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FULL-LENGTH RESEARCH ARTICLE

Design, Development and Field Evaluation of Manual-Operated Applicators for Deep Placement of Fertilizer in Puddled Rice Fields

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Abstract Deep placement of urea increases nitrogen use efficiency, rice yields, and farm profitability compared to conventional broadcast urea. However, labor shortages for deep placement pose constraints for wider adoption. Therefore, two types of manual-operated applicators, an "injector-type" (non-continuous operation) and "push-type single row" (continuous operation), were designed during 2011–2015 to deep-place fertilizer briquettes in puddled rice fields. The design of the single-row applicator was improved from a double-row design developed earlier by the Bangladesh Agriculture Research Institute. In particular, the width of the furrow opener and skid was modified to ensure the precision placement of urea briquettes (UB) to 5–7-cm soil depth and coverage of the briquettes with soil. The single-row applicator has two cage wheels and one fertilizer hopper; the double-row applicator featured one cage wheel and two hoppers. This modification reduced the weight of the single-row applicator to 4.5 kg compared to the 10.0-kg double-row applicator. The injector-type applicator, which has four mechanisms—feeding, metering, delivery, and placement—weighs 1.5 kg. Field testing across different sites and seasons showed that the push-type applicator significantly reduced the labor requirement to 15–20 h/ha compared to the injector-type applicator or hand placement (28–50 h/ha). Applicators consistently placed UB at proper depth (5–7 cm) and spacing under most rice field conditions. Grain yields of applicator-placed UB were similar to hand-placed UB. There was no significant difference in grain yields between the two applicators when compared to yields achieved following hand placement.

Keywords Urea briquette · Urea deep placement · Manual-operated applicators · Rice field · Bangladesh · Manual-operated fertilizer applicator

Introduction

Nitrogen (N) fertilizer is fundamental to producing higher rice yields. Generally, urea fertilizer is broadcast over the paddy field in floodwater two to three times during the rice-growing season. N use efficiency is very low, and only 30% of the broadcast urea is used by the plant [3, 7]. The remaining 70% is lost through volatilization, nitrification/denitrification, surface runoff, or leaching, or it is immobilized in the soil [3, 7, 12]. Studies conducted in Bangladesh have shown that urea deep placement (UDP)—in which urea briquettes (UB) of 1–3 g are placed at a depth of 7–10 cm at the center of four rice hills—increases rice yields by 15–20 with 25–40% less fertilizer [7, 8, 10]. Moreover, UDP increases farm profits, reduces the government subsidy burden in the countries where N fertilizer is subsidized, and protects the environment by reducing nitrogen losses through surface runoff, ammonia volatilization, and greenhouse gas nitrous oxide emissions [4, 10]. UDP has been adopted by a substantial number of farmers—primarily in Bangladesh but to a lesser degree in

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a range of African and Southeast Asian countries. Generally, deep placement is done manually (hand-placed) 5–7 days after rice transplanting, which is very time-consuming and labor-intensive. Due to the increasing trend of labor outmigration from agricultural communities, the availability of labor has become a major constraint to UDP adoption. Therefore, efficient applicators are needed for wider adoption of UDP; while the ultimate solution lies with mechanized application, manual applicators are an important interim step.

The development of applicators started during the 1980s. Three types of applicators were developed by the International Rice Research Institute (IRRI), namely (a) spring auger applicators for prilled urea, (b) oscillating plunger applicators for prilled urea, and (c) press-wedge applicators for urea supergranules (USG) [9]. Similarly, the International Fertilizer Development Center (IFDC) developed a plunger-type, hand-operated applicator prototype for deep placement of UB in rice fields. The field evaluation of the applicator was conducted in the Philippines and India [2, 11, 13]. Although urea deep-placed by the applicator increased grain yield consistently over broadcast prilled urea, the effective field capacity of the applicator was low (0.2 ha per working day), which required almost the same amount of time as hand placement.

Development efforts for efficient UDP applicators continued in Bangladesh by engineers at the Bangladesh Agriculture Research Institute (BARI) [5, 14], Bangladesh Rice Research Institute (BRRI) [6], and Bangladesh Agricultural University (BAU) [1]. BARI developed a double-row push-type applicator (BARI model) [14], which drops a single urea briquette at 40 cm × 40 cm distance. Similarly, the double-row push-type applicator was improved by Hossen et al. [6] at BRRI (BRRI model) to increase its use efficiency. Field evaluations of those applicators showed satisfactory results on ideal land conditions where land preparation and water control were good. However, ideal and favorable conditions are rarely found in farmers' fields, resulting in performance issues when the applicator trials were conducted on farms. Moreover, applicators were not user-friendly, particularly due to their heavy weight.

Despite the efforts made in the last three decades, there are no efficient UDP applicators suitable for precision deep placement in transplanted rice fields. On the other hand, the use of a heavy mechanized applicator is not possible in a transplanted field without damage to plants. Therefore, this study was conducted to develop a more efficient UB applicator for smallholder farmers with the following objectives:

- Redesign the injector-type and push-type single-row applicators for the placement of UB at required depths with proper furrow closing.
- Test the field performances of injector-type and single-row push-type applicators to compare them with the traditional hand placement method.

Materials and Methods

Two types of applicators, injector-type (non-continuous operation) and single-row push-type (continuous operation), were designed and promoted in Bangladesh between 2011 and 2015 under the Accelerating Agriculture Productivity Improvement (AAPI) project, which was funded by the United States Agency for International Development (USAID) and implemented by IFDC. While testing the applicators in the fields, farmers' feedback was collected regarding limitations and technical weaknesses. The limitations and weaknesses of the applicators were mainly threefold—non-uniform depth of briquette placement (low precision); poor furrow closing; and inconvenience during field operation. Based on these limitations, attempts were made to arrive at improved, user-friendly versions of the aforementioned applicators.

While redesigning the applicators, consideration was given to modifications that could reduce applicator weight, ease applicator operation, reduce applicator costs, and improve the precision of briquette placement. Parts were manufactured locally. The applicators were redesigned to feature adjustable row spacing and to accommodate two standard briquette sizes (1.8 and 2.7 g). Briquettes were elliptical in shape. The diameters of 1.8 and 2.7 g briquettes were 1.8 and 1.6 cm, respectively, while widths (at the center of the briquette) were 0.7 and 0.8 cm, respectively.

In Bangladesh, rice is cultivated three seasons per year. The three rice-growing seasons are *Aus* (May–August), *Aman* (July–November), and *Boro* (January–May). *Aus* and *Aman* are grown in wet seasons, in which rice is cultivated mainly as a rain-fed crop; whereas *Boro* is grown in the dry season under controlled irrigation. For deep placement of fertilizers, farmers use 1.8-g UB (52 kg/ha N) during the wet seasons and 2.7-g UB (78 kg/ha N) during the dry season.

Design of the Applicators: Fabrication and Operation Mechanisms

Injector-Type

The design of this applicator was developed from the plunger-type applicator [13]. The injector-type applicator consists of 15 parts (Fig. 1); these were mostly constructed from polyvinyl chloride (PVC) materials, with the

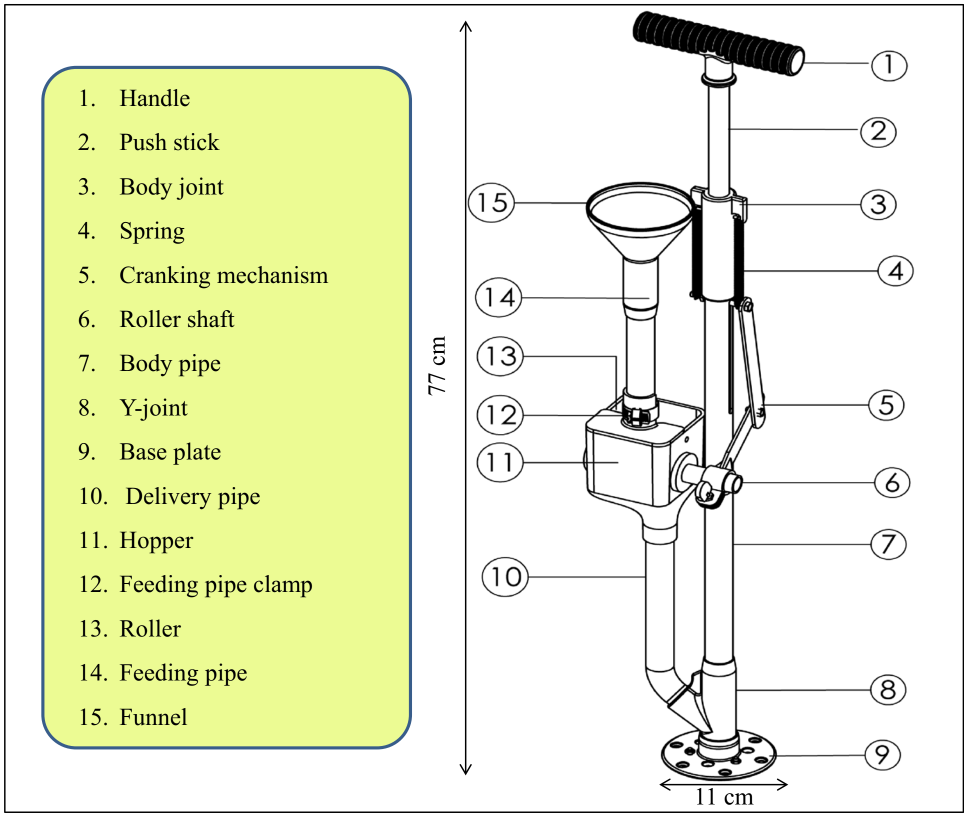

Fig. 1 Schematic diagram of injector-type applicator

exception of the spring (steel) and the cranking mechanism [mild steel (MS) flat bar]. It is manually operated and has simple operating mechanisms.

The applicator has four functional mechanisms—feeding, metering, delivery, and placement. The feeding mechanism consists of a funnel and a feeding pipe. About 60 briquettes of 2.7-g size can be placed in the funnel (hopper). The metering mechanism consists of the roller and cranking mechanism. The roller contains two holes at the periphery. There are 20- and 22-mm-diameter holes for 1.8- and 2.7-g UB, respectively. The roller hole can be adjusted vertically with the feeding pipe hole to correspond to the briquette size used. The delivery mechanism is made up of the delivery pipe, Y-joint, and base plate. This delivers and holds the briquette for proper placement. The placement mechanism consists of a handle, spring, and push stick. It places the briquette at a depth of 7–10 cm below the soil surface (Fig. 2).

During field operation, the roller hole is set according to the fertilizer requirement of the cropping season (20-mm-diameter hole for *Aus-Aman* and 22-mm-diameter hole for *Boro*). The funnel and feeding pipe are filled with the UB of the correct seasonal size, i.e., 1.8 g for the *Aus-Aman* seasons and 2.7 g for the *Boro* season. The person operating the applicator carries about 2.0 kg of UB in a small side bag. A single UB is applied by placing the applicator at the center of four rice hills and pushing the stick downward. After pushing the handle downward against the spring, the metering roller carries a single briquette through its hole and rotates about 160 degrees downward under the action of the cranking mechanism. When the hole is in the downward position, a UB is released. The UB is then delivered to the foot gasket through the delivery pipe and Y-joint. At the first push, the UB stays in the gasket; at the second push, the head of the push stick carries the UB to the point of placement in the soil. At every push thereafter, one UB is placed at a depth of 7–10 cm in the soil. After each push of the stick, it returns to the top position through spring action. When the push stick returns, a vacuum is created above the UB, and soil covers the UB. The funnel is refilled with UB before the feeding pipe is empty.

Push-Type Single-Row Applicator

The design of the single-row push-type applicator has the same operating mechanisms as the double-row push-type applicator developed earlier by BARI (BARI model). The single-row applicator retains only one hopper, metering device, skid, and furrow opener, as compared to two such sets in the double-row BARI model. However, the single-row features two cage wheels to maintain balance. It deep-places fertilizer in a single row, thereby providing fertilizer

Fig. 2 Field operation of injector-type applicator, *inset* picture shows urea briquettes

for two rows of rice (vs. four rows of rice through the BARI model). It is prepared with locally available, cheaper materials—plastics, MS flat bars, MS shafts, MS hollow boxes, nuts, and bolts (Fig. 3). The design has eight functional parts including handle, skid, hopper, cage wheel, metering device, frame, furrow opener, and furrow closer. The functions of each part and the modification from the previous version are described in Table 1.

During field operation, the skid of the applicator is placed in between two rows of rice, keeping the cage wheels in the outside rows (rows not receiving briquettes) (Fig. 4). Two-thirds of the hopper is filled with briquettes. The angle of the handle is adjusted so that the skid remains parallel to the field and pushed in a forward direction. As the skid moves forward, the cage wheels, as well as the metering device, rotate. During rotation, each cup of the metering disk collects a briquette from the hopper. As the skid moves forward, it helps the applicator glide across the surface of the flooded rice field, and the furrow opener opens a furrow. Briquettes are dropped in the furrow at a depth of 5–7 cm, with a spacing of 40 cm along the rows. Just after the placement of briquettes under the soil, the furrow is closed by the furrow closer. The total width of operation for a single pass is 40 cm. During field operation, the operator keeps his or her legs in the same rows as the cage wheels. The optimum operation speed is about 2.5 km/h.

Performance Evaluation of Applicators

After fabrication, applicators were tested in the laboratory/workshop to check their preliminary performance, such as depth of placement, uniformity of dropping (precision placement), and breakage of the briquettes in the hopper. Thereafter, applicators were tested in different farmers' fields, and the time required per unit of land (h/ha), percentage of missing briquettes, and comparison of grain yield with hand placement methods were recorded.

Laboratory Test

The test of the injector-type applicator was performed with 1.8- and 2.7-g UB for precision placement, missing placement, and broken briquettes during operation.

Fig. 3 Photograph of single-row push-type applicator showing different parts

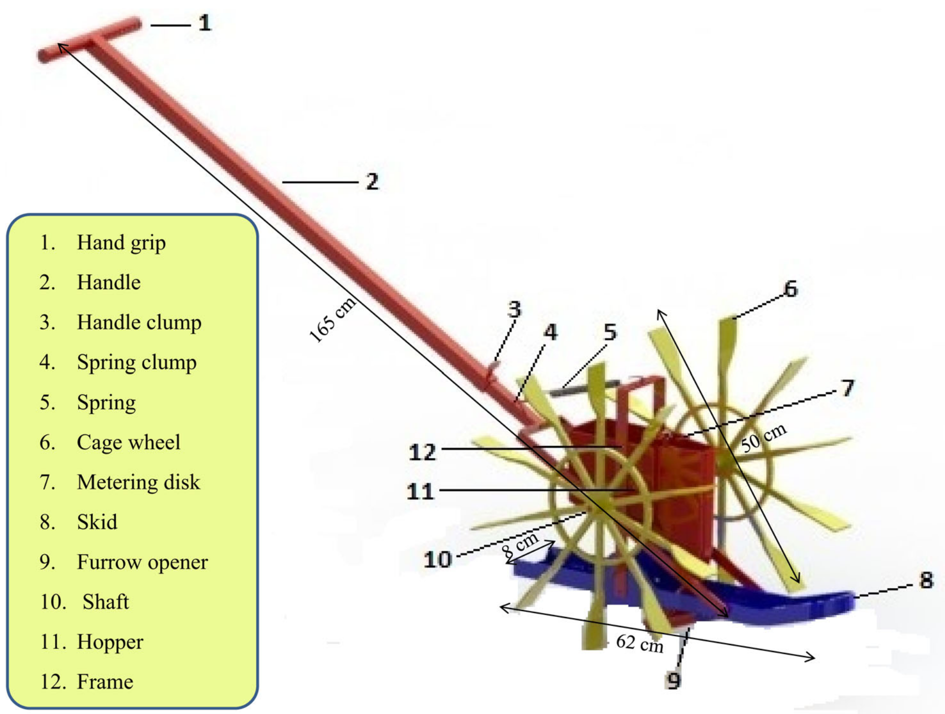

Table 1 Functional parts and their functions of single-row push-type applicator

Parts of applicator	Specific functions
Handle	It is made of MS hollow box, and the length is adjustable. It is fitted to the skid to apply the forward movement of the applicator
Spring	A stainless spring is incorporated between handle and frame to maintain horizontal/parallel position of the skid with the field. Spring tension increases or decreases based on soil conditions
Cage wheel	It is made with plastic. There is a cage wheel on each side of the skid joined with a shaft. The shaft passes through the hopper. It rotates the metering disk
Metering device	It is made of plastic. There are four cups at the periphery of the metering disk. It delivers the briquette from hopper to furrow opener. At every revolution of the cage wheel, the metering device delivers four briquettes of any size (1.8 or 2.7 g) at a spacing of 40 cm by 40 cm in rice field
Skid	It is made with plastic. It contains a furrow opener and a furrow closer, and is connected to the handle and frame. When the skid is pushed along by the handle, it skids/floats on the puddled soil surface. The width of the skid has been reduced from 10 to 8 cm from the previous design (BARI model). The narrow width allows the applicator to stay in such a position in the soil so that water is removed from the bottom of the skid. As a result, the chance of briquette accumulation inside the furrow of the applicator is much less likely
Furrow opener	It is made of plastic and attached to the skid on the bottom side. It makes the furrow for the briquette placement. The width of the furrow opener is reduced to 30 mm from 40 mm of the BARI model, which ensures proper furrow closing
Furrow closer	This is part of the skid that closes the furrow after briquette placement
Hopper	It is made with plastic. It holds the briquettes, and its capacity is about 800 g
Frame	It is made of MS flat bar and fitted to the skid. It supports the hopper and cage wheels

Fig. 4 Field operation of single-row push-type applicator

Similarly, the single-row applicator was tested in sand beds to determine whether the distribution of briquettes was uniform or not.

Field Test

After satisfactory laboratory tests, both applicators were tested in the farmers' fields across different agro-ecological zones of the country during different rice-growing seasons in 2013–2015. During field testing, the precision of fertilizer briquette dropping (the spacing of fertilizer briquette placement as well as recording of any missing briquettes), placement depth, and accumulation of briquettes in the furrow under different field conditions were recorded. Ideal fields and expert operators were used to conduct the test. The performance of the applicators in terms of grain yield was compared with traditional hand placement and prilled urea broadcast methods. Four different treatments were included—single-row applicator, injector applicator, hand placement, and prilled urea broadcast.

Recommended rates of phosphorus, potash, and zinc were applied during land preparation. In all treatments, 1.8- or 2.7-g size briquettes, based on seasonal requirements, were used to arrive at urea application of 112 or 169 kg/ha for the *Aus-Aman* and *Boro* seasons, respectively. Paddy seedlings were transplanted at 20 cm × 20 cm spacing. Individual plot sizes were 400 m^2, and total plot size for four treatments was 1600 m^2. Briquettes were placed 6–10 days after transplanting. During the deep placement of briquettes, a 2–5 cm depth of water was maintained. Time required for application, amount of briquettes applied, and breakages of the briquettes in the hopper during application were recorded. Intercultural operations were completed when necessary. Plant height, tiller and panicle numbers, and grain yield were recorded at harvest from two sample plots (5 m^2/plot).

Results and Discussions

Comparison of Design and Operation Efficiency Between Two Applicators

The injector-type applicator consistently deep-placed UB at a 7–10-cm depth and covered UB properly with soil. The weight of the injector applicator is only 1.5 kg, unlike the 3.5-kg plunger-type applicator developed earlier by IFDC [13]. It is easy to operate in the field since it can be operated by a single hand. The plunger-type applicator had two PVC plungers, two PVC delivery tubes, and two plastic skids connected by a wooden frame. In the plunger-type applicator, the operator feeds UB to the delivery pipe for each placement due to the absence of a hopper, which in turn requires two hands for operation, whereas the injector-type applicator features a feeding funnel that can contain 50–60 briquettes and requires only one hand to operate. The injector-type applicator is more effective than hand placement in terms of depth of placement and coverage of briquettes. Missing placement and broken briquettes in the hopper due to the movement of the feeding cup were less than 1% of the UB used. The results were consistent for both types of briquettes (1.8 and 2.7 g), which can also be minimized by using standard quality UB. Although the ideal floodwater depth for UDP is 2–5 cm, it was found that the injector-type applicator can be used in fields with variable floodwater depths, including submerged rice fields. Its unit cost is BDT 475 (US $6.00), which is affordable for smallholder farmers and is appropriate for both standard sizes of briquettes. However, use of this applicator remains time-consuming, requiring almost the same amount of time as hand placement methods. Because of this, the total cost of labor may not be reduced as compared to hand placement, which means that farmers are still seeking a more efficient applicator that will reduce labor requirements. Nevertheless, the injector-type applicator does reduce drudgery and back pain associated with hand placement while increasing precision.

The single-row push-type applicator is relatively convenient to operate as compared to the earlier developed double-row applicator [5, 6]. The double-row push-type applicator was uncomfortable to operate in rice fields due to its heavy weight. Poor performance of applicators in terms of nitrogen use efficiency and grain yields is mainly associated with precision placement (depth and spacing) and coverage of UB with soil. Improper coverage of UB after deep placement releases nitrogen into the soil surface and leads to losses through surface runoff and ammonia volatilization. Proper design of the furrow opener and skid (the rear of which is the furrow closer) may ensure coverage of UB with soil. Therefore, significant improvements have been made in the design of the skid, furrow opener, and furrow closer to increase working efficiency. The weight of the single-row applicator is 4.5 kg as compared to 9–10 kg for the double-row applicators developed by BARI, BRRI, and BAU. It requires less energy to push forward in flooded soils as compared to the double-row models. Depth of deep placement was found to be 5–7 cm, which is relatively less than that achieved by the injector-type applicator, but still sufficient to gain efficiencies as long as applied UB are covered with soil. Furrow opening and proper closing after briquette deep placement varied from soil to soil. Proper furrow closing was observed when deep placement was done within 7 days of transplanting. If deep placement was delayed, soils generally become hard, which creates problems for furrow opening, and briquettes may not be adequately covered, resulting in reduced efficiency of deep placement. Ideal floodwater depth for deep placement with the single-row push-type applicator is similar to that required for optimal use of the injector-type applicator, 2–5 cm.

Sand bed test results show that, on average, 3% of the briquette placement points were missed when the single-row push-type applicator was used. This was due to non-uniform speed and jerking/vibration of the applicator during operation on the sand bed. The percentage missed could be reduced during operation in a puddled field. About 48% of briquettes were placed at the recommended spacing (40 cm), 24% at 35-cm spacing, and 27% at 45-cm spacing. However, the total amount of fertilizer placed in the plots was close to the recommended rate. Overall, the pattern of briquette distribution was satisfactory but with room for improvement.

Results of field tests of the applicator for briquette dropping, placement, missed placement, and dropping more than one briquette at a place (accumulation) in different field conditions are shown in Table 2. The amount of missing UB was 5%, and accumulation of UB under puddles was negligible. Missing UB could further be reduced with increased experience of the operator. Depth of placement was set at 5–7 cm. Unit price of the single-row push-type applicator is BDT 1350 (US $17.00), which is affordable for smallholder farmers. Although the single-row applicator is relatively more expensive than the injector-type applicator, it is easy to operate in the fields and saves labor (Table 3).

Comparison of Labor Requirements

The single-row push-type applicator was faster (15–24 h/ha) than both the injector and hand placement methods in all seasons. The injector-type applicator required the highest amount of time (33–50 h/ha) but was not significantly different from the manual placement method (28–42 h/ha) (Table 3). The single-row push-type applicator reduced the time by about 51% as compared to other methods. The single-row push-type applicator is more comfortable and reduced drudgery compared to hand and injector applicator placement. The time (h/ha) reported here does not include rest cycles and related time loss associated with fatigue during operation. Generally, an

Table 2 Results of field tests of push-type single-row applicator at different field conditions (speed of applicator operation—1.5–2.0 km/h)

Location	Row length (m)	Briquette required (no)	Briquette dropped (no)	Briquette missing (%)	Depth of placement (cm)	Briquette accumulates in furrow (no)
1	20.0	51	47	7.8	6–7	0
2	18.0	46	43	6.5	6–7	0
3	17.5	44	42	4.5	6–7	0.7
4	18.0	46	44	4.3	6–7	0
5	20.0	51	49	3.9	5–6	0.7

Table 3 Comparison of time required for deep placement of urea briquettes in different methods of application during different rice-growing seasons in 2013–2015

Application methods	Time required for briquette placement (h/ha)						
	Boro 2013	*Aus* 2013	*Aman* 2013	*Boro* 2014	*Aus* 2014	*Aman* 2014	*Boro* 2015
Push-type single-row	15.5b	–	–	–	–	20.5c	23.9b
Injector-type	35.6a	44.9a	43.8a	46.5a	49.5a	33.1a	32.6a
Hand placement	32.1a	39.7a	39.8a	41.6b	42.8a	28.6b	30.7a

Within a column, means followed by the same letters are not significantly different at the 5% level by LSD test

operator requires 5–10 min of rest time per 1 h of operation.

Comparison of Grain Yields Between Applicators and Hand Placement

Grain yields obtained after the use of the injector-type and single-row push-type applicators were similar to those obtained after hand placement in the *Boro* 2013, *Aman* 2014, and *Boro* 2015 seasons (Table 4), suggesting that both applicators were effective in terms of depth and distribution of briquettes. Similarly, grain yields between the injector-type applicator and hand placement were similar across all rice-growing seasons. On the other hand, grain yields for broadcast prilled urea were significantly lower than yields obtained when placing UB through any method.

Both the injector-type and single-row push-type applicators are now commercially manufactured by "RFL—Bangladesh." They performed well in farmers' fields, reduced labor requirements (in the case of the single-row push-type applicator), and are affordable to smallholder farmers in Bangladesh. Therefore, these applicators are suitable for use in Bangladesh's rice production systems. Furthermore, the mechanism used in the push-type applicator is being used as the basis for the development of several prototype mechanized UB applicators.

Conclusions

Two types of manually operated applicators, an "injector-type" (non-continuous operation) and "single row push-type" (continuous operation), were designed for the deep placement of urea briquettes in puddled rice fields. The single-row push-type applicator solved technical weaknesses of the earlier developed double-row push-type applicator. In addition to reduction in its weight, the furrow opener and skid of the single-row push-type applicator have been modified to ensure precision placement of fertilizer briquettes at 5–7-cm soil depth. Applicators cover only one row at a time and are adjustable in farmers' fields with variable plant spacing. Applicators were compatible

Table 4 Results of field performance of different method of application during *Boro*, *Aus*, and *Aman* seasons in 2012–2015

Application methods	Grain yield (kg/ha)						
	Boro 2013	*Aus* 2013	*Aman* 2013	*Boro* 2014	*Aus* 2014	*Aman* 2014	*Boro* 2015
Single-row applicator	6.674a	–	–	–		6.014a	6.657a
Injector applicator	6.761a	4.613a	5.064a	6.827a	5.641a	5.978a	6.899a
Hand placement	6.750a	4.553a	5.066a	6.783a	5.559a	6.169a	6.978a
Prilled urea broadcast	–	4.001b	4.367b	5.976b	4.624b	5.181b	5.885b

Within a column, means followed by the same letters are not significantly different at the 5% level by LSD test with both 1.8 and 2.7 g briquettes, and briquette distribution and placement depth were found to be as recommended. The single-row push-type applicator reduced labor requirements by 51% when compared to either hand placement or placement using the injector-type applicator. Although use of the injector-type applicator required similar time as hand placement, it reduced the drudgery and back pain typically associated with placing briquettes by hand. Field performance of the applicators was comparable with hand placement methods across different tested locations of Bangladesh. Since applicators reduced labor costs significantly (in the case of the single-row push-type applicator), increased the precision of fertilizer placement (in the case of the injector-type applicator), and reduced the drudgery associated with hand placement, the availability of these applicators may encourage smallholder farmers to adopt UDP in rice production. However, full mechanization of deep placement is needed for larger-scale adoption.

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Author's Contribution MAW took part in engineering design of applicators, setup of field experiments, data collection, and preparation of draft manuscript. YKG performed data analysis and writing manuscript. ATMZ and MAH carried out engineering design of applicators.

Compliance with Ethical Standards

Conflict of interest Authors declared no conflict of interest.

References

1. Ahamed MS, Ziauddin ATM, Sarker RI (2014) Design of improved urea super granule applicator. Int J Appl Sci Eng Res 3:98–100
2. Bautista EU, Suministrado DC, Koike M (2000) Mechanical deep placement of fertilizer in puddled soils. J Jpn Soc Agric Mach 62:146–157
3. Dong NM, Brandt KK, Sorenson J, Hung NN, Hach CV, Tan PS, Dalsgaard T (2012) Effects of alternate wetting and drying versus continuous flooding on fertilizer nitrogen fate in rice fields in the Mekong Delta, Vietnam. Soil Biol Biochem 47:166–174
4. Gaihre YK, Singh U, Islam SMM, Huda A, Islam MR, Satter MA, Sanabria J, Islam MdR, Shah AL (2015) Impacts of urea deep placement on nitrous oxide and nitric oxide emissions from rice fields in Bangladesh. Geoderma 259–260:370–379
5. Hoque MA, Wohab MA, Hossain MA, Saha KK, Hassan MS (2013) Improvement and evaluation of BARI USG applicator. Agric Eng Int CIGR J 15(2):87–94
6. Hossen MA, Islam MS, Rahman MA, Huda MD, Bhuyain MGK, Nath BC (2013) Design and development of manually operated urea supper granule (USG) applicator. Agric Mech Asia Afr Lat Am 44(2):85–91
7. Huda A, Gaihre YK, Islam MR, Singh U, Islam MdR, Sanabria J, Satter MA, Afroz H, Halder A, Jahiruddin M (2016) Floodwater ammonium, nitrogen use efficiency and rice yields with fertilizer deep placement and alternate wetting and drying under triple rice cropping systems. Nutr Cycl Agroecosyst 104:53–66. doi:10.1007/s10705-015-9758-6
8. Islam SMM, Gaihre YK, Shah AL, Singh U, Sarkar MIU, Sanabria J, Biswas JC (2016) Rice yields and nitrogen use efficiency with different fertilizers and water management under intensive lowland rice cropping systems in Bangladesh. Nutr Cycl Agroecosyst 106:143. doi:10.1007/s10705-016-9795-9
9. Khan AU, Kiamco LC, Tiaugco VM, Camacho IR (1984) Applicators for improved fertilizer use efficiencies in wetland paddies. Philipp J Crop Sci 9:206–216
10. Miah MdAM, Gaihre YK, Hunter G, Singh U, Hossain SA (2015) Fertilizer deep placement increases rice production and economic returns in southern Bangladesh. Agron J 108:1–8. doi:10.2134/agronj2015.0170
11. Savant NK, Ongkingco PS, Garcia FD, Dhane SS, Khadse RR, Chavan SA, Rao KS (1992) Agronomic performance of urea briquette applicator in transplanted rice. Fertil Res 32:139–142
12. Savant NK, Stangel PJ (1990) Deep placement of urea super granule in transplanted rice: principle and practice. Fertil Res 25:1–83
13. Savant NK, Ongkingco PS, Zarate IV, Torrizo FM, Stangel PJ (1991) Urea briquette applicator for transplanted rice. Fertil Res 28:323–331
14. Wohab MA, Islam MS, Haque MA, Hossain MA, Ahmed S (2009) Design and development of a urea super granule applicator for puddle rice field. J Agric Eng 37:57–62