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Effect of zinc nutrition on yield of rice-wheat cropping system and soil properties

PEPAKAYALA VARALAKSHMI[1], POLAGANI NAGARJUNA[2], MOHAN BABU YN[3], ADI LAKSHMI G[4], ARADHNA KUMARI[5] AND SANTOSH K SINGH[6*]

ABSTRACT

A study was conducted in anongoing experiment under AICRP on micronutrients at nursery jhilli of RPCAU, research farm. The experiment consisted of thirteen treatments, of which twelve combinations were of four doses of zinc (Zn) (2.5, 5.0, 7.5 and 10 kg ha^{-1}), three frequencies (only once, alternate year and every year) of application along with control withthe no-zinc application. Rice and wheat crops were grown in succession with the recommended dosages of fertiliser viz. 120:60:40 of N: P_2O_5: K_2O applied as Urea, DAP, and Potash, respectively. Surface soil samples (0-15 cm) were collected after the harvest of the wheat crop in the year 2018, *i.e.* after completion of six years of the experiment, and analysed for soil physical and chemical properties.The availability of nitrogen, sulphur, organic carbon content and aggregate stability increased, and the bulk density, phosphorous availability decreased with increasing doses and zinc application rates. No effect on soil availability of potassium, pH and EC. The treatment T_7 *i.e.*, application of zinc @ 7.5 kg Zn ha^{-1} in alternate year application was the best treatment with regards to yield of rice-wheat cropping (982.9 q ha^{-1}) and also for good physical and chemical properties of the soil.

KEYWORDS

cropping system, dose, frequency, Rice-wheat, zinc

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INTRODUCTION

Zinc is the most deficient micronutrient in the rice-wheat cropping system. Zinc remains as an important element in the human diet. So, zinc content in the plant should be increased. But the zinc use efficiency is significantly less in calcareous soils and ultimately reduces the availability to plants (Singh and Bhatt, 2013). The causes for the spurt in Zn deficiency in Asian countries include the introduction of high yielding varieties of rice and wheat, application of high rates of high analysis fertilisers such as urea and diammonium phosphate, removal of both grain and straw from the field at harvest, reduced to almost nil application of organic manures and development and adoption of two- to three- crops a year intensive crop rotations, such as rice-wheat (Prasad, 2010) resulting in the mining of native soil nutrients. So, at the very outset, it is essential to know about the factors that affect the availability of zinc. The distribution pattern of the Zn is highly determined by soil reaction (pH), free calcium carbonate, organic carbon, and particle size fractions (Singh *et al.*,2013). Other nutrients may interact with Zn by affecting its availability from soils and its status in the plant through the processes of growth or Zn absorption, distribution or utilisation. In so doing, they may enhance or depress the response of plant growth to Zn. Conversely, Zn may affect other nutrients in the same ways. An interaction between two nutrients is considered statistically significant when the level of application of one nutrient affects plants' response to the other nutrient and vice-versa (Singh *et al.*, 2013). When plants' response to one nutrient increases with an increase in the level of the other nutrient, the interaction is said to be positive, and the nutrients are said to be synergistic. On the other hand, when the response to one nutrient decreases with an increase in the other nutrient level, the interaction is said to be negative, and the two nutrients are said to be antagonistic. Zn also shows the synergistic and antagonistic effects on other nutrients it may affect the crop growth and yield. So it important to know about the effect of higher doses of zinc on other nutrient availability and physicochemical properties. Where interaction does occur, it is important for diagnosis and effective treatment of Zn deficiency in crops.

MATERIALS AND METHODS

Field site and experimental design

A six-year long-term field experiment was initiated during *Kharif* 2012-13 with a rice-wheat cropping system under AICRP on micronutrients at the nursery jhilli area of Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India. The experimental site is situated at a latitude of 250 94 'N, a longitude of 850 67' E and an altitude of 52.00 metres above MSL. The climate is humid subtropical with a hot-humid summer and winter too cold with an average annual rainfall of 1100 mm. In this area, recurrent floods and droughts are normal. The soil belongs to the large group Calciorthent, textured sandy loam, reaction alkaline (pH of 8.52), organic

[1]Deptt. of Soil Science and Ag.Chemistry, PJTSAU, Hyderabad, Andhra Pradesh, India
[2]Deptt. of Agronomy, ANGRAU, Bapatla, Andhra Pradesh, India
[3]Deptt. of Agronomy, Kadiri Babu Rao College of Ag. and Horti., Kanigiri, Andhra Pradesh, India
[4]Department of Agronomy, ANGRAU, Tirupathi, Andhra Pradesh,India
[5]College of Agriculture, JNKVV, Ganj Basoda, Madhya Pradesh, India
[6]Department of Soil Science, RPCAU, Pusa, Samastipur, Bihar, India
*Corresponding author email : Santoshraupusa@gmail.com

carbon medium, nitrogen, phosphorus and potassium and sulphur and zinc deficient.The experiment was laid out in Randomized Block Design (RBD) with thirteen treatments (T_1-T_{13}) and three replications. Treatments (T_1-T_4) received zinc @ 2.5 kg ha^{-1}, 5.0 kg ha^{-1}, 7.5 kg ha^{-1} and 10.0 kg ha^{-1} zinc as $ZnSO_4$ respectively, only once during *Kharif*. Treatments (T_5-T_8) received same doses of zinc as treatments (T_1-T_4), in alternate years in *Kharif* and treatments (T_9-T_{12}) received same doses of zinc as treatments (T_1-T_4), every year in *Kharif*. Treatment T_{13} was the control which did not receive any dose of zinc externally. Rice and wheat crops were grown in succession with recommended doses of fertiliser viz. 120:60:40 of N: P_2O_5:K_2O applied as Urea, DAP and Potash, respectively.

At the end of the experiment, soil samples were collected after the wheat harvest in 2018. In order to evaluate the grain and straw Zn uptake, the plant samples were also obtained. Grain and straw yields of wheat for each plot were recorded at harvest. A di-acid [nitric acid (HNO3): perchloric acid (HClO4); a 9:4 ratio] digest on an atomic absorption spectrophotometer was examined for zinc in grain and straw samples (Tandon, 2005) and presented in Table 1. The collected soil samples were analysed in the laboratory to examine the N, P, K, pH, EC, OC and aggregate stability with different doses and frequencies of zinc application in calcareous soil.

Collection of soil sample

Soil samples were collected from 0-15 cm depth in all treated plots of the experimental field. The collected samples were air-dried in the shade at room temperature, ground with the help of wooden slab and roller then passed through a 2 mm sieve and kept in polythene bags with proper labeling for analysis. Standard methods were followed for analysis of physico-chemical properties of the soil are presented below.

Study of physical properties of soil

Soil texture

It was determined by international pipette method as described by Piper (1966).

Bulk density

The core sampler was pressed into the soil in such a way that soil is collected by the core. Soil samples were dried in the oven at 105^{0}c for 24 hours. Bulk density Mg m^{-3} was calculated by dividing the weight of the dried soil by the volume of core (Blake and Hartage, 1986) using the following formula.

$$\text{Bulk density (Mg m}^{-3}\text{)} = \frac{\text{Weight of oven-dry soil (Mg)}}{\text{Volume of soil (m}^3\text{)}}$$

The volume of the soil was taken as the inner volume of the core sampler, which was in turn calculated by $\Pi r^2 h$ (r = radius, h- the height of the core).

Gravimetric water content

In this method, a fresh soil is dried in an oven, and the loss of water on drying is determined. Drying of soils is done in an oven at 105^{0}C up to a constant weight, and per cent is calculated using the formula:

$$\text{\% Moisture content} = \frac{\text{Weight of fresh soil} - \text{Weight of dry soil} \times 100}{\text{Weight of dry soil}}$$

Aggregate stability

Large clods were broken by hand into smaller pieces along natural cleavage having a size greater than 8 mm. The aggregates were separated using the dry sieving technique (Chepli, 1962). After dry sieving, the soil from each sieve was weighed separately in analytical balance. Then by using this data, mean weight diameter and geometric mean weight diameter were calculated by using the following formulas.

$$MWD = \Sigma WiXi$$

Where,

Xi: Arithmetic mean diameter of each size fraction (mm)

Wi: Proportion of the total sample weight occurring in the fraction i

$$GMD = \exp \Sigma wi \log xi / \Sigma wi$$

Where,

Wi is the weight of aggregate in a size class of average diameter Xi

ΣWi is the total weight of the sample

Study of chemical properties of soil

Soil chemical properties viz. Soil pH [(Jackson, 1973)], Electrical conductivity (EC) [(Bower and Wilcox, 1965)], Organic carbon [Walkley and Black (1934)], Available nitrogen (Mineralisable nitrogen) [Subbiah and Asiji (1956)], Available phosphorus [Olsen's method (1954)], Available potassium [(Champman and Pratt, 1961)], and Available sulphur [(Chesnin and Yien, 1950)] were determined as per the procedure cited against each chemical parameter.

RESULTS AND DISCUSSION

The cumulative yield of rice-wheat system

The cumulative total yield over six years (Rice + Wheat) was recorded significantly higher with every year application of 7.5 kg Zn ha^{-1} (T_{11}) (1026 q ha^{-1}) (Table 1). It was at par with every year application of 5 kg Zn^{-1} (T_{10}) (1016.1 q ha^{-1}), 10 kg Zn ha^{-1} (T_{12}) (981.7 q ha^{-1}) and 7.5 kg Zn ha^{-1} (T_7) (982.9 q ha^{-1}), 10 kg Zn ha^{-1} (T_8) (1009.5 q ha^{-1}) at alternate years (Table 1). Effect of different doses and frequencies of zinc on macronutrients content were analysed in post-harvest soil after completion of the six years experiment. Zinc application as individual doses and yield of the wheat for the sixth year (2018) was not significantly correlated with the available macronutrients and organic carbon content. If we consider the cumulative amount of applied zinc and cumulative biological yields of both rice and wheat, over six years showed a positive correlation with most of the nutrient availability. This may due to applied zinc increases the crop growth, which ultimately adds the more organic matter to the soil through root biomass. Mineralisation of this organic matter increases the available nutrient content in the soil. Along with the addition of nutrients, it also changes some physical properties of the soil. This yield was correlated with organic matter addition. These findings are in tune with observations by Keram *et al.*(2012), based on a pooled analysis of data he revealed that yield, harvest index, nutrient (N, K and Zn) uptake and quality increased significantly with the application of recommended NPK+Zn @ 20 kg ha^{-1} by wheat as compared to NPK alone. In general, yield, harvest index, total nutrient uptake and quality increased up to the highest level of zinc, except total P uptake (Keram *et al.,* 2012).

Table 1: Effect of different doses and frequencies of zinc on cumulative yield (q ha^{-1}) of rice and wheat crops over six years

Treatment	Cumulative Zn content (kg ha-1)	RICE (grain + straw)	WHEAT (grain + straw)	TOTAL (Rice + Wheat)
T1 (2.5 kg Zn ha^{-1}during first year)	2.5	442.8	387.3	830.1
T2 (5.0 kg Zn ha^{-1}during first year)	5.0	477.8	407.6	885.4
T3 (7.5 kg Zn ha^{-1}during first year)	7.5	513.7	415.5	929.2
T4 (10.0 Zn kg ha^{-1}during first year)	10.0	515.0	421.6	936.6
T5 (2.5 kg Zn ha^{-1}at alternate years)	7.5	486.1	400.2	886.3
T6 (5.0 kg Zn ha^{-1}at alternate years)	15.0	499.5	429.3	928.8
T7(7.5 kg Zn ha^{-1}at alternate years)	22.5	510.5	472.4	982.9
T8 (10.0 kg Zn ha^{-1}at alternate years)	30.0	521.8	480.7	1009.5
T9 (2.5 kg Zn ha^{-1}every year)	12.5	491.8	428.5	920.3
T10 (5.0 kg Zn ha^{-1}every year)	30.0	528.0	486.6	1016.1
T11 (7.5 kg Zn ha^{-1} every year)	45.0	530.1	497.1	1026.1
T12 (10.0 kg Zn ha^{-1}every year)	60.0	517.0	469.7	981.7
T13 (Control)	-	415.3	380.3	795.6
SE.m±		13.3	11.6	24.8
CD (p = 0.05)	-	38.7	33.7	72.4

Chemical properties of soil

Organic carbon, Nitrogen, Phosphorous, Potassium and Sulphur content

Organic carbon content was directly related to organic matter addition. It ranged from 0.37 to 0.45 per cent. Organic carbon content was higher in T_8, T_{10} and T_{11} treatments (0.45%) as compared to all other treatments (Table 2). Nitrogen content varies from 256.67 kg ha^{-1} in control(T_{13}) to 299.8 kg ha^{-1} in T_{11} treatment and K_2O from 115 to 126 kg ha^{-1} (T_{11}), S from 13.1 in control to 15.6 kg ha^{-1} (T_{12}) and P_2O_5 from 39.0 (T_{12}) to 49.4 kg ha^{-1} (control). Treatment with Every year application of 7.5 kg Zn ha^{-1} (T_{11}) was shown the significantly higher amount of nitrogen (299.8 kg ha^{-1}) (Table 2) and was at par with every application of 5 and 10 kg Zn ha^{-1} (291.3 and 289.0 kg ha^{-1}), 7.5 (282.0 kg ha^{-1}) and 10 kg Zn ha^{-1} (282.0 kg ha^{-1}) at alternate year. The sulphur content was significantly higher (15.6 kg ha^{-1}) in the plot treated with 5 kg Zn ha^{-1} at every year (T_{10}), and it was at par with every year application of 7.5, 10 kg Zn ha^{-1} and with alternate year application of 10 kg Zn ha^{-1}. A significant effect was not found in case of potassium availability. With the increase in organic matter by one-unit, total N, available P_2O_5 and extractable K_2O increases by 0.038, 31.19 and 5.92 units, respectively, as reported by (Dinesh Khadka, 2016).

Table 2: Effect of different doses and frequencies of zinc on available N, P_2O_5, K_2O and S in post-harvest soil

Treatment	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	S (ppm)
T1 (2.5 kg Zn ha^{-1} during first year)	261.3	48.1	114.3	13.5
T2 (5.0 kg Zn ha^{-1} during first year)	274.0	48.0	117.3	13.6
T3 (7.5 kg Zn ha^{-1} during first year)	282.0	47.3	118.2	14.2
T4 (10.0 Zn kg ha^{-1} during first year)	284.0	47.9	119.5	14.3
T5 (2.5 kg Zn ha^{-1} at alternate year)	275.0	47.3	117.0	13.9
T6 (5.0 kg Zn ha^{-1} at alternate year)	276.0	46.6	120.7	14.3
T7(7.5 kg Zn ha^{-1} at alternate year)	282.0	46.3	122.0	14.3
T8 (10.0 kg Zn ha^{-1} at alternate year)	286.0	44.0	121.3	14.9
T9 (2.5 kg Zn ha^{-1} every year)	277.0	46.6	121.1	14.2
T10 (5.0 kg Zn ha^{-1} every year)	291.3	41.3	125.7	15.4
T11 (7.5 kg Zn ha^{-1} every year)	299.8	41.1	126.0	14.9
T12 (10.0 kg Zn ha^{-1} every year)	289.0	39.0	124.0	14.5
T13 (Control)	256.7	48.0	115.0	13.1
SE.m±	7.51	0.778	2.09	0.43
CD (p = 0.05)	21.9	2.3	NS	1.3

In case of availability of phosphorous significantly lower amount was observed in T_{12} treatment (39.0 kg ha^{-1}) which was at par with T_{11} (41.1 kg ha^{-1}) and T_{10} (41.3 kg ha^{-1}) treatments. It ranged from 39.0 to 48.1 kg P_2O_5 ha^{-1}. Lowest amount was obtained in T_{12} treatment (39.0 kg ha^{-1}). Phosphorous is antagonistic to the supply of zinc when it produces zinc-phosphate. The antagonistic impact often of the higher amount needed (macro) nutrient on the smaller amount required (micro) nutrient. So the supply of phosphate did not affect much by applying zinc. However, under conditions of high Zn supply, P may immobilise Zn in roots through the formation of Zn phytate and zinc phosphate, which has been shown to occur in a wide range of crop plants. Zinc deficiency leads to P accumulation in plants (Welch and Norvell, 1993), because Zn deficient plants lose control over P absorption mechanism. High doses of zinc can decrease plant absorption of P so that it accumulates in the soil. But the phosphorous is again immobilised by calcium carbonate\ and form the insoluble calcium zincate. Mineralisation of phosphorous and sulfur from organic matter is also an important source of these nutrients. But the mineralised phosphorous is again immobilised by calcium carbonate\ and form the insoluble calcium zincate. As discussed earlier, organic matter helps to hold on to positively charged potassium (K^+), calcium (Ca^{++}), and magnesium (Mg^{++}) ions (Sustainable Agriculture Research & Education, 2012) and increase their availability.

pH and EC

The pH value of the experimental plot was ranged from 8.28 to 8.42 (Table 3). Soil pH did not vary significantly with the application of different loads (doses and frequency) of zinc. The electrical conductivity of the given experimental plots ranged from 0.26-0.31 dSm^{-1} (Table 3). It was also not affected by the rate of zinc application. The experimental plot was very calcareous in nature, and the application of zinc was not affecting the pH and electrical conductivity (EC) of the soil. Similar results have been reported by Keram *et al.,* 2012. But here, the high calcium carbonate (35%) content of the experimental field acts as a buffering agent to resist the change in pH.

Table 3: Effect of different doses and frequencies of zinc on O.C, pH, EC, bulk density and moisture content

Treatment	OC (%)	pH	EC ($dS\ m^{-1}$)	Bulk density ($g\ cm^{-3}$)	Moisture content (%)
T1 (2.5 kg Zn ha^{-1} during first year)	0.39	8.31	0.27	1.34	8.60
T2 (5.0 kg Zn ha^{-1} during first year)	0.42	8.42	0.26	1.34	8.08
T3 (7.5 kg Zn ha^{-1} during first year)	0.43	8.31	0.28	1.30	8.84
T4 (10.0 Zn kg ha^{-1} during first year)	0.43	8.37	0.29	1.30	8.80
T5 (2.5 kg Zn ha^{-1} at alternate years)	0.42	8.42	0.27	1.33	8.61
T6 (5.0 kg Zn ha^{-1} at alternate years)	0.43	8.35	0.28	1.30	8.70
T7(7.5 kg Zn ha^{-1} at alternate years)	0.44	8.37	0.28	1.28	9.00
T8 (10.0 kg Zn ha^{-1} at alternate years)	0.45	8.28	0.29	1.27	9.08
T9 (2.5 kg Zn ha^{-1} every year)	0.42	8.31	0.27	1.33	8.70
T10 (5.0 kg Zn ha^{-1} every year)	0.45	8.32	0.29	1.25	9.10
T11 (7.5 kg Zn ha^{-1} every year)	0.45	8.28	0.29	1.23	9.13
T12 (10.0 kg Zn ha^{-1} every year)	0.44	8.28	0.31	1.29	8.90
T13 (Control)	0.37	8.34	0.28	1.35	8.51
SE.m ±	0.011	0.22	0.010	0.022	0.150
CD (p = 0.05)	0.03	NS	NS	0.07	0.44

Physical properties of soil

Bulk density, Moisture Content and Aggregate Satbility

Bulk density was significantly influenced by different zinc loads. It varied from 1.23 in treatment T_{11} to 1.35 g cm^{-3} in treatment T_{13} (Table 3). Treatments T_7, T_8, T_{10}, T_{11} and T_{12} had significantly lower bulk density than control (T_{13}). Considerably low bulk density was observed in 7.5 kg Zn ha^{-1} at every year (1.23 g cm^{-3}) treated plot where higher organic carbon was found. Table 3 showed that there was a significant difference in moisture content with different applications of zinc, and it varied from 9.13 to 8.51 per cent. Zinc treated plot with 7.5 kg ha^{-1} at every year (T_{11}) recorded the highest moisture content (9.13%), and it was at par with T_7, T_8, T_{10} and T_{12} and lowest moisture content was recorded in control (8.51%). Treatments T_7, T_8, T_{10}, T_{11} and T_{12} also registered significantly higher moisture content over control (Table 3).

Mean weight diameter (MWD) ranges from 2.95–3.57 mm. Higher MWD was recorded in every year treated plot with 7.5 kg Zn ha^{-1} (3.57 mm), and it was at par with T_7, T_8, T_{10} and T_{12}. Geometric mean diameter (GMD) varied from 1.36 to 1.63 mm. As MWD, every year treated plot with 7.5 kg Zn ha^{-1} was recorded higher (1.63 mm) GMD, and it was at par with T_7, T_8, T_{10} and T_{12} (Table 4). Increased rate of zinc application leads to an increase in both crop growth and yield. This ultimately leads to the increased organic matter addition through root decomposition, which adds organic carbon to the soil. It leads to the development of the soil's good physical condition, which ultimately increases the nutrient availability in the soil. The addition of different loads (doses and frequencies) of zinc was showed a significant effect on physical properties (bulk density, moisture content and aggregate stability) of soil. As we said earlier, the applied zinc increases the crop growth, which ultimately adds the more organic matter to the soil

Table 4: Effect of different doses and frequencies of zinc on aggregate stability

Treatment	GMD (mm)	MWD (mm)
T_1 (2.5 kg Zn ha^{-1} during first year)	1.43	3.06
T_2 (5.0 kg Zn ha^{-1} during first year)	1.49	3.12
T_3 (7.5 kg Zn ha^{-1} during first year)	1.54	3.18
T_4 (10.0 Zn kg ha^{-1} during first year)	1.58	3.24
T_5 (2.5 kg Zn ha^{-1} at alternate years)	1.54	3.21
T_6 (5.0 kg Zn ha^{-1} at alternate years)	1.58	3.34
T_7(7.5 kg Zn ha^{-1} at alternate years)	1.61	3.43
T_8 (10.0 kg Zn ha^{-1} at alternate years)	1.62	3.47
T_9 (2.5 kg Zn ha^{-1} every year)	1.54	3.39
T_{10} (5.0 kg Zn ha^{-1} every year)	1.59	3.52
T_{11} (7.5 kg Zn ha^{-1} every year)	1.63	3.57
T_{12} (10.0 kg Zn ha^{-1} every year)	1.61	3.53
T_{13} (Control)	1.36	2.95
SE.m ±	0.03	0.06
CD (5%)	0.08	0.17

through root biomass, which leads to a decrease in bulk density, increases in moisture-holding capacity, and stable formation aggregates.

Correlation between cumulative zinc content with physical and chemical properties of soil

The relationship between cumulative zinc content (total for 6 years) and physico-chemical properties of soil in rice wheat cropping system in calcareous soils has been presented in Table 5. Cumulative zinc content was positively and significantly correlated with Organic carbon (OC) (r = 0.695**), MWD (r = 0.862**), GMD (r = 0.718**), moisture content (0.662*), N (r = 0.742**), S (r = 0.688**) and cumulative yield of rice-wheat cropping system (0.786**). Electric conductivity and K_2O in soil did not have any correlation with applied zinc (r = 0.552 NS and 0.796 NS) and had a negative correlation with pH (r = -0.585*), B.D (r = -744**) and available P_2O_5 (r = -0.970**). Organic carbon (O.C) had significant positive correlation with MWD (r = 0.886**), GMD (r = 0.968**), moisture content (0.670*) and with available N (r = 0.896**), K_2O (r = 0.773**), S (r = 0.884**). It was negatively correlated with B.D (r = -0.848**) and P_2O_5 (r = -0.685**). No correlation was observed regarding pH and electrical conductivity of the soil. The result revealed that soil organic matter was significantly and positively correlated with primary nutrients namely; total N (r=.73**).), available P_2O_5 (r=.57**) and extractable K_2O (r=.35**). A significant and positive correlation was obtained for sulphur by Singh and Mishra (2012), Acquaye and Beringer (1989). The above observations show the indirect effect of zinc application on increased nutrient availability except for P_2O_5.

Table 5: Correlation between cumulative zinc content with physical and chemical properties of soil in rice wheat cropping system in calcareous soils

	Cum-Zn	OC	MWD	GMD	B.D	Moist cont	pH	EC	N	P2O5	K2O	S	Yield
Cum-Zn	1												
OC	0.695**	1											
MWD	0.862**	0.886**	1										
GMD	0.718**	0.968**	0.905**	1									
B.D	-0.744**	-0.848**	-0.851**	-0.817**	1								
Moist cont	0.662*	0.670*	0.773**	0.707**	-0.864**	1							
pH	-0.585*	-0.249NS	-0.479NS	-0.257NS	0.491NS	-0.649*	1						
EC	0.816**	0.489NS	0.617*	0.542NS	-0.638*	0.713**	-0.617*	1					
N	0.742**	0.896**	0.882**	0.847**	-0.966**	0.776**	-0.378NS	0.541NS	1				
P2O5	-0.970**	-0.685**	-0.832**	-0.695**	0.728**	-0.650*	0.654*	-0.766**	-0.728**	1			
K2O	0.796**	0.773**	0.868**	0.719**	-0.927**	0.798**	-0.531NS	0.603*	0.926**	-0.802**	1		
S	0.688**	0.883**	0.884**	0.828**	-0.901**	0.809**	-0.455NS	0.582*	0.912**	-0.676*	0.870**	1	
Yield	0.786**	0.967**	0.944**	0.943**	-0.928**	0.794**	-0.415NS	0.605*	0.948**	-0.768**	0.888**	0.925**	1

CONCLUSION

The cumulative yield of rice and wheat over six years was maximum in treatment $T_{11,}$ *i.e.* zinc applied @ 7.5 kg Zn ha^{-1} at every year (1026.1 q ha^{-1}). It was at par with treatments T_{10} and $T_{12,}$ i.e. zinc applied @ 5.0 and 10 kg Zn ha^{-1} every year respectively and treatments T_7 and T_8 *i.e.* zinc applied @ 7.5 and 7.5 kg Zn ha^{-1} in alternate year respectively. Thus, treatment $T_{7,}$ i.e. application of zinc @ 7.5 kg Zn ha^{-1} in alternate year application was the best treatment with regards to yield of rice-wheat cropping (982.9 q ha^{-1}).

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