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Angelin Silviya R
Ph.D Research scholar, Department of Soil Science and Agricultural Chemistry Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

P Stalin
Professor (SS&AC), Department of Soil Science and Agricultural Chemistry Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

Correspondence
Angelin Silviya R
Ph.D Research scholar, Department of Soil Science and Agricultural Chemistry Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

Response of irrigated rice to applied zinc under varying available zinc status of rice soils in Tamil Nadu

Angelin Silviya R and P Stalin

Abstract
Field experiments were conducted in the major rice growing tracts having varied soil Zn status to study the effect of Zn fertilization in irrigated rice. The treatments consisted of six levels of Zn (0 1.25, 2.50, 5.00, 7.50 and 10.0 kg ha^{-1}) in a Randomized block design. The results revealed that the growth and yield were higher in location 4 where the soil Zn content was minimum (0.87 mg kg $^{-1}$), compared to locations 6 to 12 where the soil Zn content was comparatively high (0.98 to 2.99 mg kg $^{-1}$). Averaged for all locations, the application of Zn @ 7.5 kg ha^{-1} recorded significantly the highest yield of grain (6.81 t ha^{-1}) and straw (8.09 t ha^{-1}). Hence, application of Zn significantly increased the growth and yield of rice in Zn deficient soils, while higher Zn levels showed a decline or no response in soils having high zinc status.

Keywords: Micronutrient, Zinc, Rice growth, Rice yield, Yield parameters

1. Introduction

The requirement of micronutrients by crops for their normal growth and yield is small when compared with the macronutrients but the micronutrients are desperately needed by the plants for completing their lifecycle. Among all the micronutrients (Fe, Mn, Zn, Cu, B and Mo), Zinc (Zn) plays a vital role in crop growth. The importance of Zn in plant was first established by Maze in Maize crop during 1915. Zinc is an integral component of various enzymes like alcohol dehydrogenase, carbonic anhydrase, Cu-Zn superoxidase dismutase, alkaline phosphatase, phospholipase, carboxy peptidase and RNA polymerase. It is also required for maintaining the integrity of bio membranes in the plants (Hafeez *et al.*, 2013) [4].

The cereal crops like rice, wheat and maize are highly susceptible to Zn deficiency. Among the cereal crops, rice stands as an important food crop which is consumed by more than half of the world's population. The rice forms an integral part of the culinary traditions of different cultures in the world. Rice provides 20 per cent of the world's dietary energy supply with a good source of thiamine, riboflavin, niacin and dietary fiber (Anon, 2002) [2]. In 2015, the world's rice production was recorded as 472.1 m t from an area of 157.8 m ha and nearly 92 per cent of world's rice were produced and consumed in Asian continent. In Asian continent, India has the largest area (29.4% of global rice area) under rice cropping system (Humaira *et al.,* 2015) [6]. Whereas the rice grain productivity in India (2.04 t ha^{-1}) is very low when compared with the other major rice producing countries as Japan (6.25 t ha^{-1}), China (6.24 t ha^{-1}) and Indonesia (4.25 t ha^{-1}). In India, Tamil Nadu ranks third in the rice productivity among all the other states with a cultivated area, production and productivity of 17.26 lakh ha, 71.15 m t and 4122 kg ha^{-1}, respectively (Mahata *et al.*, 2012) [10]. By 2030, India needs to produce 143 m t of rice for meeting the food requirement of the increasing population (Muthukumararaja and Sriramachandrasekharan, 2012) [13].

The deficiency of one or more micronutrients frequently occurs in agricultural soils and the impact of such deficiency was measured in crop yield loss. Micronutrient deficiencies are rampant in Indian soils with an average of 43.0, 12.1, 5.6 and 18.3 per cent of Zn, Fe, Cu, Mn and B, respectively. The DTPA extractable Zn in the Indian soils ranged in between 0.01 to 52.93 mg kg^{-1} soil. The soil samples collected across the country showed 43 per cent of Zn deficiency and the deficiency was recorded high in Tamil Nadu soils (65.5%) followed by Madhya Pradesh (61.7%), Maharashtra (54%) and Bihar (41.4%) (Shukla *et al.*, 2014). It is estimated that about 324 thousand tones of Zn ha^{-1} yr^{-1} sources will be required by 2025 for raising the crops successfully (Singh, 2009) [18].

This implies that balanced plant nutrition is essential for sustained increase in crop productivity. Keeping in view about the importance of zinc nutrition for irrigated rice, the objective was framed to study the response of rice to zinc fertilization in relation to the available Zn status of rice soils in Tamil Nadu.

Materials and Methods

The research study involved diverse works as soil survey in the major rice growing tracts of Tamil Nadu, soil sample collection, soil analysis for various physico-chemical parameters and field experimentation in different locations.

Soil Sampling

In total, 142 representative soil samples were collected from the surface layer (0–15cm) over the major rice growing tracts of Tamil Nadu viz., Erode district (Gopichettiplayam, Bhavanisagar and Sathyamangalam blocks), Coimbatore district (Aanaimalai block), Tiruvarur district (Thiruthuraipoondi block) and Tirunelveli district (Ambasamudaram block). The collected soil samples were air dried, ground in a wooden mortar, passed through 2mm sieve and stored in polythene bags for various analysis.

Soil analysis

The textural classes of the collected soil samples were determined by following the International Pipette Method (Piper, 1966). The soil samples were analyzed for pH (1:2.5 soil-water suspension) using pH meter and Electrical Conductivity (1:2.5 soil-water suspension) using conductivity meter. The cation exchange capacity (CEC) of the soil was determined using Neutral Normal NH_4OAc (Schollnberger and Dreibelbis, 1930). The Organic Carbon (OC) content of the soil was determined by following Chromic acid wet digestion method (Walkley and Black, 1934). The available Zn status in the soils was estimated by DTPA extractable method proposed by Lindsay and Norvell (1978). Based on the available soil Zn status, the soils were grouped into six categories as, ≤ 0.6, 0.6-0.9, 0.9-1.2, 1.2-1.5, 1.5-1.8 and ≥ 1.8 mg kg^{-1} of soil available Zn.

Field experiments

The field experiments were conducted during Kharif / Rabi season of 2014-2015 and 2015-2016 to study the response of rice crop to the Zn fertilization on different soils having varying soil available Zn status. Based on the soil available Zn, the soils were categorized into six categories as ≤ 0.6, 0.6-0.9, 0.9-1.2, 1.2-1.5, 1.2-1.8 and ≥ 1.8 mg kg^{-1} of soil available Zn. Twelve field experiments were conducted (two field experiments per each category) in Erode, Coimbatore, Tiruvarur and Tirunelveli districts of Tamil Nadu by adopting the Randomized Block Design with four replications and six treatments, T1 to T6 (0, 1.25, 2.5, 5.0, 7.5 and 10 kg Zn ha^{-1}).The rice variety ASD 16 was used as a test crop.

In all the treatment plots, the NPK application was carried out uniformly by following the general recommendation as 150:50:50 kg ha^{-1} of N_2O, P_2O_5 and K_2O. Nitrogen was applied in four equal splits as basal dose, active tillering, panicle initiation and heading stages. Entire dose of Phosphorous was applied as a basal dose. Potassium was applied in two equal splits as basal dose and at panicle initiation stage. The Zn fertilizer was applied in the form of $ZnSO_4$. Need based intercultural operations were carried out during the cropping period. In the experimental fields, the biometric observations (plant height and number of productive tillers per sq.m.), yield parameters (number of filled grains per panicle and test grain weight) and yield of grain and straw were recorded at harvest stage.

Results and Discussion

Soil properties

The soil samples used in the present study varied in their soil properties. The soils of various experimental locations belong to different textural classes as sandy loam, sandy clay loam, clay loam and clay. The pH of the soils ranged from 6.52 to 7.98 which were neutral to slightly alkaline in nature. The EC of the soils were free from salinity (0.12 to 0.32 d Sm^{-1}).

The cation exchange capacity (CEC) of the experimental soil ranged from 13.5 to 21.2 Cmol (P+) kg^{-1} of soil. The organic carbon ranged in between 2.5 to 5.8 g kg^{-1} which is of medium category. The soil Zn content ranged in between 0.39 to 2.99 mg kg^{-1} at various locations (Table 1).

Biometric observations

The plant height is one of the main indicators of the physiological process in any crop and they get accelerated by the soil nutrient status. Alloway (2008) reported the positive effect of Zn in many crops at his research works. The data recorded in the Table 2 revealed that, irrespective of locations the plant height got influenced by the application of $ZnSO_4$. The mean plant height ranged from 93.8 to 100.0 cm and among different locations, L4 recorded the maximum plant height of 98.9 cm and a minimum of 94.4 cm was recorded in L1. Among different treatments, T5 viz., 7.5 kg Zn ha^{-1} recorded the highest mean plant height (100.0 cm) which was 6.2 per cent higher over control, followed by T4 (99.5 cm) and T6 (98.5 cm). The Zn application significantly increased the plant height which might be attributed to the adequate supply of NPK with Zn. The Zn accelerates the enzymatic activity and auxin metabolisim in crops. Srinivasan and Naidu (1996) reported that the increase in the plant height with Zn dose might be due to the auxin metabolism that "the Zn favorably influenced the shoot length most probably through auxin metabolism". Those results were in agreement with the findings of Khan *et al.* (2007) and Humaira *et al.* (2015) [6].

Table 1: Initial soil properties of various field experiments

Locations	Soil texture	pH	EC (dSm^{-1})	CEC (Cmol (p+)kg^{-1})	OC (g kg^{-1})	Soil available Zn (mg kg^{-1})
L1	Sandy Clay Loam	6.52	0.22	16.8	3.8	0.39
L2	Sandy Loam	7.73	0.15	13.5	2.8	0.57
L3	Clay	7.40	0.32	21.2	4.5	0.64
L4	Sandy Clay Loam	7.55	0.25	18.2	5.8	0.87
L5	Clay Loam	7.50	0.18	15.5	3.5	0.98
L6	Sandy Loam	6.73	0.12	14.2	2.5	1.16
L7	Sandy Clay Loam	7.98	0.19	15.0	4.8	1.31
L8	Sandy Clay Loam	7.68	0.27	16.5	4.4	1.36
L9	Sandy Loam	6.63	0.13	14.7	2.8	1.61

L10	Clay Loam	7.44	0.18	15.0	3.3	1.77
L11	Sandy Clay Loam	7.02	0.18	15.8	3.5	1.98
L12	Sandy Loam	7.75	0.15	13.9	2.7	2.99

The number of productive tillers gets influenced by the application of Zn fertilizers. The highest number of productive tillers was recorded in T5 viz., 7.5 kg Zn ha^{-1} (269.7 tillers m^{-2}) which was 18.3 per cent higher over control, followed by T4 (263.9 tillers m^{-2}) and T6 (259.5 tillers m^{-2}). The control plot recorded the lowest number of productive tillers (220.3 tillers m^{-2}). Among all the locations, L4 recorded the highest number of productive tillers (262.1 tillers m^{-2}) and the L1 recorded the lowest number of productive tillers as 234.2 tillers m^{-2} (Table 2). The increase in the number of productive tillers might be due to the improvement in the enzymatic activity and auxin metabolism in plants. Hafeez *et al.* (2013) [4] also reported similar findings.

Yield parameters

The yield parameters comprise of number of filled grains per panicle and test grain weight (g). The application of Zn fertilizer significantly influenced the number of filled grains per panicle in rice crop. The fourth location (L4) recorded the highest number of filled grains as 108.9 per panicle (Table 3) and the lowest of 101.0 numbers of filled grains per panicle was noted in the first location (L1) where the initial soil available Zn status is very low. Among the six treatments, the T5 recorded the highest number of filled grains as 106.6 per panicle which was 4.4 per cent higher over control followed by T6 (105.3 per panicle) and T4 (105.1 per panicle). These findings were in agreement with the findings of Yadi *et al.* (2012) and Hafeez *et al.* (2013) [4].

The test grain weight (1000 grain weight) was also significantly got increased by the application of Zn fertilizer. The treatment T5 viz., 7.5 kg Zn ha^{-1} recorded the highest test grain weight of 25.1 g which is of 2.8 per cent higher over control. The lowest grain weight was recorded in the control plot (T1 – 24.4 g). Among the twelve locations, L4 recorded the highest value of 25.2 g and L11, L12 recorded the lowest value of 24.2 g (Table 3). Hemantaranjan and Grag (1988) observed that optimum utilization of Zn significantly increased thousand grain weight in wheat and similar results were also recorded by Rahman *et al.* (2008).

Yield

The crop yield determines the agricultural production and therefore the yield is an important crop sustainability indicator. The yield of grain and straw gets significantly increased by the application of Zn fertilizers. Among twelve locations, the L4 recorded the highest grain yield of 6.38 t ha^{-1} and the L12 recorded the lowest grain yield of 5.83 t ha^{-1}. Among the six treatments, the T5 viz., 7.5 kg Zn ha^{-1} recorded the highest mean grain yield of 6.81 t ha^{-1} which is of 29.2 per cent higher over control. The control (T1) recorded the lowest grain yield of 4.82 t ha^{-1}. Similar to the grain yield, the straw yield was also recorded high in T5 (8.09 t ha^{-1}) which is of 25.0 per cent higher over control and the control plot (T1) recorded the lowest straw yield (6.07t ha^{-1}). In twelve locations, the L4 recorded the highest straw yield of 7.64 t ha^{-1} whereas the L12 recorded the lowest straw yield of 7.18 t ha^{-1} (Table 4). The increased yield was recorded due to the effect of Zn on plant growth by enhancing the crop root proliferation.

Table 2: Effect of Zn on plant height (cm) and number of productive tillers m^{-2} of rice crop at harvest stage

Zn levels (kg ha^{-1})	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	Pooled mean	Per cent over control
	Plant height (cm)													
0.00	88.5	90.4	90.8	92.1	92.7	95.0	95.4	95.8	96.0	95.7	96.5	96.7	93.8	-
1.25	91.4	93.0	93.4	95.4	95.1	94.7	94.8	94.4	96.2	96.4	98.8	98.4	95.2	1.5
2.50	93.5	95.4	96.1	97.0	96.9	96.0	97.5	97.4	99.5	99.1	97.6	97.7	97.0	3.3
5.00	95.7	97.1	101.0	103.4	102.8	101.6	101.4	101.0	97.7	97.7	97.4	97.5	99.5	5.7
7.50	99.7	101.5	102.6	104.5	103.0	103.3	98.6	98.3	97.2	97.5	97.1	97.1	100.0	6.2
10.00	97.6	100.0	100.4	101.2	101.0	100.0	99.6	99.0	96.5	96.4	95.4	94.3	98.5	4.8
Mean	94.4	96.2	97.4	98.9	98.6	98.4	97.9	97.7	97.2	97.1	97.1	96.9		
SEd	0.89	0.99	0.78	1.16	0.87	0.64	0.93	0.7	0.79	0.85	0.78	0.78		
CD (5%)	1.92	2.11	1.66	2.48	1.86	1.35	1.99	1.49	1.69	1.8	1.67	1.65		
	Number of productive tillers m^{-2}													
0.00	176	192	208	214	220	224	226	234	236	236	238	240	220.3	-
1.25	192	208	240	250	250	245	245	243	240	240	260	256	239.1	7.9
2.50	242	240	256	261	254	241	237	250	264	260	245	250	250.1	11.9
5.00	262	272	268	275	270	260	272	270	258	258	252	250	263.9	16.5
7.50	291	280	280	292	285	280	268	260	252	252	250	247	269.7	18.3
10.00	242	274	275	280	278	264	260	250	248	248	248	247	259.5	15.1
Mean	234.2	244.3	254.5	262.1	259.5	252.3	251.4	251.2	249.7	249.0	248.9	248.3		
SEd	1.96	1.52	2.19	2.58	2.14	1.79	2.82	1.59	2.03	2.42	1.85	2.67		
CD (5%)	4.18	2.25	4.69	5.49	4.57	3.81	6.01	3.39	4.32	5.15	3.94	5.68		

Table 3: Effect of Zn on number of filled grains per panicle and test grain weight (g) of rice crop at harvest stage.

Zn levels (kg ha^{-1})	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	Pooled mean	Per cent over control
Number of filled grains per panicle														
0.00	91	98	99	101	101	103	104	104	105	105	106	106	101.9	-
1.25	99	101	102	104	104	105	104	104	105	105	107	107	103.9	1.9
2.50	100	104	104	108	107	106	105	105	106	107	104	104	104.9	2.8
5.00	104	105	105	108	108	106	107	107	105	104	102	100	105.1	3.1
7.50	108	110	110	122	112	109	106	105	100	98	101	98	106.6	4.4
10.00	104	106	106	110	108	107	105	105	105	103	102	102	105.3	3.2
Mean	101.0	103.9	104.4	108.9	106.6	106.0	105.2	105.1	104.3	103.7	103.6	102.8		
SEd	0.76	1.05	0.71	0.67	0.59	0.83	0.89	0.44	0.57	0.91	0.47	0.96		
CD (5%)	1.61	2.25	1.52	1.43	1.27	1.76	1.89	0.94	1.22	1.93	0.99	2.05		
Test grain weight (g)														
0.00	23.8	23.9	24.0	24.3	24.3	24.5	24.5	24.6	24.6	24.6	24.6	24.6	24.4	-
1.25	24.0	24.3	24.3	24.5	24.5	24.2	24.2	24.2	24.2	24.2	24.8	24.8	24.4	-
2.50	24.6	24.8	25.0	25.2	24.8	24.3	24.2	24.1	24.9	24.8	24.2	24.2	24.6	0.8
5.00	25.0	24.9	25.2	25.5	24.8	24.4	25.4	25.4	24.6	24.2	24.0	24.0	24.8	1.6
7.50	25.2	25.8	25.8	26.2	25.8	25.5	25.3	25.2	24.4	24.1	24.0	24.0	25.1	2.8
10.00	24.8	24.9	25.0	25.5	25.1	25.0	24.5	24.1	24.2	24.2	23.8	23.5	24.6	0.8
Mean	24.6	24.8	24.9	25.2	24.9	24.7	24.7	24.6	24.5	24.3	24.2	24.2		
SEd	0.25	0.16	0.24	0.25	0.19	0.16	0.26	0.21	0.21	0.2	0.19	0.19		
CD (5%)	0.52	0.33	0.51	0.53	0.42	0.35	0.56	0.46	0.45	0.43	0.41	0.42		

Table 4: Effect of Zn on the yield of grain and straw (t ha^{-1}) of rice crop

Zn levels (kg ha^{-1})	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	Pooled mean	Per cent over control
Grain yield (t ha^{-1})														
0.00	4.20	4.39	4.46	4.57	4.62	4.75	4.86	4.97	5.10	5.14	5.38	5.42	4.82	-
1.25	4.82	5.15	5.21	5.36	5.15	5.29	5.38	5.40	6.22	6.24	6.56	6.42	5.60	13.9
2.50	6.12	6.25	6.25	6.35	6.20	6.30	6.45	6.45	6.83	6.62	6.25	6.18	6.35	24.1
5.00	6.88	7.06	7.15	7.28	7.15	6.92	7.03	7.05	6.52	6.42	6.07	5.92	6.79	29.0
7.50	7.18	7.33	7.40	7.49	7.38	7.22	6.82	6.76	6.35	6.30	5.87	5.60	6.81	29.2
10.00	6.90	7.04	7.10	7.25	7.10	6.82	6.68	6.54	6.08	6.25	5.40	5.45	6.55	26.4
Mean	6.02	6.20	6.26	6.38	6.27	6.22	6.20	6.20	6.18	6.16	5.92	5.83		
SEd	0.06	0.06	0.06	0.42	0.05	0.07	0.07	0.06	0.14	0.05	0.04	0.06		
CD (5%)	0.14	0.13	0.13	0.89	0.09	0.15	0.14	0.13	0.29	0.11	0.09	0.13		
Straw yield (t ha^{-1})														
0.00	5.45	5.64	5.70	5.80	5.86	5.94	6.16	6.32	6.43	6.48	6.52	6.57	6.07	-
1.25	6.17	6.45	6.48	6.62	6.44	6.47	6.70	6.65	6.58	6.80	7.72	7.85	6.74	9.9
2.50	7.37	7.52	7.54	7.63	7.45	7.44	7.80	7.72	8.07	8.16	7.54	7.40	7.64	20.5
5.00	8.10	8.30	8.41	8.54	8.40	8.22	8.25	8.20	7.82	7.72	7.48	7.31	8.06	24.7
7.50	8.45	8.55	8.64	8.75	8.64	8.38	7.87	7.82	7.78	7.61	7.31	7.28	8.09	25.0
10.00	8.15	8.32	8.35	8.52	8.35	8.04	7.76	7.70	7.62	7.40	6.60	6.65	7.79	22.1
Mean	7.28	7.46	7.52	7.64	7.52	7.42	7.42	7.40	7.38	7.36	7.20	7.18		
SEd	0.08	0.07	0.09	0.08	0.03	0.05	0.07	0.08	0.07	0.06	0.04	0.07		
CD (5%)	0.16	0.14	0.19	0.17	0.07	0.11	0.15	0.16	0.15	0.13	0.08	0.16		

The increased root proliferation improved the nutrient uptake rate from soil and in turn it enhanced the supply of nutrients to the aerial part of the plants. Also the Zn fertilization improved the synthesis of carbohydrates and their transport to the site of grain production gets influenced positively. Similar findings were reported by Naik and Das (2008), Mandal and Das (2013), Keram *et al.* (2014) and Sudha and Stalin (2015)

Conclusion

Application of $ZnSO_4$ in the Zn deficient soil showed a desperate increase in the growth and yield of rice crop. The highest growth was recorded in the fourth location where the initial soil available Zn status was minimum (0.87 mg kg^{-1} of soil available Zn) and the soils with higher level of initial soil available Zn content (L6 to L12) showed a reduction in the growth and yield parameters. The study clarifies that, the soils with adverse soil Zn deficiency responded positively to the Zn application whereas declining trend was recorded by the application of Zn to the soils beyond optimum level of soil available Zn. This shows that the soil should have an optimum level of Zn for good crop growth. Lesser than the optimum level of soil Zn will lead to Zn deficiency and higher than the optimum level will lead to toxicity and hence both will reduce the growth and yield of rice.

The application of Zn @ 7.5 kg ha^{-1} recorded the highest plant height, number of productive tillers per sq.m., number of filled grains per panicle, test grain weight, grain yield and straw yield, the per cent increase being 6.2, 18.3, 4.4, 2.8, 29.2 and 25.0 per cent respectively over control (NPK alone). Hence the application of balanced fertilizer (NPK+ Zn @ 7.5 kg ha^{-1}) holds the key for increasing the rice production in the Zn deficient soils. This strategy will help in alleviating the Zn deficiency in the food chain namely, soil-plant-animal-human continuum

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