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DEVELOPMENT AND STANDARDIZATION OF NITROGEN (LIQUID UREA) APPLICATION METERING MECHANISM FOR POINT INJECTION NITROGEN APPLICATOR

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Abstract: The existing method of broadcasting urea on straw mulched direct seeded wheat crop is susceptible to nitrogen losses. Nitrogen (liquid urea) applicator could be used to forestall the hazards of nitrogen loss and a metering mechanism for nitrogen (liquid urea) is currently not available. Hence, a nitrogen (liquid urea) metering mechanism was developed and tested in the laboratory. The operating pressure and peripheral speed of metering system were found to have significant effect on the discharge rate of metering mechanism. The discharge rate of the metering system was directly correlated with operating pressure and indirectly correlated with peripheral speed of the metering system. Based on the performance parameters, a peripheral speed of 0.70 $m \cdot s^{-1}$ (forward speed of 2.5 $km \cdot h^{-1}$), operating pressure of 3 $kg \cdot cm^{-2}$ and 2.095 $l \cdot ha^{-1}$ application rate of urea solution were selected for field operation of nitrogen (liquid urea) applicator. The outcome of this study will encourage the use of point injected nitrogen (liquid urea) applicator on straw mulched crops.

Key words*: discharge rate, metering mechanism, nitrogen (liquid urea) application, peripheral speed, operating pressure*

INTRODUCTION

Rice- wheat constitutes the most productive cropping system in India, covering approximately 10–12 million hectares. Punjab contributes 40–50% of the rice and 50–70% of the wheat in the central pool, from only 1.5% of the land [5].The scarcity of

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labor and time has led to the adoption of mechanized farming in highly intensive rice-wheat system in the state. This mechanization has been achieved by the developing various machineries based on crop and need [3]. The area under combine harvested rice and wheat in Punjab during 2008-09 was about 91 % and 82 %, respectively of the total area [10]. After combine harvesting, the rice residues comprise standing stubbles, usually 30–60 cm high, plus a substantial quantity of loose straw. The loose residues interfere with tillage and seeding operation for the next crop. More than 90% of the of rice stubble in Punjab are burnt each year, resulting in thick smoke blanketing the region [8]. The burning also results in the loss of nutrients and organic matter from the soil. Incorporation of rice residue requires nearly five or more tillage operations. Keeping in view these aspects, a machine (‘Happy Seeder’) was developed by Punjab Agricultural University, Ludhiana, which could direct drill wheat into heavy rice residue loads, without burning in a single operation. The yield of wheat sown into rice residues using the ‘Happy Seeder’ was comparable to or higher than yields with conventional sowing [7].

In high residue no-till farming, efficient nitrogen fertilizer application remains a challenge because of slower nitrogen mineralization, greater nitrogen immobilization and higher de-nitrification and ammonia volatilization losses. The presence of crop residues on the soil surface containing urea increases the potential for ammonia volatilization in no-till systems [1]. About 25% of the nitrogen applied as urea is lost via ammonia volatilization [6].

Reducing fertilizer nitrogen contact with the straw mulch by placing it into the soil surface can reduce nitrogen immobilization and ammonia volatilization which can increase grain yield, plant N uptake and nitrogen use efficiency [2, 10, 4]. Therefore, a need was felt to have a nitrogen (liquid urea) applicator that can apply nitrogen fertilizer (liquid urea) into the soil surface without disturbing straw mulch in directly sown combine harvested wheat [9]. For the development of such nitrogen applicator, the main component i.e. nitrogen (liquid urea) metering mechanism is required. Fertilizer metering mechanisms for granular fertilizers are commercially available. So, there is a need to develop a metering mechanism for proper and efficient application of nitrogen (liquid urea) in straw mulched crops.

MATERIAL AND METHODS

Description of the nitrogen (liquid urea) metering mechanism. A nitrogen (liquid urea) metering mechanism to be used for point injected nitrogen applicator [9] was developed at Department of Farm Machinery and Power Engineering, Punjab Agricultural University, Ludhiana, India. Before developing actual working component, computer aided conceptual view of component was made to give exact idea for fabrication (Fig. 1). The calibration and evaluation studies were conducted in the research laboratory of Punjab Agricultural University, Ludhiana during 2012-13.

It consists of spoke wheel, distribution hub, injectors and cut-off mechanism (Fig. 2). The liquid urea solution is supplied to the spoke wheel with pressure with the help of a piston type double cylinder pump with a pressure regulator. All the injectors attached to the distributor hub are under pressure of nitrogen (liquid urea). As and when the injector touches the soil surface, a specially designed stationery cam actuated crank lever mechanism which opens the flow control valve of that injector to inject the nitrogen (liquid urea) beneath the straw mulch into the soil surface. The brief specifications are given in Tab. 1 and description of major components is given below.

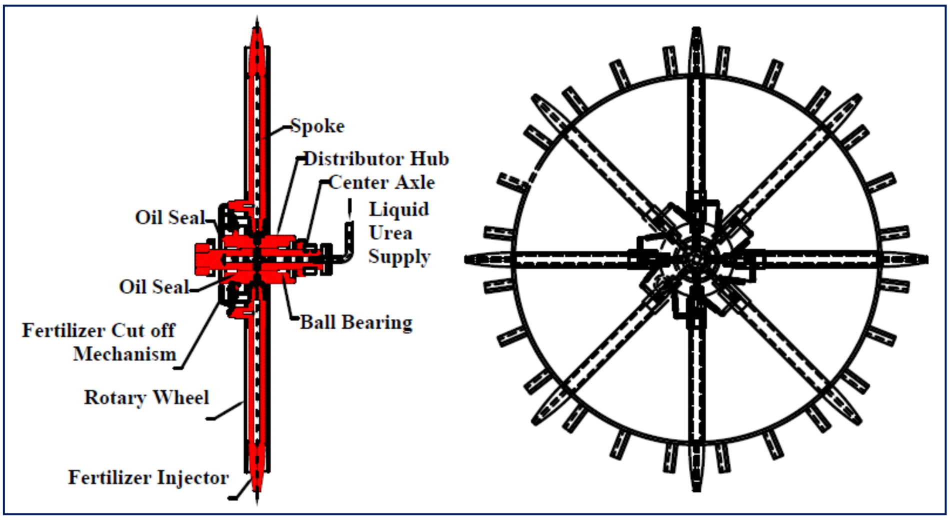

Figure1. Computer aided conceptual view of nitrogen (liquid urea) metering mechanism

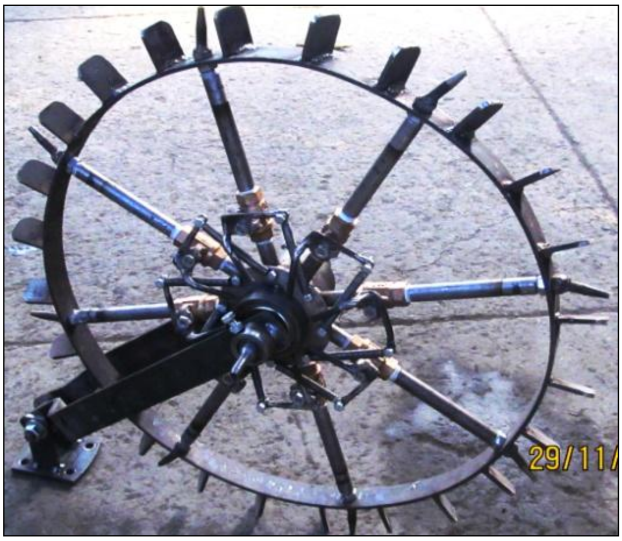

Figure 2. View of developed nitrogen (liquid urea) metering mechanism

Distribution Hub. The distribution hub acts as a reservoir in which liquid urea is supplied longitudinally from one side and exit tangentially out of eight spokes mounted on the periphery of the distribution hub. A distribution hub is made with a mild steel cylinder of 5 mm thickness, 50 mm diameter and 125 mm length. Eight numbers of hollow spokes are extended radially outward from the circumference of the distribution hub. The distribution hub includes an axle, two ball bearings and a cylindrically shaped housing with an axially aligned open centre portion in which the axle bearings are secured. Rubber seals are provided on inner side of the bearings to make it leakage free. The axle has two radial hole of 6 mm diameter on its periphery for supply of liquid urea to different spokes of the wheel. A 40 mm hollow pressure pipe has been used to serve as an axle. The axle positions the two ball bearings to permit rotational movement of the distribution hub with respect to the axle. The closed inner end and open end of the axle is connected to the liquid urea supply line. The axle surface is stair-stepped outwardly to enlarge its diameter at the centre for proper fitting of ball bearings with seal on both ends and the space between two bearings acted as housing for liquid urea.

Injector. Injectors are made from high carbon steel rod of Ø 12.5 mm and provide a cone shape at one end for easy penetration in straw mulch mat and soil surface. The injectors are fitted in slanting position with the spoke to avoid entangle of straw mulch. A bore of Ø 3 mm is bored inside the injector. The other end of the injectors with external threads is fitted inside spoke of Ø 9.5 mm.

Table 1. Specification of the developed nitrogen (liquid urea) metering mechanism

	Components	*Specifications*
1, Distribution hub		
i)	*Shape and size*	*Cylindrical, 50 x 125 mm*
ii)	*No. of spoke on hub*	*8*
2. Fertilizer injector		
i)	*Type*	*Cone shaped*
ii)	*Length of injector*	*60 mm*
iii)	*Orifice diameter of injector*	*3 mm*
3. Nitrogen (liquid urea) metering mechanism		
i)	*Type*	*Rotary valve metering*
ii)	*Diameter of spoke*	*9.5 mm*
4. Cut-off mechanism		
i)	*Type*	*Cam actuated flow control valve*
ii)	*Size of valve*	*¾ inch*

Cut-off mechanism. The nitrogen (liquid urea) cut-off mechanism consists of an inline mounted flow control valve to regulate the liquid urea flow between distributor and injector. Each flow control valve fitted in spoke assembly is provided with independent cutoff lever. A specially designed crank lever regulates the opening and closing of flow control valve. The load arm of the lever is attached with a helical tension spring; which kept the flow control valve in closed position. The effort arm of the crank lever is actuated by a stationery cylindrical cam fitted tangentially on a plate with the rotary wheel. With the rotation of rotary wheel, the effort arm of the lever strikes with the cam and is pushed back; which results into the opening of the flow control valve. As the lever arm passes the cam, the flow control valve comes to its closed position by the tension of the spring and liquid urea supply to the injectors is disconnected.

Laboratory evaluation. The metering mechanism was calibrated and evaluated in the laboratory conditions for discharge rate, application rate, spread diameter of wetted soil, depth of injection, discharge variation within injectors and discharge variation with simultaneously injectors opening. The standard test rig with variable drive was used to test the nitrogen (liquid urea) metering mechanism. The operating pressure of liquid urea was monitored by an engine operated piston type pump. A stationery view of pump with pressure regulator of the experiment set up is shown in Fig. 3. The metering mechanism was evaluated for three levels of operating pressures (2.5, 3.0 and 3.5 $kg \cdot cm^{-2}$) and three levels of peripheral speed (0.56, 0.70 and 0.83 $m \cdot s^{-1}$). Rectangular trays were used to collect the liquid urea discharged from each injector for one minute duration. Application rate of liquid urea ($l \cdot ha^{-1}$) was calculated from discharge rate and assuming row to row spacing of 40 cm and perimeter of injectors. Parameters like depth of injection and spread diameter of wetted soil were measured by operating the nitrogen applicator in field cum lab condition. Based on variable parameters, the metering mechanism was standardized for operating pressure and peripheral speed so that desired application rate could be maintained.

Figure 3. Laboratory evaluation of nitrogen (liquid urea) metering mechanism

RESULTS AND DISCUSSION

Effect of operating pressure and peripheral speed of metering system on discharge rate. The effects of operating pressure and peripheral speed on the discharge rate of the metering system was significant at 5% level of significance (Tab. 2). Discharge rate from a particular injector increased with the increase in operating pressure and decreased with increase in peripheral speed. Increase in operating pressure results in increase in flow speed of the liquid through orifice of the cut-off valve which results in increase in discharge rate whereas with increase in peripheral speed, the time for opening of the flow control valve decreases resulting in lesser discharge. The interaction of both the variables was also significant at probability level of 0.05.

Effect of operating pressure and peripheral speed of metering system on application rate. The effects of operating pressure and peripheral speed on the application rate was significant at 5% level of significance (Tab. 2). Application rate increased with the increase in operating pressure and decreased with increase in peripheral speed. The average application rate of 2095.4 $l \cdot ha^{-1}$, which was closest to liquid urea application rate used in the design of metering mechanism, was obtained at peripheral speed of 0.70 $m \cdot s^{-1}$ with operating pressure of 3 $kg \cdot cm^{-2}$. The interaction of both the variables was also significant at probability level of 0.05.

Effect of operating pressure and peripheral speed of metering system on Spread diameter. The effect of operating pressure and peripheral speed on spread diameter of wetted soil was significant at 5% level of significance (Tab. 2). Spread diameter increased with the increase in operating pressure and decreased with increase in peripheral speed. The highest average spread diameter of wetted soil (170.63 mm) was obtained at peripheral speed of 0.56 $m \cdot s^{-1}$ and operating pressure of 3.5 $kg \cdot cm^{-2}$ while the lowest average spread diameter of wetted soil (99.07 mm) was obtained at peripheral speed of 0.83 $m \cdot s^{-1}$ and operating pressure of 2.5 $kg \cdot cm^{-2}$. The interaction of both the variables was also significant at probability level of 0.05.

Table 2. Effect of peripheral speed and operating pressure on the discharge rate, application rate, spread diameter and depth of injection

Independent variables		*Dependent variables*			
Operating pressure (A) ($kg \cdot cm^{-2}$)	*Peripheral speed (B) ($m \cdot s^{-1}$)*	*Average discharge rate ($ml \cdot min^{-1}$)*	*Average application rate ($l \cdot ha^{-1}$)*	*Average spread diameter of wetted soil (mm)*	*Average depth of injection (mm)*
2.5	*0.56*	*3298.80*	*2476.57*	*120.53*	*28.00*
	0.70	*2960.93*	*1775.13*	*107.30*	*27.70*
	0.83	*2781.80*	*1390.90*	*99.07*	*27.40*
3.0	*0.56*	*3673.60*	*2757.97*	*160.67*	*35.40*
	0.70	*3495.10*	*2095.40*	*151.20*	*35.20*
	0.83	*3316.93*	*1658.47*	*140.53*	*35.00*
3.5	*0.56*	*4539.33*	*3407.90*	*170.63*	*38.30*
	0.70	*4248.43*	*2547.03*	*160.53*	*38.20*
	0.83	*3939.33*	*1969.67*	*150.40*	*38.00*
$C.D_{(0.05)}$					
A		*34.258*	*21.655*	*0.730*	*0.726*
B		*34.258*	*21.655*	*0.730*	*N.S.*
A x B		*59.336*	*37.507*	*1.265*	*N.S.*

Effect of operating pressure and peripheral speed of metering system on depth of injection. The effect of operating pressure on depth of injection was significant at 5% level of significance however; the effect of peripheral speed was not significant at 5% level of significance. Depth of injection increased with the increase in operating pressure. The peripheral speed had not significant effect on depth of injection.

Effect of operating pressure on discharge variation within injectors. The mean discharge rate for different injectors within a spoke wheel varied from 382.0 to 453.5 ml·min^{-1} at operating pressure of 2.5 kg·cm^{-2}; 456.8 to 505.1 ml·min^{-1} at 3.0 kg·cm^{-2} and 542.1 to 623.4 ml. min^{-1} at 3.5 kg.cm^{-2} operating pressure (Tab. 3). The lowest discharge variation was found at operating pressure of 3.0 kg·cm^{-2} and peripheral speed of 0.70 m·s^{-1} with highest uniformity of fertilizer application of 98.5%. The highest discharge variation among different injectors within a rotary wheel was observed at operating pressure of 2.5 kg·cm^{-2} and peripheral speed of 0.83 m·s^{-1}. The coefficient of uniformity for all the operating pressure viz. 2.5, 3.0, and 3.5 kg·cm^{-2}, was over 97 % with a range of 97.8 % to 98.5 %. The highest coefficient of uniformity in discharge rate was observed at operating pressure of 3.0 kg·cm^{-2} and peripheral speed of 0.70 m·s^{-1}.

Table 3. Effect of peripheral speed and operating pressure on discharge variation among different injectors within a spoke wheel

Peripheral speed (min^{-1})	*Injector discharge (ml·min^{-1}) Injector No.*								*Mean discharge (ml·min^{-1})*	*S.D*	*C.V (%)*	*Uniformity of fertilizer application (%)*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*				
A. Operating Pressure: 2.5 kg·cm^{-2}												
33.3	*450*	*460*	*454*	*447*	*442*	*455*	*460*	*460*	*453.5*	*9.6*	*2.11*	*97.9*
41.7	*406*	*410*	*408*	*400*	*410*	*415*	*400*	*408*	*407.1*	*6.7*	*1.65*	*98.4*
50.0	*395*	*380*	*386*	*390*	*375*	*380*	*375*	*375*	*382.0*	*8.4*	*2.19*	*97.8*
B. Operating Pressure: 3.0 kg·cm^{-2}												
33.3	*505*	*510*	*506*	*515*	*495*	*500*	*495*	*515*	*505.1*	*8.3*	*1.63*	*98.4*
41.7	*476*	*490*	*480*	*495*	*470*	*475*	*480*	*475*	*480.1*	*7.2*	*1.50*	*98.5*
50.0	*450*	*460*	*455*	*460*	*455*	*465*	*448*	*455*	*456.8*	*8.4*	*1.83*	*98.2*
C. Operating Pressure: 3.5 kg·cm^{-2}												
33.3	*620*	*615*	*615*	*625*	*630*	*625*	*635*	*630*	*623.4*	*12.9*	*2.08*	*97.9*
41.7	*580*	*590*	*595*	*585*	*585*	*575*	*590*	*575*	*584.4*	*10.2*	*1.74*	*98.3*
50.0	*540*	*550*	*545*	*540*	*548*	*540*	*535*	*540*	*542.1*	*11.5*	*2.12*	*97.9*

Effect of operating pressure and simultaneous injectors opening on discharge variation. The effect of operating pressures and number of simultaneous injectors opening on discharge variation is given in Tab. 4. There was some discharge variation with the number of injectors opening. With increase in number of simultaneous injectors opening, discharge variation increased. The highest discharge variation was recorded at operating pressure of 3.5 kg·cm^{-2} with coefficient of variation of 1.14, while the lowest discharge variation was found at operating pressure of 3.0 kg·cm^{-2} with coefficient of variation of 0.88. This discharge variation was considered small and reasonable.

Selection of the optimum peripheral speed and operating pressure. The average application rate of 1.969,67 l·ha^{-1} was obtained at peripheral speed of 0.84 m·s^{-1} and operating pressure of 3.5 kg·cm^{-2}; while the application rate of 2.095,40 l·ha^{-1} was obtained at peripheral speed of 0.70 m·s^{-1} and operating pressure of 3.0 kg·cm^{-2}, which were close to liquid urea application rate (2.000 l·ha^{-1}) used in the design of current metering mechanism. The spread diameter of wetted soil was significantly higher (151.20 mm) at peripheral speed of 0.70 m·s^{-1} and operating pressure of 3.0 kg·cm^{-2} than that of 150.40 mm at peripheral speed of 0.83 m·s^{-1} and operating pressure of 3.5 kg·cm^{-}

^{2}. It is also evident from the Tab. 4 that a peripheral speed of 0.70 m·s^{-1} and 3.0 kg·cm^{-2} operating pressure of metering system resulted into lowest coefficient of discharge variation (1.5%). Therefore, a peripheral speed of 0.70 m·s^{-1} (forward speed of 2.50 km·h^{-1}), operating pressure of 3.0 kg·cm^{-2} and application rate of 2.095 l·ha^{-1} were selected as optimum speed, operating pressure and liquid urea solution application rate for the field operation of self propelled walk behind nitrogen (liquid urea) applicator.

Table 4. Effect of operating pressure and number of injector opening on discharge variation among different rotary wheels

No. of injector opens at a time	*Average discharge rate (ml·min^{-1})*						
	Spoke wheel No.				*Mean*	*S.D.*	*C.V (%)*
	1st	*2nd*	*3rd*	*4th*			
Operating pressure: 2.5 kg·cm^{-2}							
1	*3888.33*	*0.00*	*0.00*	*0.00*	*3888.33*	*46.65*	*1.22*
2	*3885.00*	*3825.00*	*0.00*	*0.00*	*3855.00*		
3	*3846.70*	*3811.70*	*3770.00*	*0.00*	*3809.47*		
4	*3833.33*	*3795.00*	*3763.00*	*3743.30*	*3783.66*		
Operating pressure: 3.0 kg·cm^{-2}							
1	*5190.00*	*0.00*	*0.00*	*0.00*	*5190.00*	*44.98*	*0.88*
2	*5165.00*	*5110.33*	*0.00*	*0.00*	*5137.67*		
3	*5105.33*	*5100.67*	*5097.69*	*0.00*	*5101.23*		
4	*5099.10*	*5091.18*	*5089.20*	*5081.32*	*5090.20*		
Operating pressure: 3.5 kg·cm^{-2}							
1	*6368.30*	*0.00*	*0.00*	*0.00*	*6368.30*	*71.73*	*1.14*
2	*6353.30*	*6305.00*	*0.00*	*0.00*	*6329.15*		
3	*6308.30*	*6295.00*	*6288.30*	*0.00*	*6297.20*		
4	*6234.21*	*6229.43*	*6209.32*	*6128.64*	*6200.40*		

CONCLUSIONS

The operating pressure and peripheral speed of metering system had significant impact on the discharge rate of the metering mechanism which further affects the application rate of nitrogen (liquid urea) to be applied. The discharge rate of the metering mechanism decreased as the peripheral speed of mechanism increased from 0.56 to 0.83 m·s^{-1} and increased as the operating pressure of the pump increased from 2.5 to 3.5 kg·cm^{-2}. The lowest discharge variation within injectors was found at operating pressure of 3.0 kg·cm^{-2} and peripheral speed of 0.70 m·s^{-1} with highest uniformity of fertilizer application of 98.5%. There was some discharge variation with the number of simultaneously injectors opening. With the increase in number of simultaneously injector opening, discharge variation increases.

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RAZVOJ I STANDARDIZACIJA MERNOG MEHANIZMA NA UREĐAJU ZA APLIKACIJU AZOTA (TEČNE UREE) TAČKASTIM UBRIZGAVANJEM

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Sažetak: Postojeći metod primene uree na površini tretiranoj malčom slame sa direktno sejanom pšenicom je podložan gubicima azota. Azot (tečna urea) može biti apliciran kako bi se izbegao rizik od gubitka azota, ali merni mehanizam za azot (tečnu ureu) trenutno nije dostupan. Zato je razvijen i u laboratorijskim uslovima testiran uređaj za merenje azota. Radni pritisak i obimna brzina mernog mehanizma imali su značajan uticaj na normu aplikacije. Intenzitet pražnjenja je bio u direktnoj korelaciji sa radnim pritiskom i u obrnutoj korelaciji sa obimnom brzinom mernog sistema. Na osnovu ispitivanih veličina, za rad u poljskim uslovima određeni su sledeći parametri: obimna brzina od 0.70 $m \cdot s^{-1}$ (radna brzina od 2.5 $km \cdot h^{-1}$), radni pritisak od 3 $kg \cdot cm^{-2}$ i norma aplikacije rastvora azota (tečne uree) od 2.095 $l \cdot ha^{-1}$. Rezultati istraživanja u ovoj studiji će unaprediti upotrebu uređaja tačkastu aplikaciju azota (tečne uree) na parcelama sa usevima na slamenom malču.

Ključne reči*: norma pražnjenja, merni mehanizam, aplikacija azota (tečna urea), obimna brzina, radni pritisak*

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