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Nitrogen management for zero till wheat with surface retention of rice residues in north-west India

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ABSTRACT

In intensive rice–wheat systems of north-west (NW) India, surface retention of rice residues in wheat has been recommended instead of burning. Optimum nitrogen (N) management for zero till (ZT) wheat sown into rice residues may to differ from that of conventional practice (*in-situ* burning of residues followed by intensive tillage prior to sowing). Therefore, we conducted several on-farm and on-station field experiments in 2007–2008 to 2012–2013 to evaluate N management practices for ZT wheat sown into rice residues using the Happy Seeder. The optimum N rate for wheat planted into rice residues in fields with no or only a short history of rice residue retention was 120 kg N ha^{-1}, the current recommendation for conventional practice. Short-term (up to 20 d) soil N mineralization was lower in undisturbed soil than disturbed soil, while the total amount of N mineralization was similar after 40 d, suggesting that over the crop season, total soil N mineralization may be similar in tilled and non-tilled soil. Ammonia volatilization loss from urea broadcast over the residue covered surface, followed by irrigation, was low (<2 kg ha^{-1}) regardless of time of urea application. Band placement of 20% of the fertilizer N as diammonium phosphate at seeding, and topdressing of the remaining 80% as urea in two equal doses before first and second irrigations produced higher grain yield and N use efficiency than other treatments. However, surface residue retention reduces the rate of soil drying and in some situations this delays the time of the second irrigation and thus N fertilizer application beyond the optimum time. Therefore, the effect of banding various proportions of the urea N between the rows at sowing was investigated. The results showed that, on a loam soil, up to 75% of the recommended N fertilizer can be applied at sowing, 24 kg N ha^{-1} as DAP with the seed and 66 kg N ha^{-1} as urea drilled between every second wheat row, without loss of yield. In conclusion, a better applied N management strategy for ZT wheat than currently practiced is drilling of 24 kg N ha^{-1} as diammonimum phosphate into the soil at seeding followed by two top-dressings of 48 kg N ha^{-1} each just prior to first and second irrigations.

1. Introduction

Rice–wheat (RW) systems occupy 13.5 million hectares in South Asia and are critical for food security and livelihoods in the region (Ladha et al., 2009). Large scale adoption of mechanized harvesting for both rice and wheat in north-west (NW) India leaves huge quantities of crop residues in the fields. While wheat straw is generally collected from the fields for use as animal fodder, rice straw has limited use and its management is more problematic. Zero till (ZT) wheat establishment after rice harvest is beneficial in terms of yield (due to more timely sowing) and profitability (reduced establishment and irrigation cost) (Erenstein et al., 2007; Erenstein and Laxmi, 2008; Ladha et al., 2009). However, the high rice residue load and tough nature of rice straw hinders the use of ZT seed drills due to clogging of the machinery with the loose residues following combine harvesting. Therefore, in-field burning of rice residues is commonly practiced in NW India, causing serious air pollution and substantial loss of organic carbon, plant nutrients

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and soil biota (Gupta et al., 2003; Yadvinder-Singh et al., 2005). The recent development of the "Turbo Happy Seeder" now provides the ability to drill wheat into combine harvested rice residues, leaving all the residues on the soil surface as a mixture of standing straw and surface mulch (Sidhu et al., 2007, 2015, Submitted for publication). Both surface residue retention and ZT potentially induce major changes in N dynamics and thus N management in comparison with straw removal and tillage (McConkey et al., 2002; Arora et al., 2010). While ZT may reduce N mineralization by decreasing decomposition of soil organic matter, particularly in the initial 3–4 years of its adoption, crop residues can influence N dynamics from immobilization and volatilization (Drinkwater et al., 2000; Yadvinder-Singh et al., 2005). Arora et al. (2010) reported lower yields and fertilizer N use efficiency of ZT (with no surface residue) than CT wheat when both were planted on the same dates. Results of research comparing the fertilizer N requirement for wheat with rice residue retention and removal are inconsistent. Yadvinder-Singh et al. (2009) found similar optimum N rate for both, while some studies found that 25–30 kg N ha^{-1} higher N rates were required with incorporation of residues using CT or reduced tillage (Gangwar et al., 2006; Verma and Srivastava, 1994), and Rahman et al. (2005) found maximum yield with a 40 kg N ha^{-1} lower rate in ZT with rice residue mulch. The recommended N fertilizer practice in NW India for wheat sown into tilled soil in the absence of rice residues is to apply a total of 120 kg N ha^{-1}, with 24 kg N ha^{-1} as diammonium phosphate (DAP) sown with the seed, 36 kg N ha^{-1} of fertilizer N (urea) broadcast onto the soil surface shortly before sowing, and a further 60 kg N ha^{-1} as urea broadcast before the first post-sowing irrigation (Anonymous, 2008). However, with surface residue retention, broadcasting N onto crop residues can be an inefficient method of application because of immobilization in association with the microbial break down of rice residues (Rice and Smith, 1984; Thuy et al., 2008;Xu et al., 2010) and because of greater ammonia volatilization (Janssen, 1996; Patra et al., 2004; Bacon et al., 1986) than when applied to bare soil. One possible solution to these problems could be to apply only a small amount of N with the seed and delay topdressing of the majority of the N until after significant straw decomposition has occurred, followed by irrigation. Irrigation after urea application markedly reduces N volatilization losses compared to irrigation before urea application because urea is highly soluble and moves into the soil with the percolating water (Katyal et al., 1987). Another possible solution to the volatilization and N immobilization problem would be to place the fertilizer in bands below the C-enriched surface soil that results from surface placement of crop residues (Jannson and Persson, 1982; Rao and Dao, 1996). Banding the complete dose of N at seeding is a highly efficient way of managing N fertilizers in some ZT systems (Harapiak et al., 1993; Malhi et al., 2001; Johnston et al., 1997). Studies from North America have shown improved performance of ZT maize and sorghum when N fertilizer was drilled at the time of sowing compared to broadcast application at sowing or during the season (Fox and Piekielek, 1987; Bandel et al., 1984; Lamond et al., 1991). However, urea needs to be banded a few centimeters to the side of or below the seed to avoid seedling damage due to the effect of urea on soil pH (Bremner and Krogmeier, 1988; Bremner, 1995; McKenzie et al., 2007). Factors, such as soil texture, soil moisture, crop type, row spacing, opener type, and depth of seeding influence the rate of urea N that can be safely placed in the seed row (Nelson, 1982; Olson and Kurtz, 1982; Malhi et al., 2003). There is little information available on N management options for ZT wheat sown into rice residues in the irrigated rice–wheat systems of NW India. Therefore, the main objectives of the present research were to determine the optimum N rate, application time and method of urea application for maximising yield and NUE of irrigated ZT wheat sown into rice residues.

2. Materials and methods

A series of on-farm trials and on-station experiments was conducted over five years from the 2007–2008 to the 2012–2013 wheat seasons in Punjab, India. The climate of the region is subtropical, semi-arid with long term average (30 years) mean minimum and maximum temperatures of 6.7 and 22.6 °C during the wheat season (November to April), respectively. Annual mean recipitation is 760 mm, about 15% of which occurs during the wheat season.

2.1. Experiment 1. N rate response of ZT wheat with surface rice residue retention

The objective of this experiment was to determine the response of ZT wheat sown into rice residues to the rate of N fertilizer application. The hypothesis was that irrigated ZT wheat sown into rice residues needs a higher dose of N fertilizer than that currently recommended for CT wheat in the region.

Replicated on-farm trials were conducted at five locations in Ludhiana district of Punjab (India) over three wheat seasons from 2007–2008 to 2009–2010. Soil texture ranged from loamy sand to loam, with 4.1 g kg^{-1} to 5.8 g kg^{-1} organic carbon determined using the Walkley–Black wet digestion method (Nelson and Sommers, 1996). The experiments were laid out in randomized complete block design. In 2007–2008 and 2008–2009, there were three rates of N (120, 150 and 180 kg N ha^{-1}) replicated three times in each experiment. A well-fertilized rice crop was raised after the harvest of wheat each year on these plots, to minimize the residual effect of N doses in the subsequent year. The comparisons were conducted at five locations in the first year, and at three locations in the second year (in the same fields as in the first year). In the third year (2009–2010), treatments included three rates of N (90, 120 and 150 kg N ha^{-1}) applied to ZT wheat sown into ice residues (in the same fields/plots as in 2009–2010) and 120 kg N ha^{-1} applied to CT wheat sown after burning of rice residues. Plot area ranged from 200 to 250 m^2 and the plots were separated by 25–30 cm high dikes to facilitate application of the correct amount of N fertilizer to each plot. In the season preceding each wheat crop, all fields were under uniform and well fertilized puddled transplanted rice crops. The rice was harvested between 10 and 20 October using a combine harvester, leaving all the residues in the field. The amount of rice residue ranged from7.4 to 9.6 Mg ha^{-1}.

2.1.1. Crop management practices in wheat

After rice harvest, the loose residues were uniformly spread manually before seeding the wheat. Wheat (variety PBW 343) was sown using a seed rate of 100 kg ha^{-1} between 05 and 16 November. All treatments (except CT wheat in 2009–2010) were direct drilled into the rice residues using a 9-row (22.5 cm row to row spacing) Turbo Happy Seeder (Sidhu et al., 2015, this volume). In the CT plots, a stubble shaver was used to chop the stubbles 2 to 3 d after rice harvest, and then the residues were allowed to dry for another 3 to 4 d before burning. After burning, flood irrigation was applied, and a few days later the seedbed was prepared with two passes of offset discs and two passes of a tyne cultivator followed by planking. Phosphorus and potassium were applied using recommended practice (26 kg P ha^{-1} as DAP drilled with the seed and 25 kg K ha^{-1} as muriate of potash (MOP) broadcast before sowing). Urea was applied in two equal split doses. In the first two years, urea was applied as for conventional practice, with 50% of the urea broadcast on the residue surface before sowing and 50% top dressed 20 to 25 d after seeding, immediately before the first post-sowing irrigation. In the third year, the urea was broadcast before the first and second irrigations because results from Experiment 2 in 2007–2008 and 2008–2009 showed that yield of ZT wheat sown into rice residues was significantly increased by this practice in comparison with the