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Development of mechanical urea briquette applicator for SRI

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ABSTRACT

India is the second largest consumer of fertilizers in the world. In wetland paddy cultivation, only 30–40% of nitrogen applied is fruitfully utilized as about two-third is lost through gaseous losses, runoff, and leaching or is immobilized in the soil. Deep placement of urea briquette (UB) by hand after conventional line transplanting at the rate of one UB near the centre of each four rice hills and at soil depth of 7–10 cm reduces nitrogen losses and increases fertilizer use efficiency, but is a time consuming and labour intensive process. A two-row prototype urea briquette applicator was designed, developed and evaluated under simulated condition of system of rice intensification technique (25 cm × 25 cm) in the field of ICAR-IARI in 2013–14. Row-to-row spacing was 50 cm as the distance between two furrow openers. The mechanical urea briquette applicator recorded average distance of placement of 51.44 cm in the row, depth of placement of 7.66 cm, draft of 92.41 N, field capacity of 0.05 ha/h, field efficiency of 69% and field machine index of 69.6% during the operation in the field at forward speed of 0.87 km/h.

Keywords: Deep placement, Mechanical applicator, SRI, Urea briquette

India is the second largest consumer of fertilizers in the world, after China. The total annual nitrogen consumption in Indian agriculture is 16.73 Mt (FAO 2018), of which about 40% is consumed by rice. In wetland rice cultivation, only 30–40% of nitrogen applied is fruitfully utilized as about two-third is lost through gaseous losses, runoff, and leaching or is immobilized in the soil (Savant *et al*. 1992). Urea briquette deep placement resulted into 15% higher grain yield with 30% less urea consumption compared to split application (Roy 2014). Manual deep placement of USG decreased urea-N losses, improved N availability to rice plants, and increased grain yield significantly, especially at lower N-application rates (30-40 kg N/ha) that small farmers could afford. However, deep placement of USG by hand after transplanting is a slow field operation (0.07–0.12 ha/day), and thus required much labour (Rao 1983). Several attempts (Khan *et al*. 1984, Savant and Stangle 1990, Savant *et al*. 1992, Jaiswal and Singh 2001, Kadam 2001, Bautista *et al*. 2001) had been made to evaluate Urea Briquette (UB) deep placement technology by placing each ball of UB manually or with applicator in transplanted rice at 3-10 cm depth in the soil. UB is deep placed in the centre of each 4 hills of rice after 1-10 days of transplanting for minimizing labour requirement, increasing N-use efficiency (31%), increasing grain (5–83%) and straw (9–62%) yield (Kadam 2001). Study with different combinations of organic fertilizer and Azola-compost with urea fertilizer using system of rice intensification (SRI) indicated more tiller numbers (28%), more chlorophyll content at panicle initiation stage (28%) and flowering time (13.5%), more panicles/m^2 (60%), higher number of filled grains/m^2 (20.6%), spikelets/panicle (19.6%) and more grain yield (30.6%) with combined use of organic and chemical fertilizer compared with chemical fertilizer alone (Larijani and Hoseini 2012). Thus, in system of rice intensification, this technology has potential. However, applicators were scarcely available for system of rice intensification technique. Hence, present urea briquette deep placement applicator for SRI was developed to improve fertilizer use efficiency, saving on input cost and net return.

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MATERIALS AND METHODS

The mechanical urea briquette applicator was fabricated and tested at the laboratories of Division of Agricultural Engineering, ICAR-IARI, New Delhi during 2013–14. The experimental site is located at 28°38'22" N, 77°10'24" with an altitude of 228.61 m amsl.

Machine components: A two-row manually operated mechanical urea briquette applicator (Fig 1) for system of rice intensification technique was designed and developed after determining the physical and engineering properties of urea briquette. Based on the physical and engineering properties, viz. size, shape, weight, sphericity, roundness, bulk density, true density, angle of repose, coefficient of static friction, the designs of metering mechanism and other applicator parts were determined (Deo *et al*. 2019). Vertical cup feed metering mechanism, ground wheel, and hopper

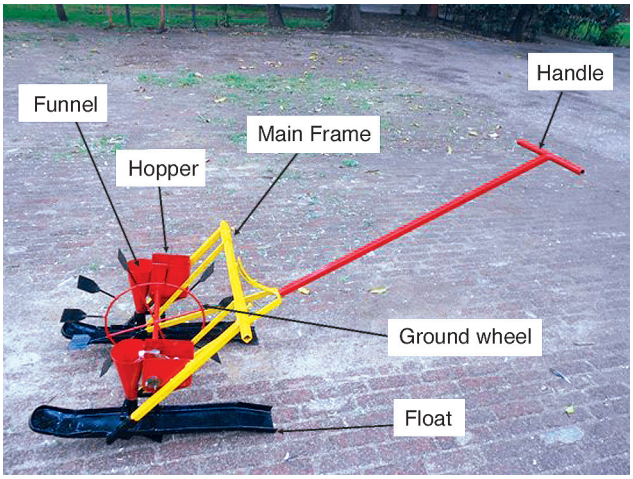

Fig 1 Fabricated unit of mechanical urea briquette applicator.

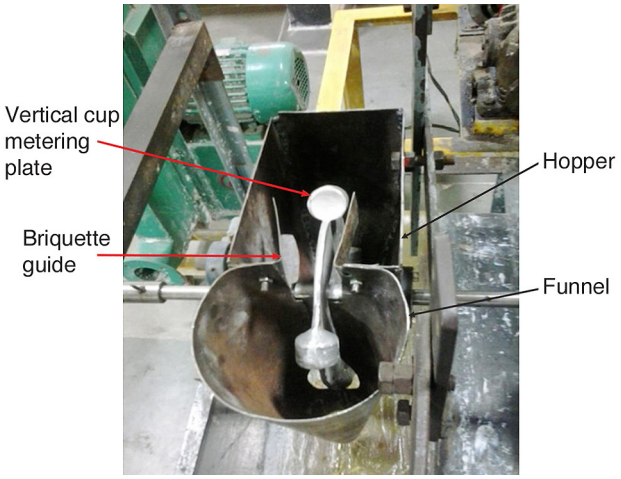

Fig 2 Urea briquette applicator hopper and metering mechanism.

were the important components from design point of view.

Hopper with briquette guide: The selection of the shape of hopper (Fig 2) was done with the basic consideration that each hopper should carry desired quantity of briquette, and the briquettes should be picked up easily and carried towards the delivery funnel attached to the hopper. The former is governed by size, shape and the latter is governed by angle of repose. Considering these, the hopper shape was selected as rectangular on top and pyramidal at the bottom. The volume of the hopper was determined on the basis of the briquette discharge rate (Y in kg/ha), density (ρ in kg/m^3), row-to-row spacing (a in m), briquette-to-briquette spacing (b in m) and number of briquettes to be dropped at a time (n_1).

Briquette delivery rate was thus determined as following: Effective area covered by a briquette on ground = $a \times b$, Where, a = Row-to-row spacing, m, and b = Briquette-to-briquette spacing, m. Number of briquettes per ha, $n = \frac{10^4}{a \times b}$, Total number of briquettes required per ha, $N = n \times n_1 = \frac{n_1 \times 10^4}{a \times b}$, Where, n_1 = Number of briquette dropped at a time, Theoretical briquette delivery rate is given by: Y, kg/ha = (number of briquette/ha) × (weight of each briquette (x) in g) = $\frac{n_1 10^4 \times x}{a \times b \times 10^3}$, In present case n_1 =1, Mean weight of each briquette of UB_1(x), g = 2.81 g, Row-to-row spacing (a), m = 0.50 m, and Briquette-to-briquette spacing (b), m =0.50 m. So, briquette discharge rate for UB_1 = $\frac{1 \times 10^4 \times 2.81}{0.5 \times 0.5 \times 10^3}$ = 112.4 kg/ha (Deo 2013).

Hopper capacity: Considering rectangular portion of the hopper with the following dimensions: B= Width of box, 9 cm, L = Length of box, 15 cm, D = Depth of box, 12 cm, h = Depth of pyramidal portion, cm, Volume of hopper = volume of upper rectangular portion + volume of lower rectangular pyramid = (L × B × D) + $\{\frac{1}{3}$ (B × L) × h$\}$ = 1620 +270 =1890 cm^3. Capacity of each hopper, Q = (Volume× Bulk density of urea briquette (ρ)) = 1890 cm^3 × 0.75 g/cm^3 =1417.5 g (1.42 kg). Thus, total area covered by the applicator, when both hopper were full, m^2 = $\frac{1.42 \times 2 \times 10^4}{112.4}$ = 252.67 m^2 (Deo 2013).

Delivery funnels and furrow opener: The delivery funnel and furrow opener were designed with consideration given to the optimum depth of briquette placement. The delivery funnel (Fig 1) was made of mild steel of 1.15 mm thickness with conical section of upper diameter 11 cm and lower diameter 3 cm. The height of the delivery funnel was kept close to the ground to achieve spacing uniformity. Triangular wedge furrow opener of 18 cm length was provided at the outlet for the discharge of briquette. For depth of briquette drop of 7 cm, maximum bottom height of the furrow opener was kept at 7 cm. The furrow opener was welded to the float. Briquettes were covered by the flow of puddled soil during operation with the help of a covering device.

Ground wheel: A ground wheel (Fig 1) of diameter 64 cm with 12 pegs was fabricated using mild steel rod of 7 mm diameter and mild steel sheet of 1.15 mm thickness. Pegs were fixed at a regular interval on the circular section of diameter 36 cm to develop traction or grip in puddled soil. Total length of each pegs was 14 cm, which consists of circular rod and rectangular section of length 6.5 and 7.5 cm, respectively. Rectangular section of each peg had dimensions of 7.5 × 5 cm^2.

Float: Two floats (Fig 1) of 83 cm length and 10 cm width were fabricated using mild steel of 1.15 mm thickness. Wedge type furrow openers were attached at the bottom of each of float, and a circular opening was provided for the delivery pipe to deliver the briquettes.

Handle: An ergonomic consideration for design of the applicator was made. The handle (Fig 1) height depends on the shoulder height (Acromial height) of the user population. It is suggested that height of push-pull type weeder should be 0.7 times the shoulder height as it gave least fatigue during operation (Data book for agricultural machinery

design 2004). Handle height ranges from 860–1020 mm, depending on regional variation. The average acromial heights of male and female workers are 1336 mm and 1266 mm, respectively. Therefore, to cover maximum population of workers, handle height of 886 mm was provided for the equipment to be operated by both male and female workers. To provide proper grip for effective force application while working, the grip dimensions were designed based on two parameters, grip diameter (inside) and middle finger palm grip diameter. The average grip diameter (inside) for male and female are 45 mm and 41 mm, respectively. So, a maximum handle grip diameter of 41 mm should be provided. The length of grip depends on the breadth of palm across thumb of the population and it should be decided based on 95th percentile person operating the machine. The minimum handle grip length should be 109 mm for male and 96 mm for female operated machine. For machine to be operated by both genders, optimum length of grip should be 109 mm.

Specifications of anthropometric dimensions of the handle of wheel hand hoe (Data book of agricultural machine design 2004) were given as: diameter of the grip 30–40 mm, length of grip greater than 12.5 cm, height of the handle grip of the wheel hoe 900–1100 mm from the ground during operation, Based on the specifications, diameter of the handle grip, length of the grip and height of the handle grip were selected as 40 mm, 35 cm and 102 cm, respectively, so that an average worker could operate the machine comfortably.

Metering mechanism: The vertical cup feed metering mechanism (Fig 2) having cups of different shapes and sizes was considered for metering of urea briquettes. For ground wheel diameter of 64 cm, row-to-row spacing of 0.50 m and briquette-to-briquette spacing of 0.50 m as per SRI recommendations, the required number of cups on the vertical rotor was determined to be 4 since the number of briquettes to be discharged per square meter of paddy field was four. Optimal vertical cup depth of 6.5 mm was selected for urea briquette of 3g weight for estimated application rate of 112.4 kg/ha (Deo 2013). The vertical cup feed metering mechanism was fabricated using 200 mm × 200 mm × 30 mm cast aluminium plate. The plate was machined and each of the four cups with outer diameter of 25 mm, inner diameter of 20.63 mm and depth of 6.5 mm were machined. Cups were integral part of rotor. The rotor had a diameter of 155 mm and 3 mm in thickness.

Main frame: The main frame (Fig 1) of the unit was fabricated using hollow iron pipe (25 mm × 25 mm × 2 mm) which was attached to two floats at the bottom. Urea briquette hopper with metering mechanism was fixed on the frame. A delivery funnel was attached to each of the hopper. The hoppers, funnel and float were made from mild steel sheet of 1.15 mm thickness. Metering mechanism was fixed to the same shaft attached to the ground wheel and got direct power transmission from the ground wheel. To steer the machine, a handle was also mounted at the rear end of the main frame (Table 1).

Table 1 Specifications of the developed applicator

Parameter	Dimension
Length	1.95 m
Width	59 cm
Height	1.02 m
Weight (empty)	15 kg
No. of hopper	2
Capacity of each hopper	1.42 kg
No. of furrow opener	2
No. of float	2
Distance between furrow opener	50 cm
Drive wheel	1 of 64 cm diameter
No. of metering rotor	2
No of cups on each rotor	4
Depth of each cup	6.5 mm

Power transmission system: The power from the ground wheel transmitted directly to the metering mechanism as both were fixed on the same shaft.

Field evaluation

Location: The urea briquette applicator (Fig 1) was evaluated for its performance in sandy loam puddled soil at ICAR-IARI, New Delhi. The field was prepared into fine puddled soil by two passes of rotavator, followed by irrigation up to 10 cm water level and again two passes of cultivator followed by two passes of leveller. The field was divided into three plots of size 10 × 10 m^2 each for testing of the applicator. A simulation condition of system of rice intensification was made in the field, through required intermittent irrigation to maintain saturation condition for one week. Tests were conducted on the eight day after drainage of excess water. The applicator was tested manually and observations with replications at random in each of the sub-plots.

Laboratory calibration: Urea briquette was filled in two hoppers of the mechanical applicator, ground wheel jacked up and 10 revolutions were given to the ground wheel. The briquette discharged from each of delivery funnel were collected separately and counted. Ten replications were taken.

Field performance: The following performance indicators were calculated using the observed data in the field: i) Draft, ii) Field capacity, iii) Field efficiency and iv) Field machine index.

Draft

Overall pulling force (P) was measured using spring dynamometer attached to a wire with the applicator, when it was operated by pulling it. The angle made by the wire was calculated and then draft was calculated as: *Draft (N)* = $PCos\theta$, where, P = Overall pull, kg, and θ = Angle made by pulling wire to the horizontal (Deo 2013).

Field capacity and field efficiency: The theoretical

Table 2 Field performances of urea briquette applicator

Performance parameter	Value
Average distance of briquette placement, cm	51.41
Average depth of placement, cm	7.66
Average draft, N	92.41
Average forward speed, km/h	0.87
Average field capacity, ha/h	0.05
Average field efficiency, %	69
Average field machine index, %	69.6
Average work output, ha/day	0.40
Average time taken to cover each plot of 10 × 10 m^2, min	11.49
Total time loss for each plot of 10 × 10 m^2, min	1.7

field capacity is the rate of field coverage that would be achieved if the applicator was operated continuously without interruption like turning at the ends and filling of hopper. The effective field capacity is the actual average rate of coverage including the time lost in filling and turning at the ends of rows. The field efficiency was determined as the ratio of effective field capacity to the theoretical field capacity multiplied by hundred (Deo 2013).

Field machine index: Field machine index (FMI) was calculated using the formula [(Tp-To-Tt)/(Tp-To)]×100, where FMI=Field machine index, per cent, To= Theoretical field time, min/plot, Tp= Total productive time, min/plot, and Tt= Total turning time, min/plot, which indicated the influence of field geometry on working capacity of the machine (Deo 2013).

RESULTS AND DISCUSSION

Laboratory calibration: In laboratory row-to-row variation in briquette metering and uniformity of briquette delivery were studied. The results indicated that variation of average number of briquettes discharged from the two rows was non-significant. An overall average of 37.5 briquettes was discharged in 10 revolutions of the ground wheel. The maximum deviation of briquette discharge of any row from the average was less than 5%. All the deviations were within the range of 7% by the Indian standards (Deo 2013).

Field evaluation: The average briquette placement depth of 7.66 cm in soil was observed, which was in the range of recommended 5-10 cm depth for deep placement of urea briquette (Table 2). The average distance of placement was 51.44 cm in the row, near to the recommended practice of 50 cm distance for system of rice intensification technique (25 cm × 25 cm). Row-to-row spacing was 50 cm and was same as the distance between two furrow openers. The urea briquette applicator could thus place the briquette at required depth and at required distance in a row. The average draft requirement of 92.41 N was recorded for the applicator. The power required to operate the applicator was 22.33 W, which was within human capability of one operator. The average field capacity was 0.05 ha/h for continuous operation of the applicator at an average forward speed of 0.87 km/h. Field efficiency of 69% was observed, which was in prescribed range of 65–75% for planter performing similar operation (Kepner *et al*. 2005). Major loss in field efficiency was due to low forward speed of applicator in puddled soil and turns at head lands. The field machine index was observed to be 69.6%.

A 2-row mechanical urea briquette deep placement applicator was developed for system of rice intensification technique. The metering mechanism and hopper were designed considering the physical and engineering properties of urea briquette. Average draft requirement of 92.41 N was recorded for the applicator, with power requirement of 22.33 W. Field capacity and field efficiency of the applicator was 0.05 ha/h and 69%, respectively, during operation at average forward speed of 0.87 km/h. Major loss in field efficiency was due to low forward speed in puddled soil and turns at head lands. The average depth of placement of briquette was 7.66 cm. The field machine index was 69.6%. Performance parameters, therefore, indicated satisfactory operation of the applicator.

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