Original Research Article

Zinc Dynamics and Yield Sustainability in Relation to Zn Application UnderSoybean (*Glycine max* L. Merrill)on Typic Haplusterts

ABSTRACT

The field experiment entitled Zinc dynamics and yield Sustainability in Relation to Zn Application Under Soybean(*Glycine max* L. Merrill) on Typic Haplustertswas 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 Zn was also evaluated. The experiment was laid out in 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 2016-17 to 2020-21. 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 grain and straw 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, Nutrient Uptake, Soyabean 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^{o}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 highquality 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). It is called the “Golden Bean” and “Wonder crop” of the twentieth century and “Miracle crop” of the 21st 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, 2021). 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, PJTSAUSoybean Outlook, 2021). In India, the area and production of soybean are 12.81 million hectares and 12.90 million tonnes (DES, MoA&FW, 2020). 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.

India, the area under this crop increased due to its high yielding potential and multifarious industrial uses. Soybean is called as boon of malnourished world because of its high nutritive value mainly due to its high protein (40%), oil (20%) and carbohydrate (35%). Soybean is triple beneficial crop and is now making headway in Indian Agriculture(Pable *et. al.*, 2010). In India it is Soybean is one of the important oil seed as well as leguminous crop. It is the cheapest and richest source of high-quality protein (40%). It supplies most of the

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Comment [MH7]: Missing in the bibliography list nutritional constituents essential for human health. Soybean occupies an intermediate position between legumes and oilseed. Soybean helps to builds up the soil fertility by fixing atmospheric nitrogen through nodules. Symbiotically soybean fixes nitrogen and leaves about 25 per cent for succeeding crop. All these qualities have made it an ideal crop in rotation. In mainly grown as ‘oilseed crop’. Hence, soybean is called as “Wonder bean” or “Miracle bean”. Soybean occupies an intermediate position between legumes and oilseed.

In India, at present area under soybean crop is 120 lakh ha. with the production of 105.3 lakh ton. In Maharashtra area under soybean is about 40 lakh ha with a total production 48.3 lakh ton having average productivity of 1100 kg ha^{-1}. In Vidarbha region area under soybean crop is 13.27 lakh ha with total production of 21.12 lakh ton (SOPA, 2019).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). 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.* 2009). 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.* 2009).

The availability of soil zinc to plant is governed by a dynamic equilibrium existing among different fraction of soil zinc whereas relative abundance of these chemical pool depending upon the physical and chemical properties of the soil. The different fraction of soil zinc showed positive and significant correlation among them. 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).

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]. 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.

Keeping all the above facts in view, the present investigation was undertaken with the objectives to study the Effect ofZinc dynamics and yield Sustainability in Relation to Zn Application Under Soybean (*Glycine max* L. Merrill) on Typic Haplusterts

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 [Choudhury *et al.* 1994]. Soluble forms of zinc are readily available to plants and the uptake of zinc has been reported to be linear with concentration in

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Comment [MH17]: The cited study is about the wheat not cotton the nutrient solution or soil [Choudhury *et al.* 1994]. 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 soyabean crop on typic Haplusterts.

MATERIALS AND METHODS

The experiment entitled to Study the Effect of Zinc dynamics and yield Sustainability in Relation to Zn Application Under Soybean (*Glycine max* L. Merrill) on Typic Haplusterts 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 $22^0$42' North latitude and $77^0$02' East longitude and at an altitude of 307.42 m above mean sea level.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 June to October month.

List 1. Experimental Details

Treatment No	**Rate of Zn Application to soybean Crop (Kg Zn ha^{-1})**	**Frequency of Zn Application to soybean Crop**
T_1	Zn_0 -2.5	Once in Six Year
T_2	Zn_1-5.0	
T_3	Zn_2-7.5	
T_4	Zn_3-10.0	
T_5	Zn_0 -2.5	Alternate Year of Zinc Application
T_6	Zn_1-5.0	
T_7	Zn_2-7.5	
T_8	Zn_3-10.0	
T_9	Zn_0 -2.5	Every Year of Zinc Application
T_{10}	Zn_1-5.0	
T_{11}	Zn_2-7.5	
T_{12}	Zn_3-10.0	
T_{13}	Zn_0 -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^{-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 soyabean 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 a per the recommended rates for soyabean in all experimental plots. The recommended rates of N, P_2O_5 and K_2O for soyabean are 30,75 30, respectively. All P and K and half of N were applied as basal at the time of sowing of soyabean. The remaining of N was top dressed in two equal doses. A basal application of Zn was made through $ZnSO_47H_2O$ (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.

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°C.

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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), phosphorous by Vanadomolybdate(Jackson, 1973), potassium by using Flame Photometer (Jackson, 1973), sulphur was estimated from di-acid extract turbidimetrically using Spectrophotometer (Chesnin and Yien, 1951) and micronutrients by using AAS (Issac and Kerber, 1971). The test of statistically significance of the experimental data was carried out as per procedure described by Panse and Sukhatme (1985).

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RESULTS

Effect of zinc fertilization on yield

Thedata pertaining to soyabean seed and stover yield as influenced by various treatments are presented in Table 1.It was found that significantly highest seed yield (28.23 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 10 kg of 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 7.5 kg Zn ha^{-1}, which was at par with alternate year soil application of 10 kg of Zn ha^{-1}.However lowest straw yield was observed with treatmentT_{13} i.e.control. In this alternate year of soil application is 7.5 kg Zn ha^{-1} was found significantly higher as compare to other treatments.

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 2 has shown that highest Nitrogen, Phosphorous, potassium and sulphur uptake(233.81,26.40,95.09 and 25.10kg ha^{-1})was observed with treatments of alternate year soil application of 7.5 Kg Zn ha^{-1} and found at par with 10 Kg Zn ha^{-1} of alternate year application.

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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 7.5 kg of Zn ha^{-1} show highest significant improvement in Zn, Fe, Cu and Mn uptake (119.98 g ha^{-1}, 512.21 g ha^{-1}, 168.90 g ha^{-1} and 330.40 g ha^{-1} respectively) andwas found at par with treatment 10 kg Zn ha^{-1} soil application alternate year and the lowest micronutrient uptake was found in T_{13} that was control.

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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-solublezinc, 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^{-1}, carbonate bound zinc was found between 1.42-2.17, Fe-Mn oxide bound zinc noticed between 11.30 to 19.45 mg kg^{-1},organically bound zinc (Table 5) found in the range 3.22 to 6.76 mg kg^{-1} and residual zinc in (Table 6) in range between 48.36 to 83.17 mg kg^{-1} and total zinc 64.72 to 112.58mg kg^{-1}.Various form of Zn found to increase with increasing levels of applied Zn, while the fractions of Zn found lowest in control.

DISCUSSION

Effect of zinc fertilization on yield

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, stated that one application of 7.5 kg Zn ha^{-1} proved highest yield in soybean followed by 1 and 5 kg Zn ha^{-1}. Our results are in agreement with those of Ghasemian *et al.*, (2010), They noticed that 40 kg ha^{-1} Zn and Mn led to the highest seed yield (3397 and 3367 kg ha^{-1}) and biological yield (7447 and 7387 kg ha^{-1}), respectively. The highest numbers of grain and seed weight per plant, pod number of soybean were registered at 40 kg ha^{-1} of Zn and Mn.Similarly Mostafavi (2012) revealed that the Zn + Fe combined treatment produced highest seed yield of soybean (1575 kg ha^{-1}) 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.

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Effect of zinc fertilization on macronutrients uptake:

Lakshmi *et al.*, (2021) 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.V*et al.*, (2020) they stated that pot culture experiment at Nagarjun Akola on swell Shrink soil and results showed that application of zinc @ 4.5 kg ha^{-1} increased the uptake of nitrogen, phosphorus and potassium by soybean.Alternate year application of zinc shown improvement potassium andsulphur 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), 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*. (2001), 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.

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Effect of zinc fertilization on micronutrients 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 and Ahmed *et al.*, 2019 reported that micronutrients uptake (Fe, Zn Mn, and Cu) was enhanced with zinc application. Similar finding was also reported by Rehman (1980).Kobraee*et al*. (2011) 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^{-1} increased Zn content in seed by 21.7, 32.6 and 40.3 mg kg^{-1}, respectively in soybean in silty clay soil.

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Relationship between soil available nutrients and soil fractions

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, stated that organic carbon content was positively and significantly correlated with different forms of zinc present in soil. Pal *et al.*, 1997, reported that organically bound zinc was positively and significantly correlated with organic carbon and clay content in soil. Similarly,P.Veerangappa*et al.* 2011, 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.

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The data pertaining to Table. 8, stated that all the forms of zinc are positively and significantly correlated witheachothers.This results suggest there is dynamic equilibrium amongst the different soil Zn fractions reported by Bahera *et al*.(2008) Nadaf and Chidanandappa(2015) also reported that there is positive and significant.

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CONCLUSION

Significantly highest grain and straw yield, total uptake of macro and micronutrients and maximum availability of different forms of zinc was recorded with 7.5 kg Zn ha^{-1}of alternate year 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 cotton-soyabean 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 Cotton-soyabean cropping system with long-term yield sustainability.

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

Treatments	Grain Yield ($q\ ha^{-1}$)	Straw yield ($q\ ha^{-1}$)
T_1 – 2.5 kg Zn ha^{-1}	22.66	33.49
T_2 – 5.0 kg Zn ha^{-1}	23.45	34.52
T_3 – 7.5 kg Zn ha^{-1}	23.79	35.32
T_4 –10.0 kg Zn ha^{-1}	24.26	36.14
T_5 – 2.5 kg Zn ha^{-1}	25.01	37.14
T_6 – 5.0 kg Zn ha^{-1}	25.88	38.28
T_7 – 7.5 kg Zn ha^{-1}	28.23	40.96
T_8 –10.0 kg Zn ha^{-1}	27.51	39.63
T_9 – 2.5 kg Zn ha^{-1}	24.69	36.05
T_{10} – 5.0 kg Zn ha^{-1}	25.50	37.34
T_{11} – 7.5 kg Zn ha^{-1}	26.51	38.36
T_{12} – 10.0 kg Zn ha^{-1}	24.83	36.39

T_{13} – Control	21.38	31.67
S.E.(m) ±	0.86	0.66
CD at 5 %	1.08	1.94

Table 2. Total N,P,K and S uptake after harvest soybean 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}	170.12	24.43	58.90	14.81
T_2 – 5.0 kg Zn ha^{-1}	179.01	25.13	62.84	16.00
T_3 – 7.5 kg Zn ha^{-1}	186.60	25.00	65.24	17.52
T_4 –10.0 kg Zn ha^{-1}	192.56	25.49	68.19	18.56
T_5 – 2.5 kg Zn ha^{-1}	195.94	25.19	72.32	19.27
T_6 – 5.0 kg Zn ha^{-1}	208.77	25.49	77.45	21.64
T_7 – 7.5 kg Zn ha^{-1}	233.81	26.40	95.09	25.10
T_8 –10.0 kg Zn ha^{-1}	223..52	25.51	87.61	23.13
T_9 – 2.5 kg Zn ha^{-1}	194.68	22.43	69.18	17.76
T_{10} – 5.0 kg Zn ha^{-1}	206.61	22.60	74.17	20.22
T_{11} – 7.5 kg Zn ha^{-1}	219.43	22.64	82.03	21.84
T_{12} – 10.0 kg Zn ha^{-1}	205.61	20.82	73.72	20.75
T_{13} – 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

Table 3. Total Zn and Fe uptake after harvest of soybean 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	73.15	453.99	153.73	284.03
T_2	78.80	464.09	155.45	285.86
T_3	84.61	463.85	154.30	284.70
T_4	90.18	458.85	154.38	287.51
T_5	90.18	495.81	163.67	306.32
T_6	99.04	492.78	165.64	311.84
T_7	119.98	512.21	168.90	330.40

T_8	118.30	496.19	166.45	312.44
T_9	98.90	456.23	142.20	283.90
T_{10}	107.79	459.76	142.32	285.90
T_{11}	118.08	454.15	138.10	282.07
T_{12}	110.01	419.04	125.38	260.22
T_{13}	67.54	364.76	126.68	237.66
S.E.(m) $\pm$	2.38	9.61	3.23	5.56
CD at 5 %	6.94	28.04	9.44	16.24

Table 4. WS + Exch. and Carbonates bound zinc fraction after harvest of soybean as influenced by various treatments of exchangeable zinc fraction (mg kg^{-1}) after harvest of Cotton.

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	0.41	0.35	0.34	1.58	1.59	1.55
T_2	0.45	0.40	0.37	1.70	1.74	1.70
T_3	0.49	0.48	0.43	1.73	1.79	1.75
T_4	0.52	0.53	0.50	1.75	1.85	1.86
T_5	0.44	0.49	0.55	1.66	1.74	1.81
T_6	0.50	0.56	0.63	1.76	1.83	1.86
T_7	0.59	0.67	0.72	1.80	1.90	1.94
T_8	0.61	0.72	0.75	1.84	1.92	1.97
T_9	0.68	0.79	0.86	1.77	1.89	1.95
T_{10}	0.74	0.82	0.89	1.85	1.97	2.02
T_{11}	0.80	0.90	0.98	1.89	2.05	2.15
T_{12}	0.82	0.93	1.03	1.96	2.10	2.17
T_{13}	0.26	0.24	0.25	1.42	1.47	1.41
S.E.(m) $\pm$	**0.04**	**0.02**	**0.04**	**0.03**	**0.03**	**0.05**

CD at 5 %	**0.12**	**0.06**	**0.12**	**0.09**	**0.10**	**0.15**

Table 5. Fe-Mn oxide and organically bound zinc fraction after harvest of soybean as influenced by various treatments exchangeable zinc fraction (mg kg^{-1}) after harvest of Cotton.

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	11.72	11.87	11.92	3.62	3.50	3.60
T_2	12.94	13.25	13.34	3.66	3.62	3.79
T_3	14.35	14.58	14.76	3.82	3.74	3.93
T_4	14.70	14.96	15.15	3.91	3.81	4.04
T_5	12.83	13.15	13.43	4.21	4.65	5.00
T_6	13.92	14.46	14.74	4.37	4.90	5.20
T_7	15.26	16.73	17.38	4.49	5.14	5.43
T_8	14.81	17.00	17.72	4.52	5.22	5.62
T_9	15.53	16.18	16.93	4.53	5.03	5.32
T_{10}	16.56	17.86	18.24	4.64	5.37	5.60
T_{11}	17.67	18.50	19.08	5.51	6.04	6.33
T_{12}	17.89	18.94	19.45	5.52	6.43	6.76
T_{13}	11.46	11.30	11.32	3.22	3.25	3.28
S.E.(m) ±	**0.42**	**0.40**	**0.76**	**0.31**	**0.13**	**0.34**
CD at 5 %	**1.24**	**1.17**	**2.22**	**0.90**	**0.39**	**1.04**

Table 6. Residual and total zinc fraction after harvest of soybean 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	53.59	54.27	54.59	70.92	71.57	72.00
T_2	54.15	55.40	55.72	72.90	74.41	74.93
T_3	55.70	56.71	57.16	76.09	77.31	78.02
T_4	55.92	56.57	57.34	76.80	77.73	78.89
T_5	56.29	57.10	57.81	75.43	77.13	78.60
T_6	58.64	60.87	61.76	79.19	82.63	84.20
T_7	61.33	63.79	65.84	83.47	88.23	91.30
T_8	63.13	65.20	67.11	84.91	90.06	93.17
T_9	63.29	66.84	67.39	85.80	90.72	92.45
T_{10}	65.14	67.39	68.52	88.93	93.41	95.27
T_{11}	70.93	72.14	73.64	96.80	99.63	102.19
T_{12}	79.12	81.53	83.17	105.3	109.94	112.58
T_{13}	48.36	48.80	49.43	64.72	65.06	65.69
S.E.(m) $\pm$	**1.60**	**1.23**	**1.28**	**1.37**	**1.36**	**1.44**
CD at 5 %	**4.67**	**3.60**	**3.75**	**4.17**	**3.97**	**4.19**

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	–	–	–	–	–	–