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Comparative analysis of a remotely-controlled wetland paddy seeder and conventional drum seeder

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Abstract. A remotely-controlled wetland paddy seeder (RCWPS) with a mechatronic seed-metering device was developed for precise sowing of pre-germinated paddy seeds in wet puddled field. The RCWPS, powered by a 180 W DC motor, utilized two lugged wheels for propulsion. Linear actuator-controlled dog clutch was connected with each wheel to discontinue the power supply while turning. The four-row seed metering unit comprised a seed metering plate with holes at 200 mm spacing, actuated by a solenoid. The diameter of the metering plate hole, operating speed, and speed of agitation were maintained at 11.18 mm, 0.84 km h^{-1}, and 37 rpm, respectively. This comparative study assessed its performance and operational costs at 1/3rd and 2/3rd seed filling levels under puddled conditions, comparing it to a conventional drum seeder. At 2/3rd seed filling, RCWPS demonstrated 96% feed index quality, no multiple index, 4% missing index, 85.46% hill-distribution uniformity coefficient, and 72.45% seed dropping uniformity coefficient. Meanwhile, the values observed for drum seeder were 78.33%, 6.67%, 15%, 69.85%, and 60.94%, respectively. Similar results were observed at 1/3rd filling level. It showed better quality seed-dropping with RCWPS compared to the conventional drum seeder at all degrees of seed filling. The total cost for seeding per hectare of land with RCWPS and drum seeder were found to be 28.05 USD and 12.77 USD, respectively and the break-even point were found 0.54 ha $year^{-1}$ and 0.038 ha $year^{-1}$, respectively.

Keywords. Pre-germinated paddy; mechatronics; wetland paddy seeder; wet seeded rice; direct seeded rice (DSR).

1. Introduction

The direct seeding method in paddy cultivation has grown immense interest in the farmers for growing paddy. Conventional manually operated drum seeders are mainly utilized for the direct seeding of pre-germinated rice in wet puddled land. However, there are a few significant shortcomings in seeding through conventional drum seeders. The seed rate is not maintained uniformly. Sivakumar [1] reported that the percentage of variation of seed rate varied from -60% to +94% and -35% and +90% at 2/3rd and half seed filling level of drums, respectively. Shee [2] observed that the seed rate of drum seeders varied widely by changing the forward speed and level of seed filling in drums. Kumar *et al* [3] observed that the seed rate of a drum seeder was consistent over an initial 10 m run. Thereafter, the seed rate was observed to increase continuously for the following consecutive runs, up to a distance of 20 m. Moreover, the hill-to-hill spacing is not consistent, hence cross wise thinning is required. The seeds dropped in scattered form with the population of seeds/hill varying widely. According to many previous studies [1, 4–6], the operators of drum seeder experience increased heartbeat and O_2 consumption rate and a decrease in endurance time. Moreover, due to continuous work in paddy fields, the farmers are affected by skin diseases like dermatitis and vector-borne diseases like Malaria, Japanese encephalitis, and Dengue. A brief summary of the development of different precision hill drop wetland paddy seeders is presented in Table 1.

The above-mentioned seeders are used for precise sowing of paddy seeds in expense of higher operating cost, soil compaction due to heavy weight of machine and also environmental hazards. Whereas, several studies [3, 14–16]

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Table 1. Summary of the development and evaluation of different precision hill drop wetland paddy seeders.

Authors	Investigations	Working	Major findings
Togashi *et al* [7]	Studied a shooting gun metering device for seeding paddy seeds	A saw-tooth rotating disc hit the seeds consistently released from a tube and hill-dropped into the soil	The optimal hill-drop effect occurred with a saw-tooth disc featuring a diameter of 190 mm, a thickness of 20 mm, 32 teeth, and made of elastic material
Khobragade *et al* [8]	Pneumatic seed metering mechanism with rotating cylindrical drum	Air pressure generated on the inner surface of a rotating cylindrical drum created an environment where seeds were released into the tube at the interface between high and low pressure zones	The intended planting results were attained with an injection pressure ranging from 1300 to 1350 N m^{-2} and an operating speed between 0.228 and 0.338 m s^{-1}
Furuhata *et al* [9]	Evaluated performance of an air-assisted strip seeder, developed by the Hokuriku Research Centre, Japan	The blower of the seeder conveyed the seeds to the injection ports; powered by the PTO of the tractor and deposited seeds in rows with interval spacing of 30 cm	The effective field capacity was 2 ha h^{-1}, for a base speed of 0.8 m s^{-1} and the field efficiency was 70%
Zhang *et al* [10]	Designed a precise pneumatic rice seed metering device	A plate equipped with a set of suction holes, allowing for the simultaneous suction and release of 3–4 seeds into the paddy field	The probabilities of dropping 3–4 seeds per hill in two moisture contents (23.43% and 26.07%) were 56.13% and 56.40% respectively
Xing *et al* [11]	Developed a six row pneumatic rice direct-seeder	The seeds gathered on the surface of the suction plate, where they were drawn into the holes of the suction plate by the vacuum created in the suction chamber shell	The optimal negative pressure was 2 kPa. The probability of empty hole was less than 2%. The probability of distance between hills (1–3 seeds per hill) at 130 mm and 170 mm was 93.8%
Bandi *et al* [12]	Designed and developed a power operated paddy hill seeder	A cell-type roller mechanism was designed to accommodate the dimensions of paddy seeds. The roller is intended to pick and drop 3–5 paddy seeds in each cycle	The missing and multiple indices were less and quality feed index was 86.1–91.1% for different combinations of operating conditions
Rajaiah *et al* [13]	Designed and developed a precision planter for direct seeding of paddy	The seed metering unit comprised a seed hopper, metering plate, and a transmission system	The mean seed spacing was 150.1 mm, accompanied by a highest quality feed index of 90.5%, and a minimal seed damage of 0.38%

reveal that mechatronic based metering mechanism can be used for precise dropping of seeds like okra, wheat, groundnut, cow pea, etc. at a very low cost. Hence, to mitigate the above-mentioned issues faced in the sowing of paddy seeds, a cost effective mechatronic precise hill-drop paddy seed metering device was designed and developed [17]. It was evaluated under controlled conditions in a laboratory and found to perform satisfactorily. The laboratory experiments revealed encouraging results concerning performance parameters such as missing, multiple, and quality feed indices, coefficients of seed dropping and hill distribution uniformity, and spacing between the hills with respective values as 93.75%, 6.25%, nil, 90.32%, 65.22%, and 235 mm, respectively. Using this metering mechanism, a multi-row remotely-controlled wetland paddy seeder (RCWPS) was developed. Nevertheless, a comprehensive study is required under real puddled field conditions to assess its performance and operational cost in comparison to a conventional manual drum seeder. This will further help to recommend the use of this machine for the small and marginal farmers to carry out seeding of paddy in wetlands.

2. Materials and methods

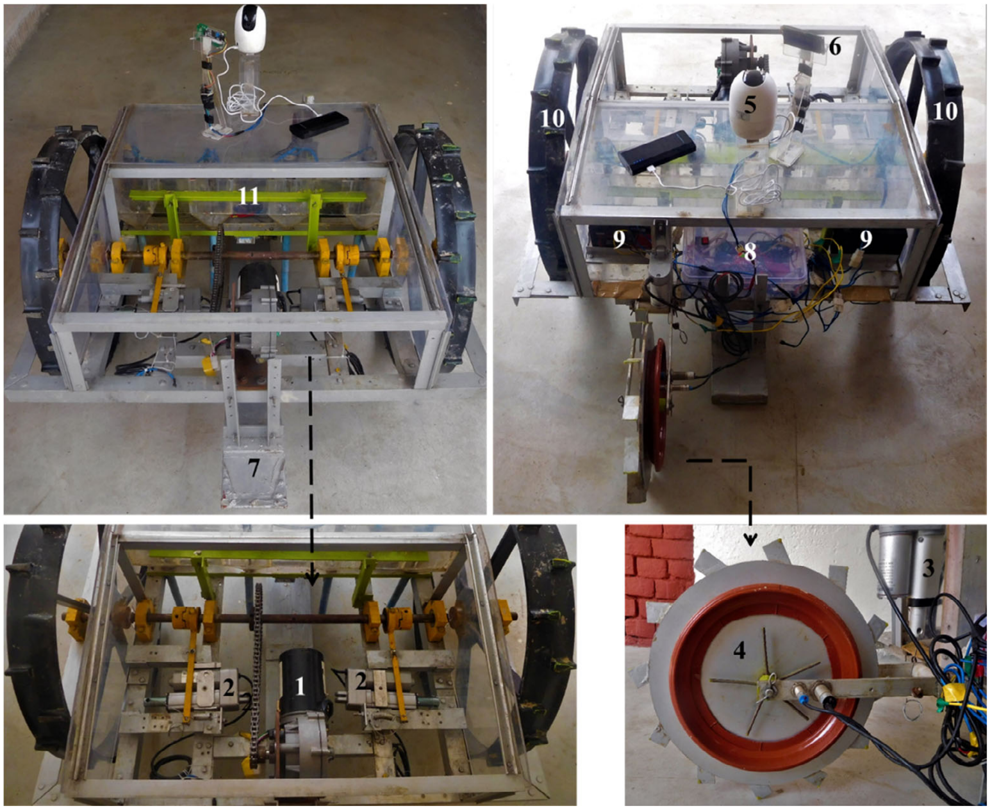
2.1 *Description of the remotely-controlled wetland Paddy Seeder (RCWPS)*

The developed prototype Remotely-controlled wetland paddy seeder (RCWPS) is shown in figure 1. It comprised two main units: seed metering and propelling unit. The seed metering unit was equipped with a hopper, push-pull type solenoid-actuated metering plate, DC motor driven agitators for avoiding seed choking at hopper outlet and a sensor wheel. The top part of the hopper was designed with a square shape, while the bottom part was formed as an inverted pyramid with a 60° inclination angle to ensure the smooth flow of paddy seeds. Because, the angle of repose for various paddy varieties ranges from 30° to 50°, depending on their moisture content levels [18, 19]. Two numbers of inductive-proximity sensors were installed in the close vicinity of the iron spokes in the sensor wheel. During forward movement, one of the two sensors recognize the iron spokes and consequently gives feedback signals to the solenoid which actuates the metering plate to allow hill-dropping of the paddy seeds. Another sensor was used for measuring linear speed of the RCWPS, which was showcased in the LCD module. The propelling unit comprised a 24 Volt, 180 W geared DC motor with nominal torque of 20 N-m at 80 rpm speed, driving chains and sprockets, a transmission shaft, 2 clutches (dog type), and 2 lugged wheels. The lugged wheels were driven by connecting the wheel axles to the driving shaft using dog clutches. To make a turn with the seeder, the dog clutch needed to be disengaged using 24 Volt linear actuators with a 50 mm stroke and a load capacity of 200 N. The capacity of the driving motor and linear actuators were selected based on the measurement of propelling torque, rotational speed and actuating force of clutch while operating in the puddled field. Two 12-Volts and seven Ampere-hours (Ah) batteries of weight 2.4 kg each were bridged in series-connection for supplying power to the motor to help in vehicle forward motion, actuating the solenoid, linear actuators and seed agitating motors in the hoppers. The increase of battery size would cause the increase of weight, which would create sinkage problem of the RCWPS in the puddled field. The operating time of the fully charged batteries was 1.2 h. Another set of recharged batteries was kept ready to replace the discharged batteries.

The main components of the electronic circuit of RCWPS were Arduino Mega microcontroller, motor drivers for controlling the speed and direction of DC motors and linear actuators, relay module for controlling the solenoid, Ardunino Nano with LCD module for displaying forward speed and proximity sensors. The remote controller unit consisted of an Arduino UNO microcontroller, three joysticks, one potentiometer knob, one DPDT (Double pole double throw) switch, and one toggle switch. The communication link among the remote-controller (transmitter) and the developed RCWPS (receiver) was established by a combination of two HC12-modules having frequencies of 433 Megahertz (MHz). A camera was mounted on the top of the vehicle and the forward speed display unit (LCD module) was kept in front of the camera. The captured video by the camera can be made visible in the smartphone of remote-controller operator through an internet connection so that he/she could operate the seeder in the right path and at optimized speed from a remote distance. The detail design of the RCWPS was explained in Hensh and Raheman [20].

2.2 *Description of the manually operated conventional drum seeder*

The conventional drum seeder had two hyperboloid-shaped drums, baffles, a main shaft, a handle, and two lugged ground wheels. The diameter of the seed drum was 200 mm which was made of Polypropylene Copolymer (PPCP) material by fixing the smaller ends of conical frustums. In each drum, 8 holes having a radius of 4.5 mm were provided throughout the periphery at 200 mm intervals. It had a fixed row-to-row spacing of 200 mm. The seeds flow easily from the cone to the metering holes because of their slope. The diameter of lugged ground wheels was 600 mm. The baffles present in the seeding drum helped to maintain the uniformity in seed dropping rate. Floats may also be provided on both sides to reduce the wheel sinkage and to ease pulling in the puddled field. The gross weight of the drum seeder was 8 kg. Each drum could be filled with up to 6.5 kg of pre-germinated paddy seeds.



1. DC motor; 2. Linear actuator for actuating dog clutch; 3. Linear actuator for actuating sensor wheel;4. Sensor wheel; 5. Camera; 6. LCD module; 7. Float; 8. Electronic control unit; 9. Battery; 10. Wheel; 11. Seed metering unit

Figure 1. Developed remotely-controlled wetland paddy seeder (RCWPS).

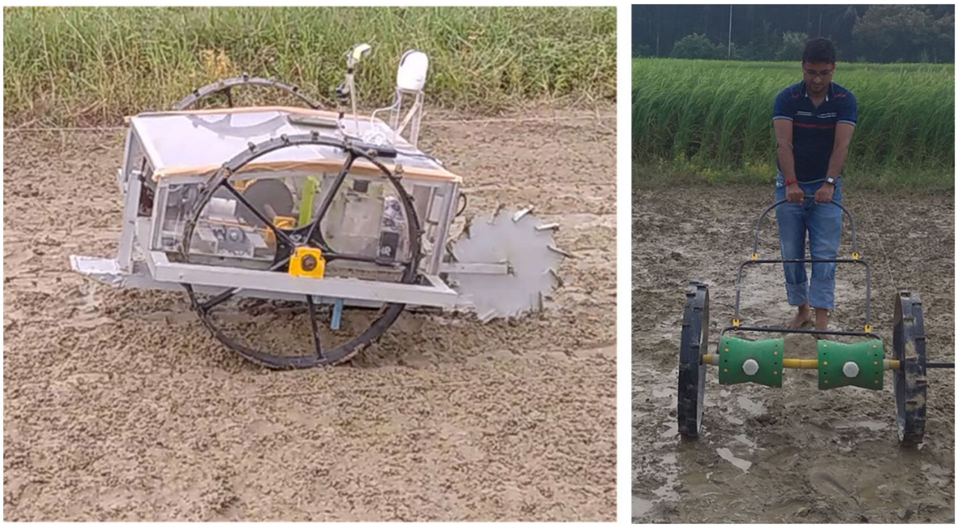
3. Research plan for field performance comparison of the RCWPS and conventional drum seeder

The field performance comparison of the four-row RCWPS was made with an existing manually operated 4-row drum seeder (figure 2). The experimental field of size 25×10 m was divided into four plots (25×2.5 m each). Thereafter, each seeder was operated at two degrees of seed filling in the hoppers i.e., 2/3rd and 1/3rd in these plots as shown in figure 3. For RCWPS, the diameter of the metering hole, operating speed, and speed of agitation was maintained at 11.18 mm, 0.84 km h^{-1}, and 37 rpm, respectively by using a remote controller as per the optimized laboratory results using Response Surface Methodology [17]. The detailed research plan for comparing the performance of RCWPS and conventional drum seeder is given in Table 2. Each test was replicated thrice and all the data sets were taken for the analysis.

3.1 *Measurement of field parameters*

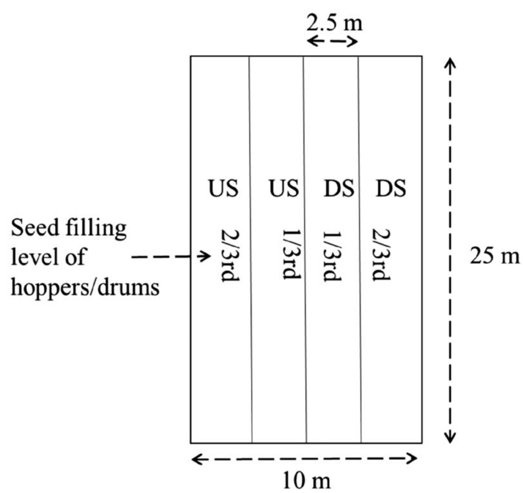
A plate-penetrometer device was developed for determining the penetration resistance (PR) of puddled soil using the plate sinkage method [21]. A mild steel plate of dimension 120×280×4 mm was fixed to the end of a graduated steel rod of diameter 12.5 mm. The other end of the rod was fastened with a circular ring of diameter 150 mm. A dial gauge was fixed at the centre of the ring. The needle of the gauge was kept in contact with the ring. A handle was attached to the ring to press the penetrometer in the soil. Whenever the pressure was applied in the circular ring, it deflected and the deflection was detected and accordingly reading was shown by the pointer of the dial gauge. The mean of each 2.5 cm graduated dial gauge value up to a total penetration depth of 15 cm indicated the PR of the puddled soil.

The puddling index was measured by following the technique as described in BIS standard IS:11531 [22]. The water-suspended soil test samples from a 100 mm depth were taken from different spots of the puddled field by using suitable glass tubes. Then these test samples were put



(a) RCWPS **(b) Conventional drum seeder**

Figure 2. Field testing with RCWPS and conventional drum seeder.



US: Plots for RCWPS operation; DS: Plots for conventional drum seeder operation

Figure 3. Demarcation of the field for operation with RCWPS and conventional drum seeder.

in four measuring glass cylinders up to a volume of 500 ml and allowed to settle in the cylinders for 48 h without any disruption. Thereafter, the index of puddling was predicted by using equation (1). The average puddling index of the four samples was considered as the puddling index of the tested plot.

$$\text{Puddling index} = \frac{Vss}{Vgs} \times 100 \quad (1)$$

where V_{ss} is the volume of the settled-soil in the cylinder; V_{gs} is the gross volume of soil-water suspension in the cylinder.

As per ISO 7256-1 [23], the missing index (I_{miss}) can be defined as the number of spacings between the hills, greater than 1.5 times the desired spacing (n_1). It was determined using Eq. (2). The multiple index ($I_{multiple}$) (equation (3)) is defined as the number of spacings between the hills, less than or equal to 0.5 times the desired spacing (n_2) [21]. The quality of feed index (I_{QF}) is defined as the number of spacings that are less than 1.5 times, but more than 0.5

Table 2. Research plan for field performance comparison of the RCWPS and conventional drum seeder.

Parameters	Levels	Level values
Common parameters		
Forward speed, km/h	1	0.84
Variety of seeds	1	IR36
Independent parameters		
Degree of seed filling in the hopper	2	2/3rd and 1/3rd
Dependent parameters		
Length of hills, mm		
Seed rate, kg ha^{-1}		
Quality of feed index (I_{QF}), %		
Missing index (I_{miss}), %		
Multiple index ($I_{multiple}$), %		
Uniformity coefficient for hill-distribution (HD_{coeff}), %		
Uniformity coefficient for seed-dropping (SD_{coeff}), %		
Germination percentage, %		
Effective field capacity, ha h^{-1}		
Field efficiency, %		

times of the desired spacing expressed as percentage [23]. It was determined using equation (4). The uniformity coefficient for hill-distribution (HD_{coeff}) was used to determine the unevenness in hill-to-hill spacings. Greater values of HD_{coeff} indicates better uniformity in hill-to-hill spacing with respect to its closeness to the desired spacing. It was calculated using equation (5) [24]. Greater values of Uniformity coefficient for seed-dropping (SD_{coeff}) signify less inconsistency in the actual number of seeds dropped in hills with respect to the desired seeds to be dropped per hill [25]. It was determined using equation (6):

$$I_{\text{miss}} = \times 100 \tag{2}$$

$$I_{multiple} = \times 100 \tag{3}$$

$$I_{QF} = 100 - \left(I_{miss} + I_{multiple}\right) \tag{4}$$

$$HD_{coeff} = \left(1 - \frac{A}{B}\right) \times 100 \tag{5}$$

where N is the total number of observations; *A* is the average of absolute differences between actual and mean hill spacings (mm); *B* is the desired spacing between hills (mm).

$$SD_{coeff} = \left(1 - \frac{C}{D}\right) \times 100 \tag{6}$$

where *C* is the average of absolute differences between actual and mean no.'s of seeds per hill; *D* is the desired no. of seeds per hill.

3.2 *Test procedure*

The experiments were conducted in sandy clay loam soil at the Research farm of the Department of AgFE, IIT Kharagpur. Initially, the fields were roto-tilled with the help of a walk-behind type tractor followed by irrigating and allowing them to soak for a whole day. After that, the puddling operation was performed thoroughly. Thereafter, the fields were leveled, and the surplus water was drained. The soil penetration resistance and puddling index were measured following the above-mentioned procedure and were found to be 18.45 kPa and 85.5%, respectively. The field was kept idle for 3–4 days to allow the soil to settle down. Therefore, the penetration resistance was measured once again, which was found to be 32.14 kPa. Then the experiments were carried out. The seeds were pre-germinated before conducting field testing. The paddy seeds were soaked in a bucket of water for 12 h. After soaking, seeds were removed from the bucket and were kept in a wet gunny bag fully covered for 36 h. After this time, sprouts were coming out from the seeds. The sprouted paddy seeds were filled in the seed hoppers. Then the seeders were operated. The sowing was carried out only when the seeder was moved in a straight path in the forward direction.

3.3 *Economic analysis*

The economic analysis of the RCWPS and conventional drum seeder was carried out by estimating the fixed and variable costs. The fixed cost was estimated by calculating the depreciation cost, interest, insurance and taxes, and housing cost. The depreciation cost per hour was calculated by using equation (7) [26].

$$D = \frac{C - S}{L \times H} \tag{7}$$

where, D is the depreciation cost; C is the initial capital cost; S is the residual value of the machine at the end of its useful life, which was considered as 5% of the initial cost; L is the life of the seeder, year; H is the annual use, hours.

The interest, insurance, and housing costs were considered as 7%, 2%, and 1.5% of the average investment over the life of the seeder, respectively. The average investment over the life of the seeder (AI) was computed by using equation (8) [26].

$$AI = \left(\frac{C + S}{2}\right) \tag{8}$$

The variable cost was assessed by deriving the battery cost, labour cost, repair, and maintenance cost, etc. The repair and maintenance costs were taken as 5% of the initial cost. Therefore, the cost of seeding per hectare of land was computed by dividing the total cost for operation by the field capacity of the seeder. After that, the break-even point (BEP) was calculated for the RCWPS and drum seeder.

Here, the BEP could be described as the minimum operating area required to be sown with the seeder annually, for getting economic benefits compared to conventional manual seeding. The BEP was determined using equation (9) [27].

$$BEP(ha/year) = \frac{\text{Annual fixed cost of seeder } (\$/\text{year})}{\text{Manual seeding cost } (\$/\text{ha}) - \text{Seeder operating cost } (\$/\text{ha})} \quad (9)$$

4. Results and discussion

4.1 *Comparative assessment between RCWPS and conventional drum seeder*

During field operation, hill drop seeding was observed in the fields sown with RCWPS as compared to scattered seeding with conventional drum seeder. The effect of hopper filling levels on the length of hills was compared for both the seeders and results are shown in figure 4. The average hill length obtained with RCWPS decreased from 37.3 mm to 23.0 mm with an increase in the degree of seed filling from 1/3rd to 2/3rd in hoppers. Whereas, the average hill length in the case of conventional drum seeder was found to be decreased from 135 to 110 mm with an increase in the degree of seed filling of drums from 1/3rd to 2/3rd, which was significantly higher ($p \leq 0.01$) than the RCWPS seeding hills. The longer hill length cause hindrances to conducting intercultural operations. Moreover, uniform plant spacing increases the yield [28]. Hence, cross-wise thinning of growing plants was required in the case of conventional drum seeders. However, this operation can be omitted in RCWPS fields due to the shorter hill lengths observed. Furthermore, upon reduction in the degree of seed filling from two-thirds to one-third, the seed rate of

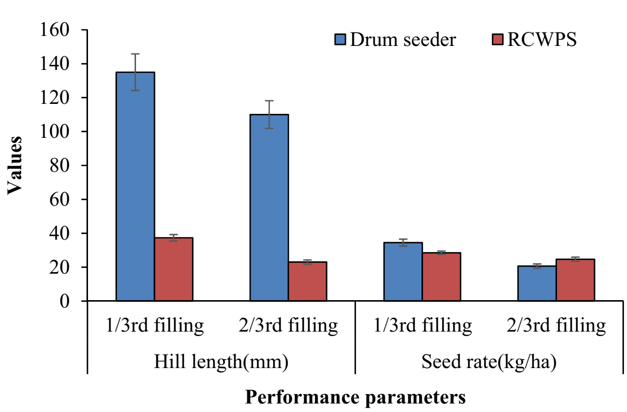


Figure 4. Variations in Hill length and Seed rate with the change in the degree of hopper seed filling for RCWPS and conventional drum seeder (error bars represent standard deviations).

drum seeder and RCWPS increased by 33.98% and 13.4%, respectively (figure 4). Kumar *et al* [3] also observed an increase in the seed rate of a drum type paddy sowing machine by 65.13% due to the decrease in seed filling level from full to 1/4th.

The results of one-way ANOVA carried out for analyzing the effect of seeder type on different performance parameters are given in Table 3. The statistical analysis was carried out by using SPSS statistics 22.0 (IBM Corporation, New York, USA) software. From Table 3, it can be seen that most of the considered performance parameters i.e., hill length, I_{QF}, I_{miss}, $I_{multiple}$, HD_{coeff}, and SD_{coeff} are significantly affected by the type of seeder used, except the seed rate and germination percentage at 0.99 confidence bound. It confirmed significant improvement in the performance of RCWPS as compared to the conventional drum seeder in terms of I_{QF}, I_{miss}, $I_{multiple}$, HD_{coeff}, and $SD_{coeff.}$ In a One-way ANOVA analysis, the sum of squares within groups refers to the summation of the squared differences between each data point and the mean of its respective group (drum seeder and RCWPS groups). On the other hand, the sum of squares between groups is the summation of the squared differences between each group mean and the overall mean, multiplied by the number of samples in each group.

The quality of feed index (I_{QF}) upon sowing with the conventional drum seeder was found to be varying from 90 to 78.33% with augmentation in the degree of seed filling from 1/3rd to 2/3rd, as shown in figure 5. At higher degrees of filling, the paddy seeds combined with their sprouts that obstructed the free flow of sprouted seeds from the drum. So, the missing hill number increased and consequently, the I_{QF} decreased. Whereas, the I_{QF} of RCWPS was found to be 100% and 96% at one-third and two-thirds degrees of seed filling, respectively. The significantly higher ($p \leq 0.01$) I_{QF} value obtained with RCWPS could be due to the incorporation of rotary agitators in the hoppers, which prevented the seeds from choking at the outlet of the hopper. Ma *et al* [29] observed that the I_{QF} of a precision paddy seeder varied from 87.14 to 93.21%. Rajaiah *et al* [30] reported that the value of I_{QF} for the mechanical and electronic precision paddy planter were 74.3% and 86.39%, respectively. The multiple index of the drum seeder decreased from 6.67 to 3.33% with an increase in the degree of seed filling from one-third and two-thirds as compared to 0% in the case of RCWPS for all degrees of the filling (figure 5). The missing index of drum seeder increased from 6.67 to 15% with an increase in the degree of seed filling from one-third and two-thirds. Kumar *et al* [3] observed that the missing index of a drum-type paddy sowing machine increased from 10 to 15% with an increase in the degree of seed filling from 1/4th to full in the drum. However, the missing index of RCWPS varied from 0% to 4% only with an increase in the degree of hopper seed filling from 1/3rd to 2/3rd.

Table 3. One-way ANOVA for analyzing the effect of seeder type on different performance parameters.

		Sum of squares	*df*	Mean square	*F*-value
Hill length	Between groups	25300.08	1	25300.08	140.80*
	Within groups	1796.83	10	179.68	
	Total	27096.91	11		
Seed rate	Between groups	3.00	1	3.00	0.09
	Within groups	343.16	10	34.31	
	Total	346.16	11		
IQF	Between groups	574.08	1	574.08	20.88*
	Within groups	274.83	10	27.48	
	Total	848.91	11		
Imiss	Between groups	225.33	1	225.33	14.89*
	Within groups	151.33	10	15.13	
	Total	376.66	11		
Imultiple	Between groups	80.08	1	80.08	25.97*
	Within groups	30.83	10	3.08	
	Total	110.91	11		
HDcoeff	Between groups	623.52	1	623.52	41.64*
	Within groups	149.70	10	14.97	
	Total	773.22	11		
SDcoeff	Between groups	720.75	1	720.75	15.61*
	Within groups	461.50	10	46.15	
	Total	1182.25	11		
Germination percentage	Between groups	6.75	1	6.75	1.00
	Within groups	67.50	10	6.75	
	Total	74.250	11		

df = degrees of freedom; *F*-value: index of the coefficient of determination; *Significant at 0.99 confidence bound.

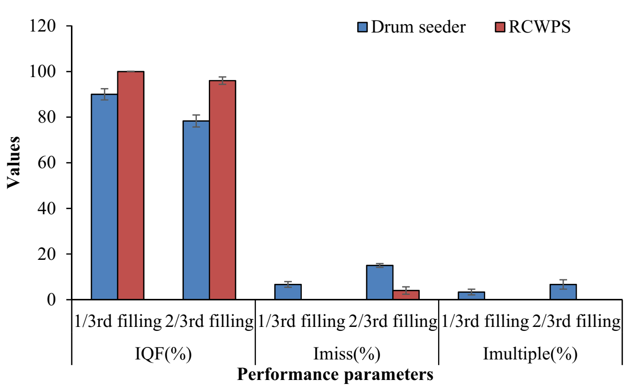


Figure 5. Variations in quality of feed, missing, and multiple indices with the change in the degree of hopper seed filling for RCWPS and conventional drum seeder (error bars represent standard deviations).

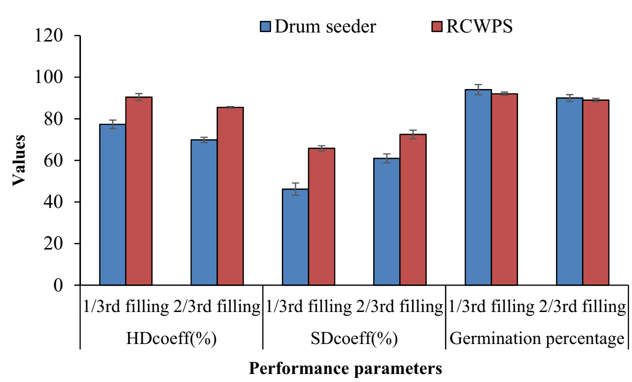


Figure 6. Variations in uniformity coefficients for hill-dropping (HD_{coeff}) and seed-dropping (SD_{coeff}) and germination percentage with the degree of hopper seed filling (error bars represent standard deviations).

The uniformity coefficient for seed-dropping (SD_{coeff}) in hills was observed to be significantly higher ($p \leq 0.01$) in RCWPS as compared to the drum seeder for both degrees of the filling (figure 6). In the case of seeding through the conventional drum seeder, the seeds dropped in scattered form, hence lesser SD_{coeff} value was obtained. Whereas, through RCWPS the paddy seeds dropped as hills, hence the higher value of SD_{coeff} was found. Kumar *et al* [3] reported that the average number of seeds per hill of drum seeder reduced from 24.16 to 9.09 at 1 km/h forward speed with an increase in the degree of seed filling from $1/4^{th}$ to the full level of the drum.

The uniformity coefficient for hill-distribution (HD_{coeff}) was observed to be significantly higher ($p \leq 0.01$) in RCWPS as compared to the drum seeder for both degrees of the filling (figure 6). The HD_{coeff} obtained with drum seeder reduced from 77.32 to 69.85% at higher degrees of seed filling from one-third to two-thirds as compared to a reduction from 90.42 to 85.46% with the RCWPS (figure 6). The wide range of variation in hill spacing obtained with drum seeder was the main reason for the lesser value of hill distribution uniformity. The germination percentage varied from 94 to 90% and 92 to 89% for drum seeder and RCWPS, respectively with the increase of filling level from 1/3rd to 2/3rd level. There was no significant variation in germination percentage among the two seeders ($p \leq 0.01$). Rajaiah *et al* [30] observed that the germination percentage of mechanical and electronic precision paddy planter varied between 88–96.2% and 91.8–96.5%, respectively.

The effective field coverage and field efficiency of the drum seeder was observed to be 0.058 ha/h and 72.5%, respectively as compared to 0.054 ha h^{-1} and 84.37% for RCWPS. Prakash *et al* [31] reported the actual field coverage and field efficiency of a four-row drum seeder with row-to-row spacing of 250 mm as 0.07 ha h^{-1} and 77.41%, respectively.

The established plants 20 days after sowing (DAS) with RCWPS and drum seeder are given in figures 7a and b, respectively. Uniform spacings between the hills of established plants were noticed with RCWPS. Whereas, the plants were established continuously without maintaining any hill-to-hill spacing in the case of the drum seeder. Hence, cross-wise thinning was required in the fields sown with conventional drum seeder to give spacing between the established plants and to obtain a better yield.

4.2 *Economic analysis of the RCWPS and conventional drum seeder*

The economic analysis of the RCWPS and conventional drum seeder was carried out by comparing the initial, fixed, and variable costs of both seeders. The initial cost of the RCWPS for materials and fabrication was found to be Rs. 80,800 (1050.4 $). The useful life and the annual uses of the seeder were taken as 10 years and 250 h, respectively. The fixed cost of the RCWPS was estimated by calculating the depreciation, interest, insurance and taxes, and housing costs. The depreciation cost per hour was computed using equation (7) and found to be Rs. 30.70 (0.42 $). The average investment over the life of the seeder was computed using equation (8) and found to be Rs. 42,420 (573.63 $). The interest, insurance, and housing cost per hour were computed to be Rs. 11.88 (0.16 $), Rs. 3.39 (0.046 $), and Rs. 2.54 (0.034 $), respectively by considering interest, insurance, and housing cost as 7%, 2% and 1.5% of the average investment over the life of the seeder. The total fixed cost per hour of the RCWPS was found to be Rs. 48.51 (0.66 $). Whereas, variable costs per hour such as battery replacement cost, battery charging cost, labour charge, and repair and maintenance cost were found to be Rs. 2.88 (0.039 $), Rs. 0.72 (0.0097 $), Rs. 16.16 (0.22 $) and Rs. 43.75 (0.59 $), respectively. Hence, the total variable cost per hour was found to be Rs. 63.51 (0.86 $). Hence, the total cost of seeding per hour with the RCWPS was found to be Rs. 112.02 (1.52 $).

On the other hand, the initial cost of the conventional drum seeder was found to be Rs. 6000 (80.70 $), which was very less as compared to the RCWPS. The fixed cost and variable cost per hour for the drum seeder were found to be Rs. 3.59 (0.049 $) and Rs. 51.20 (0.69 $). Hence, the total cost of seeding per hour with the drum seeder was found to be Rs. 54.79 (0.74 $). The total cost for seeding per hectare of land with RCWPS and drum seeder were found to be Rs. 2074.44 (28.05 $) and Rs. 944.65 (12.77 $), respectively which were calculated by dividing the total cost of seeding with the actual field capacity of the seeder. Thus, the cost of seeding per hectare with RCWPS was Rs. 1129.79 (15.28 $) higher than the manual drum seeder.

The break-even point of the RCWPS and drum seeder were calculated using equation (9), which were determined to be 0.54 and 0.038 ha year^{-1}, respectively. It means the

(a) with RCWPS **(b)** with conventional drum seeder

Figure 7. Views of established paddy plants on 20 DAS.

RCWPS and drum seeder were required to be operated annually in a minimum of 0.54 ha and 0.038 ha of land, respectively to have an economic advantage over manual sowing.

5. Conclusions

The developed remotely-controlled wetland paddy seeder (RCWPS) performed satisfactorily in the wetland. Its performance was found better than the conventional drum seeder and closer to the pneumatic type paddy seeder. The comparison was made based on the measured parameters such as length of hills, quality feed index, multiple index, missing index, uniformity coefficients for hill-distribution and seed-dropping in hills, field capacity, and cost of operation. It was observed that seeding with RCWPS resulted in hill drop seeding as compared to scattered seeding with conventional drum seeder. Higher values of quality feed index, uniformity coefficients for hill-distribution and seed-dropping in hills obtained with RCWPS as compared to the conventional manual drum seeder at all degrees of seed filling indicated better precision in sowing with RCWPS. The effective field coverage and cost of seeding with the RCWPS were predicted to be 0.054 ha h^{-1} and $28.05 per hectare, respectively in comparison to 0.058 ha/h and $12.77 with the conventional drum seeder. A minimum area of 0.54 ha for RCWPS and 0.038 ha for drum seeder were required to be sown annually to have an economic advantage over manual sowing.

To operate the developed RCWPS in the puddled field, the workers need not have to enter into the wetlands, which is otherwise very hazardous to human health. Thus, its use would increase the operator's comfort as well as reduce occupational health risks. Besides, it could be operated for long durations in the puddled fields without any diesel fuel expenditure, causing no environmental pollution. The developed environment-friendly seeder might be very beneficial for rice-growing farmers of all genders for carrying out the sowing operation of pre-germinated paddy and would help towards improving mechanization in paddy seeding in small and marginal land holdings.

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Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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