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Engineering innovation in developing rural load carrier operated jute seed drill for farm workers

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Jute provides employment to 40 million farmers and 0.2 million workers in factories in India. Weeding and pesticide spraying are serious problems in the crop due to scattered germination and higher planting density, owing to the absence of effective planting mechanisms, which increase the cost of production and decrease the yield and quality. The current research relates to a self-propelled seed drill, derived from rural load carrier (RLC), which comprises of a self propelled device and a seed drill body. The machine was designed and developed to sow jute seed considering agronomic and ergonomic considerations. RLC used a 3.94 kW diesel engine allowing field work forward speed of 1.9 to 2.8 and 6 to 8.3 kmh^{-1} for rural transportation. The control levers were placed in accordance with the anthropometric data of the user population. Around 67% germination and plant establishment was found with the developed seed drill. The effective field capacity at the mean speed of 2.1 kmh^{-1} being 0.23 hah^{-1} and fuel consumption was 1.4 Lh^{-1}. Ergonomic measured data also proved the suitability of the machine for rural workers with higher cost effectiveness.

Key words: Jute, self propelled seed drill, rural load carrier, mechanical design considerations, workplace.

INTRODUCTION

Jute (*Corchorus olitorius* and *Corchorus capsularis*) is the cheapest vegetable fiber obtained from the plant's stem and ribbon and represents the second most important vegetable fiber after cotton (Smith and Hamel, 1999), in terms of usage, global consumption, production, and availability. India is the largest jute producing and processing country in the world (FAO STAT, 2011). Jute provides employment to 40 million farmers and 0.2 million factory workers in the country. In India, according with the Department of Agriculture and Cooperation, cultivation area of jute crop is 0.91 million ha and annual production of raw jute is 11.57 million bales of 180 kg with average productivity of 2283 kg ha^{-1} in 2011-2012 (Anonymous, 2013). It is a rain-fed crop and hence sown from April to May according to rainfall and type of land and harvested from July to September. Improved methods of cultivation increase jute fiber yield and reduce cost of production in farmer's field. Labour-power cost is the largest component in the cost of cultivation for jute crop. Currently, due to industrial growth and government employments scheme, labour shortage is a major constraint in jute production in the country, especially during the peak cultivation times.

Most of the jute cultivators are small and medium farmers and their farms are not mechanized, including planting. Weeding and pesticide spraying are serious problem due to scattered germination and higher planting density (Herbek and Murdock, 2009). Weeding and thinning takes nearly 50% of the total cost of production and it is not done at proper time; the whole crop is

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adversely affected (Olubunmi et al., 2009), that account for the yield losses up to 75 to 80% (Sahoo and Saraswat, 1988). No weeding tool and machinery can be operated after the broadcasted seeds germination, which increases the cost of production and decrease the yield and quality. On the other side, drilling provides a more uniform depth, reduced seeding rate and more uniform crop emergence.

Traditionally Jute crop is sown by broadcasting at the first rainfall of the season, after levelling the field. This manual operation is expensive, having fewer advantages and more disadvantages. Poor seed soil contact, uneven planting depths (some seed too shallow for proper emergence of permanent root systems, and other seed too deep for germination), and often, poor plant distribution are found to be common in broadcasting system of jute planting. Broadcast seeding of jute is successful up to some extend when soil and seed bed conditions are optimal, and rainfall or irrigation follows broadcasting, harrowing and leveling.

Attempts made previously in developing manual drill for small seeds were also not successful owing to strenuous walking postures. In manual jute seed drill operation, the body of the operator was having an approximate inclination of 60° when walked in backwards and 53° with horizontal when pulled front wise. Draft requirement of manual drill was 402 N, which is higher than 5^{th} percentile value (135N) for eastern region's agricultural workers. Two men were required at a time to operate the four row drill in jute sowing. Low field capacity of 0.094 hah^{-1} and extended period of operation at a time of 14 min were considered as major hurdle in operating manual seed drill (Anonymous, 2010). Field performance and germination of jute crops by this drill was thus found unsatisfactory.

Poor economic conditions, small land holdings and shortage of labours are major problem in jute mechanization resulting in delayed planting of jute in rural eastern India. The objective of the current study was to design and develop a low cost jute drill. The developed drill is an attachment with the popular rural load carrier (RLC), with some mechanical and ergonomics modifications. Thus, the development is an innovation, required for the rural population, yielding to better farming for the jute cultivation. The effects of the developed seed drill on plant emergence were examined and yield obtained was compared to the conventional method of sowing.

MATERIALS AND METHODS

The design of jute seed drill and modifications in RLC were done on the basis of agronomic practices, mechanical requirements and ergonomic performance. The agronomic requirements needed were related to the seed rate, planting depth, row spacing, and fertilizer distributions. The mechanical design requirements related to power transmission, traction, soil compaction, depth control, seed metering, maneuverability, and space requirements were considered. Similarly, the ergonomics design requirements included the locations of different control, sitting posture, operator workplace, steering, and clearance. Each requirement was discussed with the agronomist, research scientists, farmers and farm workers to determine the design specifications that would best meet the eastern India farmer's anthropometry. The resulting seed drill prototype was built in the research workshop and tested in the research field of Agricultural and Food Engineering Department of IIT Kharagpur West Bengal, India.

Agronomic design considerations

Jute seed

The selected variety (JRC 321) of this region, weight 3.425 g/1000 seeds were used for this study. Average seed dimensions of jute are 2.2023×1.3205×1.0831 mm and angle of repose was 27.9°.

Seeding rate

Seeding rates were determined by pre-measurement of a given amount of seed to be planted in a predetermined length of row. Seeding mechanism must be able to maintain the seed rate of 4 to 8 kg/ha. In jute crop, thinning is required at different crop ages. The first thinning is done when plants are about 100 to 120 mm tall at 20 to 25 days crop-age. The plant-to-plant distance is kept at 60 to 80 mm apart after thinning (Rahman and Khan, 2012). The design of the seed drill is done to avoid second thinning, which is compulsorily required in traditionally grown jute crop. This saves time and cost of cultivation.

Planting depth

Sowing depth of 14 to 25 mm is ideal for good germination of jute crop (Denton et al., 2013). The seed drill was able to provide variable planting depth, depending on the requirement. The depth must be controlled and repeatedly achieved between fields depending upon variations in soil conditions. For these purpose shovel-type furrow openers were selected. A provision was available for higher depths as well, if required.

Rows spacing

A standardized row spacing of 220 mm was selected and was designed to be adjustable for different type of agronomics requirement like weeding and pesticide applications. Masum et al. (2011) concluded that plant spacing 220 to 250 mm give highest fiber yield. Two times weeding and one raking also required for economical yield. Total width of seed drill was such that adjustable row spacing would be trouble-free to achieve with some of the other desired criteria.

Fertilizer distribution

Banding fertilizer at the time of jute seeding had negative effects on the rate of emergence and plant population. No additional arrangement was provided in jute seed drill for fertilizer placement at the time of sowing.

Mechanical design considerations

The main parts of the developed seed drill are seed hopper, ground wheel, metering mechanism, frame, and furrow opener.

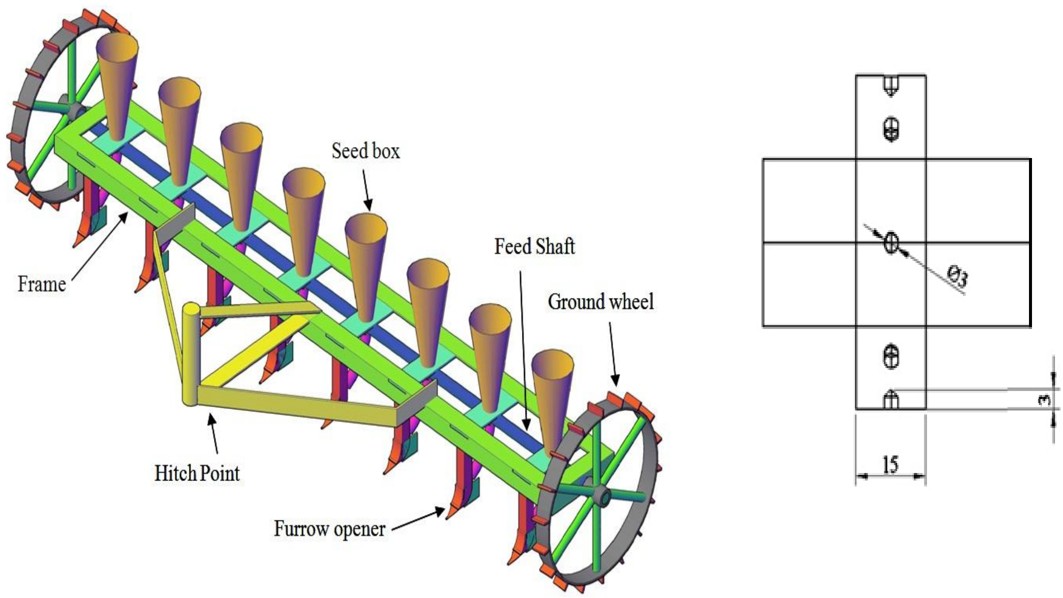

Figure 1. View of eight-furrow jute drill and metering mechanism.

Furrow opener

Narrow shovel type furrow opener was selected to provide good penetration under a wide range of soil conditions form a narrow slot for optimum and splitting placement of jute seeds into row. The openers were attached to a rigid tool bar so that they moved up and down as a unit to provide uniform depth control for all openers. The furrow opener was having a width of 52 mm, shear width of 35 mm, and boot length of 210 mm. Rack angle and boot wedge angle of 40° and 90°, respectively were considered for furrow opener (Darmora and Pandey, 1995). Pipes of 20 mm diameter were welded with small straight pointed shovels and connected to the seed box through appropriate PVC tubes.

Metering mechanism (MM)

For optimum design of the metering mechanism for the jute seed drill, four different types of MM were developed and evaluated in laboratory. Dimensions of the final design from laboratory tests were selected as 2.5 mm diameter cell with equal depth shown in Figure 1. The MM moves under an arrangement called cut off, which allows only those seeds accommodated in the cells. Cut-off mechanism brushes out excess seed from the cells of the feed mechanism (Dash et al., 2003). A square shape pad of size (80×50×5 mm) was placed around each metering mechanism, pad having a square cut of 30×10×5 mm in centre, for brushing the excess seeds. Seed rate of the seed drill was controlled by the square cut of the pad (Bhattacharya, 2013).

Traction and seed firming

For field conditions of jute cultivation, two rear wheels must serve as traction wheels as well as seed firming. Hence, all of the drill's weight was used in developing tractive effort. In addition, the wheels must be as narrow as possible to minimize the compaction effect on the prepared surface. They must also be able to flex over uneven ground for good traction and seed firming in an unprepared seed bed (Kumar and Pandey, 2009; Macmillan, 2002). Thus, the self-propelled unit has two pneumatic traction wheels (152.4 - 304.8 mm) and one steering wheel (82.6 - 406.4 mm) in rear and front side, respectively.

Seed drill

Common feed shaft is driven by the ground wheels and are located on both sides of the seed drill. The drive to the seed metering is powered by a ground driven steel wheel with diameter of 440 mm. The MM was mounted on the main shaft of 25 mm diameter and carries the seed from hopper. The MM cells were designed to receive and accommodate 1 to 2 seeds from the cone shaped hopper. Figure 1 shows an isometric view of eight-furrow jute drill with cone shaped hopper made of 1.5 mm GI sheet with a capacity of 1.15 L, designed, manufactured, and mounted in groups of equal distance at rear side of the machine (Jayan and Kumar, 2004). Seed falls from metering mechanism to the furrow opener through PVC pipe. Location of seed in hopper and metering mechanism minimizes the drop tube angle and height of each furrow openers.

Maneuverability, space requirements

Jute seed drill must be able to operate in a small field with a minimum disturbance to the surrounding plot area. This requires the ability to readily start and stop, turn in a short distance (turning circle radius of 1450 mm) and be controlled with a high degree of accuracy. Considering these requirements, a self-propelled concept minimum size of the machine with placement of the operator close to the working area was chosen for the design (Stajnko et al., 2012).

Mechanical transmission system and drive wheel

Two-speed transmissions were designed for field and transportation in rural road. A 3.94 kW diesel engine was used as a power source in rural load carrier. The power was transmitted from the engine to clutch by using the two V belts of size B-58 (Okafor, 2013). The

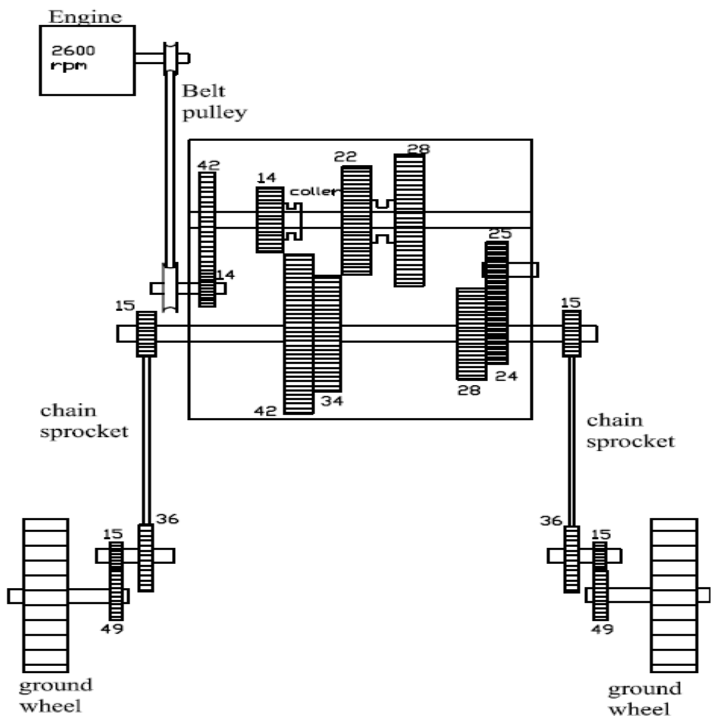

Figure 2. Layout of power transmission in neutral for self propelled jute seed drill (digits indicate the number of teeth on the gear).

speed reduction unit constitutes the drive wheels shaft through the spur gears and chain-sprocket combination. Layout of power transmission in neutral position for self-propelled unit is shown in Figure 2. The digits indicate the number of teeth on the gear and chain sprocket. Speed for field operation and rural transportation varies from 1.9 to 2.8 kmh^{-1} and 6 to 8.3kmh^{-1}, respectively.

Ergonomical considerations

This part of study supported the view expressed by Jafry and O'Neill (2000) about addressing the ergonomic issue in design of tools and equipment.

Steering

The jute drill must be easily handled and capable of maneuvering in a small space. Hence, front-wheel steering on the front axle with the wheel's axles capable of being rotated to a position perpendicular to the row is desirable. In this position, the front drive wheels could rotate the machine around the rear drive wheels. A slightly lesser turn would rotate the machine 180° and bring it into position in an adjacent field with no reverse or additional maneuvering required. Steering angle of 90° to the right or left requires utilizing the engine power for good control.

Location of controls

The controls consist of the steering handle, throttle, gearshift leaver and depth control lever, and are mounted near the driver seat. Clutch and brake pedal are provided near the left and right fender of the machine, respectively. To speed up the operation, operators need to change the gears. For this purpose, it might not require stopping but just a pause to adjust the gear leaver. Location of different controls from seat reference point (SRP) is presented in Table 1 along with angle of reach. The operators contribute to the tractive weight on the rear axle.

Operator workplace

The operators are staggered between steering and loading platforms. The operator location is designed at 610 mm behind steering bars and 100 mm ahead of loading platform. Figure 3 shows the side view of workplace and controls location for rural load carrier. Gearshift leaver was mounted at 490 mm from the SRP in front side, used for shifting the gear. In addition, the self-propelled jute seed drill has high ground clearance, which gives good vertical clearance for crop residues to move through the machine. The vertical height adjustment for the openers is 410 mm to allow 0 to 105 mm of planting depth and 260 mm of ground clearance for transport and easy loading on a trailer. Operator sitting position in seed drill should be made in such a way that it can be operated effectively by operator, achieving maximum field capacity with efficiency. Bicycle seat was provided in a row across the front of the machine for the operator.

Field performance evaluation

The performance of the seed drill was evaluated in research field of IIT Kharagpur, West Bengal, India. The methodology for this testing was adapted from the RNAM test codes and procedures (RNAM, 1995) for seeding equipment with or without fertilizing attachments.

Table 1. Ergonomical considerations in developing different components of self propelled rural load carrier for Indian farm workers.

Controls/lever	Horizontal distance from the SRP (mm)	Vertical distance from the eye height (mm)	Angel of reach (°)
Throttle	620	470	21
Steering	610	470	0
Depth control	575	600	10
Gear shift	490	600	10
Brake pedal	510	1040	12
Clutch pedal	510	1040	12

Source: Tewari et al. (2007).

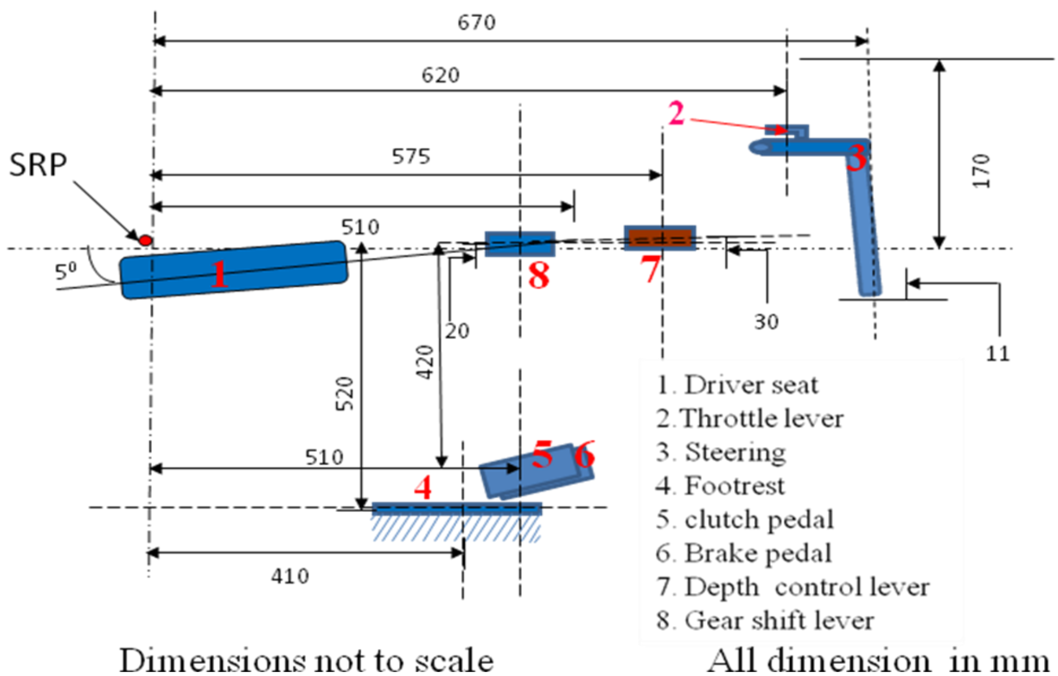

Figure 3. Workplace and controls location for self propelled rural load carrier: side view.

Based on the results obtained from laboratory testing, the performance of the machine was analyzed at field operating speed.

The field data collected for sowing operations in sandy clay loam soil at IIT Kharagpur, India. Temperature during sowing season varies between 26 to 34°C and relative humidity between 34 to 44%. Conventional sowing method and developed drill sowing was evaluated using three plots of 3000 m^2, each. The layout of testing plot was rectangle with the side in ratio of 2:1. Test fields were prepared with disk plough for primary tillage and rotary tiller for secondary tillage. During primary tillage, the depth of tillage was controlled at 125 mm. Plant populations were measured by counting the number of plants in randomly selected areas of 1 m^2 after 7 days (Ghosh and Sen, 1978). Based on the observed average values, plant population per hectare was determined. To determine yield, three randomly selected samples (1m×1m area each) from each plot were harvested. Retting of these samples were done separately. They were cleaned, weighed, and the average jute fiber yield was recorded from all the samples.

Mean emergence time (MET)

It was calculated according to the equation of Ellis and Roberts (1981) as under:

$$MET = \frac{\Sigma Dn}{\Sigma n}$$

Where n is the number of seeds, which were emerged on day D, and D is the number of days counted from the beginning of emergence.

Respondent's assessment

An inquiry was made for getting feedback from the population of farm workers. The main subject of the questionnaire focused on the adaptability of the designed equipment over conventional method.

Table 2. Feedback from respondents on adoption of self propelled Jute seed drill.

Particular	Criteria	Average response of subjects (N = 50), %
Operation of equipment		
	Ease in operation	93
	Controls operable with right/left hand turning	90
Reasons for adoption		
	Higher output	87
	Negligible missing in sowing	95
	Multiplication in sowing	45
	Cost effective	85
	Ease in movement	93
	Low time lost during sowing	84
	Suitable for sowing other small seeds	100
Purchasing the equipment		
	Higher cost	75
	Custom hiring	95
	Owning	75

According to 50 respondents on operation of equipment, reasons for adoption and purchasing the equipment are given in Table 2. Cost of sowing and levelling in traditional method was based on wage rate of farm workers (Rs 25 h^{-1}). The cost of operation per hour for operating the self-propelled jute seed drill was carried out as per the standard method considering fixed costs as it is depreciation, interest, insurance and shelter and variable cost as it is repair, maintenance and, labour charge costs as described by Singh (2007).

RESULTS AND DISCUSSION

Planting quality

The planting patterns and quality of jute seed drill in operation, as compared to traditional method are presented in Table 3. Two factors that affect the pattern of planting are the plant spacing and number of plant in a row. As per the agronomic practices, the planting depth, row spacing, and plant spacing were set at 19 mm, 220 mm, and 35 mm, respectively. The sowing with seed drill and traditional method had almost same timing of emergence. The plant population of 530000 and 775000 per ha was observed with seed drill and traditional methods, respectively. Mean Emergence duration for seed drill sown crop was 7.3 days. The 67% germination and plant establishment was found in case of crops sown using the developed seed drill. However, in case of the conventionally grown crop, no uniform germination occurred due to manual broadcasting of seed (Figure 4). It should also be noted that farmers in the region tend to use 50 to 80% more than the recommended seed rates.

Higher plant populations can lead to higher thinning cost, and reduced crop yield. Thus, the developed seed drill reduces the extra expenses involved in traditional seeding. The comparative results are presented in Table 3. The higher and non-uniform plant population from the conventional sowing also adversely affects jute yield. The jute yield obtained was higher (20 to 28%) in the case of the developed seed drill compared to conventionally sown crop under a normal climatic condition.

Field performance and field efficiency

The effective field capacity of the seed drill at the mean traveling speed range of 2.1 kmh^{-1} varied from 0.23 to 0.3 hah^{-1} as shown in Table 4. However, speed significantly affected field capacity. The major time lost was in turning at the headland at tested speed. This varied between 10 to 13% of total time. The field efficiency was 72%, affected by the skills of the driver directly. Sowing of jute seed by the developed drill consumed comparatively less fuel owing to its operation at a low speed with low draft. Average fuel consumption was 1.4 L per working hours. The machine performed effectively when the narrow opening point was utilized as the seed opener and operated at normal planting depth of 15 to 32 mm. The traveling speed was within the range of 2.1 kmh^{-1}, which did not affect sowing patterns and quality.

Work capacity

The ergonomic considerations in designing and developing the prototype helped the operator to work for longer duration. It was observed that the subject could operate the machine easily. The equipment cost was Rs.

Figure 4. Self-propelled jute seed drill in operation and crop stand grown on the slant.

Table 3. Agronomic Performance of self-propelled jute seed drill and traditional method.

Parameter	Sowing with jute seed drill	Conventional method (Broadcasting)
Row spacing (mm)	220	Not maintained
Plant to plant spacing (mm)	35	Not maintained
Depth of sowing (mm)	19	Uneven
Mean emergence duration (Day)	7.3	7.5
Germination (%)	67	58
Seed rate ($kgha^{-1}$)	5.6	10.3
Yield ($t\ ha^{-1}$)	2.78	2.28

Table 4. Mechanical Performance results of self-propelled jute seed drill in comparison to traditional method.

Parameter	Sowing with jute seed drill	Conventional method (Broadcasting)
Travelling speed (kmh^{-1})	2.1	0.9
Effective field capacity (hah^{-1})	0.28	-
Field efficiency (%)	72	-
Fuel consumption per working hours (Lh^{-1})	1.4	Nil
Fuel consumption per hectare (Lha^{-1})	5.0	Nil

28000.00 (450US$) and this cost could be reduced up to 15% after its commercialization. However, with the present cost of the equipment, economic benefit of 35.4% was observed as compared to traditional method of jute sowing. Moreover, the seed drill was designed as an attachment to the already available load carrier, making it as a versatile solution for multi-purpose operation.

The heart rate of subject while operating the jute seed drill at the time sowing was 131 beats min^{-1}. The average HR value and resulting work pulse indicated that the developed machine might not be ideal for continuous operation of 8 h. Still, considering the advantages of output and easiness of operation compared to traditional method, the developed seed drill is assumed to be a viable option of replacement of the traditional method. Sound level at their ear level during operation of the equipment was 84 to 86 db (A) (Table 5), which is within the accepted level for a self-propelled machine. The frequency weighted vibration level at the handle (steering) was found to be 3.9 $ms-^{2}$. According to ISO 5349 (2001) standards, this vibration level at the handle would allow a maximum exposure of 2 h only. A suitable

Table 5. Ergonomic performance and economics of self-propelled jute seed drill.

Particular	Average values
Ambient conditions	
Dry bulb temperature (°C)	34
Relative humidity (%)	39
Wind velocity kmh^{-1}	3.2
Cloud cover	Partial cloud
Ergonomic parameter	
Heart rate during work (beats min^{-1})	131 ± 4.6
Work pulse (beats min^{-1})	46 ± 7.4
Sound level at subjects' ear level (db (A))	84-86
Vibration level at operator's hand (ms^{-2})	3.9
Economics of sowing	
Cost of machine (Rs)	28000
Traditional (with broadcasting only) (Rs)	906
With self-propelled jute seed drill (Rs)	619

isolator or handgrip would further reduce the vibration level and thus would benefit in usage of extended hours without occurrence of hand arm vibration diseases. The study was not carried out for reduction of vibration owing to the reason that present design allowed the usage of minimum 2 h with single operator. The shifting of control leavers by hand during dynamic work was easy to the subjects.

Farm section of IIT Kharagpur had operated the equipment for only sowing of jute in 2 to 3 ha research plot. The potential of equipment could be harnessed effectively by demonstration to the target group. However, feedback data on usability of this equipment by the target group indicated that they expressed keen interest to use this equipment over their traditional method (Table 2). Custom hiring would be the right solution for the target group. With the socio-economic background of the targeted population, owning the equipment was not found to be feasible solution for the eastern region of India. The machine is simple in fabrication and can be manufactured by any category of manufacturer with a little interaction. The design thus was suitable and ideal for the rural population, where local artisans would fabricate the machine at low cost.

Conclusions

The rural road carrier mounted jute drill has functioned reasonably well in field trials. The mechanical systems for speed control, steering, depth control, and starting and breaking drives were satisfactory. The ergonomic considerations in the design of self propelled RLC operated jute seed drill enables the farm workers who can operate with either right or left hand. The traction for shallow planting using the furrow openers with the split shoe for placing seed on backside was adequate. The best seed discharge uniformity was observed for MM having eight cells at speed between 15 to 50 m min^{-1}. The output with machine was 0.28 ha/h. Mean Emergence duration for seed drill sown crop was 7.3 days. The higher plant population observed in crop grown conventionally, where growth was adversely affected, was averted with the new design of seed drill.

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