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Innovative fabrication methods for agricultural equipment: The case of a 3-D printed paddy drum seeder-cum-fertilizer applicator

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Rice is a vital staple for nearly half of the global population. It is sown through methods like transplanting and direct-seeded rice (DSR). However, DSR offers more benefits than transplanting methods. While DSR offers advantages such as reduced labour and environmental impact, the separate manual application of fertilizers poses a significant challenge. Innovative 3-D printing technology, also known as additive manufacturing, has sparked a transformative shift across multiple industries, facilitating the production of complex three-dimensional structures based on digital blueprints. Its recent application within the agricultural sector has demonstrated significant potential in the fabrication of vital components for farm machinery. Considering this, an attempt has been made to develop components of a four-row manual-operated paddy drum seeder-cum-fertilizer applicator using 3-D printing technology in the Farm Power and Soil Dynamics laboratory of the Division of Agricultural Engineering, ICAR-IARI, New Delhi. The paper is exploring the 3-D printing techniques used for fabricating a complex drum seeder, utilizing a 3-D printer with a bed size of 220×220×240 mm. The drum of the seeder is comprised of two truncated seed chambers and a central cylinder chamber for efficient seed and fertilizer application in two rows. The process of fabricating a drum through 3-D printer is followed by printing all 14 components separately, including square guides for the drive shaft, truncated conical and cylindrical chambers, hoppers, lids, and orifice covers for each chamber. The printing duration is ranged from 1 to 40 hours. The study is highlighted the significant advantages of 3-D printing technology in the fabrication of the drum seeder. 3-D printed four-row paddy drum-seeder-cum-fertilizer applicator has effectively addresses key challenges by integrating fertilizer application with the drum-seeding process.The cost of fabrication of 3-D printed drums has been found to Rs. 3290.4 which is 40% of the total cost of equipment. The cost of operation of a paddy drum seeder-cum-fertilizer applicator per hectare is found to be 2.55 times less than the earlier reported cost of operation with a four-row paddy drum seeder.

Keywords: 3-D printing, Additive manufacturing, Direct seeded rice, Paddy drum seeder-cum-fertilizer applicator, Band placement of fertilizer

1 Introduction

Rice serves as the staple cereal grain for almost half of the world's populationwhich holds immense agricultural significance. India is the second-largest producer of rice, with an annual production of 129 million metric tonnes cultivated across 46 million hectares. The methods of rice cultivation in the country are transplanting and direct-seeded rice (DSR). DSR cultivation in rows is emerging as a promising solution to address concerns related to depleting natural resources and rising production costs in transplanted rice cultivation. DSR is practised either by sowing of pre-germinated paddy seeds in puddled soil (wet-DSR) having standing water or dry seeding on a prepared seedbed (dry-DSR)[1].The sowing in wet-DSR and dry-DSR is done by using a drum-seeder or mechanical/ electronic paddy planter for direct seeding or by broadcasting. Direct seeding with the paddy drum-seeder has a high scope to be established by the farmers due to lesser energy consumption, low cost and easiness of operation[2]. However, to further enhance crop efficiency and reduce losses, it is essential to utilize fertilizers effectively. In the direct-seeded rice, band placement as a 1/3 to 2/3 split gave the greatest grain yield than transplanted rice when Prilled Urea was broadcasted

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and incorporated basally or band-place[3]. Many researchers have studied the development and performance evaluation of drum seeders, but they require manual fertilizer application after seeding. Uneven application of fertilizer can result in unequal plant growth maturity and yields. To enhance crop efficiency and reduce losses, it is essential to utilize fertilizers effectively. Application of fertilizer by mechanical means is important because it is possible to achieve uniformity of fertilizer in the root zone of all plants[4]. The development of a paddy drum seeder-cum-fertilizer applicator offers a solution to this issue, enabling simultaneous seeding and fertilizer application. This integrated approach allows for efficient resource utilization and targeted fertilizer placement between rows, optimizing crop yields. The paddy drum seeder consists of a cylindrical or hyperboloid-shaped drum, drive ground wheels with lugs, a drive shaft and a handle[5]. Floats are also used in some of the designs of paddy drum seeders. The drum that holds paddy seeds is fabricated using mild steel or cast using PVC/ plastic material, thus, quality depends on the skill and facility. Now a days, additive manufacturing technology is being tried by various researchers for making components of a machine[6-8]. In the present paper, additive manufacturing technology (3-D printing or digital fabrication technology) is attempted to be used for making a drum of paddy-seed-cum-fertilizer applicator.

2 Materials and Methods

The study, at ICAR-IARI, New Delhi, focused on the design considerations for paddy drum seeder-cum-fertilizer applicator, Seed-dropping orifice design, Seed and fertilizer chamber specifications, Drum capacity, Computer-aided design for 3D printing, and Drum fabrication process.

2.1 Designing paddy drum seeder-cum-fertilizer applicator

The machine was designed and developed in such a way that it should be capable of performing accurate sowing of seeds in a row at the equal spacing between seeds as per the agronomical practies required. The seeds were dropped by orifices of drum in the row and fertilizer (Urea) was placed in-between the rows. The design included the necessary parameters such as row-to-row spacing, seed rate, fertilizer rate, diameter of the drive wheel, dimensions of the drum, hopper capacity, and sowing area. As per the package of practice for DSR, the following design criteria were considered for the development of a paddy drum seeder-cum-fertilizer applicator as per the objectives of the study,

- The developed machine is to be operated by the workers/operators in a puddled field.
- Pre-germinated paddy seeds and fertilizer (Urea) are in one drum and the placement of fertilizer is in between rows of paddy seeds.
- Due to the better flow of seeds through orifices, a complex drum with truncated conical andcylindrical chambers was selected for pre-germinated seeds and urea, respectively.
- Fabrication of complex drum is to be printed on a 3-D printer.
- Swinging type handle was preferred for equipment to facilitate users/ farmers as per its benefit to operators[9].
- The rotation of the drum is through drive wheels.

2.2 Shape and size of the seed-dropping orifice

Different shapes of orifices were made to study the dropping pattern of the seeds. Elliptical and circular orifices were made on truncated chambers of the drum. Based on the shape and size of the selected paddy seed varieties, the dimension for elliptical orifices was 15 mm major axis and 5 mm minor axis, whereas 10 mm and 12 mm diameter orifices were made on the drums for studying the seed rate.

The number of orifices on the drum depends on the hill-to-hill spacing and ground wheel diameter. The required number of orifices in the seed chamber was calculated by Equation (1)[10],

$$\text{Number of orifices on seed section} = \frac{\pi \times d}{x \times i} \qquad \dots (1)$$

Where,
d = diameter of the drive wheel, mm
x = required spacing, mm
i = gear ratio

The diameter of the drive wheel was 600 mm. The drum and ground wheel was driven by the same shaft so that in one rotation of the ground wheel, the drum also completed its one rotation; therefore, the gear ratio is 1:1. From Equation 1, the number of orifices on the periphery of seed chamber was calculated as 12 numbers which are needed to achieve a hill-to-hill spacing of 150 mm.

2.3 Size and shape of seed and fertilizer chambers

The recommended row-to-row spacing was 200 mm. A complex drum consists of two truncated conical chambers for seed and a cylindrical chamber for Urea. The truncated conical shape facilitates seeds flow towards the dropping orifices. A drum with elliptical orifices of the major axis of 15 mm and minor axis of 5 mm and circular orifices of 10 mm diameter was made to study the fertilizer application rate. The fertilizer drum was in between the seed chambers to apply fertilizer between the rows of paddy seeds.

2.4 Capacity of the seed and fertilizer drum

The row-to-row spacing is already calculated as 200mm. This helped to decide the length of a complete drum. The overall length of the drum was kept at 220mm to accommodate orifices on the periphery of each seed chamber. The diameter of a drum was decided based on the drive (ground) wheel, whose diameter was 600 mm. The drum diameter was kept at 200 mm considering 30 mm wheel sinkage in the puddled field, 20 mm water over the surface and 150 mm clearance between drum and the surface. A drum with a 200 mm diameter showed minimal variation in seed rate due to the combined effect of the flow path trajectory of paddy seeds and the rotational speed of the drum, which acted in addition to gravity[11]. Further, the drum was divided in length and three equal compartments were made for paddy, fertilizer (Central compartment) and paddy. The opening for filling the seeds and prilled urea was kept 40 mm in diameter. The volume of the drum was calculated as per equations (2 to 4),

Volume of the paddy drum, $V_{pd} = V_{TCP} + V_{CPP}$ … (2)

Where,

V_{TCP} = Volume of the truncated conical portion

V_{CPP} = Volume of cylindrical portion at the periphery

Volume of truncated conical portion,

$$V_{TCP}= \frac{h}{3} \times \pi \times [R^2 + r^2 + (R \times r)] \quad \ldots (3)$$

For the truncated cone, r = 0.072 m

R = 0.097 m

H = 0.055 m

V_1= 0.001242 m^3

Volume of cylindrical portion, $V_{CPP} = \pi r^2 h$ … (4)

Here, r = 0.097 m

h = 0.017 m

V_{CPP} = 0.000853 m^3

Volume of the paddy drum = $V_{TCP} + V_{CPP}$

= 0.002095 m^3

The seed rate for direct-seeded rice is 25 kg ha^{-1} (dry condition). From the engineering properties of pre-germinated seeds, it has been found that weight of the pre-germinated seeds[12] has been increased to 40 kg ha^{-1}.

Bulk density of the pre-germinated seeds = 550 kg m^{-3}

Therefore, the amount of pre-germinated paddy seeds that can be filled in the seed chamber is equal to 1.152 kg. As per the literature, the drum is filled up to 75% for the better dropping of the seeds. Therefore, the capacity for pre-germinated seeds in each chamber is 0.866 kg. Thus, total a 1.723 kg of pre-germinated paddy seeds are filled in a complex drum for sowing in two rows.

The capacity of the cylindrical fertilizer drum is also calculated using Equation (4) having rof 0.097 m and 0.05m as h. Thus, volume of the cylindrical fertilizer drum came to 0.001477 m^3. The fertilizer recommendation for the Basmati variety of rice is 120 kg N ha^{-1}. 1/3 rd of the N is applied as basal dose.

Therefore, 40 kg ha^{-1} of nitrogen is to be applied as basal.

Urea has 46 % of nitrogen. Amount of Urea required meeting 40 kg N/ ha

= 86 kg of Urea

Bulk density of the prilled Urea = 750 kg/ m^3

Hence, the amount of prilled Urea that can be filled in the fertilizer chamber is 1.107 kg. Therefore, a cylindrical fertilizer drum contained 75% of 1.107 kg, i.e., 0.830 kg.

2.5 Computer-aided design for 3-D printing of seed and fertilizer chambers of a drum

As per the design parameters, the drum was designed on Solid Works software. The drum (seed and fertilizer chambers) was fabricated on an available 3-D printer with having 220mm bed size. There should be a perfect bed platform for 3-D printing. Firstly, the orifice chamber of a drum was split into two sections longitudinally. However, it did not place exactly on the available 3-D bed size. Hence, the computer-aided design of seed and fertilizer chambers, hopper opening and cap, and drum guide were made separately and assembled later on for less complicated printing. The seed and fertilizer drums were made as lock groove type. The drawing of a drum (seed and fertilizer) was prepared using Computer-aided design (CAD) software and shown in Figure 1.

The CAD of the components for printing on a 3-D printer is given below.

The cylindrical fertilizer chamber was kept in the centre of a designed drum so that urea can be placed in between two rows as band placement. This

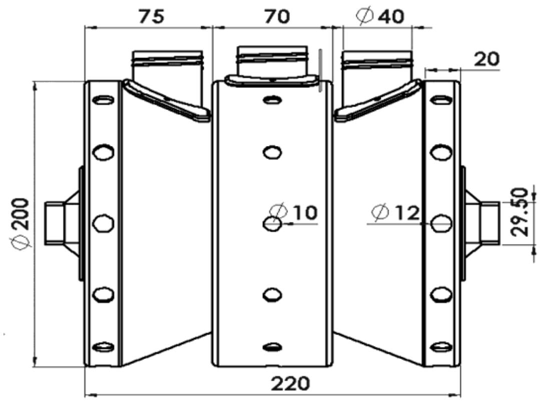

Fig. 1 — CAD drawing of a complete drum.

chamber was equipped with grooves on both sides to accommodate the truncated seed chambers. These grooves have a depth of 7 mm and a width of 6 mm to hold the seed chamber in place accurately. At the centre of the fertilizer chamber, square orifices with dimensions of 26.4 mm x 26.4 mm were incorporated on both sides to facilitate the insertion of the drive shaft. This drive shaft was essential for powering the drum during seeding and fertilizer application. To ensure smooth flow and distribution of fertilizer without clogging, the inner side of the drum was deliberately designed without sharp corners.

Additionally, the dropping orifices were angled at 30 degrees to promote the unrestricted flow of fertilizers toward the orifice outlets. The sharp edges were also avoided on the outer side for a smooth finish and aesthetic look. For convenient loading of fertilizers into the drum, a 40 mm opening was positioned on the periphery of the cylinder to serve as the hopper's opening. This opening allows easy access to fill the fertilizer in the chamber. The periphery of the cylindrical fertilizer chamber featured 11 fertilizer orifices, each with a diameter of 10 mm, evenly spaced to ensure uniform fertilizer distribution during the seeding process. A visual representation of the CAD design of the fertilizer drum is shown in Fig. 2.

The truncated cone-type seed chamber was the component of the drum in which the seeds were filled and regularly dropped through the orifices. The largest diameter of the truncated cone-type seed chamber was 20 cm with 15cm as the smallest diameter. The thickness was 3 mm. At the seed-dropping orifice section, the drum was cylindrical with a length of 2 cm. CAD of the seed chamber consisted of 6 elliptical orifices of major axis 15 mm and minor axis 5 mm and 12 orifices of 12 mm diameter were made on the periphery of this chamber.

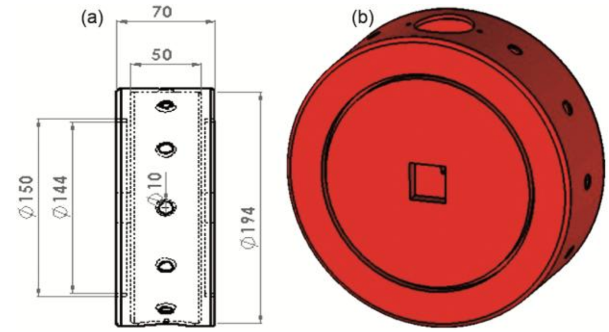

Fig. 2 — CAD of cylindrical fertilizer chamber (a) side view, and (b) isometric view of fertilizer chamber.

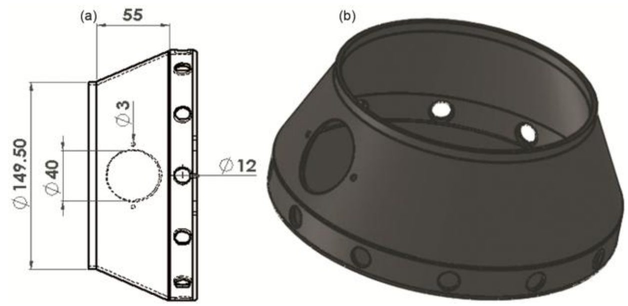

Fig. 3 — CAD of truncated conical seed chamber (a) side view, and (b) isometric view of seed chamber.

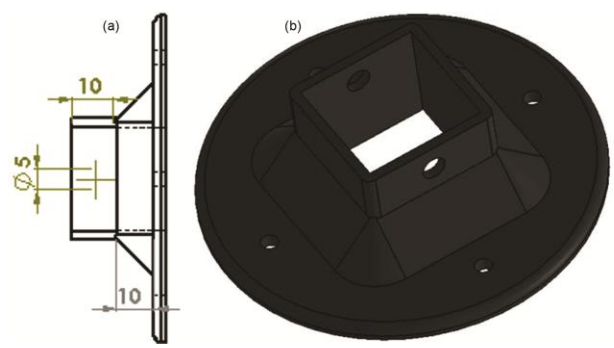

Fig. 4 — CAD of square guide for a drum (a) side view, and (b) isometric view of drum.

A 40 mm orifice was made on the truncated cone for filling the seeds into the drum. A 6 mm length and 5 mm thickness extension were made on the smaller end. Figure 3 shows the CAD of the seed chamber.

The drive shaft guide component was needed to connect the complex drum with the square drive shaft**.** CAD of the drive shaft guide was made in the Solid Works software considering the dimensions of the shaft and drum. Two drive shaft guide per complex drum was made and these were attached left and right of the seed chambers of a complex drum. This drive shaft guide was a detachable piece and it was screwed to the seed chamber for insertion to the drive shaft. The CAD of the drive shaft guide is shown in Fig. 4.

The seed and fertilizer chambers were made with 40 mm cylindrical orifices for filling the seeds and fertilizer. For closing those orifices, threaded hopper and cap were made. The CAD of the threaded hopper and cap are given in Figs 5 and 6, respectively

A seed orifice cover was provided for the seed and fertilizer chambers of a complex drum. This was to reduce the wastage of seeds and fertilizer during idle time, turning operation at the edge of the field and transportation. So, CAD of sliding type cover was designed that covered only orifices for which circular shield has been developed. The cover was 3mm thick and used to cover the orifices from one end. The dimensions of the orifice cover for the seed and fertilizer are shown in the Figs 7 and 8.

2.6 Fabrication of drum through 3-D printer

The drums were printed by the 3-D printer in the Farm Power and Soil Dynamics Laboratory. This additive manufacturing has enabled the creation of 3-D objects from digital designs. The 3-D printing method employed here was Fused Deposition Modelling (FDM) which works by melting a thermoplastic filament such as Poly Lactic Acid (PLA), and extruding it layer by layer to build the 3-D object. FDM is popular for its affordability and ease of use. It can create objects with good detail and precision. The procedure involved in 3-D printing is in various stages. The first and foremost step in the 3-D printing process is to create a drawing on a computer of the desired object. This was accomplished using the specialized 3-D modelling software Solid Works. The second step is to convert into a format that the 3-D printer can understand. For this purpose, the file was saved in the .STL (Standard Triangle Language) format with minimum values of deviation tolerance and angle tolerances. The slicing software of Cura or Simplify 3D was used to divide the model into layers for generation to a G-code file. The object placement has to be done if needed and supporting features and densities should be given before dividing into layers. This can be done by assessing instructions for constructing the object layer by layer, given in G-code for the 3-D printer. Preparation of a 3-D printer for printing the object as per the second step involved levelling the print bed, loading the printing material and setting the appropriate printing temperature. For printing paddy drum seeder components PLA material was used. The extruder temperature was kept at 210°C and the bed temperature was kept at 50°C. Thereafter, the G-code file was transferred to the 3-D printer

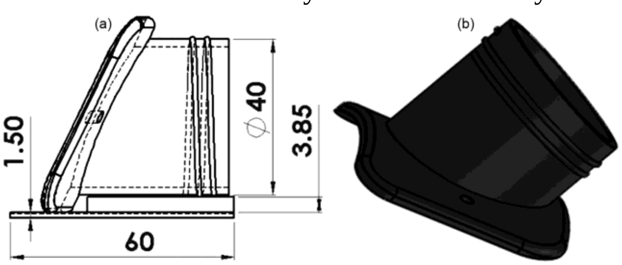

Fig. 5 — CAD of hopper for seed chamber (a) side view, and (b) isometric view of seed hopper

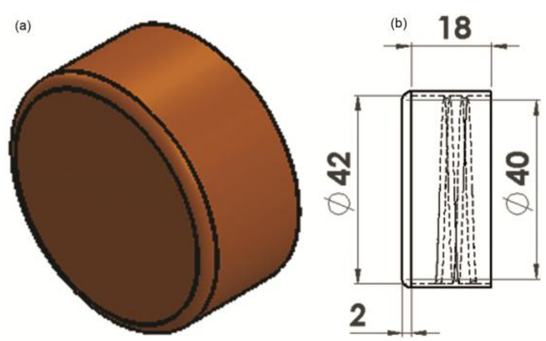

Fig. 6 — CAD of the cap (a) side view, and (b) isometric view of cap

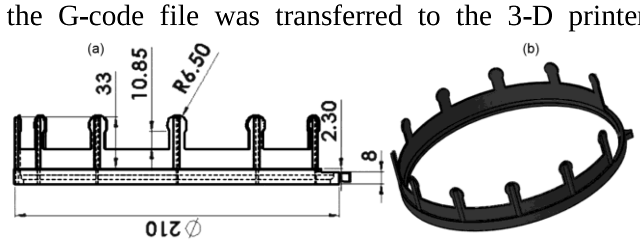

Fig. 8 — CAD of Orifice cover – fertilizer chamber (a) side view, and (b) isometric view of fertilizer orifice cover.

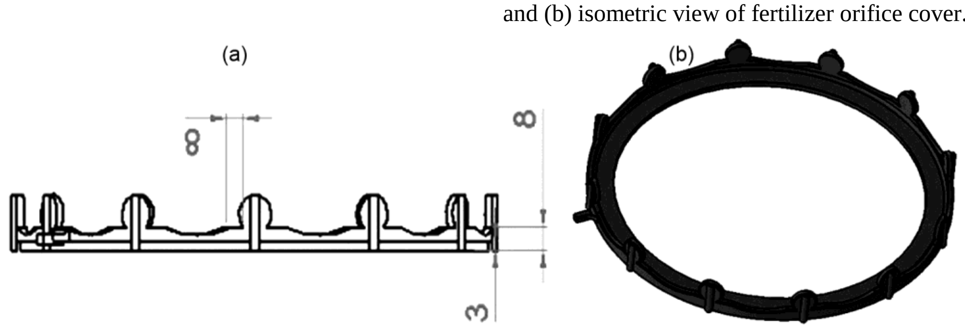

Fig. 7 — CAD of Orifice coversfor seed chambers (a) side view, and (b) isometric view of seed orifice cover

using a Secure Digital (SD) card. The 3-D printer was started. After heating the nozzle, layer by layer building the object started gradually. Monitoring is very important to observe the progress and ensure that the print proceeds correctly during the printing process. Checking the initial layer adhesion and addressing any issues like warping or shifting of layers may require adjusting printer settings or, in some cases, restarting the printer. Once the printing of the object is finished from 3-D printer. Post-processing is a necessary step to achieve the desired final result. This process involves removing the support structures.

The cylindrical drum for fertilizer was printed vertically to allow it to create its own support during the printing process.The overall diameter of the fertilizer drum was 200 mm, which was well within the dimensions of the 3-D printer's bed size. Placing the drum vertically on the printer bed ensured proper support during the printing process.For the 3-D printing, a density of 60% was specified, meaning that the interior of the drum would be printed with a sparse infill pattern to save material and printing time while maintaining structural integrity. The support structure for the drum was of the "touching bed type," which meant that the support structures touched the build platform at three points, providing stability for the overhanging parts of the object. Overall, using Solid Works for CAD design, vertical placement for self-supporting, and appropriate support structures with a 60% infill density allowed for the successful 3D printing of the fertilizer drum within the constraints of the 3-D printer's capabilities.

During slicing, the truncated seed chamber was placed so that the outer end diameter (200 mm) forms the base and circular strip at the top. The fill density given was 60% and no support was given.

The density given for printing of square guide for drum was again 30%. The time taken for printing of one component was one hour and two square guides were printed for the two-row experimental setup.

Separate threaded hoppers were designed for the truncated conical seed and cylindrical fertilizer chambers. At first, the components were radial with a threaded portion at the top. This resulted in a reduction in the strength of the components along its circular axis that broke during closing or opening. Hence a detachable triangular piece was provided in the CAD and sliced and printed so it could not spoil the threads. After printing, the detachable piece was removed from the main component.

The components that were made printed separately were assembled to make a complete seed-cum-fertilizer drill/planter. M3 allen key bolt 8 mm length was used for fixing the components.

2.7 Development of paddy drum seeder-cum-fertilizer applicator

The handle, bushes and wheels for the paddy drum seeder-cum-fertilizer applicator were fabricated in the Engineering Workshop of the Division of Agricultural Engineering, ICAR-IARI, New Delhi. The handle was made of mild steel pipe. The swinging handle was provided which can pivot or rotate up and down. This feature allowed workers of varying heights to adjust the handle's position according to their preference and comfort, enhancing ease of use and reducing strain during operation. The handle's design was based on ergonomic principles, considering workers' metacarpal III height[13]. The metacarpal III height of the 5th percentile of female workers was 581 mm and the 95th percentile of male workers was 763 mm. Hence providing a handle that swings can accommodate a wide range of farm workers. The angle of pull[14] for efficient operation is 30^{o} to 45^{o}. Considering these factors, the length of the handle was kept at 1200 mm. The handle grip diameter was 25.4 mm. The complete CAD of the paddy drum seeder-cum-fertilizer applicator is shown in Fig. 9. The specification of the developed machine is given in Table 1.

2.8 Cost economics for development of 3-D printed paddy seed cum fertilizer applicator

The cost of fabrication of a 3-D printed paddy seed cum fertilizer applicator was calculated based on the cost of electricity (Rs. 8 per unit) for printing the different components by power consumption 0.2 kW of a 3-D printer (Table 2).

The working hour per annum of paddy drum seeder cum-fertilizer applicator is calculated as per the time availability (from the first week of June and continues

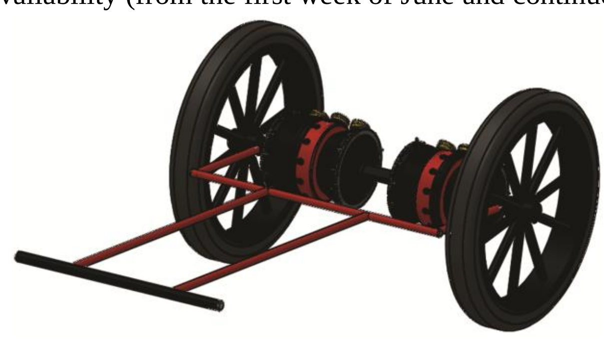

Fig. 9 — CAD of developed paddy drum seeder-cum-fertilizer applicator.

till the month's end). So, the total working hours for the paddy drum seeder-cum-applicator is 200 hours. The life of the fabricated paddy drum seeder-cum-fertilizer applicator is assumed as 5 years. The cost of operation of this equipment is given in Table 3.

2.9 Field evaluation of paddy drum seeder-cum-fertilizer applicator

The performance evaluation was done in the field of the Division of Agricultural Engineering, ICAR-IARI, New Delhi. The drums were filled with pre-germinated paddy seeds and urea and the equipment was operated in the puddle field. The required data during field evaluation was measured and given in Table 4.

Table 1 — Specifications of the four-row paddy drum seeder-cum-applicator

Particulars	Values
Total weight of equipment, kg	25
Overall dimensions (l ×w × h), mm	1500 ×1000 ×600
Diameter × width of drive wheel, mm	600 × 80
Number of drive wheels	2
Number of drum	2
Number of seed chambers per drum	2
Shape	Truncated cone
Number of orifices and its diameter (mm) for seed dropping	12 and 12
Row to row spacing, mm	200
Capacity of each chamber, m^3	0.0021
Hole diameter for the filling seeds and fertilizer in each chamber, mm	40
Number of fertilizer chambers per drum	1
Shape of fertilizer chamber	Cylindrical
Number of orifices and its diameter (mm) for fertilizer dropping	11 and 10
Capacity of fertilizer chamber in a drum, m^3	0.00148
Number of square guides per drum	2
Orifice cover for seed and fertilizer chambers per drum	3
Overall dimension of handle (l x w), mm	1200 × 750
Diameter and width of T-type handle, mm	600 and 25.4

3 Results and Discussion

3.1 Four-row paddy drum seeder-cum-fertilizer applicator

The four-row paddy drum seeder-cum-fertilizer applicator consisted of complex drums, a swinging handle, a drive wheel and a shaft. The design of the orifice covers minimized seed wastage during turning operations. 3-D printing of the drums helped in making the desired shape at highly precise manner to make a complex drum as per design. In addition to this, component making was within a minimal time. Components of each complex drum were 3-D printed that included 14 components (square guides for the drive shaft, two truncated conical chambers, a cylindrical chamber for fertilizer, hopper, and lid for each chamber, as well as orifice covers). The 3-D printing process for each drum component required a minimum of 1 hour for square guide and a maximum of 40 hours for fertilizer chamber. The 3-D printing enabled the use of bio-degradable materials and most customized parts of the drum without sharp corners that facilitates the flowability of the seeds and fertilizers. It also highlights reduction high costs from traditional manufacturing through additive manufacturing[15].

The parameters such as the capacity of the drum, shape and dimensions of the drum, type of orifices, number of orifices, row-to-row and hill-to-hill spacing and number of seeds per hill were the critical parameters in the design of the drum. The 3-D printing helped the creation of intricate and complex components, resulting in a perfectly designed drum. This technology enabled lightweight yet durable parts fabrication in less time with no sharp corners inside the drum. The orifices were made at an angle to facilitate the easy flow of the seeds. The truncated conical seed chamber proved to the easy flow of seeds towards the orifices and the filling capacity of the drum significantly affected the seed rate. A swinging handle was made considering ergonomic parameters

Table 2 — Cost of printing the components of paddy seed cum fertilizer applicator

Particulars	Unit	Total Cost, Rs
Poly Lactic Acid filament, Rs. per kg	1000	2,500.0
Electricity consumption, kWh @ Rs. 8/ unit	33.2	265.6
Labour charges	20% of material cost	500.0
A. 3-D printing cost for both drums		3265.6
Cost of material	-	210.0
Cost of wheel	2000	4,000.0
Miscellaneous (paint and labour charges @Rs. 400/)	-	700.0
B. Fabrication cost in the workshop		4910.0
Total cost of seeder-cum-applicator (A+B)		8,175.6 Say 8200

such as palm grip diameter and metacarpal III height of the workers.

3.2 Cost of making 3-D printed components

The cost of printing the components was finalised by considering the cost of Poly Lactic Acid filament, labour cost based on 20% of material cost and electricity cost in fabricating the components (Table 2). The cost of 3-D printing two drums was Rs. 3265.6 and the cost of operation of 3-D printer per hour is Rs. 1.46 (Table 3). The total monitoring time required for printing all the components were taken 17h based on 10% of total printing time. Therefore, the cost of fabrication of 3-D printed drums was Rs. 3290.4. Total cost of fabrication of the equipment is Rs. 8200. Out of this total cost, the share of 3-D printing cost was 40%. The cost of operation of paddy drum seeder-cum-fertilizer applicator is Rs. 65 per hour and about 11hours is needed to complete a hectare area with this machine. So, per hectare, cost comes to Rs. 715 which is 2.55 times less than the reported cost of operation of a four-row paddy drum seeder per ha of Rs. 1821[16].

3.3 Performance evaluation in the field

The field evaluation was done in the area of 126 m^2 and the time required to cover the entire area was 8 minutes (Table 2). The seed rate achieved was 43.2 kg/ ha and the fertilizer rate was 75 kg ha^{-1}. The recommended seed and fertilizer rates are 40 kg/ ha and 86 kg/ ha. The effective field capacity was 0.0945 ha/ h at a walking speed of 1.2 km/ h. This is similar to the results obtained by Singh[17-19]. The field efficiency of the developed paddy drum seeder-cum-fertilizer applicator was 85.9%. The average depth of sinkage of the foot was 95 mm with a S.D. of 17.32 mm for a worker weighing 66 kg and the average depth of sinkage of the drive wheel was 64.4 mm with a standard deviation of 7.96 mm for the equipment weighing 25 kg. The average scattering of seeds from the line was 3.6 mm with a S.D. of 1.2 mm.

Table 4 — Field evaluation data of paddy drum seeder cum fertilizer applicator in puddled field

Particulars	Values
Area, m^2	126
Total seed filled for four-row sowing, kg	3.5
Seed remained after seeding, kg	2.955
Total fertilizer for four-rows, kg	1.7
Seed rate, kg/ha	43.25
Fertilizer rate, kg/ha	75
Width of machine, mm	1000
Speed of operation, km/ h	1.1
Turning time, s	10
Area covered, ha/ h	0.0945
Field efficiency, %	85.9
Average row to row spacing, mm	202
Average hill to hill spacing, mm	148
Number of hills/ m length	7
Number of seeds per hill	4
Average sinkage of foot of 66 kg operator, mm	95
Average sinkage of drive wheel of 25 kg, mm	64
Pulling force, N	
Ploughed field	43.98
Asphalt road	17.01
Grassy paved field	21.25
Puddled field	110.69

Table 3 — Cost of operation of 3-D printer and paddy drum seeder cum-fertilizer applicator

Particulars	Formulas	3-D Printer	Paddy drum seeder cum-fertilizer applicator
Cost (C), Rs.	-	15,000	8200
Average cost (A), at 10% salvage value (S)	$A = \frac{C+S}{2}$	8250	4510
Life (L), Years and Working hour/ annum (H)		5 & 4000	5 & 200
A. Fixed cost			
Depreciation (D) at 10% salvage value (S)	$D = \frac{C-S}{L\ X\ H}$	0.7	7.38
Interest (I) at 14%	$I = \frac{A\ X\ i}{100\ X\ H}$	0.3	3.2
Taxes, Insurance and housing @ 3%	$T, I\ and\ H = \frac{3\ X\ A}{100\ X\ H}$	0.06	0.68
Total fixed cost (A)		**1.06**	**11.26**
B. Variable cost (Rupees per hour)			
Repair and maintenance cost (R & M) (Assumed as 10 % of the initial cost of the machine per year)	$R\ \&\ M = \frac{10\ X\ C}{100\ X\ H}$	0.4	3.31
Operator cost, Rupees/h	Rs. 400/ day	-	50
Total variable cost (B)		**0.4**	**53.31**
Total cost of operation (Rupees per hour)	A+B	**1.46**	**64.57 Say 65**

The average row-to-row spacing obtained was 202 mm and the average hill-to-hill spacing was 148 mm.

It is clear from the table that the pulling force variation in the puddled field during test was observed at a maximum of 37.78%, followed by 34.27% in the ploughed field, 26.29% in the grassy paved field and 11.75% in the asphalt field. Maximum pulling force of 110.69 (±15.13) N was observed in puddled field condition followed by 43.98 (+5.02) N in ploughed field, 21.25 (±1.72) N in grassy field and 17.01 (±1.72) N in asphalt road.

4 Conclusion

The seed rate was obtained as 43 kg/ha and 75 kg/hafor fertilizer as against the recommendation of 40 kg/ha for the seed and 86 kg/ha fertilizer rate. The effective field capacity was 0.0945 ha/ h at a speed of 1.1 km/h with a field efficiency of 85.9%. The developed four-row paddy drum-seeder-cum-fertilizer applicator eliminated the critical challenges by integrating fertilizer application with drum seeding. The cost of fabrication of 3-D printed drums was Rs. 3290.4 which is 40% of the total cost of equipment. The cost of operation of a paddy drum seeder-cum-fertilizer applicator per hectare is Rs. 715 which is 2.55 times less than the earlier reported cost of operation with a four-row paddy drum seeder.

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