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Methods of Cotton (*Gossypium hirsutum*) Establishment and Direct and Residual Zinc Fertilization Effects on Productivity, Quality and Energetics of Onion (*Allium cepa*) under 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 to evaluate the methods of cotton establishment and direct and residual zinc fertilization effects on productivity, quality and energetics of onion under cotton-onion cropping system. Onion recorded higher bulb yield, bulb quality, nutrient content, energetics and economics after transplanted cotton as compared to direct sown cotton and differences were significant with transplanted cotton as compared to direct sown cotton and differences were significant with respect to economic parameters. Direct application of 5.0 kg Zn ha^{-1} and residual effect of 5.0 and 7.5 kg Zn ha^{-1} to cotton recorded statistically similar values of bulb yield, bulb quality, nutrient content, energetics and economics which were significantly superior to control and residual effect 2.5 kg Zn ha^{-1}. Bulb yield was found to increase by 4.6, 13.4 and 12.2% and 14% during 2013–14 and 9.6, 22.4 and 26.2% and 29.2% during 2014–15 due to residual effect of 2.5, 5.0 and 7.5 kg Zn ha^{-1} and direct effect of 5.0 kg Zn /ha, respectively. Transplanted plots recorded slightly higher grade 'A' bulbs as compared to direct sown plots. Direct effect of 5.0 kg Zn ha^{-1} recorded higher grade 'A' bulbs which was at par with residual effect of 5.0 and 7.5 kg Zn ha^{-1} and significantly different from control and residual effect of 2.5 kg Zn ha^{-1}. Direct application of 5.0 kg Zn ha^{-1} recorded significantly higher protein content (4.48 and 4.38), which was at par with residual effect of 5.0 kg Zn ha^{-1} (4.41 and 4.30) and 7.5 kg Zn ha^{-1} (4.44 and 4.36) in the first season and it was also at par with residual effect of 2.5 kg Zn ha^{-1} (4.28) in the second season, respectively.

Irrigation water use efficiency also increases due to increasing level of zinc fertilization. Residual effect

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of 5.0 and 7.5 kg Zn ha^{-1} recorded higher energy productivity, energy use efficiency and energy intensity. Both residual and direct effect of Zn found to enhance the quality of bulb in terms of Zn enrichment. Direct sown plots recorded slightly higher soil zinc content as compared to the transplanted plots and residual effect of 7.5 kg Zn ha^{-1} recorded higher soil zinc content than all other residual effect of treatments. Successive increase in Zn level caused significant increase in system productivity, production efficiency, economic efficiency and irrigation water productivity up to application of 5.0 kg Zn ha^{-1}. Residual effect of 5.0/7.5 kg Zn ha^{-1} applied to Bt cotton was significant on productivity and profitability of succeeding onion and it was on par with direct application of 5.0 kg Zn ha^{-1} applied to onion.

Keywords Bulb yield, DTPA extractable zinc, Energetics, Quality, Productivity.

Introduction

Onion (*Allium cepa* L.) is one of the important commercial vegetable crops grown in India both for local consumption as well as for export purposes. India ranks first in area and second in production of onion in the world after china. It is cultivated in an area of 1064 thousand ha with a production of 15118 thousand MT (NHB 2012). The average productivity of onion in India is 14.2 MT ha^{-1}, which is low as compared to other onion producing countries of the world. Onion is a biennial plant and the bulb is the vegetative storage organ of the plant. The most important character of onion is its flavor which increases the taste of food and is widely used to increase taste of different types of food like curry, soups, fried fish and meat. Only four plant nutrients viz. N, P, K and S commonly used by the farmers of India. The importance of the use of micronutrients is mostly ignored, although they can be a chief limiting factor for crop production. Havlin et al. (2010) stated that Zn, B, Mn and Mo showed high sensitivity in onion production.

Among the micronutrient, zinc 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. Zinc is an indispensable element for healthy life of humans, animals and plants. Zinc deficiency in crop production and indirectly in human beings can be ameliorated through agronomic manipulations or genetic improvement.

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. Sometimes in northern part of India, temperature falls early in the month of November and December, resulting in delayed maturity of cotton. In such situations, delayed sowing wheat results in low yield and forced harvesting of cotton result in yield reduction due non-opening of bolls. In such situation, alternate crop like onion is better option to maximize the profit. Abedin et al. (2012) observed that the 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 methods of cotton establishment and direct and residual zinc fertilization effects on productivity, quality and energetics of onion under cotton-onion cropping system.

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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 methods of cotton establishment and direct and residual zinc fertilization effects on productivity, quality and energetics of onion under cotton-onion cropping system. The experiment site is situated at latitude of 28°40′ N and longitude of 77°12′ E and an altitude of 228.6 meters above the

Table 1. Methods of cotton establishment and direct and residual zinc fertilization effects on yield, quality parameters and irrigation water use efficiency of onion.

Treatments	'A' grade (61-above g) (t/ha)		'B' grade (41-60 g) (t/ha)		'C' grade (20-40 g)(t/ha)		Bulb yield (t/ha)		Protein content (%)		Irrigation WUE (kg/ha-mm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013 -14	2014 -15	2013 -14	2014 -15
Crop establishment method												
Direct sowing	14.19	12.69	9.48	5.95	7.32	4.62	30.58	23.25	7.13	7.05	39.7	35.8
Transplanting	14.67	13.36	10.16	5.53	7.56	4.85	32.33	23.92	7.24	7.07	42.0	36.8
SEm ±	0.16	0.17	0.50	0.31	0.17	0.25	0.17	0.17	0.02	0.04	0.22	0.27
CD=(p=0.05)	NS	NS	NS	NS	NS	NS	1.03	NS	NS	NS	1.3	NS
Zinc level (kg/ha)												
0.0	13.01	10.03	9.66	5.38	6.82	4.68	28.90	20.07	6.91	6.82	37.5	30.9
2.5 (cotton)	14.77	11.57	9.31	4.35	6.30	4.60	30.23	21.00	7.08	7.03	39.3	32.3
5.0 (cotton)	14.85	14.51	10.22	6.50	7.78	4.60	32.77	25.58	7.25	7.07	42.6	39.4
7.5 (cotton)	14.65	14.68	9.88	5.85	8.13	4.80	32.42	25.33	7.31	7.17	42.1	39.0
0.5% Zn foliar spray to cotton/5.0 Zn/ha to onion	14.89	14.33	10.03	6.63	8.15	4.98	32.95	25.94	7.38	7.21	42.8	39.9
SEm ±	0.53	0.27	0.53	0.30	0.31	0.30	0.40	0.28	0.06	0.09	0.52	0.43
CD (p=0.05)	1.59	0.82	NS	0.88	0.94	0.91	1.20	0.84	0.18	0.27	1.6	1.3

mean sea level (Arabian Sea) of 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 in respective season of 178 and 172 kg ha^{-1} alkaline permanganate oxidizable N, 14.5 and 13.8 kg ha^{-1} available P, 226 and 220 kg 1 N 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 dSm^{-1} soil EC. Ten treatment combinations 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 on the onset of monsoon) in the main-plots and 5 levels of zinc (control, 2.5 kg Zn ha^{-1}, 5.00 kg Zn ha^{-1} , 7.5 kg Zn ha^{-1} and two foliar spray of 0.5% zinc sulfate at 60 and 90 days after planting) in the sub-plots of 3 time replicated split plot design. In the succeeding winter season, sub-plots were divided into 2 sub-plots to study the residual effect of treatments on wheat and onion. Residual effect of Zn levels on wheat and onion was also compared with direct effect of Zn and for that foliar spray treatment of cotton was replaced with 5.0 kg Zn ha^{-1} to onion.

The onion variety 'Pusa Madhuri' was sown in a raised bed nursery on 5th November during respective season after following all the recommended practices for raising the nursery. About two 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^{-1} (dry weight basis) was applied 15 days before transplanting of seedlings. Crop received recommended dose of nitrogen (120 kg N ha^{-1}) as urea, phosphorus (60 kg P_2O_5 ha^{-1}) as di-ammonium phosphate and potassium (40 kg K_2O ha^{-1}) 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 two equal split after 30 and 60 days after transplanting. The plot receiving 0.5% foliar spray of Zn in cotton crop, replaced by soil application of 5.0 kg Zn ha^{-1} through zinc sulfate hepta hydrate, to compare the direct and residual effect of Zn in the onion crop. Irrigation water was provided at weekly intervals requiring 12 irrigations to the first season crop and 10 irrigations to 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 two hands weeding at 20 and 40

Table 2. Methods of cotton establishment and direct and residual zinc fertilization effects on NPK and Zn cotton of onion.

Treatments	N content in onion bulb (%)		P content in onion bulb (%)		K content in onion bulb (%)		Zn content in onion leaf (ppm)		Zn content in onion bulb (ppm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Crop establishment method										
Direct sowing	1.14	1.13	0.31	0.31	1.42	1.40	17.29	17.37	32.85	33.01
Transplanting	1.16	1.13	0.31	0.31	1.44	1.42	17.59	17.79	33.43	33.81
SEm ±	0.004	0.006	0.006	0.004	0.022	0.011	0.118	0.011	0.224	0.022
CD=(p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.13
Zinc level (kg/ha)										
0.0	1.11	1.09	0.26	0.27	1.19	1.17	14.66	14.83	27.85	28.18
2.5 (cotton)	1.13	1.13	0.30	0.31	1.30	1.29	17.08	17.18	32.45	32.63
5.0 (cotton)	1.16	1.13	0.31	0.32	1.43	1.42	18.11	18.21	34.42	34.60
7.5 (cotton)	1.17	1.15	0.33	0.33	1.61	1.58	18.24	18.43	34.65	35.02
0.5% Zn foliar spray to cotton/5.0 kg Zn/ha to onion	1.18	1.15	0.33	0.34	1.61	1.59	19.12	19.26	36.33	36.60
SEm ±	0.010	0.015	0.007	0.008	0.025	0.009	0.260	0.163	0.494	0.311
CD (p=0.05)	0.03	0.04	0.02	0.02	0.07	0.03	0.78	0.49	1.48	0.93

days after transplanting for effective weed control. As a prophylactic measures, 1 spray of Monocrotophos @ 2 l/ha was done at the time of flowering 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 per plant, leaf girth, fresh leaf weight, fresh bulb weight, total dry matter production, equatorial diameter, polar diameter, number of scale leaf per bulb and bulb yield per hectare 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 labor required for various agronomic practices under cropping sequence was noted treatment-wise and area involved in each plot. Net returns and net benefit : Cost was worked out based on cost of cultivation and gross returns. The energetics of treatments was also calculated. The data were statistically analyzed using the F-test as per the standard procedure. LSD values at p=0.05 were used to determine the significance difference between treatment means.

Results and Discussion

Seasonal variation

Across the two years of experimentation, weather conditions showed wide variations. During 2013, rainy seasons were wet and rainfall was 102% (1350 mm) higher than the average rainfall (672 mm). In contrast to this, during the rainy season of 2014, the onset of monsoon was late and there was also intermittent drought and rainfall was just 76% of the average rainfall. These variations in the 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 season trend was reverse that of rainy season and more rainfall was recorded during 2014 (316 mm) than 2013 (220 mm). The effect 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 favorable condition for lodging, insect-pests, diseases and weeds infestation and also less use-efficiency of nutrients especially nitrogen.

Bulb yield

Data pertaining to bulb yield of onion due to methods of cotton establishment and zinc levels were presented in Table 1. Bulb yield/ha was recorded about one tonne higher due to residual effect of trans-

Table 3. Methods of cotton establishment and direct and residual zinc fertilization effects on energetics of onion.

Treatments	Energy input (× 10^3 MJ/ha)		Total energy output (× 10^3 MJ/ha)		Energy return or energy balance (× 10^3 MJ/ha)		Energy productivity (kg/MJ)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Crop establishment method								
Direct sowing	22.9	21.65	48.9	36.9	26.0	15.24	1.33	1.06
Transplanting	22.9	21.65	51.7	37.3	28.8	15.68	1.41	1.08
SEm ±	–	–	0.27	0.04	0.27	0.037	0.007	0.001
CD= (p=0.05)	–	–	1.64	0.22	1.64	0.22	0.05	0.01
Zinc level (kg/ha)								
0.0	22.8	21.55	46.2	32.1	23.4	10.56	1.27	0.93
2.5 (cotton)	22.8	21.55	48.4	33.1	25.5	11.52	1.32	0.96
5.0 (cotton)	22.8	21.55	52.4	38.8	29.6	17.29	1.44	1.13
7.5 (cotton)	22.8	21.55	51.9	40.3	29.0	18.76	1.42	1.17
0.5% Zn foliar spray to cotton/5.0 kg Zn/ha to onion	23.4	22.07	52.7	41.2	29.4	19.17	1.41	1.17
SEm ±	–	–	0.64	0.49	0.64	0.488	0.017	0.014
CD (p=0.05)	–	–	1.92	1.46	1.92	1.46	0.05	0.04

Table 3. Continued.

Treatments	Energy use efficiency		Energy intensity (×10^3 MJ/Rs)		Specific energy	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Crop establishment method						
Direct sowing	2.13	1.70	0.74	0.58	0.75	0.95
Transplanting	2.25	1.72	0.78	0.59	0.71	0.94
SEm ±	0.012	0.002	0.004	0.001	0.003	0.004
CD=(p=0.05)	0.07	0.01	0.03	0.00	0.02	0.03
Zinc level (kg/ha)						
0.0	2.03	1.49	0.70	0.51	0.79	1.08
2.5 (cotton)	2.12	1.53	0.74	0.52	0.76	1.04
5.0 (cotton)	2.30	1.80	0.80	0.61	0.70	0.89
7.5 (cotton)	2.27	1.87	0.79	0.64	0.71	0.86
5.0% Zn foliar spray to cotton/5.0 kg Zn/ha to cotton	2.26	1.87	0.79	0.64	0.71	0.86
SEm ±	0.028	0.022	0.010	0.008	0.009	0.013
CD (p=0.05)	0.08	0.07	0.03	0.02	0.03	0.04

planted 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^{-1} applied to cotton was significant on the bulb yield of onion during both the season. Bulb yield was found to increase by 4.6, 13.4 and 12.2% during 2013-14 and 9.6, 22.4 and 26.2% during 2014-15 due to residual effect of 2.5, 5.0 and 7.5 kg Zn ha^{-1} applied to cotton, respectively. Direct effect of 5.0 kg Zn ha^{-1} applied to onion was significant on the bulb yield over control and over residual effect of 2.5 kg Zn ha^{-1}. Bulb yield recorded with direct effect of 5.0 kg Zn ha^{-1} was statistical on par with the bulb yield recorded with residual effect of 5.0 and 7.5 kg Zn ha^{-1},. Increase in bulb yield due to direct effect of 5.0 kg Zn ha^{-1} was 14.0 and 29.2% over control during 2013-14 and 2014-15 respectively. Similar result was also recorded by Thenmozhi and Duraisamy (2014).

Quality parameter

a) Grading of bulbs

The grading of bulbs due to methods of cotton es-

Table 4. Methods of cotton establishment and direct and residual zinc fertilization effects on NPK and zinc status of soil at harvest of onion.

Treatments	Available N in soil (kg/ha)		Available P in soil (kg/ha)		Exchangeable K in soil (kg/ha)		DTPA extractable Zn in soil (ppm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Crop establishment method								
Direct sowing	181.5	178.5	14.0	14.6	279.5	278.1	0.826	0.814
Transplanting	178.5	175.6	14.0	14.7	277.0	275.1	0.817	0.803
SEm ±	1.57	2.58	0.10	0.15	0.83	0.57	0.002	0.003
CD= (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Zinc level (kg/ha)								
0.0	187.1	185.0	14.2	15.3	284.8	283.2	0.673	0.674
2.5 (cotton)	176.7	173.5	13.9	14.5	280.5	278.3	0.842	0.826
5.0 (cotton)	176.7	173.5	13.9	14.3	275.6	274.2	0.855	0.846
7.5 (cotton)	180.8	177.7	14.1	14.5	275.2	273.4	0.866	0.843
0.5% Zn foliar spray to cotton/5.0 kg Zn/ha to onion	178.8	175.6	13.9	14.7	275.0	273.8	0.872	0.853
SEm ±	5.88	4.95	0.22	0.14	2.32	1.60	0.008	0.012
CD (p=0.05)	NS	NS	NS	NS	6.96	4.8	0.02	0.04

tablishment was found non-significant in both the season (Table 1). Transplanted plots recorded slightly higher grade 'A' bulbs as compared to direct sown plots during both the seasons. Residual effect of 5.0 and 7.5 kg Zn ha^{-1} applied to cotton recorded higher grade 'A' bulbs which were on par during both the seasons. Direct effect of 5.0 kg Zn ha^{-1} recorded higher grade 'A' bulbs which was at par with residual effect of 5.0 and 7.5 kg Zn ha^{-1} and significantly different from control and residual effect of 2.5 kg Z n ha^{-1} during both the seasons. Direct effect of 5.0 kg Zn ha^{-1} also recorded higher grade 'B' and grade 'C' bulbs during both the seasons, respectively. Similar result was also recorded by Khan et al. (2007).

b) Protein content

The protein percentage in bulb due to methods of cotton establishment was found non-significant in both the seasons (Table 1). Direct application of 5.0 kg Zn ha^{-1} recorded significantly higher protein content (4.48 and 4.38), which was at par with residual effect of 5.0 kg Zn ha^{-1} (4.41 and 4.30) and 7.5 kg Zn ha^{-1} (4.44 and 4.36) in the first season and it was also at par with residual effect of 2.5 kg Zn ha^{-1} (4.28) in the second season, respectively. Similar result was also recorded by Sankar et al. (2009).

Irrigation water use efficiency

Irrigation water use efficiency was recorded significant after transplanted and direct sown cotton in both the seasons except in 2014-15 (Table 1). Irrigation water use efficiency also depicted improvement due to increasing level of zinc up to 5.0 kg Zn ha^{-1} statistically similar irrigation water use efficiency was recorded with direct and residual effect of 5.0 and 7.5 kg Zn ha^{-1} during both the seasons. Higher irrigation water use efficiency was recorded in 2013-14 as compared to the 2014-15, respectively. Similar result was also recorded by Kumar et al. (2007).

NPK and Zn content of onion

Nutrient content (nitrogen, phosphorus, potassium and zinc) in bulb was found non-significant in both direct sown and transplanted plots during both the season except zinc content in second season (Table 2). Residual effect of 5.0 and 7.5 kg Zn ha^{-1} recorded slightly higher in nutrient content compared to 2.5 kg Zn ha^{-1} and control. Direct effect of 5.0 kg Zn ha^{-1} recorded higher nitrogen content which was significantly different from control and residual effrct of 2.5 kg Zn ha^{-1} during both the season. Zinc content in onion leaf was recorded non-significant due to methods of cotton establishment and significant due to

zinc levels during both the seasons. Zinc content in bulb was found non-significant due to residual effect of methodsof cotton establishment in both the season. Transplanted plots cotton during both the seasons. Direct application of 5.0 kg Zn ha^{-1} recorded highest zinc content (36.47 and 36.18 mg kg^{-1}), which was on par with residual effect of 5.0 and 7.5 kg Zn ha^{-1} during 2013-14 and 7.5 kg Zn ha^{-1} during 2014-15, respectively. Similar result was also recorded by Thenmozhi and Duraisamy (2014), Haque et al. (2014).

Energetics

Data pertaining to the energetics of onion due to methods of cotton establishment and zinc levels were presented in the Table 3. Energetics of onion such as energy output, energy balance, energy productivity and energy use efficiency was found significant during both the seasons due to effect of cotton establishment methods, whereas, energy intensity and specific energy recorded significant during 2013-14 and non-significant during 2014-15 respectively. During both the crop seasons, energy output and energy balance depicted conspicuous differences due to residual effect of 2.5, 5.0 and 7.5 kg Zn ha^{-1} applied to cotton crop. Residual effect of 5.0 and 7.5 kg Zn ha^{-1} recorded higher energy productivity, energy use efficiency and energy intensity which were statistically on par during both the seasons. Direct application 5.0 kg Zn ha^{-1} recorded higher energy productivity, energy use efficiency and energy intensity which were significantly different from residual effect of 2.5 kg Zn ha^{-1} and control. The higher specific energy was recorded with control as compared to the all residual effect of zinc application applied to cotton and direct effect of 5.0 kg Zn ha^{-1} applied to onion during both the seasons.

NPK and DTPA extractable zinc in soil

Nutrient status (nitrogen, phosphorus, potassium) in soil was non-significant except potassium which was significant due to effect of zinc levels in both the seasons (Table 4). Effect of methods of cotton establishment recorded non- significant in DTPA extractable zinc in soil in both the seasons. Direct sown plots recorded slightly higher soil zinc content as compared to the transplanted plots during both the seasons. Residual effect of 7.5 kg Zn ha^{-1} recorded higher soil zinc content than all other residual effect of treatments applied to cotton in both the seasons. Direct effect of 5.0 kg Zn ha^{-1} recorded significantly higher zinc content in soil which was significantly different from all other treatments. Similar results was also recorded by Thenmozhi and Duraisamy (2014).

It is concluded that successive increase in Zn level caused significant increase in onion productivity, irrigation water use efficiency and energetics up to application of 5.0 kg Zn ha^{-1}. Residual effect of 5.0/ 7.5 kg Zn ha^{-1} applied to Bt cotton was significant on productivity of succeeding onion and it was on par with direct application of 5.0 kg Zn ha^{-1} applied to onion.

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