Design and development of manually push type urea super granule applicator

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Abstract: To lessen overwhelmed high human strain and tedious work in urea application for rice cultivation, a manually operated push type Urea Super Granule (USG) applicator was designed and developed. There are four small drive wheels inserted in lieu of float which was fabricated using small steel rings instead of the traditional skid concept. The discharge tubes were reformed with the additional bent PVC tubes. The average effective field capacity and field efficiency of the USG applicator was 0.16 ha h^{-1} and 88.1%, respectively. In the field test, the average missing rate, applicator capacity, the distance amid two dropped USG, covering performance and force requirement in developed model were 6.25%, 13.21 kg h^{-1}, 41.61 cm, 77.5% and 69.18 N. The developed applicator saves cost about nineteen times than manual operation. The developed applicator may be useful to small growers of rice growing countries like Bangladesh which not only be cost effective but will also save both time and energy.

Keywords: Urea Super Granule, USG applicator, design and development, performance evaluation

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1 Introduction

Bangladesh is basically an agriculture-oriented country and around 16% Gross Domestic Product (GDP) comes from the agricultural sector. Rice is the staple food crop of the people and meets almost 80% of the food demand of the country. Shortage of labor in rice production is the chief due to migration of people to town and necessity of mechanization for rice production (Mohammad et al., 2011). Urea emerges as an important nitrogen fertilizer for rice production in Bangladesh and approximately 80% of total urea production is used by the rice plant (Prasad and Data, 1979). It was exposed that symbolic loss of urea is experienced, causing a fertilizer use efficiency of 30% only (Hoque et al., 2013).

Nitrogen loss is induced due to ammonia volatilization, surface runoff, leaching, denitrification and seepage, etc. Due to a significant loss of nitrogen, the farmer's in Bangladesh has not able to sort more resourceful use of fertilizer to upsurge their rice yields. To avoid disproportionate volatilization loss of nitrogen fertilizer; deep placement of granular urea into the anaerobic soil region is an effective method (Hoque et al., 2013). Depending on nitrogen use and different climatic condition, deep placed USG (Urea Super Granule) not only save urea fertilizer with a mean of 33%, up to 65% but also upsurge grain yields up to 50% with a mean of 15% to 20% above the same quantity of broadcasted nitrogen as prilled urea, particularly in the inferior range of nitrogen rates (Savant and Stangel, 1990). It was also stated that deep placement of USG at a depth of 6-10 cm in wet land paddy field can save 30% of nitrogen than split-applied prilled urea (Bautista et al., 2001; Hoque et al., 2013).

Placement of the fertilizer at a depth of 60-70 mm of

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the soil by manually which is not only laborious but also time-consuming. Prasad and Data (1979) outlined that only 15% to 35% of the applied nitrogen fertilizer is utilized by the rice plant. Roy (2011) discovered that 33% of urea goes unused in wetland rice production. However, urea in the form of USG (Urea Super Granule) has been proved to be superior to regular granular urea in all aspects. Instead of common doses of 247 kg of granular urea, only 160 kg of USG is required (35% less) and it upsurges rice yield up to 20% per hectare (Hossain, 1998). If urea is applied in super granule form, a significant amount of urea production could be reduced, which will end up in saving of natural gas, whereas natural gas plays a prime input to produce urea fertilizer.

Granular urea is currently applied manually just like transplanting in between rice seedlings in the field. Basically, granular urea is placed at a depth of 60-70 mm under the soil at a center of four consecutive hills of two adjacent rows. The manual placement of granular urea is labor intensive and very slow field operation i.e. 0.07 to 0.12 ha workday^{-1} (Savant et al., 1991). Therefore, it leads a path to design and develop a manually operated low-cost granular urea applicator.

In Bangladesh, International Fertilizer Development Corporation (IFDC) is working on an efficient application of fertilizer, dissemination of granular urea/USG and development its applicators for several years. Along with different research institutions and private organizations have taken initiatives towards development of USG applicator. But amid all developed applicators have some common problems i.e. high missing rate, over and above one USG per cup, blockage in the discharge tube, additional power required to operate and high rate of cracking of USG, high self-weight, soil bearing capacity is not sufficient to facilitate even movement of the wheel on the wet soil surface etc. So, concentrating on aforementioned issues, the aim of the present study is to design and development of a manually push type USG applicator along with the performance evaluation. The advantage and constructing differences were four small drive wheels inserted in lieu of float to minimize friction along with ease of handling of the applicator and unlike others a frame was inserted to enhance durability and stability of the applicator. Also cost of the applicator kept in an affordable range for the small growers.

2 Materials and Methods

2.1 Design considerations

The following factors were considered to design manually push type USG applicator: (i) the machine should be as simple to build and easy to tuning, (ii) float is replaced by the drive wheels to reduce the friction of the machine, (iii) the size of the USG (e.g. 2.7 g and 1.8 g), (iv) the modification of discharge tube, (v) distance between applied USG to USG and row to row placement, (vi) be easy to repairable and to maintain, (vii) the cost of machine need to be within the capacity of rural small farmers. The USG applicator was designed for both size 1.8 g and 2.7 g of USG. For simulation no software is used only trial and error method was followed. The diameter of an individual USG was varied from 20 to 25 mm. USG is chemically same as the fine urea, however, USG is slightly larger and harder. Since the size of the USG is bigger it has no chance to spillage from the aperture on hopper wall. Moreover, the capacity of the hopper (900 g) is maintained to prevent overtopping.

Table 1 The specification for the USG

Parameter	Value
Nitrogen concentration	46% (Minimum)
Moisture	05% (Maximum)
Biuret	1.4% (Maximum)
Granulation	2-4 mm, 90%-94% (Minimum)
Melting point	132 Degree Celsius
Colour	Standard White or Pure White
Radiation	Non-radioactive
Diameter	20-25 mm
Weight	1.8 -2.7 g
Disappear Time in water	0.373 h
Disappear Time in air	52.9 h

2.2 Design and development of manually push type USG urea applicator

The manually push type USG urea applicator (Figure 1) consists of the following major parts: cage wheel, plastic metering disk, plastic hopper, discharge tube, frame with a handle made of Mild Steel (M.S.) flat bar and Mild Steel (M.S.) sheet, drive wheel, respectively. The plastic is Poly Vinyl Chloride (PVC) because this type was readily available, durable and long lasting. The descriptions of different parts are given herein:

1) Cage Wheel: Cage wheel (Figure 2) with 24 flat

spikes were made by a plastic sheet having a diameter of 460 mm to share the dispersed weight load of the applicator equally with the small size cycle rings. The groove was made 8 mm rod at both ends and inserted into the center of cage wheel and locked by a hook. This rod assists to work the metering disk with the rotation of the cage wheel. Twenty-four flat spikes were provided to guide the metering device to drop per USG in every 40 cm distance. It also worked as a power transmission device to put the dropped USG into the soil.

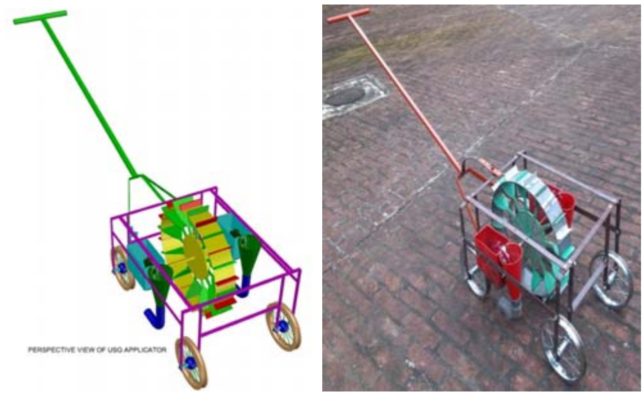

Figure 1 Isometric and photographic view of the applicator

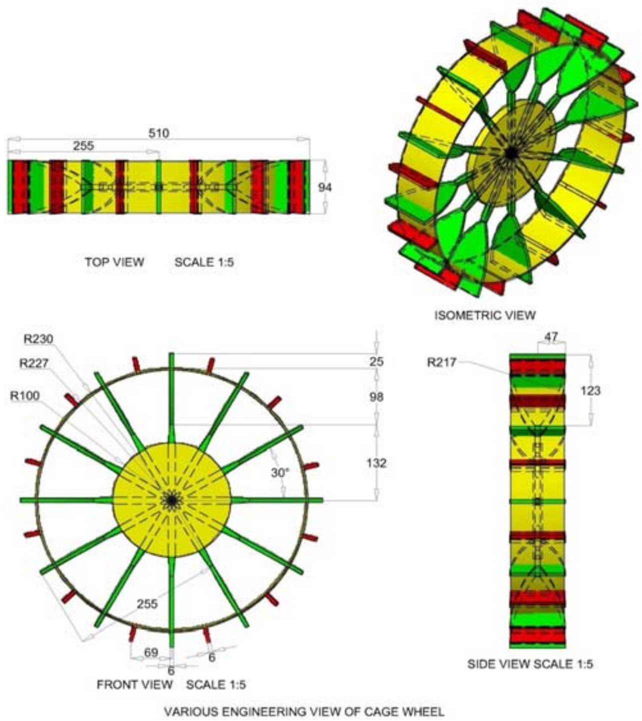

Figure 2 Different views of the cage wheel

2) Plastic Metering Disk: The metering disk (Figure 3) of 145 mm diameter with four cups at 60° angles connected with cage wheel and fixed inside the hopper with a hollow metal tube. The external and internal diameter of the USG picking cup was 22 and 20 mm, respectively. The space for a USG was 6.5 mm.

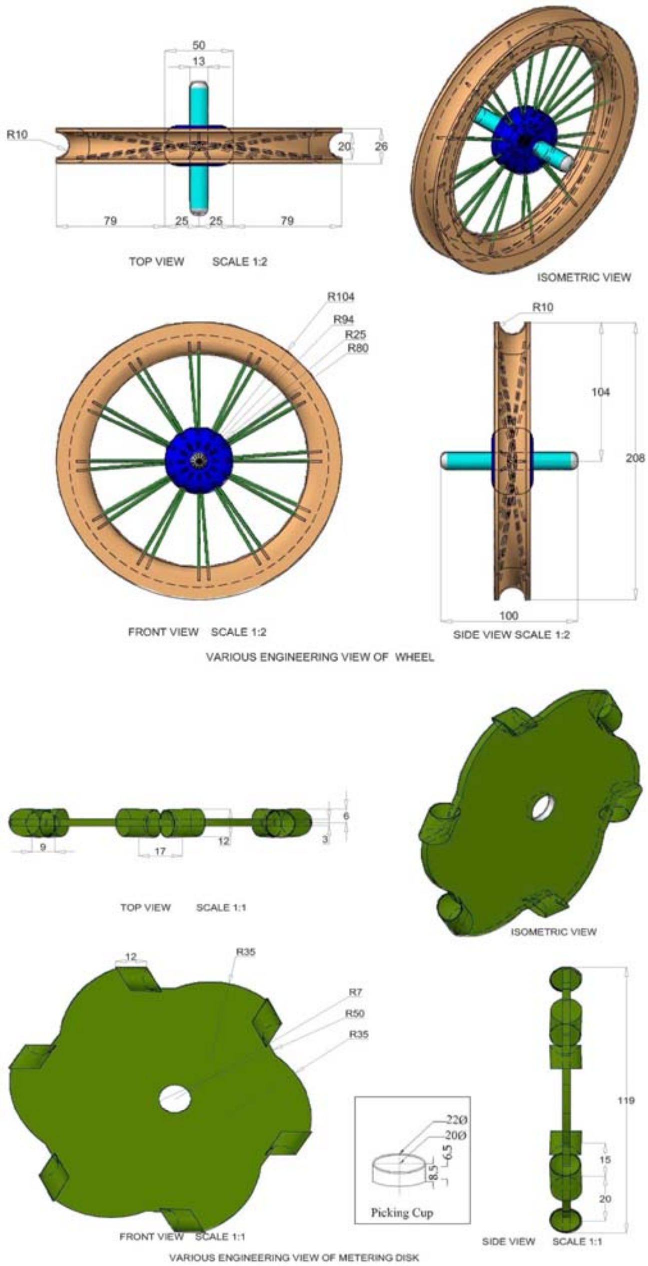

Figure 3 Different views of the drive 1heel and metering disk

3) Drive Wheel: The both external and internal diameter of the drive wheel (Figure 3) ring was 208 and 160 mm, respectively. The width of the drive wheel was 30 mm (20 mm internally). The length of the shaft of the drive wheel was 100 mm.

4) Hopper: The hopper (Figure 4) having a capacity about 900 g (measured by electric weighing scale) and both discharge tubes were made of plastic and secure with the frame, metering disk and cage wheel. The length, depth and height of hopper were 160, 120 and 90 mm, respectively with round tapering at the bottom.

5) Frame with Handle: Frames (Figure 6) for holding the different components of the applicators were made by metal including U-shape components of 20 mm flat bar to

hold each drive wheel. The length, height, and width of the frame were 600, 510, and 320 mm respectively. The frame was tightened with the drive wheel using nut and bolt. The handle was made of a square bar of 1230 mm length, attached with a 320 mm U shape components of 20 mm flat bar to push the applicator in the forward direction. The length of the holding part of the handle (Figure 5) was 304 mm. A 40 mm diameter semicircular constituent was used to hold the discharge tube rigidly.

6) Discharge tube: Discharge tube and small metal guide strip (Figure 7) were used to decrease the missing rate and were secure with hopper by a small nut. The height of the discharge tube was 330 mm with 100 and 40 mm diameter, respectively at top and bottom. The discharge tube was connected with the total components were fixed with the frame.

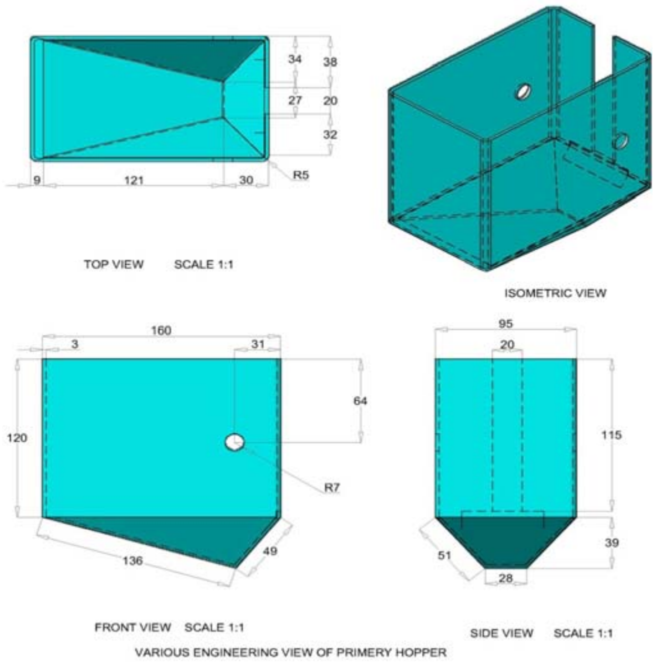

Figure 4 Different views of the hopper

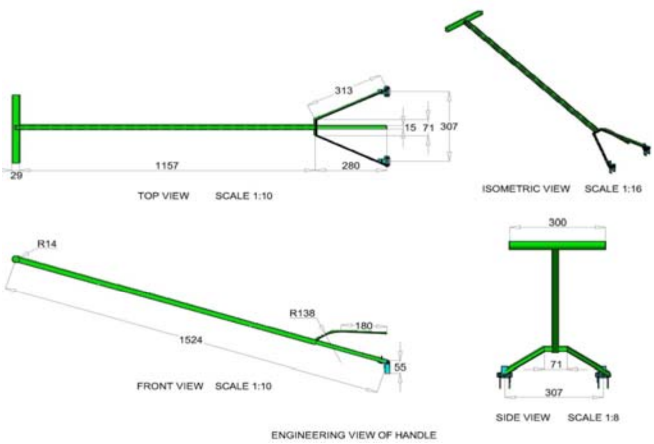

Figure 5 Different views of the handle of the applicator

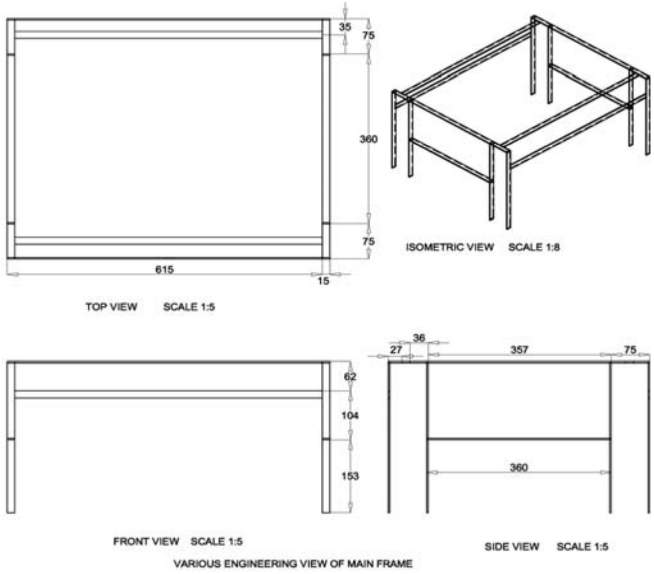

Figure 6 Different views of the frame of the applicator

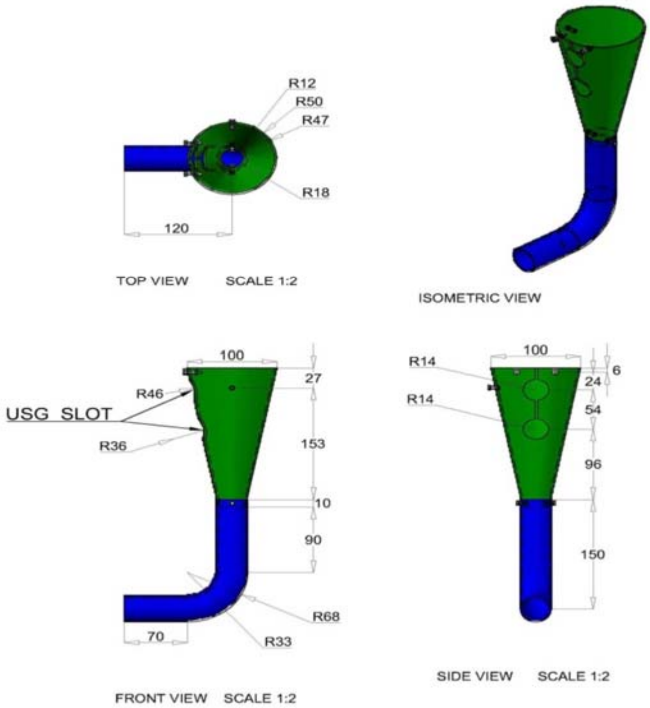

Figure 7 Different views of the discharge tube of the applicator

2.3 Theoretical considerations

The theoretical considerations were reviewed by Kepner et al. (1978) and Ahmed et al. (2013). The governing factors for the performance evaluation of USG applicator comprises: field condition, ease of operator, adjustment of applicator, soil type, soil moisture, land topography, field size and shape etc.

2.3.1 Missing rate and distance of dropped USG

The missing rate of the applicator is estimated from the ratio of number of USG missing to pick up by metering disk into discharge tube to the number of USG pickup by metering disk, if not missing occurred and not more than one per cup. Arithmetically, missing rate was expressed as follows:

$$\% \text{ missing} = \frac{N_1}{N_2} \times 100 \quad (1)$$

where, N_1 is the number of USG missing to pick up by metering disk into discharge tube; N_2 the number of USG pick up by metering disk if no missing occurred and no more than one per cup.

Distance of dropped USG was maintained by the applicator and measured very carefully. During operation, operator and one observer measured the distance of USG dropped in the field separately. After the observation, the average distance between two dropped USG is calculated.

2.3.2 Applicator capacity

The rate of urea application using the applicator is called Applicator capacity. The capacity was determined by the following equation:

$$\text{Applicator capacity } (\frac{\text{kg}}{\text{h}}) = \frac{\text{Total weight of USG dropped, kg}}{\text{Time taken to operate, h}} \quad (2)$$

2.3.3 Field capacity

The effective field capacity may be defined as the actual rate of field when the applicator was operated within a specified time. The theoretical and effective field capacity of the applicator was calculated as follows:

$$\text{Theoretical field capacity } (\frac{\text{ha}}{\text{h}}) = \frac{Sw}{10} \quad (3)$$

where, S is the forward speed, km h^{-1} and w the width of coverage, m.

$$\text{Effective field capacity } (\frac{\text{ha}}{\text{h}}) = \frac{\text{Field coverage, ha}}{\text{Actual time of operation, h}} \quad (4)$$

2.3.4 Covering performance

USG is a highly volatile in water and disappears in air within short time. Thus, covering performance is an important parameter to evaluate the performance of an applicator. If the USG remains uncovered, plants are unable to uptake the nutrient from it. Covering performance of the applicator is defined as the percentage of USG covered by the applicator. Also, the covering performance represents the coverage of USG by mud. The uncovered USG is lost by mixing with water (solvent) contact. During operation, a machinist and a spectator computed the number of USG covered by the applicator separately. The covering performance of the applicator is determined by the following equation:

$$\text{Covering performance} = \frac{C_1}{C_2} \times 100 \quad (5)$$

where, C_1 is the No. of USG covered practically and C_2 the No. of USG covered theoretically.

2.3.5 Pushing force requirement

The force requirement of operation was estimated in the field testing the bed by using spring balance and involving three persons. Spring balance was fixed between pulling wire and one person pulled the applicator, while another person logged the data of spring balance and rest person holds handle of the applicator alongside with line of action.

2.3.6 Cost comparison

The costs per hectare of operation of the applicator have been compared with the cost of manual operation. The total cost of the applicator comprises both fixed and variable cost, like depreciation, interest, labor cost, repair and maintenance cost. The cost was determined by using its maximum effective field capacity of the applicator.

3 Results and Discussion

The performance evaluation was carried out in the field experiment and for the USG size of 2.7 g only.

3.1 Missing rate

The USG applicator was tested on a field with 970 cm length and 400 cm width. It was found that on an average 6.25% of missing rate (Table 2) was occurred for both the left and right hopper, respectively. Karim et al. (2015) estimated 3% missing rate for pulling type USG applicator. Ahamed et al. (2014) calculated the missing rate of BARI, BRRI and BAU model for the USG size of 1.8 g and 2.7 g were 10.2%, 6.2% and 1.4%, respectively. Whether the constructional difference over BARI, BRRI and BAU models were improved cage wheel, metering, four drive wheels, and a main frame. On the other hand, for USG size of 1.8 g, the corresponding values were found 8.6%, 4.0% and 0.6%, respectively. The average distance among the dropped USG was found 41.61 cm (Figure 8), when the applicator was operated in dry land. Also, on the dry land, Karim et al. (2015) found average distance between USG to USG for the both hoppers were 40 cm. Wohab et al. (2017) figured that the “injector-type” and “push-type single row” applicators consistently employed USG at proper depth and spacing under different rice field conditions. However, the study proclaims an acceptable output of missing rate but several reasons identified that may increase missing rate were skidding of the applicator due to uneven surface, failure of conveying USG to the cup of the metering device, clogging in the discharge tube and type of soil etc., which left a scope to the further improvement of the USG applicator.

Table 2 Field test result of missing rate

Obs No.	Total length of field (cm)	Standard distance to drop USG (cm)	Number of USG dropped theoretically	Number of USG dropped practically		Missing rate (%)		Average Missing Rate (%)
				LH	RH	LH	RH	
1	970	40	24	23	22	4.17	8.33	
2	970	40	24	22	23	8.33	4.17	
3	970	40	24	23	22	4.17	8.33	6.25
4	970	40	24	23	22	4.17	8.33	
5	970	40	24	23	22	4.17	8.33	

Note: *LH, RH indicates left hopper and right hopper, respectively

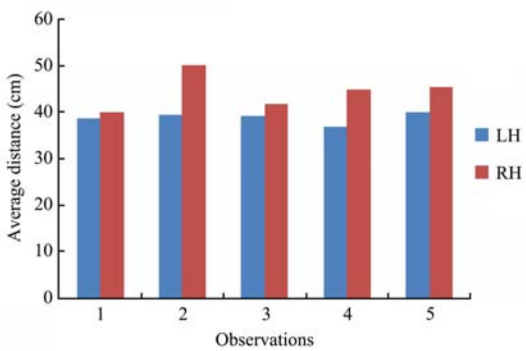

Figure 8 Average distance among dropped USG

3.2 Applicator capacity

The study demonstrates that the average applicator capacity (Table 3) for the both left and right hopper of the USG applicator was 13.21 kg h^{-1}. In case of USG size of 2.7 g, Ahamed et al. (2014) found the applicator capacity of the BARI and BAU model were 21.20 kg h^{-1} and 17.33 kg h^{-1} respectively. However, the applicator capacity of the same model was 13.60 kg h^{-1} and 15.10 kg h^{-1}, correspondingly with respect to the USG size of 1.8 g. The study reveals that the performance of the applicator capacity is reasonable because the higher value of applicator capacity will cause overfalling and lower value will result a higher missing rate.

Table 3 Field test result of applicator capacity

Obs. No.	Time taken to Operate (s)	No. of USG dropped		Weight of dropped USG (g)	No. of USG in hopper before operation		No. of USG in hopper after operation		Weight of USG dropped (g)		Total weight of USG dropped (LH+RH) (g)	Applicator Capacity (kg h^{-1})	Avg.
		LH	RH		LH	RH	LH	RH	LH	RH			
1	34	23	22	2.7	150	150	127	128	62.1	59.4	121.5	12.86	
2	35	22	23	2.7	100	100	78	77	59.4	62.1	121.5	12.50	
3	30	23	22	2.7	100	100	77	78	62.1	59.4	121.5	14.58	13.21
4	33	23	22	2.7	100	100	77	78	62.1	59.4	121.5	13.25	
5	34	23	22	2.7	100	100	77	78	62.1	59.4	121.5	12.86	

Note: LH, RH indicates left hopper and right hopper, respectively

3.3 Field capacity

Machine was operated on a field size of 40 m×10 m, for the determination of the field capacity. The estimated average effective field capacity and field efficiency (Table 4) of the USG applicator was 0.163 ha h^{-1} and 88.1%, respectively. Karim et al. (2015) estimated the effective field capacity was 0.14 ha h^{-1} and field efficiency was 78.4% of the applicator for applying USG. Furthermore, the effective field capacity was found 0.147 ha h^{-1} and 0.154 ha h^{-1} for the BARI and BAU model, respectively in case of USG size of 2.7 g. However, the corresponding findings were 0.144 ha h^{-1} and 0.146 ha h^{-1} with respect to the USG size of 1.8 g (Ahamed et al., 2014). He also assessed field efficiency for USG size of 2.7 g was 91.3% and 86.5% for the BARI and BAU model respectively and for the USG size of 1.8 g corresponding values were 91.7% and 89.6%, respectively. The study indicates a satisfactory result compared to the previously conducted studies.

3.4 Covering performance

Covering performance of the USG applicator is tabulated in Table 5. The Average covering performance was found 77.5%. Wohab et al. (2017) disclosed that in case of Injector-type and Push-type single row applicators, the average performance was quite similar. The finding shows a quite standard result to accumulate nitrogen in the soil. Also, about 22.5% USG was left uncovered which was lost by volatilizing to air. Reasons behind this loss were by skidding of the applicator due to uneven surface and the operational speed.

Table 4 Field test result of field capacity

Obs. No.	Effective field capacity (ha h^{-1})	Avg. Effective field capacity (ha h^{-1})	Speed, (km h^{-1})	Width of coverage (m)	Theoretical field capacity (ha h^{-1})	Field efficiency (%)
1	0.162					
2	0.168					
3	0.165	0.163	2.31	0.80	0.185	88.1
4	0.160					
5	0.161					

Table 5 Field test result of covering performance

Obs. No.	Length of field, (cm)	No. of USG dropped		No. of USG uncovered		No. of USG covered practically		No. of USG covered theoretically		Covering performance (%)		Avg. Covering performance (%)
		LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	
1	970	23	22	2	6	21	16	24	24	87.5	66.67	
2	970	22	23	3	5	19	18	24	24	79.17	75.00	
3	970	23	22	2	6	21	16	24	24	87.5	66.67	77.5
4	970	23	22	2	5	21	17	24	24	87.5	70.83	
5	970	23	22	2	6	21	16	24	24	87.5	66.67	

Note: LH, RH indicates left hopper and right hopper, respectively

3.5 Pushing force requirement

The field test result of pushing force requirement indicated in Table 6. For the pulling type USG applicator with the weights of 12 kg, Karim et al. (2015) figured pulling force was 108 N. With the machine weights of 11.97 kg, the average pushing force was found 69.18 N, which implies the ease of handling of the machine. Pushing force is highly correlated with two governing factors such as weight of the applicator and the amount of moisture in the muddy soil.

Table 6 Field test result of pushing force requirement

Obs. No.	Pulling force (kg)	Pulling angle (degree)	Pushing angle (degree)	Pulling force (N)	Pushing force (N)	Average pushing force (N)
1	6.6	30	25	56.07	61.87	
2	7.2	30	25	61.17	67.49	
3	7.7	30	25	65.42	72.18	69.18 N
4	7.4	30	25	62.87	69.37	
5	8.0	30	25	67.97	75.00	

3.6 Economic performance

Economic performance of the USG applicator was given in Table 7. Assuming an economic life of five years of the applicator with 10% salvage value, it was estimated that the operating cost of the applicator was Bangladeshi Tk. 256 ha^{-1}, whereas the operating cost for manual USG application was Bangladeshi Tk. 4762 ha^{-1}. Finally, the study demonstrates that the applicator saved about 19% cost compared to manual application. Additionally, the total operating time was 50 d yr^{-1}. Hoque et al. (2013) figured their applicator saved up to 16.667% cost rather than the manual application. While performing the economic performance only labor cost was taken into the account.

Table 7 Economic performance of the USG applicator

Parameters	Cost (US$)	Cost (Bangladeshi Taka)
Price of the USG applicator/US$	49.55	4000
Total operating Time / d yr^{-1}	50	
Total Operational Cost		
Total Fixed Cost, US$ yr^{-1}	13.32	1075.48
Total Variable Cost (Labour + R&M), US$ yr^{-1}	498.49	40240
Operational cost, US$$ha^{-1}$	3.17	97.93
Hand Operational cost, US$ ha^{-1}	58.99	4762

4 Conclusions

A urea super granule applicator was designed and developed to lessen the loss of urea fertilizer and safeguard the increased agricultural yield. The main constructional difference between this device and the traditional device was the insertion of a four-drive wheel instead of traditional float device. The four-drive wheel helped minimize friction and ease of handling. Also, a main frame was installed to enhance durability and stability of the applicator. For better performance the cage wheel and metering device were redesigned. The developed applicator requires a small pushing force of 69.2 N, which leads a stress-free operation of the applicator. The value of effective field capacity and field efficiency was found 0.16 ha h^{-1} and 88.1%, respectively in the field test. Furthermore, in the field test, the study reveals that the average missing rate, applicator capacity, the distance of dropped USG and covering performance were 6.25%, 13.21 kg h^{-1}, 41.61 cm, and 77.5%, respectively. And from the economic perspective, the urea super granule applicator can save approximately 19% cost compared to the manual application. The developed urea super granule applicator could be introduced to the small growers in Bangladesh as well as in other rice growing countries.

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