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Status of Zinc in Soils of Veeranam Ayacut Area and Response of Rice to Zinc Fertilization

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ABSTRACT

Two hundred surface soil samples were collected from Chidambaram taluk of Veeranam ayacut area belonging to three soil orders (Vertisol, Alfisol and Entisol) to assess the zinc status and fix critical limit of Zn in soil and rice crop. The soil had pH (6.0- 8.9), EC (0.2-1.7 dSm^{-1}), organic carbon (2.7-11.4 g kg^{-1}), $CaCO_3$ (0.33-7.54%), $KMnO_4$-N (214-391 kg ha^{-1}), Olsen-P (19-54 kg ha^{-1}), NH_4OAc-K (147-366 kg ha^{-1}) and DTPA-Zn (0.23 – 1.98 mg kg^{-1}). The zinc fractions viz., WS-Zn (0.09- 0.53 mg kg^{-1}), Ex-Zn (0.18 – 0.96 mg kg^{-1}), Com-Zn (2.02-5.50 mg kg^{-1}), Org-Zn (2.10 - 4.78 mg kg^{-1}), Occul-Zn (2.43-4.97 mg kg^{-1}), Res-Zn (70.19-120.63 mg kg^{-1}) and Total Zn (80.15-131.8 mg kg^{-1}). Different extractants were used to assess the plant available zinc. Based on the regression values, DTPA extractable zinc was found to be the best extractant. Pot experiments were conducted to study the response of rice to graded dose of zinc (0, 2.5, 5.0 and 7.5 ppm). Rice grain and straw yields increased up to 5 ppm Zn (37.04,48.64 g pot^{-1} in Vertisol and 43.02,37.45g pot^{-1} in Entisol) and decreased with further addition of zinc.

Key words: Zinc, Rice yield, DTPA, Zinc fractions

Soil is the main reservoir of nutrients from which plants absorb them directly for their growth and proper development. Zinc is absorbed by plants generally in divalent form. However, the availability of Zn from soil depends on soil physico-chemical properties. Zinc deficiency has been reported on a variety of soils ranging from arid to tropical climate due to difference in their Zn bioavailability and total Zn content in soil is not a true indicator of its bioavailability to the growing plants [1]. Zinc may bind with various organic and inorganic soil components present in different agro-ecological zones of the world [2]. Soil factors, which contributes to low Zn bioavailability, are low Zn content in soil, high pH, calcareousness, low organic matter, salt affected soil, highly weathered and coarse textured soil, clay content and type of clay minerals [3]. Zinc deficiency had been reported in almost 49 countries of the world [4]. In India, Zn deficiency is expected to increase from 42 per cent in 1970 to 63 per cent by 2025 due to continuous depletion of soil Zn fertility under intensive cropping [5]. Considering yield responses, as much as 78 per cent of soils were found low in Zn as there was a shift in Zn response and up to 69 per cent field trials showed increased response upto 500 kg ha^{-1} to Zn compared to only 43 per cent trials responding in early seventies [6] (Singh, 2011). In Tamil Nadu, 53 per cent of soils are found deficient in Zn, while in Zn deficiency in South Indian soils is most commonly seen in soils under Vertisol and Alfisol [7]. Micronutrient stress in Indian soils started appearing due to adoption of intensive agricultural technology and that zinc deficiency is the second most serious nutritional disorder limiting the yield of lowland rice. Approximately 50% of the soils used worldwide for cereal production contains low levels of plant available zinc. Response of rice to Zn has been reported by several workers in India [8-9].

MATIREALS AND METHODS

The soils of Chidambaram taluk fall under six series viz., 1) Kondal (Knd), 2) Valuthalakudi (Vid), 3) Adanur (Adn), 4) Padugai (Pdg), 5) Madukkur (Mdk) and 6) Pattukottai (Pkt) distributed in Vertisol, Alfisol and Entisol orders. The study area is located in the Cauvery delta agro climatic zone. The climate of the command area is tropical. The paddy is major crop in this area. A total of 50 composite soil samples (0-15 cm) were collected from six soil series of Chidambaram taluk. To assess the zinc status in soil. Soil samples were dried in shade, ground with wooden mallet and passed through 2 mm sieve. The processed soil samples were stored in separate polyethylene bags and used for various physico-chemical analysis. In order to estimate various Zn fractions in soil, sequential extraction of soil samples (collected from six soil series) was performed

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following the procedure of Sarkar and Deb [10]. Zinc present in different forms was analyzed using atomic absorption spectrometer. Different soil Zn fractions were correlated with soil physico-chemical properties. A pot experiment with rice variety ADT 43 was conducted in net house of Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Chidambaram, Tamil Nadu, India. Rice is grown in Vertisol and Entisol. Hence, fifty soil samples belong to Vertisol (23) and Entisol (27) were used in pot experiments.

RESULTS AND DISCUSSION

Initial soil characteristics

The experimental soil used for fixing critical limit of zinc belonged to Vertisol and Entisol. The experimental soil had pH ranging from 6.2-8.8 (slightly acidic to strongly alkaline) with a mean value of 7.6. The alkaline nature of these soils may be because of semi-arid climate, parent material (basalt), due to restricted drainage and relatively higher $CaCO_3$ and exchangeable bases in Vertisol [11]. Acidic to neutral nature of Alfisol may be due to acidic parent material from which these soils are formed. Electrical conductivity of the soil ranged from 0.27 to 1.6 dSm^{-1} with a mean value of 0.76 dSm^{-1}. During the process of weathering and soil formation, soluble salts that accumulate in soils are chlorides and sulfates of sodium, calcium and magnesium. Vertisols have appreciable amounts of calcium, magnesium and sodium which has reflected on higher salts. Low salt content in Alfisol may be due to acidic parent material. Organic carbon ranged from 2.7 to 11.4 g kg^{-1} with a mean value of 7.56 g kg^{-1}. It was low to medium status. Higher organic carbon in Vertisol could be because of regular addition of organics and incorporation of stubbles in the soil. Higher soil organic carbon in Eastern Rajasthan and Jabalpur (Vertisols) was reported by Risikesh Thakur [12], respectively. Low organic carbon in Entisol and Alfisol may be due to poor vegetation coupled with high rate of organic matter decomposition under hyperthermic temperature regime, which leads to extreme high oxidation condition [13]. Calcium carbonate ranged from 0.33 to 7.54 per cent with a mean value of 1.96 per cent. The texture of the soil was clay loam, silt clay loam, sandy clay loam and clayey. On the basis of CEC rating [14], soils have low to high CEC. Higher CEC in Vertisol is due to increased number of negative charges on soil colloids with increase in finer fraction, while low CEC in Entisol might be due to their coarse texture leading to reduced number of negative charges for adsorption of cations on the exchange sites.

Table 1 Initial soil characteristics

Soil (location)	Soil series	Textural Class (USDA)	pH	EC (dSm^{-1})	Organic carbon (g kg^{-1})	$CaCO_3$ (%)
			Vertisol			
Annamalainagar	Kondal	Clay loamy	8.6	0.83	4.2	1.23
C.Alambadi	Kondal	Clay	7.9	0.58	9.4	1.10
Kannangudi	Kondal	Clay	7.6	1.00	5.1	0.75
Kodiyalam	Kondal	Clay loam	8.2	1.23	7.4	2.50
Kelakarai	Kondal	Clay	7.9	0.32	8.5	2.60
Kodipallam	Kondal	Clay loam	8.3	0.56	5.5	1.34
Kumaramangalam	Kondal	Clay loam	8.5	0.73	9.6	0.99
Lalpuram	Kondal	Clay loam	7.5	0.86	9.2	2.34
Manalur	Kondal	Clay loam	7.4	0.69	9.2	0.96
Meedhikudi	Kondal	Clay	7.8	0.79	6.3	4.63
Nakkaravandhankudi	Kondal	Clay	7.9	0.83	6.3	1.23
Parangipettai	Kondal	Silt clay loam	8.8	0.31	2.7	0.99
Sarvarajanpettai	Kondal	Clay loam	8.2	0.56	9.3	0.77
Sivakkam	Kondal	Clay	8.3	0.76	6.3	0.98
Thunisiramedu	Kondal	Clay	7.5	0.81	9.4	2.56
Veyyalur	Kondal	Clay loam	8.6	0.85	5.5	3.10
Vasaputhur	Kondal	Clay	7.9	0.55	6.0	0.95
Vadamur	Kondal	Clay	8.3	0.63	3.6	1.20
Radhavilagam	Adanur	Clay	8.1	0.93	3.6	0.79
Kovilampoondi	Adanur	Clay	7.7	0.76	10.1	7.54
Pinnathur	Adanur	Clay	8.0	0.80	5.8	1.01
Uthamacholamangalam	Adanur	Clay loam	7.5	0.56	6.3	6.34
Thillainayagapuram	Adanur	Clay	7.8	0.64	5.8	6.45
			Entisol			
Maduvangarai	Padugai	Silt clay loam	7.8	0.80	9.3	0.33
K.Moongiladi	Padugai	Sandy Clay loam	6.5	0.92	8.9	1.10
Therkumangudi	Padugai	Sandy Clay loam	8.3	0.54	6.3	1.34
Melbhuvanagiri	Padugai	Sandy Clay loam	7.0	0.84	8.9	1.52
Orathur	Padugai	Sandy Clay loam	6.9	1.06	6.1	0.76
Karuppur	Padugai	Sandy Clay loam	8.7	1.20	10.4	0.86
Nanjaimegathuvazkkai	Padugai	Sandy Clay loam	7.0	0.71	6.3	0.99
A. Thivaraganatham	Padugai	Sandy Clay loam	6.9	0.54	11.4	3.23
Azhichikudi	Padugai	Sandy Clay loam	7.5	0.50	8.4	5.06
Miralur	Padugai	Sandy Clay loam	7.8	0.48	8.3	0.78
Sethiyathoppu	Padugai	Sandy Clay loam	6.9	0.82	10.5	0.88

Suthukuzhi	Padugai	Sandy Clay loam	7.6	0.81	10.7	2.43
Vandurayanpet	Padugai	Sandy Clay loam	7.3	0.83	8.7	3.43
Vattarayathethu	Padugai	Sandy Clay loam	6.3	0.92	7.9	2.15
Ayipettai	Padugai	Sandy Clay loam	7.8	0.63	7.3	2.36
Kizhiyanoor	Padugai	Sandy Clay loam	8.0	0.63	8.2	1.36
Keerapalayam	Padugai	Sandy Clay loam	6.9	0.62	7.2	0.96
Kathazhai	Padugai	Sandy Clay loam	7.9	1.60	6.8	1.32
Palayamserthangudi	Padugai	Sandy Clay loam	7.8	0.92	6.3	0.67
Paradhur	Padugai	Sandy Clay loam	6.2	0.68	9.2	0.45
Sathamangalam	Padugai	Sandy Clay loam	6.3	1.23	8.5	0.55
Vadaharirajapuram	Padugai	Sandy clay loam	7.8	0.55	8.8	1.30
Boothavarayanpettai	Padugai	Sandy Clay loam	6.3	1.03	8.5	0.96
Kilavaddinatham	Padugai	Sandy Clay loam	7.9	0.91	8.1	1.12
Vadakkumangudi	Padugai	Sandy Clay loam	7.8	1.20	7.8	4.53
Adhivaraganallur	Padugai	Silt clay loam	8.4	0.63	7.0	3.43
Keelbhuvanagiri	Padugai	Sandy Clay loam	8.3	0.27	7.9	0.45
	Range		6.2-8.8	0.27-1.6	2.7-11.4	0.33-7.54
	Mean		7.68	0.76	7.56	1.96

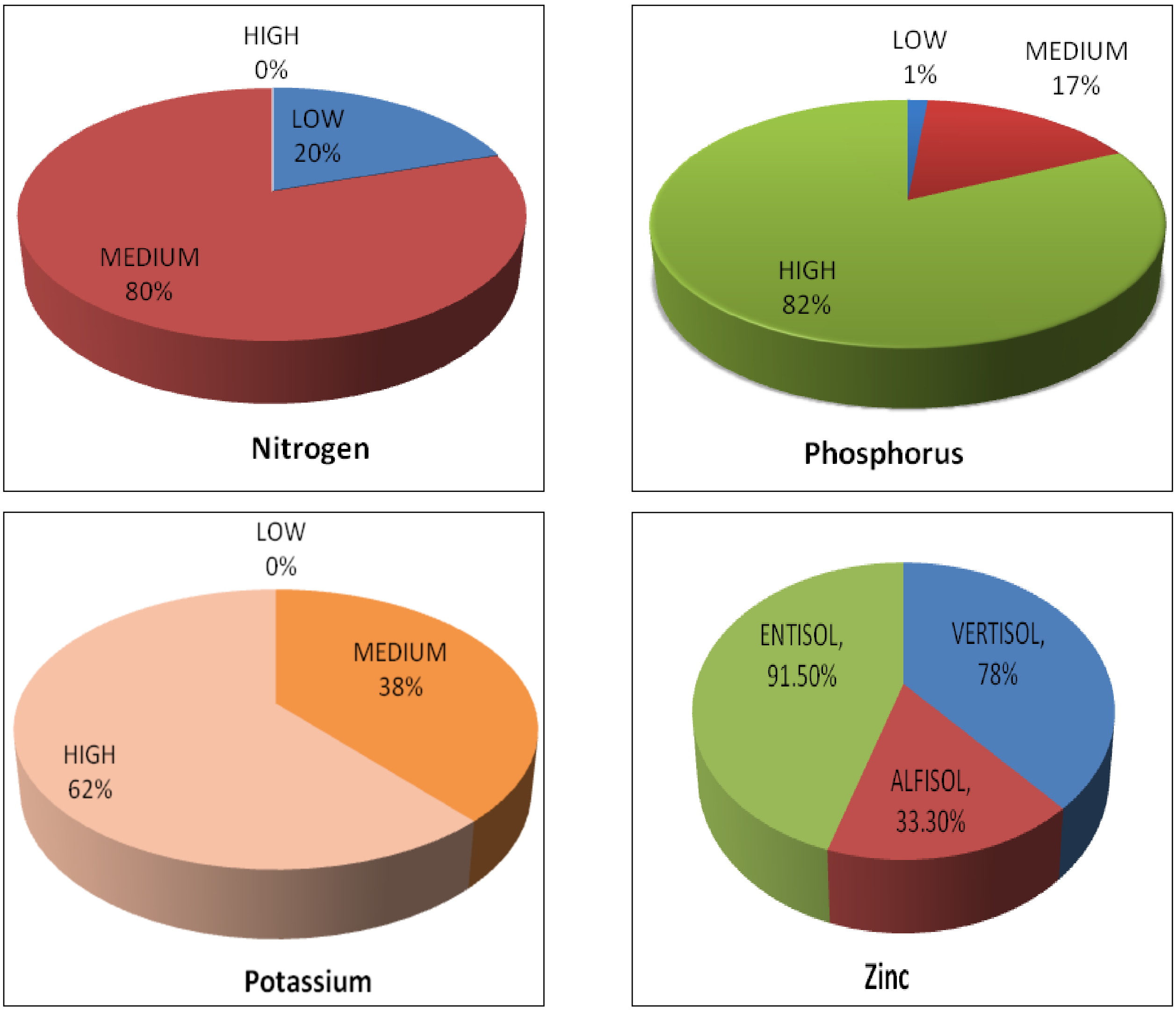

Fig 1 Nutrient status in soils of Chidambaram taluk

Soil nutrient status

The available nitrogen ranged from 213.8 to 391.2 kg ha^{-1} with a mean value of 313.8 kg ha^{-1}. The available N status was low to medium. The available phosphorus ranged from 19 to 54 kg ha^{-1} with a mean value of 33.7 kg ha^{-1}. The available phosphorus status was medium to high. The available potassium status ranged from 147 to 366 kg ha^{-1} with a mean value of 281.4 kg ha^{-1}. The available potassium status was medium to high. The DTPA extractable zinc ranged from 0.48 to 1.90 mg kg^{-1} with a mean value of 0.78 mg kg^{-1} (Table 1). Available nitrogen in soils of Chidambaram taluk varied from 103.6 to 436.0 kg ha^{-1}. Soil fertility based on available N was low to medium. Available N was relatively higher in Vertisol than Entisol and Alfisol. Low status with respect to available N could be due to losses of N mainly through volatilization. Percentage of soil low and medium in available N was 20 and 80 respectively (Fig 1). Considerable variation in available P was noticed in soils of Chidambaram taluk. Higher amount of available phosphorus was noticed in Vertisol than Alfisol and Entisol. Percentage of soil low, medium and high in available phosphorus was 1.5, 16.5 and 82.0 respectively (Fig 1). Ammonium acetate potassium in soil varied from 143.1 to 446.3 kg ha^{-1} and overall fertility status of available K was medium to high. The percentage of soil medium to high in available K was 38.5 and 61.5 respectively (Fig 1).

Available zinc content in soils of Chidambaram taluk was very low (deficient) to high (sufficient). Per cent contribution of DTPA-Zn to total Zn was 0.38 to 1.31. Available zinc was higher in Vertisol compared to Alfisol and Entisol. This is because available zinc increases with finer fraction of the soil and increases with increase in CEC of the soil due to more availability of exchange sites in the soil colloids [15]. Per cent deficient in available zinc is 74 in Chidambaram taluk (78.0 in Vertisols, 33.3 in Alfisol and 91.5 in Entisol) (Fig 1). Overall Zn in soils of Nagaur district of Rajastan ranged from 0.1 to 1.7 ppm and 46 per cent of the soil was deficient in Zn [16] and 48 per cent of the Indian soils was deficient in DTPA-Zn [17-18]. DTPA-Zn in Trans Gangetic plain ranged from 0.11 to 5.05 ppm [19]. Variations in zinc among soils might be result of variable intensity of different pedogenic process taking place during soil development [20]. Higher content of DTPA-Zn could be due to higher organic carbon content in soil [21].

Evaluation of different zinc extractants

Results of extractable zinc by different extractants are furnished in (Table 2). The amount of extractable zinc varied markedly depending on the soils and the extractants used and it differed significantly. The lowest amount of zinc was extracted by 1N NH_4OAC (pH 7.6) and the highest with 0.005 M DTPA. The zinc extracted by 0.005 M DTPA ranged from 0.48 to 1.8 and 0.53 to 2.48 mg kg^{-1} with a mean value of 0.86 and 0.96 mg kg^{-1}; 0.01 M EDTA + 1 M $(NH_4)_2CO_3$ ranged from 0.58 to 1.02 mg kg^{-1} and 0.65 to 1.86 mg kg^{-1} with a mean value of 0.76 and 0.91 mg kg^{-1}; 0.01 M EDTA+TEA ranged from 0.42 to 0.93 mg $kg^{-1}$and 0.49 to 0.93 mg $kg^{-1}$with a mean value of 0.69 and 0.72 mg kg^{-1}; 0.01 M EDTA + 1N NH_4OAC ranged from 0.39 to 1.06 mg $kg^{-1}$and 0.53 to 1.40 mg $kg^{-1}$with a mean value of 0.69 and 0.78 mg kg^{-1}; 1 N NH_4OAC + 0.01% Dithiazone ranged from 0.36 to 1.06 mg $kg^{-1}$and 0.41 to 1.26 mg kg^{-1} with a mean value of 0.56 and 0.69 mg kg^{-1}; 0.01 M EDTA ranged from 0.36 to 0.97 mg kg^{-1} and 0.43 to 0.93 mg kg^{-1} with a mean value of 0.64 and 0.70 mg kg^{-1}; 1 N NH_4OAC ranged from 0.20 to 0.63 mg kg^{-1} and 0.28 to 0.83 mg kg^{-1} with a mean value of 0.38 and 0.47 mg kg^{-1} in Vertisol and Entisol, respectively.

Based on the amount of zinc extracted by different extractants, the relative efficiency were of the following order 0.005 M DTPA (pH 7.3) > 0.01 M EDTA + 1 M $(NH_4)_2CO_3$ (pH 8.6) > 0.01 M EDTA + TEA (pH 6.7) > 0.01 M EDTA + 1 N NH_4OAC (pH 7.0) > 1 N NH_4OAC + 0.01% Dithizone > 0.01 M EDTA > 1 N NH_4OAC (pH 7.0) for both Vertisol and Entisol. The amount of Zn extracted by different extractants was correlated with Bray's per cent yield, plant tissue zinc concentration and zinc uptake by rice crop (Table 2). Among the extractants, DTPA-Zn correlated the highest with Bray's per cent yield (r=0.623** and r=0.833**) which gave positive and significant relationship as compared to other extractants in both Vertisol and Entisol. Further DTPA-Zn also recorded higher significant positive correlation with zinc content (r=0.779** and r=0.802**) and Zn uptake (r=0.716** and r=0.847**) in Vertisol and Entisol respectively. Variations in zinc among soils might be result of variable intensity of different pedogenic process taking place during soil development [22]. Higher content of DTPA-Zn could be due to higher organic carbon content in soil [23].

Table 2 Mean, standard deviation (SD) and range of different fractions of zinc in soils

Parameter	Water soluble Zn	Exchangeable Zn	Complexed Zn	Organic Bound-Zn	Occluded Zn	Residual Zn	Total Zn	Available Zn
				Vertisol				
Mean	0.25	0.43	2.91	3.29	3.62	84.23	94.71	0.75
SD	0.09	0.11	0.58	0.55	0.52	8.44	8.77	0.19
Range	0.09-0.49	0.18-0.96	2.02-5.50	2.10-4.78	2.43-4.97	70.19-120.63	80.15-131.80	0.13-1.73
				Alfisol				
Mean	0.38	0.43	2.85	3.39	3.00	80.02	90.07	0.85
SD	0.04	0.05	0.44	0.53	0.58	6.02	5.81	0.08
Range	0.31-0.46	0.37-0.54	2.31-3.60	2.18-4.34	2.56-3.65	72.69-92.06	83.40-102.40	0.71-0.98
				Entisol				
Mean	0.25	0.46	3.12	3.14	3.26	79.45	89.68	0.71
SD	0.10	0.08	0.72	0.78	0.71	5.31	5.06	0.12
Range	0.10-0.46	0.28-0.62	2.13-4.74	1.30-4.34	1.54-4.56	69.24-90.86	80.30-99.30	0.45-0.98

Grain and straw yield

Perusal of the data in (Table 3) indicated significant influence of graded dose of zinc, soils and their interaction on grain and straw yield over control. The mean grain yield ranged from 18.70 (control) to 37.53 g pot^{-1} and straw yield increased from 26.68 g pot^{-1} (control) to 48.64 g pot^{-1} upto 5.0 mg Zn kg^{-1} and then decreased at 7.5 mg Zn kg^{-1}. The per cent increase in grain yield ranged from 66.7 to 100.7 due to different Zn levels over control. When per cent increase in grain yield due to incremental dose of 2.5 mg Zn kg^{-1}over previous dose was noticed, there was distinct increase of 66.7 per cent over control on application of 2.5 mg Zn kg^{-1}. When further addition of 2.5 mg Zn kg^{-1} was applied, it brought about 20.4 per cent increase over previous dose and further addition of 2.5 mg Zn kg^{-1} resulted in 1.8 per cent reduction in grain yield over previous dose. Similarly, the per cent increase in straw yield ranged from 56.9 to 82.3 due to different Zn levels over control. The grain yield response was 12.47, 18.83, 18.15 g pot^{-1} due to $Zn_{2.5}$, $Zn_{5.0}$ and $Zn_{7.5}$ over control (no zinc) respectively. The grain and straw yield was statistically comparable at $Zn_{5.0}$ and $Zn_{7.5}$ respectively. Grain and straw yield of rice responded significantly to zinc application. The per cent increase in grain and straw yield due to application of 5 mg Zn kg^{-1} was 5.75 and 4.69 respectively over control. The increase in grain and straw yield with application of zinc was attributed to adequate supply of zinc that might have increased the availability and uptake of other essential nutrients resulting in improved metabolic activities [24]. This was confirmed by significant positive correlation of grain yield with available N (r=0.61*), available P (r=0.92**) and available K (r=0.94**), N uptake (r=0.97**), P uptake (r=0.98**) and K uptake (r=0.98**). It is also due to the effect of zinc on the proliferation of roots so that uptake rate from soil was increased and supplying to the aerial parts of the plant [25]. Favorable effect of zinc on rice yield could be due to enhanced activity of metallo enzymes like proteinases and peptidases leading to increased vigour, photosynthetic accumulation and better translocation of photosynthates [26].

Table 3 Effect of zinc application on grain and straw yield (g pot^{-1})

Zn levels (mg kg^{-1})	Grain yield		Mean	Straw yield		Mean
	S_1	S_2		S_1	S_2	
0	13.68	23.73	18.70	18.48	34.89	26.68
2.5	25.68	36.66	31.17	30.67	53.06	41.86
5.0	32.04	43.02	37.53	37.45	59.84	48.64
7.5	31.36	42.34	36.85	37.03	59.42	48.22
Mean	25.69	36.43		30.90	51.80	
	Zn	S	Zn × S	Zn	S	Zn × S
SEd	0.36	0.26	0.52	0.44	0.31	0.63
CD (p=0.05)	0.76	0.54	1.08	0.93	0.66	1.32

CONCLUSION

Study revealed that major portion of the area was suffering from zinc deficiency. Hence, to overcome zinc deficiency and achieve maximum yield in rice-pulse cropping system in soils of Chidambaram taluk, it is recommended to go for soil application of 5.0 mg Zn kg^{-1} (50 kg $ZnSO_4$ ha^{-1}).

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