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Design and development of ICAR-NRRI urea applicator for rice transplanter

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Abstract
Mechanization in rice transplanting is utmost important to overcome labour shortage. Urea is the most important and highly used fertilizer in rice production. Urea applicator was designed for self-propelled transplanter to place the urea in briquette form to minimize the losses and to avoid one manual operation of fertilizer application. Engineering properties of urea briquettes were measured to get the optimum values for designing the metering unit. Metering unit was designed with cup diameter and depth as 20 mm and 5.5 mm on the basis of maximum length (16.59±1.284) and thickness (9.3±0.249) of urea briquette. Self-propelled rice transplanter with urea applicator at speed of operation of 1.66 kmph the field capacity and field efficiency of were 0.191 ha h^{-1} and 67.82% respectively and fuel consumption was 1.81 l h^{-1}. The percentage of missing, floating and buried hills were 10%, 3.75% and 2.5% using self-propelled rice transplanter working with urea briquette applicator.

Keywords: deep placement, mechanization, rice transplanter, urea applicator, urea briquette

1. Introduction

Rice is one of the main food crops in the world, especially in Asia and Africa. In India, total area and production of rice crop during 2015-16 was 43.81 Mha and 104.4 MT, respectively [1, 2]. Manual rice transplanting method requires about 306 man-h ha^{-1}, which is roughly 42 per cent of the total labor requirement of rice production [3]. Due to increasing labour cost and non-availability of labour during peak time of transplanting the best alternative is the self-propelled rice transplanter. Mechanical transplanting systems increased yield, improved labor efficiency, ensured timeliness in operation and faster transplanting [4, 5]. Production of rice is also input intensive, particularly, the modern varieties of rice, which depends on the use of inorganic fertilizers and irrigation [5, 6]. Nitrogen (N) plays a key role in rice production and is required in large amount. It is also the most limited nutrient in rice production and suffers from heavy system losses when applied as inorganic sources in the puddle field. In wetland paddy cultivation, only 30-40% of nitrogen applied is successfully utilized [7]. There is a need to improve nitrogen use efficiency of paddy crop to saves manufacturing cost of chemical nitrogen and also minimize nitrogen emission to atmosphere [8]. The most widely used nitrogen fertilizer is urea, which contains 46% N, the highest of all solid fertilizers. Nitrogen fertilizer is usually broadcast as prills in paddy fields prior to transplanting, followed by one or more topdressing in the floodwater within the period from transplanting to flowering [9].

Farmer's practices of nitrogen fertilizer application generally include basal broadcasting without incorporation before transplanting and/or one or two top dressings in the floodwater immediately after transplanting up to flowering (reproductive stage) [6]. But such practices are inefficient because only about one third of the fertilizer nitrogen is used by plants. The remaining is lost through gaseous losses, runoff, and leaching or is immobilized in the soil. The efficiency of N fertilizer use is generally low for lowland rice crop as only 30% of applied N is utilized by crops and the remaining 70% of it is lost through various processes causing serious environmental problems [10]. Deep placement of nitrogenous fertilizer (N) is one of the alternatives for increasing the nitrogen use efficiency of rice crop [6].

To reduce the drudgery and labour requirement in manual placement of urea, different machines have been fabricated and evaluated to facilitate urea placement at a depth of 5-10 cm below the surface. Manual operation in puddle soil produce drudgery to operator and also it is very costly because of applicators low field capacity. These prototypes were not popular due to inconsistency in performing well in terms of agronomic and mechanical problems when worked in puddled field [11, 12]. To mechanize urea deep placement operation in user friendly manner a new mechanical applicator for application of urea briquettes with self-propelled rice transplanter was designed and evaluated.

2. Material and Methods

2.1 Urea briquettes preparation method

The prilled urea was used for making briquettes. The prilled urea contains N-46% of fertilizer. The briquettes were made by compaction process. The prilled urea feed in the hopper of briquette making machine. The machine has two opposite rotating rollers with reduced spacing for making briquettes. The opposite rotating roller had pockets on its periphery. The urea briquettes were collected at discharge end. The good quality, broken, uneven briquettes were separated manually. The prepared urea briquettes were white in color and odourless.

2.2 Design Consideration for Developing of Urea Briquette Applicator

The urea briquette applicator attachment for self-propelled rice transplanter was developed based on the following design concerns.

a. The transplanter is adjustable to different spacing, but urea briquette applicator is mostly considering row to row and plant to plant spacing 20×15 cm.
b. The depth of placement of urea briquette may be 4-5 cm in puddled soil.
c. Only one urea briquette is supplied every four hills.
d. The briquette placement should be at alternate rows at centre of four hills, so spacing between urea briquettes 30 cm.
e. The minimum depth of standing water should be maintained 2-2.5 cm for smooth operation

2.3 Development process

The urea briquette applicator consists of hopper, metering mechanism, seed metering shaft, furrow openers and delivery tube. Technical specification developed urea applicator were given in table 1.

2.4 Main frame

The main frame of applicator was made-up by using M.S angle which was attached to transplanter. The main frame was made in rectangular shape with dimensions 1150 × 1700 × 1200 mm as length, breadth and height. The frame was designed to support hoppers, gear, sprocket and bearings. Metering mechanism was driven by ground wheel. The ground wheel was connected to frame by using chain-sprocket and gears. Furrow openers were attached at the bottom of frame.

2.5 Hopper

Hopper was prime most important component of applicator. Hopper for urea briquette applicator was designed to hold and supply urea briquettes. Applicator had four hoppers for alternative rows of self-propelled rice transplanter. The cross-section of hopper was triangular and trapezoidal. The selection of the shape of hopper was done with the basic consideration that each hopper should carry desired quantity of briquette and the briquette should pick up easily towards the delivery tube. The former is governed by size, shape and latter is governed by angle of repose.

Volume of hopper given by

$$V_h = 1.1\,\frac{W}{\rho}$$

Where,

W = weight of briquettes, gm

ρ = Bulk density of briquettes, gm cm^{-3}

For light weight and easy operation of the urea briquette applicator the capacity of hopper is considered as 3 kg per each hopper. As the applicator has four hoppers the capacity of the applicator was 12 kg.

So, theoretical volume of hopper required,

$$V_h = \frac{1.1 \times 3000}{0.78} = 4230\ cm^3$$

Volume of triangular section $= \frac{1}{2} \times 17 \times 18 \times 11$

$= 1683\ cm^3$

In triangle, height "h" determined by

$h = b \times \tan\theta$

$= 17 \times \tan 33.6^\circ$

$= 11.29\ cm \approx 11\ cm$

Where θ = Angle of repose of the briquette = 33.6°

Volume of trapezoidal section = $19 \times 13\ (\frac{8+12}{2}) = 2470\ cm^3$

Total volume of hopper = $1683\ cm^3 + 2470\ cm^3 = 4153\ cm^3$

2.6 Metering mechanism

The metering mechanism helps to meter the briquette with its uniform rate and spacing. The metering mechanism maintains the application rate of the applicator. Vertical cup feed metering mechanism was selected, because the urea briquettes were nearly spherical in shape. Vertical cup feed metering mechanism consist of cups mounted on edges of metering plate. The metering plate with cups passes through a hopper containing urea briquettes. Briquettes are picked up in the cups and dropped on the top of the inlet of delivery tube. While designing the metering mechanism for urea briquettes, prime considerations were given to use simple design, not to cause any mechanical damage to briquettes and easily pick one briquette per cup. The design of vertical cup feed metering plate for applicator involved determining the number of cups on metering plate, shape and depth of cup and depending upon the required planting pattern.

The number of cups on one metering plate is calculated as

$$N = \frac{\pi \times D}{i \times a}$$

Where,

D = Diameter of ground wheel, cm,

a = Row spacing, cm, and

i = Transmission ratio.

The number of cups on one metering plate (N) $= \frac{3.14 \times 40}{1 \times 30} = 4.18 \approx 4$

4 numbers of cups were selected on one metering plate.

2.7 Cup of metering plate

The vertical cup metering mechanism was selected for meter the urea briquettes. The dimensions of cup were decided based on the engineering properties of urea briquettes. The depth of cup was 5.5 mm and diameter of cup was 20 mm.

2.8 Ground wheel

The type of ground wheel to be used on applicator depends on the ground conditions. The basic function of ground wheel is to provide power to metering mechanism. The dimension of drive wheel was determined as given below

The hill spacing of the paddy considered as 15 cm.

a. required spacing between two urea briquettes is 30 cm.

b. In one revolution of ground wheel, 4 briquettes will dropped at spacing of 30 cm. Assuming drive wheel to metering disk speed ratio is 1:1.

c. If the D as diameter of ground wheel in meter, then

d. Spacing between briquettes × No. briquettes dropped in one revolution of drive wheel

$= \pi \times D \times N$

e. Diameter of drive wheel =

D = (4 × 0.30) / 3.14 = 0.384 m ≈ 400 mm.

Based on the above calculations the ground wheel was fabricated with MS flat of length 950 mm was selected. The M.S flat was rounded by hammering. Pegs were cut from MS flat. A ground wheel of diameter 300 mm with 12 pegs was fabricated using M.S flat of 5 mm thickness and width of 20 mm. The length of each peg was 100 mm which of rectangular section. Pegs were welded on the outer periphery of ground wheel at a uniform spacing of 98 mm.

2.9 Delivery tubes

The main purpose of delivery tube was to deliver the urea briquettes from hopper to the soil. Delivery tubes were made up of plastic with outer diameter of 30 mm and length of 300 mm.

2.10 Furrow openers

Furrow openers were opens the puddle soil like furrow and drop the urea briquette easily at desired depth. The shovel type furrow openers were made with MS angel. The MS angel was heated to high temperature and hammered to get desired shape. The length of furrow opener was 300 mm. The furrow openers were clamped on the main frame.

Table 1: Technical specification of urea briquette applicator attachment

Particulars	Specification
Overall dimensions (L x W x H), mm	1150 x 1700 x 1200
Height, mm	670
Weight, kg	40
Number of hoppers	4
Distance between two hoppers, mm	350
Capacity of one hopper, kg	3
Number of cups on metering mechanism	4
Type of metering mechanism	Cup type
Diameter of cups, mm	20
Depth of cups, mm	8
Diameter of delivery tube, mm	25 (inner) 30 (outer)
Length of delivery tube, mm	300
Diameter of ground wheel, mm	400
Number of spikes on ground wheel	12
Dimensions of spikes(L×W×B), mm	100×20×5
Type of furrow opener	Shovel type
Gear ratio	1:1

Fig 1: ICAR-NRRI urea briquette applicator

2.11 Laboratory test

2.11.1 Missing percentage and over falling percentage

The urea applicator was filled with urea briquettes at different levels of hopper capacity i.e full capacity of hopper, 3/4th of hopper capacity and half of the hopper capacity. The ground wheel of applicator jacked up. The ground wheel was rotated manually. The polythene covers were used to collect the briquettes at the end of delivery tube. Ten readings were taken for at each level (full capacity of hopper, 3/4th of hopper capacity and half of the hopper capacity) hopper filling capacity. The dropped urea briquettes were counted manually. The missing and over falling percentage of urea briquette applicator was calculated using following formula:

$$\text{Missing and over falling percentage} = \frac{(\text{N} \times \text{Y}) - \text{NG}}{(\text{N} \times \text{Y})} \times 100$$

Where,

N = Number of turn of drive wheel,

Y = Number of cups on metering plate,

NG = Total number of urea briquette

If value is negative, it is over falling

2.12 Field experiment

The experiment was conducted at ICAR-NRRI, Cuttack during 2017-18. Transplanting was done using self-propelled transplanter along with urea briquette applicator attachment. The field was prepared by using power tiller. The depth of standing water was 5-10 cm during the initial puddling. The field was left with water for 3-4 days to decompose the residues of previous crop. Then final puddling was done with power tiller. One day sedimentation period was maintained before testing the transplanter attached urea briquette applicator.

2.12.1 Distance between urea briquettes

A field area of 2×10 m^2 was prepared to measure dropping distance of urea briquettes.

The measurement of distance between two consecutive briquettes was measured using scale. Ten observations were taken and the mean was determined to represent distance between urea briquettes.

2.12.2 Application rate

Application rate of the urea briquette applicator is the amount of urea briquettes dropped per unit area of the field. The application rate was determined by measuring the weight of urea briquettes received at four delivery tubes of applicator. The ground wheel was jack up and revolved for 10 revolutions. The distance covered in ten revolutions was calculated. The urea briquettes dropped in ten revolutions was weighed by electric balance. The weight of urea briquettes obtain in ten revolutions was divided by the area covered in ten revolutions. The application rate was expressed in kg ha^{-1}.

2.12.3 Effective field capacity

It is the actual rate of coverage of area by a machine. Effective field capacity was determined using the following relationship:

$$\text{Effective field capacity}, \frac{\text{ha}}{\text{h}} = \frac{\text{Total area covered, ha}}{\text{Total time taken, h}}$$

The total time taken in above relationship includes time losses in turning, loading of trays and machine adjustment required during the operation.

2.12.4 Field efficiency
Field efficiency is the ratio effective field capacity and theoretical field capacity. It was determined by the formula given below:

$$\text{Field efficiency}(\%) = \frac{\text{Effective field capacity}}{\text{Theoritical field capacity}} \times 100$$

The theoretical field capacity was determined by following relationship:

$$\text{TFC} = \frac{\text{W} \times \text{S}}{10}$$

Where,
TFC = Theoretical field capacity, ha h^{-1}
W = Width of machine, m
S = Speed of operation, km h^{-1}.

Fig 2: ICAR-NRRI urea applicator with self-propelled rice transplanter

3. Result and Discussion
3.1 Effect of hoppers filling on the performance of metering mechanism
The missing and over filling percentage of urea briquette applicator was determined in the laboratory with different levels of hoppers filling of applicator as per process given in material and methods. The missing, over falling rates were observed in half-filling, 3/4th and full filling of hoppers. In half filling 0.34% over falling rate and 4.37% missing rate was observed (Fig. 3). In 3/4th filling and full filling missing was 0.12% and 0.27% respectively. The over falling rate was observed as 2.07% and 6.65% in 3/4th filling and full filling respectively. The 3/4th fill of hoppers were considered as optimum for further evaluation.

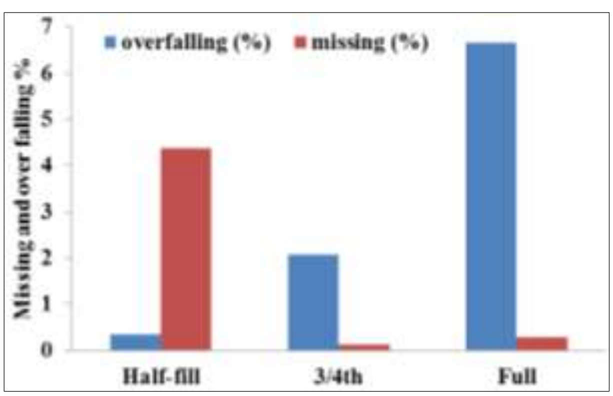

Fig 3: Effect of hopper filling on performance of metering unit

3.2 Application rate and uniformity
The application rate of the urea briquette applicator ranged from 89.2-92.13 kg ha^{-1}. A field area of 2×10 m^2 was prepared to measure the distance between the dropped urea briquettes. The mean distance between the two urea briquettes was 32 cm. The depth of placement of urea briquette was 4-6 cm.

3.3 Performance of self-propelled transplanter with ICAR-NRRI urea briquette applicator
The evaluation was done based on the operating speed, hill spacing, number of plants per hill, depth of transplanting, missing hills, floating hills, buried hills, damaged hills, field capacity, field efficiency, machine index, angle of planted seedling and fuel consumption was measured.
At the time of operation depth of standing water was 2.5-3 cm. The average distance between transplanted hills was 15.2 cm. The distance between rows was 23.8 cm. The number of seedlings per hill was 2-3. The average standing angle of transplanted hill was 83˚.

3.3.1 Field evaluation of self-propelled rice transplanter with applicator
The field capacity of the self-propelled transplanter with attachment of deep placement urea briquette applicator was 0.191 ha h^{-1} with field efficiency of 67.82 %. The operating speed of self-propelled transplanter with attachment of deep placement urea briquette applicator was 1.66 km h^{-1}. The working time includes the productive time (transplanting) and non-productive (time lost in field) times. Non-productive time includes the turning losses, supply the seedling mats, cleaning and adjustments. The fuel consumption of self-propelled transplanter with attachment of deep placement urea briquette applicator was 1.81 l h^{-1} or 9.44 l ha^{-1}. The field machine index of self-propelled transplanter with attachment of deep placement urea briquette applicator was 84.10 %. The percentage of transplanting time was calculated as 66.93 %. The percentage of turning time loss and per cent time consumed for tray feeding were 12.67 and 20.40.
The average missing hills percentages for self-propelled transplanter with attachment of deep placement urea briquette applicator were 10 % and average floating seedlings were 3.75 %. The mean depth of transplanting was observed 6.0 cm. No plant damage was observed and the average buried hills were 2.5 %.

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