Univerzitet u Beogradu Poljoprivredni fakultet Institut za poljoprivrednu tehniku Naučni časopis ***POLJOPRIVREDNA TEHNIKA*** Godina XLI Broj 2, 2016. Strane: 1 – 10	University of Belgrade Faculty of Agriculture Institute of Agricultural Engineering Scientific Journal ***AGRICULTURAL ENGINEERING*** Year XLI No. 2, 2016. pp: 1 – 10

UDK: 633.11

Originalni naučni rad
Original scientific paper

SELF PROPELLED SPOKE WHEEL NITROGEN APPLICATOR FOR RICE RESIDUE MULCHED WHEAT CROP

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Abstract: In order to reduce nitrogen losses sustained in broadcasting of urea under high rice straw mulched wheat crop and to enhance crop yield, a self propelled spoke wheel nitrogen applicator for injecting nitrogen in liquid form beneath the soil surface was designed, developed and evaluated under actual field conditions. The machine comprised four sets of spoke wheel having radial injectors attached to a distribution hub with inline mounted flow control valve and cut-off system. Constant supply of liquid urea to the distribution hub by means of a piston pump produced pressure adequate to expel urea solution through the flow control valve as it opened. The opening and closing of flow control valve was regulated through a specially designed lever and stationery cam. The average field capacity and efficiency of the machine were found to be 0.36 $ha \cdot h^{-1}$ and 88.9%, respectively. Yield and nitrogen use efficiency (*NUE*) of wheat crop fertilized with spoke wheel nitrogen applicator was 20 and 47 % respectively higher than that of broadcasting method of nitrogen application. Lower nitrogen accumulation in mulch and higher nitrogen uptake in wheat crop indicated reduced nitrogen losses in case of point injected nitrogen application over broadcasting. Hence, spoke wheel nitrogen applicator acquires a promising option not only for enhancing crop yield but also environment protection.

Key words*: spoke wheel nitrogen applicator, broadcasting, rice straw mulch concentration, nitrogen use efficiency, nitrogen uptake, yield*

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INTRODUCTION

The sustainable food security for ever-increasing human population along with environmental protection and conservation of natural resources have emerged as the prime concerns for the global agriculture. Green revolution changed Indian agriculture scenario and Punjab had major contribution in this revolution. Use of fertilizers, pesticides, insecticides, high yielding varieties, and advanced machines helped in agriculture growth. Rice-wheat cropping system became popular in Punjab [8]. The developments of machinery like ‘Happy seeder’ for simultaneously mulching rice straw while sowing wheat have provided the option of surface applied rice residue rather than burning and incorporation [7]. Mulched rice residue result in less N immobilization and also provide benefits viz. conservation of soil, water and weed suppression. No difference in grain yield and biomass production has been reported for direct drilling of wheat in the rice stubbles compared to traditional method of sowing. Some field studies from India and China with reduced or no-till wheat and other cereal crops revealed that mulching rice residue increased crop productivity [1].

The rapid adoption of mulch-tillage system in wheat after rice has led to increased demand of nitrogenous fertilizer (urea) due to inefficient and improper application method. About 40% of the N fertilizer applied to irrigated wheat is only utilized by the plants due to inefficiency in application (wrong method or timing of application) [9]. The mulch retained the broadcasted fertilizer granules and ammonia volatilization losses enhances, leading to a low N efficiency. The presence of crop residues on the soil surface containing urea increases the rate of urea hydrolysis, thus increasing the potential for ammonia volatilization in no-till systems. Where urea or urea-based fertilizers are surface applied, particularly in the presence of organic residues, crop yields are often reduced. There have been reports in the literature that suggests that higher nitrogen rates are required to crops sown in straw mulch because fertilizer use efficiency of the plants is limited in such conditions and crop becomes deficient of nitrogen at recommended rate of fertilizer application [3].

Therefore, a new innovation to overcome the problem of improper and inefficient top dress nitrogen application in high residue mulched no-till wheat in the *RW* system is warranted. An approach that has not been well explored is the use of point injection of urea in mulch seeded wheat. The objective of this study was to design and develop a spoke wheel nitrogen applicator for application of liquid urea in rice straw mulched wheat crop.

MATERIAL AND METHODS

The self-propelled spoke wheel nitrogen applicator was designed and developed based on its required function. The design of nitrogen (liquid urea) applicator is based on the idea that using a narrow spoke wheel with injectors on its periphery shall work as liquid urea applicator in straw mulched wheat crop. The cone shaped injector on spoke wheel periphery would penetrate the straw mulch more easily by the weight of the machine and require less vertical force. To increase further penetration of liquid urea in the soil and also to prevent clogging of injectors, the liquid urea needs to be applied at some pressure.

Keeping in view conceptual and functional design, a prototype model of nitrogen (liquid urea) application mechanism (Fig. 1) was fabricated and evaluated under simulated conditions for its working performance. The water was applied at variable operating pressure ranging from 2.0 to 4.0 kg·cm^{-2} with sprayer pump. It was observed that operating pressure ≤ 2 kg·cm^{-2} leads to clogging of injectors and insufficient depth of injection while operating pressure ≥ 3.5 kg·cm^{-2} leads to leakage and excessive disturbance of soil. The prototype model worked satisfactorily at operating pressures ranging from 2.0 to 3.5 kg·cm^{-2}. The average depth of injection was found varying from 25.80 -36.50 mm at operating pressure range of 2.0 - 3.5 kg·cm^{-2}. The average spread diameter of wetted soil was observed in the range of 75.90 - 104.70 mm. Observing the satisfactory performance of prototype model of nitrogen applicator, a 4-row self propelled spoke wheel nitrogen applicator prototype was conceived and developed.

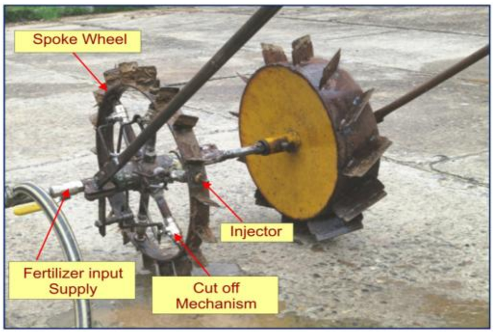

Figure 1. View of prototype model of nitrogen (liquid urea) applicator

Constructional details of the machine. The spoke wheel nitrogen applicator was developed as a rear mounted attachment to self propelled engine unit (Fig. 2). The basic components of the machine were 4 sets of spoke wheel 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.

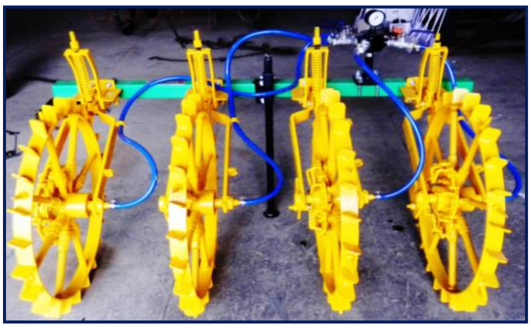

Figure 2. View of self propelled spoke wheel nitrogen applicator

Main frame. The tool bar served as a support to attach the spoke wheel assembly to a prime mover. The tool bar assembly comprised two support arms rotation secured at one end to the spoke wheel assembly and another end to a support plate. The support plate was used for attachment of the implement to a tool bar by two U-clamps. The four units of spoke wheel nitrogen applicator were clamped on the tool bar at uniform spacing of 400 mm between consecutive spoke wheels. The spring biased joint used a coil spring to keep the support arm in a downward direction to prevent skidding and permitted the support arm to move upward if spoke wheel encountered any obstruction.

Spoke wheel. A set of four spoke wheels were mounted on the frame. The spoke wheel assembly included a fertilizer metering and cut-off mechanism and a circular rim that is concentric with the distribution hub. The circular rim of 640 mm diameter was welded with trapezoidal shaped lugs on the periphery for the positive rotation under mulch conditions. The rim served as a means for bracing and stabilizing the position of the spokes with respect to distribution hub and controlling depth of penetration in the soil.

Fertilizer Metering and Cut-off mechanism. It consisted of a distribution hub acting as a reservoir in which water dissolved urea was supplied longitudinally from one side and exit tangentially out of spokes mounted on the periphery of the distribution hub. The distribution hub mounted on an axle with two ball bearings at both ends and acted as a rotary valve for metering and supplying liquid urea from the main supply to the spokes fitted on the periphery of the distribution hub. An inline mounted flow control valve was provided to regulate the liquid urea flow between distributor and injector. Each flow control valve fitted in spoke assembly was provided with independent cutoff lever. A specially designed crank lever regulated the opening and closing of flow control valve. The load arm of the lever was attached with a helical tension spring, which kept the flow control valve in closed position. The effort arm of the crank lever was actuated by a stationery cylindrical cam fitted tangentially on a plate with the spoke wheel. The cam was so designed that it operated the cutoff lever for 30° of rotation of spoke wheel as an injector touches the soil surface. With the rotation of spoke wheel, the effort arm of the lever strikes with the cam and is pushed back; which resulted 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.

Pump. A double cylinder piston pump was used for the supply of liquid urea at constant pressure to the distribution hub. A control valve assembly was provided to regulate the pressure and bypass the extra quantity of liquid fertilizer to the fertilizer tank. The pump could develop maximum pressure up to 28 $kg \cdot cm^{-2}$ at 950 min^{-1} with suction capacity of 13 $l \cdot min^{-1}$.

Fertilizer Tank. A mild steel tank having capacity of 100 L was used to store the liquid urea solution. The urea solution is fed to the pump from the tank by pump and at the open end of the suction pipe a strainer was provided to prevent the flow of foreign materials with the liquid urea solution. The open end of the bypass pipe was connected with the tank so that the liquid urea solution which was not utilized by the spoke wheels could go back to the tank. The fertilizer tank was sufficient for liquid urea application of 480 m^2 area.

Pressure Gauge. A pressure gauge was provided to check the operating pressure at which liquid urea solution has to be delivered to the distribution hub by the main supply. A control valve was provided in each supply line to maintain the desired flow rate.

Prime-mover. A diesel engine of 4.48 kW was selected as prime mover for operating the spoke wheel nitrogen applicator. It had two narrow rubber wheels which were powered from the engine through gears and chains. The ground clearance of the machine was kept 500 mm taking in view the crop height at the time of fertilizer application. A third wheel was provided at the rear to act as transport wheel. A provision was made to adjust the track width from 900 to 1050 mm. A pump operating lever was provided on the handle to operate the pump during the nitrogen (liquid urea) application in the field. A transmission clutch lever was also provided on the handle to control the transmission system of the machine. An accelerator lever regulated the forward speed of the machine.

Field evaluation of the machine. The developed machine was evaluated in straw mulched wheat crop twice during the crop season. The operating pressure of pump was fixed at 3.0 $kg \cdot cm^{-2}$ and machine was operated at a forward speed of 2.5 $km \cdot h^{-1}$ in the field. At this operating pressure and forward speed, the machine delivers 2095 $lit \cdot ha^{-1}$ solution of urea [2]. Accordingly, the solution of urea was prepared by mixing required dose of urea with water. The fertilizer tank was filled with solution of urea. A hand lever has been provided for the on/off operation of the pump. With the engagement of lever, the pump starts the supply of urea solution to the spoke wheel. During rotation of the spoke wheel, it carries urea solution into the distribution hub and delivers them to the injectors through spokes. Fertilizer applicator delivers the urea solution at 250 mm spacing along the row and 400 mm row spacing (alternate row).

An experiment was laid out in a factorial randomized block design with three replications comprising of six treatments with two levels of rice straw mulch concentration and three levels of methods of fertilizer application. The plots size of each plot was 14 x 12 m^2. Following were the treatments:

A. Methods of Nitrogen Application (3 methods)

M_1: Application of N with developed machine (0 + ½ N after 1^{st} irrigation + ½ N after 2^{nd} irrigation)

M_2: Broadcasting of N as per University package of practice (½ N during sowing + $1/4^{th}$ N after 1^{st} irrigation + $1/4^{th}$ N after 2^{nd} irrigation)

M_3: Broadcasting of N general practice followed by farmers using 'Happy seeder' (0 + ½ N before 1^{st} irrigation + ½ N before 2^{nd} irrigation)

B. Rice Straw Mulch Concentration (2 levels)

L_1: Low straw mulch concentration (4.6 $t \cdot ha^{-1}$)

L_2: High straw mulch concentration (8.0 $t \cdot ha^{-1}$)

Constant Parameters: Wheat directly sown in combine harvested paddy field using 'Happy seeder'.

All the experimental plots were sown uniformly using 'Happy Seeder' under two rice straw mulch concentration conditions. Wheat (variety *PBW*-621) was sown on November 9, 2012 and all the plots received a basal dose of 26 $kg \cdot P \cdot ha^{-1}$ and 25 $kg \cdot K \cdot ha^{-1}$ prior to sowing. Fertilizer nitrogen 110 $kg \cdot N \cdot ha^{-1}$ was applied as per treatments of methods of N application. In all M_1 treatments, nitrogen fertilizer (water dissolved urea) was point injected in two splits using spoke wheel nitrogen (liquid urea) applicator (Fig. 3). In M_2 treatment, recommended dose of urea was broadcasted in three splits after 4-5 days of irrigation while in M_3 treatment, recommended dose of urea was broadcasted in two splits before the application of irrigation. All other practices for growing wheat crop were followed as recommended by Punjab Agricultural University, Ludhiana.

Figure 3. Real and field operational view of self propelled spoke wheel nitrogen applicator

RESULTS AND DISCUSSION

The Average operating time, field capacity and operation efficiency of the self-propelled spoke wheel nitrogen applicator were 2.78 $h \cdot ha^{-1}$, 0.36 $ha \cdot h^{-1}$, 88.9%, respectively. The fuel (High speed diesel) consumption of self propelled nitrogen (liquid urea) applicator was 0.980 $lit \cdot h^{-1}$.

Effect of Methods of Nitrogen Application on N Uptake and yield attributes.

Total Plant N Uptake. N-uptake is interplay of biomass production and N-concentration. Highest total plant N uptake at maturity (121.44 $kg \cdot ha^{-1}$) occurred in case of M_1 method of N application at high straw load while lowest N uptake (76.16 $kg \cdot ha^{-1}$) was observed in case of M_2 method of N application at high straw mulch concentration (Fig. 4). Total plant N uptake did not differ at different straw mulch concentration with M_1 method of N application while plant N uptake differ significantly at different straw mulch concentration with M_2 and M_3 methods of N application.

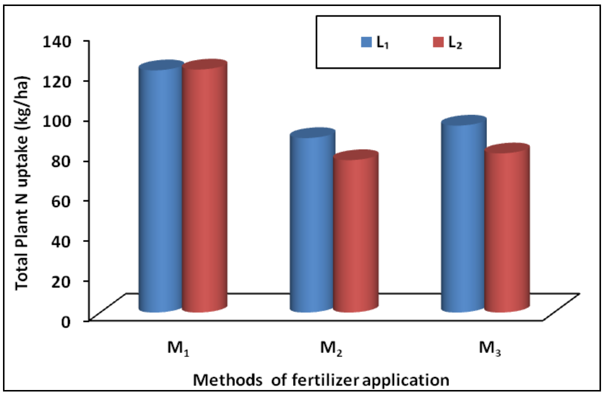

Figure 4. Effect of methods of nitrogen application on plant N uptake

Nitrogen accumulation in straw mulch. Nitrogen accumulation in straw mulch indicating nitrogen loss tended to be similar among treatments at the time of sowing. The

N accumulation in straw mulch in case of broadcast (M_2 & M_3) methods of N application increased or remained same during the crop growing season whereas it showed decreasing trend in case of M_1 method of N application. At 70 *DAS*, mean N accumulation in mulch was significantly lower in case of M_1 than M_3 and M_2 methods of N application. But no significant difference of N accumulation in mulch among M_2 and M_3 methods of N application was observed at this stage. At the time of crop maturity, the N accumulation in straw mulch in case of M_1 method of N application was significantly lower than that of M_2 and M_3 methods (Fig. 5). The lower accumulation of N in straw mulch indicated low nitrogen loss in M_1 method of nitrogen application. This might be due to non contact of nitrogen fertilizer with straw mulch during application which could be coupled with the favourable effect for enhancing the crop yield.

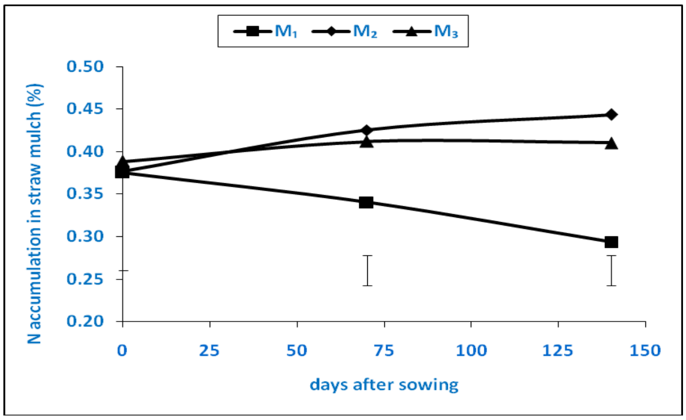

Figure 5. Effect of methods of nitrogen application on N accumulation in straw mulch

Grain Yield and attributes. Methods of N application had significant effect on the number of earhead per m row length (P <0.05), length of earhead (P < 0.05), grain number per earhead (P <0.01), 1000-grain weight (P <0.05) and the grain yield (P <0.01). Mean comparisons showed that point injected nitrogen through spoke wheel nitrogen applicator increased all of the above yield components (Tab. 1). The highest number of earhead per m row length, higher earhead length, higher numbers of grains per earhead resulted for point injected nitrogen (liquid urea) applied by nitrogen applicator (M_1) at recommended dose than other broadcasting treatments (M_2 and M_3) but there were no significant difference of number of grains per earhead among the treatments M_2 and M_3. Similar trends were obtained for 1000 grain weight with highest 1000 grain weight in case of point injected nitrogen application (M_1). The higher 1000 grain yield in case of M_1 might be due to higher nitrogen concentration in plant tissue. The researcher [6] also reported higher 1000 grain weight in case of fertilizer injection as compared to broadcasting method. It can also be observed from the table that significantly higher grain yield for point injected nitrogen application with nitrogen applicator (M_1) than that of broadcasting urea (M_2 & M_3). There were no significant differences of grain yield between M_2 and M_3 treatments of N application. The researcher [4] also observed 15.5% significant higher wheat yield by injection method in comparison with the conventional method (broadcasting).

Nitrogen Use Efficiency (NUE). The NUE in case of urea solution injected with spoke wheel nitrogen applicator (M_1) was 47.1% more than that of broadcasting of urea (M_2) (Fig. 6). Lower wheat *NUE* in broadcasting of urea under straw mulch conditions was due to lesser availability of N to the plant and lower grain yield and higher wheat NUE in nitrogen application with spoke wheel nitrogen applicator may be ascribed to more N uptake and higher grain yield. Based on the result findings, the researcher [5] strongly recommended injection fertilization in case of minimum or zero tillage cereal crops.

Table 1. Effect of different nitrogen application methods on Yield Components

Treatment	*Yield attributes**				
	No of ear-heads per m row length	*Ear-head length [cm]*	*Number of grains per ear-head*	*1000 grain weight [gm]*	*Grain yield [q·ha^{-1}]*
M_1	97.61a	11.00a	54.42a	42.18a	54.23a
M_2	86.56b	10.10b	42.56b	39.38b	45.28b
M_3	93.42c	10.33c	44.33b	39.16b	46.92b

Note: Common letter in the same column are not significantly different at P≤ 0.05 by LSD
**Average values at two straw mulch concentration*

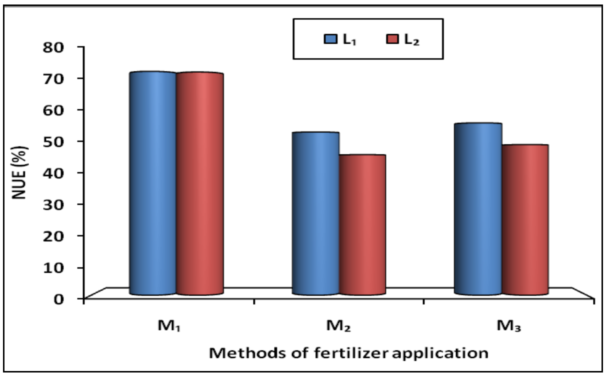

Figure 6. Effect of methods of nitrogen application on nitrogen use efficiency (NUE)

CONCLUSIONS

The developed spoke wheel nitrogen applicator was found efficient and environmentally viable for injection of nitrogen (liquid urea) in straw mulched wheat crop. The point injected nitrogen application in rice straw mulched wheat crop enhanced 20 % grain yield and 47 % nitrogen use efficiency over broadcasting of urea. The lower N accumulation in straw mulch in case of point injected N application through spoke wheel nitrogen applicator indicated the reduced N loss under this system of fertilizer urea application particularly under straw mulched conditions. Significant higher N uptake was observed in case of point injected N application over surface broadcast in the presence of rice straw mulch.

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SAMOHODNI APLIKATOR ZA UBRIZGAVANJE TEČNOG AZOTA U USEVU PŠENICE NA USITNJENIM ŽETVENIM OSTACIMA PIRINČA

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Sažetak: Sa ciljem smanjenja gubitaka azota pri ubacivanju uree pod usitnjene žetvene ostatke radi povećanja prinosa, konstruisan je samohodni aplikator za ubrizgavanje tečnog azota pod površinu zemljišta. Mašina se sastoji od četiri kompleta točkova sa paocima i injektorima postavljenim na haubu sa ugrađenim ventilom za kontrolu protoka i isključenje sistema. Konstantan dotok tečne uree do distributera preko klipne pumpe obezbeđen je odgovarajućim pritiskom za izbacivanje rastvora uree kad je kontrolni ventil otvoren. Otvaranje i zatvaranje kontrolnog ventila je regulisano specijalno konstruisanom ručicom. Srednji poljski kapacitet i efikasnost mašine su iznosili 0.36 $ha \cdot h^{-1}$ i 88.9%, redom. Prinos i efikasnost iskorišćenja azota (*NUE*) kod pšenice đubrene ovim aplikatorom azota bili su 20 i 47%, redom, viši nego pri uobičajenom rasturanju azota. Niža akumulacija azota u malču i više usvajanje azota kod pšenice ukazuju na manje gubitke azota kod tačkastog ubrizgavanja azota u odnosu na rasturanje. Tako ovaj aplikator azota predstavlja povoljniju opciju, ne samo za povećanje prinosa nego i za zaštitu okoline.

Ključne reči: *orebreni točak za aplikaciju azota, emisija, koncentracija usitnjene slame pirinča, efikasnost iskorišćenja azota, usvajanje azota, prinos*

Prijavljen: *Submitted*:	29.09.2015.
Ispravljen: *Revised*:	
Prihvaćen: *Accepted*:	28.05.2016.