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Zinc dynamics and yield sustainability in relation to Zn application under cotton crop on Typic Haplusterts

SS Hadole, PA Sarap, MD Sarode, Kritika Soni and SD Nandurkar

Abstract
Globally, widespread micronutrient deficiencies have become a serious challenge for sustaining crop production systems and food security of all micronutrients; zinc (Zn) is the most deficient one. Hence, efficient Zn management is essential to achieve potential crop yields. A four-year field experiment was conducted on Typic Haplusterts with Cotton crop to study the direct and residual Zn management effect on Cotton crop. The effect on soil available Zn was also evaluated. Three Zn application frequencies, *viz*. once (single year), alternate (every alternate year), and continuous (every year) at four Zn application rates, *viz*. 2.5, 5.0, 7.5, and 10.0 kg ha^{-1} along with one control (no Zn) were investigated from 2013 to 2019. The Zn application significantly improved the crop yields, system sustainability, DTPA-Zn, and different Zn pools without causing any environmental risk. In general, the alternate year application of Zn at 7.5 kg ha^{-1} produced the maximum number of bolls, boll weight, maximum yield and system productivity. Similarly, the maximum macro and micronutrients uptake was also observed with alternate year application of Zn at 7.5 kg ha^{-1}.

Keywords: Zinc dynamics, yield, cotton crop, Typic Haplusterts

Introduction

Cotton (*Gossypium hirsutum* L.) is an industrial crop which has an important place in the world agriculture and trade. India got 1st place in the world in cotton acreage with 120.69 Lakh Hectares area under cotton cultivation i.e. around 36% of world area of 333 Lakh Hectares. Around 67% of India's cotton is grown on rain-fed areas and 33% on irrigated area. In terms of productivity, India is on 38th rank with yield of 510 kg ha^{-1}. Both plant growth and yield are negatively affected by deficiency of nutrient elements and lint quality is decreased as well. Among macro nutrient elements, cotton plant utilizes calcium (Ca) mostly followed by nitrogen (N) and potassium (K). Besides these elements, cotton plant needs zinc (Zn) which is a micro nutrient element and it can be sensitive in case of deficiency (Kacar and Katkat, 2007) [14]. Zinc is an indispensable element for healthy life of humans, animals and plants. It has important functions in protein and carbohydrate metabolism of plants. Furthermore, zinc is an element which directly affect yield and quality because of its function such as its activity in biological membrane stability, enzyme activation ability and auxin synthesis (Marschner, 1997; Oktay *et al.*, 1998) [40, 41].

Deficiencies of Zn are usually associated with concentrations of less than 20 ppm, and toxicities will occur when the Zn leaf concentration exceeds 400 ppm. Cultivars differ in their ability to take up Zn, which may be caused by differences in zinc translocation and utilization, differential accumulation of nutrients that interact with Zn and differences in plant roots to exploit for soil Zn [Tisdale *et al*., 1993] [35]. Higher crop yields naturally have higher demands of nutrients and more pressure on the soil for available forms of nutrients. As cropping intensity and yield levels go up, the uptake and removal of plant nutrients through harvested crop and other routes from the soil are likely to increase. The available zinc content of several soil samples collected from different district of Bangladesh varied from extremely deficient to fairly adequate level. The present study is to evaluate the nutrient content of postharvest soil may be effective or not and the actual status of the soil after application of the zinc fertilization.

Review of Literature

Plant tissue analyses are performed to access plant nutrient status and to determine the fertiliser requirement of the current and future crop grown in the field.

Application of zinc fertiliser may increase or decrease levels of other nutrient in the crop plant. Field experiment was conducted to study the zinc dynamics with four rates of Zn fertilization on nutrient concentrations in leaf tissue of cotton plants at different growth stages. Zn is present in the soil in a number of discrete chemical forms, the deficiency in their solubility and availability to plant, depends mostly upon the amount of zinc present in the water soluble, exchangeable and organic fractions of the soil (Choudhary *et al.* 1994) [7]. Soluble forms of zinc are readily available to plants and the uptake of zinc has been reported to be linear with concentration in the nutrient solution or soil [Choudhary *et al.* 1994] [7].

We explored comparative effects of two readily available namely $ZnSO_4$ and Zn DTPA and their dynamics and their effect on the yield suitability.

Aim of study

To study the Zn dynamics and yield sustainability by applying different rates of zinc in cotton crop on typic Haplusterts.

Materials and Methods

Site Description

The four year long study was conducted during 2013-2015-2017-2019 at the experimental farm of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India. The experimental site is characterized by semiarid climate with annual average temperature 28 °C and mean precipitation of 650 mm. Nearly 85% of annual precipitation is received during.

Experimental Details

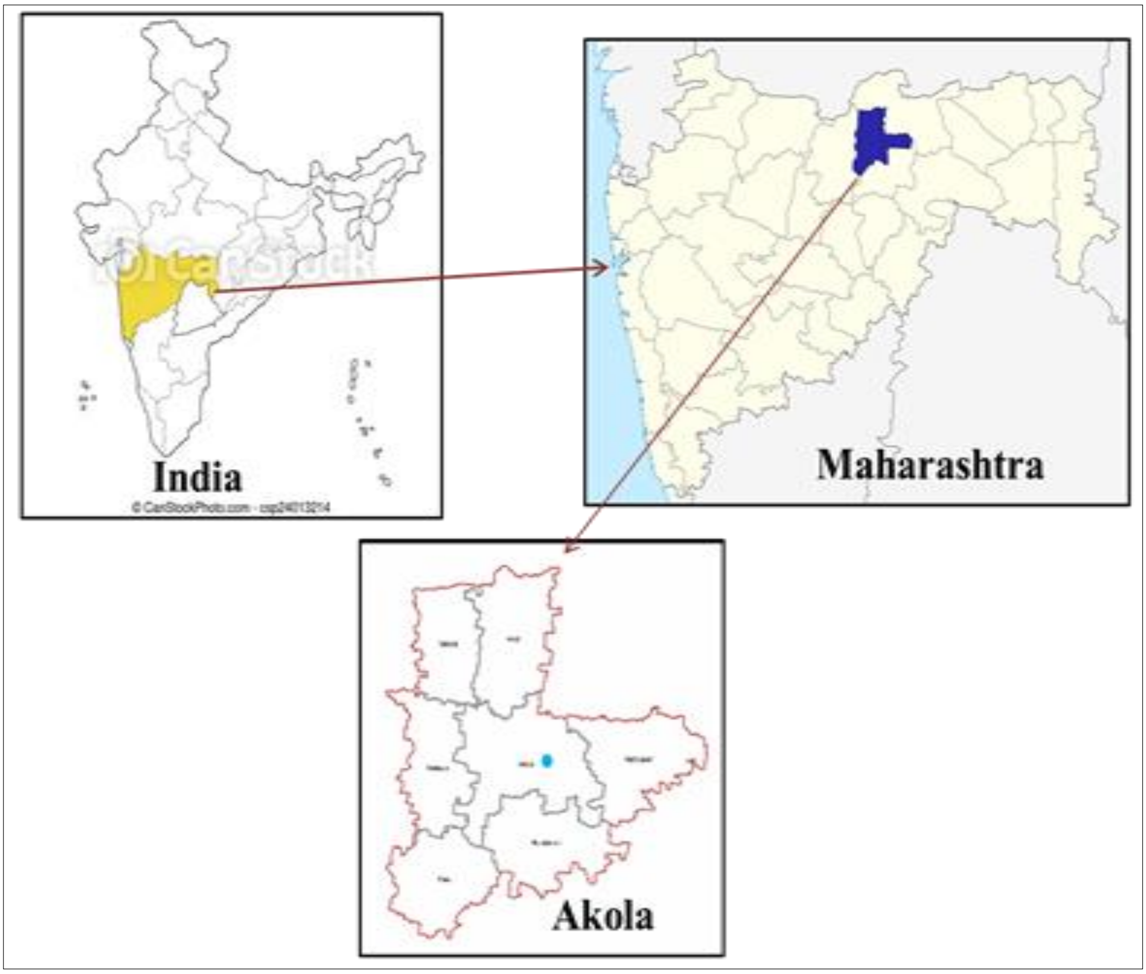

Fig 1: Show the map of India state of Maharashtra Akola

The field experiment was conducted at Research farm of Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during kharif season. Initial composite soil sample was collected from experimental site and analyzed for soil properties. The experimental site was slightly alkaline in reaction (8.26), non-saline (0.29dS m^{-1}), medium in organic carbon (5.30 g kg^{-1}), calcareous in nature (8.13%), low in available N (216.2 kg ha^{-1}), low in available P (14.17kg ha^{-1}), very high in available K (346.2 kg ha^{-1}), deficient in available S (9.83 mg kg^{-1}) and sufficient in DTPA - Fe, Cu, Mn and deficient in Zn (mg kg^{-1}).The zinc deficient site was selected and the experiment was laid as per schedule. The cotton crop was sown as per recommended practices. The zinc was applied as per treatment in the first year, alternate year and every year. In addition, xero-Zn control was also set up in three replicated plots. The same amount of nitrogen (N), phosphorous (P) and potassium (K) fertilizers were applied a per the recommended rates for cotton in all experimental plots. The recommended rates of, P2O5 and K2O for cotton are 120, 60, 60, respectively. All P and K and half of N were applied as basal at the time of sowing of cotton. The remaining of N was top dressed in two equal doses. A basal application of Zn was made through $ZnSO_4 7H_2O$ (Zn 21%) at 2.5, 5.0, 7.5, 10.0 kg Zn ha^{-1}. The Zn was broadcast into Plots and incorporated into soil with ploughing at the time of sowing.

Table 1: Treatment Details

Table	Treatment Details	
Treatment No	Rate of Zn Application to Cotton Crop (Kg Zn ha^{-1})	Frequency of Zn Application to Cotton Crop
T_1	Zn_0 -0.0	Once in Six Year
T_2	Zn_1-2.5	
T_3	Zn_2-5.0	
T_4	Zn_3-10.0	
T_5	Zn_0 -0.0	Alternate Year of Zinc Application
T_6	Zn_1-2.5	
T_7	Zn_2-5.0	
T_8	Zn_3-10.0	
T_9	Zn_0 -0.0	Every Year of Zinc Application
T_{10}	Zn_1-2.5	
T_{11}	Zn_2-5.0	
T_{12}	Zn_3-10.0	
T_{13}	Zn_0 -0.0	No Zinc Applied

The crop was harvested and collected for analysis. The treatment wise soil samples were collected for analysis. The samples were air dried and then oven dried at 64 °C. The treatment wise samples were ground by using grinding mill and stored with proper labelling in brown paper bags. The powered samples were used for the analysis of N, P, K, S and micronutrients. Di-acid digested samples were use for estimation of nitrogen content by using micro Kjeldahl's method (Jackson, 1973) [13], phosphorous by Vanadomolybdate (Jackson, 1973) [13], potassium by using Flame Photometer (Jackson, 1973) [13], sulphur was estimated from di-acid extract turbid metrically using Spectrophotometer (Chesnin and Yien, 1951) [6] and micronutrinets by using AAS (Issac and Kerber, 1971) [11].

The test of statistically significance of the experimental data was carried out as per procedure described by Panse and Sukhatme (1985) [25].

Results

Effect of zinc fertilization on yield

The data pertaining to seed cotton and stalk yield as influenced by various treatments are presented in Table 2. It was found that significantly highest seed cotton yield (12.05 q ha^{-1}) was recorded with 7.5 kg Zn ha^{-1} soil application in alternate year, whereas this was found at par with soil application of 7.5 kg Zn ha^{-1} every year, 10 kg of Zn ha^{-1} of alternate year of application. However lowest seed cotton yield was observed with treatment T_{13} i.e. control.

Table 2: Yield of seed cotton, cotton stalk, number of bolls and boll weight of cotton as influenced by various treatments (Pooled mean)

Treatments	Seed Cotton yield (q ha^{-1})	Stalk yield (q ha^{-1})	Number of bolls	Boll weight (g)
T_1 – 2.5 kg Zn ha^{-1}	10.26	18.83	27.87	3.48
T_2 – 5.0 kg Zn ha^{-1}	10.66	19.81	30.46	3.75
T_3 – 7.5 kg Zn ha^{-1}	11.10	20.44	31.67	4.19
T_4 –10.0 kg Zn ha^{-1}	10.75	20.57	33.57	3.85
T_5 – 2.5 kg Zn ha^{-1}	10.40	19.29	28.43	3.62
T_6 – 5.0 kg Zn ha^{-1}	10.83	20.07	31.53	4.01
T_7 – 7.5 kg Zn ha^{-1}	12.05	22.67	35.60	4.38
T_8 –10.0 kg Zn ha^{-1}	11.27	21.01	35.09	4.12
T_9 – 2.5 kg Zn ha^{-1}	10.60	19.27	30.24	3.78
T_{10} – 5.0 kg Zn ha^{-1}	10.90	20.41	31.38	3.94
T_{11} – 7.5 kg Zn ha^{-1}	11.61	22.44	35.17	4.28
T_{12} – 10.0 kg Zn ha^{-1}	10.86	20.86	34.66	4.06
T_{13} – Control	9.73	17.57	21.16	3.40
S.E.(m) +	0.15	0.37	0.32	0.03
CD at 5%	0.44	1.06	0.91	0.08

Stalk yield was also significantly improved with application of Zn. Data presented in Table 2. Indicated that significantly maximum stalk yield was found with alternate year soil application of 7.5 kg Zn ha$_{-1}$, which was at par with every year soil application of 7.5 kg of Zn ha-1.However lowest seed cotton yield was observed with treatment T13 i.e. control.

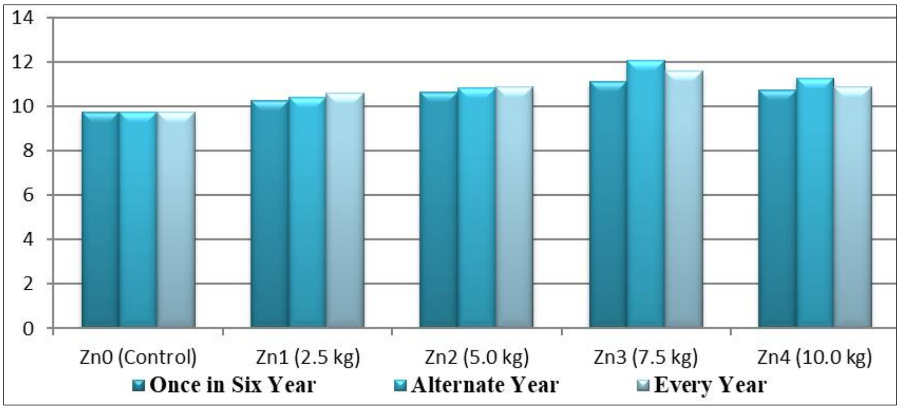

Fig 2a: Effect of frequency and levels of zinc application on seed cotton yield

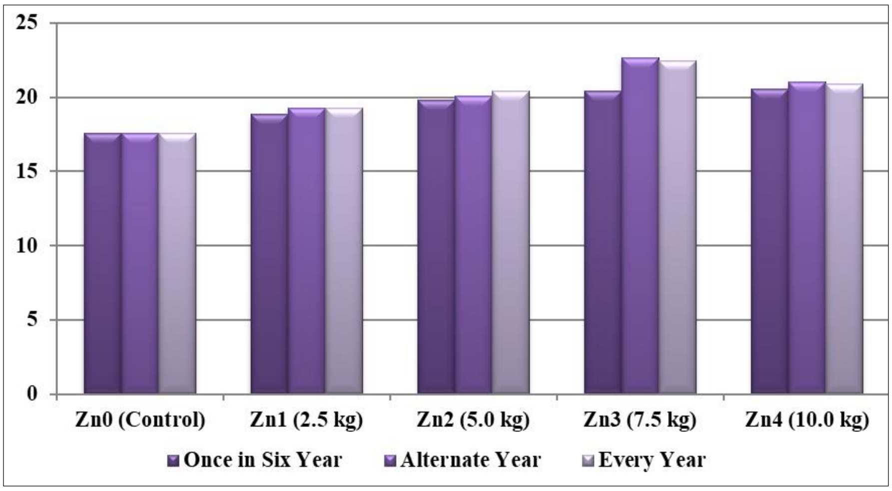

Fig 2b: Effect of frequency and levels of zinc application on stalk yield of cotton

In interaction effect alternate year soil application of7.5 kg Zn ha^{-1}was found significantly higher as compare to other treatments.

Number of bolls per plants was also Significantly Improved with Application of Zn. Significantly highest number bolls per plant (35.60) was recorded with the application of 7.5 kg Zn ha^{-1} (T_7) which was found at par with treatment T_{11} (7.5 kg Zn ha^{-1}) every year and T_8 (10 kg Zn ha^{-1}) at alternate year application. The effect of zinc levels was found to be significant in respect of number of bolls (Table 2). However maximum boll weight was observed with treatments T_7 with application of 7.5 kg Zn ha $^{-1}$.

Effect of zinc fertilization on macronutrient uptake

Significant improvement in NPK and S uptake was observed with soil application of Zn. Data presented in Table 5. indicated that highest Nitrogen and Phosphorous uptake was observed with treatments of alternate year soil application of 7.5 kg of Zn ha^{-1} and found at par with 7.5 kg of Zn ha^{-1} of every year application. Similarly data pertaining in Table 6 represented indicated that Potassium and Sulphur uptake (45.97 kg ha^{-1},8.72 kg ha^{-1}) was found maximum with treatment T_7 i.e. alternate year soil application of 7.5 kg Zn ha^{-1} (45.34 kg ha^{-1},8.24 kg ha^{-1}) and 10 kg Zn ha $^{-1}$ of every year application.

Table 3: Total N and P uptake after harvest cotton as influenced by various treatments (Pooled mean)

Treatments	Nitrogen (kg ha^{-1})	Phosphorous (kg ha^{-1})	Potassium (kg ha^{-1})	Sulphur (kg ha $^{-1}$)
T_1 – 2.5 kg Zn ha^{-1}	34.56	6.77	36.79	5.42
T_2 – 5.0 kg Zn ha^{-1}	37.11	7.69	38.93	6.17
T_3 – 7.5 kg Zn ha^{-1}	39.23	8.68	40.98	6.96
T_4 –10.0 kg Zn ha^{-1}	39.52	9.10	41.22	7.20
T_5 – 2.5 kg Zn ha^{-1}	36.74	7.37	37.93	6.13
T_6 – 5.0 kg Zn ha^{-1}	39.24	8.43	40.30	7.09
T_7 – 7.5 kg Zn ha^{-1}	45.44	10.46	45.97	8.72
T_8 –10.0 kg Zn ha^{-1}	42.91	9.96	43.32	8.24
T_9 – 2.5 kg Zn ha^{-1}	37.82	8.22	38.89	6.33
T_{10} – 5.0 kg Zn ha^{-1}	40.45	9.06	41.44	7.24
T_{11} – 7.5 kg Zn ha^{-1}	45.13	10.44	45.34	8.56
T_{12} – 10.0 kg Zn ha^{-1}	42.61	9.73	42.73	8.28
T_{13} – Control	30.87	6.15	33.52	4.21
S.E.(m) +	0.76	0.33	0.59	0.17
CD at 5%	2.18	0.94	1.70	0.49

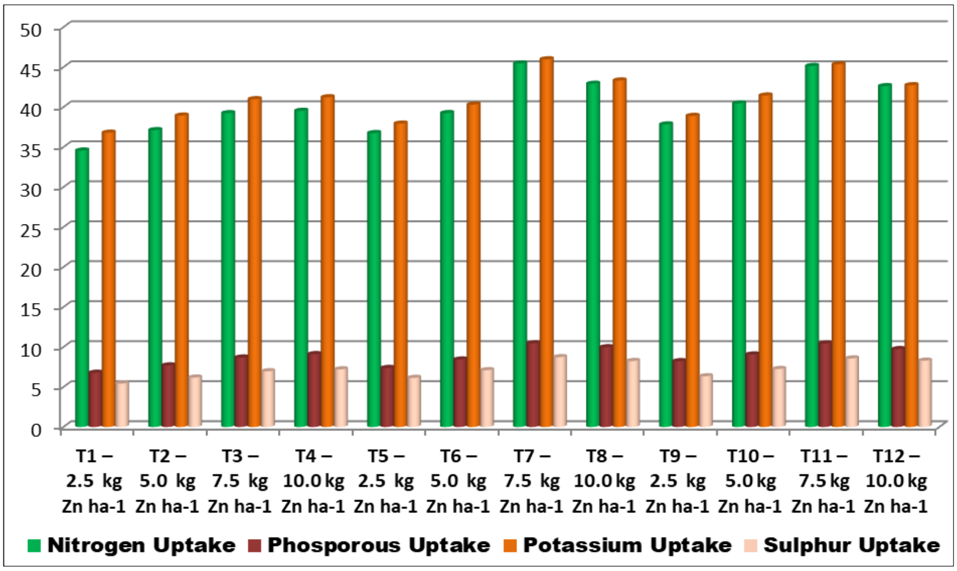

Fig 3: Total N and P uptake after harvest cotton as influenced by various treatments (Pooled mean)

Effect of zinc fertilization on micronutrient uptake

Soil application of Zn also found effective with improvement in micronutrients uptake. Data presented in Table Stated that alternate year soil application of 7.5 kg of Zn ha-1 show significant improvement in Fe, Mn, Zn, and Cu uptake (441.9 g ha^{-1}, 109.9 g ha^{-1}, 91.55 g ha^{-1} and 53.10 g ha^{-1} respectively) and found which was found at par with treatment 10 kg Zn ha^{-1} soil application every year.

The total uptake of copper (53.10 g ha^{-1}) was recorded highest in treatment 7.5 kg Zn ha^{-1} alternate year application followed by the treatment 7.5 kg Zn ha^{-1} every year application (51.08 g ha^{-1}) and total uptake of manganese (109.6 g ha^{-1}) was recorded highest in treatment 7.5 kg Zn ha^{-1} alternate year application followed by the treatment 7.5 kg Zn ha^{-1} every year application (106.5 g ha^{-1}) (Table 4).

Table 4: Total Zn and Fe uptake after harvest of cotton as influenced by various treatments (Pooled mean)

Treatments	Zn (g ha^{-1})	Fe (g ha^{-1})	Cu (g ha^{-1})	Mn (g ha^{-1})
T_1	64.88	387.1	39.96	86.4
T_2	70.93	395.6	43.28	92.2
T_3	76.47	412.1	46.33	97.4
T_4	77.19	404.9	45.36	95.6
T_5	69.74	373.9	42.23	89.7
T_6	77.60	391.6	45.56	95.4
T_7	91.55	441.9	53.10	109.9
T_8	85.37	409.2	48.76	101.6
T_9	72.25	373.4	41.79	91.1
T_{10}	79.29	386.1	45.02	96.3
T_{11}	88.80	415.7	51.08	106.5
T_{12}	83.20	383.8	46.78	99.1
T_{13}	57.80	321.4	35.24	78.0
S.E.(m) +	1.57	7.72	0.95	1.68
CD at 5%	4.62	22.15	2.71	4.81

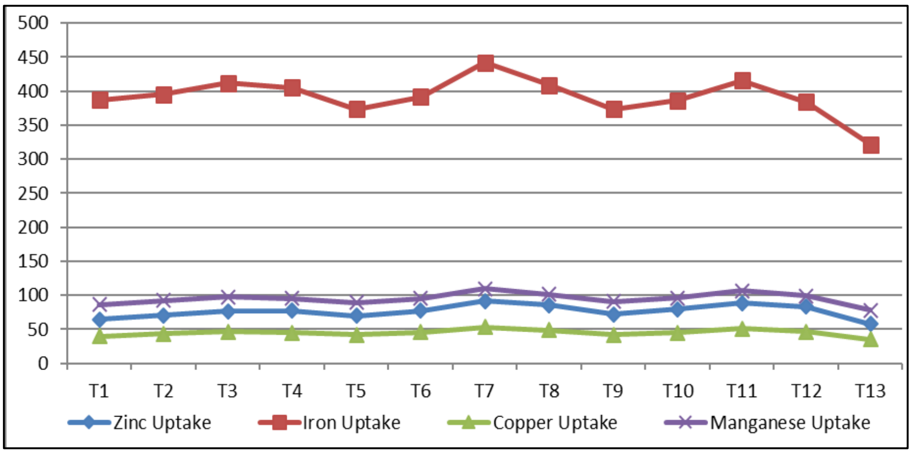

Fig 4: Total Zn and Fe uptake after harvest of cotton as influenced by various treatments (Pooled mean)

Zinc fractions after harvest of cotton

In the results of zinc fraction, it was clearly observed that increased soil application of Zn also increased the availability different forms of zinc in soil. In every year soil application of zinc Maximum availability of Water-soluble zinc, Exchangeable zinc, Carbonate bound zinc, Fe-Mn bound zinc and Residual zinc were noted.

Zinc exists in soil in various forms which affect its bioavailability to plants. The availability of Zn in water soluble and exchangeable form (Table 5) was recorded in the range of 0.25 to 0.88 mg kg^{-1}, carbonate bound zinc was found between 1.42-2.01, Fe-Mn oxide bound zinc noticed between 11.28 to 18.34 mg kg^{-1}, organically bound zinc (Table 6) found in the range 3.20 to 5.60 mg kg^{-1} and residual zinc (Table 7) in range between 48.08 to 79.41 mg kg $^{-1}$. Various form of Zn found to increase with increasing levels of applied Zn, while the fractions of Zn found lowest in control.

Table 5: WS + Exch. and Carbonates bound zinc fraction after harvest of cotton as influenced by various treatments

Treatments	WS + Exch. zinc (mg kg^{-1})			Carbonates bound zinc (mg kg^{-1})		
	2015-16	2017-18	2019-20	2015-16	2017-18	2019-20
T_1	0.37	0.39	0.34	1.56	1.61	1.57
T_2	0.43	0.42	0.38	1.67	1.73	1.73
T_3	0.47	0.45	0.45	1.69	1.78	1.77
T_4	0.51	0.50	0.51	1.70	1.83	1.84
T_5	0.42	0.47	0.54	1.62	1.72	1.78
T_6	0.47	0.56	0.62	1.73	1.81	1.85
T_7	0.55	0.64	0.70	1.76	1.85	1.92
T_8	0.49	0.68	0.73	1.81	1.90	1.95
T_9	0.65	0.73	0.83	1.73	1.80	1.93
T_{10}	0.71	0.79	0.87	1.77	1.88	2.00
T_{11}	0.76	0.86	0.94	1.84	1.96	2.11
T_{12}	0.80	0.89	0.96	1.89	2.00	2.14
T_{13}	0.28	0.23	0.23	1.38	1.45	1.43
S.E.(m) +	0.03	0.02	0.03	0.07	0.03	0.03
CD at 5%	0.09	0.06	0.08	0.21	0.09	0.08

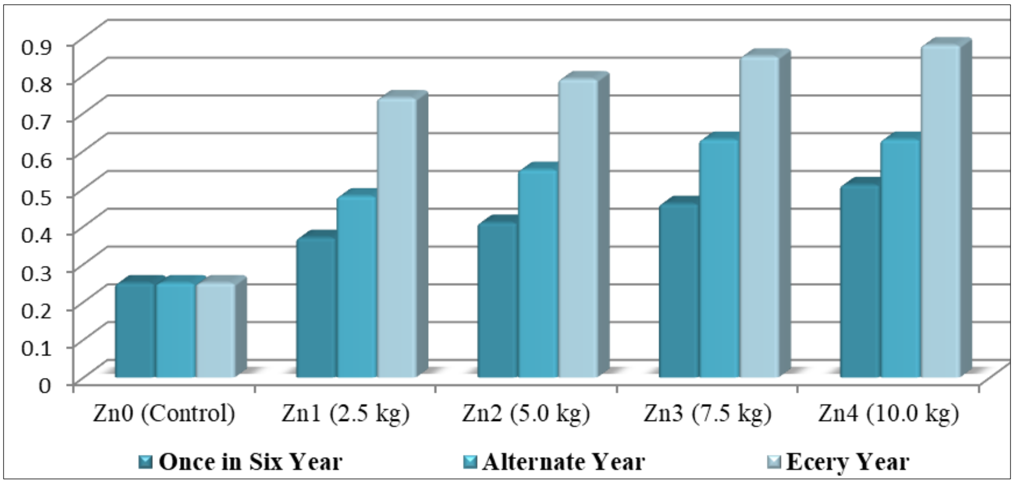

Fig 5a: Effect of frequency and levels of zinc application on water soluble and exchangeable zinc fraction (mg kg^{-1}) after harvest of cotton

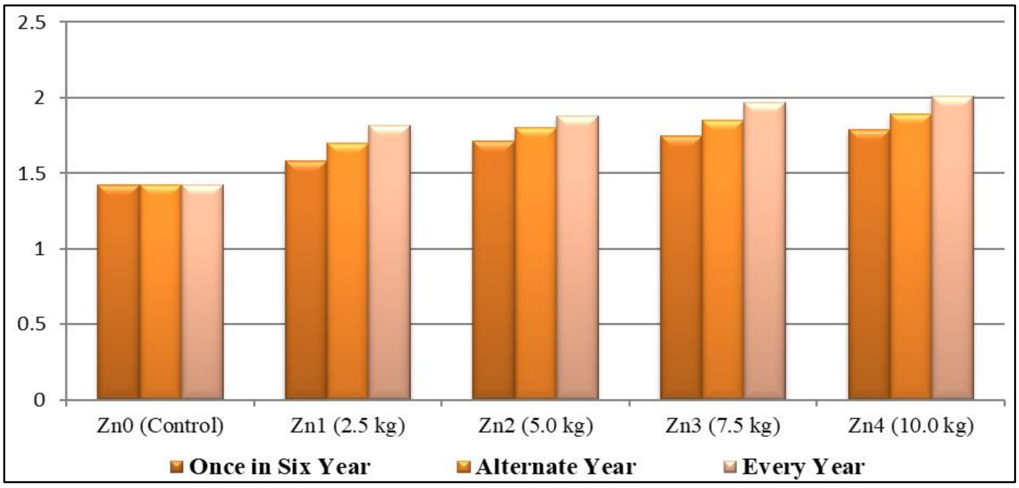

Fig 5b: Effect of frequency and levels of zinc application on carbonate bound zinc fraction (mg kg^{-1}) after harvest of cotton

Table 6: Fe-Mn oxide and organically bound zinc fraction after harvest of cotton as influenced by various treatments

Treatments	Fe-Mn oxide bound zinc (mg kg^{-1})			Organically bound zinc (mg kg^{-1})		
	2015-16	2017-18	2019-20	2015-16	2017-18	2019-20
T_1	11.48	11.80	11.90	3.36	3.45	3.54
T_2	12.54	13.07	13.31	3.52	3.56	3.67
T_3	13.97	14.50	14.70	3.58	3.61	3.78
T_4	13.84	14.83	15.10	3.64	3.69	3.90
T_5	12.40	12.97	13.32	3.53	4.38	4.81
T_6	13.55	14.33	14.61	3.57	4.74	5.04
T_7	14.71	15.90	17.24	3.66	4.80	5.29
T_8	14.93	16.37	17.56	3.74	4.93	5.45
T_9	15.18	16.03	16.79	3.93	4.61	5.19
T_{10}	16.79	17.00	18.10	4.03	4.75	5.52
T_{11}	17.31	18.07	18.87	4.19	5.67	6.21
T_{12}	17.58	18.20	19.23	4.36	5.81	6.63
T_{13}	11.23	11.27	11.34	3.18	3.13	3.30
S.E.(m) +	0.77	0.43	0.31	0.26	0.20	0.16
CD at 5%	2.26	1.26	0.89	0.75	0.59	0.46

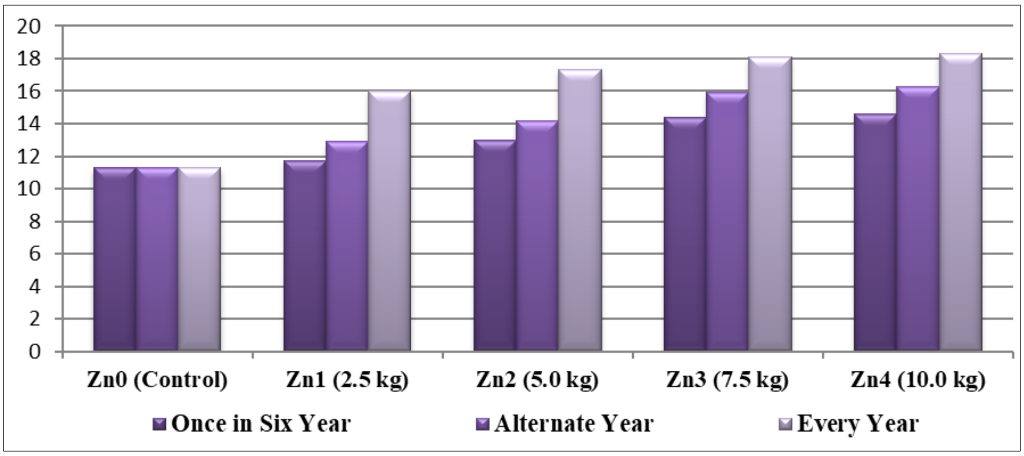

Fig 6a: Effect of frequency and levels of zinc application on Fe-Mn oxide bound zinc fraction (mg kg^{-1}) after harvest of cotton

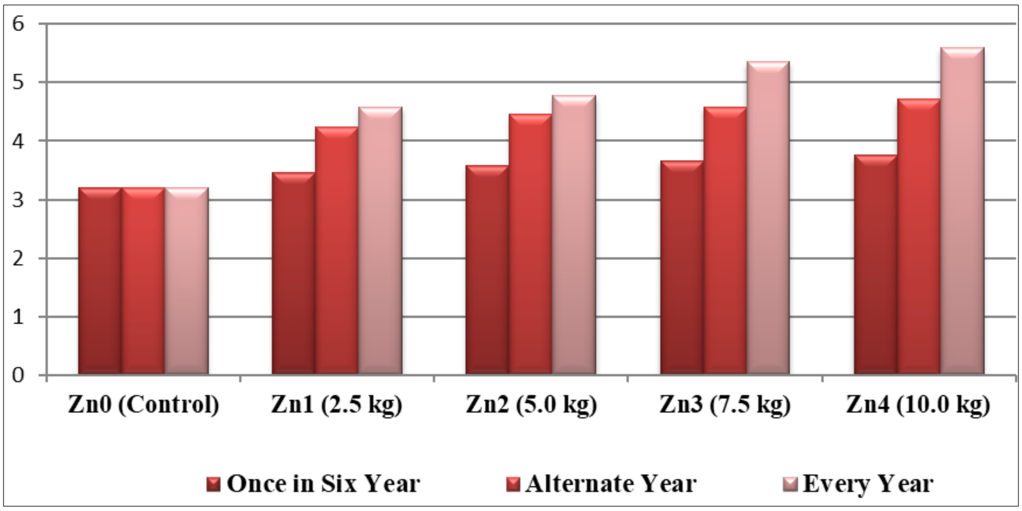

Fig 6b: Effect of frequency and levels of zinc application on organically bound zinc fraction (mg kg^{-1}) after harvest of cotton

Table 7: Residual and total zinc fraction after harvest of cotton as influenced by various treatments

Treatments	Residual zinc (mg kg^{-1})			Total zinc (mg kg^{-1})		
	2015-16	2017-18	2019-20	2015-16	2017-18	2019-20
T_1	52.54	54.00	54.52	69.31	71.25	71.88
T_2	53.12	55.07	55.67	71.28	73.85	74.75
T_3	54.34	56.13	57.10	74.05	76.48	77.80
T_4	54.62	56.40	57.25	74.32	77.26	78.62
T_5	54.59	56.73	57.62	72.55	76.27	78.06
T_6	57.30	59.20	61.50	76.63	80.64	83.62

T_7	60.25	61.67	65.27	80.93	84.86	90.42
T_8	62.74	63.83	66.43	83.71	87.70	92.12
T_9	61.67	63.40	67.26	83.17	86.57	92.01
T_{10}	62.78	65.97	68.10	86.08	90.38	94.59
T_{11}	67.01	71.33	73.22	91.11	97.89	101.4
T_{12}	75.05	80.30	82.89	99.67	107.2	111.9
T_{13}	47.19	47.50	49.55	63.27	63.57	65.85
S.E.(m) +	5.19	0.85	0.76	5.08	0.95	0.97
CD at 5%	15.15	2.48	2.21	14.82	2.76	2.82

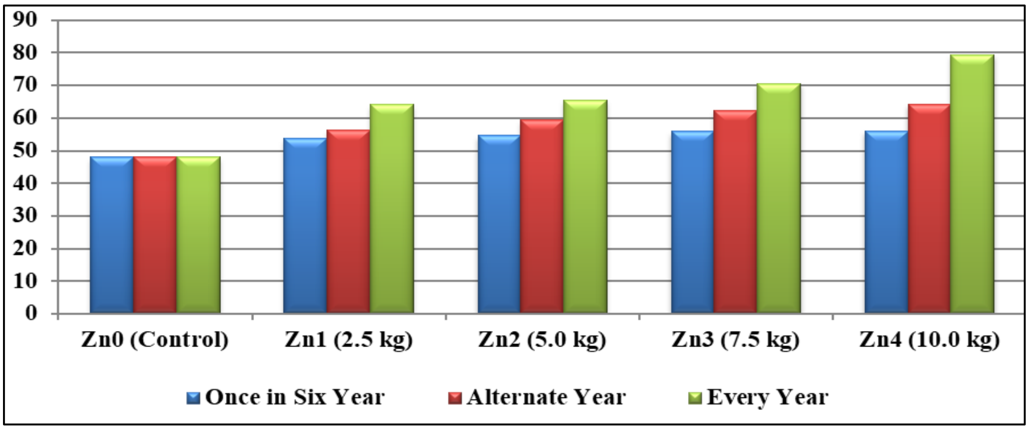

Fig 7a: Effect of frequency and levels of zinc application on residual zinc fraction (mg kg^{-1}) after harvest of cotton

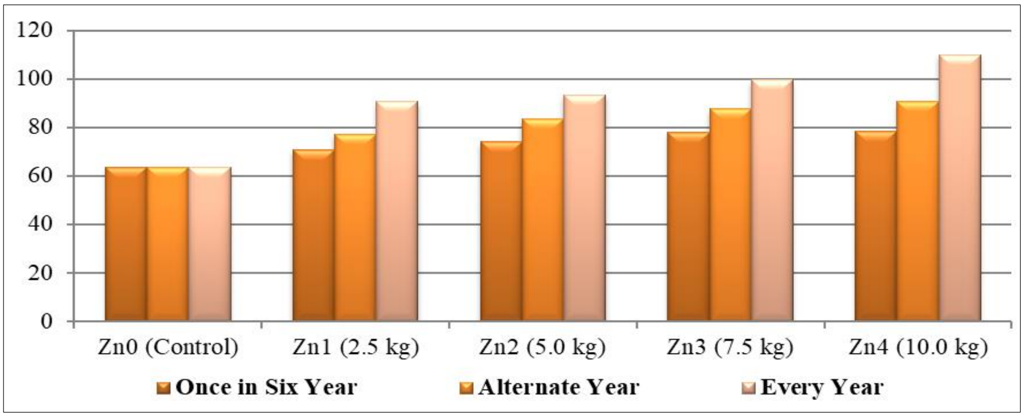

Fig 7b: Effect of frequency and levels of zinc application on total zinc fraction (mg kg^{-1}) after harvest of cotton

Table 8: Correlation coefficients (r) between Zn fractions and soil properties

	Water+Ex	Carbonates	Fe-Mn	Organically	Residual	Total
pH	0.01	0.10	0.05	0.01	-0.06	-0.03
EC	0.45	0.29	0.38	0.18	0.27	0.35
OC	0.87	0.80	0.88	0.76	0.82	0.85
N	0.49	0.66	0.55	0.59	0.47	0.46
P	-0.35	-0.14	-0.34	-0.12	-0.42	-0.41
K	0.62	0.75	0.70	0.66	0.58	0.60
S	0.64	0.73	0.70	0.69	0.61	0.64
Fe	-0.30	-0.02	-0.27	-0.22	-0.37	-0.33
Mn	0.06	0.16	0.00	0.04	-0.08	-0.03
Cu	0.21	0.37	0.22	0.35	0.19	0.22

Table 9: Correlation coefficients (r) among different Zn fractions

Fractions of zinc	WSEX-Zn	Carbonates bound Zn	Fe-Mn bound Zn	Organically bound Zn	Residual Zn	Total Zn
Water + Ex	–	–	–	–	–	–
Carbonates	0.91	–	–	–	–	–
Fe-Mn	0.96	0.93	–	–	–	–
Organically	0.88	0.88	0.84	–	–	–
Residual	0.94	0.89	0.93	0.87	–	–
Total	0.94	0.88	0.94	0.81	0.98	–
Avail. Zn	0.92	0.72	0.86	0.74	0.87	0.89

Discussion

Effect of zinc fertilization on yield

According to results it was observed alternate year of zinc application was getting maximum number of bolls per plant, higher boll weight and maximum crop yield as compare to every year soil application. These means no need to apply Zn fertilisers every year, alternate year application is sufficient to get maximum crop yield. Similar finding was also reported by Abid *et al*. 2013 [1], stated that one application of 7.5 kg Zn ha-1 proved two cycles of cotton and wheat crop. Our results are in agreement with those of Potarzycki and Grzebisz (2009) [27], who reported that Soil application of Zn effects higher plant leaf Zn concentration would accumulate toward higher assimilation of photosynthates from source to sink, resulting higher number of boll and weight subsequently maximum crop yield. McHan and Jonson, 1979 [19], reported that the presence of sufficient amount of Zn in rhizosphere enhanced Nitrogen assimilation. The increased Nitrogen assimilation enhanced the economical and biological yield of plant. Resposne of cotton to zinc was been reported by Ohki, 1976 [23], Nageswararao, 1976 [21], found that the application of zinc @ 30 kh ha-1 in soil increased cotton yield by 21 to 29%. Randhawa, 1998 [42] reported that the favourable response of cotton to micronutrients and concluded that application of zinc sulphate to zinc deficient soil improved fertilizers use efficiency and resulted in higher cotton yield. Sharma and Gupta 1990 [43], reported that zinc sulphate @25 ha-1 gives 2.03 to 2.1 t ha-1 cotton yield. Similarly our results are also found in line of Mangal Prasad and Rajendra Prasad, 1994 [28], Venkatakrishnan, 1994 [38], Khurana *et al.*, 1996 [15] and Wankhade *et al*. 1999 [39].

Effect of zinc fertilization on macronutrients uptake

It has reported that presence of sufficient quantity of Zn in rhizosphere enhanced N assimilation in plants (McHan and Jonson, 1979) [19]. A positive correlation between Zn and N (r-0.79) is indicative of synergetic interaction. Moreover, this relationship signifies that cotton plant absorb higher quantities of N in the presence of Zn nutrient in rooting medium and maintained greater proportion of Zn concentration in various parts of plant. Similar to this, Marschner (1995) [17] reported that plants absorb the higher quantity of N by application of Zn fertilizers. Similar finding was reported by Esmailnia *et al.* (2013) [8] stated that nitrogen uptake is increases with zinc application in cotton under salt stress conditions. In the case of phosphorous uptake, it is increase with increased application of Zn in soil. Our results are not line with the results of Gupta 1995 [9], Imtiaz *et al.*, 2006 [44], Loneragan *et al.* 1982 [16], they stated that phosphorous concentration in plants is greatly reduced with Zn application.

Alternate year application of zinc show improvement potassium and sulphur uptake this is might be due to synergetic effect of Zn with potassium and sulphur. Similar finding was also reported by Tiwari, Nigam and Pathak, 1982 [36], they stated that zinc application increased the uptake of potassium and sulphur. There is positive and significant correlation between potassium and added zinc fertilizers. Our results are also in the line with results of Ahmed *et al*. 2019 [45], stated that potassium content in plants was also increased with zinc application. Increased S content in plant is also might be due to application of Zn as a Zinc sulphate.

Effect of zinc fertilization on macronutrients uptake

Soil application of zinc has positive and significant effect in increased in micronutrients uptake in plants although there was and some antagonistic effect. Sial *et al.*, 2015 [33] and Ahmed *et al*., 2019 [45] reported that micronutrients uptake (Fe, Zn Mn, and Cu) was enhanced with zinc application. Similar finding was also reported by Ceylan *et al.*, 2016 [5], and Menon and Rahman, 2015 [18].

Relationship between soil available nutrients and soil fractions

The data pertaining to Table. 8 indicated that organic carbon, nitrogen, potassium and copper were positively correlated with different form of zinc present in soil. Whereas organic carbon, nitrogen, potassium and sulphur was significantly correlated. However phosphorous and iron were negatively correlated with different forms of Zn present in soil.

Similar finding was also reported by Neilsen *et al.* 1986 [22], stated that organic carbon content was positively and significantly correlated with different forms of zinc present in soil. Prasad and Sakal, 1988 [46]; Pal *et al.*, 1997 [26], reported that organically bound zinc was positively and significantly correlated with organic carbon and clay content in soil. Similarly, P. Veerangappa *et al.* 2011 [37], stated that Soil available N, P, K, Ca. Mg, S, Zn, Cu, Mn, Fe was positively and significantly correlated with water soluble + exchangeable zinc, organically bound zinc, residual zinc and total zinc and negatively Fe and Mn oxide bound zinc.

The data pertaining to Table. 9, stated that all the forms of zinc are positively and significantly correlated with each other. This result suggests there is dynamic equilibrium amongst the different soil Zn fractions reported by Bahera *et al*., 2008 [3], Nadaf and Chidanndappa, 2015 [20], Priyanka *et al.* 2017 [29]. Also reported that there is positive an Significant.

Conclusion

Significantly highest seed cotton yield, total uptake of micro and micronutrients and maximum availability of different forms of zinc was recorded with 7.5 kg Zn ha^{-1} over other treatments but at par with treatment 10 kg Zn ha^{-1}. The Zn fertilization at higher rates and frequencies increased the Zn availability, productivity and sustainability of the maize-wheat cropping system on a Zn deficient Typic Haplusterts. The optimum Zn application rate for obtaining higher system sustainability with maximum possible economic returns. Results indicated that insufficient or excessive Zn fertilization led to productivity and economic loss. These findings provide an insight into aspects (productivity, sustainability, profitability, and environmental risk) that are of substantial importance in achieving food security and sustainability goals. Further studies are needed to study the relationship of soil applied Zn with the availability of other nutrients and screening Zn-responsive cultivars for different crops. These interventions will further enhance the crop Zn utilization efficiency, hence, more economically viable and environmentally sound maize-wheat cropping system with long-term yield sustainability.

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