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Optimization of machine field parameters of liquid urea applicator

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Abstract
To address the problem of nitrogen losses during the application of granular urea (broadcasting) in rice residue fields, a tractor-operated spoke wheel-type liquid urea applicator was developed and tested in real field conditions. This machine featured five numbers of wheels with radial injectors connected to a distribution centre, equipped with an inflow circular pipe, control valve and cut-off system. A sensor-based electronic cut-off system was used to control the flow control valve's opening and closing. The machine's field capacity was determined from 0.25 to 0.44 hectares per hour. The field efficiency of the machine varied from 61 to 75% at different speeds of operation. Wheat crops fertilized with the developed machine also exhibited a higher yield as compared to crops treated with the traditional broadcasting method which is due to the higher nitrogen use efficiency (NUE). Consequently, the spoke wheel-type liquid urea applicator represents a promising option for enhancing crop yield while also protecting the environment. As a result, the spoke wheel-type liquid urea applicator appears to be a potential choice for increasing agricultural productivity while safeguarding the environment.

Keywords: Efficiency, field capacity, mulch field, wheat crop

Introduction

Ensuring sustainable food security for the continuously growing global population, while also prioritizing environmental protection and the conservation of natural resources, has become a critical concern in agriculture [1]. The Green Revolution significantly transformed Indian agriculture, with Punjab playing a major role in this. Agriculture expanded due to the use of fertilisers, herbicides, insecticides, high-yielding crop types, and sophisticated machinery [2]. In Punjab, the rice-wheat cropping system gained popularity. To address the issue of rice straw management, the development of machinery like the 'Happy seeder' enabled simultaneous mulching of rice straw during wheat sowing, offering an alternative to burning or incorporating the residues into the soil [3, 4]. Mulching rice residue provides several benefits, including reduced nitrogen immobilization, soil and water conservation, and weed suppression. When compared to traditional sowing methods, no-till sowing of wheat into residue fields, no differences in yield or biomass of the crop were seen [5, 6]. Studies in India and China have demonstrated that field mulching with crop residue can increase productivity in no-till sowing systems for crops [7, 8]. However, the widespread adoption of the mulch-tillage system has tended to increase the requirement for nitrogen application due to wrong and unsystematic application methods [9]. Around nearly 40-45% of the applied nitrogen fertilizer is not effectively utilized by the crops due to incorrect application methods or timing. The presence of crop residues on the soil surface, particularly in no-till systems, can lead to increased ammonia volatilization and reduced nitrogen efficiency [10]. Moreover, the review of the literature suggests that more nitrogen applications are often required for crops grown in residue mulch, as the plant's fertilizer use efficiency is restricted by mulch, potentially resulting in nitrogen deficiency even with recommended fertilizer application rates [11]. Therefore, there is a need for innovative solutions to address the issues of wrong and uneven broadcasting urea application in residue mulched no-till wheat within the rice-wheat system. One promising perspective that has not been extensively investigated is the point injection of liquid urea in residue mulched wheat. This study aimed to develop and field test tractor operated spoke wheel-type liquid urea applicator.

Material and Methods
A liquid urea applicator operated by a tractor was specifically designed and developed to fulfil its intended purpose. The concept behind the design of this applicator is centred on utilizing a spoke wheel equipped with injectors positioned along its periphery to effectively distribute liquid urea in residue wheat crops. The injectors, shaped like cones, are designed to penetrate the straw mulch with minimal vertical force due to the weight of the machine. Additionally, applying the liquid urea under some pressure serves two purposes: it enhances the injection of the urea into the soil's upper layer and helps prevent injector blocking. Considering the conceptual and functional design aspects, a prototype model for the application of liquid urea was constructed and assessed under simulated conditions to determine its operational efficiency.

Constructional and working details of the machine
The spoke wheel-type liquid urea applicator was developed as a rear-mounted attachment of the tractor. The basic components of the machine were 5 sets of spoke wheels with fertilizer metering and cut-off mechanism, a pump, a fertilizer tank and a pressure gauge. The function of each part and development are as follows.

Machine's construction and operational specifications
We developed a liquid urea applicator as a rear-mounted type attachment for a tractor. The key elements of the machine comprised a fertilizer tank, pump, five number of spoke wheels integrated with metering and cutoff mechanisms, and pressure gauge. Here, an overview is provided of each component's purpose and development process.

Main Frame
Two mild steel frames were developed to clamp the rotary wheel to the 3-point linkage frame of the machine. One side end of the MS frames was fitted on the circular shaft and the other end of MS the frames was fixed with a specially designed clamping unit. A high-tension spring in the clamming unit protected the wheel from damage on undulated land surfaces and also aids in smooth rotary motion during operation. The clamps were further fitted on the main frame of the machine with the help of the U-clamp bolts. The five numbers of the spoke wheel liquid urea applicator was fixed on the toolbar at the equal spacing (400 mm) between wheels.

Spoke wheel
The equipment consisted of a configuration of five number of wheels (refer to Fig. 1) securely fixed to the main frame. Each spoke wheel assembly featured an electronically controlled mechanism responsible for metering and cut-off of fertilizer, along with a circular ring positioned concentrically around the hub. The ring played a crucial role in supporting and stabilizing the spokes in relation to the distribution hub, as well as regulating the penetration into the soil.

Fig 1: View of spoke wheel

The mechanism for Metering and Cut-off Fertilizer
The main system of the control device was the electronically actuated metering mechanism, which acts as a main part of the input signal. The selection of electronic components for the hardware was conducted in accordance with the specified system needs. It could adjust the quantity of fertilizer injection and pipeline pressure in response to variations in the machine's travelling speed. The system ensured consistent injection of fertilizer per unit area, thereby promising uniformity during field operations. It comprised a distribution hub that served as a reservoir, receiving water-dissolved fertilizer longitudinally from one side and exiting tangentially through spokes positioned along the periphery of the hub. The distribution hub was fixed on an axle supported by two ball bearings at both ends, functioning as a rotary valve for metering and supplying liquid urea from the main source to the spokes located on the hub's periphery. Each spoke assembly featured an independent cut-off system facilitated by a flow control valve. To regulate the opening and closing of the solenoid

flow control valve, a specifically designed electronic circuit was implemented.

Pump

A DC-operated diaphragm pump was selected to provide liquid urea at fixed pressure to the hub. A valve was provided to manage the pressure and diverse the extra amount of liquid into the tank. The DC diaphragm pump was used to force the liquid urea to flow from the tank to the distribution pipe two portable multi-purpose electric (12V), self-priming water diaphragm pump with 6.8 bar of pressure was selected. The pump had a maximum pressure capacity of 220 psi and a flow rate of 9 litres per minute

Fertilizer Tank

At the initial stage, a storage tank made of mild steel with a capacity of 100 litres was employed for storing the liquid urea solution. The capacity of the tank may be increased according to the requirement. The pump draws the solution from the tank through a suction pipe, while a strainer is installed at the open end of the pipe to prevent the passage of impurity/foreign materials along with the solution.

Pressure Gauge

To monitor the operational pressure required for delivering the fertilizer solution to the hub through the main supply line, a pressure gauge was installed.

Field Evaluation

The machine (Fig. 2) was assessed in a straw residue field in the wheat crop. The pump operating pressure for the field assessment of the machine was selected from laboratory testing. The applicator was assessed at different forward speeds in the field. Accordingly, the liquid fertilizer solution was developed by mixing the recommended dose of granular urea with water. The prepared solution was filled in the tank of the applicator. As the wheel rotates, it transports the prepared solution into the hub and subsequently delivers it to the injectors. The fertilizer applicator delivers the urea solution at 300 mm spacing along the row and 400 mm row spacing (alternate row). An experiment was laid out with two levels of soil and three levels of forward speed with three replications as shown in below Table 1. All rest parameters were the same for all treatments. The treatments were uniformly sown using a 'Happy Seeder' under rice residue conditions. Before sowing, wheat was planted in all the plots, and each plot received a basal dose as per the recommended guidelines outlined by PAU’s (Punjab Agricultural University) packages of practice. The recommended practices by Punjab Agricultural University, Ludhiana, were adhered to for all other aspects of growing the wheat crop. A view of the developed machine is given below in Fig. 3.

Table 1: Selected parameters for field test of developed machine

S. No.	Independent Parameters	Levels
1	Soil Type	2
2.	Forward Speed, km/h	3
3.	Control (C) – Broadcasting (Traditional method of applying granular Urea)	

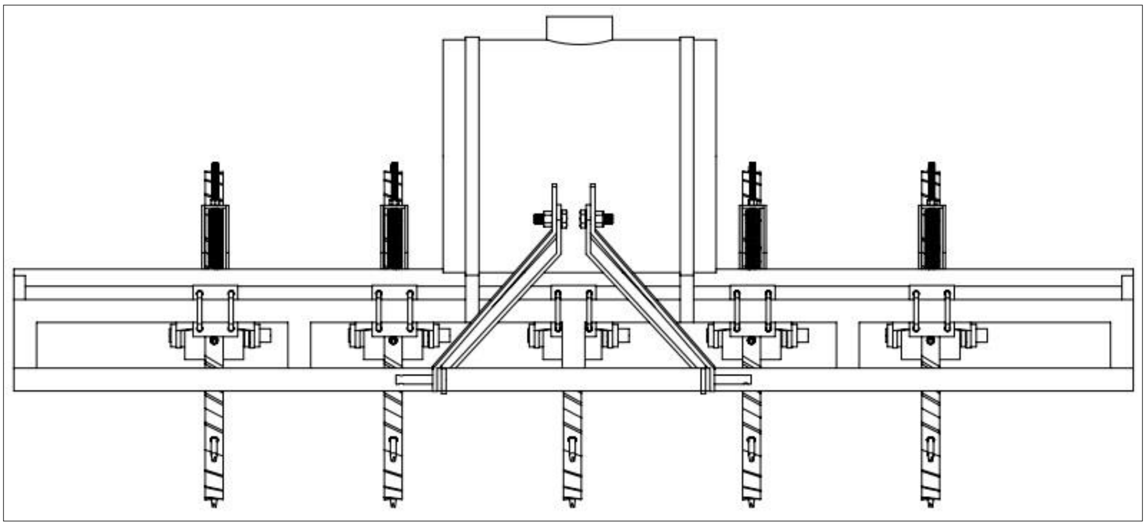

Fig 2: View of a prototype model of liquid urea applicator

Actual field capacity (FC)

The effective field capacity refers to the average rate of coverage achieved by the machine, taking into account the total time spent in the field. It depends on factors such as the travel speed, width of the machine, the percentage of the rated width effectively utilized, and any time lost during the operation. Time lost in the loading, turning and adjustments is known as non-productive time.

$$FC = \frac{A}{Tp - Tn}$$

Where,

FC = Actual field capacity, ha h^{-1}

A = Actual area covered, ha

T_p = Productive time, h

T_n = Non-productive time

Fuel consumption (F_c)

To quantify the fuel consumption of the tractor, a fuel meter was installed on the tractor in the fuel supply line. The reading of the fuel meter was recorded both before and after the operation to determine the amount of fuel consumed.

Field Efficiency (%): This percentage represents the ratio of the actual field capacity to the theoretical field capacity. It takes into account the impact of time lost during field operations and any failure to utilize the machine's full width.

FE (%) = FC/TFC x 100.
FC: Actual field capacity.
TFC: Theoretical field capacity.

Fig 3: Real view of spoke wheel type liquid urea applicator

Results and Discussion

Actual Field Capacity (FC)

The statistics represented in Table 2 show that the different soil types and forward speeds effects were found significant (S). The coefficient of variance (CV) was 3.70 and the mean-field capacity was found 0.35 ha/h in the field. It is observed that field capacity was increased with increasing in forward speed, whereas no effect was observed on change of soil type. Maximum field capacity (0.44 ha/h) was found in the S1*F1 and S2*F1 combination of treatments, whereas minimum field capacity (0.25 ha/h) was obtained from the S1*F3 as shown in Fig. 4. However, field capacity was significantly different (at 5% significance). The treatment's effect on field capacity in soils (S1 and S2) corresponding to forward speed was found significant. The replication effect of forward speed on each type of soil was observed as non-significant (at 5% significance). The homogeneity variance between different types of soil was checked using Levene's test for homogeneity of variance of field capacity. Analysis of variance (ANOVA) of absolute deviation from group mean of different soils (S) is given for field capacity. It observed that variance was homogenous at a 5% level of significance for field capacity. This permit further variance analysis of the data on the field capacity corresponding to types of soil and forward speed. Additionally, the replication effect in respect to soil was observed non-significant. Both soil types had non-significant effects on each other.

Field Efficiency (%)

The field efficiency of the developed urea applicator was observed from 61 to 75% at different treatment combinations. It is observed from Fig. 5 that minimum field efficiency (61%) was found at the lowest speed of operation and maximum field efficiency (75%) was found at the highest speed of operation in both types of soil. It was may due to the time lost during turning and other non-productive time activities.

Table 2: Statistics of soil type (S) and forward speed (F, km/h) effect on Field Capacity (FC, ha/h) and Fuel Consumption (F_c, l/h)

Head	DF		Sum of square		Mean of square		F-Value		P-Value		Sig.	
	FC	F_c	FC	F_c	FC	F_c	FC	F_c	FC	F_c	FC	F_c
S	1	1	0.00002	0.00642	0.00002	0.00642	0.13	0.31	0.7287	0.5955	NS	NS
rep (S)	4	4	0.00089	0.01969	0.00022	0.00492	1.29	0.23	0.3506	0.9114	NS	NS
F	2	2	0.09724	0.60111	0.04862	0.30056	282.32	14.30	<.0001	0.0023	S	NS
S*F	2	2	0.00031	0.02804	0.00016	0.01402	0.90	0.67	0.4429	0.5395	NS	NS

Fuel Consumption (F_c)

The Fuel consumption at any different speed of operation was found from 4.07 to 4.52 l h^{-1}. A non-significant difference was found in fuel consumption between different types of soil and a similar type of trend was found in the effect of different types of soil and forward speed was found non-significant (at 5%) (Table 1). The S2*F3 combination of treatment had the highest fuel usage (4.53 l/h), whereas the S2*F2 combination of treatment had the lowest (4.07 l/h) as shown in Fig.

The results indicate a notably higher crop yield for point-injected liquid urea application using the applicator, in comparison to the broadcasting method of applying urea. However, there were no significant differences in crop yield were found among the treatments of liquid urea application by the developed applicator. In a study conducted by the researcher [2], it was observed that the injection method of fertilization led to a significantly more than 15% increase in wheat yield compared to the conventional broadcasting method. Based on these findings, the researcher [2] strongly recommends adopting injection fertilization, particularly for minimum or zero tillage cereal crops in residue conditions.

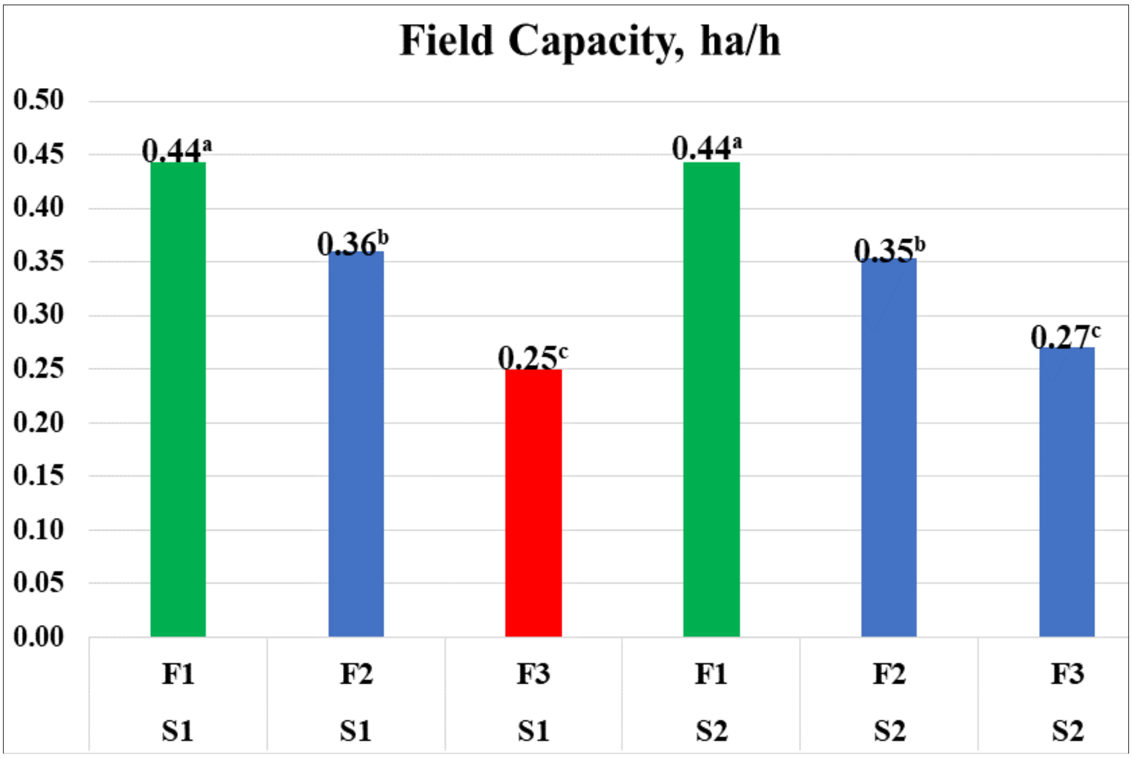

Fig 4: Mean field capacity at different soil and forward speed

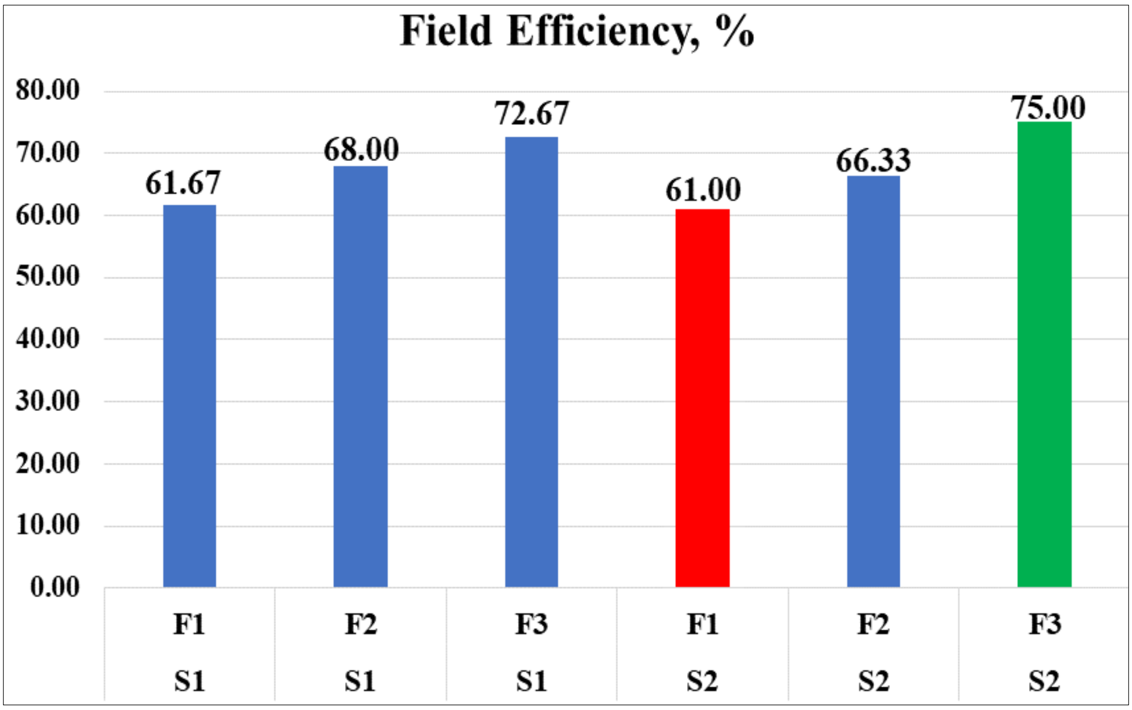

Fig 5: Field efficiency at different soil and forward speed

Conclusions

The developed applicator, utilizing a spoke wheel type, was proven to be efficient, effective and environmentally sustainable for injecting liquid urea in rice residue wheat crops. The average field capacity, time of operation, and field efficiency of the urea applicator were measured as 0.36 hectares per hour, 2.45 hours per hectare (h/ha), and 70%, respectively. The average fuel consumption of a tractor-operated spoke wheel type applicator was 4 litre per hour. The point-injected liquid urea application in rice residue wheat crops also increases grain yield over broadcasting of urea due to higher nitrogen use efficiency. The developed machine can also be evaluated for the application of different types of liquid fertilizers other than urea application.

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