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RESEARCH ARTICLE

Development of a Tractor Operated Sugarcane Cutter Planter for Mechanisation of Sugarcane Planting in Deep Furrows

A. K. Singh[1] · P. R. Singh[1]

Abstract A tractor operated sugarcane cutter planter was designed and developed at ICAR-Indian Institute of Sugarcane Research, Lucknow (IISR) for planting of sugarcane. It was equipped with deep furrow opener to facilitate furrow method of sugarcane planting. The designed planter consisted of deep furrow opener, sharp edged blades to cut whole cane into 350 mm long pieces as seed material, metering device for application of fertiliser and insecticide, soil covering shovels and tamping roller for pressing soil cover. It was a mounted type equipment rigidly attached with tractor through three-point linkage. Planter was pulled by the tractor and its cutting blades and fertiliser metering rollers were driven by tractor PTO shaft. Planter was field tested at IISR farm in sandy loam soil. At forward speed of 0.5 ms^{-1}, mean overlapping between two successive setts were 72 mm, which was acceptable and well within the desired overlapping range of 50–100 mm for subtropical India. Effective field capacity (output) of the planter was 0.16 ha h^{-1}. Its performance was compared with conventional method of planting. Depth of furrow was 250 mm in case of the planter as against 120 mm in conventional method. Mean soil covering depth over planted setts was 80 mm. Mean bud emergence improved by 3.7 % in case of the planter as compared to conventional planting. Only 25 labour-h ha^{-1} labour is involved for planting with the developed planter which is about 11 times less than the conventional method of planting (280 labour-h ha^{-1}). Cost of planting operation was also saved by about 63 % using the developed planter.

✉ A. K. Singh
aksingh8375@gmail.com

[1] ICAR- Indian Institute of Sugarcane Research, Lucknow, India

Introduction

Sugarcane, an important cash crop, is cultivated in an area of about 5.3 million hectares in India, with an annual production of about 366 million tonnes (Anon 2016). Planting of sugarcane is highly labour and time intensive operation. It involves sett cutting for preparing seed material, furrow opening in field, placing seed-setts in furrows, mixing of fertiliser, application of insecticide and then coverage of setts with soil. These operations are arduous, energy, labour and drudgery intensive. Conventionally, opening of furrow using tractor operated ridgers are only mechanised operation and rest of the sugarcane planting operations are done manually. In addition to this, the bud damage due to excessive handling of seed cane, desiccation of setts and loss of soil moisture could hardly be checked. Conventionally, flat method of planting is practiced in North India. Furrow method of planting in deep furrows facilitates furrow irrigation which is the most efficient surface irrigation method. Furrow method of sugarcane planting also reduces the lodging of sugarcane due to better and deep root growth. It also helps in better ratooning. Efforts were made at ICAR-Indian Institute of Sugarcane Research, Lucknow (IISR) to develop individual machines for cutting setts and for planting them in the soil. Setts were dropped either manually in case of the IISR semi-automatic planter or mechanically with an automatic planter, which had mechanical device to feed straight cane setts. Attempts were made in Pakistan and at IISR, Lucknow to develop a suitable whole cane cutter planter. These planters were for planting of sugarcane in flat

method (Khalid 1987; Sharma et al. 1995; Singh et al. 2011, 2016). In this method after cane planting field is levelled and method of irrigation followed is flood irrigation. In North India, recommended row spacing is 900 mm for autumn planting and 750 mm for spring planting. There was a need for development of a planting device for mechanising sugarcane planting to facilitate furrow planting and have provision for adjustment of row spacing of 750 or 900 mm. In view of the above, a new planting machine was designed, developed and field evaluated at IISR for performing all unit operations involved in sugarcane planting simultaneously in its single pass.

Materials and Methods

Development of the Planter

The planter consisted of furrow opening, sett cutting, fertiliser metering, power transmission, insecticide solution application and soil covering units (Fig. 1). All the units are mounted on rigid and sturdy mild steel (MS) framework. Detailed technical specification of the planter is presented in Table 1.
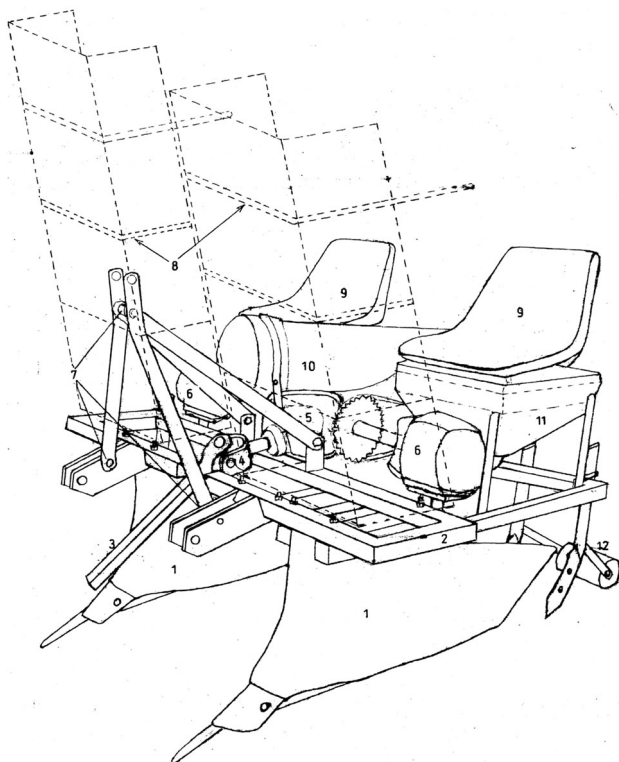
Fig. 1 Schematic view of the sugarcane planter. *1* Furrow opener, *2* Main frame, *3* Telescopic propeller shaft, *4* Universal Joint Cross, *5* Reduction gear box, *6* Bevel gear box, *7* Three-point linkage, *8* Seed cane tray, *9* PVC Seat, *10* Insecticide solution tank, *11* Fertiliser box, *12* Soil covering reversible shovel and tamping roller

Furrow Opening Unit

Two furrow openers, one for each row, were mounted on MS frame. Provisions were made for adjustment of row spacing between two furrow openers either at 750 or 900 mm. Each furrow opener consisted of two mould board plough bottoms (mould board, share bar, share, landside) joined together (Fig. 2). The selected materials were 3 mm thick MS sheet for mould board, 3 mm thick high carbon steel for share, 25.4 mm × 25.4 mm square high carbon steel solid rod for share bar and 12 mm thick MS plate for landside.

Sett Cutting Unit

It consisted of two blades mounted on a rotating disc and a pair of guiding ring for each row. Whole canes are fed up to the depth of furrow bottom manually through the guiding ring to the rotating blades. The diameter of the guiding ring was 100 mm to facilitate feeding of even the bend cane stalks without any damage to the buds. Designed sett cutting blades were curved to provide sharp cut with minimum force (Fig. 3). The selected material for cutting blade was 3 mm thick high carbon steel. A safety cover was provided over the blades for avoiding any accident. Planter was designed to provide the desired overlapping of 50–100 mm of seed-setts at a tractor operating speed of 0.50 ms^{-1}. Seed box was designed to accommodate 100 kg of whole seed cane.

Fertiliser Metering Unit

Fertiliser metering unit consisted of MS fertiliser box, PVC casings, PVC edge cell circular rotors and PVC pipe to guide the metered fertiliser to the desired location in furrow bottom. Rate of fertiliser was regulated by adjusting the clearance gap between the casing and rotor within allowable range. For further variation of rate of fertiliser different size rotors could be selected. The capacity of each fertiliser box was 20 kg.

Power Transmission Unit

Sett cutting and fertiliser metering units were powered through tractor power take off (PTO) shaft (Fig. 4). Tractor PTO power was transmitted to sett cutting blades through universal joint crosses, propeller shaft, reduction gear box and bevel gear box. Power from output shaft of reduction gear box was transmitted to fertiliser metering rollers through chain and sprockets.

Insecticide Solution Application Unit

PVC pipe of 200 mm diameter and 1150 mm length was attached with the main frame for insecticide solution. Liquid solution was applied over setts in furrow through

Table 1 Technical specification of the developed planter

S. no.	Particular	Detail
1.	Framework	MS square pipe 50 mm × 50 mm × 5 mm
	Length	1500 mm
	Width	1210 mm
2.	Furrow opener	Two mould board plough bottoms (mould board, share bar, share, landside) joined together
	Mould board	Two
	Material	MS sheet
	Thickness	3 mm
	Share bar	One
	Material	High carbon steel square rod
	Size	620 mm long, 25.4 mm square rod
	Share	Two
	Material	High carbon steel
	Thickness	3 mm
	Size	Width 90 mm, Height 160 mm
	Land side	One
	Material	Mild steel plate
	Thickness	12 mm
	Size	Length 460 mm, height 520 mm
3.	Sett cutting unit	
	Guiding ring material	Mild steel
	Guiding ring diameter	100 mm
	Gap between two guiding ring for movement of rotary sett cutting blades	5 mm
	Material of cutting blade	High carbon steel
	Thickness of cutting blade	3 mm
	Shape and size of cutting blade	Curved, length 135 mm, width 30 mm
4.	Seed Tray	
	Material	1 mm thick MS sheet and 20 mm MS square pipe
	Dimension	Height 1370 mm, width 540 mm, depth 360 mm
	Capacity	100 kg of whole seed cane stalks
5.	Fertiliser metering unit	
	Fertiliser box	
	Material	Mild steel sheet
	Thickness of sheet	1 mm
	Capacity of box	20 kg
	Metering mechanism	
	Type	PVC casing and edge cell pvc rotors
	Width of rotor	25 mm
	Diameter of rotor	90 mm
	Number of cells on each rotor	10
6.	Power transmission	
	Reduction gear box speed reduction	15:1
	Bevel gear box speed ratio	1:1.8
	Speed reduction from tractor PTO to cutting blades	8.3:1
	Speed reduction from tractor PTO to fertiliser metering rollers	4.15:1

Table 1 continued

S. no.	Particular	Detail
7.	Insecticide solution application	Flows under gravity regulated by gate valve
	Type of container	PVC cylindrical pipe (200 mm dia, 1150 mm length)
	Volume of container	35 l
8.	Soil covering	Reversible shovel attached with adjustable tyne at both ends of furrow for soil covering and rotary mild steel rollers for compressing soil cover
9.	Overall dimension of planter	
	Length	1900 mm
	Width	1500 mm
	Height	2000 mm

Fig. 2 Schematic view of furrow opener. *1* Share bar, *2* Share, *3* Mould board, *4* Landside, *5* Wing of mould board
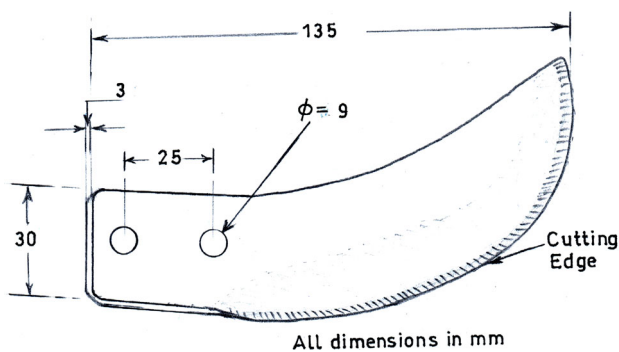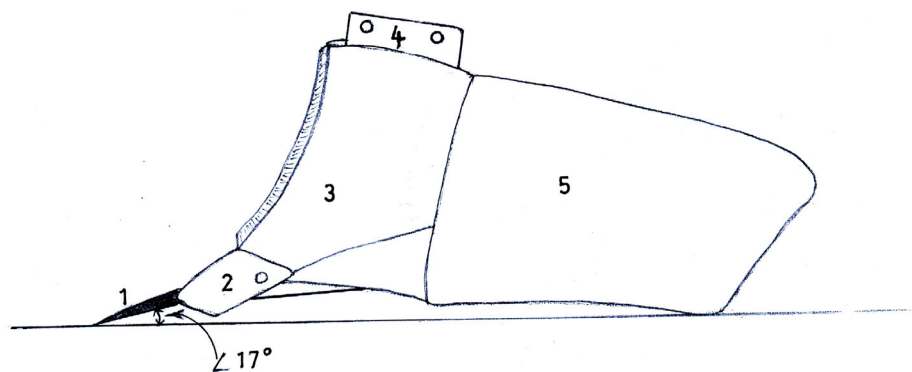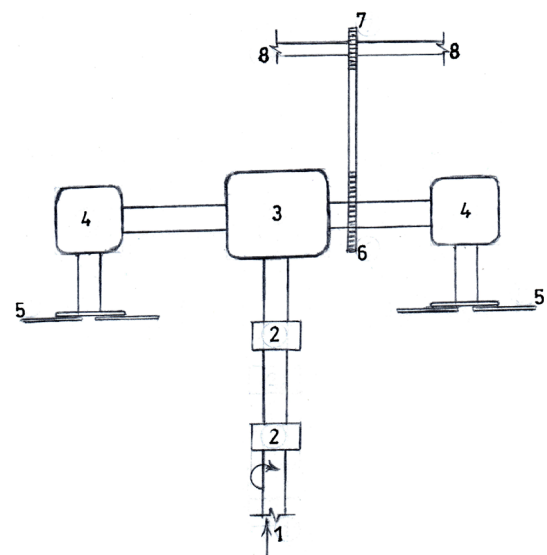

Fig. 3 Schematic view of sett cutting blade

PVC pipe under gravity force. A gate valve was also provided to regulate the chemical solution application. An arrangement was made to distribute the solution in five peaks before falling over the setts. The capacity of the insecticide solution storing pipe was 35 l.

Sett Covering Unit

It consisted of covering tynes with reversible shovels and a tamping roller for each row on a 'U' frame. While sett

Fig. 4 Schematic view of power transmission from tractor PTO to sett cutting and fertiliser metering rollers. *1* Power from PTO shaft, *2* Universal Joint Cross, *3* Reduction gear box (15:1), *4* Bevel gear box (1:1.8), *5* Cutting blade, *6* Driving chain-sprocket (32 T), *7* Driven chain-sprocket (16 T), *8* Fertiliser metering roller

Fig. 5 Sugarcane planter in field operation

covering was provided with the help of shovels, the tamping roller was used to press the blanket of soil lightly for conserving the soil moisture.

The planter was fabricated in the workshop of Agricultural Engineering Division of IISR. In addition to the above sub units, the equipment was provided with two seats for feeding the seed canes. All the moving parts were guarded to avoid any accident.

Field Evaluation of the Planter

Performance of the planter was evaluated in the field of IISR located at 26°56′N, 80°52′E and 111 m above sea level with semi arid subtropical climate having dry hot summer and cold winter. The soil of the field was sandy loam (14 % clay, 26 % silt and 60 % sand) of Indo-Gangetic alluvial origin, pH 7.6, very deep (>2 m), well drained, flat and classified as non-calcareous mixed *hyper thermic udic ustochrept*. Performance trials of the planter were conducted in 10 ha fields during 2014–2015 and 2015–2016 (Fig. 5). Crop parameters like variety, average length and weight of whole seed cane stalks, field parameters like length and width of field were recorded. Performance of the planter was compared with conventional method of planting i.e. furrow opening by tractor operated ridger and rest of the operations including sett cutting manually. A 30 kW tractor was used for operating the planter as well as conventional ridger.

Performance Parameters

Planter performance parameters like sett length, number of setts cut and dropped per m length of furrow, depth of furrow, depth of soil cover, wheel slippage of tractor were recorded. Time utilisation study (Singh and Mani 2006) was conducted for recording the time utilised in different activities of sugarcane planting i.e. time lost in turning of planter

at head land, filling of seed, fertiliser, insecticide solution and miscellaneous activities. Following mathematical relationships were used for analysing the performance results;

Forward speed of tractor (s), m s^{-1}
$$= \text{Distance travelled, m/time taken to travel the distance, s,}$$

Effective width of coverage (w), m
$$= \text{Number of rows covered} * \text{row spacing,}$$

Theoretical field capacity (tfc), ha h^{-1}
$$= (s*w)*(60*60)/10,000,$$

Effective field capacity (efc), ha h^{-1} = tfc $*(1-tl)$,

Fuel consumption, l ha^{-1} = fuel consumption, l h^{-1}/efc,

where tl percentage of total planter operation time lost in turning, filling of seed, fertiliser and insecticide solution and miscellaneous time loss, decimal.

Cost of Operation

Total cost of planting operation was analysed by adding the fixed and variable cost of the tractor and planter. The parameters used in the analysis of cost components were either based on the actual performance data of the planter or as Bureau of Indian Standards (Anon 1979) for estimation of cost of farm machinery operations. Values of different parameters used during cost analysis are presented in Table 2.

Results and Discussion

Performance of the Planter

Once the prototype was fabricated and its main components fully operational, it was rigorously evaluated at

Table 2 Values of different parameters used during cost analysis

S. no.	Parameter	Value
1.	Purchase price of tractor, ₹	400,000
2.	Purchase price of the planter, ₹	100,000
3.	Purchase price of conventional ridger, ₹	20,000
4.	Salvage value factor for agriculture equipments, decimal	0.05
5.	Economic life of tractor, y	10
6.	Economic life of conventional ridger and the planter, y	6
7.	Working hours of tractor per year, h	1000
8.	Working hours of conventional ridger and the planter per year, h	300
9.	Working hours per day, h	8
10.	Rate of interest on investment, decimal	0.12
11.	Insurance factor (% of average purchase price), decimal	0.02
12.	Shelter charge factor (% of average purchase price), decimal	0.015
13.	R & M factor of tractor (% of purchase price/1000 h), decimal	10
14.	R & M factor of planter and ridger (% of purchase price/300 h), decimal	10
15.	Average fuel consumption of tractor for operating planter, l ha^{-1}	15.0
16.	Average fuel consumption of tractor for operating ridger, l ha^{-1}	6.67
17.	Average oil consumption of tractor, l ha^{-1} :	3.0 % of fuel consumption
18.	Price of diesel fuel, ₹ l^{-1}	55
19.	Price of oil, ₹ l^{-1}	265
20.	Wages of tractor driver, ₹ man-d^{-1}	250
21.	Wages of labour, ₹ man-d^{-1}	200
22.	Number of labours needed to work with the planter	4
23.	Effective field capacity of planter, ha h^{-1}	0.16
24.	Effective field capacity of ridger, ha h^{-1}	0.60
25.	Labour required for manual sett cutting and application of inputs like seed-setts, fertiliser, insecticide solution in case of conventional planting, labour-h ha^{-1}	280

the workshop. A pre-field test performance was carried out, simulating its probable behaviour in the field for various operational settings. Field testing of the planter was conducted in the sandy loam soil of IISR farm at row spacing of 750 mm. Field performance results are presented in Table 3. Mean value of cut seed-sett length was 363 mm. At forward speed of 0.5 ms^{-1}, mean overlapping between two successive setts was 72 mm, which was well acceptable and within the desired overlapping range of 50–100 mm for subtropical India. When forward speed of the tractor increased speed ratio of sett cutting blade and tractor decreased resulting in decreased overlapping between planted setts. Mean tractor wheel slippage at load was 5.2 %. With the increase in tractor wheel slippage overlapping between planted setts increased due to increased speed ratio of sett cutting blade and tractor.

Output of the Planter

The mean theoretical field capacity and effective field capacity of the planter was 0.27 and 0.16 ha h^{-1}, respectively. The effective field capacity of the planter was low because of low forward speed (0.50 ms^{-1}) of the tractor for maintaining the desired overlapping of setts and large time lost in refilling of seed cane (6000 kg ha^{-1}), fertiliser (>300 kg ha^{-1}), insecticide solution (800 l ha^{-1}), turning of the planter at the headland, minor breakdown, operator personal time, etc. The total time lost in the above was 41 % of the total operating time of the planter. The effective field capacity of the planter (output) varied with the field and crop parameters. For less field length, number of headland turning increased, resulting in increased time lost in turning. Similarly, for small seed cane length seed tray accommodate less seed resulting in increased time lost in refilling of seed.

Table 3 Field performance of the planter

Crop parameters	Values
Variety	Co 0239, CoPk 05191, CoLk 94184
Mean length, mm	2200
Mean diameter, mm	22
Mean cane weight, g	774
Field parameters	
Field size	182 m × 55 m
Type of soil	Sandy loam
Moisture content, % d.b.	13
Performance parameters	
Mean length of setts, mm	363
Mean overlapping of setts, mm	72
Mean percentage falling in 0–100 mm overlapping range	85 %
Number of filling of seed box per ha	36
Number of filling of fertiliser box per ha	8
Number of filling of insecticide solution per ha	12
Mean percentage of tractor wheel slippage at load, %	5.2
Forward speed, ms^{-1}	0.5
Effective width of coverage, m	1.5
Percentage of total planting time lost in filling of seed, fertiliser and insecticide solution and miscellaneous activities (tl), decimal	0.41
Theoretical field capacity, ha h^{-1}	0.27
Effective field capacity, ha h^{-1}	0.16
Field efficiency, %	59
Cost of operation of sugarcane planting, ₹ ha^{-1}	2740

Comparative Performance with Conventional Method of Planting

Performance of the planter was compared with conventional planting. The results are presented in Table 4. Planter performed all the unit operations involved in sugarcane planting including sett cutting simultaneously in single pass of the machine. In conventional system, tractor operated ridger is used for furrow opening and rest of the operations are performed manually including sett cutting. Bud damage was 1.5 % more in the planter due to blind cutting mechanism. However, bud emergence improved by 3.7 % in case of the planter as compared to conventional planting because of saving of soil as well as seed moisture due to simultaneous operations of sett cutting, furrow opening and soil covering with the planter. Depth of

Table 4 Comparative performance of planter with conventional planting

Particulars	Conventional planting	Developed planter
Seed pre-requisite	Separately cut setts	Whole cane stalks
Source of mechanical power	Tractor 30 kW	Tractor 30 kW
Tractor PTO power	No	Yes
No. of rows in one pass	2	2
Mean depth of furrow bottom, mm	120	250
Mean depth of soil cover, mm	80	80
Minimum labour required to work with the machine (excluding tractor driver)	–	4
Mean length of setts, mm	353	363
No. of setts per m row length	3.35	3.33
Mean number of buds per m row length	10.0	10.1
Mean percentage of bud damage due to cut on the nodes, %	1.8	3.3
Labour requirement for planting, Man-h ha^{-1}	280	25
Saving of labour in planting by the planter, Man-h ha^{-1}	–	255 (91 %)
Cost of operation of sugarcane planting, ₹ ha^{-1} (including sett cutting)	7380	2740
Saving in cost of planting operation in case of planter, ₹ ha^{-1}	–	4640 (62.8 %)
Mean bud emergence (germination) after 45 days of planting, %	34.4	38.1

planting was 250 mm for the planter as against 120 mm in conventional flat method. Depth of furrow intact after soil covering was 120 mm (250 mm if height of ridge, which is formed due to piling of soil coming out during furrow opening, is also added) in the field planted by the planter which facilitated furrow method of irrigation. Furrow method of irrigation is an improvement over the conventional flat method in terms of increased water use efficiency and saving of irrigation water.

Economics

Cost of planting operation per ha was ₹ 2740 in case of the sugarcane planter as against ₹ 7380 in conventional planting. Four labours are required for smooth operation of the planter, two for feeding seed canes through guiding rings for sett cutting and remaining two to fill the planting inputs like seed, fertiliser and insecticide solution. Only 25 labour-h ha^{-1} was required for planting using the developed sugarcane planter (planter effective field capacity 0.16 ha h^{-1}) which is about 11 times less than the labour requirement in conventional planting (280 labour-h ha^{-1}). It is imperative from the above that there was a

saving of about 63 % in cost of operation and 91 % in labour requirement in case of the developed planter. In addition to that planter reduces the human drudgery involved in sugarcane planting operations.

Conclusions

A new multifunctional planter was designed and developed for mechanising furrow method of sugarcane planting. During field trials, its mean effective field capacity (output) was 0.16 ha h^{-1} at a forward speed of 0.5 ms^{-1} with average overlapping of 72 mm between two successive planted setts. Depth of planting was 250 mm as against the 120 mm in conventional method. Only 25 labour-h ha^{-1} labour is involved for planting with sugarcane planter which is about 11 times less than the conventional method of planting (280 labour-h ha^{-1}). Cost of planting operation reduced by about 63 % and mean bud emergence improved by 3.7 % in case of the developed planter as compared to conventional planting.

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