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Research Paper

Methods of cotton (*Gossypium hirsutum*) establishment and zinc fortification in cotton-based cropping systems: Direct and residual effect on onion (*Allium cepa*) and system productivity of cotton–onion cropping system

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ABSTRACT

A field experiment was conducted during rainy (*kharif)* and winter (*rabi*) seasons of 2013–14 and 2014–15 at New Delhi, to evaluate the effect of 2 methods of cotton establishment (direct sowing and transplanting) and 5 zinc-levels (control, 2.5, 5.0, 7.5 kg Zn/ha and 0.5% zinc sulphate foliar spray at 60 and 90 days after planting) on cotton *(Gossypium hirsutum* L.) and their residual and direct effect of 5.0 kg Zn/ha in place of foliar treatment on the succeeding wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] and onion (*Allium cepa* L.) crop. In this research paper residual effect of treatments applied to cotton and direct effect of Zn on onion has been presented along with system productivity and resource-use efficiency. Productivity of cotton and onion was higher during 2013–14 than 2014–15. Onion recorded significantly higher economic parameters and nutrient uptake after transplanted cotton than direct sown. Onion produced statistically similar growth and yield attributes, bulb yield, gross and net returns and nutrient uptake, due to direct application of 5.0 kg Zn/ha and residual effect of 5.0 and 7.5 kg Zn/ha to cotton, which were significantly superior to control and residual effect of 2.5 kg Zn/ha. Based on 2 years average, gain in net returns was ₹40,350, ₹43,200 and ₹47,950/ha due to residual effect of 5.0/7.5 kg Zn/ha and direct effect of 5.0 kg Zn/ha over control. Both residual and direct effect of Zn found to enhance the quality of bulb in terms of Zn enrichment and on an average 32.0, 31.8% and 36.2% increase in Zn uptake was recorded due to residual effect of 5.0/7.5 kg Zn/ha and direct effect of 5.0 kg Zn/ha respectively. Based on 2-years average, system productivity in terms of seed cotton equivalent yield (9.45 t/ha), production efficiency (27.0 kg/ha/day), economic efficiency (736.9₹/ha/day) and irrigation water productivity (1.16 kg/m^3) of transplanted cotton–onion cropping system was significantly greater than the direct sown cotton–onion system. Successive increase in Zn-levels caused significant increase in system productivity, production efficiency, economic efficiency and irrigation water productivity up to application of 5.0 kg Zn/ha. So based on the study it is concluded that in Bt cotton–onion cropping systems 5.0 kg Zn/ha to Bt cotton is sufficient to meet the zinc requirement of both the crop and transplanted cotton is better than direct sown cotton.

***Key words* :** Bulb yield, Cotton–onion system, Direct and residual effect, Nutrient uptake, System productivity, Zinc

In the north India, cotton is irrigated but productivity levels are still very low. Optimum time of sowing of cotton in the north is second fortnight of May. Higher ambient temperature especially of soil during sowing period of crop, results in sub-optimal plant population. In certain area, salinity also adversely affects the establishment of seedlings under high temperature and water scarcity. Rains during sowing time also results in crust formation and promote weed infestation, which may add to poor crop stand. Direct sown cotton requires 4–5 irrigation before onset of monsoon for better crop establishment and growth. It is very difficult to get optimum plant stand of the crop, despite frequent irrigation and repeated gap filling, which is the most important reason for the low yield of cotton. With frequent irrigation weed infestation increases, resulting in competition between the crop and weeds for limited resources and cost escalation due to frequent weeding. Establishment of an acceptable population of cotton seedlings is important to obtain high yields. Its contribution

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ranged from 22.0% to 32.7% towards cotton yield, while method of crop establishment helps a lot for obtaining required plant population of crops under adverse situations (Ali *et al*. 2010; Rajpoot *et al.* 2014).

Among the micronutrient, Zn is the most limiting in Indian soils and its deficiency in soil and plant resulting in deficiency of Zn in humans and animals. Notably more than 50% of the cultivated soils in India are classed as Zn-deficient. Zn is an indispensable element for healthy life of human, animals and plants. Zn aids in the synthesis of plant growth substances, enzyme systems, chlorophyll and carbohydrates, essential for promoting certain metabolic reactions and directly affects yield and quality of produce (Marschner 1997 and Cakmak *et al*., 1996). Efforts are now underway to reduce Zn deficiency in soils, which is a barrier in achieving crop yield goals and results in low Zn content in grains and straw leading to poor Zn nutrition of humans and animals, which has recently received considerable attention (Shardt *et al*., 2006). Zinc deficiency in crop production and indirectly in human beings can be ameliorated through agronomic manipulations or genetic improvement.

Cotton–wheat is a long established crop production system of north-western plains of the Indian sub-continent and this rotation occupies prestigious place in the agricultural growth of India and Pakistan, the leading wheat producing nations of the world (Mayee *et al*., 2008). In recent years, trends in agricultural production systems have changed towards achieving high profitability and resource-use efficiency and promote sustainability over time. As maturity of cotton extend up to end of November or early December, wheat sowing becomes late under some situations. Sometime in north part of India, temperature falls early in the month of November and December, resulting in delayed maturity of cotton. In such situations, late sown wheat results in low yield and forced harvesting of cotton result in yield reduction due to non-opening of bolls. In such situation, alternate crop like onion, cauliflower, cluster bean and radish are better option to maximize the profit. Of these options, cultivation of onion after cotton has been reported to record the highest productivity, profitability and resource-use efficiency. Onion has very high export potential beside local consumption. Havlin *et al*. (2010) stated that Zn, B, Mn and Mo showed high sensitivity in onion production. The normal concentration of Zn in dry matter of plant ranges from 25 to 150 mg/g. Khan *et al.* (2009) reported residual effect of Zn applied to wheat on succeeding rice crop. Abedin *et al*. (2012) observed that Zn+ B treatment produced a significant increase in yield and yield contributing parameters of onion.

However, information pertaining to Zn-management in cotton-based cropping systems and direct and residual effect of Zn on succeeding crops yield and quality are very limited and thus proposed study was undertaken to evaluate the effects of methods of cotton establishment and Zn fertilization on the productivity, profitability and quality of cotton and succeeding crop of onion.

MATERIALS AND METHODS

The field experiments were conducted across the rainy (*kharif*) and winter seasons (*rabi*) of 2013–14 and 2014–15 at the research farm of the Division of Agronomy, Indian Agricultural Research Institute, New Delhi to evaluate the effects of methods of cotton establishment and zinc fortification on the performance of cotton-based cropping systems. In this research article, the direct and residual effect of the treatments on onion and on the performance of cotton–onion system presented. The experiment site is situated at a latitude of (28°40' N, 77°12' E and 228.6 meters above the mean sea-level) north-western plain zone. The mean annual rainfall of Delhi is 672 mm and more than 80% generally occurs during the south-west monsoon season (July–September) with mean annual evaporation of 850 mm. The soil of experimental field was sandy loam with initial values of soil properties in respective season were 178 and 172 kg/ha alkaline permanganate oxidizable N, 14.5 and 13.8 kg/ha available P, 226 and 220 kg 1N ammonium acetate exchangeable K, 0.35% and 0.34% organic carbon, 7.5 and 7.6 (1:2.5 soil and water ratio) soil pH and 0.30 and 0.32 dS/m soil EC, based on the standard methods for their determination. Treatments to Bt cotton consisted of 2 methods of cotton establishment (Direct sowing of cotton at the end of May and transplanting of cotton seedlings raised in the nursery with onset of monsoon) in the main-plots and 5-levels of zinc (control, 2.5 kg Zn/ha, 5.00 kg Zn/ha, 7.5 kg Zn/ha and 2 foliar spray of 0.5% zinc sulphate at 60 and 90 days after planting) in the sub-plots in a split plot design with three replications. In the succeeding winter season, sub-plots were divided into 2 sub-sub-plots to study the residual effect of treatments given to cotton on wheat and onion. Residual effect of Zn-levels on onion and wheat was also compared with direct effect of Zn and for that foliar spray treatment of cotton was replaced with 5.0 kg Zn/ha to wheat and onion.

Direct sowing of cotton (‘SP 7007 BG II’) was done by dibbling method with a row spacing of 90 cm and plant to plant spacing of 45 cm on May 27 and 28 during 2013 and 2014, respectively. Gap filling was done twice, 7 and 12 days after first sowing. Direct sown crop received 5 and 7 irrigation during 2013 and 2014. For weed control, pre-emergence application of pendimethalin was done @ 1.0 kg/ha followed by 2 hand-weeding. For nursery raising, poly glass of 15 cm height were filled with soil and farm yard manure in the ratio of 3:1. Two seeds were sown in each poly glass on May 27 and 28 during 2013 and 2014, respectively and they were watered alternate day till their transplanting in the field. 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 July, 3 and 20 during 2013 and 2014, respectively, with the onset of monsoon. Transplanted cotton received 1 and 2 irrigation during 2013 and 2014 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, di-ammonium phosphate and muriate of potash. Zn as per treatment was given through zinc sulphate. Foliar spray of 0.5% zinc sulphate was done at 60 and 90 DAS using 400 and 600 litres water/ha respectively. Through foliar spray 6.0 kg zinc sulphate was sprayed which was equal to 1.20 kg Zn/ha. Half of N and full dose of P, K and Zn was given at the time of sowing and remaining N was given before flowering. Crop received well distributed rainfall after the onset of monsoon during 2013, while onset of monsoon was late during 2014 and there were also intermittent drought. Seed cotton was picked from the net plot at appropriate stage to avoid deterioration of produce quality and seed cotton harvested from each net plot was converted to seed cotton yield/ha.

The onion variety 'Pusa Madhuri' was sown in a raised bed nursery on November 5 during respective season after following all the recommended practices for raising the nursery. About 2 months old seedlings of onion were uprooted and transplanted to the main field during first week of January during both the seasons maintaining 10 cm × 10 cm crop geometry. Farmyard manures (10 tonnes/ha on dry weight basis) was applied 15 days before transplanting. Crop received recommended dose of N (120 kg N/ha as urea), P (60 kg P_2O_5/ha as di-ammonium phosphate) and K (40 kg K_2O/ha as muriate of potash). One-third dose of N and full dose of P and K were applied with last field operation. Remaining two-third N was given in 2 equal split after 30 and 60 days after transplanting. In the plots where foliar spay of Zn was done in cotton crop, in the same plot succeeding crop of onion received 5 kg Zn/ha through zinc sulphate hepta hydrate, to compare the direct and residual effect of Zn in the onion crop. Irrigation was given as per requirement of the crop amounting to 12 irrigations in the first season and 10 irrigations to the second season crop. For weed control pendimethalin @ 0.75 kg/ha was mixed with 10 kg fine sand and uniformly spread after transplanting. Thereafter crop received 2 hand-weeding at 20 and 40 days after transplanting for effective weed control. As a prophylactic measures, 1 spray of Monocrotophos @ 2 litre/ha was done at 60 days after transplanting of onion. Observations on growth and yield attributes were made on 5 tagged plants from the third line. Growth and yield parameters such as plant height, number of leaves/plant, leaf girth, fresh leaf weight, fresh bulb weight, total dry-matter production, equatorial diameter, polar diameter, number of scale leaf/bulb and bulb yield/ha were recorded following standard procedure. The weight of onion bulb from net plots in each treatment was weighed and weight was expressed in tonnes/ha. The total number of labour required for various agronomic practices under different cropping sequences were noted treatment-wise and area involved in each plot. Net returns and net benefit: cost ratio was worked out based on cost of cultivation and gross returns. System productivity in terms of seed cotton-equivalent yield (SCEY) was calculated as: SCEY= Seed cotton yield of cotton + [(Yield of succeeding onion crop × Price of seed onion)/Price of cotton]. Production efficiency (PE) was expressed as the ratio of system productivity in term of seed cotton equivalent yield in kg/ha to total duration of the cropping system in days. 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. The data were statistically analysed using the *F*-test as per the procedure given by Gomez and Gomez (1984). LSD values at P=0.05 were used to determine the significance difference between treatment means.

RESULTS AND DISCUSSION

Seasonal variations

Across 2-years of experimentation, weather conditions showed wide variations. The *kharif* season of the first year (2013) was wet one. Rainfall was 102% (1350 mm) higher than the average rainfall (672 mm). In contrast to this, during 2014, the onset of monsoon was late and there was also intermittent drought and rainfall was 76% of the average rainfall. These variations in rainfall resulted in more irrigation to cotton during 2014 than 2013. Crop yield was also affected due to rainfall and it was less during 2014 than 2013. In the winter (*rabi*) season trend was reverse of the rainy season and more rainfall was recorded during 2014 (316 mm) than 2013 (220 mm). The effect of abnormal rainfall during winter season of 2014 was observed on onion as well as wheat crop and productivity of both the crops was less during 2014 than 2013. Winter crop irrigation requirement was less during 2014 than 2013. This adverse effect of high rainfall during winter season may be owing to favourable condition for lodging, insect-pests, diseases and weeds infestation and also less use-efficiency of nutrients especially nitrogen.

Onion

Growth parameters

Growth attributes (plant height at harvest, LAI at 90 DAT and leaf numbers/plant at harvest) of onion were not affected due to methods of cotton establishment (Table 1). However, residual effect of 5.0 and 7.5 kg Zn/ha given to Bt cotton was significant over the control treatment. Direct effect of 5.0 kg Zn/ha on growth attributes of onion was at par with residual effect of 5.0 and 7.5 kg Zn/ha. The favorable effect of Zn on plant growth may be due to its role in many physiological processes and cellular function within plants. In addition, Zn plays an essential role in improving plant growth, through the biosynthesis of endogenous hormones, which are responsible for promotion of plant growth (Hänsch and Mendel, 2009). It is quite obvious that the experimental soil was deficient in Zn, so residual and direct effect was found favourable on the growth of onion.

Yield parameters

Similar to growth attributes, residual effect of methods of crop establishment was also not observed on yield attributes of onion during both the crop seasons (Table 2). Direct as well as residual effect of Zn was significant on the yield attributes of onion such as fresh and dry weight/bulb, equatorial/polar diameter/bulb and volume/bulb. Residual effect of 2.5 kg Zn/ha was significant only on fresh/dry weight/bulb at harvest over control, while that of 5.0 and 7.5 kg Zn it was significant on all the yield attributes except scale numbers/bulb during both seasons. Residual effect of 5.0 and 7.5 kg Zn on yield attributes was statistically similar. Direct application of 5.0 kg Zn/ha recorded the highest values of most of the yield attributes,

Table 1. Direct and residual effect of cotton establishment methods and zinc on growth parameters of onion in Bt cotton–onion crop sequence

Treatment	Plant height at maturity (cm)		LAI at 90 DAT		Leaf numbers/plant at maturity	
	2013	2014	2013	2014	2013	2014
Cotton establishment method						
Direct sowing	51.3	48.5	2.55	2.52	7.73	7.98
Transplanting	53.4	51.3	2.64	2.60	8.00	8.07
SEm±	2.02	1.6	0.085	0.063	0.20	0.24
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Zinc level (kg/ha)						
0 (To cotton)	49.2	46.8	2.47	2.41	7.33	7.43
2.5 (To cotton)	51.8	48.5	2.50	2.53	7.54	7.68
5.0 (To cotton)	53.2	51.7	2.72	2.67	7.92	8.14
7.5 (To cotton)	53.5	52.0	2.78	2.73	8.28	8.28
5.0 (To onion)	53.0	52.3	2.78	2.69	8.16	8.33
SEm±	1.2	1.12	0.066	0.062	0.18	0.21
CD (P=0.05)	3.2	3.1	0.20	0.19	0.51	0.60

Table 2. Direct and residual effect of cotton establishment methods and zinc on yield attributes of onion in Bt cotton–onion crop sequence

Treatment	Fresh weight/ bulb (g)		Dry weight/ bulb (g)		Equatorial diameter/ bulb (cm)		Volume/bulb (cm^3)		Scale numbers/bulb		Polar diameter/ bulb (cm)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Crop establishment method												
Direct sowing	61.1	51.9	7.63	6.57	5.42	4.57	67.6	57.0	9.16	7.82	4.51	3.83
Transplanting	61.8	52.5	7.72	6.56	5.52	4.71	68.0	57.2	9.18	7.84	4.66	3.93
SEm±	1.06	0.90	0.130	0.166	0.067	0.144	1.13	0.94	0.083	0.147	0.047	0.036
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc level (kg/ha)												
0 (To cotton)	56.4	47.9	7.05	5.99	5.14	4.44	61.7	55.3	8.83	7.46	4.47	3.79
2.5 (To cotton)	61.1	51.9	7.64	6.49	5.46	4.53	67.5	57.9	9.28	8.08	4.50	3.87
5.0 (To cotton)	62.2	52.9	7.77	6.80	5.57	4.64	68.9	58.6	9.39	7.93	4.67	3.89
7.5 (To cotton)	63.3	53.8	7.92	6.73	5.61	4.75	70.0	56.0	9.11	7.60	4.60	3.96
5.0 (To onion)	64.2	54.5	8.02	6.82	5.58	4.85	70.8	58.1	9.22	8.08	4.70	3.89
SEm±	0.98	0.83	0.123	0.129	0.073	0.174	1.96	1.99	0.205	0.229	0.108	0.056
CD (P=0.05)	2.9	2.5	0.37	0.39	0.22	NS	5.9	NS	NS	NS	NS	NS

however these were statistically at par with values recorded with residual effect of 5.0 and 7.5 kg Zn/ha. Direct as well as residual effect of Zn-levels was not noticed on the scale numbers/bulb. This may be due to the improved growth characters as a of result residual effect of Zn, which would have enhanced photosynthesis and other metabolic activities, which lead to increase in cell division and elongation (Hatwar, *et al*., 2003). Average volume of bulb in the main plot was non-significant in both the years. Significant differences in bulb volume were observed in all the Zn receiving treatments in the first year and in the second year it was non-significant. The scale numbers of bulb in the main plot as well as in the sub-plot observed non-significant in both the years.

Bulb yield

Bulb yield/ha was recorded about 1 tonne higher due to residual effect of transplanted cotton as compared to direct sown cotton during both the seasons, however the differences in bulb yield were not statistically significant. Residual effect of 2.5, 5.0 and 7.5 kg Zn/ha applied to cotton had a significant effect on onion bulb yield in both the season. Bulb yield increased by 4.6, 13.4 and 12.2% in 2013–14 and 9.6, 22.4 and 26.2% in 2014–15 due to residual effect of 2.5, 5.0 and 7.5 kg Zn/ha applied to cotton, respectively. Direct effect of 5.0 kg Zn/ha applied to onion was significant on the bulb yield over control and over residual effect of 2.5 kg Zn/ha. Bulb yield recorded with direct effect of 5.0 kg Zn/ha was statistical on par with the bulb yield recorded with residual effect of 5.0 and 7.5 kg Zn/ha. Increase in bulb yield due to direct effect of 5.0 kg Zn/ha was 14.0 and 29.2% over control during 2013–14 and 2014–15 respectively. This may be due to effect of Zn, which is one of the most important elements in the carbohydrates metabolism. Enzymes such as carbonic anhydrase, fructose-1,6-bisphosphate and aldolase which play important role in metabolism are activated by Zn. The activity of these enzymes decreased in zinc deficiency condition (Marschner and Cakmak, 1989). Similar finding were reported by (Abd El-Samad, *et al*., 2011; Ballabh Khashti and Rana, 2012; Manna, 2013 and Trivedi and Dhumal, 2013).

Correlation

Correlation and regression analysis revealed that bulb yield and yield attributes are highly correlated and there is a positive relationship between them (Fig. 1 and 2). Onion bulb Yield is positively correlated with equatorial diameter of bulb (R^2 =0.83 to 0.88) in both the seasons. Leaf area index at 90 DAT and fresh weight of bulb recorded slightly lower correlation with bulb yield both under residual and direct effect of Zn-levels. This may be due to the growth characters variations and yield attributes as a result of residual and direct effect of Zn.

Nutrient uptake

NPK uptake by onion bulb/ha due to residual effect of methods of cotton establishment was statistically not significant in both the seasons except N uptake in the first season. Onion after transplanted cotton had significantly higher N-uptake than after direct sown cotton (Table 3). Direct as well as residual effect of Zn levels applied to cotton was perceptible on the NPK uptake in onion bulb over control during both the crop seasons. Direct application of Zn (5.0 kg/ha) recorded maximum uptake of NPK during both the seasons, which was on par with residual

Table 3. Direct and residual effect of cotton establishment methods and zinc levels on bulb yield and economics of onion in Bt cotton–onion crop sequence

Treatment	Bulb yield (t/ha)		Gross returns (× 10³ ₹/ha)		Net returns (× 10³ ₹/ha)		Benefit: cost ratio	
	2013	2014	2013	2014	2013	2014	2013	2014
Cotton establishment method								
Direct sowing	30.90	22.90	305.8	230.6	239.8	167.1	3.64	2.63
Transplanting	31.95	24.27	323.3	233.3	257.4	169.8	3.90	2.67
SEm±	0.20	0.21	1.687	0.229	1.688	0.229	0.026	0.004
CD (P=0.05)	NS	NS	10.27	1.39	10.27	1.39	0.16	0.02
Zinc level (kg/ha)								
0 (To cotton)	28.90	20.07	289.0	200.7	223.3	137.3	3.39	2.17
2.5 (To cotton)	30.23	21.00	302.3	206.7	236.5	143.3	3.60	2.26
5.0 (To cotton)	32.77	25.58	327.7	242.7	261.9	179.4	3.98	2.83
7.5 (To cotton)	32.42	25.33	324.2	251.9	258.4	188.6	3.93	2.98
5.0 (To onion)	32.95	25.94	329.5	257.8	262.9	193.6	3.95	3.02
SEm±	0.40	0.28	4.004	3.050	4.004	3.050	0.061	0.048
CD (P=0.05)	1.20	0.84	12.00	9.14	12.00	9.14	0.18	0.14

effect of 5.00 and 7.5 kg Zn/ha but significantly superior to residual effect of 2.5 kg Zn/ha and control. On an average increase in N uptake was 3.4, 9.8 and 9.7%, in P uptake was 16.5, 28.9 and 31.6% and in K uptake was 12.9, 30.7 and 37.2% due to residual effect of 2.5, 5.0 and 7.5 kg Zn/ha over control respectively. Increase in N, P and K uptake in onion bulb/ha due to direct application of 5.0 kg Zn was 21.6, 34.7 and 38.7% over control. This increase in uptake of NPK due to direct and residual effect of Zn may be ascribed to favourable effect of Zn on growth and development of onion plants as evidenced by the data presented in Table 1 and 2 and its further effect on bulb and root system of the crop, which taped more soil surface for the uptake of nutrients. Similar priming effect of Zn application on the uptake of N, P and K was also reported by Sharma and Jain (2014) and Mauriya *et al.* (2015). The uptake of Zn in onion bulb was found significant both due to residual effect of methods of cotton establishment and Zn levels. Significantly higher zinc uptake was found in after transplanted cotton (135.7 and 101.9 g/ha) in both the years. Direct application of 5.0 kg Zn recorded highest zinc uptake (149.6 and 118.7 g/ha), which was significantly the highest from all the residual treatments. The uptake of zinc in onion bulb was recorded on par due to residual effect of 5.0 (141.1 and 110.7 g/ha) and 7.5 kg Zn/ha (140.3 and 110.9 g/ha) in both the years respectively. On an average, 17.8, 32.0 and 31.8% increase in Zn uptake was recorded due to residual effect of 2.5, 5.0 and 7.5 kg Zn/ha and 36.2% due to direct effect 5.0 kg Zn/ha. Higher removal of Zn by the crop due to direct and residual effect is closely related to increase in availability of the Zn in the soil. Chaudhary *et al.* (2014) also reported residual effect of Zn applied to greengram on the uptake of Zn both in grain and straw of wheat and they reported significant improvement with successive increase in Zn levels i.e. 0, 2.5, 5.0, 7.5 and 10.0 kg/ha.

Economics of onion

Gross and net returns and benefit cost ratio were markedly higher after transplanted cotton than direct sown in both the seasons (Table 3). Based on 2-years average, increase in gross and net returns due to residual effect of transplanted cotton was ₹11,300/ha and ₹10,150/ha, respectively. This increase in gross and net returns may be traced to variations in bulb yield of onion under residual effect of transplanted and direct sown cotton. During both the crop seasons, gross and net returns/ha depicted conspicuous differences due to residual effect of 2.5, 5.0 and 7.5 kg Zn/ha applied to cotton. On an average increase in net returns due to 2.5, 5.0 and 7.5 kg Zn/ha were ₹9,600, ₹40,350 and ₹43,200/ha over the control. Direct application 5.0 kg Zn/ha induced marked improvement in the gross, net and benefit: cost ratio during both the seasons. On an average, increase in net returns due to direct application of Zn was ₹95,900 over the control and ₹76,700 over residual effect of 2.5 kg Zn/ha respectively. Net retuns was the highest with direct application of Zn, however it was on a par statistically with the residual effect of 5.0 and 7.5 kg Zn/ha. This increase in gross returns, net returns and benefit cost ratio due to direct and residual effect of Zn may be attributed to improvement in bulb yield as given in Table 3. The favourable effects of Zn application on the economics of onion production has also been reported by Trivedi and Dhumal (2013) and Ballabh and Rana (2012).

Table 4. Direct and residual effect of cotton establishment methods and zinc levels on nutrient uptake in bulb of onion in Bt cotton–onion crop sequence

Treatment	N uptake in onion bulb (kg/ha)		P uptake in onion bulb (kg/ha)		K uptake in onion bulb (kg/ha)		Zn uptake in onion bulb (g/ha)	
	2013	2014	2013	2014	2013	2014	2013	2014
Cotton establishment method								
Direct sowing	43.7	32.9	11.7	9.1	54.5	41.2	126.0	96.8
Transplanting	46.9	33.9	12.5	9.5	58.5	42.8	135.7	101.9
SEm±	0.26	0.43	0.17	0.15	1.17	0.18	1.36	0.61
CD (P=0.05)	1.6	NS	NS	NS	NS	1.1	8.3	3.7
Zinc level (kg/ha)								
0 (To cotton)	40.0	27.4	9.5	6.7	43.1	29.2	100.6	70.7
2.5 (To cotton)	42.8	29.5	11.3	8.1	49.1	33.9	122.7	85.7
5.0 (To cotton)	47.5	36.2	12.7	10.1	58.9	45.4	141.1	110.7
7.5 (To cotton)	47.4	36.3	13.2	10.5	65.2	49.9	140.3	110.9
5.0 (To onion)	48.6	37.4	13.7	11.1	66.2	51.7	149.7	118.7
SEm±	0.76	0.65	0.36	0.25	1.31	0.48	1.94	1.84
CD (P=0.05)	2.3	1.9	1.1	0.7	3.9	1.4	5.8	5.5

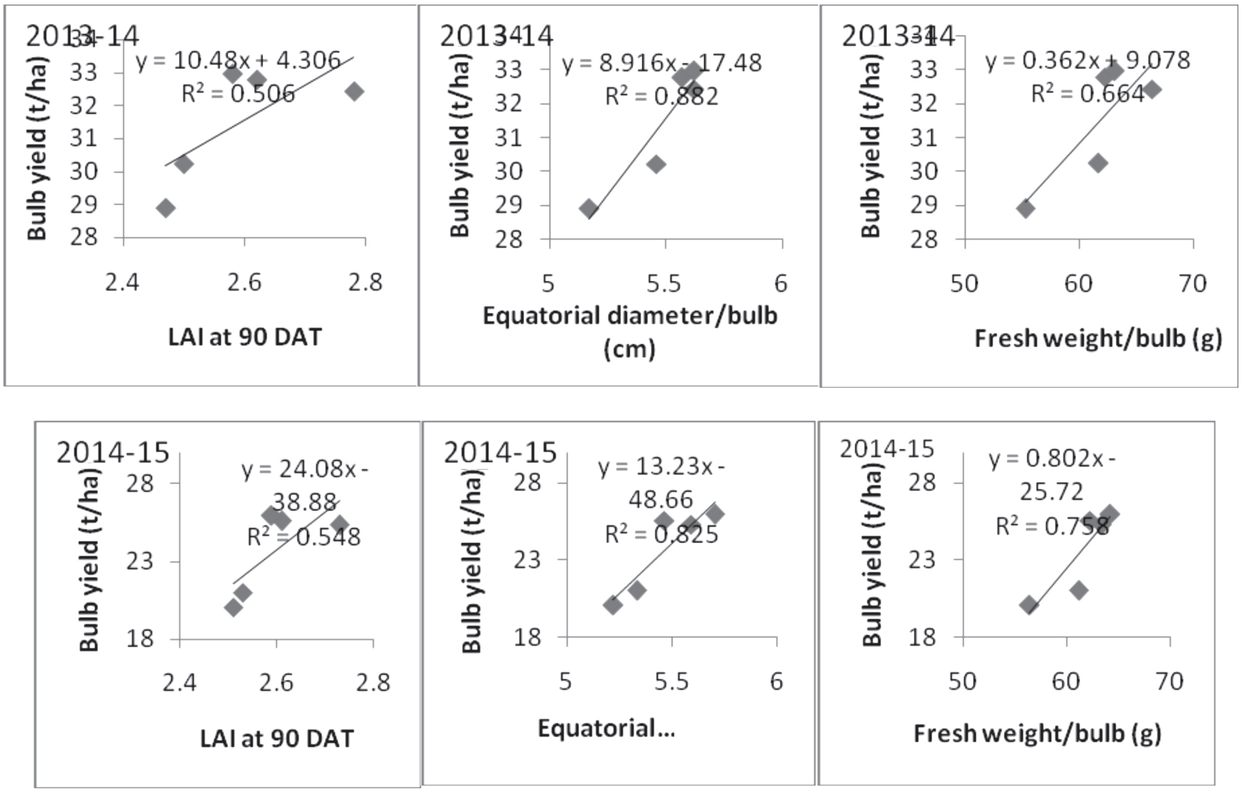

Fig. 1. Correlation and regression analysis of bulb yield and yield attributes (2013–14 and 2014–15)

Cotton–onion system

System productivity

System productivity of transplanted cotton–onion cropping system was markedly higher than direct sown cotton–onion system during both the years (Table 5). This increase in system productivity was 4.1 and 5.5% during 2013–14 and 2014–15. Both the seed cotton yield and bulb yield of onion were comparatively higher under transplanted cotton–onion system as compared to direct sown cotton–onion system, which jointly contributed for significant variation in the system productivity. Direct and residual effect of Zn levels induced marked variation in the system productivity of cotton–onion system. Successive increase in Zn-levels caused significant increase in system productivity up to 5.0 kg Zn/ha. System productivity recorded 4.9, 11.2 and 10.4% increase during 2013–14 and 4.1, 14.8 and 16.8% during 2014–15 due to direct and residual effect of 2.5, 5.0 and 7.5 kg Zn/ha over control respectively. Foliar application of Zn to cotton and direct application of 5.0 kg Zn to onion also induced perceptible increase in system productivity, which was 10.4% and 17.0% higher over control during 2013–14 and 2014–15, respectively. This behaviour of system productivity is attributed to the direct and residual effect of Zn-levels on the productivity of component of crops of the system. Similar results were also reported by Chaudhary *et al.* (2014) and Sharma and Jain (2014).

Production and economic efficiency

Production efficiency and economic efficiency of cotton–onion system were found non-significant due to methods of cotton establishment except economic efficiency during 2013–14, where transplanted cotton–onion system was superior to direct sown cotton–onion system. Direct and residual effect of Zn was also found statistically comparable on the production and economic efficiency. With successive increase in zinc-levels perceptible increase in production and economic efficiency was recorded up to 5.0 kg Zn/ha. Foliar application of Zn to cotton and direct application of Zn to onion also recorded significant increase in production and economic efficiency over control, but this treatment was on par with direct and residual effect of 5.0 and 7.5 kg Zn/ha. This behaviour of production and economic efficiency under direct and residual effect of Zn may be traced to their effect on the yield of component crops of the system. Similar effect of nutrients application including Zn were reported by Sharma and Jain (2014).

Table 5. Direct and residual effect of cotton establishment methods and zinc levels on system productivity, production efficiency, economic sufficiency and irrigation water productivity of Bt cotton–onion crop sequence

Treatment	System productivity (Seed cotton equivalent yield, t/ha)		Production efficiency (kg/ha/day)		Economic efficiency (₹/ha/day)		Irrigation water productivity (kg/m^3)	
	2013	2014	2013	2014	2013	2014	2013	2014
Cotton establishment method								
Direct sowing	10.20	8.23	29.15	23.51	800.6	609.9	0.95	0.77
Transplanting	10.62	8.27	30.33	23.64	853.7	620.1	1.26	1.06
SEm±	0.070	0.020	0.201	0.056	8.46	3.47	0.008	0.003
CD (P=0.05)	NS	NS	NS	NS	51.5	NS	0.05	0.02
Zinc level (kg/ha)								
0 (To cotton)	9.62	7.34	27.50	20.96	751.1	523.2	1.02	0.82
2.5 (To cotton)	10.12	7.65	28.91	21.85	803.4	545.7	1.08	0.85
5.0 (To cotton)	10.83	8.61	30.95	24.61	881.2	652.1	1.15	0.95
7.5 (To cotton)	10.74	8.82	30.69	25.20	852.3	676.7	1.14	0.98
5.0 (To onion)	10.74	8.84	30.67	25.26	847.9	677.4	1.14	0.98
SEm±	0.111	0.077	0.316	0.219	12.93	10.01	0.013	0.008
CD (P=0.05)	0.33	0.23	0.95	0.66	38.8	30.0	0.04	0.03

Water productivity

Transplanted cotton–onion system recorded higher irrigation water productivity during both the seasons, which may be ascribed to higher irrigation requirement of direct sown cotton as compared to transplanted cotton. Irrigation water productivity also depicted improvement due to increasing levels of Zn up to 5.0 kg Zn/ha. Statistically similar irrigation water productivity was recorded with direct and residual effect of 5.0 and 7.5 kg Zn/ha and also of foliar spray of zinc to cotton and direct application to onion.

It is concluded that transplanted cotton–onion system was more productive, profitable and resource-use efficient than direct sown cotton–onion system. Successive increase in Zn-levels caused significant increase in system productivity, production efficiency, economic efficiency and irrigation water productivity up to application of 5.0 kg Zn/ha. Residual effect of 5.0/7.5 kg Zn applied to cotton was significant on productivity and profitability of succeeding onion and it was at par with direct application of 5.0 kg Zn/ha applied to onion.

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