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RESEARCH ARTICLE

Development of Sugarcane-cum-Potato Planter for Mechanisation of Simultaneous Planting of Sugarcane and Potato

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Abstract Sugarcane and potato are the two major cash crops cultivated in the Indo-Gangetic plains of South Asia. Growing potato as intercrop with sugarcane has a synergistic effect on sugarcane, resulting in increased economic returns to farmers. In order to mechanise simultaneous planting of sugarcane and potato for intercropping, a new planting machinery named as sugarcane-cum-potato planter was designed and developed at ICAR-Indian Institute of Sugarcane Research, Lucknow, India. It was equipped with furrowers for opening of furrow and ridge making in between furrows, sett cutting unit for cane planting, potato seed tuber metering mechanism for potato planting, covering unit to cover planted sugarcane setts and potato and insecticide application unit. The designed equipment planted two rows of sugarcane in furrows and two rows of potato on ridges simultaneously in single pass. Picking and dropping of seed potato were automatic, whereas sugarcane seed stalk feeding for sett cutting was manual. Field testing of the developed planter was conducted at IISR farm in sandy loam soil. The effective field capacity of planter was 0.127 ha h^{-1}. Average soil cover on sugarcane setts was 45 mm. Average depth of seed potato tuber placement on the ridges was 40 mm, and average tuber to tuber spacing was 192 mm. Developed machine-planted sugarcane at furrow spacing of 750 mm with average overlapping of 68 mm between the setts. The cost of planting operation with developed equipment was rupees 3160 ha^{-1} as against rupees 13,600 ha^{-1} in conventional planting. Saving in cost of planting operation was about 76% and labour about 90% with the developed planter as compared to conventional planting. Irrigation water use efficiency, yield attributes and total yield increased significantly in potato–sugarcane intercropping as compared to relay cropping of potato and sugarcane. Benefit/cost ratio in mechanised intercropping of potato and sugarcane with the developed planter was 2.57:1 followed by conventional manual intercropping (2.26:1) and manual potato–sugarcane relay cropping (1.84:1).

Keywords Mechanisation · Sugarcane · Potato · Sugarcane-cum-potato planter · Simultaneous planting · Intercropping

Introduction

Sugarcane and potato are the two important cash crops of India. Sugarcane contributes 1.9% to GDP of India (Mandal and Maji 2008), whereas potato contributes 2.9% to agricultural GDP of India (Anon 2016). Availability of land and water for cultivation is limited; therefore, it is important to maximise the utilisation efficiency of these scarce resources. Sugarcane plant canopy does not close during first 3–4 months after planting. During this period, the interrow space remains unoccupied and the young sugarcane plants do not require much light, water and land. Hence, there is a great scope to grow short duration crop in the available unoccupied space between sugarcane rows. In India, intercropping in sugarcane is done in 6–8% area. Intercropping of potato with sugarcane can be used as a means to increase land and water utilisation efficiency vis-à-vis income of the farmer. About 80% of the potato produced in Mauritius comes from an intercrop with sugarcane (Cadersa et al. 2001). It has been observed that due to

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resource sharing and synergistic effect of sugarcane and potato when grown together, the productivity of these two crops is increased with higher profitability. Autumn-planted sugarcane is most suitable for growing intercrops due to its slow growth because of low temperature during November to February, and conditions are favourable for short duration crops. Sugarcane planted under autumn season gives about 20–25% higher cane yield and also 0.5 unit higher sugar recovery as compared to spring-planted cane. It was found that cane and sugar yields of intercropped cane treatments were statistically at par as compared to monoculture cane (Govinden 1990) rather it enhanced sugarcane yield (Imam et al. 1990). Potato is planted in every inter row of sugarcane and is harvested before the cane canopy closes. On the basis of total edible energy production, intercropping of potato is estimated to be more productive than sole cane by 22%. Land equivalent ratio of the system is estimated to be more than 1.17. Sugarcane farmers derived as much as 63% more net returns from intercropping sugarcane with potato than from sole cropping of sugarcane (Govinden 1990).

Manual planting of sugarcane and potato is highly labour intensive, tedious and time-consuming operation. To ensure good crop stand, entire planting operation has to be completed in a very short time period between withdrawal of monsoon and start of intense cold winter season. To plant one hectare area with sugarcane and potato crops, it requires 350 man-hour (Yadav et al. 2003) and 208 man-hour (Singh and Singh 2006), respectively. Availability of labour at right time at reasonable rates in desired numbers is another challenge farmers are facing. Planting season of autumn sugarcane and potato coincides with harvesting season of paddy and sowing of wheat and other *rabi* crops which further worsen the labour problem. Use of machinery helps in labour saving and timeliness of operations, reduces drudgery, helps in improving quality of work, reduces cost of operation and ensures effective utilisation of resources. This leads to enhanced production and profit. Therefore, mechanised planting is desired to ensure timely planting at reasonable cost.

Individual machines are available to plant sugarcane and potato as sole crop (Singh et al. 2011; Singh and Singh 2016). These planters cannot be used for planting potato as intercrop with sugarcane. Therefore, a need was felt to develop a planter which can simultaneously plant potato as intercrop with sugarcane. In view of the above, a tractor-operated machine named as sugarcane-cum-potato planter was designed and developed at ICAR-Indian Institute of Sugarcane Research, Lucknow, India (IISR) for mechanisation of simultaneous planting of potato along with sugarcane in a single pass of the machine. It was field tested in sandy loam soil at IISR farm.

Materials and Methods

Description of the Equipment

Developed sugarcane-cum-potato planter consisted of different units viz. main frame, furrow opening and ridge making, sett cutting, seed potato picking and metering, power transmission, liquid insecticide application and soil covering (Fig. 1). It performed planting of sugarcane in furrows and potato on the ridges. The entire equipment was fabricated on a sturdy rectangular frame of mild steel square section pipe. Weight of the equipment was 530 kg. Detailed technical specification of planter is presented in Table 1. Details of different units and components are presented below:

Main Frame

Main frame of the equipment was fabricated with 50-mm square pipe with wall thickness of 5 mm. The size of rectangular main frame was 1500 mm × 1550 mm. Main frame was provided with three-point hitching system to hitch the equipment with tractor. On the main frame, all components of the equipment viz. seed cane trough, liquid pesticide tank along with application mechanism, sett cutting and dispensing mechanism, furrow openers for

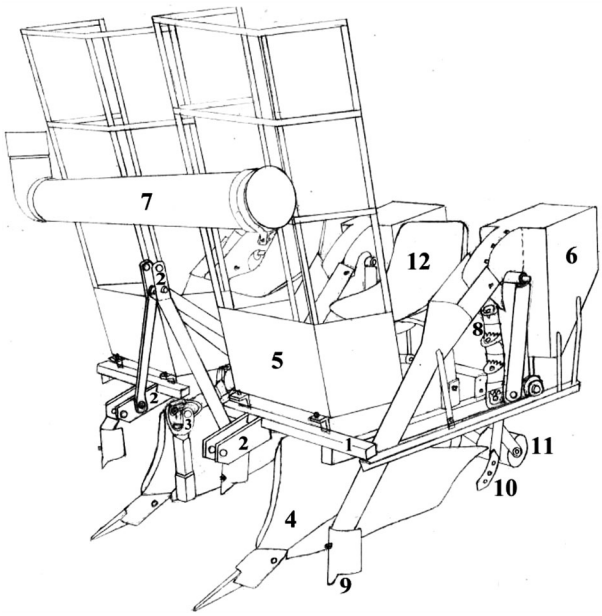

Fig. 1 Schematic view of the sugarcane-cum-potato planter. *1* main frame, *2* three-point linkage, *3* universal joint cross, *4* furrow opener, *5* seed cane tray, *6* seed potato hopper, *7* insecticide solution PVC container, *8* seed potato metering cups, *9* miniature furrower for potato planting, *10* reversible shovels for soil covering over planted sugarcane setts, *11* tamping roller for pressing the soil cover, *12* PVC Seat

Table 1 Technical specification of the sugarcane-cum-potato planter

S. no.	Particular	Detail
1.	Framework material	50 mm MS square pipe having 5 mm wall thickness
	Length	1550 mm
	Width	1500 mm
2.	Furrow openers for sugarcane	
	Number of furrow openers	Two
	Type of furrow openers	Two way mould board plough (two opposite direction mould boards having common share bar joined together)
	Mould board material	MS sheet of 3 mm thickness
	Share bar	High carbon steel 620 mm long, 25.4 mm square rod
	Share	High carbon steel sheet of 3 mm thickness having 90 mm width and 160 mm height
	Land side	12-mm-thick MS plate having 460 mm length and 520 mm height
	Furrow openers for potato	
	Number of furrow openers	Three
	Type of furrow openers	Reversible shovel type
	Material of furrow openers	Mild steel body with high carbon steel cutting edge
3.	Sett cutting unit	
	Guiding rings	100 mm diameter fabricated from mild steel
	Gap between two guiding rings	5 mm
	Cutting blades	3-mm-thick high carbon steel curved blades; 135 mm long and 30 mm width
4.	Sugarcane 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.	Seed potato metering unit	Endless chain and cup type
	Cup material, shape and size	Conical PVC cups of 40 mm diameter and 10 mm depth
	Cup to cup spacing on chain	105 mm
6.	Seed potato hopper	Trapezoidal in shape having slanting bottom and vertical side walls made up of 3-mm-thick MS sheet
	Top dimensions	400 mm × 300 mm (L × W)
	Bottom dimensions	15 mm × 30 mm (L × W)
	Depth	500 mm
	Capacity of hopper	20 kg
7.	Power transmission	
	Reduction gear box speed reduction ratio	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
	Speed reduction from tractor PTO to potato metering unit	26.4:1
8.	Insecticide solution application	Flows under gravity regulated by gate valve
	Type of container	PVC cylindrical tank (200 mm diameter, 1150 mm length)
	Volume of container	35 l
9.	Soil covering and compacting	Reversible shovel attached with adjustable tyne at both ends of furrow for soil covering and rotary mild steel floating rollers for compressing soil cover
10.	Overall dimension of planter	
	Length	1550 mm
	Width	1700 mm
	Height	2000 mm
11.	Weight	530 kg

sugarcane planting, seed potato trough, seed potato metering and dropping mechanism, miniature furrow openers on the ridges for potato planting, sugarcane sett and seed potato covering unit were fitted. The main frame was also fitted with two seats for sitting labours feeding the seed cane to sett cutting blades.

Furrow Opener

The furrow opener designed by Singh and Singh (2016) was used for this planter. Two furrow openers were provided for opening of furrows for planting of sugarcane. Each furrow opener consisted of two mould board plough bottoms (mould board, share bar, share, land side) joined together. Materials were 3-mm-thick MS sheet for mould board, 3-mm-thick high carbon steel sheet for share, 25 mm × 25 mm square high carbon steel solid rod for share bar and 12-mm-thick MS plate for land side. It opened a narrow but deep furrow to accommodate sugarcane setts, at the same time it formed a ridge between two furrows for planting of potato. One miniature furrow opener was provided in front of every seed potato conveying chute for opening shallow furrow on the ridge to plant seed potato.

Sugarcane Seed Sett Cutting Mechanism

Individual sett cutting units were provided for planting of each row of sugarcane. Two curved sharp blades of 3 mm thickness made up of high carbon steel were mounted on a disc to ensure clean cut. These blades rotated in the horizontal plane within guiding rings. Guiding rings of 100 mm diameter were provided to facilitate the feeding of even bent canes without any possible bud damage. The sett cutting mechanism derived power from tractor PTO. The sett cutting mechanism was so designed that at the tractor forward speed of 0.50 m s^{-1}, the setts' overlapping ranged 50–100 mm. The capacity of seed cane box was 100 kg.

Seed Potato Picking and Metering Mechanism

It consisted of conical (40 mm diameter and 10 mm deep) plastic seed potato picking and holding cups mounted at a spacing of 100 mm on vertical endless chain. One side of this cup-fitted chain moved in upward direction inside the seed potato hopper and picked up the seed potato (Fig. 2). While going down, seed potato in the cup was dropped into the conveying chute for planting on the ridges. Seed potato metering mechanism was so designed that potato seed (cut or whole) spacing of 180–200 mm was maintained without any gap. The side walls of the seed potato hopper were vertical, whereas the bottom was slanting having an angle of 40° with horizontal which was greater than the angle of repose of a heap of potatoes (33°25′ for Kufri khyati and 35°15′ for Kufri fry sona). The capacity of seed potato hopper was 20 kg.

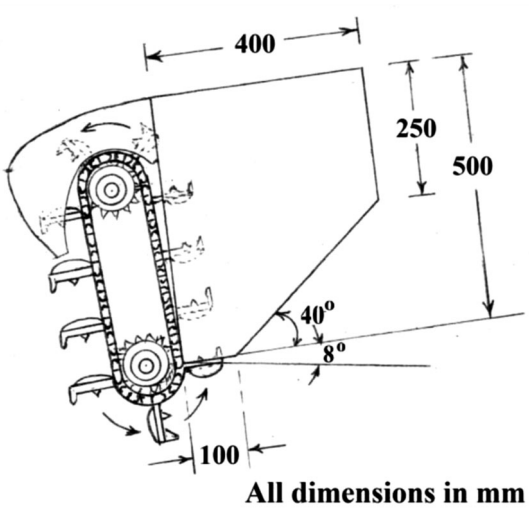

Fig. 2 Schematic view of potato seed hopper and metering mechanism

Insecticide Solution Application Unit

Insecticide solution tank was fabricated with 200-mm-diameter PVC pipe. Length of the tank was kept at 1150 mm. This tank was horizontally mounted on the main frame of the machine to ensure least variation in the flow rate due to liquid head difference. The flow of insecticide was regulated with a valve, and it was trickled over the setts. The capacity of insecticide storage tank was 35 l.

Sugarcane Sett and Seed Potato Covering Unit

Seed potatoes were covered from the soil thrown by the mould boards of furrow openers. Sett covering unit for each furrow consisted of two covering tines fitted with reversible shovels and a floating tamping roller fitted behind the shovels. Covering tines scraped a small amount of soil from the furrow walls and dropped it on setts and tamping roller pressed the soil gently for better sett–soil contact and soil moisture conservation.

Power Transmission Unit

Rotary power from tractor PTO was transmitted through universal joint and flexible propeller shaft to reduction gear box fitted on the main frame. From reduction gear box, power was transmitted to sett cutting blades through bevel gear box, and to seed potato and fertiliser metering units through chain and sprockets (Fig. 3).

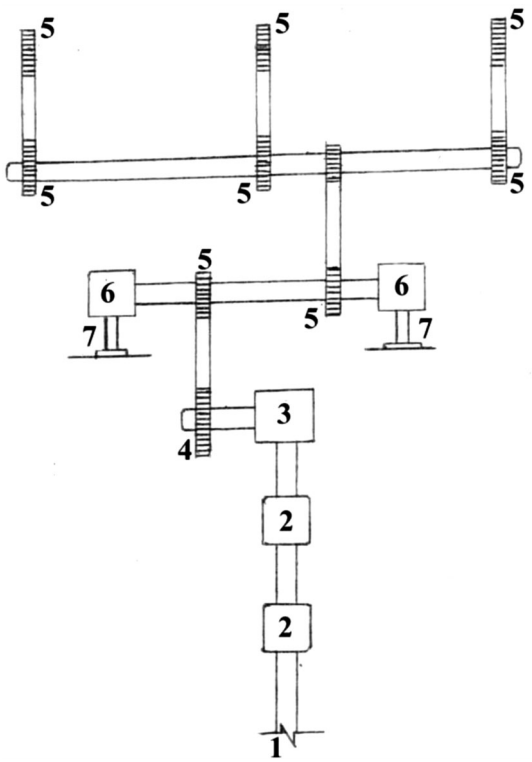

Fig. 3 Schematic view of power transmission mechanism of developed sugarcane-cum-potato planter. *1* Power from PTO shaft, *2* universal joint cross, *3* reduction gear box (15:1), *4* chain-sprocket (24 T), *5* chain-sprockets (16 T), *6* bevel gear box (1:1.8), *7* power to sugarcane sett cutting blades

Field Performance Evaluation

Field performance of the developed planter (Fig. 4) was evaluated at experimental farm of IISR located at 26°56′N, 80°52′E and 111 m above sea level. Soil of the field was sandy loam (58% sand, 27% silt and 15% clay) with 1.4 Mg m^{-3} bulk density. Crop parameters like variety, average length and weight of whole seed cane stalks, average seed potato tuber, field parameters like length and width of field were recorded. Field performance evaluation was conducted by following the RNAM Test Codes (Anon 1983). Planter performance parameters like sett length, number of setts cut and dropped per unit length of furrow, depth of furrow, depth of soil cover, height of ridge, number of seed potatoes dropped per unit length of ridge and wheel slippage of tractor were recorded. Performance of the planter was compared with manual planting as intercrop and manual planting as relay crop. A 30 kW tractor was used for operating the planter in first low gear at 1100 engine rpm. At this combination of gear and engine rpm, the forward speed of tractor was 0.5 m s^{-1}.

Fig. 4 Developed sugarcane-cum-potato planter in field operation

Calibration of Metering Mechanisms

Calibration of sugarcane sett cutting, seed potato metering and fertiliser application rate was done by mounting the planter on tractor by three-point linkage system, and the planter was powered by tractor PTO. Tractor was operated in first low gear at 1100 engine rpm for a distance of 50 m. Total number of setts cut and seed potato tubers dropped were collected and counted. This procedure was replicated three times, and average was calculated.

Bud Damage Count

In order to determine bud damage, 100 setts were selected randomly and number of buds damaged was recorded. Three replications were made, and average was calculated.

Length of Sugarcane Setts

One hundred setts were randomly taken, and length of each sett was measured. This observation was repeated three times to determine average length of sett.

Overlapping Between Sugarcane Setts

Procedure suggested by Dafa'allah and Humiedia (1991) was followed to determine overlap. For this purpose, planter was run in the field for 50 m length. All setts dropped were collected, and number of setts and length of each sett were measured. The machine was operated at a forward speed of 0.5 m s^{-1}. Overlap was computed from the following relationship:

$$\text{Average overlap} = (\text{Total length of setts} - \text{Distance}) / \text{Total number of setts}$$

Theoretical Field Capacity

Theoretical field capacity of planter was calculated from speed of operation and theoretical width of the planter.

$$\text{Theoretical field capacity, ha h}^{-1} = \text{Theoritical width of implement, m} \times \text{speed, m s}^{-1} \times \frac{9}{25}$$

Effective Field Capacity

Plot of 0.2 ha area having length 50 m and width of 40 m was selected, and the time taken to cover this area was noted. Time taken for turning, seed hopper filling, insecticide tank filling and other operational obstructions was also recorded.

Field Efficiency

Field efficiency was computed using following formula;

$$\text{Field efficiency} = \left(\text{Effective field capacity, ha h}^{-1} / \text{Theoretical field capacity, ha h}^{-1}\right) \times 100$$

Cost of Planting Operation

Cost of planting operation was computed by adding the fixed and variable cost of tractor as well planter as per the procedure followed by Singh and Singh (2016).

Working of the Equipment

The designed equipment was provided with three seed potato metering units and two sett cutting units. Two seed potato metering units were provided on the outer side of the machine and one in between sett cutting units. While onward travel, the machine-planted seed potatoes on left and central ridges and sugarcane setts in both the furrows. But while on return, it planted seed potato on the central and right ridges and sugarcane setts in both the furrows. For activating and deactivating the outer side seed potato metering units, dog clutches were provided. The person sitting on the seat for feeding sugarcane seed can operate the dog clutch through lever. Picking and dropping of seed potato were automatic, while seed cane was fed to the cutting unit manually.

Crop Performance Evaluation

Crop performance experiment in randomised block design with three treatments and five replications was conducted at experimental farm of the IISR. The plot size was 5.25 m × 10 m, accommodating six rows of sugarcane and seven rows of potato. The results were analysed statistically using INDOSTAT software. Soil texture of the field was sandy loam with 229.31, 29.14 and 198.76 kg ha^{-1} available N, P_2O_5 and K_2O, respectively. Three modes of planting, viz., planting with developed sugarcane-cum-potato planter (mechanised intercropping); manual planting of potato as intercrop with sugarcane (manual intercropping) and manual planting of potato and manual planting of sugarcane after potato harvesting (manual relay cropping) were compared. Recommended dose of fertiliser 150 kg N, 60 kg P, 60 kg K for sugarcane and 120 kg N, 80 kg P, 80 kg K for potato was applied. Half dose of nitrogen and full dose of phosphorous and potassium of both the crops were applied as basal dose at planting. Remaining nitrogen of potato was applied at two earthing up operations (after 30 and 60 days of planting), and remaining nitrogen of sugarcane was applied in two splits at tillering stages. Both the crops were irrigated at 1.00 IW/CPE ratio. Amount of irrigation water applied from planting to harvesting of potato was 240 mm, and from harvesting of potato to harvesting of sugarcane was 960 mm. Sugarcane variety CoPk 05191 and potato varieties Kufri Khyati and Kufri Fry Sona were selected for field experiment. The shape factor as defined by Buitenwerf et al. (2006) based on all three dimensions of potato tuber for Kufri Khyati and Kufri Fry Sona was 127 and 235, respectively. Based on the shape factor, Kufri Khyati is termed as round and Kufri Fry Sona as oval (Anon. 1981). The average weight of seed potato tubers was 47 g. Large size tubers were cut in pieces. Recommended agronomical practices were followed to raise the crop. Water metre was used to volumetrically measure the irrigation water applied during each irrigation. Yield, irrigation water use efficiency (IWUE) and benefit/cost ratio were worked out in all the planting methods. For analysing the benefit/cost ratio, the benefit was the total returns from sale of potato as well as sugarcane produce, whereas cost was the total cost of cultivation of sugarcane and potato. Parameters used for calculating the cost of cultivation were cost involved in seed bed preparation, planting, interculturing, earthing up, plant protection measures, irrigation, harvesting and also cost of inputs like seed, fertilisers, agro-chemicals, etc.

The potato yield was expressed in terms of sugarcane yield for better comparison and understanding of the impact of potato intercropping on profitability and water productivity. For this, potato yield was multiplied with prevailing market rate of potato (rupees 8 kg^{-1}). The value so arrived at was divided by prevailing market rate of sugarcane (rupees 2.80 kg^{-1}). The value so arrived at was the sugarcane equivalent potato yield.

Results and Discussion

Performance of the Planter

Prior to actual field testing of the developed equipment, it was calibrated in the field for different metering mechanisms and necessary adjustments were made. Field testing of the planter was conducted in sandy loam soil at IISR farm. It performed planting of two rows of sugarcane in furrows and two rows of potato on ridges simultaneously. Field performance results are presented in Table 2. Mean value of cut cane seed sett length was 354 mm. Speed of cutting blade was 42 rpm at operating tractor PTO speed of 350 rpm. At tractor forward speed of 0.5 m s^{-1}, mean overlapping between two successive setts were 68 mm, which was within the desired overlapping range of 50–100 mm for the study area. Mean bud damage observed was 2.3% which was within the permissible limit. Mean tractor wheel slippage at load was 5.4%. Insecticide flow rate was 4.71 lpm. Soil cover on setts and seed potato tubers was 45 and 40 mm, respectively. The average spacing between seed potato tubers was 192 mm. Missing of seed potato tubers in the cups of metering unit was 7.1%. Picking of more than one seed potato tubers was 5.4%. Missing and multiple picking of seed potato tubers complemented each other, and therefore desired seed rate was maintained. The slight variation due to missing and multiple picking did not affect the uniformity of the crop stand.

Planter Output

Theoretical field capacity of the planter was 0.27 ha h^{-1}. Time lost in filling of seed, insecticide solution, turning, miscellaneous settings and other activities in terms of total planting time was 47% of total operating time. It was observed that maximum time was lost in filling of inputs followed by turning of the tractor. The effective field capacity (output) of the planter was 0.127 ha h^{-1}, thus to plant 1 ha area it would take approximately 8 h time. The lower output was due to lower forward speed of operation (0.5 m s^{-1}) purposely kept for obtaining proper overlapping of setts and also for avoiding rupture of seed potato tubers and missing in picking of seed potato tubers. The output of planter may be enhanced by increasing the capacity of seed hoppers and insecticide tank so that time wasted in refilling of inputs may be reduced. The cost of planting operation with developed planter was $\sim$3160 ha^{-1}, whereas it was $\sim$13,600 ha^{-1} when planting was done manually. Thus, there was 76.8% cost saving in planting with developed machine. The labour requirement with planter was significantly low as compared to manual planting. It required 56 man-h ha^{-1} to plant with developed planter, whereas manual planting required 567 man-h ha^{-1}. Thus, saving in labour by planting with developed machine was 90.1%.

Table 2 Field performance of the sugarcane-cum-potato planter

Parameters	Values
Crop parameters	
Variety	Sugarcane: CoPk 05191 Potato: Kufri Khyati and Kufri Fry Sona
Mean cane length	2276 mm
Mean cane diameter	24 mm
Mean cane weight	845 g
Seed potato tuber shape factor and shape	KufriKhyati: 127 (round) Kufri Fry Sona: 235 (oval)
Average weight of planted seed potato tuber	47 g
Field parameters	
Field size	50 m × 40 m
Type of soil	Sandy loam
Soil moisture content at planting	15.7% (dry basis)
Performance parameters	
Average forward speed	0.5 m s^{-1}
Mean length of setts	354 mm
Mean overlapping of setts	68 mm
Mean bud damage	2.3%
Average soil cover on setts	45 mm
Mean weight of seed tubers	47 g
Average tuber to tuber spacing	192 mm
Missing of tubers in the cups	7.1%
Picking of more than one tuber	5.4%
Average soil cover on seed potato	40 mm
Number of filling of seed cane box per ha	36
Number of filling of insecticide solution per ha	12
Number of filling of seed potato box per ha	40
Tractor wheel slippage at load	5.4%
Theoretical width of coverage	1500 mm
Effective width of coverage	1500 mm
Fraction of total planting time lost in filling of seed, insecticide solution, turning and miscellaneous activities	0.47
Theoretical field capacity	0.270 ha h^{-1}
Effective field capacity	0.127 ha h^{-1}
Field efficiency	53%
Cost of operation of sugarcane and potato planting	rupees 3160 ha^{-1}

Table 3 Effect of mode of planting on crop growth attributes

Mode of planting	Crop growth attribute for potato				Crop growth attribute for sugarcane					
	Plant height (cm)		Average tuber weight (g)		Cane stalk length (cm)		Cane stalk diameter (cm)		Number of millable canes (000/ha)	
	Intercrop variety		Intercrop variety		Intercrop variety		Intercrop variety		Intercrop variety	
	KufriKhyati	Kufri Fry Sona	KufriKhyati	Kufri Fry Sona	KufriKhyati	Kufri Fry Sona	KufriKhyati	Kufri Fry Sona	KufriKhyati	Kufri Fry Sona
Sugarcane-cum-potato planter	75.3	67.4	69.5	57.3	238.4	239.4	2.41	2.43	98.5	101.1
Sugarcane–potato intercropping (manual planting)	77.1	66.3	69.7	56.7	237.1	235.8	2.44	2.42	96.3	96.7
Potato–sugarcane relay cropping	75.5	68.2	67.5	58.3	211.3	210.1	2.37	2.36	82.9	79.6
CV	11.53	10.76	9.76	11.32	2.12	2.03	6.23	7.18	4.01	3.22
SeM±	2.91	3.11	2.73	2.86	2.17	2.08	0.15	0.21	1.66	1.33
CD, 0.05	NS	NS	NS	NS	7.1	6.8	NS	NS	5.4	4.4

Table 4 Effect of different modes of planting on sugarcane and potato yield

Mode of planting	Sugarcane yield (t ha^{-1})		Potato yield (t ha^{-1})		Sugarcane equivalent potato yield (t ha^{-1})	
	Intercrop variety		Intercrop variety		Intercrop variety	
	Kufri Khyati	Kufri Fry Sona	Kufri Khyati	Kufri Fry Sona	Kufri Khyati	Kufri Fry Sona
Sugarcane-cum-potato planter	72.13	71.51	24.00	19.20	68.57	54.86
Sugarcane–potato intercropping (manual planting)	70.34	73.65	24.89	20.13	71.11	57.51
Potato–sugarcane relay cropping	57.11	55.18	25.68	19.36	73.37	55.31
CV	5.36	5.32	7.04	10.57	7.04	10.57
SeM±	1.60	1.58	0.78	0.92	0.36	0.76
CD, 0.05	5.21	4.65	NS	NS	NS	NS

Comparative Crop Performance

Crop performance experiment was conducted to ascertain the effectiveness of planting by the developed machine. The results are presented in Tables 3, 4 and 5. From Table 3, it is clear that height of potato plant and weight of potato tuber are not significantly affected by mode of planting. Cane stalk length and number of millable canes are significantly lower in potato–sugarcane relay cropping. The possible reason for lower cane stalk length and number of millable canes in potato–sugarcane relay cropping might be reduced growth duration for sugarcane crop. However, cane stalk length and number of millable canes in the sugarcane–potato intercropped plots are statistically similar whether it is planted by the machine or manually. This observation indicates that the machine is performing planting operation as efficiently as being performed manually. Similarly, sugarcane yield and potato yield of sugarcane–potato intercropping treatments planted manually and by machine are statistically similar to each other but significantly higher than potato–sugarcane relay cropping (Table 4). Total sugarcane and sugarcane equivalent potato yield, irrigation water applied, irrigation water use efficiency (IWUE), and benefit/cost ratio of different planting treatments are presented in Table 5. Total yield was significantly influenced by modes of planting. IWUE and total yield of potato–sugarcane relay cropping were significantly lower than the potato–sugarcane intercropped treatments, whether planting was done manually or by machine. These results indicated the superiority of potato–sugarcane intercropping as compared to relay cropping. Highest benefit/cost (2.57:1) was observed in case of mechanised

Table 5 Effect of different modes of planting on irrigation water use efficiency and benefit/cost ratio

Mode of planting	Total yield (t ha^{-1}) (Sugarcane + sugarcane equivalent potato)		Irrigation water applied (ha cm)	Irrigation water use efficiency (kg $ha^{-1}cm^{-1}$)		B:C ratio
	Intercrop variety			Intercrop variety		
	Kufri Khyati	Kufri Fry Sona		Kufri Khyati	Kufri Fry Sona	
Sugarcane-cum-potato planter	140.70	126.37	120	1172.5	1053.1	2.57:1
Sugarcane–potato intercropping (manual planting)	141.45	131.67	120	1178.8	1097.3	2.26:1
Potato–sugarcane relay cropping	128.22	110.49	120	1068.5	920.8	1.84:1
CV	2.30	4.62		2.30	4.62	
SeM±	1.40	2.53		11.70	21.13	
CD 0.05	4.59	8.28		38.2	69.0	

planting with the developed planter followed by manual intercrop planting (2.26:1) and manual relay cropping (1.84:1). Benefit/cost ratio was maximised with developed planter due to saving in cost of planting operation of potato–sugarcane intercrop.

Conclusions

Tractor-operated sugarcane-cum-potato planter was designed and developed for mechanising simultaneous planting of two rows of sugarcane in deep furrows and two rows of potato on ridges as intercrop. Performance of the developed planter was tested in the field in sandy loam soil. Effective field capacity of the planter was 0.127 ha h^{-1} at forward speed of 0.5 m s^{-1}. Developed planter saved 511 man-h ha^{-1} (90%) labour and rupees 10,440 ha^{-1} (76%) cost of planting compared to conventional manual method. Irrigation water use efficiency, yield attributes and total yield increased significantly in potato–sugarcane intercropping as compared to relay cropping of potato and sugarcane. Benefit/cost ratio was 2.57:1 in case of mechanised planting with the developed planter, 2.26:1 in manual intercrop planting and 1.84:1 in case of manual relay cropping of potato and sugarcane.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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