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Tillage and phosphorus management in maize (*Zea mays*) under maize-wheat cropping system

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ABSTRACT

A field experiment was conducted during *kharif* 2018–19 under maize-wheat cropping system (MWCS) to study the effect of 4 crop-establishment and tillage management (CETM) practices [FBCT–FBCT, Flat bed–conventional tillage (FBCT) both in maize & wheat; RBCT–RBZT, Raised bed–CT (RBCT) in maize & RB–zero tillage (RBZT) in wheat; FBZT–FBZT, FBZT in both crops; PRBZT–PRBZT, Permanent-raised bed–ZT (PRBZT) in both crops], and 5 P-fertilization practices in both crops [P_{100}: 100% (basal); P_{50}+2FSP: 50% P (basal) + 2 foliar-sprays of 2% DAP (2FSP); P_{50}+PSB+AMF: P_{50}+PSB+AM-fungi; P_{50}+PSB+AMF+2FSP: P_{50}+PSB+AMF+2FSP; P_0: No-P (P_0) with 100% NK as control] on maize growth and yield. Results revealed that CETM practices exhibited significant influence on growth parameters with highest values under PRBZT–PRBZT followed by RBCT–RBZT, FBZT–FBZT and FBCT–FBCT, respectively. PRBZT–PRBZT resulted in significantly higher grain (6.08; 6.19 t/ha) and stover yield (8.07; 8.22 t/ha) in maize during both years, however, it remained statistically at par with RBCT–RBZT and least under FBCT–FBCT. Harvest index was highest under PRBZT–PRBZT although non-significant among CETMs. P-fertilization significantly influenced the growth parameters, days taken to different phenological-stages and growth-indices (CGR, RGR, NAR). The P_{50}+PSB+AMF+2FSP exhibited significantly higher grain (6.24; 6.37 t/ha) and stover yield (8.65; 8.98 t/ha) in maize over rest of the treatments during both years. Overall, PRBZT–PRBZT alongwith P_{50}+PSB+AMF+2FSP proved vital for enhancing growth and yield of maize under MWCS in semi-arid Indo-Gangetic-plains.

Key words: Foliar-P, Maize growth, Phosphorus, Residue-retention, Raised-beds, Zero-tillage

In India, maize (*Zea mays*) is grown on ~8.71 m-ha area producing 27.14 mt grains with 3.12 t/ha average yield (AGRICOOP 2017). Worldwide, maize is consumed in ~94 developing countries comprising >4.5 billion people where it supplies ~30% of total calorie needs. Global maize-demand is estimated to increase 2-folds by the year 2050. Due to multiple uses and high yield potential, maize is also vital for ensuring national food security besides being an alternative for diversification of rice-wheat system especially in Indo-Gangetic-plains-region (IGPR) to curtail prevailing resource- and production-vulnerabilities (Choudhary *et al*. 2018). Major issues of concern in IGPR are declining ground-water table, soil organic matter (SOM) and soil health which lead to poor crop and water-productivity, excessive nutrient-mining and low resource-use-efficiency, etc. (Varatharajan *et al*. 2019a, Choudhary *et al*. 2018, 2020). Hence, location-specific climate-resilient conservation agriculture (CA) practices may sustain the productivity and soil health with better resource-conservation, reduced farm and environmental-risks (FAO 2010, Paul *et al*. 2014, Varatharajan *et al*. 2019a, 2019b). Therefore, designing of CA-based crop-establishment and tillage management (CETM) assumes prime importance to harness high yield potential in maize while coping-up above production- and resource-constraints (Choudhary *et al*. 2018, 2020).

Alluvial soils in Indian IGPR are the most fertile but now majority is diagnosed with low soil-P status. Thus, precise P-fertilization in nutrient-exhaustive maize that too under hybrids becomes more critical to get better yield (Yadav *et al.* 2015, Kumar *et al.* 2015). In general, P-fertilizers have very low P-use-efficiency (~15–20%) in most of global arable soils (Kumar *et al.* 2015, Yadav *et al.* 2018). P-fertilizers are also very costly due to dependency on P-imports (Yadav *et al*. 2018). Foliar-P fertilization may also resolve above issues as evident from encouraging results across the globe (Amanullah *et al*. 2016, Rafiullah *et al*. 2017). Foliar-P fertilization may also prove beneficial to enhance maize productivity and P-use-efficiency with high economic-returns. Hence, we investigated the effect of different CETMs and P-fertilization practices on growth and yield of maize for developing an efficient CETM and P-fertilization technology for maize under maize-wheat

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cropping system in IGPR.

MATERIALS AND METHODS

Experimental details and crop management: A field experiment was conducted during *kharif* 2018–19 at experimental farm of ICAR-Indian Agricultural Research Institute, New Delhi [Latitude-28°63'N; Longitude-77°15'E; Altitude-228.6 m] under maize-wheat cropping system. Experimental site is located in semi-arid sub-tropics having sandy-loam soil belonging to Typic-Ustochrepts. Average annual rainfall is ~650 mm 80% of which received through South-west-monsoons during July-September. Soil (0-15 cm depth) at initiation of experiment had *p*H 8.0, oxidizable soil organic-C 0.421%, alkaline-$KMnO_4$ oxidizable-N 137.9 kg/ha, 0.5 M $NaHCO_3$ extractable-P 12.9 kg/ha and 1 N NH4OAc-extractable-K 302.8 kg/ha (Rana *et al*. 2014). Experiment was laid-out in split-plot-design thrice-replicated with 20-treatment combinations comprising 4 main-plot treatments i.e. crop-establishment and tillage management methods [FBCT–FBCT, Flat bed–conventional tillage (FBCT) both in maize & wheat; RBCT–RBZT, Raised bed–CT (RBCT) in maize & RB–zero tillage (RBZT) in wheat; FBZT–FBZT, FBZT in both crops; PRBZT–PRBZT: Permanent raised bed–ZT (PRBZT) in both crops] and 5 sub-plot treatments i.e. P-fertilization practices in both crops [P_{100}, 100% P; P_{50}+2FSP, 50% P (P_{50}) + 2 foliar-sprays of phosphorus (2FSP) as DAP (2%) at knee-high (KHS) and pre-tasseling stage (PTS); P_{50}+PSB+AMF: P_{50}+PSB+AM-fungi (AMF); P_{50}+PSB+AMF+2 FSP: P_{50}+PSB+AMF+2FSP; P_0: no-P (P_0) with 100% NK as control]. Crop-residues of preceding wheat and maize were applied to all ZT-plots @ 3 t/ha except CT-plots after sowing of succeeding maize and wheat, respectively. Maize (hybrid PMH-1) was sown in gross plot-size of 5.0 m × 4.2 m at spacing 60 cm × 25 cm using seed-drill with seed @ 20 kg/ha with fertilizer N: P_2O_5: K_2O @ 150: 60: 40 kg/ha on 12th and 9th July and harvested on 29th and 24th October during *kharif* 2018–19, respectively. Whole-K and treatment-wise fertilizer-P were applied as basal while N applied in 3-equal splits (basal, top-dressed at KHS and PTS). Foliar P-fertilization was done at KHS and PTS using 2% DAP (Diammonium-phosphate) in 750 L water/ha. Maize was grown using standard practices (Rana *et al.* 2014, 2018), expect treatments.

Plant growth and yield: Plant height, leaf-area-index and dry-matter accumulation studies were done at 30-days interval using standard procedures (Rana *et al*. 2014). Crop growth rate (g/m^2 ground area/day), relative growth rate (mg/g dry matter/day) and net assimilation rate (g/m^2 leaf area/day) were computed using standard equations (Kumar *et al*. 2015). After harvesting, the crop was sun-dried, threshed plot-wise, grains cleaned and sun-dried till 10% seed moisture and then grain and stover yield and harvest-index were determined using standard procedures (Rana *et al.* 2014). Statistical analysis ($P<0.05$) was done using SAS 9.1 software.

RESULTS AND DISCUSSION

Growth parameters and growth indices: Among CETM practices, significantly taller plants were observed under PRBZT–PRBZT (Permanent raised bed–zero tilled plots both in maize and wheat) at 30 & 60 DAS and at harvest followed by FBZT–FBZT and least under FBCT–FBCT (Table 1). Among P-fertilization practices, 50% P+PSB+AMF+2 foliar sprays of DAP at knee high and pre-tasseling stage (P_{50}+PSB+AMF+2FSP) produced significantly taller plants followed by P_{50}+PSB+AMF, P_{50}+2FSP, P_{100} and P_0, respectively. At 30 DAS, P_{50}+PSB+AMF+2FSP

Table 1 Influence of CETM and P-fertilization practices on plant height and dry matter accumulation at 30 days interval in maize under MWCS

Treatment	Plant height (cm)								Dry matter accumulation (g/plant)							
	30 DAS		60 DAS		90 DAS		At harvest		30 DAS		60 DAS		90 DAS		At harvest	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Crop-establishment and tillage management (CETM)																
FBCT–FBCT	45.8	46.1	157.9	159.3	170.1	173.1	171.3	174.6	29.0	29.7	72.3	74.2	142.7	146.3	168.3	173.4
RBCT–RBZT	46.2	47.1	164.8	166.2	188.1	190.9	189.2	192.5	33.9	34.8	78.6	81.4	149.8	155.8	184.2	190.9
FBZT–FBZT	46.0	47.4	162.8	167.5	187.2	191.8	188.8	193.3	32.4	32.8	76.6	77.6	144.7	151.3	180.6	187.8
PRBZT–PRBZT	46.8	49.5	173.1	175.5	201.0	203.1	202.7	204.9	35.1	35.5	81.4	84.3	155.0	163.0	186.4	193.9
CD (P=0.05)	NS	NS	8.7	9.5	12.0	12.5	12.3	12.8	2.6	2.8	4.8	2.5	6.5	6.7	11.2	11.4
P-fertilization practices																
P_{100}	46.0	46.7	164.6	166.2	183.8	186.9	185.5	188.3	31.6	32.3	71.6	73.3	141.3	148.9	171.3	179.8
P_{50}+2FSP	44.6	46.9	166.2	167.9	187.6	188.8	188.8	190.1	29.2	30.0	79.0	82.5	151.4	159.0	188.2	196.6
P_{50}+PSB+AMF	48.4	49.8	165.2	168.1	187.4	189.8	189.2	191.0	37.7	38.2	80.0	81.9	147.3	155.0	175.5	183.9
P_{50}+PSB+AMF+2FSP	48.4	50.9	175.0	178.3	197.2	201.5	199.0	202.2	37.0	38.2	87.2	90.1	164.1	170.9	199.7	208.2
P_0	43.8	42.2	1524	151.9	177.1	177.3	177.6	178.0	27.5	27.4	68.4	68.9	136.2	136.8	164.7	164.1
CD (P =0.05)	4.7	4.9	8.7	7.1	8.6	12.2	8.9	12.9	3.0	2.7	4.9	3.6	6.9	6.6	7.7	8.0

Table 2 Influence of CETM and P-fertilization practices on NAR, CGR and RGR at various growth stages of maize under MWCS.

Treatment	CGR (g/m^2/day)				RGR (mg/g/day)				NAR (g/m^2/day)			
	30-60 DAS		60-90 DAS		30-60 DAS		60-90 DAS		30-60 DAS		60-90 DAS	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Crop-establishment and tillage management (CETM)												
FBCT–FBCT	9.62	9.87	15.64	16.04	30.77	30.77	22.64	22.62	0.66	0.66	0.83	0.82
RBCT–RBZT	9.94	10.35	15.83	16.53	28.19	28.44	21.60	21.71	0.64	0.65	0.77	0.80
FBZT–FBZT	9.84	9.95	15.13	16.38	28.80	28.88	21.37	22.35	0.64	0.62	0.71	0.77
PRBZT–PRBZT	10.28	10.84	16.35	17.49	28.38	29.17	21.66	22.14	0.64	0.64	0.76	0.78
CD (P=0.05)	1.16	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
P-fertilization practices												
P_{100}	8.89	9.09	15.48	16.81	27.35	27.39	22.72	23.64	0.59	0.58	0.77	0.82
P_{50}+2FSP	11.05	11.68	16.10	17.01	33.11	33.75	21.85	21.98	0.70	0.71	0.76	0.78
P_{50}+PSB+AMF	9.41	9.72	14.95	16.23	25.40	25.77	20.49	21.27	0.61	0.61	0.73	0.77
P_{50}+PSB+AMF+2FSP	11.16	11.54	17.09	17.95	28.68	28.70	21.13	21.40	0.68	0.67	0.75	0.76
P_0	9.09	9.23	15.07	15.07	30.64	30.97	22.90	22.73	0.65	0.65	0.84	0.83
CD (P=0.05)	1.43	1.04	NS	1.70	4.26	3.31	NS	NS	NS	0.06	NS	NS

and P_{50}+PSB+AMF produced taller plants. At 60 DAS onwards, plant height trend was P_{50}+PSB+AMF+2FSP> P_{50}+PSB+AMF>P_{50}+2FSP>P_{100}>P_0, respectively till harvest (Table 1). Dry-matter-accumulation (DMA) during initial 30 DAS was very slow whereas a drastic incremental increase was found at 60-90 DAS (Table 1). DMA was significantly higher under PRBZT–PRBZT followed by RBCT–RBZT, FBZT–FBZT and FBCT–FBCT, respectively at all growth-stages during both years. For P-fertilization, DMA at 30 DAS was significantly higher under P_{50}+PSB+AMF+2FSP or P_{50}+PSB+AMF. At 60, 90 DAS and at harvest, significantly higher DMA was observed using P_{50}+PSB+AMF+2FSP. In general, leaf-area-index (LAI) increased consistently and reached maximum at 60 DAS and then decreased when crop advanced towards maturity due to leaf-senescence (Fig 1). Amongst CETMs, significantly highest LAI was found under PRBZT–PRBZT during both years at 30, 60 and 90 DAS. LAI was highest under P_{50}+PSB+AMF+2FSP while P_{50}+BSB+AMF, P_{50}+2FSP and P_{100} remained at par with each other at 30, 60 and 90 DAS. Crop growth rate (CGR) at 30-60 and 60–90 DAS revealed a gradual increase as crop advanced towards maturity (Table 2). CETM-practices had significant influence on CGR for initial 30-60 DAS during 2018. PRBZT–PRBZT exhibited highest CGR during 30-60 and 60-90 DAS during 2018–19. CGR was highest under P_{50}+PSB+AMF+2FSP. RGR had no-significant effect due to CETMs at 30-60 and 60-90 DAS during both years.

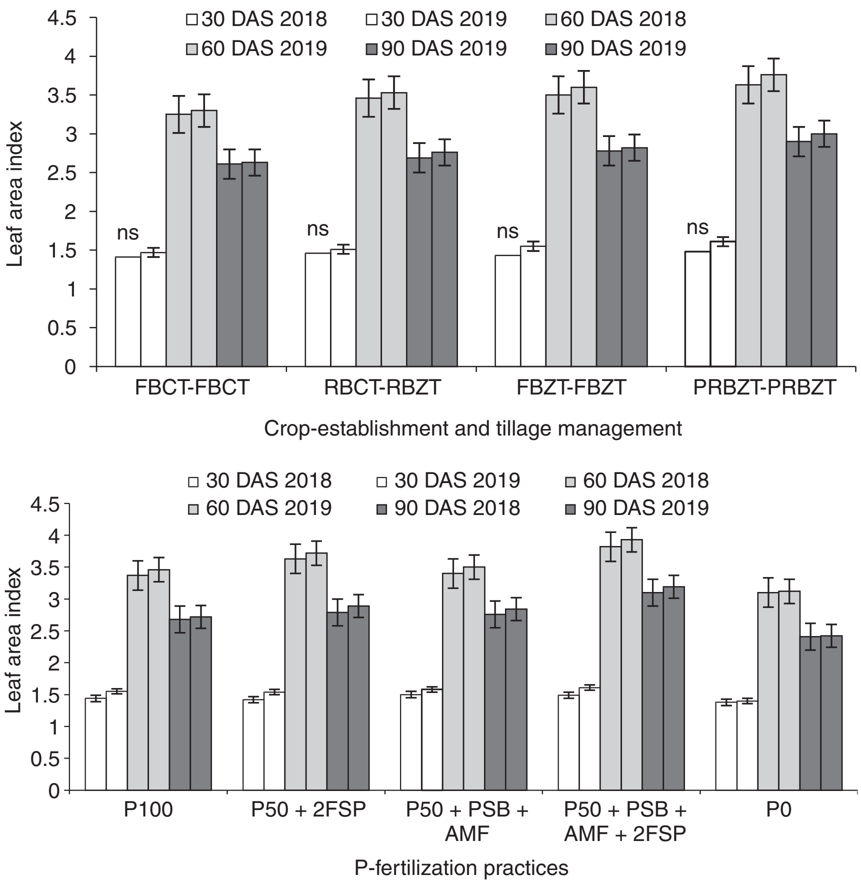

Fig 1 Influence of CETM and P-fertilization practices on leaf-area-index at 30-days interval in maize under MWCS.

Yet, highest RGR at 30-60 and 60-90 DAS was found under FBCT–FBCT during both years. RGR was highest at 30-60 DAS under P_{50}+2FSP during both years while at 60–90 DAS during 2019 it was highest in P_{100}. FBCT–FBCT exhibited highest NAR at 30–60 and 60–90 DAS. P-fertilization exhibited non-significant influence on NAR except at 30-60 DAS during 2019. NAR was highest at 30-60 DAS under P_{50}+2FSP, while at 60-90 DAS it was highest under P_0 during both years.

Under PRBZT–PRBZT, growth parameters were highest due to favorable effects of crop-residue-retention on soil physico-chemical and microbiological properties, soil temperature modulation, soil moisture retention, etc. (Zhang *et al*. 2009, Ram *et al.* 2013, Varatharajan *et al.* 2019a, 2019b). Since beginning, LAI in ZT-plots was higher over CT-plots owing to less temperature stress, weed-competition and water-stagnation stress (Varatharajan *et al.* 2019a, 2019b). ZT-plots with residues retained more soil moisture which alters the micro-climate with reduced soil temperature during dry-spells which in turn reduce plant water-stress over CT-plots (Ram *et al.* 2013, Varatharajan *et al.* 2019a, 2019b). Singh *et al*. (2020a) found that residues in ZT-plots gradually start decomposing by the microbe-action which in turn adds nutrients to soil, thus, creating favorable environment for shoot and root growth which finally improved the growth indices like RGR, CGR and NAR as well (Varatharajan *et al.* 2019a, 2019b). Next to nitrogen, phosphorus (P) plays an important role in plant processes like energy storage, transfer and bonding; hence favorably influencing plant shoot and root growth due to improved nutrient-acquisition, photosynthesis, cell-division, meristemtic tissue formation and other metabolic activities (Kumar *et al*. 2015, 2016). That's why; P-applied plots had better growth over no-P plots (Rana *et al.* 2018). Improved meristemtic tissues directly improve the number of functional leaves/plant eventually enhancing LAI (Sobhana *et al.* 2012). Likewise, P-fertilization alongwith PSB and AMF have synergistic effect on P-availability owing to better P-solublization and P-mobilization (Suri *et al.* 2011, Kumar *et al.* 2016). Likewise, foliar-P helps in effective P-absorbance through foliage leading to better growth and yield over soil applied-P (Rafiullah *et al*. 2018). Thus, integrated-use of P_{50}+PSB+AMF+2FSP proved beneficial for improving the maize growth parameters with resultant better growth indices even better over sole P_{100} (Kumar *et al*. 2015, 2016, Amanullah *et al*. 2016).

Phenological stages: CETM practices showed non-significant influence on phenological stages in maize, however, FBZT–FBZT (52.4 days) and PRBZT–PRBZT plots (51.2 days) took minimum days during 2018–19, respectively to attain 50% tasseling. For 50% silking, maize in PRBZT–PRBZT plots took less days (58.7; 56.4 days) during both years. FBCT–FBCT maize took maximum days to 50% tasseling and silking. P-fertilization showed significant influence on phenological stages where P_{50}+PSB+AMF+2FSP took minimum days for 50% tasseling (50.5; 49.7 days) and 50% silking (56.5; 55.8 days) which was followed by P_{50}+2FSP, P_{100}, P_{50}+PSB+AMF while P_0 took more days for both 50% tasseling and silking. The 50% tasseling and silking occurred early in ZT-based raised-bed (RB) or flat-beds (FB) owing to better growth due to temperature modulation, less water-stagnation, more weed-suppression and better nutrition (Varatharajan *et al.* 2019a, 2019b). Dual application of PSB and AMF also enhanced the P-availability due to combined effect on P-solublization and mobilization (Suri *et al.* 2011, Kumar *et al.* 2015). In addition, foliar-P through 2% DAP improved the N and P acquisition through foliage. Hence, P_{50}+PSB+AMF+2FSP exhibited faster growth and development; and finally took minimum days for different phenological stages (50% tasseling and silking) in maize over sole use of soil applied-P_{100}.

Maize productivity: PRBZT–PRBZT resulted in significantly higher grain (6.08; 6.19 t/ha) and stover yield (8.07; 8.22 t/ha) though it remained statistically at par with RBCT–RBZT but significantly higher than FBCT–FBCT during both years. Harvest-index was highest in PRBZT–PRBZT (43; 43.1%) during both years, respectively. P-fertilization had significant effect on grain and stover yield during both years except harvest-index (Fig 2). Significantly higher grain (6.24; 6.37 t/ha) and stover yield (8.65; 8.98 t/ha) were obtained using P_{50}+PSB+AMF+2FSP over the rest treatments during both years, however, P_{50}+2FSP, P_{50}+PSB+AMF and P_{100} were statistically on par with each other. Interaction effect between CETM and P-fertilization for grain and stover yield was found significant following similar trend as discussed above. Under PRBZT–PRBZT, initial plant growth was better due to crop-residues-retention on soil surface which reduced soil temperature while improving soil moisture and nutrient-availability (Mashingaidze *et al*. 2009). Thus, raised-bed ZT plots gave higher yield due to less machine-trafficking (Paul *et al*. 2014), less water-stagnation (Ram *et al.* 2013) and better soil hydro-thermal properties and more moisture-conservation in rainless-span (Choudhary *et al.* 2018, 2020). Higher SOM with better microbial diversity and activity leading to improved nutrient-availability are other reasons for higher productivity under CA-based CETMs (Varatharajan *et al*. 2019a, 2019b, Singh *et al.* 2020a, 2020b). Maize sown on PRBZT-PRBZT/RBZT-RBZT / raised-beds might have increased root aeration, root growth, chlorophyll and DMA which altogether led to higher maize productivity (Varatharajan *et al*. 2019a, 2019b). Higher harvest-index under PRTZT–PRBZT indicates better ability of maize plants to have efficient source-sink relationships (Choudhary *et al*. 2010). P-fertilization directly influenced the root growth which improved the vegetative growth and metabolism influencing reproductive growth (Rana *et al.* 2018). P-fertilization alongwith PSB and AMF was more effective in enhancing P-availability and crop yield (Suri *et al.* 2011, Kumar *et al.* 2015). In addition, two foliar-P sprays (2% DAP) led to improved nutrient absorption through foliage which enhanced shoot and root growth and photosynthetic-activity leading to improved

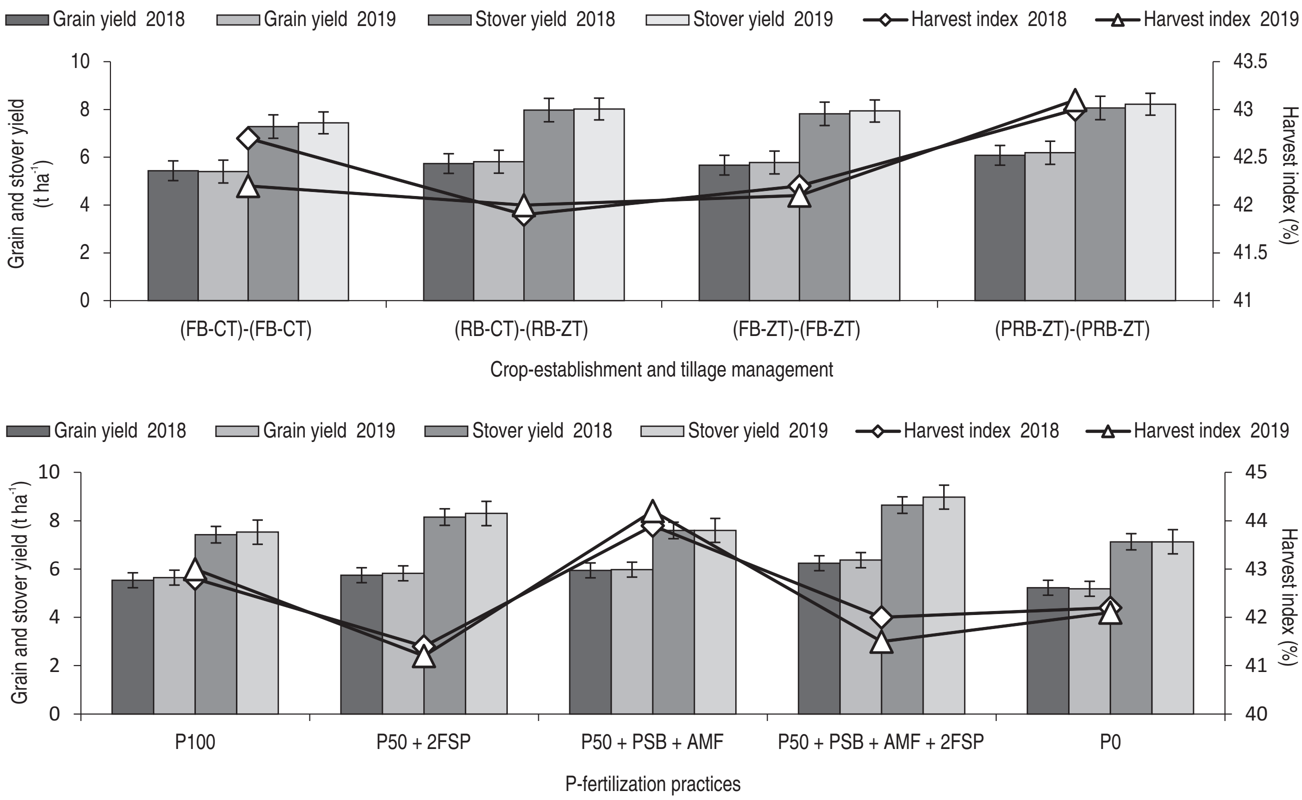

Fig 2 Influence of CETM and P-fertilization practices on grain and stover yield and harvest index of maize under MWCS.

yield. In alkaline soils, applied-P in general, reacts with calcium and magnesium ions, thereby, getting precipitated/ fixed as Ca and Mg phosphates and unavailable to plant acquisition (Havlin *et al*. 2007, Kumar *et al*. 2015, 2016). Thus, foliar P-fertilization might have enhanced the P-use efficiency and maize productivity in current study (Rafiullah *et al*. 2018). Grant *et al*. (2011) observed that combined application of soil applied-P and foliar-P is beneficial to enhance the productivity over soil applied-P alone. Thus, P_{50}+PSB+AMF+2FSP proved superior even over sole P_{100} due to synergistic effect of PSB+AMF on P-solubilization and mobilization besides enhanced P-absorption through foliar-P.

The CA-based crop-establishment and tillage management (CETM) practices imbedded with ZT and crop-residue-retention alongwith permanent-raised-beds or raised-beds exhibited better plant growth and productivity over CT-based CETMs. Integrated use of P_{50}+PSB+AMF+2FSP also gave superior maize growth and yield even over sole use of P_{100} owing to synergistic effect of PSB+AMF on P-solublization and mobilization besides enhanced P-absorption through foliar-P. Hence, PRBZT–PRBZT system coupled with P_{50}+PSB+AMF+2 foliar-P sprays through 2% DAP at knee-high and at pre-tasseling stages may prove highly beneficial for enhancing the growth and yield of maize under MWCS in semi-arid IGPR.

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