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Effects of tillage and mulch on the growth, yield and irrigation water productivity of a dry seeded rice-wheat cropping system in north-west India

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ABSTRACT

Depletion and/or degradation of natural resources, increasing farm labour scarcity, and high production cost are major threats to the rice-wheat cropping system of north-west India. Conservation agriculture (CA) is a potential solution which can be achieved by switching from puddling then transplanting of rice to dry seeding (DSR), together with changing from conventional tillage (CT) to zero tillage (ZT) for wheat with surface retention of rice residues. Whether the use of ZT for both crops confers additional benefits to either crop is not known. The effects of surface retention of rice residues in wheat on the subsequent DSR crop are also unknown, nor how this is affected by tillage for DSR. Therefore, a field study was conducted during 2012-14 to investigate the interactions between tillage for rice and wheat (CT, ZT), and rice residue management (removed, retained on the soil surface), on the performance of a dry seeded rice-wheat system.

There were no significant interaction or main treatment effects on wheat grain yield in the first two years, but in the third year, yield of ZT wheat (5.5 t ha^{-1}) was significantly lower than yield of CT wheat (6.0 t ha^{-1}). Yield of wheat decreased significantly over the three years, for example from 7.7 to 6.3 to 5.8 t ha^{-1} in the control system (CT for both crops, no rice straw mulch). Weather data analysis and simulation modelling suggested that this was entirely due to differences in seasonal weather conditions. Growth of non-mulched ZT wheat was inferior to that of mulched ZT wheat, and that of CT wheat with and without mulch, regardless of tillage for rice, although this was not reflected in wheat grain yield. Mulch delayed wheat crop development and the time of irrigation to varying degrees depending on seasonal conditions, and reduced irrigation amount by 50–100 mm in two of the three years.

Tillage and rice residue management treatments did not affect the yield of DSR in the first year (mean yield 6.0 t ha^{-1}). However, in the second year, growth and grain yield of ZTDSR (3.2 t ha^{-1}) were inferior to that of CTDSR (3.8 t ha^{-1}), regardless of tillage treatment for wheat. There was a consistent trend for poorer growth of DSR following wheat mulched with rice straw (significant in the first year), suggesting the need to examine the possibility of allelopathic effects of surface rice straw retention in dry seeded rice-wheat systems. There was a decline in rice growth and grain yield over the two years in all treatments. For example, yield of rice in the control declined from 5.9 t ha^{-1} in 2012 to 4.3 t ha^{-1} in 2013. Seasonal conditions and simulated growth and yield were similar each year; the poorer observed rice growth and yield in 2013 were due to disease during grain filling, greater weed infestation during the early vegetative stage, and unexplained factors during the middle of the season.

Total system rice equivalent yield (REY) was not affected by tillage or mulch treatments nor their interactions in 2012 (mean REY 13.3 t ha^{-1}), but was significantly lower in systems with ZTDSR (9.4 t ha^{-1}) than CTDSR (10.0 t ha^{-1}) in 2013. Treatment effects on irrigation input to rice and the total system were

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small. The net result was no treatment effects on total cropping system irrigation water productivity (WPi) in 2012 (mean 0.83 kg m^{-3}), and significantly higher system WPi in 2013 in systems with CTDSR (0.69 kg m^{-3}) than ZTDSR (0.63 kg m^{-3}).
The results suggest that in a dry seeded rice-wheat cropping system, surface retention of rice residues can improve the growth of ZT wheat right from the first crop, although this did not affect yield in the first three years. However, whether there is an adverse carry over effect of the rice residues on DSR requires further investigation.

1. Introduction

Rice-wheat cropping systems are practised on about 13.5 Mha in South Asia, mostly in the Indo-Gangetic Plains (IGP), and are critical for food security in India where rice and wheat are grown in rotation on about 10.5 Mha (Timsina and Connor, 2001). However, the ability to sustain, let alone increase, the productivity of these systems to meet the needs of the growing population is threatened by depletion and/or degradation of natural resources (water, air, soil, biodiversity), increasing farm labor scarcity, and high production costs (Erenstein et al., 2007; Ladha et al., 2003, 2009; Rijsberman, 2006). Current practice involves intensive tillage for both crops and removal of all crop residues. Rice is established by manual transplanting into puddled soil, followed by continuous flooding for the first six to eight weeks after transplanting. Thereafter, farmers in Punjab generally practice some form of alternate wetting and drying (AWD) water management, irrigating 2–3 times per week when there is insufficient rainfall to keep the topsoil close to saturation. The rice residues are removed by burning (after combine harvesting) or manually at harvest, after which the soil is intensively tilled ("dry" tillage) prior to sowing wheat. In Punjab the wheat crop is usually irrigated 4–6 times during the season, although in good rainfall years fewer irrigations are applied. Most of the wheat residues are removed after harvest for fodder, and any remaining residues are usually burnt (Gajri et al., 2002). The stagnation of productivity growth in these intensive cropping systems has led to strong advocacy for the use of resource conservation technologies to rebuild soil health (FAO, 2007; Gupta and Sayre, 2007; Hobbs, 2007; Hobbs et al., 2008).

Conservation agriculture (CA) is an approach for improving the biophysical and economic sustainability of cropping systems, and is based on three main principles: reduced tillage, surface cover at all times, and judicious crop rotation (Derpsch et al., 2014; Palm et al., 2014). Conversion to a CA rice-wheat system has many potential benefits, including greatly reduced crop establishment costs and more timely establishment of both crops (Gathala et al., 2011b; Gupta and Sayre, 2007; Gupta et al., 2003, 2010; Jat et al., 2014; Laik et al., 2014). It is also likely to result in improved soil structure and fertility leading to higher wheat yield (Gathala et al., 2011b; Jat et al., 2009; Yadvinder-Singh et al., 2005), and ultimately, reduced fertilizer requirement, especially N and K (Yadvinder-Singh et al., 2005). Surface rice residue retention in wheat also suppresses weeds (Gathala et al., 2011a; Sidhu et al., 2007; Yadvinder-Singh et al., 2005) and soil evaporation (Balwinder-Singh et al., 2011a), reducing herbicide and irrigation requirement (Balwinder-Singh et al., 2011c; Ram et al., 2013).

Over the past 15 years, many farmers in north-west India have begun to adopt elements of CA in their rice-wheat systems, starting with zero till (ZT) wheat around the beginning of the 21st century (Erenstein and Laxmi, 2008; Harrington and Erenstein, 2005). Adoption of ZT wheat was driven mainly by the reduced cost of crop establishment, and partly because it enabled more timely sowing of wheat (and thus higher yield), improved weed, insect and pest control, and reduced land preparation costs (Erenstein et al., 2007; Erenstein and Laxmi, 2008). However, where rice is harvested by combine harvester, as in north-west India, sowing into the rice residues was not possible in the past because of clogging of the conventional ZT seed drill with the loose rice straw. Therefore, the rice residues in combine harvested fields are normally burnt *in situ* prior to sowing ZT wheat. However, with the recent development of the Turbo Happy Seeder (Sidhu et al., 2007, 2015) it is now possible to sow wheat directly into the combine harvested rice residues immediately after rice harvest. The Turbo Happy Seeder cuts and shreds the straw in a narrow strip in front of each inverted T-shape sowing tyne, and at the same time the flails sweep the straw away from the tyne, with the result that the sown rows are not covered with residues. More recently, driven primarily by labor scarcity, farmers have also begun to replace puddled transplanted rice (PTR) with dry seeded rice (DSR) sown by seed drill into non-puddled (dry tilled as for wheat) soil, especially in north-west India (Mahajan et al., 2013), with an estimate of 115,000 ha dry seeded in Punjab in 2014 (Thind et al., 2015). With dry seeding of rice, farmers have also adopted AWD water management throughout the season. As a result, irrigation input to DSR is lower than to PTR, due to avoidance of puddling and transplanting and the use of AWD.

In combination, all of the above developments create the possibility of implementation of CA rice-wheat cropping systems, involving dry seeding of rice, reduced or zero tillage for both rice and wheat, and retention of rice residues. However, adoption of the full CA rice-wheat system has barely begun in farmers' fields.

Experimental evidence from two different production environments in India suggests that in rice-wheat systems, system yield benefits of conversion to CA (with ZT for both crops and rice residue retention) begin to appear after 2–3 years (Gathala et al., 2011b; Jat et al., 2014). A common scenario is for rice (DSR) yields in the CA system to be lower than in the conventional (PTR) system for the first few years, but for significantly higher yields of wheat in the CA system beginning in the second or third year. However, findings are inconsistent regarding the medium to long term effects on the yield of rice in CA systems compared with conventional systems. Gathala et al. (2011b) found similar rice yields in both systems over years 3–7, while Jat et al. (2014) found similar rice yields over years 4 and 5, and significantly higher rice yield in the CA than the conventional system in years 6 and 7.

The most likely initial farmer adoption scenario for a CA rice-wheat system is conventionally (dry) tilled DSR (CTDSR) following ZT wheat (ZTW) with rice residues burnt prior to sowing, unless legislation banning straw burning is enforced. However, evidence from maize-wheat systems in Mexico is that changing to ZT with residue removal has adverse effects on cropping system performance over time, and that with adoption of reduced tillage and residue retention, it takes five years for the soil to improve to the degree that yields are significantly increased (Govaerts et al., 2005). In contrast, Jat et al. (2014) observed that the use of ZT for wheat without residue retention gave higher yield than CT in a rice-wheat cropping system from the second year onwards in a seven year experiment. In past studies in rice-wheat systems, the relative contributions of the different system components (tillage practice for