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Physico-mechanical properties of sugar cane stalks related to mechanical harvesting

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Abstract

A study was under taken to investigate the base cutting and lifting actions of a sugar cane harvester. To obtain preliminary data required for the study, laboratory and field measurements were made to ascertain the cutting and lifting behaviour of sugar cane stalk that can be used by designers for design of the sugar cane harvester. An apparatus was developed to measure the lifting moment of sugarcane stalk from the lodged position to vertical under field conditions. Laboratory studies were conducted to measure the mechanical properties of sugarcane stalk. To measure the cutting energy a pendulum type impact cutting device was used. Flexure test were conducted for measuring the modulus of elasticity. The maximum lifting moment varied from 30.62 Nm to 129.11 Nm and the lifting moment was dependent upon the field conditions and degree of entanglement. The specific cutting energy increased linearly when the oblique angle was increased from 0 to 35^0 and the specific cutting energy was lowest at a tilt angle of 20^0 when the oblique angle was 30^0. The flexure test on sugarcane stalk as a simple supported beam gave Young's modulus values of 1165.27 to 1667.11 M Pa. The same when loading was done as cantilever beam was 2266.17 to 2905.61 M Pa.

Key words: Sugarcane, Stalks, Mechanical harvesting, Young's modulus

Introduction

Sugarcane cultivation in India is a labour intensive process. Farmers depend mainly on human power and it requires continuous engagement of labour throughout the crop cycle. Scarcity of labour is often felt in the agricultural sector. For want of sufficient labour at reasonable wages, most of the cultural operations are delayed or not taken up at all, resulting in low production and productivity. Yadav (2008) estimated that, 134 man hours are required per metric tonne of sugar produced. Of this, one third is required for production whereas remaining two third is utilized for harvesting, cleaning and loading.

Among the various operations of sugarcane production, harvesting alone (including base cutting, de-topping, de-trashing and loading onto trucks) requires between 850 to 1500 human h ha^{-1} in India, which is the highest as compared to other cultural operations (Yadav, 2008). Hence mechanization of sugarcane harvesting is essential not only for reducing the production cost but also for reducing drudgery involved in manual harvesting operations, and also to ensure quality produce. Shortage of labour is one of the reasons why many farmers have walked away from this promising crop. Mechanization is considered as an alternative to solve the problem of labour shortage.

Keeping these in view, a study was conducted at the Department of Farm Machinery of the Tamil Nadu Agricultural University, Coimbatore during 2007 – 2010. Physico-mechanical properties of plant stems are important in the design of a harvester

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as the force and energy requirements are by and large dependent on these properties. Lifting and cutting are two important processes in harvesting of sugarcane. The physical and mechanical properties of the plant material significantly influence the performance of these operations. So the study of these properties was done. The cutting energy for different blade geometry, lifting characteristics of the plant and the bending properties of the plant stem were studied in the laboratory and in the field.

Materials and Methods

Force required for lifting lodged cane:

Lifting of lodged plant stalk is a challenge to harvesting machinery. Proper design of the lifting mechanism for the harvesting equipment requires thorough study of the forces required for lifting lodged cane. An apparatus was developed to measure the moment resisting lifting of sugarcane stalk in the field. The device for measuring lifting force consists of a transportable frame, uni-directional winch type rope winding mechanism, wire rope, pulleys, load cell for measuring lifting force, a digital force indicator and a power supply. The frame was made of mild steel pipe sections with joints for quick dismantling and assembling and for easy transport to field. There was a V-shaped base provided with three leveling feet for proper placement and leveling of the instrument on ridges. The force for lifting cane was applied by winch mechanism fixed on vertical post. The force applied for lifting the cane was transferred through a wire rope and a load cell of 300 kg capacity. The lifting force was sensed by the load cell and was read from the indicator. The force indicating system was powered by a portable power source. The apparatus and the experimental set up for measuring lifting force are shown in Plate 1.

Lifting force for lodged cane was recorded from farmers' fields at Vellamadai (F1) and Annur (F2), and at Sugarcane Research Station, Sirugamani (F3). Sugarcane stalk was lifted with the instrument at a point of known distance (l) from the base. The plumb angle at that point was measured using a plumb bob and protractor (Fig. 1). The angle of inclination of the cane stalk was calculated from the plumb angle.

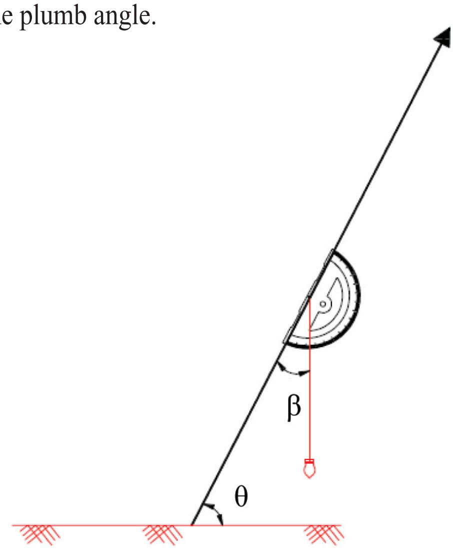

Figure1. Measurement of degree of lodging of sugarcane

Angle of inclination of the stalk, $\theta = 90 - \beta$.
The stalk was lifted for a particular height and the lifting force L_f was obtained from the digital force indicator. The plumb angle after lifting was measured and the angle of inclination of the stalk after lifting was found out. The lifting moment of the stalk was calculated based on Fig. 2 as

Vertical component of lifting force

$$= L_f \cos\theta \qquad \text{— (1)}$$

Lifting moment $= l \times L_f \cos\theta$ — (2)

The angle of inclination of the sugarcane stalk before lifting and after lifting to a known height were measured and corresponding lifting moments were calculated using the equation. Then the average value of the lifting moments before and after lifting was calculated.

Measuring Modulus of Elasticity using Flexure test:
Flexure tests were conducted in the lab for sugarcane stalk as simple supported beam and as cantilever beam for studying the stiffness characteristics.

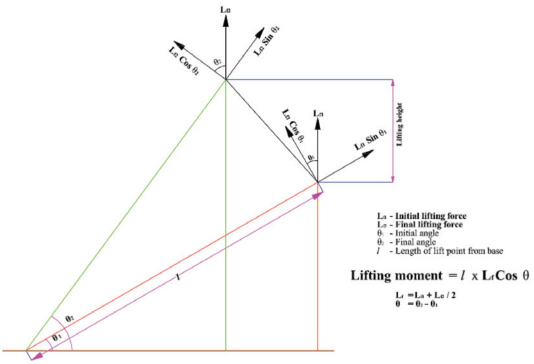

Figure 2. Schematic representation of lifting moment calculation

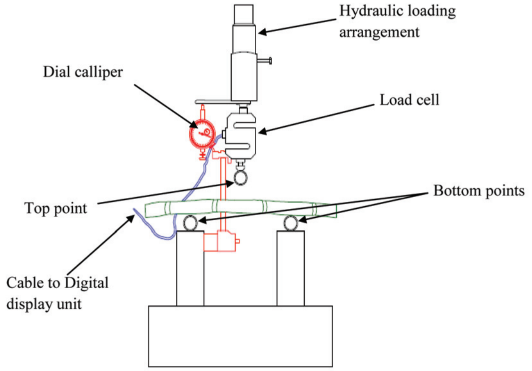

Figure 3. Schematic of experimental set up for measuring modulus of elasticity using simple supported bending test

Plate1. Lifting force measuring apparatus and its field measurement

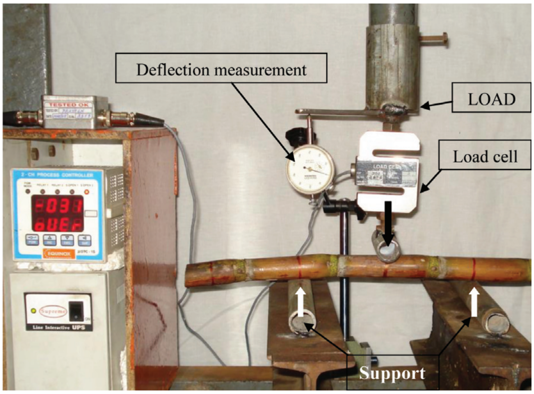

Plate 2 Set up for measurement of modulus of elasticity using simple supported beam

Knowing the load and deflection, the modulus of elasticity of the plant stem was calculated. An experimental set up was made in the laboratory to study the bending characteristics of the cane stalk in both simple supported and cantilever loading.
The experimental test rig for determination of modulus of elasticity by bending of cane as a simple supported beam consisted of two bottom points where the sugarcane stalk was supported and a top middle point through which the load was applied. The central loading point was fixed to apply load through a load cell. A dial gauge was also provided as shown in Fig. 3 and plate 2 to measure the deflection of the specimen when load was applied.

The load applied can be read from the digital display unit connected to the load cell and the deflection of the stalk was obtained from the dial gauge. Test specimen was prepared out of sugarcane variety CO 86032 of different lengths and diameters. The experiment was conducted for different effective lengths of the test specimen *viz.,* 200, 400, and 700 mm. The load was increased from 10 N to 120 N in increments of 10 N. The corresponding deflections and the diameter of the specimen were noted and the Young's modulus was calculated using the following expression (Mohsenin, 1996).

$$D = PL^3 / 48EI \quad — \quad (3)$$

where, *D* - deflection
P - load
L - effective length of sample
E - Young's modulus
I - moment of inertia

For round sections

$$I = \Pi d^4/64$$

where, *d* - diameter of sugarcane stalk

Modulus of elasticity using cantilever beam

The experimental set up for conducting cantilever bending test consists of a holding jaw, a bench vice and a lifting mechanism with load cell (Fig. 4).

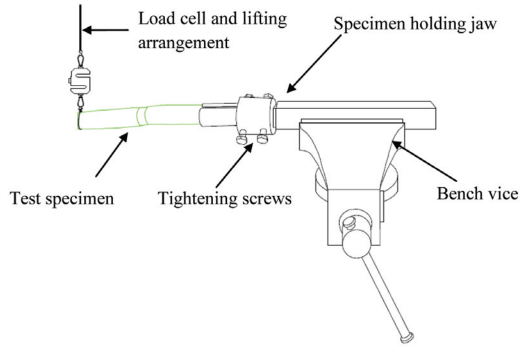

Figure 4. Schematic of experimental set up for measuring modulus of elasticity using cantilever bending test

The holding jaw is provided with a socket for holding one end of sugarcane stalk specimen and is held firmly by tightening clamping screws. The socket is fixed to a square pipe and can be fitted to a bench vice horizontally. The test specimen, held by the jaw at one end, will remain at horizontal cantilever position. Load for bending the specimen was applied at the free end through a lifting mechanism and load cell. The force required to lift the stalk can be read from the digital display unit connected to the load cell and the deflection could be measured by using a measuring scale. The experiment was conducted for different cantilever lengths of 25, 50, 75 and 100 mm. CO 86032 variety of sugarcane was used. Load was applied at the free end through a lifting arrangement in increments of 10 N. The corresponding deflections of the specimen were noted and the experiment was repeated for different diameters of the specimen. Young's modulus for each test was calculated using the equation (Mohsenin, 1996).

$$D = PL^3 / 3EI \qquad \text{—— (4)}$$

Cutting energy

The prevailing practice in harvesting is the cutting of the plant material using a cutting knife. The cutting process of plant materials is complex but it needs to be understood in order to develop an efficient method of harvesting. Sugarcane plant structure is complex and can vary between fields and even between plant stools making it very difficult to understand.

The power required by a cutting blade depends on the kinetic energy imparted to the knife, the length of cut and shearing resistance of plant material and the sharpness of the cutting blade. Bevel angle of cutting edge, tilt and oblique angles of the blade at the time of cut also influences the cutting energy. Bevel angle of cutting edge shows the angle of the cutting edge measured from the X-Z plane in the Y-Z plane as shown in the Fig. 5. It determines the sharpness of the blade cutting edge and affects the quality of cut.

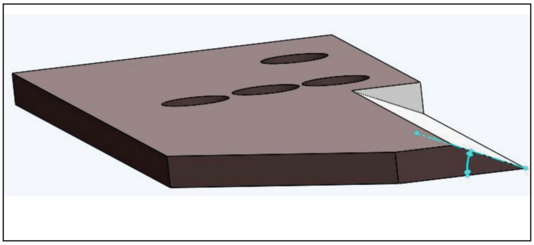

Figure. 5 Measurement of bevel angle of blade cutting edge

Rotation of the blade about X-Z Plane and measured in the X-Y plane is the tilt angle and the rotation of the blade about X-Y plane and measured in the X-Z plane is the oblique angle. Position of the blade in the co-ordinate planes system showing tilt and oblique angles is presented in Fig. 6.

Pendulum type impact test rig

A pendulum type impact test rig was developed in the laboratory to measure the cutting energy

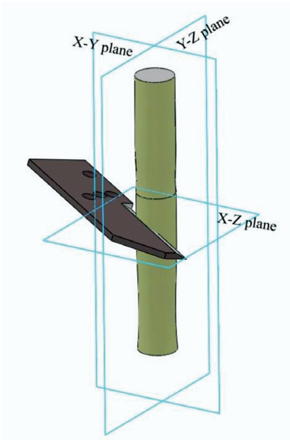

Figure. 6 Position of cutting blade showing tilt and oblique angles with respect to the co-ordinate planes

required to cut sugarcane stem at different blade oblique angles and tilt angles. The schematic view of developed test rig is shown in Fig. 7. It consists of frame made of mild steel angle sections, a swinging pendulum from the top of frame (on which the cutting blades are fixed), an angle indicator, a holder for cutting blade, a specimen holding vice and a stopper mechanism for pendulum.

The overall height of the frame was 1400 mm and width was 400 mm. The pendulum was freely suspended from a shaft mounted on the top of the frame with ball bearings at both ends. The swinging arm of the pendulum was made of rectangular tube sections of 50 x 10 x 3 mm size and having a length of 1178 mm. A holding vice was fixed at the bottom of the frame to hold the test specimen vertically below the pivot shaft of pendulum. A stopper and release arrangement for the pendulum was made on one side of the frame so that the pendulum could be raised and stopped at an angle of 60^0 from the vertical. During the test, the pendulum was smoothly released from this. An angle indicator with a graduated angular scale and pointer fixed on the pendulum pivot shaft showed the angular deflection of the pendulum. A stopper needle was also fixed to show the maximum swinging angle of the pendulum.

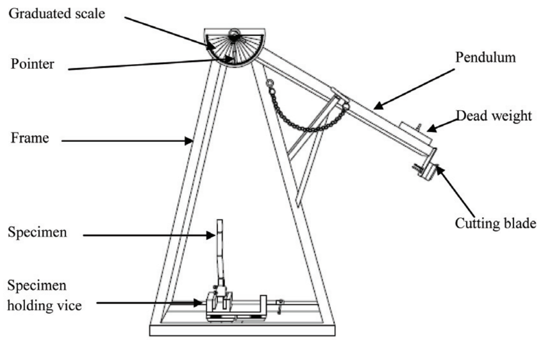

Figure. 7 Schematic of pendulum type impact test rig.

The position of centre of gravity of the pendulum was found out by lifting the pendulum end to horizontal position and the force for lifting was found using load cell.

The weight of the pendulum was 12.54 kg and an additional weight of 5 kg was added to increase the momentum.

The impact cutting experiments were done for the cane variety CO-86032. Stalk samples with diameter in the range of 27 to 30 mm from the bottom 10 cm of the plant were selected and the trials were done in 5 replications for each tilt angle and oblique angle combination. The moisture contents of the samples were found out by oven drying method. The cutting energy per unit cross sectional area of the plant stem was calculated.

The test specimen was firmly clamped in a special jaw and is fixed to the holding vice so that it is vertically mounted directly below the pendulum hinge point. The clamping fixture was provided with an adjustable slot for centering the specimen in the same position. The pendulum was held in the release point. After making sure that the swing plane of the pendulum arm is clear, the pendulum was released to cut the specimen. Plate 3 shows the fixing of test specimen on the impact test rig and the specimen.

Plate 3 Specimen in impact test rig before and after cut

Three samples of uniform dimension were tested for each combination of blade tilt angle and oblique angle. The various oblique angles of the blade selected were 0, 30, 35 and 40º and the tilt angles were 0, 10, 15, 20 and 25º. The edge bevel angle of the cutting edge of the blade was kept $25^{0.}$

Provision for changing the tilt angle and oblique angle were provided on the blade mount. Tilt angle was changed by angled wooden blocks set (Fig. 6) at required angles between the blade and blade holder. Oblique angles were changed by fixing the

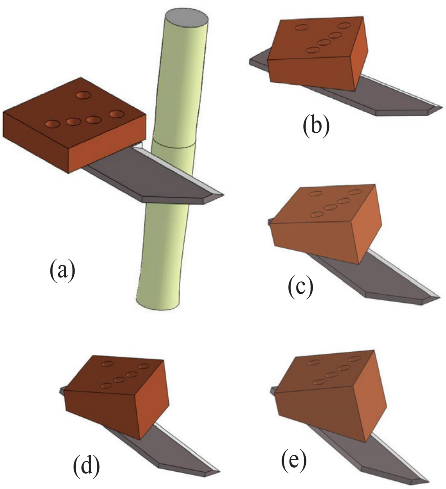

Figure. 8 Angled wooden blocks blade at different Tilt and Oblique angles

(a) 0^{O} Tilt and 0^{O} Oblique angle (with position of Sugarcane stalk)

(b) 10^{O} Tilt and 30^{O} Oblique angle

(c) 15^{O} Tilt and 35^{O} Oblique angle

(d) 20^{O} Tilt and 35^{O} Oblique angle

(e) 25^{O} Tilt and 40^{O} Oblique angle

blade at different orientation using a set of alternate mounting holes.

The energy expenditure for cutting of sugarcane stalk was determined using the following expression.

$$E = W \times r\,(\cos\theta_1 - \cos\theta_2) \qquad (5)$$

where,
- E - Cutting energy, N m
- W - Weight of the pendulum, N
- r - Distance to the CG of pendulum from the pivot point, m
- θ_1 - Angle of pendulum at initial position, degrees
- θ_2 - Maximum angle of pendulum after cutting, degrees

Results and Discussion

Moment for lifting lodged cane

Lifting forces and lifting moments are measured from fields in three locations out of which two were farmers' fields at Vellamadai and Annur and the third field was at Sugarcane Research Station, Sirugamani. In all the fields the crop variety was CO-86032, which is the popular cultivated variety in Tamil Nadu. The result of the study indicated that, there is a large variation in power required for lifting the cane from the lodged position to erect position. The maximum lifting force found at farmer field at Vellamadai was 300 N and the maximum lifting moment was 129.11 Nm. At Sirugamani the maximum lifting force obtained was 105 N and the maximum lifting moment was 30.62 Nm. Again at farmer's field at Annur the maximum lifting force was 190 N and the lifting moment was 45.9 Nm. There was no definite trend in the lifting force or lifting moment in the field. The lifting force is influenced by the pattern of lodging of the crop. If the lodged plants criss-cross the force required to lift was observed to be more.

Cutting energy

The cutting energy at different tilt angles and at different oblique angles was plotted and is presented in Fig. 10 and Fig. 11.

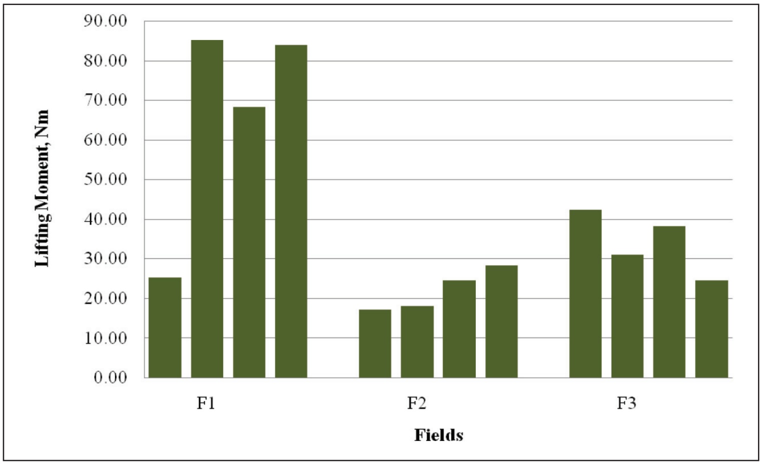

Figure. 9 Average Lifting Moment observed from fields at different locations

The specific cuttig energy was in the range 25000 to 37000 J m^{-2} at 0^0 oblique angle and reduced to a minimum value at 15 to 25^0 oblique angle and later increased as the oblique angle was increased to 35^0. From these curves it is clear that upto 25^0 oblique angle the specific cutting energy will decrease for all tilt angles and the reduction will be maximum for 20^0 tilt angle blade. When the oblique angle was increased beyond 20^0 the specific cutting energy increased almost in a linear fashion and the slope of this segment was almost identical for all tilt angles. Hence it can be concluded that a blade at 20^0 tilt angle at an oblique angle of 10 to 30^0 can be used with a specific cutting energy of less than 20,000 Jm^{-2}. The average diameter of the cane during harvest is taken as 30 mm based on field observbations. Hence taking a specific cutting energy requirement of 20,000 Jm^{-2}, the energy required for cutting a single cane will be 14.13 J.

The same data plotted against tilt angle for different values of oblique angles is given in Fig. 11. Though considerable scatter in the plot was observed the specific cutting force at zero degree oblique angle varied around 30000 Jm^{-2}. However the specific cutting energy at 30 and 35^0 oblique angle was slightly lesser at tilt angle of 5 to 20^0. When the oblique angle was incresed to 40^0 the specific cuttting energy shows a distinct upward shift and the average value increased to 35000 J m^{-2}. Hence for energy efficient cutting a tilt angle of 20^0 and an oblique angle of 20^0 can be adopted.

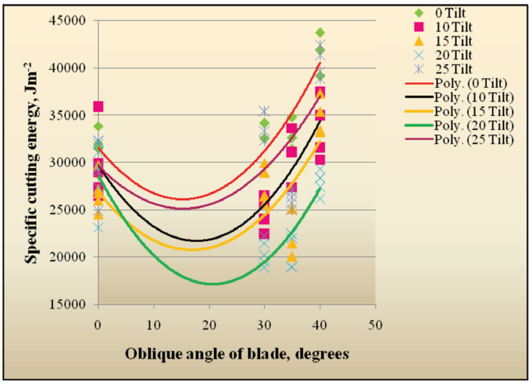

Figure. 10 Specific cutting energy Vs Oblique angles for different Tilt angles

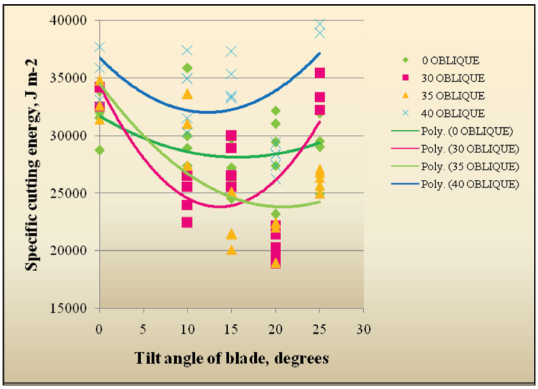

Figure. 11 Specific cutting energy Vs Tilt angles for different Oblique angles

Flexure test to calculate modulus of elasticity

The Young's modulus of the cane stalk specimen was found out for different span lengths of the stalk and is tabulated in Table 1.

Table 1. Young's Modulus based on flexure test

Diameter of cane (cm)	Test type	Young's Modulus (M Pa)
3.00	Simple Supported	1667.11
2.75	Simple Supported	1165.27
3.00	Cantilever	2905.61
3.00	Cantilever	2266.17

It was observed that the Young's modulus as determined by simple supported beam loading was 1165.27 to 1667.11 M Pa and the same for cantilever beam loading was 2266.17 to 2905.61 M Pa. The values can be used to model the deflection behaviour of cane when it is lifted, bent and cut at the base.
Hence it can be concluded that

1. The energy for cutting sugarcane by using a pendulum type impact cutting knife showed that the specific cutting energy was in the range of 27000 J m^{-2} to 37000 J m^{-2} at zero degree oblique angle. The cutting energy was minimal at 15^0 to 25^0 oblique angles. The specific cutting energy increased linearly when the oblique angle was increased to 35 degree.
2. It was observed that specific cutting energy was minimum at a tilt angle of 20^0 when the oblique angle is 30^0.
3. A test rig to measure the lifting force required to lift the lodged cane was developed and the moment required for moving a lodged cane towards the vertical position was evaluated. The maximum lifting moment varied from 30.62 Nm to 129.11 Nm and the lifting moment was dependent upon the field conditions and degree of entanglement.
4. The flexure test on sugarcane stalk as a simple supported beam gave Young's modulus values of 1165.27 to 1667.11 M Pa. The same when loading was done as cantilever beam was 2266.17 to 2905.61 M Pa.

References

Chattopadhyay, P. S. and Pandey, K.P.1999. Mechanical properties of Sorghum stalks in relation to Quasi-static deformation. J. Agric. Eng. Res., 73: 199-206.

Kroes, S., and Harris, H.D.. 1997. *The optimum harvester forward speed*. Proceedings of Australian Society of Sugar Cane Technologists. 19: 147-154.

Mohsenin, N.N. 1996. *Rheological properties, Physical properties of Plant and Animal materials*, Gordon and Breach Science Publishers Inc: 250-252.

McRandal, D. M., and McNaulty, P.B.. 1980. Mechanical and physical properties of grass. Transaction of ASAE, 23 (2): 816-821.

Prasad, J. and Gupta, C. P. 1975 Mechanical properties of maize stalk as related to harvesting. J. of Agric. Eng. Res., 20:79-87.

Persson, S. 1987. *Mechanics of cutting plant material*. American Society of Engineers, St. Joseph, Michigan, U.S.A.

Yadav, R.N.S. 2008. Mechanization of sugarcane production in India, Sugar Cane Internat. 26(2) : 12-17.