
Design of tractor front mounted Pigeon pea stem cutter

Atul R. Dange^{1*}, S.K.Thakare², I. Bhaskarrao¹ and Umarfarooq Momin¹

¹Central Research Institute for Dryland Agriculture, Hyderabad-500059 (A.P.) India, ²Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola- 444104 (M.S.) India

Atul R. Dange, S.K.Thakare, I. Bhaskarrao and Umarfarooq Momin (2012) Design of tractor front mounted Pigeon pea stem cutter. Journal of Agricultural Technology 8(2): 417-433.

In this research work was made to investigate the cutting energy and force required for the pigeon pea crops. Commercially available blades, sharpened at 30° were selected for the experiment. It was attached to the lower end of the arm of pendulum type dynamic tester which cut the stalk at 90° to the stalk axis with knife velocity ranging between 2.28 m/s to 7.23 m/s. The blade 30° bevel angle required 141.96 Nm cutting energy and 747.25 N force for 30 mm diameter stem at 42.6% (wb) moisture content. The study investigated the cutting energy and cutting force were directly proportional to cross-sectional area and moisture content at the time of harvesting of pigeon pea crop. In view of this a tractor operated front mounted pigeon pea stem cutter was design and developed in Department of Farm Machinery and Power, Dr. PDKV, Akola. All the components were designed with standard procedure. The average cutting efficiency and field capacity was found 94.55 % and 0.176 ha/hr respectively. The average operation cost of newly developed tractor operated front mounted pigeon pea stem cutter was 64.71% less as compared with manual harvesting of pigeon pea crop. The time saved was almost 1/3rd to that of manual harvesting.

Key words: Pigeon pea, cutting energy, force, efficiency, performance, field capacity

Introduction

Deccan (India) region pigeon pea is one of the important cash crop for the farmers, mainly in Yeotmal, Amravati, Akola, Wardha and Nagpur, Adilabad, Wamal, Nizamabad districts and generally, pigeon pea is taken as intercrop in soybean, cotton in pair row cropping system (Anonymous, 2003). Timely harvesting is important to reduce damage due to molds, birds, insects and losses due to shattering and rain. Crops should be harvested when they are physiologically mature, when the moisture content of the grain is about 25-30%. In pigeon pea, pods dry and seeds develop a typical color of the variety and become hard at physiological maturity (Bisht *et al.*, 2006).

* Corresponding author: Atul R. Dange; e-mail: dangeatul@gmail.com

Pigeon pea (*Cajanus cajan* L. Mills.) is important pulse crops of India and ranks second to chickpea in area and production. Pigeon pea is grown throughout the tropical countries of world especially in Africa, West Indies, Ceylon, Australia and Malaya. In India, it is grown mainly in Uttar Pradesh, Maharashtra, Madhya Pradesh, Gujarat and Rajasthan both kharif and rabi season. It is important source of protein (22-24 per cent) especially for vegetarian and economically poor population of this country (Singh, 2003).

Two types of cutting mechanism, reciprocating type and rotary impact type, used for harvesting sorghum harvesting, forage harvesting, weeding, lawn mowing, etc. The latter is being increasingly used in these operations due to its simplicity in construction, low maintenance cost and ability to cut both small and large diameter stalks (McCrannal *et al.*, 1978). A pendulum type impact shear test apparatus was designed and constructed for paddy stems cutting energy and bale optimum parameters. The results show that blade bevel angle of 28° , oblique angle of 30° , tilt angle of 35° and blade velocity of 2.24 ms^{-1} are optimum (Reza, 2007). Single element impact cutting is an economical method of cutting unrestrained vegetation (Klenin *et al.*, 1985). Traditionally harvesting of pigeon pea is done manually with sickle which demands considerable amount of labour, drudgery and time to harvest. It was estimated that harvesting operation of crop consumes about the 25-30 per cent of total labour requirement of the crop production system. Total 176 man-hours per hectare was required to harvest pigeon pea crop. The shortages of labour during season and vagaries of the weather cause high losses to the farmer's. Timely harvest of the crop is vital to reduce losses and achieve quality produce. This reflects on harvesting cost and the total production cost of the crop. The shortage of labour is thus to be bridged by mechanization. A suitable tractor operated machine for harvesting of pigeon pea crop is an immediate need which can remove drudgery, reduce losses and increase productivity, reduce turn about time in two crop season, avoid weather risk, achieve low cost of harvesting and derive benefit from early marketing of produces.

The present study was aimed to measure the cutting energy and force for pigeon pea stems and to develop a small tractor operated front mounted machine, which cut and windrow the stem of pigeon pea efficiently and economically.

Material and methods

The study was carried out in 2007-2008 in Department of Farm Power and Machinery, Dr. PDKV, Akola, India. For designing of blades and power requirement for cutting pigeon pea stems cutting energy and force needed to determine.

Determination of cutting energy and force

A pendulum type dynamic tester was like stem diameter, moisture contain at harvesting time, etc. of pigeon pea stems were noted (Table 1).

Table 1. Physical parameter of pigeon pea crop

Particulars	
Variety	AKT-8811, BDN-2, AKT-9817
Stem diameter	8 mm (minimum) to 30 mm (maximum)
Date of sowing	22 nd June 2007
Moisture content in stem at harvesting time	41.8 to 45.2 % (wb)
Height of first branch from ground	152 mm
Date of harvesting	12 th January 2008

Pendulum type dynamic tester

It consisted basically of a pendulum suspended on two ball bearings (UCS-204). It has a fixed hand vice for holding the stems. Cutting blade could be mounted on the tip of the pendulum. On the top there was a fixed circular aluminum plate graduated in degrees also called dial. A pointer actuated by a pin projecting from the upper arm of the pendulum showed the angle of swing of the pendulum on this graduated scale. The bench vice could be moved at right angle to the plane of the pendulum swing in order to vary the height of cut.

During experiment swinging angle (θ_s) and θ_1 were initially recorded by allowing the pendulum to swing freely before the crops were clamped in the vice. A pigeon pea stem of selected diameter was first clamped in the vice. The pendulum was then subsequently released through the same angle and the clamped crops were severed. Angle θ_2 was recorded during the process of severing. Two replications of θ_2 were taken and the average value was then found out. Cutting energy was then measures by substituting the values of W , L , θ_2 and θ_1 in equation 1. The maximum blade velocity V corresponding to θ_s was then calculated from equation 2.

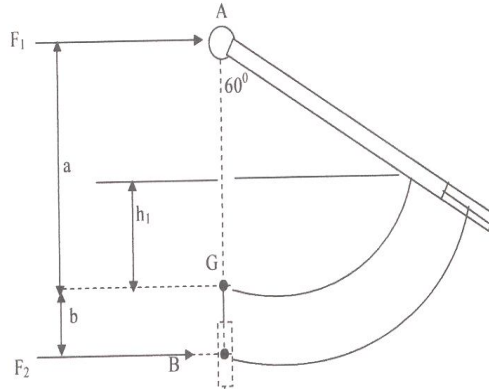


Fig. 1. Line sketch of pendulum type dynamic tester

Where,

F_1 and F_2 - Force acting at pivot (A) and at cutting point of blade (B)

Distance between pivot point and centre of gravity

Distance between centre of gravity and cutting point of blade (B)

h_1 - Distance between centre of gravity and centre of gravity of pendulum at releasing angle

The energy dissipated in cutting a specimen in given formula

$$E = W.L(\cos\theta_1 - \cos\theta_2) \quad (1)$$

Where,

E = Energy dissipated, (kgm)

W = Weight of the swinging part, (kg)

L = Distance of centre of gravity of the swinging part from the pivot point of the pendulum, (metre)

θ_2 = Maximum angle of deflection on the pendulum frame from vertical after cutting the specimen, (deg)

θ_1 = Maximum angle of deflection of the pendulum from vertical at the end of free swing, (deg)

The maximum blade velocity at impact can be determined by noting the angle of swing between the vertical and rest position. When the pendulum weight W is released through an angle θ ,

$$V = \sqrt{2gL(1 - \cos\theta_s)} \quad (2)$$

Moisture content

The moisture content of the pigeon pea stem was measured according to standard method. About 1.2 kg sample of stem was kept in an oven for 24 hours at 105⁰ C. the loss in weight of the sample was recorded and the moisture content in percent was determined as in equation.

$$MC = \frac{W_i \times W_d}{W_i} \times 100$$

Where,

MC = Moisture content, per cent

W_i = Initial weight, kg

W_d = Dried weight of sample, kg

After determination of the cutting energy and force for pigeon pea stem, the power requirement for newly developed pigeon pea stem cutter calculated. As per power requirement all the components of pigeon pea stem cutter was fabricated in the Research Workshop of Department of Farm Power and Machinery, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra (India).

Knife material

The knife is assumed to be made from a material, sufficiently hard relative to the body to resist permanent deformation during cutting with regard to edge radius. The steel used in a mower blade may typically have an analysis of C-0.82 per cent, Si-0.13 per cent, Mn – 0.51 per cent and Cr-0.12 per cent. The trailing edge of a knife is often made of or covered with a material that is extremely hard and high in carbides to prolong edge sharpness (Persson, 1987).

A high carbon steel knife was used which is easily available in local market. The main part which was used in the fabrication of the equipment was power transmission shaft, chain and sprocket arrangement and bevel gear. The considerations for designing/selection of these parts are as given below.

Power transmission

The rotary power from pto of tractor was used for cutting the pigeon pea stem. The power flow diagram show the transmission of power given below
Tractor pto

Belt and pulley arrangement → Propeller shaft → Universal joint → Gear box
→ Main shaft → Chain and sprocket assembly → Cutter

Length of belt and angle of contact between the belt and pulley

The power or rotary motion from one shaft to another at a considerable distance is transmitted by flat belt, V- belts running over the pulleys. When the driver rotates, it carries the belt due to grip between its surface and the belt. The belt in turn carries the driven pulley which starts rotating. The grip between the pulley and the belt arises from the pressure between the belt and the pulleys. The friction grip, if required, is increased by tightening the belt.

P.T.O pulley diameter, d_1	= 0.127 m	$r_1 = 0.064$ m
Diameter of pulley on shaft, d_2	= 0.127 m	$r_2 = 0.064$ m
Distance between two shaft, l	= 0.36 m	
pto pulley rpm, N_1	= 540	
Maximum tension in belt, T_1	= 2000 N	
Coefficient of friction, μ	= 0.25	

1) Speed and Length of Belt

Speed of belt

$$v = (3.14 \times d_1 \times N_1) / 60 = (3.14 \times 0.127 \times 540) / 60$$
$$= 3.58 \text{ m/s}$$

Length of belt (L)

We know that length of belt

$$L = 3.14(r_1 + r_2) + 2l + (r_1 + r_2)^2 / l$$
$$= \pi (0.064 + 0.064) + 2 \times 0.36 + (0.064 + 0.064)^2 / 0.36$$
$$L = 1.17 \text{ m}$$

Angle of contact between the belt and each pulley

θ = Angle of contact between the belt and each pulley

From the geometry of figure

$$\sin \square = (r_1 + r_2) / l = 0.064 + 0.064 / 0.36 = 0.3556$$
$$\square = 20.8^\circ$$
$$\theta = 180 + 2\square = 180 + 2 \times 20.8 = 221.6^\circ$$
$$= 221.6 \times 3.14 / 180 = 3.866 \text{ rad}$$

Power transmitted by belt

T₁ = Tension on the tight side of the belt
 T₂ = Tension on the slack side of the belt
 Then calculating tension of belt on slack side as

$$2.3 \log \left(\frac{T_1}{T_2} \right) = \mu \theta$$

$$= 0.25 \times 3.866 = 0.9665$$

$$\log \frac{T_1}{T_2} = \frac{0.9665}{2.3} = 0.4202 \text{ (antilog of 0.4202)}$$

$$2000$$

$$T_2 = \frac{2000}{2.63} = 760 \text{ N}$$

The power transmitted by belt

$$P = (T_1 - T_2) \times v$$

$$P = (2000 - 760) \times 3.58$$

$$= 4439 \text{ W}$$

$$P = 4439 / 746$$

$$= 5.95 \text{ hp}$$

Design of cutting blade shaft

The cutting blade shaft is supposed to be rest on two bushes bearing on each end and a sprocket is mounted at the centre of the shaft. The shaft is subjected to twisting moment and bending moment. So the diameter of shaft can be calculated by using equation as

Torque (T) transmitted by shaft

$$T = P \times 4500 / 2\pi N$$

Where,

$$P = 45 \text{ hp}$$

$$N = 1800 \text{ rpm}$$

$$\therefore T = 1791 \text{ kgf.cm}$$

Tangential force (F_t) on gear teeth,

$$F_t = 2T / D$$

Where,
 D = Diameter of pinion
 $\therefore F_t = 1023 \text{ kgf}$
 Bending Moment

$$M = \left(F_t \frac{D}{2} \right)$$

$$M = 1791 \text{ kgf.cm}$$

\therefore Equivalent twisting moment (T_e)

$$T_e = \sqrt{M^2 + T^2}$$

$$= 2532.86 \text{ kgf.cm}$$

We know,

$$T_e = \frac{\pi}{16} \times F_s \times d^3$$

Where,

F_s = Shear stress of M.S. rod

T_e = Equivalent twisting moment.

$$\therefore d = 2.69 \text{ cm}$$

$$= 26.9 \text{ mm}$$

So, the diameter of shaft can be taken as 27 mm.

Design considerations for chain drive

The chain drive consists of an endless chain whose links engage the teeth of sprockets keyed to the driving and driven shafts of the conveying and cutting blade unit.

Design of Chain drive

Computation of design power,

$$P_d = P \times S_{F1} \times S_{F2}$$

Where,

P = Power, hp

S_{F1}, S_{F2} = Service factors for chain loading and atmospheric conditions

$$\therefore P = 11.76 \text{ hp}$$

Selection of chain and small sprocket

For this type of specific application, power rating table was checked and table showed that 10 tooth sprocket is required. However, because of physical constrains and availability in the market 12 tooth sprocket was selected.

Selection of large sprocket

The number of teeth for the large sprocket is computed from equation,

$$N_2 = \frac{N_1 \times RPM_1}{RPM_2}$$

Where,

N₂ = Number of teeth of large sprocket

N₁ = Number of teeth of small sprocket

RPM₁ & RPM₂ = Revolution per minute of large and small sprocket respectively

$$\therefore N_2 = 24 \text{ teeth}$$

Chain length

The approximate chain length is calculated as,

$$L = 2C + \left(\frac{N_2 + N_1}{2} \right) + \left(\frac{N_2 - N_1}{4\pi^2 C} \right)$$

Where,

C = Centre distance in chain pitches

N₂ = Number of teeth on larger sprocket

N₁ = Number of teeth on smaller sprocket

Center distance , C = 40.15

$$\therefore L = 1.22 \text{ m}$$

Corrected Center Distance

The approximate length 1.22 m is modified to a whole as 1.5 m.

$$C = \left[\frac{L - (N_2 - N_1)}{2} \right] + \left[\frac{L - (N_2 + N_1)^2 - 8(N_2 - N_1)^2}{2 \times 4\pi^2} \right]^{1/2} / 4$$

$$\therefore C = 0.52 \text{ m}$$

Parts of Pigeon pea stem cutter

Mainframe

A frame of length 1260 mm x 510 mm width was fabricated from M.S. 'C' channel of size 70 x 40 x 6 mm. All components described below were mounted on the frame to form tractor front mounted pigeon pea stem cutter.

Implement mounting

To mount the implement in front of tractor, a frame of square sections was made. This frame was combination of trapezoidal and rectangular shapes when viewed from top. These square sections were made by welding the m.s. angle (40 x 35 x 4 mm). Hydraulic cylinder was attached with inverted 'U' section. At the center of inverted 'U' section a vertical plate was provided to adjust the height of implement.

Drive system

Power was transmitted from pto of tractor to gear box of implement by means of shaft and belt pulley arrangement which was further transmitted to gear box of implement through two universal joints. The shaft of length 1440 cm and diameter 25 mm was attached to chassis of tractor from lower side with the help of two pedestal bearings.

Gear box

A gear box, available commercially was selected for transmission of power from the tractor power take off drive to the stem cutter. The gear box was fixed with the frame on the stand fabricated from m.s. angle of size 50 x 50

x 4 mm. The stand was provided to facilitate the level of gear box with power take off of tractor.

Power transmission system

The power transmission unit was a combination of gear box, main shaft, chain, sprockets etc, which receives power from tractor pto. The power transmitted from the gear box (1:2 gear ratio) to main shaft and then to chain and sprockets assembly. This chain and sprocket assembly helps to provide motion to cutting blade assembly. The sprockets of 24 teeth and 12 teeth were used on main drive and cutting blade assembly respectively (Fig. 2).

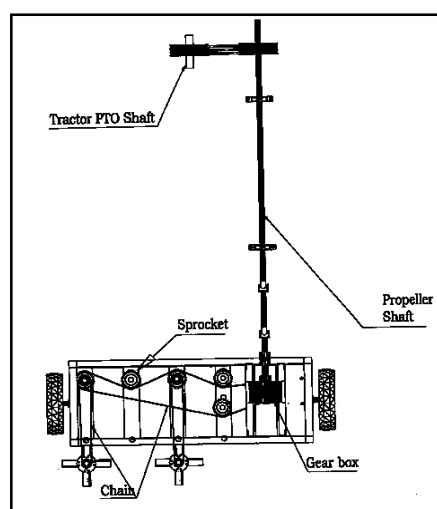


Fig. 2. Conceptual power transmission design of pigeon pea stem cutter

Cutting unit

The m.s. bar was turned in four steps of diameter 24 mm, 27 mm, 20 mm and 14 mm having length 5 mm, 95 mm, 40 mm and 30 mm respectively. The rotation of the shaft was supported with the help of two ball bearings one at the top of the shaft (UCFL 205) and another at a distance of 250 mm from the top mounted bearing. In between these two bearing a chain and sprocket arrangement was provided to rotate the shaft on which cutting blades assembly was mounted.

Cutting blade

High carbon steel impact shearing type cutting blade was used for fabrication of cutter. Cutting blade having width 40 mm, thickness 4 mm and bevel angle 30° was selected and were fixed on 5 mm thick m. s. plate of diameter 100 mm with the help of rivets (Fig. 3).

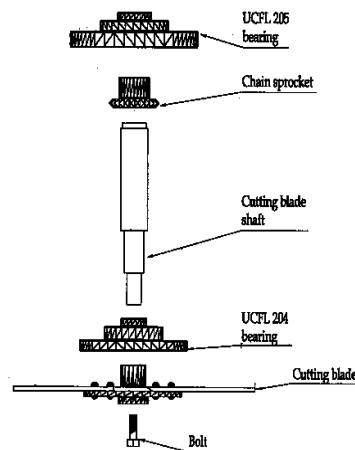


Fig. 3. Shaft of cutting blade

Row divider and collectors

Row dividers were fabricated from the C.R. sheet of size 1219.2 x 1219.2 x 1 mm. These dividers were mounted on the main frame to feed the crop to the cutting blade. Row Collector plays same role as star wheel in reaper. Row collector was fabricated from M.S. circular flanged of diameter 139.7 mm having 5mm thickness. In order to fix flanged on shaft, and 25 mm bored was drilled at centre of flanged. Eight M.S. square bar (8 x 8 mm) 203.2 mm long were welded symmetrically on the circular flanged.

Conveying unit for developed pigeon pea stem cutter

Conveying mechanism of pigeon pea stem cutter consist of conveying tray, lugged belt, belt tensioner unit, pulley, driving shaft, hydraulic motor, hydraulic mounting arrangement, row divider, row collector (star wheels).

Conveying tray was made from M.S. sheet supported on rectangular frame of M.S. angle have dimensions 35 X 35 X 4 mm. Other components such lugged belt, belt tensioner unit, pulley, driving shaft were mounted on conveying tray. A lugged belt of 3410 mm length having dimension 76.2 X 5

mm were installed on pulleys around the conveying tray. Two types of lugs were installed on conveying belt. Big size lugs were installed on top belt and small size lugs were installed on lower belt. Lugs were made from trapezoidal and rectangular section with a height of 101 mm for bigger naps. Sixteen such naps were attached on each belt at the spacing of 215.9 mm. The tension of the belt was maintained by adjusting the nut bolts resulting in tightening and loosening of the belt. All the four nuts were tightened or loosen simultaneously to adjust the belt equally.

Four pulleys were installed on the shafts for supporting the conveying belt. Pulley was fabricated from M.S. circular pipe of diameter 101.6 X 4 mm. Circular plates of 127 X 4 mm were welded on both side of circular pipe. Also bushes were welded on two opposite circular plates so as to support the pulley on the shaft. The lugged belt was supported on the conveying tray with three supporting shafts. Shaft serves two purposes of supporting the belts as well as giving drive to belt.

Hydraulic motor and mounting arrangement

Hydraulic motor was fixed on mounting arrangement. It was used to rotate the conveying belt. The 34 toothed sprocket was installed on hydraulic motor and power transmitted to the 17 toothed sprocket installed on driving shaft with the help of steel alloy chain.

The pigeon pea stem cutter is a tractor front mounted compact machine. It cuts the crops and lays it in a windrow which can be easily picked up by the farm labours for threshing or storage (Fig. 4). The machine performance was tested in laboratory as well as in field as per RNAM test code. Cost economic of machine was also calculated based on its performance.

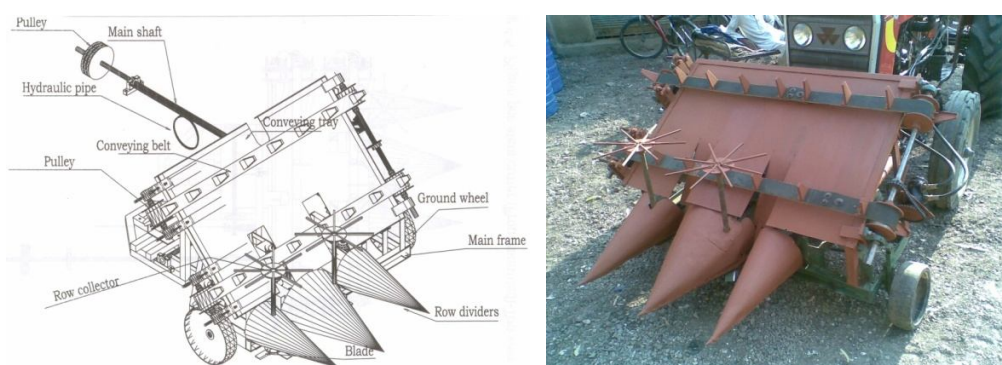


Fig. 4. Newly developed pigeon pea stem cutter

Results and discussions

The physical characteristics of pigeon pea stem, diameter of stem ranges from 6 mm to 30 mm as reported by Wanjari *et al.* (2000). The moisture content of stem at the time of harvesting found 41.8 % to 45% (wb). Three replications were taken for different cross sectional area of pigeon pea stem. The dial showed the indicated angle for cutting pigeon pea stem and corresponding cutting energy and force were calculated using formula (Table 2).

Table 2. Cutting energy and force required for pigeon pea stem

Pendulum dropped at an angle, degree	Stem diameter, mm	Indicated angle (degree)		Cutting energy, Nm	Cutting force, N
		Swing of arm from pivot with cutting angle, degree	Swing of arm from pivot without cutting angle, degree		
30	8	8	24	17.38	232.50
40	12	12	32	29.48	296.80
55	18	8	41	47.86	337.75
70	24	5	58	100.72	709.00
90	30	6	69	141.96	747.25

In the experiment, with cutting blade (bevel angle 30°) energy required to cut the stem of the pigeon pea was minimum for 8 mm diameter 17.38 Nm and maximum for 30 mm diameter 141.96 Nm, whereas cutting force for the stem diameter 8 mm was 232.5 N and for stem 30 mm diameter, it was found 747.25 N (Table 1). It was also observed that the cutting energy and force for pigeon pea stems decreases with increases in moisture content with cutting blade bevel angles, blade sharpness, etc as stated by Chancellor (1958) (Fig. 5).

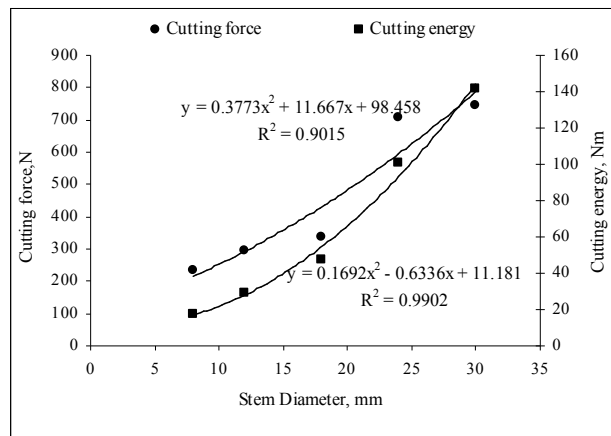


Fig. 5. Cutting energy and force against stem diameter of pigeon pea crop

It showed that the cutting energy and force required for cutting pigeon pea stems increased gradually as the diameter of the stem increases from 8 mm to 18 mm. The cutting energy and maximum cutting force were directly proportional to the cross-sectional area and inversely proportional to the moisture content of the stalk as stated by Prasad and Gupta (1975). But energy and force suddenly increases from stem diameter 18 mm to 24 mm (Fig. 6). It may due to full maturity of plants. Full mature plants cellulose became compact and hard so the force required to cut was increased as diameter increased.

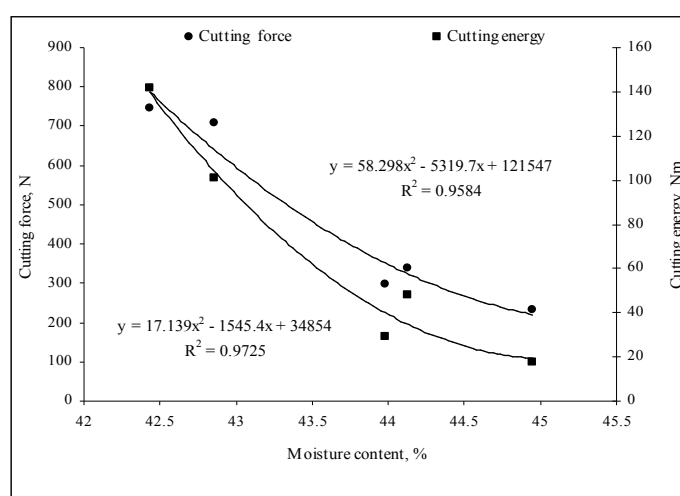


Fig. 6. Cutting force and energy against moisture content of pigeon pea crop

Cutting energy was minimum at velocity 2.28 m/s for 30° bevel angles of cutting blade. It increased sharply when the velocity was increased beyond 3.98 m/s⁻¹ as also reported by Chattopadhyay and Pandey (1999). This may happen due to the fact that at lower velocity, impact is too less to sufficiently fail the stem and hence energy requirement is increased. At higher velocities, the increase in the cutting energy may be owing to the kinetic energy imparted by the pendulum to the separated parts of the stem after cutting.

Overall performance of newly developed stem pigeon pea stem cutter

The front mounted pigeon pea stem cutter was tested for different gear. The height of cut was adjusted by using Hydraulic cylinder up to 300 mm from ground. Three replications were taken for each test. The performance characteristics of the tractor front mounted pigeon pea stem cutter were shown in Table 3.

Table 3. Comparative performance characteristics of newly developed pigeon pea stem cutter with manual harvesting

Particulars	Harvesting with newly developed pigeon pea stem cutter	Manual(10 labour at Rs150/day
Effective field capacity, ha/hr	0.176	0.021
Cutting efficiency, %	94.55	100
Plant damage, %	6.3	Nil
Fuel consumption, lit/ha	4.74	---
Speed of operation km/hr	2.7	---
Time required, hr /ha	5.77	15.24
Speed of operation (km/hr)	2.7	---
Cost of operation, Rs/ha	1058.52	3000

Average field capacity of newly developed pigeon pea stem cutter for test was 0.176 ha/hr. Increase in field capacity may be due to increases coverage area with time. The plant damage was increased 29.72 % as speed of operation increased. It may be due to at higher speed the plant wrap around the plant collector. To avoid the plant damage optimum speed of blade and plant collector required. Compared to manual harvesting of pigeon pea, it was observed that 64.71 percent less cost with the newly developed pigeon pea stem cutter (Fig. 7). It is easy to operate and control.

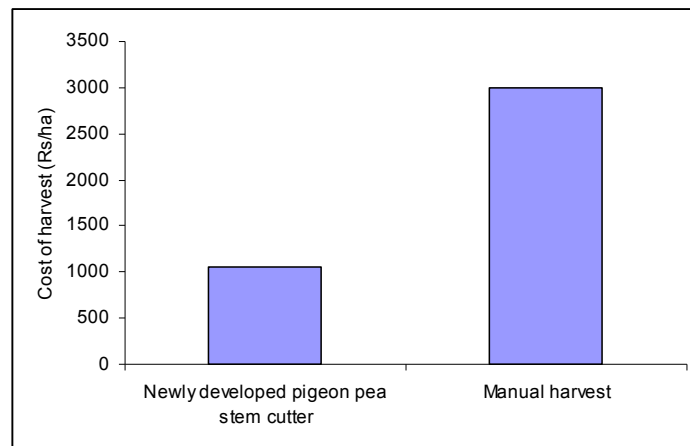


Fig. 7. Cost economics of pigeon pea harvesting

Conclusions

Effect of blade velocity indicated that the cutting energy was a minimum at 2.28 m/s. Blade velocities ranging between 2.28 m/s to 7.23 m/s for cutting the pigeon pea stems of diameter ranging from 8 mm to 30 mm. Cutting energy and force decreased with increase in moisture content of the stem. The fuel consumption and plant damage was increased with 3.11% and 29.72 % as speed of operation increased. On an average the time required for cutting pigeon pea by newly developed stem cutter was recorded 1/3rd to that of manual harvesting. The cutting cost of tractor front mounted pigeon pea stem cutter was 64.71 % less than with manual harvesting of pigeon pea stem.

References

- Anonymous, (2003). Indian Agriculture. Ministry of Agriculture, India: 180-182.
- Bisht, D.S., S.K. Dasdupa and P.M. Menon (2006). Agricultural Research station Development and Management, ICRISAT. 156-157.
- Chancellor, W.J. (1958). Energy requirement for cutting forage. *Agricultural Engineering*. 30(10): 633-636.
- Chattopadhyay, P.S. and K.P. Pandey (1999). Effect of knife and operational parameters on energy requirement in fail forage harvesting. *Journal Agri. Engg. Research*. (23): 3-12.
- Klenin, G.L., I.F. Popov and V.A. Sakun (1985). *Agricultural Machines*. Amerind Publication Co. Pvt. Ltd., New Delhi, 507-509.
- McRandal, D.M. and McNulty, P.B. (1978). Impact cutting behavior of forage crops. *International Journal of Agricultural Engineering Research*, (23):313-328.
- Prasad, J. and C.P. Gupta (1975). Mechanical properties of maize stalk as related stalk in relation to harvesting. *Journal of Agril. Engg. Research*. (20):79-87.
- Persson, S. (1987). Development of rotary counter shear mover. *ASAE*, 36(6):1517-1523.
- Reza, T.K. (2007). Paddy stems cutting energy and suggested blade optimum parameters. *Pakistan Journal of Biological Sciences* 10(24):453-4526.
- Singh, G.P. (2003). *Modern technique of raising field crop*. Oxford and IBM publication Co. Pvt Ltd. IInd edition, pp: 229-230.
- Wanjari, K.B., A.N. Patil and M.C. Patel (2000). A short duration Pigeon peahybrid for the central zone of India. *ICPN*. 6: 39-40.

(Published in March 2012)