

## Original Research Article

### **“Zinc Dynamics and Yield Sustainability in Soybean (*Glycine max* L. Merrill) under Various Zinc Application Frequencies on Typic Haplusterts”**

#### **ABSTRACT**

The field experiment entitled “Zinc Dynamics and Yield Sustainability in Soybean (*Glycine max* L. Merrill) under Various Zinc Application Frequencies on Typic Haplusterts” was undertaken during the Kharif of 2015-16, 2017-18 and 2019-20 at Experimental Farm Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The effect on soil available Zinc was also evaluated. The experiment was laid out in Three Zinc application frequencies, viz. once (single year), alternate (every alternate year), and continuous (every year) at four Zinc application rates, viz. 2.5, 5.0, 7.5, and 10.0 kg ha<sup>-1</sup> along with one control (no Zinc) were investigated from 2015-16, 2017-18 and 2019-20. The Zinc application significantly improved the crop yields, system sustainability, DTPA-Zn, and different Zinc pools without causing any environmental risk. In general, the alternate year application of Zinc in Treatment T<sub>7</sub> at 7.5 kg ha<sup>-1</sup> produced the maximum grain and straw yield and system productivity. Similarly, the maximum macro and micronutrients uptake was also observed with alternate year application of Zinc at T<sub>7</sub> of 7.5 kg ha<sup>-1</sup>.

**Keywords:** Zinc dynamics, Yield, Nutrient Uptake, Soybean and Typic Haplusterts

#### **INTRODUCTION**

Soybean (*Glycine max* L. Merrill) is a kharif crop belonging to Leguminosae family. It can be grown in a wide range of climates and soils varying from sandy loam to clay soil. An average temperature of 26 - 30°C is required for growing soybean. It is one of the major oilseed crops of the world accounting for nearly 50% of the world area and production of oilseeds. It contains 40% of high quality protein and 20 % of oil. It is a rich source of amino acids like arginine, lysine, vitamin C, minerals, salts (thiamine and riboflavin) Singh *et al.* 2003 [1]. It is called the “Golden Bean” and “Wonder crop” of the twentieth century and “Miracle crop” of the 21<sup>st</sup> century because of its high nutritional value and myriad forms of uses. Soybean oil serves as a raw material for antibiotics, paints, varnishes, lubricants etc and food products such as textured vegetable protein (TVP), soybean curd, fried and roasted soynut. Soybean helps in preventing heart diseases, diabetes, obesity etc Kim *et al.* 2021 [2]. The global soybean production in the world is estimated at 333.67 million tonnes from an area of 120.50 million hectares and ranks fourth in area and fifth in production (Agricultural Market Intelligence Centre, PJTSAU Soybean Outlook, 2021) [3]. Among the various oilseed crops of the world, soybean stood first in contributing approximately 23% of vegetable oil production. In India, Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, Andhra Pradesh, Chhattisgarh are the major soybean cultivating states.

Soybean is triple beneficial crop and is now making headway in Indian Agriculture Pable *et al.* 2010. [4]. Micronutrient deficiency has become a limiting factor for crop productivity in many parts of the world. Zn is the most widespread productivity constraint in rainfed production Srinivasarao *et al.* 2009 [5]. The deficiency of micronutrient may emerge when the supply of micronutrients to the soil is less compared to removal through crop

harvest which in turn limits crop productivity Shukla *et al.*[6]. In severe deficiency conditions, the yield loss could reach as high as 100% due to omission of micronutrients in the cropping system. Yield loss with omission of Zn fertilization was reported as 10% in India Shukla *et al.* [ [6]. 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[7].

Keeping all the above facts in view, the present investigation was undertaken with the objectives to study the Effect of “Zinc Dynamics and Yield Sustainability in Soybean (*Glycine max* L. Merrill) under Various Zinc Application Frequencies on TypicHaplusterts”

## MATERIALS AND METHODS

The experiment entitled to study the Effect of “Zinc Dynamics and Yield Sustainability in Soybean (*Glycine max* L. Merrill) under Various Zinc Application Frequencies on TypicHaplusterts” was undertaken during the *Kharif* during 2016-17 ,207-18 and 2019-20 at Experimental Farm Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The site is situated in the sub-tropical region at 22°42’ North latitude and 77°02’ East longitude and at an altitude of 307.42 m above mean sea level.

### Experimental Details

Treatment No	Rate of Zn Application to soybean Crop (Kg Zn ha <sup>-1</sup> )	Frequency of Zn Application to soybean Crop
T <sub>1</sub>	Zn <sub>0</sub> -2.5	Once in Six Year
T <sub>2</sub>	Zn <sub>1</sub> -5.0	
T <sub>3</sub>	Zn <sub>2</sub> -7.5	
T <sub>4</sub>	Zn <sub>3</sub> -10.0	
T <sub>5</sub>	Zn <sub>0</sub> -2.5	Alternate Year of Zinc Application
T <sub>6</sub>	Zn <sub>1</sub> -5.0	
T <sub>7</sub>	Zn <sub>2</sub> -7.5	
T <sub>8</sub>	Zn <sub>3</sub> -10.0	
T <sub>9</sub>	Zn <sub>0</sub> -2.5	Every Year of Zinc Application
T <sub>10</sub>	Zn <sub>1</sub> -5.0	
T <sub>11</sub>	Zn <sub>2</sub> -7.5	
T <sub>12</sub>	Zn <sub>3</sub> -10.0	
T <sub>13</sub>	Zn <sub>0</sub> -0.0	No Zinc Applied

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<sup>-1</sup>), medium in organic carbon (5.30 g kg<sup>-1</sup>), calcareous in nature (8.13%), low in available

N ( $216.2 \text{ kg ha}^{-1}$ ), low in available P ( $14.17 \text{ kg ha}^{-1}$ ), very high in available K ( $346.2 \text{ kg ha}^{-1}$ ), deficient in available S ( $9.83 \text{ mg kg}^{-1}$ ) and sufficient in DTPA - Fe, Cu, Mn and deficient in Zn ( $\text{mg kg}^{-1}$ ). The zinc deficient site was selected and the experiment was laid as per schedule. The soybean 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, zero-Zn control was also set up in three replicated plots. The same amount of nitrogen (N), phosphorous (P) and potassium (K) fertilizers were applied as per the recommended rates for soybean in all experimental plots. The recommended rates of N,  $\text{P}_2\text{O}_5$  and  $\text{K}_2\text{O}$  for soybean are 30:75:30  $\text{kg ha}^{-1}$  respectively. All P and K and half of N were applied as basal at the time of sowing of soybean. The remaining of N was top dressed in two equal doses. A basal application of Zn was made through  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  (Zn 21%) at 2.5, 5.0, 7.5, 10.0  $\text{kg Zn ha}^{-1}$ . The Zn was broadcast into Plots and incorporated into soil with ploughing at the time of sowing.

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  $65^\circ\text{C}$ . The treatment wise samples were ground by using grinding mill and stored with proper labelling in brown paper bags. The powdered samples were used for the analysis of N, P, K, S and micronutrients. Di-acid digested samples were used for estimation of nitrogen content by using micro Kjeldahl's method phosphorous by Vanadomolybdate method, potassium by using Flame Photometer Jackson, 1973 [8] sulphur was estimated from di-acid extract turbidimetrically using Spectrophotometer Chesnin and Yien, 1951 [9] and micronutrients by using AAS Issac and Kerber, 1971 [10]. The test of statistical significance of the experimental data was carried out as per procedure described by Panse and Sukhatme (1985) [11].

## RESULTS AND DISCUSSION

### Effect of zinc fertilization on yield

The data pertaining to soybean seed and stover yield as influenced by various treatments are presented in Table 1. It was found that significantly highest seed yield ( $28.23 \text{ q ha}^{-1}$ ) was recorded with treatment  $T_{7.5 \text{ kg Zn ha}^{-1}}$  soil application in alternate year, whereas this was found at par with soil application of  $10 \text{ kg Zn ha}^{-1}$  of alternate year of application. However lowest grain yield was observed with treatment  $T_{13}$  i.e. control. Straw yield was also significantly improved with application of Zn. Data presented in Table 1 has shown that significantly maximum straw yield was found with alternate year soil application of treatment  $T_{7.5 \text{ kg Zn ha}^{-1}}$ , which was at par with alternate year soil application of  $10 \text{ kg Zn ha}^{-1}$ . However lowest straw yield was observed with treatment  $T_{13}$  i.e. control. In this alternate year of soil application is  $7.5 \text{ kg Zn ha}^{-1}$  was found significantly higher as compare to other treatments.

According to results it was observed alternate year of zinc application was getting maximum grain and straw 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 Kanse *et al.* 2008, [12] stated that one application of  $7.5 \text{ kg Zn ha}^{-1}$  proved highest yield in soybean followed by 1 and 5  $\text{kg Zn ha}^{-1}$ . Our results are in agreement with those of Ghasemian *et al.*, (2010) [13]. They noticed that  $40 \text{ kg ha}^{-1}$  Zn and Mn led to the highest seed yield ( $3397$  and  $3367 \text{ kg ha}^{-1}$ ) and biological yield ( $7447$  and  $7387 \text{ kg ha}^{-1}$ ), respectively. The highest numbers of grain and seed

weight per plant, pod number of soybean were registered at 40 kg ha<sup>-1</sup> of Zn and Mn. revealed that the Zn + Fe combined treatment produced highest seed yield of soybean (1575 kg ha<sup>-1</sup>) and the maximum number of pods per plant (36.36). Number of pods per plant showed positive and significant correlation with number of seed per pod (r=0.498) and 1000-seed weight (r=0.588). Furthermore, number of seed per pod had positive significant correlation (r=0.615) with 1000-grain yield of soybean. The interaction of fertilizer and time of fertilizer application showed that Fe treatment at the beginning of flowering produced maximum number of seed per pod (2.36), maximum 1000 grain weight was found at 10 leaf stage (168.3 g), Zn+Fe combination treatment produced maximum 1000-grain weight.

**Table 1. Yield of Grain and straw of soybean as influenced by various treatments (Pooled mean)**

Treatments	Grain Yield (q ha <sup>-1</sup> )	Straw yield (q ha <sup>-1</sup> )
T <sub>1</sub> – 2.5 kg Zn ha <sup>-1</sup>	22.66	33.49
T <sub>2</sub> – 5.0 kg Zn ha <sup>-1</sup>	23.45	34.52
T <sub>3</sub> – 7.5 kg Zn ha <sup>-1</sup>	23.79	35.32
T <sub>4</sub> – 10.0 kg Zn ha <sup>-1</sup>	24.26	36.14
T <sub>5</sub> – 2.5 kg Zn ha <sup>-1</sup>	25.01	37.14
T <sub>6</sub> – 5.0 kg Zn ha <sup>-1</sup>	25.88	38.28
T <sub>7</sub> – 7.5 kg Zn ha <sup>-1</sup>	28.23	40.96
T <sub>8</sub> – 10.0 kg Zn ha <sup>-1</sup>	27.51	39.63
T <sub>9</sub> – 2.5 kg Zn ha <sup>-1</sup>	24.69	36.05
T <sub>10</sub> – 5.0 kg Zn ha <sup>-1</sup>	25.50	37.34
T <sub>11</sub> – 7.5 kg Zn ha <sup>-1</sup>	26.51	38.36
T <sub>12</sub> – 10.0 kg Zn ha <sup>-1</sup>	24.83	36.39
T <sub>13</sub> – Control	21.38	31.67
S.E.(m) ±	0.86	0.66
CD at 5 %	1.08	1.94

## Effect of zinc fertilization on macronutrient uptake

Significant improvement Nitrogen, Phosphorous, potassium and sulphur uptake Was observed with soil application of Zn. Data presented in Table 2 has shown that highest NPK and sulphur uptake(233.81,26.40,95.09 and 25.10kg ha<sup>-1</sup>) was observed with treatments of alternate year soil application of treatment T<sub>7</sub>7.5 Kg Zn ha<sup>-1</sup> of T<sub>7</sub> and found at par with 10 Kg Zn ha<sup>-1</sup> of T<sub>10</sub> alternate year application. Lakshmi *et al.*, (2021) [14] stated that with the phasing of zinc application as regular application, alternate year application and only first year application of zinc and study revealed that zinc fertilization shown the improvement in uptake of zinc in rice- wheat cropping system. Similar to this Rohini.Vet *al.*, (2020)[15] they stated that pot culture experiment at Nagarjun Akola on swell Shrink soil and results showed that application of zinc @ 4.5 kg ha<sup>-1</sup> increased the uptake of nitrogen, phosphorus and potassium by soybean. Alternate year application of zinc shown 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)[16] they stated that zinc application increased the uptake of potassium and sulphur. There is positive and significant correlation between potassium and added zinc fertilizers.

**Table 2. Total N,P,K and S uptake after harvest soybean as influenced by various treatments (Pooled mean)**

Treatments	Nitrogen (kg ha <sup>-1</sup> )	Phosphorous (kg ha <sup>-1</sup> )	Potassium (kg ha <sup>-1</sup> )	Sulphur (kg ha <sup>-1</sup> )
T <sub>1</sub> – 2.5 kg Zn ha <sup>-1</sup>	170.12	24.43	58.90	14.81
T <sub>2</sub> – 5.0 kg Zn ha <sup>-1</sup>	179.01	25.13	62.84	16.00
T <sub>3</sub> – 7.5 kg Zn ha <sup>-1</sup>	186.60	25.00	65.24	17.52
T <sub>4</sub> – 10.0 kg Zn ha <sup>-1</sup>	192.56	25.49	68.19	18.56
T <sub>5</sub> – 2.5 kg Zn ha <sup>-1</sup>	195.94	25.19	72.32	19.27
T <sub>6</sub> – 5.0 kg Zn ha <sup>-1</sup>	208.77	25.49	77.45	21.64
T <sub>7</sub> – 7.5 kg Zn ha <sup>-1</sup>	233.81	26.40	95.09	25.10
T <sub>8</sub> – 10.0 kg Zn ha <sup>-1</sup>	223.52	25.51	87.61	23.13
T <sub>9</sub> – 2.5 kg Zn ha <sup>-1</sup>	194.68	22.43	69.18	17.76
T <sub>10</sub> – 5.0 kg Zn ha <sup>-1</sup>	206.61	22.60	74.17	20.22
T <sub>11</sub> – 7.5 kg Zn ha <sup>-1</sup>	219.43	22.64	82.03	21.84
T <sub>12</sub> – 10.0 kg Zn ha <sup>-1</sup>	205.61	20.82	73.72	20.75
T <sub>13</sub> – Control	156.01	18.86	52.21	12.61
S.E.(m) ±	0.76	0.25	1.53	0.34
CD at 5 %	2.18	0.72	2.17	1.00

## Effect of zinc fertilization on micronutrient uptake

Soil application of Zn also found effective with improvement in micronutrients uptake. Data presented in Table 3. Stated that alternate year soil application of treatment T<sub>7</sub> 7.5 kg of Zn ha<sup>-1</sup> show highest significant improvement in Zn, Fe, Cu and Mn uptake (119.98 g ha<sup>-1</sup>, 512.21 g ha<sup>-1</sup>, 168.90 g ha<sup>-1</sup> and 330.40 g ha<sup>-1</sup> respectively) and was found at par with treatment 10 kg Zn ha<sup>-1</sup> soil application alternate year and the lowest micronutrient uptake was found in T<sub>13</sub> that was control. 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 [17] reported that micronutrients uptake (Fe, Zn Mn, and Cu) was enhanced with zinc application. Similar finding was also reported by Rehman (1980) [18]. Kobraee *et al.* (2011) [19] reported that the application of micronutrient such as Zn, Fe and Mn increased the Zn content in different plant part. Zn application @ 0, 20 and 40 kg ha<sup>-1</sup> increased Zn content in seed by 21.7, 32.6 and 40.3 mg kg<sup>-1</sup>, respectively in soybean in silty clay soil.

**Table 3. Total Zn and Fe uptake after harvest of soybean as influenced by various treatments (Pooled mean)**

Treatments	Zn (g ha <sup>-1</sup> )	Fe (g ha <sup>-1</sup> )	Cu (g ha <sup>-1</sup> )	Mn (g ha <sup>-1</sup> )
T <sub>1</sub>	73.15	453.99	153.73	284.03
T <sub>2</sub>	78.80	464.09	155.45	285.86
T <sub>3</sub>	84.61	463.85	154.30	284.70
T <sub>4</sub>	90.18	458.85	154.38	287.51
T <sub>5</sub>	90.18	495.81	163.67	306.32
T <sub>6</sub>	99.04	492.78	165.64	311.84
T <sub>7</sub>	119.98	512.21	168.90	330.40
T <sub>8</sub>	118.30	496.19	166.45	312.44
T <sub>9</sub>	98.90	456.23	142.20	283.90
T <sub>10</sub>	107.79	459.76	142.32	285.90
T <sub>11</sub>	118.08	454.15	138.10	282.07
T <sub>12</sub>	110.01	419.04	125.38	260.22
T <sub>13</sub>	67.54	364.76	126.68	237.66
S.E.( m) ±	2.38	9.61	3.23	5.56
CD at 5 %	6.94	28.04	9.44	16.24

## Zinc fractions after harvest of soybean:

In the results of zinc fraction, it was clearly observed that increased soil application of Zn also increased the availability of 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 4) was recorded in the range of 0.24 to 1.03 mg kg<sup>-1</sup>, carbonate bound zinc was found between 1.42-2.17, Fe-Mn oxide bound zinc noticed between 11.30 to 19.45 mg kg<sup>-1</sup>, organically bound zinc (Table 5) found in the range 3.22 to 6.76 mg kg<sup>-1</sup> and residual zinc in (Table 6) in range between 48.36 to 83.17 mg kg<sup>-1</sup> and total zinc 64.72 to 112.58 mg kg<sup>-1</sup>. Various form of Zn found to increase with increasing levels of applied Zn, while the fractions of Zn found lowest in control.

The data pertaining to Table. 7 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 [20] stated that organic carbon content was positively and significantly correlated with different forms of zinc present in soil. Pal *et al.*, 1997 [21] reported that organically bound zinc was positively and significantly correlated with organic carbon and clay content in soil. Similarly, P. Veerangappa *et al.* 2011 [22] 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. 8, stated that all the forms of zinc are positively and significantly correlated with each other's. This results suggest there is dynamic equilibrium amongst the different soil Zn fractions reported by Bahera *et al.* (2008) [23] Nadafet *et al.* (2015) [24] also reported that there is positive and significant.

**Table 4. WS + Exch. and Carbonates bound zinc fraction after harvest of soybean as influenced by various treatments of exchangeable zinc fraction (mg kg<sup>-1</sup>) after harvest of Cotton.**

Treatments	WS + Exch. zinc (mg kg <sup>-1</sup> )			Carbonates bound zinc (mg kg <sup>-1</sup> )		
	2015-16	2017-18	2019-20	2015-16	2017-18	2019-20
T <sub>1</sub>	0.41	0.35	0.34	1.58	1.59	1.55
T <sub>2</sub>	0.45	0.40	0.37	1.70	1.74	1.70
T <sub>3</sub>	0.49	0.48	0.43	1.73	1.79	1.75
T <sub>4</sub>	0.52	0.53	0.50	1.75	1.85	1.86
T <sub>5</sub>	0.44	0.49	0.55	1.66	1.74	1.81
T <sub>6</sub>	0.50	0.56	0.63	1.76	1.83	1.86
T <sub>7</sub>	0.59	0.67	0.72	1.80	1.90	1.94
T <sub>8</sub>	0.61	0.72	0.75	1.84	1.92	1.97
T <sub>9</sub>	0.68	0.79	0.86	1.77	1.89	1.95
T <sub>10</sub>	0.74	0.82	0.89	1.85	1.97	2.02
T <sub>11</sub>	0.80	0.90	0.98	1.89	2.05	2.15
T <sub>12</sub>	0.82	0.93	1.03	1.96	2.10	2.17
T <sub>13</sub>	0.26	0.24	0.25	1.42	1.47	1.41
S.E.(m) ±	<b>0.04</b>	<b>0.02</b>	<b>0.04</b>	<b>0.03</b>	<b>0.03</b>	<b>0.05</b>
CD at 5 %	<b>0.12</b>	<b>0.06</b>	<b>0.12</b>	<b>0.09</b>	<b>0.10</b>	<b>0.15</b>

**Table 5. Fe-Mn oxide and organically bound zinc fraction after harvest of soybean as influenced by various treatments exchangeable zinc fraction (mg kg<sup>-1</sup>) after harvest of Cotton.**

Treatments	Fe-Mn oxide bound zinc (mg kg <sup>-1</sup> )			Organically bound zinc (mg kg <sup>-1</sup> )		
	2015-16	2017-18	2019-20	2015-16	2017-18	2019-20
T <sub>1</sub>	11.72	11.87	11.92	3.62	3.50	3.60
T <sub>2</sub>	12.94	13.25	13.34	3.66	3.62	3.79
T <sub>3</sub>	14.35	14.58	14.76	3.82	3.74	3.93
T <sub>4</sub>	14.70	14.96	15.15	3.91	3.81	4.04
T <sub>5</sub>	12.83	13.15	13.43	4.21	4.65	5.00
T <sub>6</sub>	13.92	14.46	14.74	4.37	4.90	5.20
T <sub>7</sub>	15.26	16.73	17.38	4.49	5.14	5.43
T <sub>8</sub>	14.81	17.00	17.72	4.52	5.22	5.62
T <sub>9</sub>	15.53	16.18	16.93	4.53	5.03	5.32
T <sub>10</sub>	16.56	17.86	18.24	4.64	5.37	5.60
T <sub>11</sub>	17.67	18.50	19.08	5.51	6.04	6.33
T <sub>12</sub>	17.89	18.94	19.45	5.52	6.43	6.76
T <sub>13</sub>	11.46	11.30	11.32	3.22	3.25	3.28
S.E.(m) ±	<b>0.42</b>	<b>0.40</b>	<b>0.76</b>	<b>0.31</b>	<b>0.13</b>	<b>0.34</b>
CD at 5 %	<b>1.24</b>	<b>1.17</b>	<b>2.22</b>	<b>0.90</b>	<b>0.39</b>	<b>1.04</b>

**Table 6. Residual and total zinc fraction after harvest of soybean as influenced by various treatments**

Treatments	Residual zinc (mg kg <sup>-1</sup> )			Total zinc (mg kg <sup>-1</sup> )		
	2015-16	2017-18	2019-20	2015-16	2017-18	2019-20
T <sub>1</sub>	53.59	54.27	54.59	70.92	71.57	72.00
T <sub>2</sub>	54.15	55.40	55.72	72.90	74.41	74.93
T <sub>3</sub>	55.70	56.71	57.16	76.09	77.31	78.02
T <sub>4</sub>	55.92	56.57	57.34	76.80	77.73	78.89
T <sub>5</sub>	56.29	57.10	57.81	75.43	77.13	78.60
T <sub>6</sub>	58.64	60.87	61.76	79.19	82.63	84.20
T <sub>7</sub>	61.33	63.79	65.84	83.47	88.23	91.30
T <sub>8</sub>	63.13	65.20	67.11	84.91	90.06	93.17
T <sub>9</sub>	63.29	66.84	67.39	85.80	90.72	92.45
T <sub>10</sub>	65.14	67.39	68.52	88.93	93.41	95.27
T <sub>11</sub>	70.93	72.14	73.64	96.80	99.63	102.19
T <sub>12</sub>	79.12	81.53	83.17	105.3	109.94	112.58
T <sub>13</sub>	48.36	48.80	49.43	64.72	65.06	65.69
S.E.(m) ±	<b>1.60</b>	<b>1.23</b>	<b>1.28</b>	<b>1.37</b>	<b>1.36</b>	<b>1.44</b>
CD at 5 %	<b>4.67</b>	<b>3.60</b>	<b>3.75</b>	<b>4.17</b>	<b>3.97</b>	<b>4.19</b>

**Table 7. Correlation coefficients (r) between Zn fractions and soil properties**

	Water + Ex	Carbonates	Fe-Mn	Organically	Residual	Total
pH	0.04	0.13	0.04	0.07	0.02	0.03
EC	-0.07	-0.02	-0.01	-0.02	0.01	0.01
OC	0.59	0.60	0.59	0.59	0.55	0.57
N	0.80	0.85	0.81	0.86	0.79	0.82
P	-0.60	-0.36	-0.52	-0.52	-0.60	-0.59
K	0.76	0.81	0.78	0.81	0.74	0.77
S	0.80	0.88	0.86	0.77	0.81	0.83
Fe	0.94	0.81	0.86	0.88	0.90	0.90
Mn	-0.44	-0.22	-0.41	-0.41	-0.50	-0.48
Cu	0.20	0.36	0.19	0.20	0.09	0.13

**Table 8. 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	0.94	–	–	–	–	–
Fe-Mn	0.96	0.95	–	–	–	–
Organically	0.95	0.91	0.91	–	–	–
Residual	0.95	0.90	0.93	0.94	–	–
Total	0.97	0.93	0.96	0.95	1.00	–
Avail. Zn	–	–	–	–	–	–

## CONCLUSION

Significantly highest grain and straw yield, total uptake of macro and micronutrients and maximum availability of different forms of zinc was recorded with treatment T<sub>7</sub> is 7.5 kg Zn ha<sup>-1</sup> of alternate year over other treatments but at par with treatment T<sub>10</sub> is 10 kg Zn ha<sup>-1</sup>. The Zn fertilization at higher rates and frequencies increased the Zn availability, productivity and sustainability of the cotton-soybean cropping system on a Zn deficient TypicHaplusterts. 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 Cotton-soybean cropping system with long-term yield sustainability.

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