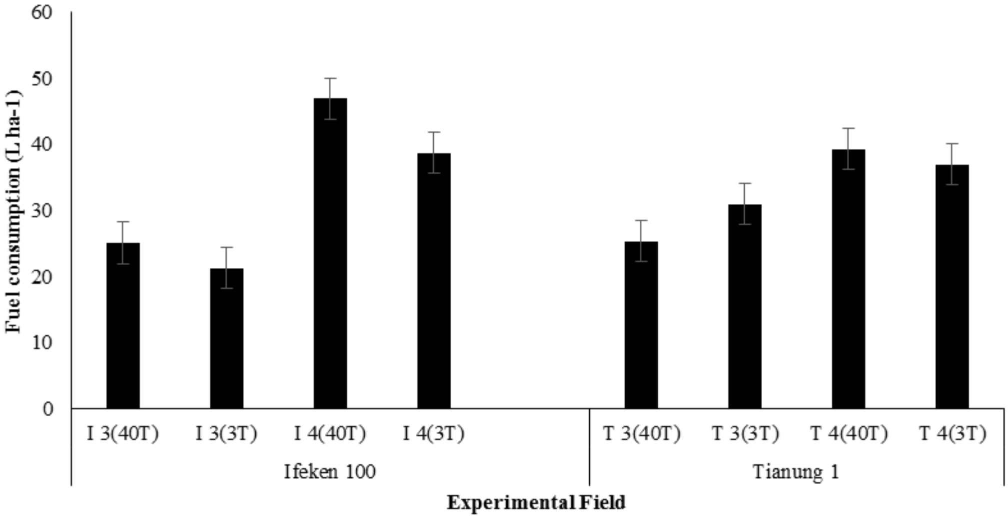


Figure 7 Fuel consumption of the kenaf harvesting machine

Table 7 ANOVA for fuel consumption of the kenaf harvesting machine

Source of Variation	DF	SS	MS	F-stat	P-value
V	1	0.08266	0.08266	0.00205	0.96502
M	1	876.308	876.308	21.7047	0.00163*
B	1	19.1188	19.1188	0.47354	0.51082
VM	1	93.2673	93.2673	2.31007	0.16703
VB	1	58.0263	58.0263	1.43721	0.26489
MB	1	38.409	38.409	0.95133	0.35795
VMB	1	3.26706	3.26706	0.08092	0.78328
Error	8	322.993	40.3742		
Total	15	1411.47			

Note: * significant in its effect ($p < 0.05$)

4 Conclusions

The average stubble height of kenaf stem left on the field after harvesting was 30 mm while a tractor mounted harvester can only achieve a minimum height of 70 mm. This implies that the kenaf harvester used in this study reduced harvest losses due to the stubble height on the field. However, this can only be achieved where there are little or no stumps and stones that could damage the kenaf harvester blade. The machine performed equally well on both kenaf varieties with consistency in the good quality cut. It can be used on undulating and plain terrain. Little knowledge is required to operate the machine hence, it can be easily adapted by local kenaf farmers as this will eliminate the drudgery with manual harvesting. The harvester was suitable for harvesting whole kenaf stalk as it was able to harvest the two kenaf varieties used for this study when fitted with the 3-tooth and 40-tooth brush cutter blades.

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Nomenclatures

L: length

W: width

H: height

rpm: revolution per minute

df: degree of freedom

ss: sum of square

ms: mean square