PERFORMANCE EVALUATION OF A TRACTOR MOUNTED KENAF HARVESTING MACHINE

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ABSTRACT

The potential of kenaf (Hibiscus cannabinus L.) as an industrial commercial crop has been exploited in recent times. Recent findings from field studies have drawn attention to the need to develop an efficient kenaf harvesting machine. Hence, field equipment for harvesting whole kenaf stems continues to be of interest in Kenaf production. In this study, kenaf harvesting machine incorporating a rotary serrated cutting system was developed at Universiti Putra Malaysia. The kenaf harvester which can harvest both row and broadcast planted kenaf is tractor mounted and comprises of hydraulic, cutting and the gathering systems. The parameters evaluated were the harvesting field efficiency (FE), effective field capacity (EFC) and machine material capacity (MC). Kenaf varieties V36 and FH 952 were used for the experiments to determine the performance of the machine. Different tractor speeds ranging from 2.0 to 7.7 km hr^{-1} were used. The optimal operating forward speed at 3.7 km hr^{-1} achieved an efficiency of 76%. Results of the field test showed that the tractor speed had a significant effect on the performance of the machine, in terms of its effective field capacity, field efficiency and the machine material capacity.

Keywords: Tractor speed, harvester, Kenaf (Hibiscus cannabinus L.), machine material capacity, performance evaluation.

INTRODUCTION

In any country, forests play a vital role in its social, environmental and economic development. However, about 13.0 million hectares of forests are diminishing every year in developing countries as a result of consumption of wood-based products; consequently there is a high demand for supplemental non-wood fiber sources (Ashori, 2008). Kenaf (Hibiscus cannabinus L.) is an annual crop with a high fiber yield (Bakhtiari et al., 2011; Ghahraei et al., 2011; Mazumder et al., 2005). Its high CO_2 fixation ability has increased its global attention as a source of cellulose fiber (Hossain et al., 2011; Lam et al., 2003). Hence, the utilization of kenaf as an alternative raw material to wood will lead to reduction in deforestation, and subsequent increase in environmental stabilities. It is a third world crop after wood and bamboo; which is introduced as a source of renewable industrial crop in the developed economies. It is also an annual warm-season fiber crop that grows in both temperate and tropical regions (Abdul Khalil et al., 2010). Its stems comprises of two important components: bast fibers in the bark, and core fibers in the center of the stems (Ghahraei et al., 2011; Mazumder et al., 2005; Tahir et al., 2011). The inner core fiber which produces low quality pulp is about 60 -75%, and an outer bast fiber 25–40%, which produces high quality pulp, in the stem (Abdul Khalil et al., 2010).

Kenaf fibers can be blended with synthetic fibers for making carpet. The fiber can also be used in making coarse bags, ropes, nets etc. (Jonoobi et al., 2011; Saha et al., 2010). Its industrial applications include automobile, agriculture, construction, chemical process and

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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 and horticulture potting mix from the core; livestock feed from the leaf (Jonathan and Frank, 2010; Juliana et al., 2012a; Juliana et al., 2012b).

In harvesting kenaf, forage harvesters are generally used, however, kenaf stems are cut into too short fragments when forage harvesters are used (Kobayashi et al., 2003). Two major approaches are taken in the development of whole-stalk harvesters; forage-type harvesters and sugarcane-type harvesters. But adapting existing equipment in both approaches is what scientists and industries have their concentrations on, rather than developing a completely unique kenaf harvester (Webber III et al., 2002). Standard equipment for forage cutting, baling and chopping was used for kenaf harvesting (Webber III and Bledsoe, 1993). Regular farm balers did not satisfactorily bale finely chopped kenaf (Kemble et al., 2002). Small sugarcane harvester was used to develop kenaf harvester (Webber III et al., 2002). This harvester enabled to harvest kenaf while avoiding cutting stems into too short fragments. Also sugar cane harvesters, with or without modification, have also been used to harvest kenaf. The drawbacks of the sugarcane-type harvesting systems were the transport and storage of the low density Kenaf stalks or stalk segments (Webber III et al., 2002).

Kenaf harvesting, storage, transportation, and post-harvest processes are still labour intensive and time consuming (Ghahraei et al., 2011). Therefore, evaluation of procedures for harvesting kenaf continues to be an important aspect of commercialization (Charles et al., 2002).

The objective of this study was to evaluate the performance of a tractor mounted kenaf harvesting machine developed at Universiti Putra Malaysia.

MATERIALS AND METHODS

Kenaf Harvesting Machine Description and Principles of its operation

Figures 1and 2 presents the schematic diagram of the kenaf harvesting machine and the developed harvester. Details of the specifications of the harvester are shown in Table 1. The developed kenaf harvester is simple to operate, maintain and compact machine operated by hydraulic system. It was also developed in such a manner that it can easily be transported to and from the farm on narrow farm roads. It comprises of three major operating systems; the hydraulic, the cutting and the gathering systems.

The hydraulic system which serves as the source of power to the other systems consists of the hydraulic tank, filter, pump, motor, control and the hoses.

The cutting system has rotary serrated cutting blades arranged in series at overlap positions in order to have effective cutting without missing any kenaf stem. This covers an effective cutting width of 980 mm of the harvester. It derives its power from the harvester hydraulic system by means of chains and sprockets.

The gathering system consists of three rotary grabbing fingers mounted right on top of the cutting system, this grabs the kenaf stems keeping them upright and guides them towards the cutter and subsequently guides the stems backwards after cutting. The gathering system obtains its operating power from the tractor hydraulic system which drives the grabbing fingers via a mild steel shaft by means of chains and sprockets.

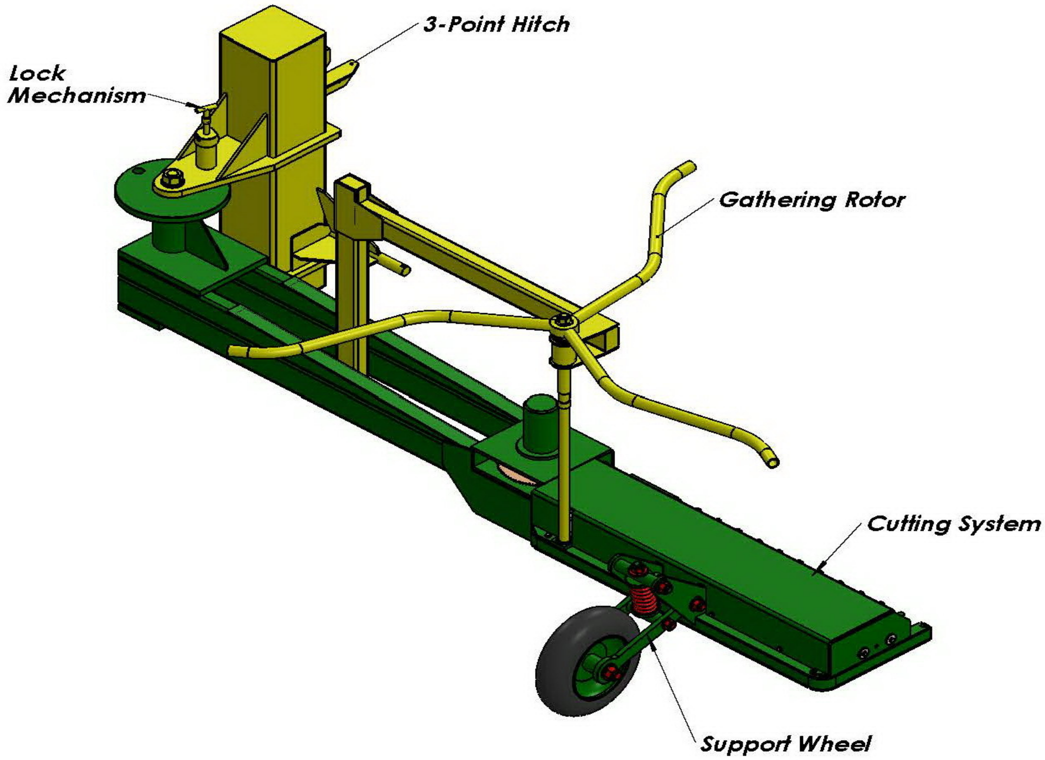

Figure 1. Schematic diagram of the kenaf harvester

Figure 2. Developed kenaf harvester mounted on a tractor

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Table 1. Technical details of the new kenaf harvester

Parameters	*Specifications*
General Dimensions	
Overall length	2968 (mm)
Overall width	685 (mm)
Overall height	920(mm)
Ground clearance	150 (mm)
Total weight	400 (kg)
Transmission	
Power source	Tractor/PTO
Tractor required	55~70 (hp)
PTO	540 (rpm)
Transmission	PTO/hydraulic system/chain-sprocket/hydraulic motor
Harvesting Head (Cutting System & Gathering)	
Number of harvesting rows	Broadcast/row
Length	980 (mm)
Width	1630 (mm)
Height	920 (mm)
Height adjustment	Hydraulic system
Cutting System	
Type	Rotary serrated type
Cutting system width	980 (mm))
Cutting system height from the ground surface	100 (mm)
No. of grabbing fingers	3
No. of rotary shaft	1
Transmission	Hydraulic motor, Chain – sprocket
No. of tires	1

EXPERIMENTAL PROCEDURES

The study presented here-in was conducted at the Taman Pertanian Universiti (TPU) INTROP research field. Harvesting of Kenaf V 36 and FH 952 varieties was done at 12 - 16 weeks after sowing on an 8×3.5 m^2 research plots with 0.10 m intercrop spacing and 0.30 m row spacing manually planted with an average yield of about 76.80 t ha^{-1} for FH 952 and 77.03 t ha^{-1} for V 36. Physical properties of pods, seeds and other agricultural materials are fundamental information for the design and construction of agricultural machinery (Ishola et al., 2011). Therefore, the maximum plant height recorded was 310 cm and the lowest was 150 cm. Maximum stem diameter was 30 mm and the smallest was 14 mm. The moisture contents were determined by oven dry method at 104 ^{0}C for 24 hours (ASABE, 2012; ASABE, 2008b). The moisture contents determined ranged between 73-75% (wet basis) for V 36 at harvest and 60.3-62.3% (wet basis) for FH 952. The harvester was evaluated at seven harvesting speeds in order to determine and suggest an optimum and appropriate speed range for the harvester. To determine this, the harvesting speed and the travel time were noted for pre-marked 10 m distance of the field. This was done based on the calibrated existing tractor gears.

Before the commencement of the field test, the field dimensions were measured using a measuring tape. The cutting height was adjusted to about 10 cm from the ground level with the tractor hydraulic system. Both productive and non-productive times were measured using a stop watch so as to calculate the field capacity and efficiency. Total non-productive time in this respect refers to stops for equipment servicing (cleaning, troubleshooting, and adjustments), and turning time at the end of fields. To determine the effective material and field capacities, whole kenaf stems were harvested and weighed

Field Capacity Tests

The primary parameters used to evaluate the performance of the kenaf harvester were the Field capacity (FC) (effective and theoretical) and field efficiency (FE) (ASABE, 2008a). While the area of land processed per unit time for a particular field operation was represented by FC, the ratio between theoretical and effective field capacities is defined as FE and relates to the actual and estimated time required to complete a particular field operation (with no reference to the area) (Viacheslav et al., 2011). Machine capacity measurements or estimates are used to schedule field operations, labour and power units, and also estimating machine operating costs (Hunt, 2001). For productive work at all the time, no farm machinery is consistently used. Time taken in making field repairs, adjustments and turning at field ends are lost as unproductive time and invariably reduces machine capacity (Renoll, 1981).

The harvester's theoretical field capacity (TFC) is dependent only on the average forward travel speed of the tractor in the field and its overall cutting width. It depicts the maximum possible field capacity that can be achieved at the specified field speed when the effective operating width of the harvester is being utilized. It can be calculated from equation (1) (Hunt, 2001; Renoll, 1981; Hanna, 2002).

$$TFC = \frac{W\ X\ S}{10} \qquad (1)$$

Where:
TFC = Theoretical field capacity (ha/ hr)
W = Effective harvesting width (m)
S = Forward speed (km/h)

A machine's TFC cannot be maintained over a very long periods of time. Therefore the machine's field efficiency (FE) is the ratio of effective or actual field capacity (EFC) to the theoretical TFC.

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Field efficiency is precisely the percentage of a machine's TFC which is achieved under prevailing real conditions. This accounts for the harvester's failure to utilize its full operating width and inclusive of many other time delays. These might include turning, cleaning a plugged machine, idle travel across headlands, checking a machine's performance and making adjustments, etc. Other delays in activities that occur outside the field, such as daily service, movement to and from the field and major repairs, are not considered in field efficiency measurements (Hanna, 2002; Hunt, 2001). This can be calculated using equation 2.

$$FE\ (\%) = \frac{EFC}{TFC} X\ 100 \qquad (2)$$

Where:

FE = Field efficiency (%)

EFC = Effective field capacity (ha/hr)

TFC = Theoretical field capacity (ha/hr)

Conversely, if a machine's EFC needs to be estimated and one has an estimate of FE; equation (3) is used.

$$EFC = TFC\ X\ FE\ (\%) \qquad (3)$$

Generally harvesting machine working capacity is measured by the quantity of material harvested per hour. This capacity is called the harvester's material capacity (MC), expressed as bushels per hour or tons per hour. It is the product of the harvester's EFC and the average yield of crop per hectare, and can be calculated from equation (4). (Hanna, 2002).

$$MC = EFC\ X\ Y \qquad (4)$$

Where:

MC = Machine's Material capacity, (t/hr)

EFC = Effective Field Capacity (ha/hr)

Y = Crop Yield (t/ha)

Soil Moisture Content Determination

A test soil sample was dried in an oven at a temperature of 110 °C until a constant mass was reached. The loss of mass due to drying is considered to be mass of water (ASTM, 1998).

It was therefore calculated using equation 5.

$$W = \frac{(Mcws - Mcs)}{(Mcs - Mc)} X\ 100 = \frac{Mw}{Ms} X\ 100 \qquad (5)$$

Where:

W = Water content (%)

Mcws = Mass of container and wet specimen (g)

Mcs = Mass of container and oven dry specimen (g)

Mc = Mass of container (g)

Mw = Mass of water (g)

Ms = Mass of solid particles (g)

RESULTS AND DISCUSSION

The field condition data for the performance tests conducted at Taman Pertanian Universiti (TPU) INTROP research field is presented in Table 2. The evaluation tests were conducted on a flat planting system. The row spacing and the intercrop spacing were 0.30 m and 0.10 m respectively. Summary of the average performance of the Kenaf harvester is presented in table 3.

Table 2. Crop and field characteristics prevailing during kenaf harvester evaluation

Parameters	*Varieties*	
Kenaf cultivar	FH 952	V 36
Age of plants (weeks)	12 - 16	12 - 16
Row spacing (m)	0.30 x 0.10	0.30 x 0.10
Average number of stems in 1 row	160 - 200	100 - 200
Plant population on the field (plants ha^{-1})	715,000	715,000
Approximate yield of Kenaf stem (t ha^{-1})	76.80	77.03
Maximum height of Kenaf stem above the ground surface (m)	3 - 4	3 - 4
Average cutting height of Kenaf stem above the ground surface (cm)	15	15
Average moisture content of Kenaf stems at harvest time (%) wb	61.3	74
Average diameter of Kenaf stems (mm)	14.32	22.98
Average soil moisture content at the time of harvest (%)	30.20	29.14

Table 3. Harvester performance parameters (8hrs day^{-1})

Tractor forward speed (km hr^{-1})	*TFC (ha day^{-1})*	*EFC (ha day^{-1})*	*FE (%)*	*MC (t day^{-1}) FH 952*	*MC (t day^{-1}) V 36*
2.0	1.57	1.19	76	91.52	91.8
2.5	1.96	1.39	75	106.87	107.19
3.7	2.90	2.15	76	164.86	165.35
4.6	3.61	2.81	70	216.04	216.68
5.8	4.55	3.14	69	240.97	270.86
6.9	5.41	3.52	65	270.05	317.06
7.7	6.04	3.68	61	282.81	283.66

At the time of harvest, approximate yield of Kenaf stem was slightly different among the two varieties, while maximum plant height was uniform (3-4 m) with the cutting height of stem set at 10 cm above the ground level. Other crop parameters set equal and the average moisture contents varied between 74.0 and 61.3% for V 36 and FH 952respectively and average stem diameter significantly higher in V 36 (22.98 mm) than FH 952 (14.32 mm). This may possibly be a source of variation in machine capacities for both varieties.

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Effect of Variety on the Machine Material Capacity

The effect of variety on the machine material capacity was recorded as shown in Figs. 3 and 4. The varieties behaved differently under same harvesting conditions with resultant increase in machine capacity from 91.52 to 282.81 t day^{-1} in FH 952 while the increase was from 91.80 to 283.66 t day^{-1} in V 36. Correlation analysis on the effect on machine material capacity indicated a positive high correlation showing significant contribution of variety to the machine material capacity.

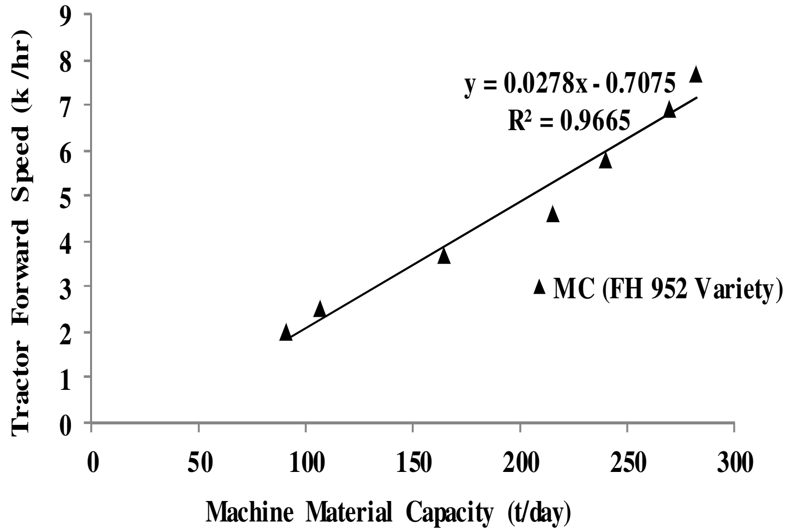

Figure 3. Effect of FH 952 variety on machine material capacity

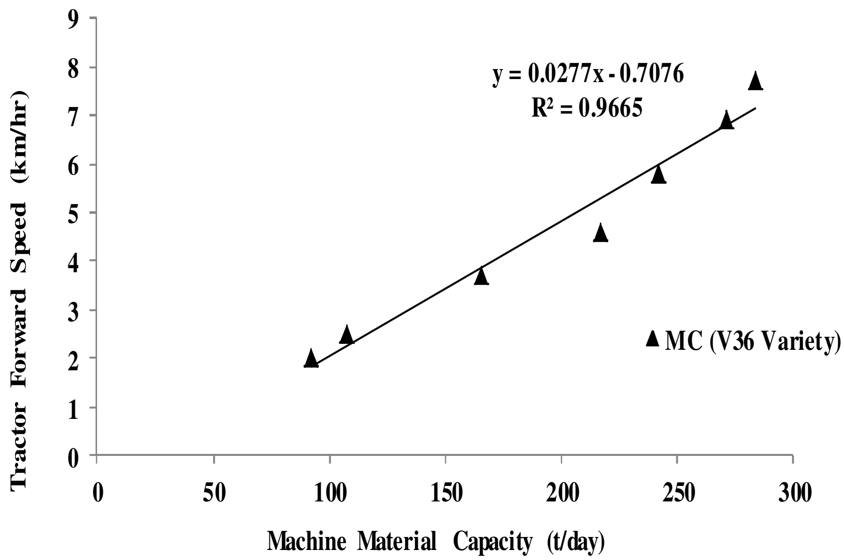

Figure 4. Effect of V 36 variety on machine material capacity

Effects of Speed on Effective Field Capacity

The effects of tractor forward speeds on the effective field capacity indicated that increasing the speed from 2.0 to 7.7 km hr^{1} increased the effective field capacity from 1.19 to 3.68 ha day^{-1} (Figure. 5). This is in agreement with similar studies conducted on rice and wheat by Helmy et al., (2010) and Ismail and Abdel-Mageed, (2010).

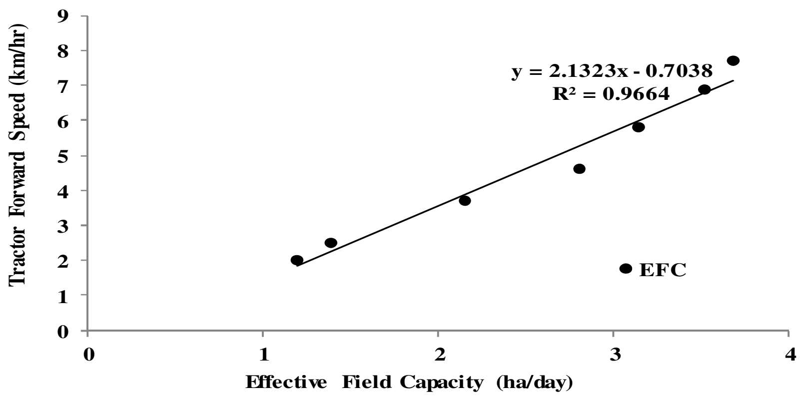

Figure 5. Effect of speed on effective field capacity

Effects of Speed on Field Efficiency

The effects of tractor forward speeds on the field efficiency revealed that by increasing the forward speed from 2.0 to 7.7 km hr^{-1}, there was a decrease in the efficiency from 76 to 61%. The highest efficiency was recorded at 3.7 km hr^{-1} and the lowest was recorded at 7.7 km hr^{-1} (Figure. 6).

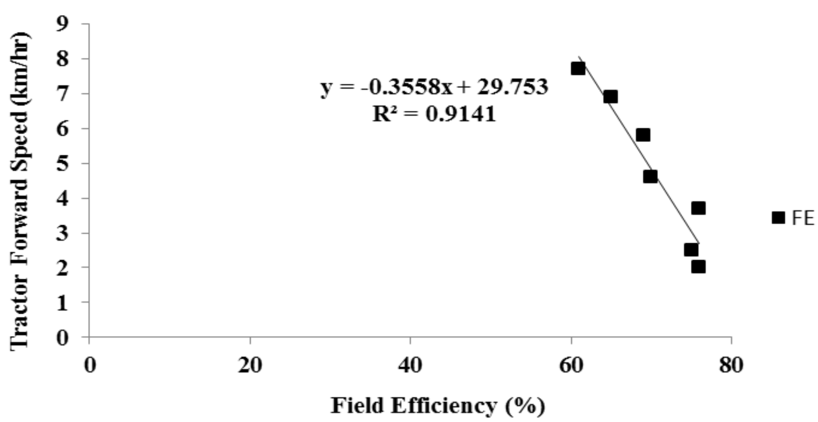

Figure 6. Effect of speed on field efficiency

CONCLUSION

A broadcast/row planted tractor mounted kenaf harvester has been developed and its performance evaluated. Test results of the machine using kenaf varieties V36 and Fh 952 gave a harvesting field efficiency of 61 – 76%, effective field capacity of 1.19 – 3.68 ha day^{-1} and machine material capacity of 91.8 – 283.66 tons day^{-1} when tested at 2.0 – 7.7 km hr^{-1} tractor forward speeds.

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The results of the performance evaluation also revealed that the tractor speed have great influence on the performance of the harvester. The field capacity and the machine material capacity increased with increase in the tractor speed; while the field efficiency started decreasing at speeds above 3.7 km hr^{-1}. Therefore, to achieve optimum performance, a tractor forward speed of 3.7 km hr^{-1}. is absolute. The non-uniformity in diameter and height of the kenaf stems also greatly influenced the performance of the machine. Similarly, varietal differences had effects on the machine material capacity.

The harvester revealed a satisfactory performance of the cutting system and it is found suitable for harvesting whole kenaf stems.

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