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Development of a manually operated fertilizer applicator with precision metering mechanism for enhanced crop growth and sustainable agriculture

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Abstract
Fertilizer application plays a crucial role in supporting plant growth. Excessive application of fertilizers leads to deterioration of plant health and leads to soil degradation and nutrient imbalances. Conversely, inadequate fertilizer application can result in diminished crop yields and nutrient deficiencies. Previous studies have shown that imbalanced fertilizer application has vast consequences on both plants' health and Environment. To address these challenges a manually operated fertilizer applicator was developed at Vaugh Institute of Agricultural Engineering and Technology, SHUATS, Prayagraj.
The fertilizer applicator was equipped with fluted metering mechanism comprising two fluted rollers controlled by a crank, thus enabling precise fertilizer dispensing at three distinct rates of full, half and quarter. The metering mechanism is attached to hopper with a capacity to hold 25 kg of fertilizers, a chain drive mechanism, a ground wheel and two auxiliary support wheels, and a handle designed using anthropometric measurements. Two fertilizer delivery tubes with spacing of 20 cm is attached to the fluted rollers, which is suitable for crops such as foxtail millet. The fertilizer applicator has been calibrated to distribute urea fertilizer at specified rates of 40kg/ha with crank fully open, 30kg/ha of with crank half open and 20 kg/ha of urea with crank quarterly open. When tested at Crop Research Farm, SHUATS the applicator has shown 97.5% of efficiency for fully open crank. The fertilizer applicator was developed at a price of 5000 rupees which is suitable for small scale farmers.

Keywords: Fertilizer application, manual fertilizer applicator, precision farming, urea, foxtail millets

Introduction
Foxtail millet (*Setaria italica* L.) is considered as an important crop in worldwide. It is highly adaptable to drought and low fertility area and uses water very efficiently. The foxtail millet yield is constrained mainly due to the mismanagement of nitrogen (N) fertilizer. (Wang *et al*., 2011) [2]. The broadcasting method for fertilizer application is associated with potential for non-uniform distribution across agricultural fields, leading to spital heterogeneity in nutrient levels. Consequently, certain areas within the field may receive excessive fertilizer, while others may be inadequately supplied. This non-uniform distribution can result in inefficiencies in fertilizer utilization and suboptimal crop growth outcomes. Efforts to minimize unnecessary nitrogen (N) application are crucial due to its diminishing returns in crop production (Tilman, 2011) [16]. Applying excessive N fertilizer not only proves ineffective for crop growth but also diminishes N use efficiency (Ata-Ul-Karim, 2013) [3]. Moreover, elevated application rates leading to nitrogen losses can result in leaching (Gheysari, 2009) [8], causing contamination in surface and subsurface water (Barton and Colmer, 2006) [4], as well as affecting aquatic ecosystems (Fischer, 2010) [7]. Consequently, it becomes essential to enhance N use efficiency by applying appropriate N fertilizer levels through improved management (Yousaf, 2016) [17]. This can be achieved by applying necessary amount of fertilizer using metering mechanisms.
The fluted roller is effective for dispensing granular urea fertilizer using its volumetric flow metering system. It employs parameters like flute roller dimensions, rotational speed, flute characteristics, and the fertilizer fills individual pockets on roller surface and discharges pocket by pocket, causing uneven flow to its batch-like nature.
Optimizing machine parameters can mitigate the unevenness caused by the fluted roller. Uneven fertilizer flow during field application leads to inconsistent nutrient distribution in soil, impacting plant nutrient uptake and growth. Reducing this flow disparity is crucial. Alternative metering systems, like helical fluted-roller, belt-type, multi-flight screw meters have been

studied in previous findings. The flute rollers have steadier material flow. Despite their steadiness, these alternatives are more complex and costly. The traditional fluted rollers remain cost effective and effective for free flowing of urea fertilizer.

Materials and Methodology

The development and testing of manually operated fertilizer applicator were carried out in Vaugh Institute of Agricultural Engineering and technology, SHUATS, Prayagraj.

Physical characteristics of granular Urea

Size, Shape and Sphericity

the physical characteristics of urea were determined, revealing dimensions of 1.82±0.4 mm, 1.84±0.4 mm, and 1.850.4 mm, for its shape and size, with a sphericity of 0.99±0.004 mm%. the moisture content is 18.7%, the shape of urea is round. The angle of repose for urea fertilizer is 35.04 degrees. To ensure smooth urea flow, the hopper's slope increased than the angle of repose.

Design of Fertilizer Applicator

Power Developed by the Operator

The power of work done by human beings is given by HP = 0.35-0.092 log t (Campbell, 1990) [5].

To operate the manually operated fertilizer applicator continuously for 3-4 hours, the power developed by the operator would be: 0.13-0.14 HP.

The operating speed of the machine is 1km / h (0.27 m /s) = 39.44 kgf, 1.5 km/h (0.416 m/s) = 25.60 kgf, 2 km/h (0.55 m/s) = 19.36 kgf

Size of the fertilizer applicator

Working width of the planter (W) = Z x (a) Row to Row Distance (Sharma and Mukesh, 2010) [6].

W = 2 x 60 = 120 cm

Design of Hopper

The fertilizer hopper's design incorporated a 25 kg fertilizer capacity, constructed using (galvanized Iron) steel sheet with a gauge of 18. the volume of the hopper was determined utilizing the formula. (Sharma and Mukesh, 2010) [6].

The Bulk density of Urea was 0.760 g/cm^3

For 25 kg Volume of the hopper is = 6,184.21 cm^3

Design of Metering Mechanism

The fertilizer metering mechanism used in the Fertilizer applicator is of fluted roller type, as shown in Figure 3. Two fluted rollers are mounted at the bottom of the fertilizer hopper. A fluted roller having ten grooves and a diameter of 50 mm is mounted over a roller shaft of 16.5 mm diameter. The roller is divided into three different rates 10 mm – quarterly open, 20mm – half open, 40mm- fully open.

Design of Power Transmission System

The chain and sprocket-type power transmission were utilized. It consists of two sprockets and a gear of 18(at the drive wheel), an intermediate shaft, and 28 (at the fluted roller shaft) teeth. The smaller sprocket was mounted on one side of an 18.5 mm diameter shaft. A bicycle wheel of 450 mm diameter has been mounted on the other side of this shaft for transmitting power from the ground to the fluted roller shaft. In this fertilizer applicator, the ground wheel the prime mover. The ground wheel is made of steel of size 12 mm. Fields are sandy loamy. Therefore, rubber was provided on the periphery of the ground wheel for uniform power transmission to the fluted roller shaft.

1. From the ground wheel to the intermediate shaft

The length of the chain is 0.406 m.

1. From intermediate shaft to the metering mechanism

The length of the chain is 0.508 m.

Design of Handle

A handle has been provided to control the fertilizer operator during operation. While designing the handle, the ergonomic aspect was considered for the comfortability point of view of the farmers during the operation of the machine in the field such that the 50th percentile of the user population was statistically operated it. The handle's length is determined by considering the average standing elbow height of male operators. The distance from the frame to handle is 147.13 cm.

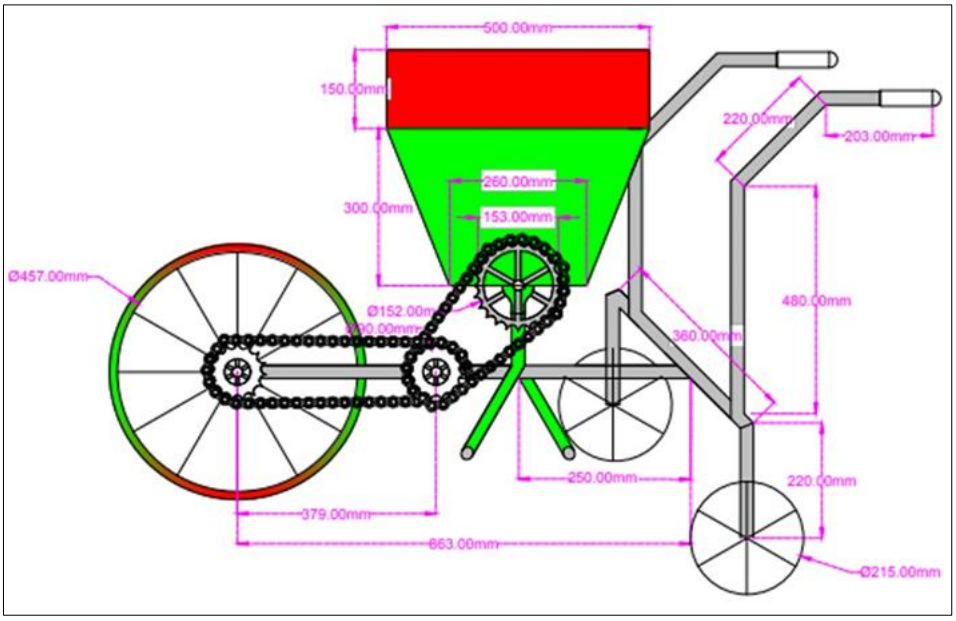

Fig 1: CAD of the manually operated fertilizer applicator

Table 1: Specifications of fertilizer applicator

S. No	Material of construction	Specifications
1	Material of construction	Mild Steel
2	Number of Hoppers	1
3	Shape of fertilizer box	Trapezoidal
4	Capacity of each fertilizer box	25 kgs
5	Ground Wheel Diameter	45 cm
6	Diameter of metering roller	4.9 cm
7	Number of Flutes	2
8	Space between flutes	10 cm
9	No of flutes	10
10	Type of flute	grooved
11	Length of each flute	4 cm
12	Number of Fertilizer delivery tubes	2
13	Diameter of the Fertilizer delivery tube	1.5 cm
14	Length of handle (cm)	90
15	Diameter of the handle pipe	1.5 cm
16	Power source	Manual drawn

Parts of fertilizer applicator

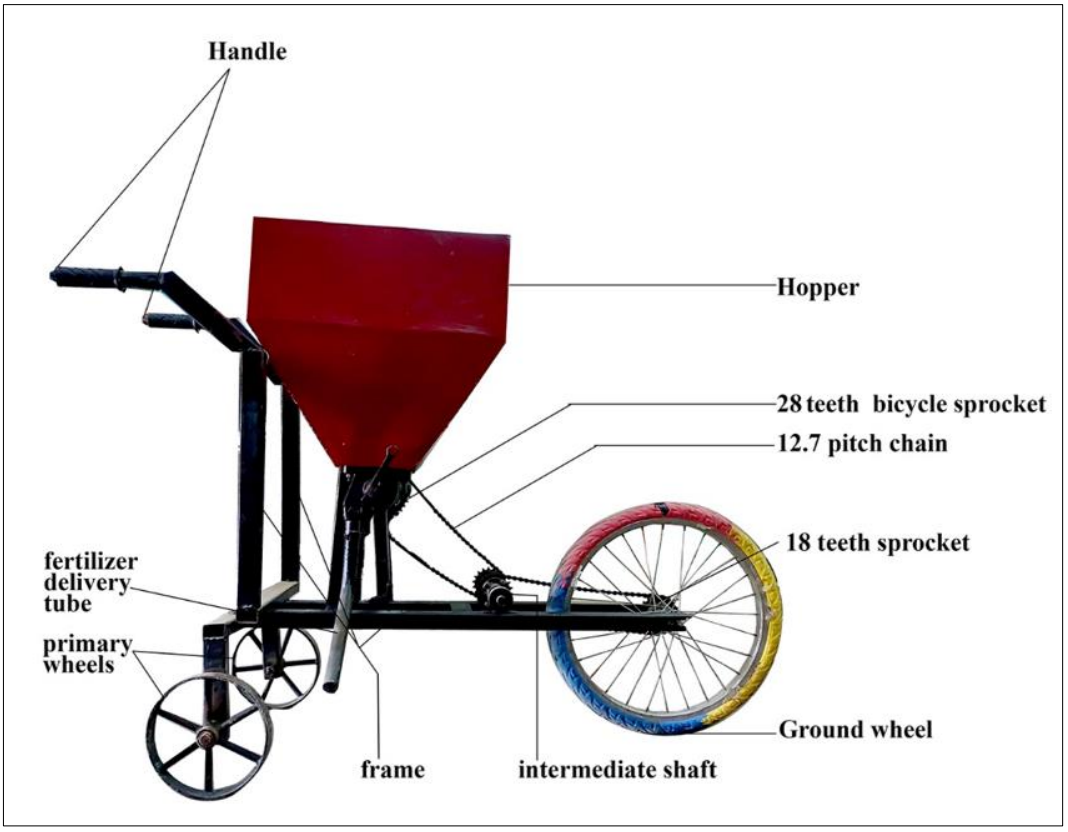

Fig 2: Manually operated fertilizer applicator

Frame
The fertilizer applicator's structure is established by the frame, in which all the parts of applicator was affixed onto this frame. The frame structure is made of mild steel (MS) angle, the frame's dimensions are 88 cm in length, 36 cm in width, and 0.5 cm in thickness. These measurements were chosen while considering the bending moment and applied load on the frame.

Fertilizer hopper
The fertilizer hopper was developed by using 18-gauge GI (Galvanized Iron) sheet for carrying fertilizer of 20-25 kg. The hopper's shape is trapezoidal with a conical bottom. An opening is situated at the bottom of the hopper to unload fertilizers from the hopper. The hopper was mounted on a frame with the help of MS flat, and the height of the hopper is 60 cm from the ground level.

Ground wheel
The bicycle wheel is a ground wheel with a diameter of 45.7 cm. Two supporting wheels are used for running the fertilizer applicator on the field, and the diameter of each wheel is 21.5 cm.

Fertilizer metering mechanism

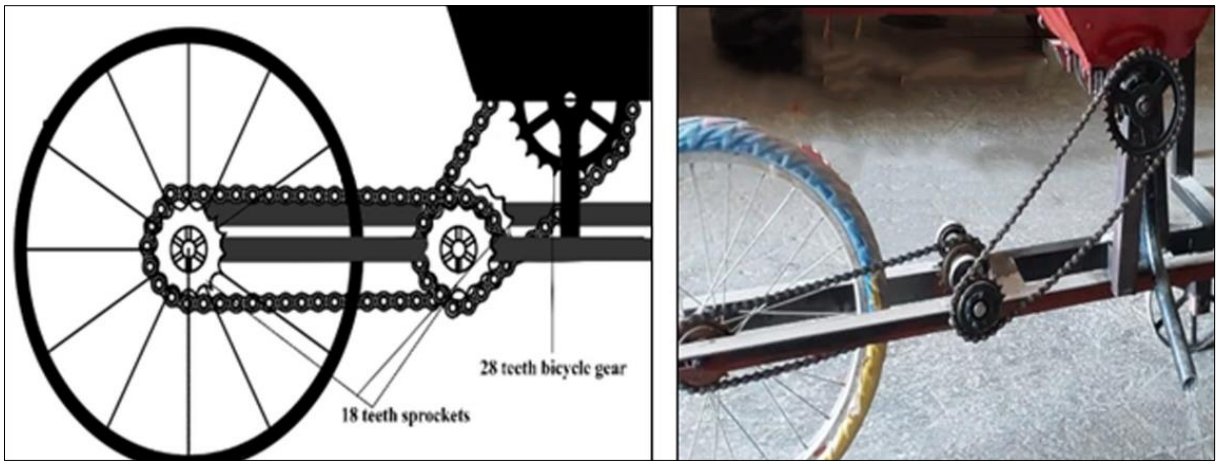

Fig 3: Power Transmission

It is a mechanism consisting of fluted rollers fixed in the fertilizer hopper that receive the fertilizers into longitudinal grooves and drop them in the Fertilizer delivery tube. By shifting the rollers sideways, the length of the grooves exposed, and the fertilizer rate is increased or decreased. 10 longitudinal grooves of 10 mm width and 40mm length. The rate of fertilizer discharge is divided into 3 rates.(10mm) quarter open is the minimum discharge rate. (20 mm) half open is the medium discharge rate.(40mm) fully open is the maximum discharge. the quantity of fertilizers can be regulated by the sideways movement of fluted rollers.

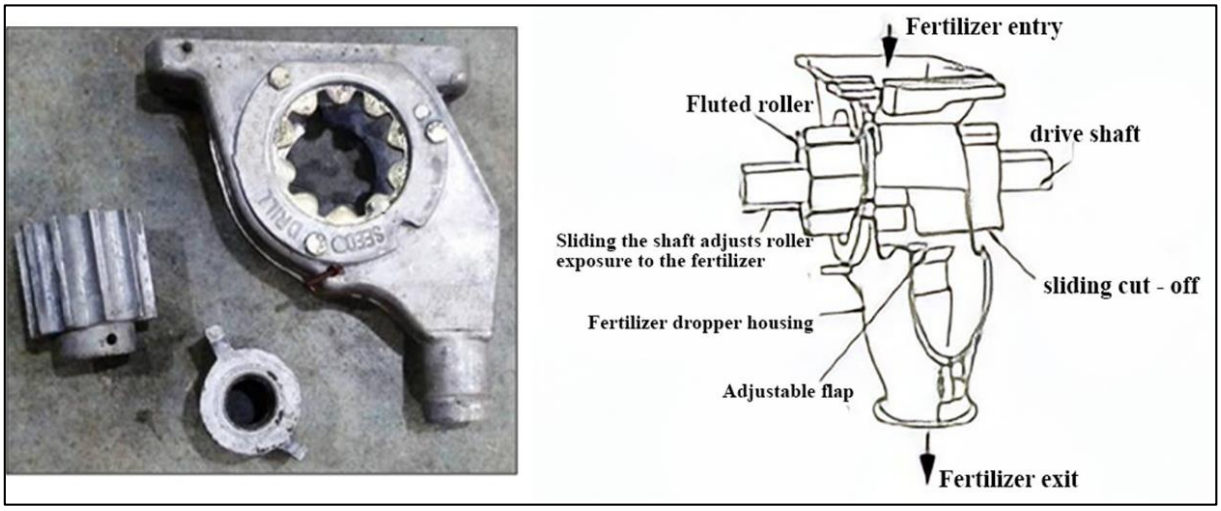

Fig 4: Fluted Roller (metering mechanism)

Fertilizer delivery tube

The diameter of the Fertilizer delivery tube was 1.5 inches. The fertilizer falling from the fluted roller grooves was collected and delivered to the Fertilizer delivery tube.

Handle

The handle consists of mild steel pipes of 15 mm internal diameter and a whole length of 1100 mm. These pipes are fabricated ergonomically suitable for the operator.

Shaft

The shaft is 30 cm in length, and a diameter of 1.5 cm is used to rotate the fertilizer metering disc.

Results and Discussion

Laboratory Performance evaluation

The following tests were conducted in laboratory.

Calibration of fertilizer applicator

In the lab testing, the fertilizer applicator underwent calibration for a specific application rate of 40 kg\ha. Urea discharged from each fluted roller tube was collected and weighed across three replications. The average discharge rate for the fertilizer application is presented in the table 2.

Table 2: Calibration of fertilizer applicator for fluted rollers (40 kg/ha)

Discharge of urea for 20 revolutions of ground wheel				
Sr. No	**D. tube - 1**	**D. tube – 2**	**Application rate kg/ha**	**Mean Discharge**
1	0.203	0.201	41	0.2021
2	0.214	0.2156	39	0.215
3	0.242	0.238	35	0.24
Mean	0.220	0.218	38.33	--

A) Performance of metering mechanism
Exposed length of flutes

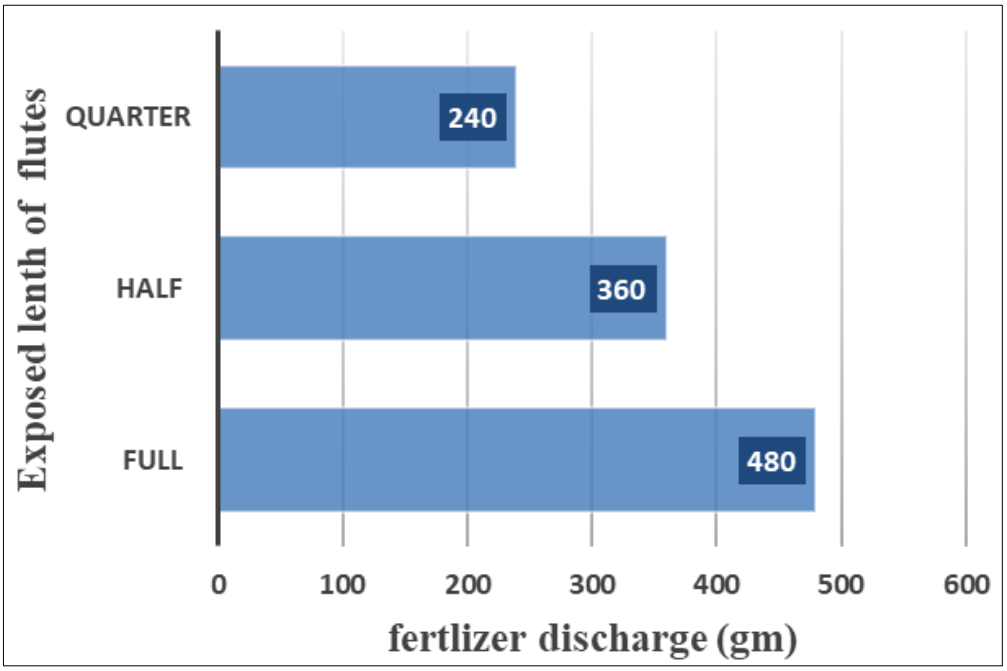

Fig 5: fertilizer discharge rate of different exposed length of flutes

Fertilizer application rate (F.R)
Fertilizer in grams and total experimental area in m^2 respectively while, F.R is fertilizer rate in grams/m^2**.** The result after testing for fertilizer application rate is 110.50 gm/m^2.

B) Test for uniformity
Black Mat Method
The fertilizer applicator is operated on black mat for showing the spreading of fertilizer application at the average feed rate setting, with the hopper half full and at the speed of 1.0, 1.5, 2.0 km/h.

Coefficient of uniformity
When tested with 3 no of observations the result is 98.8%.

Field Performance evaluation
A) Size of area per trail
The size of area per trail for fertilizer applicator testing is 252 m^2 and for three trails 756 m^2.

B) Operating speed
Average speed 1km/h
Fertilizer rate varied with the same trend for full, half, and the quarterly open exposed length of flutes at 1 km/h speed. However, the average fertilizer rate obtained with a quarterly length of flutes at 1 km/h speed was 30.0 kg/ha, which was lesser than the average fertilizer rate obtained with the combination of half exposed length of flutes and 1 km/h speed, i.e., 35.17 kg/ha. The average fertilizer rate for the fully open length of flutes was 40.53 kg/ha, which was higher than the other two combinations.

Average speed 1.5km/h
Fertilizer rate varied with the same trend for full, half, and the quarterly open exposed length of flutes at 1.5 km/h speed. However, the average fertilizer rate obtained with a quarterly length of flutes at 1.5 km/h speed was 26.2 kg/ha, which was lesser than the average fertilizer rate obtained with the combination of half exposed length of flutes and 1.5 km/h speed, i.e.,29 kg/ha. The average fertilizer rate for the fully open length of flutes was 35 kg/ha, which was higher than the other two combinations.

Average speed 2km/h
Fertilizer rate varied with the same trend for full, half, and the quarterly open exposed length of flutes at 2 km/h speed. However, the average fertilizer ratio obtained with a full length of flutes at 2 km/h speed was 23 kg/ha, which was lesser than the average fertilizer rate obtained with the combination of half exposed length of flutes and 2 km/h speed, i.e.,26.5 kg/ha. The average fertilizer rate for the quarterly open length of flutes was 31 kg/ha, which was higher than the other two combinations.

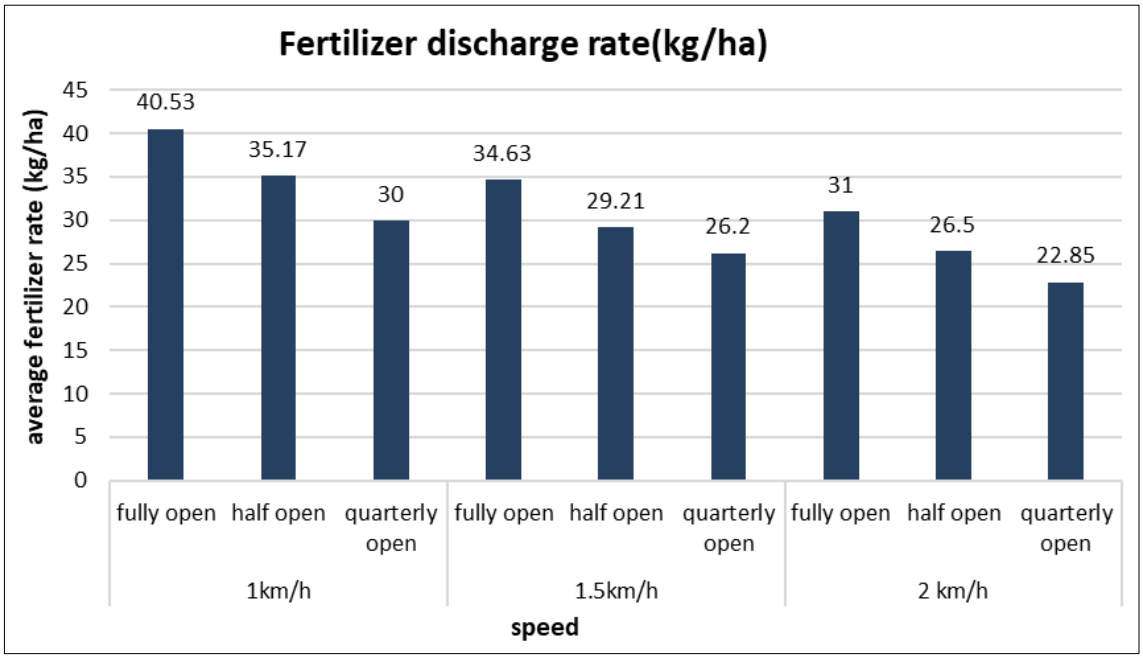

Fig 6: Average fertilizer rate (kg/ha) at different travel speed

C) Application rate

Average fertilizer application rate (kg/h)

This study involved different exposure levels of flutes, and the results depict the performance across these variations. The highest average fertilizer application rate achieved was 40.53 kg/ha, observed at a travel speed of 1km/h, and with flutes exposed to a quarter of their length. Conversely, the lowest rate recorded was 22.85 kg/ha, which occurred at an average travel speed of 2km/h, and with the flutes fully exposed. In sandy loamy oil, the manually operated fertilizer applicator exhibited a fertilizer application efficiency of 81% under maximum condition and 77% under minimum conditions.

Field capacity and field efficiency

The fertilizer applicator's effective field capacity and efficiency were evaluated across plots1.2 and 3. data in Table 3 demonstrates that the theoretical field capacity remained consistent across all three plots, averaging 0.65 ha/h. During the field testing, the effective field capacity was found to be lower in comparison to the theoretical field capacity. Due to the turning loss, refilling time.

Table 3: Performance data of manual operated fertilizer applicator is used for spreading Urea fertilizer.

Factors	Plot 1	Plot 2	Plot 3
Total operating time, sec	150	197	295
Total turning time, sec	10	15	15
Loading time, sec	15	14	14
Actual operation time, sec	125	168	266
Actual area covered, ha	0.0082	0.0082	0.0082
Travel speed, km/h	2	1.5	1
Theoretical field capacity, ha/h	0.04	0.06	0.08
Effective field capacity, ha/h	0.028	0.046	0.065
Field efficiency (%)	71.6	77.2	81.25

Conclusion

The examination encompassed the physical attributes of fertilizer, encompassing granular urea's size, shape, sphericity, density, and hundred particle weight with a determined bulk density of 0.760 g/cm³, the basis for designing the fertilizer hopper's capacity to hold 25 kg/ha was established.

In the fertilizer applicator, the operational mechanism hinged upon the fluted roller. The fluted roller, measuring 4 cm in length, was partitioned into three sections: fully open, half open, and quarterly open. Through 50 revolutions, distinct exposed lengths of flutes yielded corresponding fertilizer delivery rates of 480gms, 360gms, and 240gms.

Optimal fertilizer rates were achieved under various conditions: fully exposed flutes at 1 km/h resulted in 30 kg/ha, half exposed flutes at 1.5 km/h attained 35.17 kg/ha, and quarter exposed flutes at 2 km/h demonstrated the highest rate of 40.53 kg/ha, surpassing the other two combinations.

During fertilizer application, the fertilizer applicator showcased a field capacity of 0.014 ha/h, coupled with a field efficiency of 81%.

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