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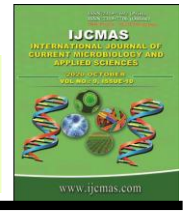

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Estimation of Critical Limits of Zinc in Soil and Plant for Predicting Response of Maize (*Zea mays* L.) to Zinc and Nutrient Uptake in Acid Soils, Manipur

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A pot experiment was conducted in 2018 to assess the effects of zinc fertilization on dry matter yield and nutrients uptake of hybrid maize. The treatments consisted of three doses: 0.0, 2.5 and 5.0 kg Zn ha^{-1} as $ZnSO_4.7H_2O$ and hybrid maize variety PAC-740 was as test crop arranged in a completely randomized block design (RCBD) with three replications. The soils were acidic in nature, EC were low, organic carbon in the soils were fairly high (mean 17.71 g kg^{-1}) and the mean CEC of the soils was 16.36 [cmol(P^+)kg^{-1}]. All the collected soil samples were clay in textural class. The results showed the addition of Zn substantial differences in dry matter yield and nutrients uptake of hybrid maize. Positive and significant correlations were obtained between DTPA-Zn and Bray's per cent yield (r=0.444*), dry matter yield in control (r=0.916**), Zn concentration in control (r=0.966**), Zn uptake in control (r=0.959**) and Bray's per cent uptake (r=0.492*). The critical limits of Zn in soils and 45 days old maize plant was 0.88 mg kg^{-1} and 22 mg kg^{-1}, respectively. The study concludes that, on the basis of critical limits in soil and maize plant, Zn fertilization may be carried out for economic yield.

Introduction

Zinc (Zn) is an indispensable element for plants, animals and humans for various reproductive and physiological processes. Zinc deficiency is more pronounced among the micro-nutrients in India. In the world, half of the cultivated soils are deficient in zinc. In India, the zinc deficiency was the first time was observed on field-scale was in rice crop in *tarai* soils by Nene in 1966. The zinc deficiency is more severe in North-East Indian soils (Kumar *et al.*, 2016). At the present time, 49% of the cultivated Indian soils are deficient in zinc (Singh, 2000). In India the extent of zinc deficiency in different agro-ecological zones, this ranged from 20% to 77% (Singh, 2000 and 2001b).

Zinc is one of the important micronutrients for many crop plants such as rice, maize, wheat, and soybean, which all are worldwide cultivated. Zn influences quality and yields of crops (Alloway, 2003). It is a trace element needed in small but in critical concentrations. If the amount of zinc is not adequate in soils, plants will agonize from a physiological stress resulting from the dysfunction of several enzyme systems and other plant metabolic activities because it plays a vital role in several plant metabolic processes; it acts as a enzymes activator and also involved in the protein synthesis process and carbohydrate, lipid metabolism and nucleic acid (Marschner, 1986; Pahlsson, 1989). Nevertheless, like other all heavy metals (Doncheva, 1998) when Zn is stored in additional in plant tissues, it results in alterations in vital growth processes like chlorophyll biosynthesis and (Doncheva *et al.,* 2001) and membrane integrity also (De Vos *et al.,* 1991). According to (Chaoui *et al.,* 1997) an additional quantity of Zn also has been stated to have an undesirable effect on mineral nutrition.

Maize belongs to Maideas tribe and grass family of Poaceae /Gramineae is categorized as the most sensitive cereal crop to Zn deficiency. However, Zn deficiency mainly occurs in maize crop plants as Zn plays so many important structural and functional roles in plant growth and development and a lack of Zn resulted to decreased seed formation (Bell and Dell, 2008). Zinc deficiency in human being also looks to be a critical nutritional and health hazards in the whole world. The severe challenge is being looked to enhance grain Zn concentration in agricultural crops to overawed widespread malnutrition problem especially in under developing and economically poor countries (Bouis and Welch, 2010). Therefore, with the increasing levels of Zn content in grain is results in providing more Zn to people, who belief directly or indirectly on pea-derived food. Zinc is also essential for the transportation of calcium throughout the maize plant.

Maize *(Zea mays* L.) is the third most important cereal crop of the world as well as India after wheat and rice. In India, maize is cultivated in 9.47 million hectares with an annual production of 28.72 million tonnes with the average productivity of 3,032 kg ha^{-1} (Anonymous, 2018). Over 85% of maize produced in the country grown throughout the year as three seasons as *kharif, rabi and jayad* season.

Maize is growing in Manipur in some pocket. Recently, the large scale cultivation of maize has picked up for grain crop as well as forage crop. Among the various agronomical practices for cultivation of maize crop, adequate and balanced fertilization plays an important role for increasing yield. Correcting the nutrient content in the soil and their ratio in plant parts during crop growth with yield and yield attributes is prerequisite to find out critical nutrients for optimum yield and quality of crop. Nutrient deficiency of plant can be corrected well in advance before heavy losses. However, a few research work has done on this aspect in NE Region, in general and Manipur, in particular and therefore, the present study was carried out to find out the response of maize to Zn fertilization in acidic soils and evaluate the critical limits of Zn in soil and plant.

Materials and Methods

Twenty soil samples (0-15 cm depth) were collected from various cultivated paddy fields of Imphal East district in the month of Mid-December, 2018 in clean polythene bags for pot culture study. The soil samples were thoroughly dried in shade, ground with wooden pestle and mortar and passed through 2 mm sieve separately without any mixture of foreign material. The soil samples were stored in separate clean polythene bags with proper labels and used for further analyses of various physico-chemical properties of the soils.

Sl No.	Place of Collection/ Village	Latitude	Longitude
1.	Khurai	N-24˚49’24.46	E-093˚58’32.53
2.	Khabeisoi-1	N-24˚50’29.08	E-093˚58’50.81
3.	Khabeisoi-2	N-24˚51’04.61	E-093˚59’31.61
4.	Cingarel-1	N-24˚51’37.40	E-090˚00’00.00
5.	Sawombung-1	N-24˚52’23.22	E-094˚00’44.49
6.	Sawombung-2	N-24˚53’06.86	E-094˚01’31.97
7.	Keibikhullen-1	N-24˚54’37.15	E-094˚02’19.73
8.	Keibikhullen-2	N-24˚55’01.96	E-094˚02’25.40
9.	Lamboikhul-1	N-24˚55’58.31	E-094˚02’53.71
10.	Lamboikhul-2	N-24˚56’29.88	E-094˚02’39.06
11.	Chingarel-2	N-24˚51’33.25	E-093˚59’58.41
12.	Phaknung-1	N-24˚52’01.23	E-094˚00’44.08
13.	Phaknung-2	N-24˚51’27.44	E-094˚00’08.06
14.	Waiton	N-24˚52’09.12	E-093˚59’36.92
15.	Pangei	N-24˚51’59.32	E-093˚58’32.99
16.	Basihkhong	N-24˚45’11.06	E-093˚57’11.45
17.	Uchkeckon	N-24˚46’14.04	E-093˚58’09.98
18.	Yaralpat	N-24˚46’30.31	E-093˚58’11.16
19.	Keikhu	N-24˚47’11.03	E-093˚58’02.78
20.	Kongba	N-24˚45’45.87	E-093˚57’06.54

Mechanical analysis was carried out by hydrometer method (Bouyoucos, 1962). These samples were analysed for soil pH, EC and CEC using standard procedures as described by Jackson, (1973) and Borah *et al.*, (1987). Available N, P_2O_5 and K_2O were determined by Subbiah and Asija (1956), Bray and Kurtz No.1 method (1945) and Jackson (1973), respectively.

Organic carbon was determined by wet oxidation method (Walkley and Black, 1934). Available zinc of the soil was determined by using Atomic Adsorption Spectrophotometer (ASS) as described by Lindsay and Norvell (1978).

Three kg of soils were filled in pots and Zn were applied 0.0, 2.5 and 5.0 kg Zn ha^{-1} through $ZnSO_4.7H_2O$. The treatments were replicated thrice in completely randomized design. A basal dose of N:P:K @ 100:50:40 ha^{-1} in the form of urea, SSP and MOP were applied in each pot. Hybrid maize variety PAC-740 was sown and thin to one plant in each pot after germination. The moisture level was maintained at field capacity in all the pots by watering with distilled water as and when needed.

The crop was harvested at 45 days of growing. The plant samples were washed to remove the dirt and then oven dried at 65^0C for 48 hours and the dry matter yield was recorded. The plant samples were ground and powdered samples were analysed for N by microkjeldahl method, P, K and Zn by di-acid, HNO_3: $HClO_4$ digestion and using vanadomolybdophosphoric acid yellow colour method by spectrophotometry and plant potassium by flame photometry method (Jackson, 1973) and Zn by using Atomic Adsorption Spectrophotometer (ASS) as described by Lindsay and Norvell (1978). The critical limits of soil and plant were determined by technique of Cate and Nelson (1965). Bray's per cent yield and uptake of maize was calculated as:

$$\text{Bray's per cent yield} = \frac{\text{Yield without fertilizer}}{\text{Maximum yield in fertilizer treated pots}} \times 100$$

$$\text{Bray's per cent uptake} = \frac{\text{Uptake without fertilizer}}{\text{Maximum uptake in fertilizer treated pots}} \times 100$$

All data obtained from the present experiment were computed as per method described by Gomez and Gomez, (1984) to obtain the mean and standard deviation of zinc conc. in the different pools. In addition correlation analysis was done to obtain the relationship among zinc conc. in various pools and various soil properties. The significance of various effects was tested at 5% level of probability.

Results and Discussion

The initial physico-chemical properties of the soils of Imphal East district of Manipur are presented in Table 1. All the soil samples were clay in textural class. The soils were acidic in nature which ranged from 5.01 to 6.08 pH (mean 5.42), EC varied from 0.04 to 0.18 dSm^{-1} at 25^0C, CEC ranged from 12.59 to 23.75 [$cmol(p^+)kg^{-1}$], and organic carbon content of the soils are high, it varied from 8.28 to 23.77 g kh^{-1}. The available N, P_2O_5 and K_2O content of the different soils samples collected from various paddy fields ranged from 214.12 to 407.09, 21.21 to 39.49 and 226.44 to 322.94 kg ha^{-1}, respectively.

Dry matter yield

The dry matter yield of hybrid maize PAC-740 was affected with the fertilization of Zn regardless of the initial soil properties. Dry matter yield of control ranged from 2.80 to 4.82 g/pot as compared with 2.95 to 5.00 g/pot in 2.5 kg $ZnSO_4$ ha^{-1} and 3.18 to 5.28 g/pot in 5.00 kg $ZnSO_4$ ha^{-1} (Table 2). The fertilization of 5.00 $ZnSO_4$ ha^{-1} results in highest dry matter yield significantly. The increased dry matter yield due to Zn fertilization might be due to increase plant high and leave area of the plant. Application of zinc produced the higher straw yield of paddy was also reported by Mustafa *et al.*, (2011). This result is in conformity with findings of Keram *et al.*, (2012) in wheat and Singh *et al.*, (1999) reported that the application of 5.0 mg Zn Kg^{-1} increased dry matter yield of rice significantly. Application of 6 kg Zn ha^{-1} increased the green foliage and dry matter yield of maize was also reported by Singh and Singh (2017). Application of Zn and Cu had significant increased the dry matter production was reported by Eteng *et al.*, (2014).

Nitrogen, phosphorus, potassium and zinc uptake

The nitrogen, phosphorus, potassium and zinc uptake by the maize plant increased with the increasing level of Zn fertilization (Table 2 and 3) which is significantly superior to the other treatments except phosphorus uptake. The uptake of these nutrients by the plant might be the combined effect of higher nutrient concentration in the plant and higher dry matter yield. Application of Zn fertilizer had increased the N concentration and N uptake by the plant (Potarzyeki and Grzebisz, 2009). N and Zn uptake had increased with the application of Zn (Sarwar *et al.*, 2012). Increased Zn uptake by the maize plant with the application of Zn fertilizer was not only due to the plant biomass but also due to the Zn concentration in the plant (Grzebisz *et al.*, 2008). Zn fertilization increased the Zn uptake by the maize was also reported by Eteng (2017). Application of Zn along with RDF had increased the uptake of N, P, K, S and Zn by the baby corn (Kumar *et al.*, 2015).

Table.1 Some physico-chemical properties of the

Soil samples	pH (mol/lit.)	EC (dSm^{-1})	Org. C ($g\ kg^{-1}$)	Av. N ($kg\ ha^{-1}$)	Av. P_2O_5 ($kg\ ha^{-1}$)	Av. K_2O ($kg\ ha^{-1}$)	CEC [$cmol(P^+)kg^{-1}$]	Sand (%)	Silt (%)	Clay (%)	Textural Class
1.	5.25	0.04	17.09	253.64	37.66	257.85	15.41	17.63	32.15	50.22	Clay
2.	5.58	0.09	8.96	272.66	38.75	236.59	13.82	10.12	26.43	63.45	Clay
3.	6.05	0.10	22.10	274.88	28.46	291.06	16.14	9.80	23.28	66.92	Clay
4.	5.85	0.09	21.67	286.46	26.70	285.33	15.58	10.50	31.80	57.70	Clay
5.	5.90	0.07	16.32	301.62	37.38	270.19	12.59	16.39	36.03	47.58	Clay
6.	5.28	0.06	15.75	292.67	36.20	250.23	15.84	19.84	34.46	45.70	Clay
7.	5.69	0.13	8.28	221.45	39.49	226.44	18.72	10.15	30.50	59.35	Clay
8.	6.08	0.11	19.60	268.70	32.91	306.52	15.62	8.61	27.85	63.54	Clay
9.	5.02	0.06	15.68	214.12	31.88	242.09	17.44	23.94	32.56	43.50	Clay
10.	5.95	0.09	20.17	287.37	28.44	322.75	16.60	9.90	34.03	56.07	Clay
11.	5.01	0.08	20.07	402.69	23.15	265.56	14.40	11.40	31.50	57.10	Clay
12.	5.05	0.16	19.63	407.09	22.49	296.08	15.07	11.86	27.64	60.50	Clay
13.	5.03	0.18	23.77	341.45	21.21	322.94	23.75	10.00	23.54	66.46	Clay
14.	5.35	0.05	19.10	348.48	25.41	253.71	16.00	12.50	27.63	59.87	Clay
15.	5.60	0.15	18.11	425.83	22.02	253.78	16.12	12.20	38.95	48.85	Clay
16.	5.40	0.10	17.66	249.76	37.20	282.70	16.28	10.34	36.10	53.56	Clay
17.	5.07	0.06	17.51	238.85	32.49	270.56	18.65	18.49	29.50	52.01	Clay
18.	5.03	0.11	15.70	289.21	27.17	267.76	16.48	25.35	27.34	47.31	Clay
19.	5.02	0.13	16.96	247.42	36.27	236.38	14.01	17.78	22.73	59.49	Clay
20.	5.10	0.15	20.12	370.40	21.84	291.73	18.75	10.65	31.50	57.85	Clay
Mean	**5.42**	**0.10**	**17.71**	**299.74**	**30.36**	**271.51**	**16.36**	**13.87**	**30.28**	**55.85**	

Table.2 Effects of Zn application on dry matter yield, zinc concentration and its uptake by Maize crop

Soil samples	DTPA extractable-Zn	Dry matter yield (g/pot) Zn level (kg ha^{-1})			Bray's % yield	Zn conc. in plants (ppm) Zn level (kg ha^{-1})			Zn uptake by plant (mg/pot) Zn level (kg ha^{-1})			Bray's % Zn uptake
		0	2.5	5.0		0	2.5	5.0	0	2.5	5.0	
1.	0.94	3.95	4.12	4.28	92.29	24.00	23.93	25.67	0.09	0.10	0.11	86.31
2.	0.75	3.30	3.44	3.62	91.16	21.60	21.00	23.33	0.07	0.07	0.08	84.03
3.	0.92	3.65	3.80	3.96	92.17	23.00	24.00	25.55	0.08	0.09	0.10	83.00
4.	0.88	3.80	3.90	4.22	90.05	22.00	23.00	24.82	0.08	0.09	0.10	79.89
5.	0.66	2.80	2.95	3.18	88.05	18.63	20.00	22.58	0.05	0.06	0.07	72.65
6.	0.87	3.68	3.85	4.05	90.86	22.00	22.00	24.13	0.08	0.08	0.10	82.84
7.	0.82	3.60	3.72	3.98	90.45	22.00	22.00	24.13	0.08	0.08	0.10	82.55
8.	0.72	3.00	3.24	3.38	88.76	18.97	21.00	23.35	0.06	0.07	0.08	72.10
9.	0.98	4.05	4.16	4.24	95.52	24.83	24.83	26.46	0.10	0.10	0.11	89.65
10.	1.15	4.20	4.44	4.61	91.11	26.00	28.00	28.76	0.11	0.12	0.13	82.32
11.	1.26	4.30	4.50	4.68	91.88	28.00	28.00	29.57	0.12	0.13	0.14	87.03
12.	1.24	4.72	4.94	5.22	90.42	30.00	32.00	34.22	0.14	0.16	0.18	79.27
13.	1.70	4.82	5.00	5.28	91.29	33.63	35.13	35.80	0.16	0.18	0.19	85.67
14.	1.35	4.40	4.60	4.78	92.05	28.00	28.97	30.34	0.12	0.13	0.15	84.90
15..	1.40	4.62	4.80	4.96	93.15	28.97	31.00	32.67	0.13	0.15	0.16	82.58
16.	0.98	3.98	4.20	4.41	90.25	24.00	24.00	26.46	0.10	0.10	0.12	81.82
17.	0.99	4.12	4.34	4.46	92.38	24.83	26.00	27.26	0.10	0.11	0.12	84.15
18.	1.23	4.30	4.50	4.69	91.68	28.00	28.97	29.56	0.12	0.13	0.14	86.84
19.	0.74	3.05	3.20	3.38	90.24	21.57	20.00	23.35	0.07	0.06	0.08	83.62
20.	1.37	4.46	4.70	4.88	91.39	30.00	31.00	31.12	0.13	0.15	0.15	88.12
Mean	**1.05**	**3.94**	**4.12**	**4.31**	**91.26**	**25.00**	**25.74**	**27.46**	**0.10**	**0.11**	**0.12**	**82.97**
		CD at 5% for Zn = 0.04 CD at 5% for soil = 0.10 CD at 5% for Zn x soil = 0.17			**CD at 5% for Zn = 0.192 CD at 5% for soil = 0.496 CD at 5% for Zn x soil = 0.860**				**CD at 5% for Zn = 0.19 CD at 5% for soil = 0.49 CD at 5% for Zn x soil = 0.85**			

Table.3 Effect of zinc application on nitrogen, phosphorous and potassium uptake by maize crop

Soil samples	N Uptake by plants (mg/pot) Zn level (kg ha^{-1})				P Uptake by plants (mg/pot) Zn level (kg ha^{-1})				K Uptake by plants (mg/pot) Zn level (kg ha^{-1})			
	0	**2.5**	**5.0**	**Mean**	**0**	**2.5**	**5.0**	**Mean**	**0**	**2.5**	**5.0**	**Mean**
1.	125.66	132.72	139.58	132.66	9.48	9.48	9.85	9.60	90.09	96.45	101.91	96.15
2.	88.92	93.72	101.16	94.60	7.59	7.57	7.61	7.59	73.95	79.85	84.74	79.51
3.	82.52	130.12	136.28	116.31	8.76	8.75	8.72	8.74	84.72	89.79	95.87	90.13
4.	109.46	118.61	130.88	119.65	9.51	9.36	9.29	9.39	85.99	90.52	99.64	92.05
5.	72.27	76.64	83.35	77.42	6.16	6.19	6.68	6.34	35.86	40.09	47.08	41.01
6.	105.17	115.55	125.61	115.44	8.47	8.47	8.92	8.62	83.20	88.59	96.43	89.41
7.	102.28	106.41	118.42	109.04	8.64	8.70	9.15	8.83	73.47	80.09	88.32	80.62
8.	79.64	87.62	92.09	86.45	7.05	7.13	7.44	7.21	45.62	53.91	56.92	52.15
9.	132.90	139.84	145.92	139.55	9.72	9.57	9.76	9.68	94.81	100.72	105.20	100.24
10.	151.26	163.46	171.82	162.18	10.51	10.66	11.07	10.75	102.39	110.16	117.67	110.07
11.	161.89	172.87	180.72	171.83	10.76	10.81	10.77	10.78	105.82	114.34	120.79	113.65
12.	191.24	201.64	217.25	203.38	13.22	13.36	14.12	13.57	124.82	140.36	152.32	139.16
13.	200.25	216.92	234.53	217.24	13.98	14.01	14.28	14.09	130.45	142.39	155.65	142.83
14.	173.44	183.00	194.29	183.57	11.44	11.50	10.53	11.16	112.25	120.56	128.41	120.41
15.	182.57	190.28	203.45	192.10	12.49	12.49	12.41	12.46	117.40	123.97	133.15	124.84
16.	136.06	146.22	157.95	146.74	9.55	9.24	9.71	9.50	93.89	102.52	110.30	102.24
17.	141.79	153.58	161.52	152.30	10.31	10.40	10.26	10.32	97.28	104.99	110.66	104.31
18.	166.91	176.47	185.80	176.39	10.32	11.16	10.32	10.60	106.68	115.25	124.02	115.32
19.	81.27	86.86	94.12	87.42	7.02	7.04	7.10	7.05	59.50	65.63	71.69	65.61
20.	176.25	187.91	197.73	187.30	11.60	11.75	12.20	11.85	114.22	124.28	135.88	124.80
Mean	**133.09**	**144.02**	**153.62**	**143.58**	**9.83**	**9.88**	**10.01**	**9.91**	**91.62**	**99.22**	**106.83**	**99.23**
CD at 5% for Zn = 2.73 **CD at 5% for soil = 7.05** **CD at 5% for Zn x soil = 12.22**					**CD at 5% for Zn = 0.19** **CD at 5% for soil = 0.50** **CD at 5% for Zn x soil = 0.87**				**CD at 5% for Zn = 1.87** **CD at 5% for soil = 4.83** **CD at 5% for Zn x soil = 8.37**			

Fig.1 Scatter diagram showing relationship between Bray's per cent yield of Maize crop plant and DTPA extractable zinc in soil

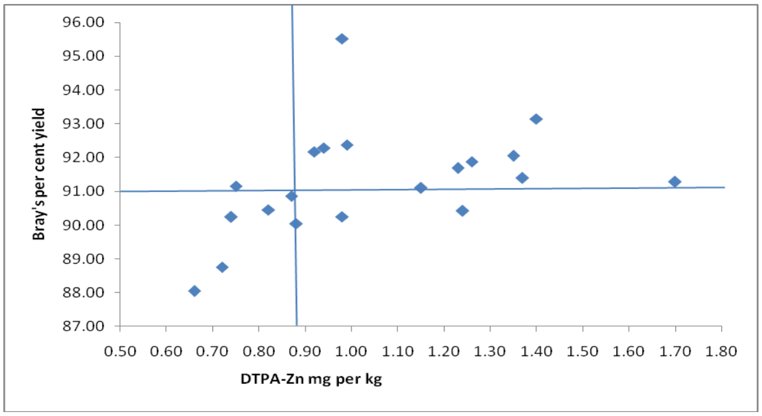
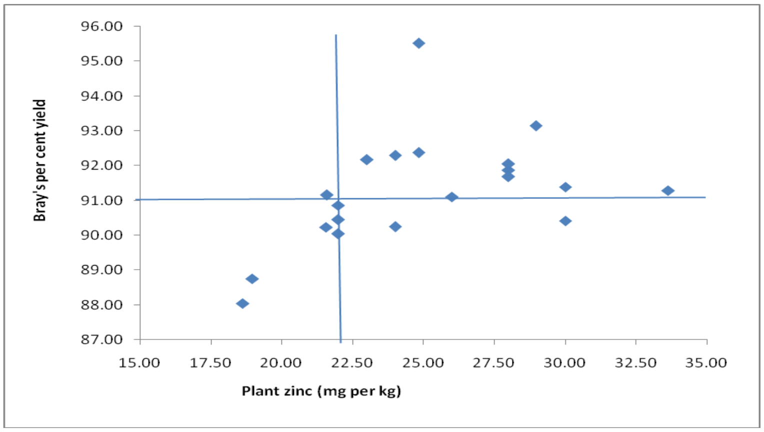


Fig.2 Scatter diagram showing relationship between Bray's per cent yield and tissue zinc concentration in Maize crop plant



Critical limit of Zn in soil and plant

Base on the graphical procedure of Cate and Nelson (1965), the critical limit of Zn in soils and maize plant (hybrid PAC-740) were 0.88 mg kg^{-1} (Fig. 1) and 22 mg kg^{-1} (Fig. 2), respectively. A soil was to be considered as non-responsive to Zn fertilization where Bray's per cent dry matter was more than 91. All the soil testing below 0.88 mg kg^{-1} by DTPA-extractable Zn may be responded to Zn fertilization for growing maize plant. A value of 22 mg kg^{-1} could distinguish the Zn deficient plants from those of sufficient ones, partitioning the two dimensional percentage yield versus Zn content in 45 days old plant scattered into two groups. Similarly, Kumari *et al.*, (2013) reported that the critical limit of available Zn was 0.75 mg kg^{-1} and the critical concentration of Zn in 45 days old maize plant tissue was 22.5 mg kg^{-1}. Thus, the present study lays emphasis on Zn fertilization on maize plant on the basis of critical values in the soils and plant.

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