

FABRICATION AND PERFORMANCE EVALUATION OF VARIABLE WIDTH WHOLE-STALK SUGARCANE HARVESTER

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Sugarcane is one of the most important cash crops grown in Pakistan which accounts for 3.4% share in agriculture value addition and 0.7% in gross domestic products (GDP). It is a tropical and perennial grass sensitive to the soil type, climate change, irrigation, insects, fertilizers, varieties and the harvest period. Pakistan annually produces 81.1 million metric tons (MMT) of sugarcane but unfortunately, about 30% sugarcane crop is lost at harvesting stage particularly due to deficiency of mechanized harvesting approaches. This study has been carried out to fabricate and performance evaluate a tractor propelled sugarcane harvester to reduce sugarcane losses during harvesting in Pakistan. The major components of indigenously developed sugarcane harvester include hydraulically operated bottom cutter, top cutter, blower and conveyor and all of them are fixed on a movable iron frame. For optimization, the sugarcane harvester was operated at three different gears (G_1 , G_2 and G_3) and engine speeds ($N_1=1800$, $N_2=1900$ and $N_3=2000$ rpm) of tractor and working widths ($Kw_1=0.85$, $Kw_2=0.92$ and $Kw_3=1.02$ m) of harvester for sugarcane variety CP-77400 to determine the maximum field efficiency and material capacity. The results showed that maximum field efficiency was found to be 75.10% and material capacity was 12.87 ton/hr at G_3 , N_3 and Kw_3 .

Keywords: Sugarcane, sugarcane harvester, field efficiency, material capacity.

INTRODUCTION

Agriculture sector holds 18.9% share in gross domestic product (GDP) of Pakistan with a 3.81% growth rate in 2017-18 and provides 42.3% labor force and responsible for resourcing 62% of rural population for their income (GOP, 2018). The temperate to tropical region allow to produce a variety of cash crops, fruits and vegetables in Pakistan among which, sugarcane (*Saccharum officinarum* L.) is the second largest cash crop accounting for a 3.4% agriculture value addition and 0.7% in GDP of the country (GOP, 2018). It is grown perennially and requires 600 mm of rainfall with semi-hot and humid weather conditions to thrive. At harvesting stage, stems become stalks and attains 25 to 50 mm diameter and 3000 mm to 4000 mm height which contain approximately 2-3% non-sugars, 12-16% soluble sugars, 11-16% fiber and 63-73% water (Qureshi and Afghan, 2005). Being the main raw source to sugar industries, sugarcane is a vital crop grown in Pakistan and its production has been reached to 81.1 million tons during 2017-18 which is 7.4% higher as compared to the last year (GOP, 2018). Pakistan has been ranked at twelfth position among the sugarcane producing countries around the world by growing different varieties of sugarcane e.g. CP 77-400, CP 72-2086, CP 43-33, CPF-237 and BL-4, etc. (Mian and Saeeda, 2003).

Despite the fact of large share in agriculture, the yield potential of the existing cane varieties in Pakistan is less than

that grown in other countries of the world. Yet agricultural technology in vogue is poor and inadequate to explore their inherent potential to maximum extent (Niaz, 1990). Unfortunately, sugarcane sucrose losses for delay in harvesting and processing due to shortage of skilled labor and non-availability of mechanized harvesting machinery varies between 30-35%. The major causes of these losses are unbalanced land distribution system, lack of farm mechanization and socio-economic issues of under-developed farming communities of the country which are the outcomes of illiteracy about advance farm inputs, provision of technological trainings, poor financial conditions of farmers, hesitancy towards adoption of latest machinery and inadequate modern agro-technical practices (Iqbal, 2006; Naseer *et al.*, 2016). According to the World Bank report, there are 98% farmers that belongs to small land holder's group and shares 55% in agriculture production of Pakistan (Khan *et al.*, 2013). These small-scale farmers are compelled to perform conventional farm practices as they are not well-aware as well as not financially strong enough to rent/buy the advance farm machinery for their farm use. These factors result in increased pre-harvest, harvest and post-harvest losses which ultimately lead the Pakistani farmers to a challenging scenario with the world's agricultural sector (Ashfaq *et al.*, 2014).

In sugarcane crop production, harvesting is the most time consuming, labor intensive practice and expensive which

takes about 45 to 48% of total crop production cost (Bastian and Shrider, 2014). Mechanized sugarcane harvesting is often practiced in the developed world. Southern USA, Australia and Japan are the leaders to initiate commercial designs of sugarcane harvesters where the sugarcane production has been reached to fully mechanized level now a days (Mawla and Hemeida, 2015; Schmitz *et al.*, 2017). Mainly, sugarcane harvesters are categorized as whole stalk harvester and cut-chop-harvesting or chopper harvester in which chopper harvester design has the upper edge with the ability to remove the leaves and convert the sugarcane stalk into billets (Cock *et al.*, 2000; Kumar *et al.*, 2002). Besides this edge, harvested billets must be transported for the processing facilities on same day otherwise quality deterioration starts (Ma *et al.*, 2014). On the other side in under-developed world, sugarcane harvesting is carried out by the farmer manually due to cheaper cost which consists of manual cutting, de-topping, de-trashing, bundling and loading canes into the transportation vehicles stages. These conventional practices ultimately result in increased harvesting losses and serious ergonomics issues to the farming communities (Arboleda and Duran, 2009; Mawla and Hemeida, 2015).

Keeping in view the above facts, there is a need of economically viable technological interventions especially from local industries to promote a mechanized agriculture sector in Pakistan. This study was specifically aimed to locally design and develop an indigenous sugarcane harvester to minimize the cost and time for sugarcane harvesting. The sugarcane harvester was designed to efficiently run on tractor power and entirely fabricated with locally available materials at Engineering Workshop, Kot Addu, District Muzaffargarh, Pakistan. Field efficiency and material capacity of developed harvester were evaluated at different gears and engine speeds of tractor and working width of harvester to optimize the field operation conditions.

MATERIALS AND METHODS

The developed harvester mainly consists of conveyor belt, bottom cutter, top cutter and blower, all are powered by power take off (PTO) shaft of a Massey Ferguson tractor for the forward moment and hydraulic operation of different components. The design and working principle of different parts is discussed in following sub-sections and fabricated sugarcane harvester is shown in Figure 1.

Conveyor: A special conveyor comprises of two chain conveyors and 63 rubber catchers is fabricated to hold the sugarcane stalk for cutting and then convey to back end of the harvester. Two chain type conveyors are installed parallel on the main steel frame and their inner sides run very close together exactly above the bottom cutter. The rubber catchers, each of which is 350 mm long, 75 mm wide and 5 mm thick, installed on the both chain conveyors to hold the sugarcane stalk in such a way that the stalk is being trapped between two

opposite catchers just before cutting. After cutting, trapped sugarcane is moved towards the back end of harvester. The conveyors are run by two hydraulic motors fixed at back end of the harvester. The isometric view of conveyor and rubber catchers are shown in Figure 2 and 3, respectively.

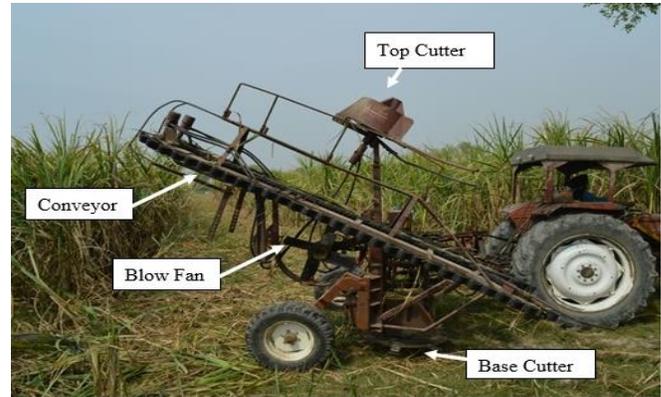


Figure 1. Fabricated sugarcane harvester.

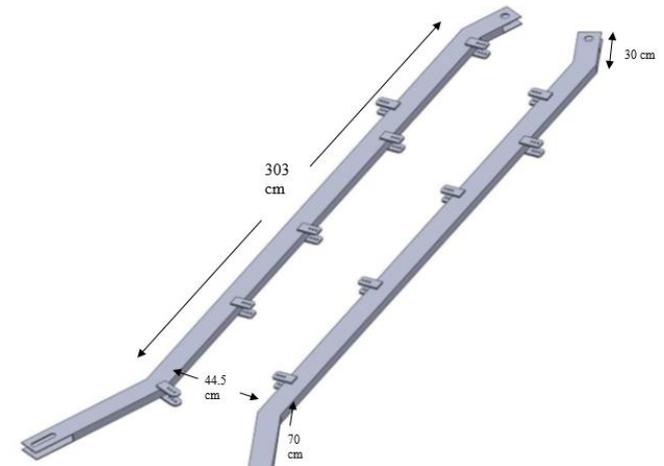


Figure 2. Isometric view of conveyor.

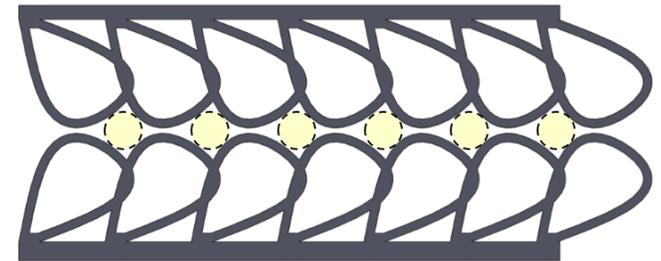


Figure 3. Installation pattern of rubber catchers on conveyor.

Bottom cutter: A 815 mm in diameter bottom cutter fixed with 8 cutting blades of 110 x 76.2 x 5 mm (length x width x thickness) is used to cut the sugarcane from the roots just above the ground surface instantly as it is being trapped in

conveyor catchers. The bottom cutter is made of cast iron and attached with the bottom of main frame of harvester with nuts and bolts. It is driven through the chain sprocket mechanism directly from PTO shaft. After being cut, sugarcane is moved backwards to the top cutter. The design of bottom cutter is shown in Figure 4.

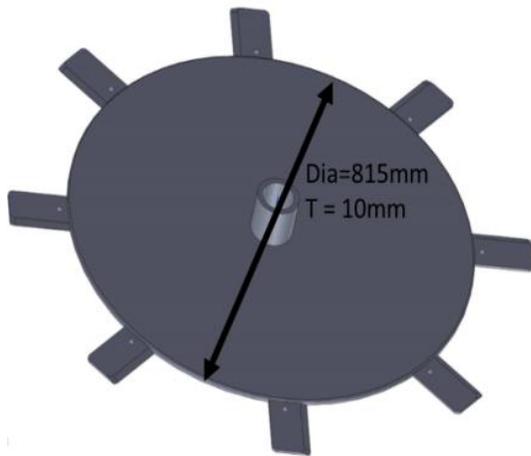


Figure 4. Design of bottom cutter.

Top cutter: The top cutter having 380 mm diameter and covered by an iron cover has been mounted on the central support pole and rotated by a hydraulic motor. A hydraulic pump is also attached with the top cutter assembly to adjust the height of cut from 2.13 to 2.75 m according to crop specification. Both the parts get power for rotation and height adjustment through hydraulic control system. The main function of top cutter is to cut upper leafy portion of sugarcane as it conveyed towards back end by the conveyor. An isometric view of the design of top cutter are shown in Fig 5.

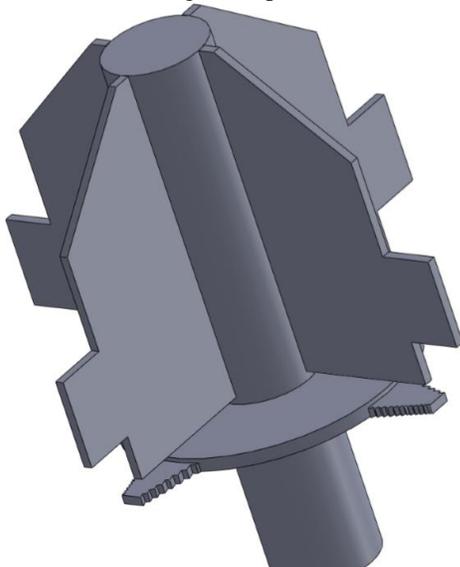


Figure 5. Isometric design view of top cutter

Blower: A blower fan consisting of 4 curved steel blades is installed beneath the conveyor frame to remove the dry matter from the bottom of sugarcane after cutting operation. The fan is run with a 5hp hydraulic motor of the harvester.

Performance Evaluation of Sugarcane Harvester:

Experimental procedure: The field trials were conducted at different sugarcane farms in Kot Addu, District Muzaffargarh, Pakistan. Firstly, the sugarcane harvester is attached with MF-375 (75hp) tractor and all the necessary hydraulic connections were established to the machine parts and checked. The performance evaluation of the harvester was carried out by harvesting the sugarcane at three different gears (G_1 , G_2 and G_3) and engine speeds (N_1 , N_2 and N_3 rpm) of tractor and three different working widths (kw_1 , Kw_2 and Kw_3 m) of harvester to optimize the harvester in terms of maximum field efficiency (FE) and material capacity (MC). The height of cut for bottom cutter was adjusted to just above the ground level (10 mm) to preserve the maximum length of sugarcane stalk whereas the height of cut for top cutter was adjusted according to average height of stalk (2.438 m) in the field. The area of each selected farm was 1 ha in which canes were planted at a row to row and plant to plant distance of 30 ± 4 and 40 ± 7 mm respectively. Average effective working width of the machine was being calculated by determining row to row spacing of the crop. Different steps involved (flow chart) in acquiring experimental data and performance evaluation of the sugarcane harvester are shown in Fig. 6.

Mathematical calculations: All the recorded data were entered in an excel sheet using MS Excel 360 software and different parameters for determining the harvester's performance were mathematically calculated by modelling the equations. The mathematical equations used for calculations are given below (Omrani *et al.*, 2013).

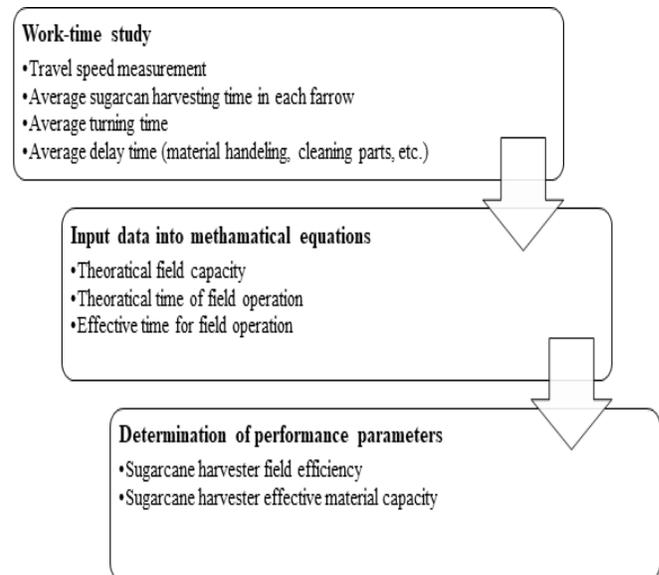


Figure 6. Flow chart of data acquisition and results.

Theoretical field capacity: The theoretical field capacity was calculated using Eq. 1.

$$TFC = \frac{V \times W}{10} \quad (1)$$

Where; *TFC*, *V* and *W* are the theoretical field capacity (hah⁻¹), forward travel speed (kmh⁻¹) and working width (m) respectively.

Theoretical time required for field operation

The theoretical time required for field operation was calculated using Eq. 2.

$$TTR = \frac{A}{TFC} \quad (2)$$

Where; *A* and *TTR* are area under cultivation (ha) and theoretical time required for field operation (h) respectively.

Effective time required for field operation

The effective time required for field operation was calculated using Eq. 3.

$$ETR = \frac{TTR}{K_w} \quad (3)$$

Where *ETR* and *K_w* are effective time required for farm operation (h) and effective working width respectively.

Sugarcane harvester field efficiency: The sugarcane harvester field efficiency was calculated using Eq. 4.

$$SHFE (\%) = \frac{TTR}{ETR + T_h + T_a} \times 100 \quad (4)$$

Where *SHFE* is field efficiency, *T_h* is delay time which are not proportional with area under cultivation (h) and *T_a* is losses time which are proportional with area under cultivation (h).

Sugarcane harvester effective material capacity:

The sugarcane harvester effective material capacity was calculated using Eq.5

$$SHMC = V \times W \times Y \times \frac{SHFE}{10} \quad (5)$$

Where, *SHMC* is effective material capacity (tonh⁻¹) and *Y* is yield of crop (tonha⁻¹).

Statistical Analysis: The experimental data was evaluated using IBM-SPSS Statistics software by applying complete randomized design (CRD) under 4-factor factorial.

RESULTS AND DISCUSSION

Effect of gear, engine speed and working width on SHFE:

The experimental results revealed that maximum SHFE (71.24%) was observed at Kw₃ with G₁ followed by 63.30% at gear G₂ and N₁ whereas comparatively low value 55.15% was recorded at G₃ and N₁ as shown in Table 1. Similar trend of decrease in value was observed at other two working widths. Moreover, maximum SHFE (75.10%) was recorded in gear (G₁) followed 65.47% at gear (G₂), whereas relatively low value 54.01% was observed in gear (G₃) and N₁. There was a slight difference in values of SHFE at a same gear at all three engine speeds (N₁, N₂, N₃). It is clear from the findings that engine speed has negligible effect on the SHFE with all combinations of gear and working width. It is due to the fact that at lower tractor gear, forward speed of sugarcane harvester is lesser, therefore, it cuts the stalks more accurately. These findings are similar with the results of Omrani *et al.* (2013) who also determined the performance of a sugarcane harvester and recorded maximum field efficiency at lower tractor gears.

Effect of gear, engine speed and working width on SHMC:

It is evident from Table 2 that maximum sugarcane harvester effective material capacity (SHEMC) was observed for gear G₃ (13.67,13.88 and 14.04 ton/hr) followed by G₂ (10.85,10.71 and 11.27 ton/hr) whereas comparative low values were observed in gear G₁ (7.99,8.25 and 8.58 ton/hr) at three rpms (N₁, N₂ and N₃), respectively.

There was a slight difference in values of SHEMC for same gear at three rpms, while variation was more due to change in gears. SHEMC and gears are directly proportional with each other. SHEMC was maximum (14.4 ton/hr) at G3 for the working width (Kw₃), medium (12.48 ton/hr) with working widths (Kw₂) and minimum (11.33 ton/hr) at working width (Kw₁). As it was observed section 3.3 that maximum SHFE was obtained at G₁, N₁ and Kw₁, hence a comparatively lower SHMC is also acceptable on these configurations. It is

Table 1. Effect of gear, engine speed and working width on SHFE (%).

Gear	SHFE (%)								
	Kw ₁			Kw ₂			Kw ₃		
	N ₁	N ₂	N ₃	N ₁	N ₂	N ₃	N ₁	N ₂	N ₃
G ₁	68.13	67.49	66.66	71.24	70.48	69.61	75.10	74.23	73.11
G ₂	61.50	61.33	60.20	63.30	63.55	62.08	65.47	65.90	64.09
G ₃	54.18	53.60	53.23	55.15	54.56	54.12	56.01	55.30	54.83

Table 2. Effect of gear, engine speed and working width on SHMC (Ton/h).

Gears	SHMC (Ton/h)								
	Kw ₁			Kw ₂			Kw ₃		
	N ₁	N ₂	N ₃	N ₁	N ₂	N ₃	N ₁	N ₂	N ₃
G ₁	6.02	6.24	6.54	6.84	7.08	7.37	7.99	8.25	8.58
G ₂	8.44	8.37	8.84	9.36	9.45	9.85	10.85	10.71	11.27
G ₃	10.99	11.20	11.33	12.14	12.33	12.48	13.67	13.88	14.02

Table 3. Effect of gear, engine speed and working width on TTR.

Gears	TTR								
	Kw ₁			Kw ₂			Kw ₃		
	N ₁	N ₂	N ₃	N ₁	N ₂	N ₃	N ₁	N ₂	N ₃
G ₁	5.44	5.19	4.89	5.00	4.77	4.53	4.51	4.32	4.09
G ₂	3.56	3.49	3.27	3.49	3.21	3.02	2.97	2.89	2.73
G ₃	2.37	2.3	2.25	2.18	2.12	2.08	1.97	1.91	1.88

because efficient working of the sugarcane harvester is more important to reduce the sugarcane losses.

Effect of gear, engine speed and working width on TTR: Data in Table 3 shows that theoretical time required (TTR) per ha (hr) was maximum (5.44 hr) at 1800 rpm at gear (G₁) followed by (5.19 hr) at 1900 rpm whereas comparatively least value (4.89 hr) at 2000 rpm. Comparatively lower values (3.56, 3.49, 3.27 hr) at gear (G₂) and least values (2.37, 2.30 and 2.25 hr) were recorded with gear (G₃) at three rpms (1800, 1900 and 2000), respectively. TTR was found inversely proportional to gear and engine rpm. At same gear, there was slight (TTR) variation found in the experimental data due to small difference in engine rpm. Findings are close to Gopi *et al.* (2018) who recorded the theoretical time required per ha up to 3 hr per acre. Effective time required was greater than theoretical time required due to time losses during turning, unskilled operator and movements with in field at uncultivated area.

Effect of gear, engine speed and working width on TFC: The effect of gear, engine speed and working width on TFC are shown in Figure 7. It was observed that TFC increases as the gear, engine speed and working width are increased. Maximum TFC (0.44 ha/h) was obtained at G₃, N₃ and Kw₃ followed by G₂, N₂ and Kw₂ (0.31 ha/h) and least TFC (0.21 ha/h) was attained at G₁, N₁ and Kw₁. This is due to the fact that at G₃, N₃ and Kw₃, the tractor moves at faster forward speed and allows the harvester to cut the stalks at higher rate along with wider working width. Therefore, greater TFC was achieved at G₃, N₃ and Kw₃ and a direct co-relation between TFC and gear, engine speed and working width were observed. These findings were found to be similar with the work of other researchers (Sharief *et al.*, 2006; Gopi *et al.*, 2018), whom evaluated the performance of tractor operated sugarcane harvester and determined same parametric effect.

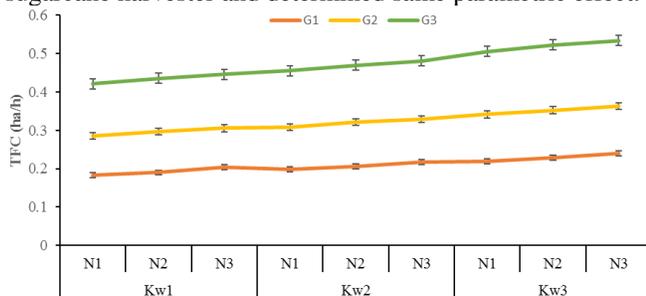


Figure 7. Effect of gear, engine speed and working width on TFC.

Effect of gear, engine speed and working width on ETR: The theoretical time required (ETR) was found to be minimum (2.65 h) at G₃, N₃ and Kw₃ whereas maximum time (6.39 h) was required at G₁, N₁ and Kw₁ to harvest the sugar cane crop per hectare as shown in Figure 8. There was direct co-relation found between ETR and gear, engine speed and working width. As the gear, engine speed and working width were increased, TTR was reduced which ultimately resulted in lesser ETR. Gopi *et al.* (2018) also highlighted the same effect of these parameters on ETR.

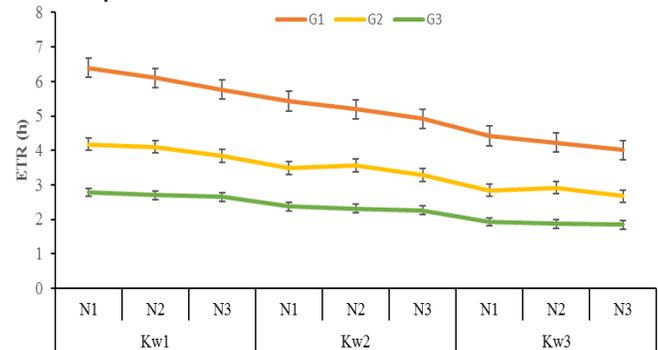


Figure 8. Effect of gear, working width and engine speed on ETR.

Conclusions: The current study was conducted for design and performance evaluate a tractor mounted sugarcane harvester for the advancement of agricultural mechanization in Pakistan. Locally developed whole-stalk sugarcane harvester was tested in sugarcane farms situated in Kot Addu, District Muzaffargarh, Pakistan. The sugarcane harvester was operated at three different gears, engine speeds and working widths to optimize these operational parameters for maximum sugarcane harvester field efficiency (SHFE) and sugarcane harvester material capacity (SHMC). The results of performance evaluation revealed that the harvester showed maximum SHFE (75.10%) efficiency with 12.87 ton/h material capacity at gear G₃, 2000 rpm and 1.02 m working width (Kw₃) during the harvesting of sugarcane variety CP-77400. The developed technology can be support the small scale farming community in a well manner to replace the manual and conventional sugarcane harvesting techniques for reducing sugarcane harvesting losses.

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REFERENCES

- Arboleda, F.M. and R.Q. Duran. 2009. Trash management after green cane harvesting and its effect on productivity and soil respiration. *Proc. Int. Soc. Sugarcane Technol.* 27:1-6.
- Ashfaq, S., A. Ghaffoor, M. Ahmad and Q. Yaqub. 2014. Performance evaluation of sugarcane stripper for trash recovery. *Int. J. Renew. Energy Res.* 4:992-997.
- Bastian, J. and B. Shridar. 2014. Investigation on mechanical properties of sugarcane stalks for the development of a whole cane combine harvester. *Indian J. Appl. Res.* 4:1-3.
- Cock, J.H., C.A. Luna and A. Palma. 2000. The trade-off between total harvestable production and concentration of the economically useful yield component: cane tonnage and sugar content. *Field Crops Res.* 67:257-262.
- Government of Pakistan (GOP). 2018. Economic survey of Pakistan. 2017-2018;
- Gopi, K., J. Srinivas, N. Manikyam, R.H. Nag, D. Maheshwar, B. Anjaneyulu and C.S. Kumar, 2018. Performance evaluation of mechanical and manual harvesting of sugarcane. *Int. J. Current Microbiol. Appl. Sci.* 7:3779-3788.
- Iqbal, M. 2006. Effect of farmer's field school on rice, sugarcane and tomato productivity in District Malakand. M.Sc (Hons) Thesis, Univ. of Agric., Peshawar, Pakistan.
- Khan, F.Z., M. Sagheer, M. Hasan, H. Tahira, F. Hassan, S. Amir and A. Wahid. 2013. Agricultural dynamics in Pakistan: Current issues and solutions. *Russ. J. Agric Socio-Econ. Sci.* 20:186-193.
- Kumar, A., D. Mohin, R. Patel and M. Vaghes. 2002. Development of grain threshers based on ergonomic design criteria. *Appl. Ergon.* 33:503-508.
- Ma, S., M. Kakree, P.A. Scharf and Q. Zang. 2014. Sugarcane harvesting technology: A critical review. *Appl. Engg. Agric.* 30:727-739.
- Mawla, H.A. and B.E. Hemeida. 2015. Sugarcane mechanical harvesting-evaluation of local applications. *J. Soil Sci. Agric. Eng., Mansoura Univ.* 6:129-141.
- Mian, M.N. and Saeeda. 2003. Farm productivity size and tenure and estimation of domestic resource cost for major crops in NWFP. Center for Appl. Econ. Studies, The University of Peshawar, Pakistan; pp.106-116.
- Naseer, A. 2016. Current Status and Key Trends in Agricultural Land Holding and Distribution in Punjab, Pakistan: Implications for Food Security. *J. Agric Res* 4:14-27.
- Niaz, M. 1990. Some policy issue in sugarcane and sugar production. *Pakistan Sugar. J.* 4:1-4.
- Naseer, A., M. Ashfaq, M. Abid, A. Razzaq and S. Hassan. 2016. Current status and key trends in agricultural land holding and distribution in Punjab, Pakistan: Implications for food security. *J. Agric. Stud.* 4:14-27.
- Omrani, A., M.J. Shiekhdavoodi and M. Shomeili. 2013. Determine sugarcane harvester field efficiency using global position system GPS data. *Elixir Agric.* 56:13260-13263.
- Qureshi, M.A. and S. Afghan. 2005. Sugarcane cultivation in Pakistan. *Pakistan Sugar Book 2005*, Shakarganj Sugar Research Institute, Jhang, Pakistan.
- Schmitz, A., P.L. Kennedy and M. Salassi. 2017. Sugarcane yields and production: Florida and Louisiana. In: A. Schmitz, P. Lynn Kennedy, Troy G. Schmitz (eds.), *World Agricultural Resources and Food Security (Frontiers of Economics and Globalization)*. Emerald Publishing Limited, United Kingdom; pp.143-157.
- Sharief, H.M., N.A. Aviara and M.A. Haque. 2006. Performance evaluation of a tractor-operated sugarcane harvester. *Agric. Mech. Asia, Africa, Latin America* 37:79-84.