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Wheat (*Triticum* spp) roots influenced by crop residue and phosphorus under maize (*Zea mays*)-wheat system

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ABSTRACT

A field experiment was initiated with maize (*Zea mays* L.)-wheat (*Triricum* spp.) cropping system in the year 2013 to assess the impact of crop-residue retention (CCR) and phosphorus fertilization on root growth, growth parameters and nutrient content of wheat at ICAR-Indian Agricultural Research Institute Research Farm, New Delhi. Treatments of main-plot were of different CRR and that of subplot were of different P fertilizer management accounting for 20 treatments combinations. For the present study, collected samples were analyzed during 2014–15 and 2015–16 using appropriate methods. Results indicated that mean root-weight densityof wheat at 40 and 75 days after sowing (DAS) was significantly increased from 0.64 (control) to 0.84 mg/cm^3 and 2.19 (control) to 2.82 mg/cm^3 with 50% crop-residue retention (CRR), respectively. Similarly, the root-growth rate of wheat was also affected significantly due to CRR under different treatments over control. The treatment 50% RDP + PSB amd AM significantly enhanced dry root weight density (0.91 mg/cm^3 at 40 and 2.82 mg/cm^3 at 75 DAS of wheat with root-growth rate of 48.5 µg/cm^3/day). Moreover, significant highest root-growth rate was noticed (49.2µg/cm^3/day) under 150% RDP treatment which was statistically similar to 50% RDP + PSB and AM treatment. Significant highest P content in wheat at different stages as well as in grain was recorded with 50% CRR along with 50% RDP + PSB and AM treatment combination. Application of 50% RDP+PSB and AM in combination with 50% CR was found most beneficial in terms of improving root-growth rate, root-weight density, growth attributes and P content in wheat at different stages as well as in grain.

Keywords: Crop-residue retention, P content, PSB and AM, Root-growth rate, Root-weight density, Wheat

Crop-residue retention (CRR) is vital for conserving soil productivity by acting as a primary substrate for the replenishment of soil organic matter and serve as an important source of plant nutrients. Long-term CRR coupled with appropriate fertilization have been shown to enhance soil quality and crop productivity (Malhi *et al.* 2011), thus they are increasingly advocated as effective alternatives to *in-situ* residue burning. Stratification of soil organic carbon and different plant nutrients, especially immobile nutrients (P) in soils under reduced and no-tillage with CRR on soil surface is widely reported (Moreno *et al.* 2006). So understanding the dynamics of CRR practices along with P fertilization on phosphorus distribution and stratification is important. Improving P availability is an additional advantage of CA in weathered soils through reduced P fixation (Kumawat *et al.* 2016). Conservation agriculture improves soil structure and/or aggregation (Kumar *et al.* 2018) and may be conducive to greater P availability which results in better root development. Phosphorus fertilization along with phosphate solubilizing bacteria (PSB) and arbuscular-mycorrhizal fungi (AMF) are reported to improve yield, P-use efficiency and phosphorus uptake of crop (Kumawat *et al.* 2018). Arbuscular-mycorrhizal fungi (AMF) and plant-growth promoting rhizobacteria are considered as potential bio-fertilizers (Adesemoye and Kloepper 2009). The AMF are almost omnipresent in all agricultural soils and can establish beneficial symbiosis with the rooting systems in 80% of the terrestrial plants. The combined applications of fertilizer and AMF are used to improve the nutrient-use efficiency of fertilizers and phyto-remediation (Xun *et al.* 2015), increase the crop yield (Kumawat *et al.* 2018), enhance fruit quality (Bona *et al.* 2016) and for reducing the application of chemical fertilizers (Adesemoye and Kloepper 2009).

However, combination of P fertilizer with bio-fertilizer has not been much studied under field conditions in terms of root characteristics leading to scarcity of information in this regard. So the present investigation was undertaken to study the effect of CRR and P fertilization along with bio-fertilizer on root and plant development and nutrient concentration in wheat crop under maize (*Zea mays* L.)-wheat (*Triticum*

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spp.) cropping system in semi-arid condition of India.

MATERIALS AND METHODS

Present study was undertaken in wheat under ongoing experiment on maize–wheat cropping system during 2014-15 to 2015–16 at Experimental Research Farm, ICAR-IARI, New Delhi. Treatments of main-plots consisted of varying percentage of CRR, i.e. T_1: residue removal (no-residue), T_2: 25% crop residue (2 t/ha), T_3: 50% crop residue (4 t/ha), T_4: 75% crop residue (6 t/ha) and sub-plot treatments were of different phosphorus management, viz. S_1**:** No-phosphours, S_2**:** 50% recommended dose of phosphorus (RDP), S_3**:** 100% RDP, S_4:150% RDP, S_5**:** 50% RDP + PSB and AM, accounting for 20 numbers of treatment combinations and it was evaluated in a split-plot design. Previous maize crop was harvested and above ground biomass were retained as per treatments in the plots. Recommended dose of N-P-K were 150-80-60 kg/ha, respectively for wheat was applied. Entire amount of P (diammonium phosphate) and K (muriate of potash) was applied as basal at the time of sowing. Fertilizer N (urea) was applied in two equal splits at tillering stage and heading stage of wheat. The dose of N and K were applied uniformly to all the plots, whereas P was applied as per the treatment's requirement.Wheat variety HD CSW-18 was sown in last week of November and harvested in April during both the years 2014–15 and 2015–16. The root samples were collected up to 15 cm soil depth at 40 and 75 days after sowing (DAS) of wheat with the help of root sampler. Root weight density was calculated using volume of root sampler and weight of roots. The collected plant samples (grain and straw) after harvest of the crop were digested using di-acid mixture (HNO_3:$HClO_4$) and P content was estimated by vanado-molybdo yellow colour method (Jackson 1973). Statistical analysis was performed using SAS and SPSS software and the least significant difference (LSD) values were tested at 5% of significance level (P=0.05).

RESULTS AND DISCUSSION

Root-weight density: Different levels of CRR significantly influenced the root-weight density (RWD) of wheat at 40 DAS, which ranged from 0.69 mg/cm^3 (No-CR) to 0.84 mg/cm^3 (50% CR). The maximum wheat RWD of 0.84 mg/cm^3 was recorded with @ 50% CRR followed by 0.81 mg/cm^3 with 75% CRR (Table 1). The CRR in wheat crop showed 25 and 40% higher root-weight and root-weight density compared to no-mulch in subsurface layers, due to more retention of soil moisture and minimizing soil temperature fluctuation (Chakraborty *et al.* 2010). Wheat RWD at 40 DAS increased significantly with increasing

Table 1 Effect of crop residues and phosphorus fertilization on root growth parameters of wheat (pooled of two years)

Crop residue (CR)	Phosphorus rates (P)					
	No-P	50% RDP	100% RDP	150% RDP	50% RDP + PSB & AM	Mean
	Dry root weight density (mg/cm^3) at 40 DAS					
No-CR	0.49	0.61	0.77	0.79	0.80	0.69
25% CR (2 ton/ha)	0.58	0.66	0.90	0.92	0.92	0.79
50% CR (4 ton/ha)	0.62	0.72	0.94	0.95	0.98	0.84
75% CR (6 ton/ha)	0.60	0.67	0.91	0.94	0.95	0.81
Mean	0.57	0.66	0.88	0.90	0.91	
LSD (P≤ 0.05)	CR = 0.011, P = 0.012 and CR × P = 0.024					
	Dry root weight density (mg/cm^3) at 75 DAS					
No-CR	1.35	1.62	2.49	2.77	2.74	2.19
25% CR (2 ton/ha)	1.75	2.01	2.77	2.95	2.99	2.49
50% CR (4 ton/ha)	1.99	2.38	3.04	3.28	3.42	2.82
75% CR (6 ton/ha)	1.80	2.19	2.89	3.09	3.16	2.63
Mean	1.72	2.05	2.80	3.02	3.08	
LSD (P≤ 0.05)	CR = 0.101, P = 0.113 and CR x P = NS					
	Root growth rate (µg/cm^3/day)					
No-CR	19.6	23.1	39.2	45.8	44.0	34.3
25% CR (2 ton/ha)	26.8	30.3	42.0	47.2	47.2	38.7
50% CR (4 ton/ha)	31.1	37.2	47.6	55.0	54.7	45.1
75% CR (6 ton/ha)	27.0	33.9	43.5	49.0	48.3	40.4
Mean	26.1	31.1	43.1	49.2	48.5	
LSD (P≤ 0.05)	CR = 3.36, P = 3.76 and CR × P = NS					

PSB, Phosphorus solubilizing bacteria; AM, Arbuscular mycorrhiza.

P-fertilizer rate (Table 1). Significant highest root-weight density (0.91 mg/cm^3) was recorded with application of 50% RDP + PSB and AM, which was 37.8% higher over 50% RDP, indicating the capacity of the above treatment in reducing about 50-60% P fertilizer application rate, with significant increase in the root-weight density of wheat.The highest root-weight density (0.98 mg/cm^3) was obtained in 50% CR with 50% RDP + PSB and AM combination, which is nearly 100% higher over control (Table 1).

At 75 DAS (Table 1), root-weight density of wheat increased significantly with increasing rate of CRR up to 50%, thereafter it was decreased at 75% CRR. The 50% CRR recorded significantly higher root-weight density 2.82 mg/cm^3 at 75 DAS followed by 75% CRR (2.63 mg/cm^3). Insufficient amount of CRR is detrimental for soil quality through loss of soil organic matter, whereas excessive amounts of CRR can impair soil-seed contact, immobilize N, and/or keep soils cool and wet finally leads to poor growth and development of the crop (Clay *et al.* 2019). Phosphorus fertilization, significantly improved root-weight density at 75 DAS which ranged from 1.72 mg/cm^3 (No-P) to 3.08 mg/cm^3 (50% RDP + PSB and AM). The enhancement in root-weight density of wheat may be attributed to better supply of phosphorus nutrient to plant which plays vital role in development of plant roots through PSB and AM. Saxena *et al.* (2013) also reported application of PSB along with AMF recorded the highest dry root weight of the wheat crop which was about 230.8% higher than that of control at 110 DAS. Crop residues retention and phosphorus fertilization either alone or in combination enhanced the RWD at 75 DAS of wheat over control (1.35 mg/cm^3).The maximum RWD (3.42 mg/cm^3) was observed in 50% CRR with 50% RDP + PSB and AM combination, with the tune of 153% increase over control. However, integrated use of 50% CRR with 100% RDP and 75% CRR with 150% RDP resulted in statistically similar wheat RWD at 75 DAS. Improved soil conditions with CRR in rice-wheat cropping system significantly improved root growth of both the crops (Kumar *et al.* 2018).

Root-growth rate: Wheat root growth rate was significantly affected due to CRR over control and ranged from 34.3 to 45.1 μg/cm^3/day during growth period between 40 and 75 DAS (Table 1). Significant highest root-growth rate 45.1 μg/cm^3/day was recorded @ 50% CRR followed by 75% CRR and 25% CRR treatments (40.4 and 38.7 μg/cm^3/day, respectively). The mean highest root-growth rate (49.2 μg/cm^3/day) was recorded with 150% RDP and it was found statistically at par with 50% RDP + PSB and AM (48.5 μg/cm^3/day) but both the above treatments were significantly higher to 100% RDP (43.1 μg/cm^3/day). Integrated use of 50% CRR + 150% RDP or 50% CRR + 50% RDP + PSB and AM resulted in more or less same root-growth rate of 55.0 μg/cm^3/day and 54.7μg/cm^3/day, respectively.

Growth parameter of wheat crop: The results revealed significant positive impact of crop residue retention rates as well as P fertilization rates on plant height of wheat over control treatment. Plant height of wheat under different CRR was observed between 95.6 and 99.0 cm (Table 2). Plant height of wheat was significantly increased up to 50% CRR treatment and 75% CRR recorded similar plant height of wheat to that of CRR @ 25% treatment. Among the various phosphorus fertilization rates, the significant highest plant height of wheat was recorded under 50% RDP + PSB and AM (101.5 cm) with an increase by 8.3% over control.

Table 2 Effect of crop residues retention and phosphorus fertilization on growth parameters and phosphorus content (%) at different stages of wheat

Treatment	Growth parameters				Phosphorus content (%)			
	Plant height (cm)	Effective tillers/m row	Ear length (cm)	1000-grain weight (g)	At 40 DAS	At 75 DAS	Straw at harvest	Grain at harvest
Crop residue retention (CRR)								
No-CR	95.6	67.9	12.3	43.0	0.406	0.187	0.046	0.312
25% CR (2 ton/ha)	96.8	71.9	12.7	44.1	0.431	0.21	0.050	0.321
50% CR (4 ton/ha)	99.0	75.1	13.2	45.1	0.456	0.245	0.058	0.340
75% CR (6 ton/ha)	97.8	73.8	13.1	44.6	0.440	0.23	0.057	0.334
LSD (P≤ 0.05)	1.33	1.91	0.50	0.67	0.01	0.01	0.003	0.004
Phosphorus fertilization rates (P)								
No-P	93.7	65.5	12.2	41.7	0.360	0.161	0.039	0.285
50% RDP	96.0	68.8	12.6	42.9	0.394	0.194	0.047	0.31
100% RDP	96.9	73.3	12.8	44.9	0.458	0.231	0.056	0.339
150% RDP	98.4	75.3	13.0	45.3	0.462	0.242	0.059	0.345
50% RDP+ PSB & AM*	101.5	78.1	13.6	46.2	0.491	0.262	0.063	0.355
LSD (P≤ 0.05)	1.49	2.14	0.57	0.75	0.012	0.01	0.004	0.005
CRR × P	NS	NS	NS	NS	NS	NS	NS	NS

PSB, Phosphorus solubilizing bacteria; AM, Arbuscular mycorrhiza.

Effective tillers of wheat were significantly and positively influenced by CRR up to 50% CRR, after that, it was slightly reduced at 75% CRR treatment. CRR increased effective tillers from 67.9 (control) to 75.1 (50% CRR). The effective tillers were recorded significantly higher (78.1) in 50% RDP + PSB and AM, followed by 150% RDP (75.3) and 100% RDP (73.3) treatments. An improvement in ear length was observed under increasing levels of CRR and P fertilization (Table 2). Application of different CRR rates increased the ear length of wheat from 12.3 (Control) to 13.2 cm (50% CRR). Significantly higher ear length of wheat was recorded 13.6 cm in 50% RDP + PSB and AM. However, the P fertilization rates, i.e. 50%, 100% and 150% RDP were not significantly differed in ear length of wheat.

The 1000-grain weight of wheat under CRR treatments ranged from 43.0 (control) to 45.1 g (50% CRR). Among various P fertilization rates, the maximum 1000-grain weight of wheat (46.2 g) was recorded with 50% RDP + PSB and AM. Treatment 50% RDP + PSB and AM was significantly superior in 1000-grain weight of wheat from 100% RDP treatment. Rice straw and *dhaincha*, CRR showed significant increase in plant height, number of tillers/m^2, number of earheads/m^2, number of grains/earhead, test weight, straw and grain yield of wheat crop (Dhar *et al.* 2014). Similar increments in grain yield upon application of PSB were reported by other researchers (Dwivedi *et al.* 2017).

P content in wheat plant at different stages: Phosphorus content in wheat plant at 40 DAS significantly increased with increasing amount of CRR up to 50% (0.456%), which had significantly higher P content and it recorded about 12.3% higher P content over no-CRR treatment and 6.1% higher over 50% CRR treatment (Table 2). Among different P fertilization rate, phosphorus content in wheat plant at 40 DAS increased with increasing rate of P fertilization up to 100% RDP. Significant highest P content (0.491%) was observed under 50% RDP + PSB and AM, which recorded 7.25% higher P content over 100% RDP. At 75 DAS, phosphorus content in wheat plant ranged from 0.187 (control) to 0.245% (50% CRR) and significantly higher P content in wheat plant was recorded in 50% CRR treatment. The P content in wheat plant at 75 DAS increase with increasing rates of P fertilization rate and significantly higher at 50% RDP + PSB and AM (0.262%) treatment.

P content in wheat straw at harvest: Phosphorus content in wheat straw at harvest decreased as compared to early growth stage of wheat under CRR and P fertilization treatments (Table 2). The P content in wheat straw ranged from 0.046 (control) to 0.058% (50% CRR) under CRR management and 0.039 (control) to 0.059% (150% RDP) under P fertilized plots. The 50% CRR treatment recorded 26% higher straw P content over no-CRR treatment. In case of P fertilization management, treatment 50% RDP + PSB and AM recorded significantly higher P content (0.063%) in wheat straw at harvest as compared to 100% RDP treatment.

P content in wheat grain at harvest: The CRR rates enhanced the P content in wheat grain over control. Maximum P content (0.340%) was found in 50% CRR followed by 75% CR (0.334%), 25% CRR (0.321%) and no-CRR (0.312%) treatment. The 50% CRR recorded significantly higher P content in wheat grain as compared to rest of the treatments. Application of 50% RDP along with PSB and AM inoculation recorded significant highest P content (0.35%) as compared to rest of other P managements in wheat grain. All phosphorus fertilization rates significantly differed with each other in respect of P content of wheat grain. The bio-fertilizer inoculation had significantly higher phosphorus accumulation in the oat leaves (Liu *et al.* 2019).

Crop-residue retention can improve the soil environment and reduced soil compaction for root development. The present study has also demonstrated higher root-weight density as well as root-growth rate; nutrient contents in CRR plots. Overall, application of phosphorus solubilizing bacteria and AM fungi along with CRR can curtail P fertilization up to 50% besides strong roots system of plant and nutrient supply ultimately improved the crop yield, NUE and quality of grain vis-a-vis economic benefit to farmers.

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