Development and evaluation of nitrogen (liquid Urea) applicator for straw mulched no-till wheat

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Abstract: The broadcasting of urea under high straw no-till farming often exhibit suppressed yields because of lesser nitrogen availability due to slower soil mineralization and greater N immobilization, de-nitrification and ammonia volatilization. Prior to development of nitrogen (liquid urea) applicator, appropriate machines were not available for application of urea into the soil surface in a directly sown high straw mulched wheat crop. To solve the problems of urea application in high straw no-till farming, self-propelled nitrogen (liquid urea) applicator was developed and evaluated under actual field conditions. Average field capacity and efficiency of the applicator were found to be 0.33 ha/h and 80.49%, respectively. Total plant N uptake at maturity was higher with wheat fertilized with developed nitrogen applicator (121.24 kg ha^{-1}) in comparison to conventional broadcasting (81.69 kg ha^{-1}). Yield of wheat fertilized with the developed nitrogen (liquid urea) applicator was 20% higher than with broadcasting. The increase in wheat yield under nitrogen applicator was primarily due to higher spike density, higher spike length, more grains per spike, more grain weight and higher nitrogen uptake. Among point injection nitrogen application, the grain yield was at par at different straw load conditions; however, in case of broadcast N application, significantly lower grain yield was obtained under high straw load conditions compared to that of low straw load conditions. This effect was attributed to the low accessibility of fertilizer N to the plant at high straw load in case of broadcast of urea.

Keywords: Nitrogen (liquid urea) applicator, broadcasting, straw load, field capacity, nitrogen uptake, yield

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1 Introduction

In South Asia, Rice –wheat (RW) is a well-established crop production system of the north-western plains of the Indian sub-continent and adjoining areas of Pakistan. Reduced and no tillage in wheat after rice has been increasingly adopted by farmers in north-west Indo-Gangetic Plain (IGP) since the late 1990s (Grover and Sharma, 2011; Ladha et al., 2009), with reported large cost savings through reduced use of fuel and labor, and irrigation water saving of 20%–30%. There are several reports (Bijay Singh et al., 2008) showing similar rice and wheat yields under different residue management practices (burning, removal, incorporation or mulching). The developments of machinery like Happy seeder for simultaneously mulching rice straw while sowing wheat (Sidhu et al., 2007) have provided the option of surface applied rice residue rather than burning and incorporation. Mulched rice residue results in less N immobilization and also provides benefits viz. conservation of soil, water and weed suppression. Majid et al. (1987) found no difference in grain yield and biomass production 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 (Bijay Singh et al., 2008).

Despite these encouraging results, one factor that continues to be a problem in high residue no-till farming systems is proper and efficient application of nitrogenous

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fertilizer (urea). Only about 40% of the N fertilizer applied to irrigated wheat is utilized by the plants due to inefficiency in application (wrong method or timing of application) and/or the inherent properties of current fertilizer products (Singh et al., 2008). In Punjab, India, about 125-150 kg ha^{-1} N is applied in wheat crop production, with more than 75% applied as top dressing through broadcasting. The mulch retained the broadcasted fertilizer granules and ammonia volatilization losses enhanced, 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 (Barreto and Westerman, 1989). Where urea or urea-based fertilizers are surface applied, particularly in the presence of organic residues, crop yields are often reduced (Singh et al., 2004). There have been reports in the literature suggesting 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 (Gangwar et al., 2006).

Therefore, a new innovation to overcome the problem of proper and efficient top dress nitrogen application in high residue mulched no-till wheat in the RW system is warranted. In comparison with the rapid spread of residue mulched no-till wheat planting in the RW system of South Asia, the development of machinery for top dress urea application in residue mulched wheat crop has not yet taken place. The efficient top dress nitrogen application in high residue mulched wheat crop without disturbing the mulch and crop is possible only by point injected nitrogen applicator. Schnier et al. (1988) reported higher N recovery (94%) from the split USG points placement than broadcasting (52%). Blackshaw (2002) found consistently higher wheat shoot N concentration and yield with banded or point-injected N compared with broadcast N. However, none of the present mechanical planters or fertilizer applicators is capable of applying top dress fertilizer urea into high residue mulched no-till wheat crop. The aim of the present study was to develop and evaluate a nitrogen (liquid urea) applicator capable of applying urea solution beneath the straw mulch into top layer of soil surface under high residue mulched no-till wheat.

2 Materials and methods

2.1 Constructional details of the machine

The nitrogen (liquid urea) applicator is developed as a rear mounted attachment to self propelled engine unit. It consists of a light weight power unit and a nitrogen (liquid urea) application unit. The nitrogen application unit consists of 4 sets of spoke wheel with fertilizer metering and cut-off mechanism, a pump, a fertilizer tank and a pressure gauge (Figure 1). The specifications of the machine are given in Table 1. The descriptions of different components are given below.

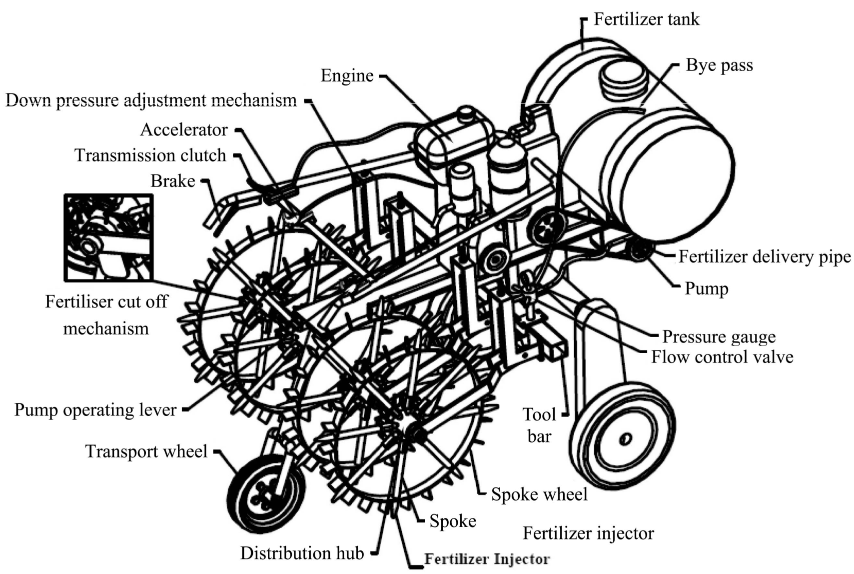


Figure 1 Isometric view of developed Self propelled nitrogen (liquid urea) applicator

Table 1 Specification of self propelled point injected nitrogen (liquid urea) applicator

Specification	Units
Type	4 row self propelled walk behind
No. of spoke wheel	4
Diameter of spoke wheel, mm	697
No. of injector per spoke wheel	8
Spacing between consecutive injector, mm	250
Spacing between consecutive spoke wheel	Adjustable (200-500 mm)
Pump	Piston pump, 13 L min^{-1} suction capacity, 29 kg cm^{-2} max. pressure at 950 r min^{-1}
Tyre Thickness, mm	100
Track width, mm	900-1050
Power source	6 hp diesel engine
Fertilizer injector	hollow cone shaped, 3 mm Φ, 60 mm length
Metering mechanism	Rotary valve metering
Cut-off mechanism	Cam actuated flow control valve
Transport wheel	Rubber wheel on rear side

2.2 Main frame

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

2.3 Spoke wheel

A set of four spoke wheels are mounted on a rectangular tool bar. The spoke wheel assembly includes 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 is welded with trapezoidal shaped lugs (50 mm length, 30 mm tip width) on the periphery for the positive rotation under straw mulch conditions. The rim is made of 40 mm mild steel flat. The rim served as a means for bracing and stabilizing the position of the spokes with respect to the distribution hub and controlling depth of penetration in the soil.

2.4 Fertilizer metering and cut-off mechanism

The fertilizer metering mechanism consists of a distribution hub which acts as a reservoir in which liquid urea is supplied longitudinally from one side and exit tangentially out of injectors mounted on the periphery of the distribution hub. The distribution hub mounted on an axle with two ball bearings at both ends and acts as a rotary valve for metering and supplying liquid urea from the main supply to the injectors fitted on the periphery of the distribution hub. Two holes on the periphery of axle facilitate the exit of liquid urea into the cylindrical hub. An inline mounted flow control valve is provided 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 spoke wheel. The cam is so designed that it operates 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 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.

2.5 Pump

A piston pump is used for the supply of liquid urea at constant pressure to the distribution hub. A control valve assembly has been provided to regulate the pressure and bypass the extra quantity of liquid fertilizer. The pump could develop maximum pressure up to 28 kg cm^{-2} at 950 r min^{-1} with suction capacity of 13 L min^{-1}.

2.6 Fertilizer tank

A mild steel tank having capacity of 100 L is used to store the liquid urea solution. The tank is cylindrical in shape with 480 mm × 480 mm in size. The liquid urea is fed to the pump from the tank by a suction pump and at the open end of the suction pipe a strainer is provided to prevent the flow of foreign materials with the liquid urea solution. The open end of the bypass pipe is connected with the tank so that the liquid urea solution which is not utilized by the spoke wheels could go back to the tank. The fertilizer tank is sufficient for liquid urea application of 450 m^2 area.

2.7 Pressure gauge

A pressure gauge is 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 has been provided in each supply line to maintain the desired flow rate.

2.8 Prime mover

A diesel engine of 6 hp (4.48 kW) is selected as prime mover for operating the nitrogen applicator. It has two narrow rubber wheels which are powered from the engine through gears and chains. The ground clearance of the machine is kept 500 mm. A third wheel is provided at the rear to act as transport wheel. The nitrogen (liquid urea) application unit is mounted at the rear side of the power unit. A provision is made to adjust the track width from 900 to 1,050 mm. A pump operating lever is provided on the handle to operate the pump during the nitrogen (liquid urea) application in the field. A transmission clutch lever is also provided on the handle to control the transmission system of the machine. An accelerator lever regulates the forward speed of the machine.

2.9 Operation of the self propelled nitrogen (liquid urea) applicator

Before using in the field, the nitrogen (liquid urea) applicator was calibrated for fertilizer application rate. The operating pressure of urea solution supply was fixed at 3.0 kg cm^{-2} and machine was operated at a forward speed of 2.53 km h^{-1} in the field. At this operating pressure and forward speed, the machine delivers about 2,095 L ha^{-1} solution of urea. Accordingly, the solution of urea was prepared by mixing required dose of urea with water. The fertilizer tank was filled with solution of urea. The applicator was guided within the rows of the wheat. 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 then 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).

2.10 Experimental layout and treatments

The nitrogen (liquid urea) applicator was evaluated for the application of liquid urea in residue mulched no-till wheat during 2012–2013 (Figure 2). The experiments were laid out in a factorial randomized block design with three replications comprising of six treatments with two levels of straw load and three levels of methods of nitrogen application. The plots size of each plot was 14 × 12 m^2. Following were the treatments:

A. Methods of Nitrogen Application (3 methods)

M_1: Point Injected N with Nitrogen applicator (0 + ½ N after 1^{st} irrigation + ½ N after 2^{nd} irrigation)

M_2: Broadcasting of N as per 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. Straw Load (2 levels)

L_1: Low straw load (4.6 t ha^{-1})

L_2: High straw load (8.0 t ha^{-1})

Figure 2 Self propelled nitrogen (liquid urea) applicator in operation

No-till wheat was sown in all experimental plots with the same variety PBW 621 at a rate of 100 kg ha^{-1} using 'Happy Seeder' at two straw load conditions (low straw load and high straw load). Agronomic practices were as recommended by the Punjab Agricultural University, Ludhiana (Bajwa, 2011), and were the same for all the treatments except for the methods of nitrogen application. A uniform dose of nutrients (125 kg ha^{-1} N, 62.5 kg ha^{-1} P and 30 kg ha^{-1} K) was applied. P as DAP and K as muriate of potash were broadcast at the time of sowing, and nitrogen dose were applied as per treatment layout and design. In M_2 and M_3 treatments, nitrogen was applied in form of granular urea whereas in M_1 treatments, nitrogen in form of urea solution (recommended dose of urea + 2095 L water ha^{-1}) was applied with developed prototype.

2.11 Measurement of dependent variables

Germination count, yield components, grain yield and total plant N concentration were measured. The number of wheat plants that had emerged through the soil was counted at 25 days after sowing. Spike density, spike length and number of grains/spike were recorded at maturity. Both plant density and spike density were measured in three randomly selected locations within each plot from one metre row length. Grain yield was determined on an area of 3 m^2 in the middle of each plot and reported on the basis of air-dry weight. Average grain weight (dry) was determined on 1000 grains randomly sampled from the large-area harvest. The grain and straw harvested from each treatment were dried at 60°C till constant weight, ground, powdered and analyzed for nitrogen content to determine N concentration by micro- Kjeldahl digestion with H_2SO_4 and subsequent analysis of NH_4 by steam distillation (Mulvaney, 1996). Nitrogen uptake was estimated by multiplying yield and nitrogen content.

2.12 Statistical analysis

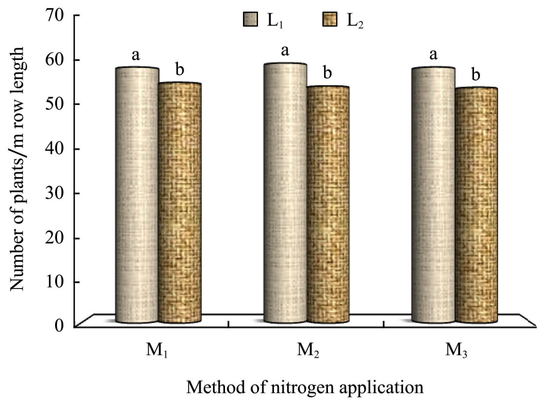
The data were statistically analyzed with the procedure described by Cochran and Cox (1967) and adapted by Cheema and Singh (1991) in statistical package CPCS-1 for significant differences between treatments. Graphics were prepared using Microsoft Excel.

3 Results and discussion

The Average operating time, field capacity and operation efficiency of the nitrogen applicator were 3.03 h ha^{-1}, 0.33 ha h^{-1}, 80.49%, respectively. The fuel (High speed diesel) consumption of self propelled nitrogen (liquid urea) applicator was 0.980 L h^{-1}.

3.1 Germination count

Germination count after establishment was slightly higher in M_2 (57.35 plants m^{-1} row length) and M_1 plots (57.30 plants m^{-1} row length) compared with M_3 (56.73 plants m^{-1} row length). The mean value of plant emergence was at par with different methods of N application; however straw load significantly affected plant emergence (Figure 3). The lower plant emergence (54.88 plants m^{-1} row length) under high straw load condition was possibly due to improper furrow filling and poor seed–soil contact.

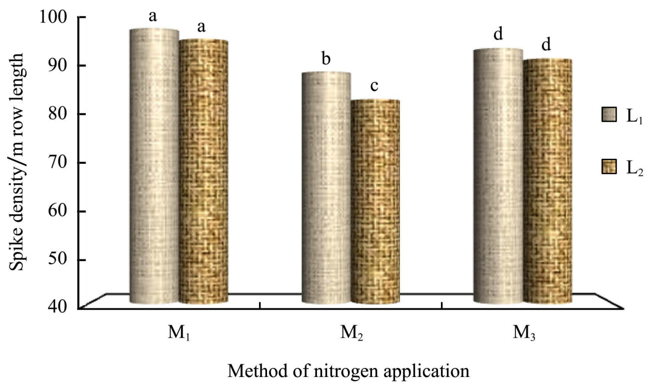


Note: Common letter on cylindrical bar indicates non significant difference between each other by Duncan Multiple Range Test at $p < 0.05$

Figure 3 Effect of methods of N application at different straw load on germination count

3.2 Spike density

Crop performance to a great extent is governed by the spike density. It is, therefore imperative that if the spike density is higher, the grain yield will be higher. Spike density was significantly ($p < 0.05$) higher in point injected N application treatment (M_1) compared with broadcast nitrogen application (M_2 and M_3). Increasing in spike density in point injected N application could have been attributed to the better nitrogen availability compared to broadcasting methods of fertilizer application. Among point injected N application treatments, spike density was significantly at par in low straw and high straw load conditions (Figure 4) due to non contact of liquid urea with straw mulch. The lowest spike density in M_2 treatment was possibly due to less nitrogen availability to wheat plants from surface broadcast application of urea in residue mulched no-till wheat field. The direct contact of fertilizer urea to residue mulch might enhance nitrogen losses and crop became deficient of nutrient nitrogen. Further, higher spike density in M_3 treatment than M_2 might be due to less losses of nitrogen because of irrigation applied after fertilizer urea broadcasting in this treatment. Kushnak et al. (1992) have reported lesser nitrogen loss (0.32 kg $acre^{-1}$) in point injected fertilizer application (PIFA) than broadcasting (2.6 kg $acre^{-1}$).



Note: Common letter on cylindrical bar indicates non significant difference between each other by Duncan Multiple Range Test at p < 0.05

Figure 4 Effect of methods of N application at different straw load on spike density

3.3 Spike length

Spike length was significantly ($p < 0.05$) higher in point injected N application treatment compared with broadcast nitrogen applications at different residue mulch load conditions (Table 2). Among point injected N application treatments, spike length was significantly at par in low straw and high straw load conditions. However among broadcast N application treatments, spike length differed significantly in low straw and high straw load conditions. Reduced spike length at high residue mulch load condition with broadcast N application might be attributed to higher N losses with broadcast N application at high residue mulch. Significantly higher spike length was found with broadcast N applications M_3 compared to broadcast N application M_2; which revealed that irrigation applied after fertilizer urea broadcasting might have reduced N losses and improved N availability to the plants.

Table 2 Effect of methods of nitrogen application at different straw load on average Spike length (mm)

Method of Nitrogen Application (M)	Spike length/mm		
	Residue mulch load (L)		Mean
	L_1	L_2	
M_1	110.70	109.29	109.99
M_2	102.20	99.87	101.04
M_3	104.97	101.54	103.26
Mean	105.96	103.57	
$C.D._{(0.05)}$			
M			1.47
L			1.20
M × L			N.S.

Note: M_1: Point injected N application with nitrogen applicator (0 + ½ N after 1st irrigation + ½ N after 2nd irrigation); M_2: Broadcasting as per package of practice (½ N during sowing + 1/4th N after 1st irrigation + 1/4th N after 2nd irrigation); M_3: Broadcasting general practice followed by farmers using 'Happy seeder' (0 + ½ N before 1st irrigation + ½ N before 2nd irrigation); L_1: Low residue mulch load (4.6 t/ha); L_2: High residue mulch load (8.0 t/ha).

3.4 Number of grains per spike

Both, nitrogen application methods and straw load had significant ($p < 0.05$) effect on number of grains per spike (Table 3). More number of grains/spikes in the crop fertilized with point injected nitrogen (liquid urea) applicator (M_1) might be attributed to better nitrogen availability and conducive temperature at anthesis and grain development stages as compared with broadcast N application (M_2 and M_3) under residue mulch conditions. Spike length in the crop fertilized with broadcast N applications (M_2 and M_3) was observed at par at 5% level of significance. The slower decomposition of residue mulch (due to non contact of liquid urea and mulch) with point injected N application could have helped in maintaining conducive temperature and soil moisture at anthesis and grain filling stages.

Table 3 Effect of methods of nitrogen application at different straw load on average Number of grains per earhead

Method of Nitrogen Application (M)	No. of grains/earhead		
	Residue mulch load (L)		Mean
	L_1	L_2	
M_1	54.84	53.99	54.42
M_2	44.08	41.04	42.56
M_3	46.55	42.10	44.33
Mean	48.49	45.71	
$C.D._{(0.05)}$			
M			2.58
L			2.11
M × L			N.S.

3.5 Grain weight

Average grain weight of wheat fertilized with point injected nitrogen (liquid urea) applicator (M_1) was 7.1% higher compared with that of wheat fertilized with conventional (broadcast) method of nitrogen application (M_2) and the differences were significant at 5% level of significance (Table 4). The effect of straw load on 1000 grains weight was non-significant. These results are in accordance with those of Sedlar et al (2011), who reported a significant increase in 1000-grain weight of barley fertilized with point injected nitrogen compared with that broadcast nitrogen application.

Table 4 Effect of methods of nitrogen application at different straw load on 1000 grains weight

Method of Nitrogen Application (M)	1000 grain weight, gm		
	Residue mulch load (L)		Mean
	L_1	L_2	
M_1	42.09	42.27	42.18
M_2	39.73	39.02	39.38
M_3	38.67	39.65	39.16
Mean	40.16	40.31	
$C.D._{(0.05)}$			
M			0.98
L			N.S.
M × L			N.S.

3.6 Grain yield

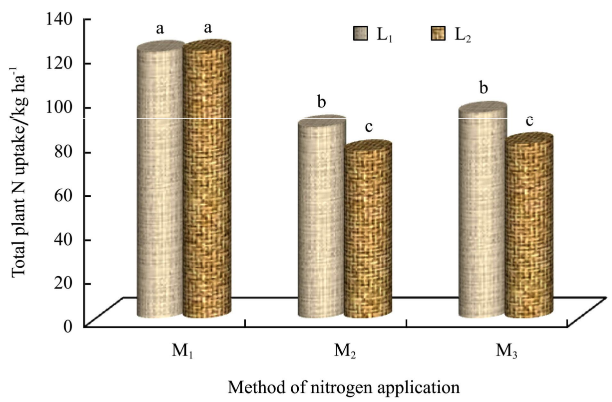
Grain yield of wheat fertilized with innovative point injected nitrogen (liquid urea) applicator (M_1) was 20% higher compared with that of wheat fertilized with conventional (broadcast) method of nitrogen application (M_2) and the differences were significant at 5% level of significance (Table 5). Average grain yield of wheat fertilized with broadcast of N application (M_2) was 3.6% lower compared with that of wheat fertilized with broadcast of N application (M_3); however, the differences were not significant. The better nitrogen availability under point injected nitrogen application compared with broadcast nitrogen application increased the spike density, spike length, number of grains/spikes and average grain weight leading to higher wheat yield. Among point injected nitrogen application, the grain yield was at par at different straw load conditions; however, among broadcast N application treatments, grain yield differed significantly in low straw and high straw load conditions. This is consistent with the observation made by Bandel, 1986 and Kubesova et al. (2013), who reported 15% - 20% higher grain yield from soil injected nitrogen application compared with surface application.

Table 5 Effect of methods of nitrogen application at different straw load on average Grain yield

Method of Nitrogen Application (M)	Grain yield, kg ha^{-1}		
	Residue mulch load (L)		Mean
	L_1	L_2	
M_1	5478.2	5368.1	5423.15
M_2	4690.8	4365.2	4528.00
M_3	4805.0	4578.4	4691.70
Mean	4991.33	4770.57	
$C.D._{(0.05)}$			
M			173.93
L			142.01
M × L			N.S.

3.7 Nitrogen uptake

N-uptake is interplay of biomass production and N-concentration. Highest total plant N uptake at maturity (121.44 kg ha^{-1}) occurred in case of point injected N application (M_1) at high straw load while lowest N uptake (76.16 kg ha^{-1}) was observed in case of M_2 method of N application at high straw load condition (Figure 5). Total plant N uptake did not differ significantly at different straw loads with point injected N application whereas it differed significantly at different straw loads with M_2 and M_3 methods of N application. The higher N uptake with point injected N application may be related to the higher biomass yield and higher shoot N concentration



Note: Common letter on cylindrical bar indicates non significant difference between each other by Duncan Multiple Range Test at $p < 0.05$

Figure 5 Total Plant N uptake under different straw load conditions under this method of N application. The uptake of nitrogen increased probably because it was being used for plant growth. Blackshaw et al. (2002) also observed higher N uptake in case of point injected than surface broadcast in the presence of weeds. On the basis of their results, point injection is a proper method of nitrogen application, particularly for straw mulched (weed infested) field.

4 Conclusions

There was 20% average yield benefits with point injected nitrogen application in residue mulched no-till wheat using self-propelled nitrogen (liquid urea) applicator in the rice-wheat system of north-west India. Yield and its attributes were significantly decreased at high straw load in case of broadcast of nitrogen application while, with developed prototype, yield parameters were at par at different straw loads. Total plant N uptake did not differ significantly at different straw loads with point injected nitrogen (liquid urea) application whereas it differed significantly at different straw loads with broadcast of nitrogen application. The results from the current study showed that broadcast of nitrogen is an inappropriate method of nitrogen application particularly under residue mulched no-till wheat and point injected nitrogen (liquid urea) applicator can be a better alternative.

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