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Crop establishment methods and Zn nutrition in *Bt*-cotton: Direct effects on system productivity, economic–efficiency and water–productivity in *Bt*-cotton–wheat cropping system and their residual effects on yield and Zn biofortification in wheat

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ABSTRACT

A field experiment was conducted at New Delhi (India) during *kharif* and *rabi* seasons of 2013–14 and 2014–15 to assess the performance of 2 crop establishment methods (CEMs) of *Bt*-cotton [Direct sowing and transplanting] and 5 zinc (Zn) levels [0, 2.5, 5, 7.5 kg Zn/ha through zinc sulphate hepta hydrate (ZSHH) and 0.5% $ZnSO_4$ (ZSHH) foliar spray at 60 and 90 days after planting] applied to *Bt*-cotton on the system productivity, production–efficiency, economic–efficiency and water–productivity of *Bt*-cotton–wheat cropping system; as well as their residual effects on succeeding wheat in a *Bt*-cotton–wheat cropping system (CWCS) in a semi–arid Indo–Gangetic Plains Region (IGPR). In succeeding wheat, the residual effects of Zn levels applied to cotton were also compared with direct effect of Zn applied to wheat by replacing the foliar Zn spray treatment of cotton with Zn @ 5 kg/ha in wheat. The results revealed that direct and residual effects of cotton CEMs were non–significant on yield attributes and yield of wheat. However, the residual effects of Zn @ 5 and 7.5 kg/ha were significant on yield attributes and yield of wheat. Direct effect of Zn @ 5 kg/ha applied in wheat was at par with residual effects of 5 and 7.5 kg Zn/ha applied to cotton. In general, wheat grain yield was enhanced by 12.6, 12.3 and 12.9% during 2013–14, and 9.9, 8.1 and 8.3% during 2014–15 over control due to direct and residual effect of 2.5, 5 and 7.5 kg Zn/ha, respectively. Similarly on wheat straw yield. The influence of cotton CEMs on CWCS system productivity was non–significant. However, direct and residual effects of Zn levels induced a marked variation in CWCS system productivity as well as residual Zn fertility. Successive increase in Zn levels from 0 to 5 kg/ha in cotton resulted in significant increase in system productivity; thereafter, application of Zn @ 7.5 kg/ha revealed a non–significant influence. On an average, CWCS system productivity enhanced by 7.7% due to direct effect of 5 kg Zn/ha applied to wheat, and by 4.8, 10 and 9.9% due to residual effect of 2.5, 5 and 7.5 kg Zn/ha over control. With successive increase in Zn–levels to cotton, a significant Zn–enrichment of wheat grain and straw was also observed. Cotton CEMs exhibited a significant influence on Zn content and uptake in wheat straw but with non-significant influence on wheat grains. Again, cotton CEMs exhibited a non–significant influence on system production–efficiency (PE), economic–efficiency (EE) and profitability. On the other hand, successive increase in Zn levels to cotton resulted in perceptible increase in system PE and EE up to 5 kg Zn/ha. Foliar Zn spray to cotton and direct Zn application to wheat also exhibited significant increase in system PE and EE over control, but, this treatment was at par with direct and residual effects of 5 and 7.5 kg Zn/ha. There was a significant influence of CEMs and Zn levels on water–use–efficiency (WUE) and water–productivity (WP) in CWCS. Residual effects of 5 and 7.5 kg Zn/ha applied to cotton resulted in significantly higher net returns (NR) and benefit: cost ratio (BCR). Direct effect of 5 kg Zn/ha to wheat also exhibited higher NR and BCR in CWCS over control and residual effect of 2.5 kg Zn/ha. Overall, successive increase in Zn–levels led to significant enhancement in system productivity, PE, EE and water productivity up to 5 kg Zn/ha. The residual effects of 5 and 7.5 kg Zn/ha applied to *Bt*-cotton exhibited a significant influence on productivity, profitability and Zn biofortification of succeeding wheat which also remained at par with direct application of 5 kg Zn/ha applied to wheat in a *Bt*-cotton–wheat cropping system in a semi–arid IGPR.

Key words: *Bt*-cotton–wheat cropping system, Economics, Production–efficiency, Residual effects, Residual Zn fertility, Water productivity, Zn biofortification

Cotton (*Gossypium hirsutum* L.)–wheat (*Triticum aestivum* L.) is a well–established cropping system of north–western plains of Indian sub–continent. This production system is a lifeline to over 8 million people

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engaged in farming, processing, trade and textile industry in south-Asia (Mayee *et al*. 2008). In northern plains of India, cotton is grown under irrigated conditions, but still its productivity is very low. The optimum sowing time of cotton in the northern zone is second fortnight of May. However, high ambient temperature especially soil and frequent light showers during sowing period, results in sub–optimal plant population and crop establishment due to crust formation. In certain areas, salinity adversely affects the establishment of cotton seedlings under high temperature and water scarcity. Moreover, direct sown cotton requires 4–5 irrigations before onset of monsoon for better crop establishment and growth. However, it is very difficult to get optimum plant stand despite of frequent irrigations and repeated gap filling resulting in low productivity (Rajpoot *et al.* 2016). Frequent irrigations to crop also bring severe weed infestation which cause cost escalation due to frequent weeding. Thus, establishment of an optimum population of cotton seedlings is an important issue in cotton to harness higher yields. An optimum plant population in cotton contributes to about 22 to 32.7% rise in cotton yield, thus, crop establishment methods (CEMs) may play a vital role in obtaining required plant population under adverse situations (Ali *et al*. 2010).

Similarly, zinc (Zn) is the most limiting micronutrient in Indian soils. Notably, more than 50% of the cultivated soils in India are classed as Zn–deficient. Its deficiency in soils and plants lead to Zn malnutrition in humans and animals. Zn is an essential micronutrient that determines nutritional quality of grains (Suri *et al.* 2011). Zn aids in the synthesis of plant growth substances, enzymes systems, chlorophyll and carbohydrates etc. which directly affect the yield and quality of crops (Cakmak *et al*. 1996). Efforts are now underway on Zn fertilization to achieve higher crop yields and Zn nutrition in man and animals (Suri *et al*. 2011). But, still fertilizer Zn recommendations on cropping system basis are not yet available. Since, cotton–wheat cropping system (CWCS) is an exhaustive production system responsible for massive nutrient mining. Thus, it was highly important to study the direct, residual and cumulative effects of Zn applied to cotton on succeeding wheat so as to develop a rational fertilizer Zn recommendations on cropping system basis. Moreover, information pertaining to Zn–management in cotton and its direct and residual effects on yield and quality of succeeding wheat is very limited. Therefore, current study aimed at evaluating the direct and residual effects of cotton CEMs and Zn nutrition on wheat productivity and Zn biofortification *vis-a-vis* system productivity, profitability, economic–efficiency, production–efficiency and water–productivity in *Bt*-cotton–wheat cropping system in a semi–arid Indo-Gangetic-Plains-Region (IGPR).

MATERIALS AND METHODS

The field experiments were conducted across the rainy (*kharif*) and winter (*rabi*) seasons of 2013–14 and 2014–15 at Experimental Farm of Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi [28°40’ N latitude; 77°12’ E longitude; 228.6 m altitude] to evaluate the influence of cotton establishment methods (CEMs) and zinc fertilization on the performance of *Bt*-cotton–wheat cropping system (CWCS). The mean annual rainfall of New Delhi is 672 mm more than 80% of which generally occurs during south–west monsoon (July–September) with 850 mm mean annual evaporation. The soil of experimental field was sandy-loam which had 178 and 172 kg $KMnO_4$ oxidizable N/ha, 14.5 and 13.8 kg 0.5 N $NaHCO_3$ extractable P_2O_5/ha, 226 and 220 kg 1.0 N NH_4OAc exchangeable K_2O/ha, 0.35 and 0.34% soil organic carbon, 7.5 and 7.6 soil pH, 0.72 and 0.76 ppm DTPA–extractable Zn, and 0.30 and 0.32 dS/m soil EC at the start of the experiment during 2013-14 and 2014-15 (Rana *et al*. 2014). Treatments to *Bt*-cotton consisted of 2 CEMs (Direct sowing of cotton at the end of May; & transplanting of cotton seedlings raised in the nursery on the onset of monsoon) in main–plots and 5 Zn levels (control, 2.5, 5, 7.5 kg Zn/ha through zinc sulphate hepta hydrate (ZSHH); and one treatment with 2 foliar sprays of 0.5% zinc sulphate (ZSHH) at 60 and 90 days after planting) in the sub–plots in split plot design replicated thrice. Residual effect of Zn levels applied in cotton on succeeding wheat was also compared with direct effect of Zn applied to wheat and for that the foliar Zn spray treatment of cotton was replaced with 5 kg Zn/ha to wheat.

Direct sowing of *Bt*-cotton (SP 7007, BG II) was done by dibbling method with plant spacing of 90 × 45 cm on May 27 and 28 during 2013 and 2014, respectively. Gap filling was done twice on 7th and 12th days after first sowing. Direct sown crop received 5 and 7 irrigations (6 cm each) during 2013 and 2014, respectively. For weed management, pre–emergence application of pendimethalin followed by 2 hand weeding was done. For *Bt*-cotton nursery raising, poly-glass of 15 cm height and 10 cm diameter were filled with soil and farm yard manure (FYM) in the ratio of 3:1. Two *Bt*-cotton seeds were sown in each poly-glass on 27 and 28 May during 2013 and 2014, respectively, and finally retaining one plant/glass; which were watered on alternate day till transplanting of one month old seedlings. Gap filling and thinning was also done to retain one plant in each glass. For transplanting, field was prepared before the onset of monsoon and transplanting was done on 3 and 20 July during 2013 and 2014, respectively. Transplanted cotton received one and two irrigation during 2013 and 2014, respectively, and one hand weeding after 15 days of transplanting. Crop received recommended dose of 150 kg N, 60 kg P_2O_5 and 40 kg K_2O through urea, diammonium phosphate (DAP) and muriate of potash (MOP). Zinc as per treatment was given through zinc sulphate hepta hydrate (ZSHH). Foliar spray of 0.5 % zinc sulphate (ZSHH) was done at 60 and 90 days after planting using 400 and 600 litres water/ha, respectively. Through foliar spray 6 kg Zn sulphate (ZSHH) was sprayed which is equal to 1.2 kg Zn/ha. Half N and full dose of P, K and Zn was given as basal dose at the time of sowing and remaining half N was given before flowering. Picking of seed cotton from net plot was done at appropriate stage to avoid deterioration

Table 1 Residual effect of crop establishment methods of *Bt*-cotton and direct and residual effect of Zn fertilization on yield attributes and yield of wheat

Treatment	Spikes/m^2 (No.)		Grains/spike (No.)		1 000-grain wt. (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Crop establishment methods of Bt-cotton										
Direct sowing	419	388	48	47	41.6	40.9	5.26	4.69	6.29	5.76
Transplanting	425	406	49	47	41.9	41.5	5.31	4.74	6.27	5.80
SEm ±	1.6	3.2	0.3	0.4	0.13	0.36	0.01	0.02	0.06	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zn levels (kg/ha)										
0.0 (control)	374	346	46	44.0	40.1	39.2	4.85	4.44	5.74	5.27
2.5 kg Zn/ha to cotton	397	384	47.0	45.9	41.0	40.4	4.94	4.53	6.26	5.37
5.0 kg Zn/ha to cotton	443	417	49.0	48.0	42.6	41.6	5.53	4.83	6.40	6.04
7.5 kg Zn/ha to cotton	445	418	49.5	48.3	42.2	42.0	5.57	4.84	6.55	6.09
0.5% Zn foliar spray to cotton/5.0 kg Zn/ha to wheat	449	421	49.2	48.2	43.0	42.6	5.55	4.93	6.47	6.13
SEm ±	4.5	6.3	0.94	0.40	0.63	0.60	0.06	0.05	0.19	0.05
CD (P=0.05)	13.4	18.8	2.82	1.19	1.9	1.81	0.16	0.13	0.58	0.15

of quality of produce and seed cotton harvested from each net plot was converted to yield/ha.

The wheat DWR 544 was sown during first week of December in both years maintaining 22.5 cm spacing and receiving 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha through urea, DAP and MOP, respectively. The 1/3rd N and full dose of P and K were applied with last field operation. Remaining 2/3rd N was given in two equal splits after 30 and 60 DAS. The plot receiving Zn foliar spray in cotton was supplied with 5 kg Zn/ha in succeeding wheat through ZSHH to compare the direct and residual effect of Zn in wheat crop. Irrigation water was provided at about 15 days intervals requiring 6 irrigations (6 cm each) to the first season crop and 4 irrigations to second wheat. For effective weed control, pendimethalin @ 0.75 kg a.i./ha was mixed with 10 kg fine sand and uniformly spread after sowing followed by 2 hand-weedings at 20 and 40 DAS. As a prophylactic measures, one spray of monocrotophos @ 2 l/ha was done at the time of wheat flowering. Yield attributes, grain and straw yield were recorded following standard procedures (Rana *et al.* 2014). The weight of grain and straw from net plots in each treatment was weighed and expressed in tonnes/ha. Economic analysis was done following prevailing market prices of the inputs and outputs during respective crop seasons following standard procedures. The Zn analysis of soil and plant samples was done following standard procedures (Rana *et al.* 2014). Accordingly, the Zn balance sheet was also synthesized using initial and final Zn status in the soil, Zn input/applied and Zn uptake by the *Bt*-cotton–wheat cropping system in two years' study. System productivity in terms of seed cotton–equivalent–yield (SCEY) was calculated as: SCEY = Seed cotton yield + [(yield of succeeding wheat crop × price of wheat)/price of seed cotton]. Production–efficiency (PE) was expressed as the ratio of system productivity in term of SCEY in kg/ha to total duration of the cropping system in days (Kumar *et al*. 2015a). Like–wise, economic–efficiency was expressed as the ratio of net returns from the cropping system in ₹/ha to total duration of the system in days (Kumar *et al.* 2015b). Irrigation water–use efficiency (IWUE) and irrigation water–productivity (IWP) was worked-out using standard procedures (Choudhary *et al.* 2006, Pooniya *et al.* 2015). The data were statistically analyzed using *F*–test as per the procedure given by Gomez and Gomez (1984). Critical difference (CD) values at *P*=0.05 were used to determine the significant of difference between treatment means.

RESULTS AND DISCUSSION

Seasonal variations vis–à–vis crop productivity

Weather conditions showed a wide variation across the 2 years' experimentation. Rainy season was wet during 2013 with 102% higher rainfall (1350 mm) than average rainfall (672 mm). In contrast, during *kharif* 2014, onset of monsoon was late with intermittent drought receiving just 76% rainfall of average value. These variations in rainfall led to more irrigations to cotton during 2014 (7 irrigations in direct seeded; 2 irrigations in transplanted) than 2013 (5 irrigations in direct seeded; 1 irrigation in transplanted). Crop yield was also affected accordingly with fewer yields during 2014 than 2013 (Table 3). In winter season, more rainfall was recorded during 2014 (316 mm) than 2013 (220 mm), again, affecting wheat productivity with fewer yields during 2014 than 2013 (Table 1). Irrigation requirement of wheat was less during 2014 (4 irrigations) than 2013 (6 irrigations). This adverse effect of high rainfall during winter season during 2014 may be attributed to favourable conditions for crop lodging, insect–pests, diseases and weed infestation and less use–efficiency of nutrients especially nitrogen.

Residual effect on wheat crop

Wheat productivity : Crop establishment methods (CEMs) in *Bt*-cotton exhibited a non-significant residual effect on yield attributes (spikes/m^2, grains/spike, and 1000 grain weight) and grain and straw yield of wheat in current study (Table 1), however, the magnitude of above parameters was more under transplanted cotton (TPC) over directed-seed cotton (DSC). In contrast, the increasing Zn fertilization in cotton revealed a consistent and significant increase in yield attributes and wheat yield up to 5 kg Zn/ha, thereafter, the magnitude of enhancement was non-significant (Table 1). Direct effect of 5 kg Zn/ha applied to wheat revealed a slightly higher wheat grain and straw yield over residual effects of 5 and 7.5 kg Zn/ha applied to cotton, however, all these treatments remained statistically at par w.r.t. grain yield (Table 1). Increase in grain yield due to direct effect of 5 kg Zn/ha was 12.6 and 11% during 2013–14 and 9.9 and 8.1% during 2014–15 over control and residual effect of 2.5 kg Zn/ha, respectively. Increase in straw yield due to direct effect of 5 kg Zn/ha was 11.4% during 2013–14 and 14% during 2014–15 over control. Grain yield was found to increase by 12.3 and 12.9% during 2013–14 and 8.1 and 8.3% during 2014–15 due to residual effect of 5 and 7.5 kg Zn/ha owing to residual fertility (Cakmak *et al*. 1998). Improved yield attributes and yield of wheat also reported by Ali *et al.* (2011). This may also be attributed to multifarious role of Zn in plant biological processes, and being most important elements in carbohydrate metabolism (Cakmak *et al.* 1996).

Zn biofortification: *Zn content*: Zn content in wheat grain was found non-significant due to residual effect of cotton CEMs during both years (Table 2). However, TPS plots recorded slightly higher Zn content than DSC plots during both seasons. Direct application of 5 kg Zn/ha to wheat recorded highest Zn content (36.5, 36.2 mg/kg), which remained at par with residual effect of 5 and 7.5 kg Zn/ha during 2013–14 and 7.5 kg Zn/ha during 2014–15, respectively. Zn content in wheat straw was found significant due to residual effect of cotton CEMs and Zn levels. Significantly higher Zn content was observed in transplanted cotton (18.29, 17.80 mg/kg) over DSC in both seasons. Direct application of 5 kg Zn recorded highest Zn content (20.2, 19.8 mg/kg) which was on par with residual effect of 5 and 7.5 kg Zn/ha but significantly higher over residual effect of 2.5 kg Zn/ha and control during both the seasons. The higher Zn content in wheat grain and straw is closely related to its direct and residual influence on soil fertility w.r.t. Zn availability (Suri *et al.* 2011).

Zn uptake: Zn uptake in wheat grain was found non-significant due to residual effect of cotton CEMs during both years (Table 2). However, TPC plots recorded slightly higher Zn uptake (179.7, 157.9 g/ha) than DSC plots. Zn uptake in wheat grain was at par due to residual effect of 5 (193, 166.1 g/ha) and 7.5 kg Zn/ha (197.1, 170 g/ha) during both the respective seasons. Direct application of 5 kg Zn/ha recorded highest Zn uptake (202.3, 178.4 g/ha), which was significantly highest over the residual effect of 2.5 kg Zn/ha and control in both the seasons. Zn uptake in wheat straw was found significant both due to residual effect of cotton CEMs and Zn levels. Significantly higher Zn uptake was found in transplanted cotton (115.8, 104.2 g/ha) in both the seasons. Direct application of 5 kg Zn recorded highest Zn uptake (130.7, 121.4 g/ha), which was at par with residual effect of 5 and 7.5 kg Zn/ha during 2013–14 and 7.5 kg Zn/ha during 2014–15, respectively. The higher removal of Zn by the crop due to direct and residual effect is closely related to increase in Zn availability in the soil (Suri *et al.* 2011). Chaudhary *et al.* (2014) also reported residual effect of Zn applied to greengram on Zn uptake in succeeding crop.

Seed cotton yield and system productivity : Seed cotton yield (SCY) in *Bt*-cotton was found non-significant under both CEMs during both crop seasons (Table 3). However, Zn levels significantly influenced the SCY where 5 and 7.5 kg Zn/ha being at par resulted in significantly higher SCY over control and 2.5 kg Zn/ha. Foliar application of 0.5% ZSHH recorded statistically at par SCY to 2.5 kg Zn/ha, but inferior to 5 and 7.5 kg Zn/ha. Increase in SCY due to Zn fertilization was largely a function of improved growth,

Table 2 Residual effect of crop establishment methods of *Bt*-cotton and direct and residual effect of Zn fertilization on yield attributes and yield of wheat

Treatment	Zn content (mg/kg)				Zn uptake (g/ha)			
	Grain		Straw		Grain		Straw	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Crop establishment methods of Bt-cotton								
Direct sowing	33.2	32.5	17.0	16.8	175.1	153.1	107.9	97.8
Transplanting	33.6	33.2	18.3	17.8	179.7	157.9	115.8	104.2
SEm ±	0.25	0.38	0.05	0.11	1.55	2.17	0.98	0.48
CD (P=0.05)	NS	NS	0.32	0.67	NS	NS	5.96	2.93
Zinc levels (kg/ha)								
0.0 (control)	29.7	28.7	12.3	12.3	144.1	127.7	70.9	64.9
2.5 kg Zn/ha to cotton	30.5	29.9	17.1	16.9	150.6	135.3	106.8	90.6
5.0 kg Zn/ha to cotton	34.9	34.4	19.1	18.6	193.0	166.1	122.0	112.1
7.5 kg Zn/ha to cotton	35.4	35.1	19.7	19.1	197.1	170.0	128.8	116.0
0.5% Zn foliar spray to	36.5	36.2	20.2	19.8	202.3	178.4	130.7	121.4
SEm ±	0.74	0.53	0.31	0.27	4.57	3.04	3.73	1.85
CD (P=0.05)	2.2	1.6	0.9	0.8	13.7	9.11	11.17	5.54

Table 3 Direct and residual effects of crop establishment methods of *Bt*-cotton and Zn fertilization on seed cotton yield, system productivity, system production–efficiency, system economic–efficiency and system water productivity of *Bt*-cotton–wheat cropping system

Treatment	Seed cotton yield (t/ha)		System productivity (Seed cotton equivalent yield (SCEY) (t/ha)		System production efficiency (kg/ha/day)		System economic efficiency (₹/day)		System water use efficiency (kg/ha–mm)		System water productivity (₹/m³)	
	2013	2014	2013–14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Crop establishment methods of Bt-cotton												
Direct sowing	2.39	2.37	4.79	4.64	15.27	14.8	284.2	288.3	7.3	7.0	15.7	15.9
Transplanting	2.37	2.35	4.79	4.64	15.24	14.8	291.0	293.1	11.1	12.5	24.7	28.9
SEm ±	0.03	0.02	0.03	0.03	0.107	0.09	3.75	4.11	0.06	0.05	0.17	0.31
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.4	0.3	1.1	1.9
Zn levels (kg/ha)												
0.0 (control)	2.24	2.23	4.45	4.36	14.19	13.89	261.0	269.6	8.5	9.2	18.3	20.8
2.5 kg Zn/ha to cotton	2.36	2.32	4.68	4.56	14.91	14.53	283.9	279.9	9.0	9.6	19.9	21.7
5.0 kg Zn/ha to cotton	2.47	2.45	4.98	4.80	15.85	15.28	315.6	305.0	9.6	10.1	22.2	23.6
7.5 kg Zn/ha to cotton	2.50	2.47	4.99	4.78	15.90	15.23	298.8	305.2	9.6	10.1	20.8	23.4
0.5% Zn foliar spray to cotton/5.0 kg Zn/ha to wheat	2.33	2.31	4.84	4.69	15.43	14.95	278.7	293.8	9.3	9.9	19.9	22.7
SEm ±	0.03	0.02	0.042	0.04	0.14	0.11	10.73	5.88	0.09	0.07	0.70	0.38
CD (P=0.05)	0.09	0.07	0.13	0.10	0.40	0.33	32.17	17.62	0.3	0.2	2.1	1.2

translocation of more photosynthates towards sink and consequent development of yield attributes (Ali *et al*. 2011, Abid *et al*. 2013).

Likewise, system productivity in terms of seed cotton equivalent yield (SCEY) of transplanted cotton–wheat cropping system (CWCS) was found non–significant with direct sown CWCS (Table 3). On the other hand, direct and residual effect of Zn levels was found to induce marked variation in system productivity (SCEY) of CWCS. Successive increase in Zn levels led to significant increase in system productivity up to 5 kg Zn/ha. On an average, system productivity exhibited 7.7% increase due to direct effect of 5 kg Zn/ha applied to wheat and 4.8, 10 and 9.9% increase due to residual effect of 2.5, 5 and 7.5 kg Zn/ha applied to cotton over control, respectively. This behaviour of system productivity is attributed to the direct and residual effect of Zn levels on productivity of component crops of CWCS. Small amount of applied fertilizer Zn is removed in harvested parts of wheat and cotton crops (Rafique *et al*. 2006, Ahmed *et al*. 2010). Conclusively, fertilizer Zn requirement for optimum crop productivity in CWPS was less for cotton (5 kg Zn/ha) compared to wheat (7.5 kg Zn/ha). This may be due to deep and extensive root system of cotton crop compared to wheat that might have helped the plants in taking up nutrients more efficiently (Gulick *et al*. 1989).These results are also supported by the findings of Chaudhary *et al.* (2014).

System production–efficiency and economic–efficiency: Production–efficiency (PE) and economic–efficiency (EE) of CWCS were found non–significant due to cotton CEMs (Table 3). With successive increase in Zn levels perceptible increase in PE and EE was recorded up to 5 kg Zn/ha. Foliar application of 05% ZSHH to cotton and direct application of 5 kg Zn/ha to wheat also led to significant increase in PE and EE over control, but this treatment was at par with direct and residual effect of 5 and 7.5 kg Zn/ha applied to cotton in this study. This variation in PE and EE in CWCS are attributable to direct and residual effects of Zn–levels on productivity of respective component crops (Chaudhary *et al.* 2014, Manea *et al.* 2015).

System irrigation water–use efficiency and productivity : On an average, transplanted CWCS exhibited less irrigation water–use (IWU) over direct-seeded CWCS owing to transplanting of cotton at onset of south-west monsoons requiring less irrigation water (Table 3). In turn, transplanted CWCS recorded higher irrigation water–use efficiency (IWUE) and irrigation water productivity (IWP) than direct sown CWCS during both years. IWUE and IWP showed an improvement owing to increasing Zn levels up to 5 kg Zn/ha. The direct and residual effect of 5 and 7.5 kg Zn/ha as well as 05% ZSHH foliar spray to cotton and direct application of 5 kg Zn/ha applied to wheat exhibited statistically similar magnitude of IWUE and IWP. Higher IWUE and IWP under transplanted CWCS and Zn plant nutrition was the resultant of optimum plant population, efficient water use, better growth and yield attributes with higher system productivity (Kumar *et al.* 2015b).

Table 4 Direct and residual effects of crop establishment methods of *Bt*-cotton and Zn fertilization on economics of *Bt*-cotton–wheat cropping system

Treatment	Cost of cultivation (×10³ ₹)		Gross returns (×10³ ₹)		Net returns (×10³ ₹)		BCR	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Crop establishment methods of Bt-cotton								
Direct sowing	84.9	84.9	235.7	190.1	103.7	105.2	1.22	1.24
Transplanting	83.2	81.5	244.2	188.5	106.2	107.0	1.28	1.31
SEm ±			3.00	1.50	1.37	1.50	0.02	0.02
CD (P=0.05)			NS	NS	NS	NS	NS	NS
Zinc levels (kg/ha)								
0.0 (control)	83.0	82.2	216.0	180.6	95.3	98.4	1.15	1.20
2.5 kg Zn/ha to cotton	83.4	82.6	249.7	184.8	103.6	102.2	1.24	1.24
5.0 kg Zn/ha to cotton	83.8	83.0	256.8	194.3	115.2	111.3	1.37	1.34
7.5 kg Zn/ha to cotton	84.2	83.4	243.9	194.8	109.1	111.4	1.29	1.34
0.5% Zn foliar spray to cotton/5.0 kg Zn/ha to wheat	85.6	84.8	233.3	192.0	101.7	107.2	1.19	1.27
SEm ±			7.74	2.15	3.92	2.15	0.05	0.03
CD (P=0.05)			23.2	6.4	11.7	6.4	0.14	0.08

System profitability: The economic parameters of CWCS such as gross returns (GR), net returns (NR) and benefit: cost ratio (BCR) were found non–significant under both cotton CEMs in both crop seasons (Table 4). Residual effect of 5 and 7.5 kg Zn/ha recorded significantly higher GR, NR and BCR over control and 2.5 kg Zn/ha. Direct effect of 5 kg Zn/ha applied to wheat resulted in higher GR, NR and BCR over control and residual effect of 2.5 kg Zn/ha. This increase in GR, NR and BCR due to direct and residual effect of Zn fertilization may be attributed to improvement in SCY and wheat yield (Table 1 and 3). These results are in accordance to Ali *et al*. (2011) and Chauhan *et al*. (2014).

Zn balance sheet

Zinc balance sheet of the *Bt* cotton–wheat cropping system (2013–15) is presented in Table 5. At the end of two years experimentation in CWCS, there was an improvement in available Zn over the initial value except control. Highest value of available Zn was recorded with direct application of 5.0 kg Zn/ha to wheat followed by residual effect of 7.5 kg Zn/ha owing to the direct and residual effects of higher Zn–levels. In case of CEMs, available Zn balance was slightly higher under DSC than TPC. Apparent Zn balance followed the similar trend to that of available Zn at the end of experimentation except direct application of 5.0 kg Zn/ha to wheat where apparent

Table 5 Direct and residual effects of crop establishment methods of *Bt*-cotton and Zn fertilization on zinc balance sheet of *Bt* cotton–wheat cropping system

Treatment	Initial available Zn (kg/ha)	Total Zn added (kg/ha)	Total Zn input (Available+ Added)	Total Zn uptake (kg/ha)	Residual Zn (kg/ha)	Apparent balance of Zn (kg/ha)	Actual Zn balance over initial value (kg/ha)
Crop establishment methods of Bt-cotton							
Direct sowing	1.59	8.0	9.59	1.033	1.814	8.557	0.224
Transplanting	1.59	8.0	9.59	1.046	1.801	8.544	0.211
Zinc levels (kg/ha)							
0.0 (control)	1.59	0.0	1.59	0.835	1.496	0.755	–0.094
2.5 kg Zn/ha to cotton	1.59	5.0	6.59	0.965	1.817	5.625	0.227
5.0 kg Zn/ha to cotton	1.59	10.0	11.59	1.129	1.861	10.461	0.271
7.5 kg Zn/ha to cotton	1.59	15.0	16.59	1.158	1.900	15.432	0.310
0.5% Zn foliar spray to cotton/5.0 kg Zn/ha to wheat	1.59	10.0	11.59	1.113	1.964	10.477	0.374

Note: Initial available Zn: DTPA-extractable Zn status before initiation of the experiment; Total Zn added: Total Zn addition to cotton and wheat crops during both years; Total Zn input: Total Zn (available + added); Total Zn uptake: Total Zn removal by the crops in CWCS; Residual Zn: DTPA-extractable Zn status after two years of CWCS; Apparent balance of Zn: Total Zn input – Total Zn uptake; Actual Zn balance over initial value: Residual Zn – Initial available Zn.

balance was lower than 7.5 kg Zn/ha to cotton. Actual balance over initial value was positive under all the treatments except control, with maximum magnitude under direct application of 5.0 kg Zn/ha to wheat followed by 7.5 kg Zn/ha to cotton. Apparent Zn balance exhibited highest value due to application of 7.5 kg Zn/ha to cotton alone followed by 5.0 kg Zn/ha to wheat. Overall, actual Zn balance was positive over initial value under all the treatments except control where actual balance was negative due to no Zn additions.

The study conclusively indicated that crop establishment methods in *Bt*-cotton had non–significant but positive influence on system productivity, profitability, production–efficiency and economic–efficiency in CWCS. However, transplanted CWCS exhibited significantly higher irrigation water–use efficiency and productivity than direct–sown CWCS besides sharp reduction in irrigation requirement. On the other hand, successive increase in Zn fertilization led to significant improvement in system productivity, profitability, production–efficiency, economic–efficiency, irrigation water–use efficiency and productivity up to 5 kg Zn/ha in CWCS. Residual effect of 5 and 7.5 kg Zn/ha applied to *Bt*-cotton had significant and pronounced influence on productivity, profitability and Zn–biofortification of succeeding wheat but remained at par with direct application of 5 kg Zn/ha applied to wheat. Overall, application of 5 to 7.5 kg Zn/ha to cotton or 5 kg Zn/ha to wheat on cropping system basis may enhance the system crop and water productivity, Zn biofortification in wheat vis-a-vis residual Zn fertility in *Bt*-cotton–wheat cropping system in a semi–arid IGPR.

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