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Effect of tillage and residue management in rice-wheat system

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ABSTRACT

The declining soil health in Indo-Gangetic plains due to intensive tillage practice and residue burning is threatening the sustainability of rice-wheat system (RWS) in this region. Zero tillage (ZT) and residue recycling (incorporation/ mulching) can improve soil health and sustainability of RWS. With this hypothesis an experiment was conducted at ICAR-Central Soil Salinity Research Institute, Karnal (Haryana) to study the effect of ZT and residue recycling in rice and wheat crops on productivity, carbon sequestration, biomass accumulation and physiological growth. The highest grain yield in rice (over varieties) was recorded in PTR+RI (4.71 t/ha) followed by PTR-WR (4.45 t/ha). However, the highest shoot biomass (14.5 t/ha) and carbon sequestration (6.5 t/ha) was recorded in PTR-WR. In wheat crop (over varieties), CTW+RI produced the highest grain yield (5.10 t/ha), shoot biomass (13.6 t/ha), carbon sequestration in above ground parts (4.25 t/ha) and chlorophyll content. Rice variety CSR 36 performed better in terms of grain yield (4.91 t/ha), shoot biomass (14.7 t/ha) and carbon sequestration (6.8 t/ha) while two wheat cultivars produced similar grain yield. So, based on our experiment it can be concluded that residue incorporation in conventional practice in both the crop i.e., conventional tilled puddle transplanted rice and conventional tilled wheat performed better than residue mulched under zero tillage condition.

Keywords: Carbon sequestration, Residue incorporation, Residue mulch, Salt tolerant rice varieties, Wheat, Zero tillage

The rice-wheat cropping system (RWS) is the most important system occupying 10.3 million hectare (m ha) in the Indo-Gangetic plains (IGP) in India (FAO 2017). This region is pivotal for the food security of India contributing more than 75 and 45% of total wheat and rice, respectively, produced in the country (Kumar *et al*. 2018). The higher productivity of RWS is exhausting the natural resources (land, water and energy) at faster rate. The productivity and sustainability of RWS is under strain due to poor efficiency of conventional practices on one hand and resource degradation on other hand. Conventional practices for rice and wheat crops are adversely affecting the soil health. Puddling in rice makes sub-surface hard pan which reduces the root development and yield of next wheat crop. It is documented that repeated tillage practices affect overall soil (Bhattacharyya *et al*. 2012). Also, excessive tillage practices delays sowing of wheat which causes yield penalty of 35–60 kg/day/ha.

The time window between rice harvesting especially basmati and wheat seeding is 7-10 days, which makes residue management very difficult. So, residue burning is very common practice in North-West India which causes loss of nutrients, has negative impact on soil microflora and causes environmental pollution (Mishra *et al*. 2014). About 25 Mt of rice and wheat residue is burnt every year causing serious health problems. Therefore, efforts are increasingly devoted to adopt zero tillage with residue recycling in RWS in North-West India to increase grain yield and improve soil health. Different varieties have different genetic potential and screening is essential to select best variety. The current study was carried out with the hypothesis that residue management in zero-tillage in RWS might increase productivity and improve soil health. The objective of the study was to assess the effect of different degree of tillage and residue management on productivity, biomass accumulation and carbon sequestration in rice and wheat crops in North-West India.

MATERIALS AND METHODS

The field experiment was conducted for three years (2012–13 to 2014–15) at Research Farm of ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India, with rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. The monthly mean maximum and minimum temperature during experimentation was 37.7°C (in June) and 6.0°C (in January) and 710 mm average rainfall, of which 70% received within a short span of July to September months.

Four tillage and residue management (TRM) treatments

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and two varieties were evaluated in both rice and wheat crops. In rice crops, treatments included conventionally tilled puddle transplanted rice with 1/3rd wheat residue incorporated (PTR+RI), conventionally tilled puddle transplanted rice without residue (PTR-WR), zero tilled direct seeded rice without residue (ZT-DSR-WR) and conventionally tilled DSR without residue (CT-DSR-WR). Two salt tolerant rice varieties Basmati CSR 30 and CSR 36 were evaluated. In wheat crop, four TRM treatments were conventionally tilled wheat with 1/3rd residue incorporation (CT+1/3RI), conventional tilled wheat with residue removed (CT-WR), zero till wheat with 33% rice residue mulched (ZT+ 1/3 RM), and zero till wheat with 100% rice residue mulched (ZT+ FRM). The two wheat varieties KRL 213 and HD 2894 were also evaluated.

Rice was cultivated during June to October and wheat during November to April on the same experimental plots. Rice was sown using 25 kg/ha seed under DSR and 12.5 kg/ha for nursery rising under PTR in the first fortnight of June every year. In PTR, first puddling was done, thereafter, 30 days old seedlings were transplanted at 20 cm × 20 cm spacing in the second week of July. Rice was harvested at physiological maturity in the end of October. Seeding of wheat was done using 100 kg/ha in the first fortnight of November and the crop was harvested in the third week of April. In rice (CSR 36) and wheat crops, fertilizers at the rate of 150:60:30 kg/ha of $N:P_2O_5:K_2O$ were applied, while for basmati CSR 30 the fertilizer dose was as per region recommendation 60:30:30 kg/ha of $N:P_2O_5:K_2O$. 1/3rd nitrogen and full dose of phosphate and potash were at the time of transplanting/sowing. Remaining 2/3rd N was applied to rice in 2–equal splits i.e. 3 and 6 weeks after transplanting under PTR, and to wheat with first and second irrigation. In DSR, N application was done in 3–splits equally at 20, 40 and 60 days after sowing (DAS). The N was applied through urea, whereas, P and K sources were DAP and MoP, respectively.

At harvest yield attributes were recorded for both crops. To estimate above ground biomass accumulation, the weight of total produce harvested from net plot of each treatment was recorded after sun drying and expressed as biological yield in t/ha. For below ground biomass root samples were collected to a depth of 30 cm with a narrow, flat-bladed shovel and handsaw. Soil containing roots was gently rotated and dispersed through tap water, then passed through a series of sieves to collect roots, dried under the sun, kept in the electric oven at 65°C for complete drying and their weight was recorded when samples attained a constant weight. The weight was expressed in t/ha. For estimation of carbon sequestration, carbon content in root and shoot was estimated by CHNS analyzer. The dried samples were grinded with Wiley mill grinder and passed through a 0.150 mm sieve for carbon analysis. All the data were analyzed using analysis of variance as applicable to randomized complete block design using SAS 9.4 (SAS Institute 2012) and treatment means were compared at 5% level of significance.

RESULTS AND DISCUSSION

Yields attributes and yield of rice and wheat: Different tillage and residue management (TRM), and variety had significant effect on yield attributes and grain yield of rice (Table 1). Among different TRM, the highest value of yield attributes i.e. effective tillers/hill (13.6) and 1000-grain weight (26.5 g) were recorded in PTR+RI treatment, while the minimum value of these attributes was recorded in PTR-WR (12.5) and ZT-DSR-WR (24.4 g), respectively. Across rice varieties the highest grain yield was recorded in PTR+RI (4.71 t/ha) which was at par with PTR-WR (farmers' practice) (4.45 t/ha) and significantly higher than ZT-DSR-WR and CT-DSR-WR. The grain yield in PTR+RI treatment was ~33 and 27% higher than ZT-DSR-WR and CT-DSR-WR, respectively. The higher weed infestation in DSR reduced its grain yield as compared to PTR (Singh *et al*. 2018). Also, residue recycling improves soil health which results into higher grain yield in PTR+RI treatment (Jat *et al*. 2019).

Over TRM among two salt tolerant varieties of rice, significantly higher 1000-grain weight (27.0 g) and grain yield was recorded in CSR 36 (4.91 t/ha) while no-significant varietal effect was observed on effective tillers/hill and panicle length. Higher grain yield in CSR 36 as compared

Table 1 Yield attributes and yield of rice and wheat crop as influenced by different tillage and residue management, and variety (pooled data of three years)

Treatment/rice	Effective tillers/hill (no.)	Panicle length (cm)	1000-grain wt. (g)	Grain yield (t/ha)
PTR+RI	13.6	26.6	26.5	4.71
PTR-WR	12.5	26.6	24.6	4.45
ZT-DSR-WR	13.6	25.6	24.4	3.14
CT-DSR-WR	12.9	25.7	24.7	3.44
LSD (P=0.05)	0.9	NS	1.3	0.55
Variety/rice				
Basmati CSR 30	13.1	26.3	23.0	2.96
CSR 36	13.1	26.0	27.0	4.91
LSD (P=0.05)	NS	NS	0.9	0.39
Treatment/wheat	*Effective tillers/m^2 (no.)*	*Grains/spike (no.)*	*1000-grain wt. (g)*	*Grain yield (t/ha)*
CTW+ RI	586	60.8	38.6	5.10
CTW-WR	650	57.8	39.1	5.03
ZTW+ 1/3 RM	532	59.1	38.3	4.40
ZTW+ FRM	581	60.6	38.3	4.75
LSD (P=0.05)	23.5	NS	NS	0.62
Variety/wheat				
KRL 213	575	58.2	39.6	5.0
HD 2894	599	60.9	37.6	4.6
LSD (P=0.05)	16.6	NS	1.4	NS

to Basmati CSR 30 was expected as CSR 36 is coarse rice variety and yield potential of coarse rice is always higher than the basmati type. Highest number of effective tillers/m^2 (650) were recorded in CTW-WR treatment followed by CTW+ RI (586), ZTW+ FRM (581) and the lowest in ZTW+ 1/3 RM (532). Across varieties the highest grain yield of wheat was recorded in CTW+ RI (5.10 t/ha) treatment at par with CTW-WR (5.03 t/ha) and ZTW+ FRM (4.75 t/ha), and lowest in ZTW+ 1/3 RM (4.40 t/ha). The grains per spike and 1000-grain weight of wheat were not significantly influenced by different tillage and residue management treatments (Table 1). Residue incorporation in conventional tillage (CTW+RI) improved soil health (more aggregate stability, carbon sequestration) and provide congenial environment for better crop growth and yield (Singh *et al*. 2019). The lower grain yield in ZT wheat was due to lower number of effective tillers than CT wheat. However, grain yield in ZT wheat with 100% residue mulched was higher (though non-significant) than ZT with $1/3^{rd}$ residue mulched which indicated the positive effect of crop residue retention. Similar results of lower grain yield of wheat under ZT with residue retention than conventional practice during initial years was also reported by Jat *et al*. (2019).

Biomass accumulation: In rice crop, the share of shoot and root biomass to total biomass ranged from 82.2–85.7% and 14.4–17.9%, respectively, across different tillage, residue and varieties of rice (Table 2). The corresponding value for biomass accumulation in wheat crop in shoot and root across different treatments was 92.5–93.9% and 6.1–7.5%, which made it clear that in wheat crop the proportionate biomass accumulation in roots was less than accumulated in rice crop.

Different TRM treatments had significant effect on shoot biomass of rice while root biomass accumulation under different treatments was statistically at par with each-other. Across varieties, maximum shoot biomass accumulation in rice crop was in PTR-WR (14.5 t/ha) treatment followed by CT-DSR-WR (13.6 t/ha), PTR+RI (12.8 t/ha) and the lowest in ZT-DSR-WR (11.7 t/ha). The shoot biomass was higher in PTR than DSR which may be due better crop establishment in flooded condition in PTR and closer plant to plant spacing in DSR which increases competition resulting in lower biomass accumulation in DSR than PTR (Jnanesha and Kumar 2017). Over TRM treatments, significantly higher shoot biomass accumulation was in CSR 36 (14.7 t/ha) than Basmati CSR 30 (11.6 t/ha). However, root biomass accumulation in both varieties of rice was numerically same.

Across wheat varieties, under different tillage and residue management treatments the highest shoot biomass was accumulated in CT+ RI (13.6 t/ha) treatment which was at par with CT-WR (12.9 t/ha), ZT+ FRM (12.5 t/ha), and the lowest in ZT+1/3 RM (10.7 t/ha). While, the highest root biomass accumulation was recorded in CT-WR (0.96 t/ha) followed by ZT+ FRM (0.91 t/ha), CT+RI (0.89 t/ha), and lowest in ZT+ 1/3 RM (0.86 t/ha). The biomass accumulation in root as well shoot in both the cultivars of wheat was statistically similar.

Table 2 Biomass accumulation in rice and wheat crops and chlorophyll content of wheat crop in different tillage and residue and varietal treatments (data pooled over three years)

Treatment	Biomass accumulation (t/ha)				
	Rice		Wheat		
	Shoot biomass	Root biomass	Shoot biomass	Root biomass	
PTR+RI/ CTW+ RI	12.8	2.5	13.6	0.89	
PTR-WR/CTW-WR	14.5	2.6	12.9	0.96	
ZT-DSR-WR/ZTW+ 1/3 RM	11.7	2.4	10.7	0.86	
CT-DSR-WR/ ZTW+ FRM	13.6	2.5	12.5	0.91	
LSD (P=0.05)	1.4	NS	0.81	0.05	
Variety					
CSR 30/ KRL 213	11.6	2.5	12.5	0.93	
CSR 36/ HD 2894	14.7	2.5	12.4	0.89	
LSD (P=0.05)	0.9	NS	NS	NS	
Tillage and residue management	*Chlorophyll content (SPAD) days after sowing*				
	110	117	124	131	145
CT+ RI	48.2	64.8	40.0	44.1	5.98
CT-WR	48.2	67.7	40.8	36.6	4.48
ZT+ 1/3 RM	52.2	62.1	43.0	36.6	3.28
ZT+ FRM	52.4	64.4	41.0	38.1	5.67
LSD (P=0.05)	NS	NS	NS	NS	2.69
Variety/wheat					
KRL 213	48.7	63.0	40.2	37.2	3.93
HD 2894	51.8	66.5	42.2	40.5	5.77
LSD (P=0.05)	NS	NS	NS	NS	NS

Carbon sequestration: Carbon sequestration in shoot portion in rice varied significantly under different treatments, being the highest in PTR-WR (6.5 t/ha) at par with CT-DSR-WR (6.1 t/ha) and PTR+RI (6.0 t/ha), while lowest in ZT-DSR-WR (5.3 t/ha). The higher carbon sequestration in PTR-WR and CT-DSR-WR treatments was due to more biomass accumulation in shoot portion than PTR+RI and ZT-DSR-WR.

Significantly higher carbon sequestration was recorded in CSR 36 (6.8 t/ha) than Basmati CSR 30 (5.2 t/ha) owing to higher shoot biomass and grain yield. However, no significant effect of different tillage and residue management and varieties was recorded on below ground carbon sequestration in rice crop. The carbon sequestration in wheat crop was significantly different in different tillage and residue management, and varietal treatments. The highest above ground carbon sequestration was recorded in CTW+ RI (4.25 t/ha) at par with CTW-WR (4.20 t/ha), ZTW+FRM (3.99 t/ha) while significantly higher than ZTW+1/3 RM (3.49 t/ha). The carbon sequestration in two wheat varieties did not differ significantly, which can be ascribed to statistically similar shoot and root biomass in both the wheat cultivars.

Across wheat varieties, below ground carbon sequestration was significantly higher in CTW-WR (1.51 t/ha) followed by CTW+ RI (1.37 t/ha), ZTW+FRM (1.22 t/ha) and lowest in ZTW+1/3 RM (0.96 t/ha). The carbon sequestered in roots in two wheat varieties was almost similar. Based on the above results, it may be inferred that carbon sequestration was higher under conventional tillage than zero tillage while both the wheat varieties sequestered statistically similar carbon in both above ground and below ground biomass.

Photosynthetic rate: In general, the chlorophyll content (SPAD) increased from 110–117 DAS of wheat, then decreased to 124 DAS, then again increased at 131 DAS and then decreased up to 145 DAS (Table 2). No significant difference in chlorophyll content in different treatments was recorded up to 131 DAS. However, chlorophyll content differed significantly at 138 and 145 DAS, being the highest under CT+RI (26.7 and 5.98, respectively) followed by ZT+FRM (23.9 and 5.67, respectively) and CT-WR (18.0 and 4.48, respectively)while the lowest under ZT+1/3 RM (16.7 and 3.28) at 138 and 145 DAS. Both the wheat varieties had statistically similar chlorophyll content at all the stages of observation except at 138 DAS, where higher SPAD value was noted in wheat variety HD 2894 (25.3) than KRL 213 (17.0).

Study concluded that residue incorporation in conventional tilled rice (PTR+RI) and wheat (CTW+RI) produced higher grain yield than residue retention under zero tillage due to higher biomass accumulation, carbon sequestration and photosynthetic rate. Long term experimentation is suggested to evaluate the effect of residue retention under ZT in rice and wheat crops.

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