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Design and evaluation of vertical cup metering mechanism for urea briquette application

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ABSTRACT

Vertical cup feed metering device was designed and evaluated at Division of Agricultural Engineering, ICAR-IARI, New Delhi during 2013–14 for singulation and uniform placement of urea briquettes in two forms, viz. UB_1 (3 g) and UB_2 (2 g). Performance parameters like average spacing, multiple index, missing index, quality feed index and precision were measured. The metering device was tested for different cup size depth of 6.5mm (CS_1), 3.5mm (CS_2) and 2.5 mm (CS_3) with hemi-spherical shape. The average spacing was significantly ($P<0.05$) influenced by different sizes of cup and sizes of briquette. Miss index was highly influenced by different cup sizes ($P<0.05$). The cup size (CS) influenced missing the most, followed by briquette size, but UB size did not influence missing index significantly. The briquette size influenced the multiple index most, followed by cup size of the metering mechanism ($P<0.05$). Quality of feed index was highly influenced by UB size, followed by CS of the metering mechanism. General mean of quality of feed index was 94.77%. The effect of urea briquette and cup size was found to be non-significant in case of precision. The general mean of precision was 13.30%. Based on the above parameters, optimum metering cup size was selected 6.5 mm and size of urea briquette UB_1 for applicator development.

Keywords: Metering device, Miss index, Multiple index, Precision, Urea briquettes.

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. Urea briquette is the compacted form of prilled urea, and contains about 1-3 g of urea. Deep placement of urea briquette (UB) by hand after 1-10 days of 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 up to 30%, but is a time consuming and labour intensive process (Savant *et al*. 1992). Several researchers (Savant and Stangel 1990, Savant *et al*. 1992, Jaiswal and Singh 2001, Bautista *et al*. 2001, Kadam 2001) carried out research on deep placement of urea briquette manually or with applicators and reported that rice yields with hand-placed urea briquettes and machine placed urea briquettes were either statistically similar or even better than the split-broadcast of prilled urea. Performance of urea briquette applicator mainly depends on its ability to place urea briquettes a given distance apart and at proper depth. Because of problems associated with fertilizer granules, and improper metering mechanism, machines developed to place them gave inconsistent results. Physical and engineering properties of urea briquettes play an important role in designing of urea briquette metering mechanism. Deo *et al*. (2019) studied the physical and engineering properties of urea briquettes for the design of urea briquette applicator and its metering mechanism. Based on these properties, vertical cup cell size of 20.63 mm and hopper slope of 52°C was selected for the design of metering mechanism. Kachman and smith (1995) and Rajaiah *et al*. (2016) tested and compared the most widely used measures of a seed metering mechanisms as mean, standard deviation, quality of feed index, multiple index, miss index and precision. Those measures were based on theoretical spacing (X_{ref}), specified in ISO 7256-1 standard (1984) and gave good indication of the spacing distribution. Keeping all this in mind a vertical cup feed metering mechanism was designed and evaluated for the development of urea briquette applicator.

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MATERIALS AND METHODS

Metering device is the main component of the applicator which places urea briquettes uniformly at a desired briquette discharge rate with minimum damage, and also controls briquette spacing in a row. Mechanical urea briquette metering devices in an applicator usually have cups on vertical rotor to have positive briquette metering. The commonly recommended metering systems on planters are

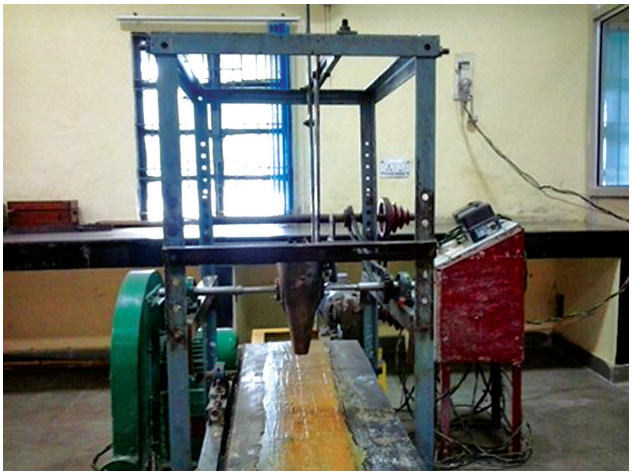

Fig 1 Sticky belt test set-up.

horizontal plate, inclined plate, vertical rollers with cells etc. (RNAM 1991). A vertical cup feed metering device was designed and evaluated at Division of Agricultural Engineering, ICAR-IARI, New Delhi during 2013–14 having cups of different sizes. The performance of different cup sizes was evaluated by varying the depth of cups for metering urea briquettes in both forms UB_1 (3g) and UB_2 (2g) for optimising the metering device dimensions.

Design of metering device: Vertical cup feed metering mechanism consisted of cups mounted on the periphery of a vertical rotor. The vertical rotor with cup passed through a hopper containing urea briquettes (Fig 1). Briquettes (Fig 2) were picked up in the cups and were dropped on the top of the inlet of the delivery funnel through a pair of guides. The rotor and outer cups were machined accurately to provide uniform cup size for precision planting of briquettes. The vertical cup feed metering mechanism having cups of different shapes and sizes was considered for metering of urea briquettes. The design of vertical cup feed metering mechanism for applicator involved determining the number of cups on a rotor, shape and depth of cup as per the required plant geometry.

Let,

a = Distance between rows, m, and

b = Briquette to briquette spacing distance in a row, m.

Then,

$$\text{S, number of briquette/m}^2 = \frac{1}{(b \times a)} \qquad (1)$$

The number of cups in the rotor was calculated as:

$$N = N = \frac{\pi \times d_g \times S \times a}{i} \qquad (2)$$

where, d_g = Diameter of ground wheel, m; S = Number of briquettes/m^2; a = Row spacing; i = Transmission ratio.

With the rotor fixed on the ground wheel drive shaft, the value of i is 1.

For diameter of ground wheel of 64 cm, row-to-row spacing of 0.50m, and briquette to briquette spacing of 0.50 m, the number of briquettes to be discharged per square metre of field could be completed as:

Row-to-row spacing (a), m = 0.50 m, and

Briquette-to-briquette spacing (b), m =0.50 m.

$$\text{S, number of briquettes/m}^2 = \frac{\pi \times 0.64 \times 4 \times 0.50}{1} = 4.01 \cong 4$$

Thus, the number of cups on vertical plate can be determined as;

$$\text{N, number of cups} = \frac{\pi \times 0.64 \times 4 \times 0.50}{1} = 4.01 \cong 4$$

Accordingly, a vertical cup feed metering mechanism with four cups was used in further studies. Cups of three sizes were considered for laboratory investigation for metering of urea briquettes in order to determine the optimum cup shape. Design of metering device and hopper and material selection were based on the physical and engineering properties of urea briquette (Deo *et al*. 2019). Design variables based on maximum dimensions of the physical and engineering properties for the optimization of metering mechanism were selected as follows; cup diameter of 20.63 mm, cup depths of (6.5, 3.5, and 2.5 mm) with an angle of repose of 52° for hopper.

Uniformity test of metering mechanism: The uniformity test of metering mechanism was conducted for two types of urea briquettes (UB_1 (3 g), and UB_2 (2 g)) for comparison of performance of different sizes of cups (6.5, 3.5, 2.5 mm) having hemispherical shape for metering of briquettes. Sticky belt test (Fig 1) was conducted to study the uniformity of briquette placement by the vertical cup feed metering mechanism with different cup sizes. Each experiment of 30 numbers of urea briquette distance measurement on sticky belt was repeated thrice and data was collected under Randomized Block Design (RBD) and analysed using SAS software.

Sticky belt set-up: The Sticky belt set up which was used to test the briquette uniformity consisted of a 400 cm long endless canvass belt mounted on two end to end rollers, each of 120 mm diameters. The end rollers were spaced 380 cm apart. Provision was on the frame to mount urea briquette hopper and power transmission unit. A 1.12 kW electric motor was used as a prime mover. Power was transmitted from motor to reduction gear and driving roller through belt pulley system. An idler was provided for belt tightening. The speed of the belt was 0.37 m/s. From driving roller, power was transmitted to metering unit shaft through chain and sprocket. The theoretical spacing for the uniformity testing was 35 cm. Total 30 numbers of distance measured for each replication.

The following six parameters were used for evaluating the performance of metering mechanism: i) Mean spacing, ii) Standard deviation, iii) Miss index, iv) Multiple index, v) Quality feed index, vi) Precision

Mean spacing

The mean (X) spacing (Rajaiah *et al*. 2016) between briquette is:

$$X = \sum_{i=1}^{n} \frac{Xi}{N} \qquad (3)$$

where, Xi = Distance between i^{th} briquette and the next briquette in the row, cm, and N = Total number of distances measured.

Standard deviation

The standard deviation (σ) (Rajaiah *et al*. 2016) of the urea briquette spacing is:

$$\sigma = \sqrt{\sum \frac{(x_i - x)^2}{N}} \qquad (4)$$

where, σ = Standard deviation; x=Mean distance between briquette, cm; x_i=i^{th} distance between briquette (i=1,2,3,……, n), cm; N = Total number of distances measured.

If the spacing were uniform, the standard deviation would be zero. If spacing varied more due to multiples, misses and variability in briquette placement, the standard deviation would increase. The difficulty with interpreting either the mean or standard deviation is that they are composite measures. Hence, measures based on the theoretical spacing, i.e. multiple index, miss index, quality of feed index and degree of variation were considered to evaluate the performance of the urea briquette metering mechanism**.**

Miss index: The miss index (M) is the percentage of spacing greater than 1.5 times the theoretical spacing (Rajaiah *et al*. 2016):

$$M = \frac{n_3}{N} \qquad (5)$$

where, n_3= number of spacing in the region ≥ 1.5 times the theoretical spacing.

Miss index is thus an indicator of how often the briquette skips the desired spacing.

Multiple index

The multiple index (D) is the percentage of spacing that are less than or equal to half of the theoretical spacing (Rajaiah *et al*. 2016):

$$D = \frac{n_1}{N} \qquad (6)$$

where, n_1= Number of spacing in the region ≤ 0.5 times of theoretical spacing; N= Total number of observations.

Thus, it is an indication of more than one briquette dropped within a desired spacing.

Quality of feed index: The quality of feed index (A) is the percentage of spacing that are more than half but not more than 1.5 times the theoretical spacing. The quality of feed index is mathematically expressed as follows (Rajaiah *et al*. 2016):

$$A = \frac{n_2}{N} \qquad (7)$$

where, n_2 = Number of spacing between 0.5 times the theoretical spacing and 1.5 times of the theoretical spacing; N= Total number of observations.

The quality of feed index is the measure of how often the spacing were close to the theoretical spacing

Precision: Precision (C) is a measure of the variability in spacing after accounting for variability due to both multiples and skips (Rajaiah *et al*. 2016). The precision is the coefficient of variation of the spacing that is classified as singles. That is

$$C = \frac{S_2}{X_{ref}} \qquad (8)$$

where, S_2= sample standard deviation of the n_2 observation, and X_{ref}= theoretical spacing.

RESULTS AND DISCUSSION

Mean urea briquette spacing: The mean spacing (Table 1) varied from 34.8±5.3-to-35.7±3.6 cm for urea briquette of 3 g (UB_1), with the cup size of 6.5 mm (CS_1), whereas, its maximum value of 38.9±13.3 was observed for urea briquette of 3 g with cup size of 2.5 mm. In all other cases, the standard deviation was higher. The mean spacing was significantly (P<0.05) influenced by different sizes of cup and sizes of briquette **(**Table 2). Cup size of metering device influenced the mean spacing the most followed by size of briquette. It was clear that cup size of 6.5 mm (CS_1) was the optimum size for the metering mechanism and thus it performed better in combination of UB_1. Cell shape and size affected the spacing (Rajaiah *et al*. 2016) of the briquette in the uniformity testing.

Missing index: Miss index is a measure of the skips in briquette metering within a desired spacing. Miss index for the different treatments varied form 0–8% (Table 1). The Miss index was significantly (P<0.05) influenced by different cup sizes. The cup size (CS) influenced missing

Table 1 Performance parameters of urea briquette vertical cup feed metering mechanism

	Average spacing (cm) ± SD			Missing index (%)			Multiple index (%)			QFI (%)			Precision (%)		
	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
UB_1CS_1	35.5±3.9	35.7±3.6	34.8±5.3	0.0	0.0	0.0	0.0	0.0	2.0	100	100	98	11.1	10.3	8.1
UB_1CS_2	35.5±4.8	35.3±5.5	35.6±4.4	0.0	0.0	0.0	0.0	0.0	0.0	100	100	100	13.7	15.7	12.5
UB_1CS_3	38.9±13.3	39.0±15.5	38.5±12.7	8.0	4.0	6.0	2.0	0.0	0.0	90	96	94	12.8	11.1	17.4
UB_2CS_1	34.2±8.8	34.5±5.9	35.6±5.5	4.0	0.0	2.0	4.0	2.0	0.0	92	98	98	13.2	10.4	9.5
UB_2CS_2	35.5±11.9	30.1±12.2	34.8±21.3	2.0	0.0	6.0	6.0	10	12	92	90	82	7.8	15.3	25.1
UB_2CS_3	38.1±14.8	36.2±13.5	38.9±13.2	8.0	4.0	6.0	2.0	4.0	0.0	90	92	94	13.2	15.3	16.8

UB_1=3g Urea Briquette, UB_2=2g Urea Briquette, CS_1, CS_2 and CS_3= cup size of 6.5 mm, 3.5 mm, and 2.5 mm, R1, R2, R3=Replication, SD=Standard Deviation, and QFI=Quality of Feed Index.

Table 2 F-values for mean performances parameters of vertical cup urea briquette metering mechanism

Source	Average spacing	Missing Index	Multiple index	Quality of feed index	Precision
R	1.96	4.06	0.06	0.72	0.78
UB	7.27*	4.62	18.20*	14.53*	0.65
CS	22.69*	19.91*	5.62*	4.21*	2.20
UB*CS	1.38	1.23	8.09*	5.05*	0.02

R=Replication, UB= Urea briquette, and CS= Cup size, *Significant at 5 per cent level of significance.

the most, followed by urea briquette size as indicated by F-value, but briquette size did not significantly ($P<0.05$) influence the missing index (Table 2). The missing index was observed lesser in comparison to other machine (Rajaiah *et al*. 2016), it was due to the briquette guard (Fig 3) provided in the hopper, which helped in the delivery of briquette, which was picked by the metering cup to delivery funnel. In smaller sizes cup (CS_2 and CS_3), the picking problem was observed. Thus based on F-values for missing index of metering mechanism, UB_1 in combination of CS_1 was selected.

Multiple index: Multiple index is an indicator of more than one briquette being dropped within a desired spacing (Rajaiah *et al*. 2016). Multiple index varied from 0–12%. The minimum multiple index was observed in the case of CS_1 with UB_1, and UB_2 (Table 1). It was observed that multiple index was significantly ($P<0.05$) influenced by cup size, and urea briquette size. Briquette size influenced the multiple index most, followed by cup size of the metering mechanism as indicated by the F-values (Table 2). Lower value of multiple index was due to briquette guard present in the hopper. It was also reported earlier that lower the multiple index, better the metering mechanism (Rajaiah *et al*. 2016).Thus UB_1 in combination with CS_1 showed potential to be selected as metering mechanism.

Quality of feed index: Quality of feed index is a measure of how often the spacing is close to the theoretical spacing. The quality of feed index decreased with the increase in miss index, multiple index or both (Rajaiah *et al*. 2016). Quality of feed index varied from 82–100%. UB_1 in combination with CS_1, and CS_2 gave better result compared to others (Table 1). It was due to better picking in the case of CS_1 and CS_2. After picking, briquette guard (Fig 3) played the role of guide, in the delivery of briquette to delivery funnel. Quality of feed index was highly influenced ($P<0.05$) by briquette type followed by cup type of the metering mechanism as indicated by F-values, General mean of quality of feed index was 94.77%. Quality of feed index varied significantly ($P<0.05$) with the change in cup size with CS_1 and CS_2 performed similar, while CS_3 was different (Table 2).

Precision: Precision is a measure of the variability in spacing between briquettes after accounting for variability due to both multiples and skips. It is the coefficient of variation of the spacing, which is classified as singles. Lower the value of coefficient of variation in singles, better is the performance of metering mechanism (Rajaiah *et al*. 2016). The general mean of precision was 13.30%. The effect of urea briquette and cup size was found to be non-significant in case of precision (Table 2).

Optimization of metering mechanism: The final selection of metering system for urea briquette applicator was done on the basis of all performance parameters, i.e. average spacing, miss index, multiple index, quality of feed index and precision. Highest value of quality of feed index was observed in the case of UB_1 in combination to CS_1 and similarly lower value of missing and multiple index was observed in the case of UB_1 in combination to CS_1. Precision value was also lower in this case. UB_1 application rate was 112.4 kg/ha, whereas in case of UB_2 application rate was 71.2 kg/ha .Since UB_1 contained more nutrient in comparison to that of UB_2, and considering the above parameters, optimum metering cup size was selected as CS1 (6.5 mm cup depth) for urea briquette of 3 g size.

It was concluded from above study that the average spacing, missing index, multiple index, quality of feed index and precision were the important parameters for the evaluation of vertical cup feed metering mechanism. With decrease in cup size and urea briquette size average spacing standard deviation, missing index, multiple index, precision increased but quality of feed index decreased. The briquette guard provided in the hopper, played an important role in the delivery of the urea briquette to the delivery funnel. Summarizing, Urea briquette, UB_1 (3 g) in the combination of cup size, CS_1 (6.5 mm) performed better in comparison to other combinations and recommended for the development of mechanical applicator.

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