Indian J. Dryland Agric. Res. & Dev. 2014 29(1) : 63-67

Verification of Critical Limit of Zinc in Selected Soils of Southern Karnataka for Finger Millet (*Eleusine coracana* L.)

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ABSTRACT: A pot culture experiment was conducted with finger millet (GPU-48) with twelve different levels of zinc containing soils of selected zones of southern Karnataka to determine the critical limit of zinc in soils and crop. Among the different soils studied, significantly highest dry matter yield (27.00 g/pot) was recorded in ZARS, Mandya soil having 2.60 mg/kg of native Zn with application of 1.00 mg/kg fertilizer Zn, whereas the lowest dry matter yield of 11.68 g/pot was recorded in pathakote soil having 0.35 mg/kg of native Zn without application of any external Zn. But the highest Zn content of 103.13 mg/kg in finger millet shoot was recorded in ZARS, GKVK, soils having 1.65 mg/kg of soil Zn, where 1.00 mg/kg of Zn was applied through fertilizer whereas the lowest shoot Zn content of 44.38 mg/kg was noticed in Pathakote soil has 0.35 mg/kg of native Zn, without application of any external Zn. The critical limit of zinc for soil was worked out by plotting the DTPA extractable Zn against relative yield (Cate and Nelson's graphical method) calculated from yield obtained in pot culture experiment. Similarly, critical limit of zinc in finger millet crop was calculated by plotting shoot zinc content against relative yield. The critical limit of Zn was found to be 0.66 mg/kg for soil and 54.00 mg/kg for finger millet crop.

Key words: Finger millet, zinc, critical limit, relative yield, Cate and Nelson's graphical method

Zinc (Zn) is considered as one of the essential micronutrients in crop production. In India, the deficiency of Zn in soil has reached to an extent of 48% (Soumitra Das and Andrew Green, 2013) and in case of Karnataka, it has been reported to be up to 73%. Deficiency of micronutrients is mainly attributed to continuous mining of nutrients for increasing cropping intensity and neglecting the application of micronutrients. The information on Zn fertilizer use generated by soil testing laboratories should be based on the critical limit of extractable Zn for different soils and crops. Critical limit of a nutrient refers to the concentration of nutrient below which the crop will readily respond to its application. This limit varies with crops, soils and extractants used. Chhibba *et al.* (1997) observed significant relation between dry matter yield and available Zn status of the soil (r=0.86**). Both graphical and statistical methods of Cate and Nelson indicated 0.76 mg/kg and 8.8 mg/kg as the critical values of Zn deficiency in soils and plants, respectively, below which sorghum may be expected to respond to Zn application. The situation of deficiency justifies a need to determine the critical limit of Zn in soils and finger millet in order to formulate the optimum fertilizer dose of Zn for finger millet to get sustainable yield. Since finger millet is an important crop of southern Karnataka and responds to Zn application, study on verification of critical limit of Zn in these soils is required for enhancing the production (Anonymous, 2011). Hence, a pot culture experiment was conducted with finger millet (GPU-48) with twelve different levels of Zn containing soils of selected zones of southern Karnataka (Pathakote, Kettiganalli, Zonal Agricultural Research Station, Gandhi Krishi Vigyan Kendra (ZARS-GKVK) and, ZARS-Mandya) to determine the critical limit of Zn in soils and crop.

Materials and Methods

A pot culture experiment was conducted with finger millet (*Eleusine coracana* L.) (GPU-48) under green house condition. Bulk soil samples were collected from four different places which were having three different levels of DTPA-extractable Zn viz., Pathakote village in Chikkaballapura district (0.35, 0.55 and 0.65 mg/kg), Kettiganahalli village in Chikkaballapura district (1.05, 1.25 and 1.40 mg/kg), ZARS-GKVK (1.55, 1.65 and 1.95 mg/kg) and from ZARS-Mandya (2.28, 2.30 and 2.60 mg/kg). Twenty kg of soil samples were collected up to 30 cm depth from each area. These soils were found to be acidic to neutral in soil reaction, EC was normal and medium in organic carbon content in the four different villages. The texture of the soils was sandy to loamy in all the four villages. Plastic pots of 16 cm bottom diameter and 26 cm height were filled with 5 kg soil and recommended dose of FYM (5 t/ha) was mixed thoroughly. The experiment was conducted with three replications. Six finger millet seedlings were maintained at equidistance and recommended dose (100:50:50 kg NPK/ha) of fertilizers were applied (100% P and K with 50% N as split application) before transplanting to the soil as basal dose. Six graded levels (0, 0.50, 0.75, 1.00, 1.25 and 1.50 mg/kg) of Zn ($ZnSO_4$) were imposed after three days of NPK fertilizer application and the remaining 50% of N was top dressed 20 days after transplanting. Necessary plant protection measures were taken till the harvest (panicle initiation stage) of crop. The fresh weight of the plant was recorded from each pot immediately after the harvest. The plant samples were dried in oven at 70^0 C for 48 h and the dry matter yield of the crop was recorded. Plant samples were chopped, powdered and then digested with triacid mixture (9:4:1). The digested sample was made up to known volume and used for the estimation of available Zn along with other micronutrients (Fe, Cu and Mn) by using Atomic Adsorption Spectrometer (Perkin-Elmer *AAnalyst* 700). Shoot Zn, Fe, Cu and Mn contents were estimated and Zn uptake by finger millet was calculated. The relative yield was worked out by using the formula, Relative yield= [{1-(maximum yield-check yield/check yield)}*100]. The critical limit of Zn for soil and finger millet was calculated in a graphical method (Cate and Nelson, 1971) by plotting soil available Zn on X-axis and relative yield on the Y-axis.

A transparent overlay with horizontal line and an intersecting vertical line was drawn so as to maximize the number of yield points in the first and third quadrants. The soil test value of Zn on X-axis corresponding to the point of intersection by vertical line was taken as the critical limit of Zn for soil. Similarly, shoot Zn content was plotted against the relative yield. Intersection of vertical line on X-axis, was taken as critical limit of shoot Zn.

Results and Discussion

Dry matter yield of finger millet

Dry matter yield of finger millet crop was found to be significantly highest (21.52 g/pot) where 0.75 mg/kg of Zn was applied in Pathakote soils having 0.55 mg/kg of DTPA extractable Zn. Lowest yield (11.68 g/pot) was recorded in soil having 0.35 mg/kg Zn and no external Zn was applied. Overall, Pathakote soils responded to Zn application up to 0.75 mg/kg, irrespective of Zn content in the soil (0.35, 0.55 and 0.65 mg/kg) (Table 1).

Similarly, in Kettiganalli soils having three levels of DTPA extractable Zn (1.05, 1.25 and 1.40 ppm), the dry matter yield of finger millet was significantly increased due to application of graded levels of fertilizer Zn. The response was positive in 1.40 ppm Zn containing soils, where up to 1.50 ppm zinc application has significantly increased the dry matter yield as compared to treatments where no external Zn was applied (Table 1).

In case of ZARS-GKVK soils, application of fertilizer Zn up to 1.00 mg/kg increased the dry matter yield of finger millet significantly, irrespective of different levels of soil Zn (1.55, 1.65 and 1.95 mg/kg). Significantly highest (15.70 g/pot) dry matter yield was recorded in soil with Zn content of 1.55 mg/kg by application of 1.25 mg/kg fertilizer Zn, whereas, significantly lowest yield (11.59 g/pot) was recorded with no external Zn application in soil containing 1.55 mg/kg of Zn (Table 1).

Soils of ZARS-Mandya, irrespective of their Zn content (2.28, 2.30 and 2.60 mg/kg), responded to Zn application up to 1.00 mg/kg in increasing the dry matter of the crop and there was a decrease in dry matter yield as the Zn application was increased up to 1.50 mg/kg. Significantly highest (27.00 g/pot) dry matter was recorded with 1.00 mg/kg of Zn application in 2.60 mg/kg Zn containing soil and the lowest (22.65 g/pot) dry matter was noticed in soils with Zn content of 2.28 and 2.30 mg/kg where no Zn was applied (Table 1).

Dry matter yield of the finger millet, harvested at panicle initiation was significantly higher with increase in levels of Zn fertilizer application in all the soil samples collected from different places, irrespective of the soil Zn content, indicating that the sufficient supply of Zn can be made by addition of external Zn. Higher dry matter production is due to more vegetative growth as evidenced from plant height and tillers (data not presented). Improved growth and dry matter production is attributed to the full yield potential by the crop when trace elements are applied along with NPK fertilizers. The effect of Zn fertilization on growth and yield of many plants such as alfalfa, wheat, maize, barley, cotton and potato were investigated in numerous researches and observed increasing in yield with zinc application (Kinaci and Kinaci, 2005; Shaheen *et al.,* 2007; Galavi *et al.,* 2011; Efe and Yarpuz, 2011). In general, other nutrients were also responsible for the increase in dry matter yield since Zn has responsible

Table 1 : Effect of graded levels of zinc application on shoot dry matter yield (g/pot) of finger millet in soils containing different levels of Zn

Zinc level units	DTPA-Zn in Pathakote soil (mg/kg)				DTPA-Zn in Kettiganalli soil (mg/kg)				DTPA-Zn in ZARS-GKVK soil (mg/kg)				DTPA-Zn in ZARS-Mandya soil (mg/kg)			
	0.35	**0.55**	**0.65**	**Mean**	**1.05**	**1.25**	**1.40**	**Mean**	**1.55**	**1.65**	**1.95**	**Mean**	**2.28**	**2.30**	**2.60**	**Mean**
Control	11.68	11.75	12.45	11.96	11.62	11.80	12.25	11.89	11.59	12.35	13.00	12.31	22.65	22.65	23.60	22.97
0.50	15.36	14.48	16.38	15.40	12.98	12.48	12.90	12.79	14.53	13.48	13.35	13.79	24.60	24.48	25.00	24.69
0.75	18.48	21.52	17.48	19.16	12.69	12.65	13.35	12.90	15.00	14.23	13.40	14.21	25.50	25.62	26.30	25.81
1.00	16.59	17.90	16.82	17.10	12.48	13.18	13.48	13.05	15.48	14.48	14.50	14.82	25.80	26.20	27.00	26.33
1.25	17.48	16.60	16.28	16.78	12.72	12.56	14.58	13.29	15.70	12.90	13.70	14.10	24.39	25.50	24.40	24.76
1.50	16.50	15.48	16.52	16.17	13.09	14.40	15.40	14.30	14.39	13.50	11.60	13.16	24.98	22.70	24.26	23.98
Mean	16.01	16.28	15.98	-	12.60	12.84	13.66	-	14.45	13.49	13.26	-	24.65	24.52	25.09	-
SEm±		1.54				0.74				0.46				0.84		
CD (P=0.05)		4.30				2.02				1.16				2.70		

role in ensuring the higher uptake efficiency of other nutrients (Mohammad, 2008).

Shoot Zn content of finger millet

Significantly highest (59.38 mg/kg) shoot Zn content in finger millet was recorded in Pathakote soils (DTPA Zn 0.55 mg/kg soil) with 1.00 mg/kg of Zn application and significantly lowest shoot Zn content (44.38 mg/kg) was recorded in both 0.35 and 0.55 mg/kg Zn containing soils with no Zn application. Irrespective of different levels of Zn in Pathakote soils (0.35, 0.55 and 0.65 mg/kg), shoot Zn content responded positively with Zn application up to 1.00 mg/kg. However, decrease in shoot Zn content was noticed as the Zn application was increased (above 1.00 mg/kg (Table 2).

In general, Zn content of crops increases with increase in Zn application, but it in some soils it was found to be decreased as the Zn application increased. This might due to less translocation of Zn to shoots from roots, eventhough uptake from soil was good, could be due to immobile nature of this nutrient element (Herren and Feller, 1994). A significant increase in Zn content of finger millet shoot (78.75 mg/kg) was noticed in soil containing 1.05 mg/kg Zn, where 1.25 mg/kg Zn was applied externally and the lowest Zn content (61.88 mg/kg) in shoot was recorded in soils containing 1.05 mg/kg Zn with no Zn application (Table 2). In soils of ZARS, GKVK, with three different levels of Zn (1.55, 1.65 and 1.95 mg/kg), significantly highest (103.13 mg/kg) shoot Zn content in finger millet was noticed in soil containg 1.65 mg/kg Zn with 1.00 mg/kg Zn application and the lowest (88.13 mg/kg) shoot Zn content was found in soil containing 1.55 mg/kg Zn without any Zn fertilizer application (Table 2). Similarly, in soils of ZARS, Mandya, significantly highest (90.75 mg/kg) shoot Zn content in finger millet was recorded with soils containing 2.60 mg/kg Zn with application of 0.75 mg/kg of Zn application. Whereas, the lowest (81.88 mg/kg) shoot Zn content was found in both the soils which were having 2.30 and 2.60 mg/kg Zn (Table 2).

The perusal of the shoot Zn content of different soils clearly indicated that, increase in shoot Zn content was maximum with soils of ZARS, GKVK as Zn application was increased up to 1.00 mg/kg, particularly in soils containing 1.55 mg/kg and 1.65 mg/kg Zn. This suggests that, plant can take up Zn wherever it is sufficiently available in soils (Nable and Webb, 1993).

Zn uptake

Soils of Pathakote having 0.65 mg Zn/kg recorded significantly highest (0.132 g/pot) Zn uptake by finger millet shoot with 1.00 ppm of Zn application and the lowest (0.052 g/pot) Zn uptake was found in 0.55 mg/kg of Zn containing soil where no external Zn application was done.

Three different levels (1.05, 1.25 and 1.40 mg/kg) of DTPA extractable soil Zn of Kettiganalli showed that, there was a gradual increase in Zn uptake by finger millet with Zn application up to 1.00 mg/kg in soil having DTPA zinc to the extent of both 1.05 and 1.25 mg/kg, however, in soil containing 1.40 mg Zn/kg, the crop responded up to 1.25 mg/kg of Zn application. Significantly highest (0.109 g/pot) Zn uptake was found in 1.40 mg Zn/kg (Kettiganalli) where no Zn was applied (Table 3). Significantly highest (0.153 g/pot) Zn uptake was recorded from

Table 2 : Effect of graded levels of zinc application on shoot zinc content (mg/kg) in finger millet under soil containing different levels of Zn

Zinc level units	DTPA-Zn in Pathakote soil (mg/kg)				DTPA-Zn in Kettiganalli soil (mg/kg)				DTPA-Zn in ZARS-GKVK soil (mg/kg)				DTPA-Zn in ZARS-Mandya soil (mg/kg)			
	0.35	**0.55**	**0.65**	**Mean**	**1.05**	**1.25**	**1.40**	**Mean**	**1.55**	**1.65**	**1.95**	**Mean**	**2.28**	**2.30**	**2.60**	**Mean**
Control	44.38	44.38	46.25	45.00	61.88	67.50	72.50	67.29	88.13	95.13	92.50	91.92	85.00	81.88	81.88	82.92
0.50	47.13	53.63	46.25	49.00	68.13	71.88	71.25	70.42	90.00	93.13	96.00	93.04	81.90	89.38	87.50	86.26
0.75	48.13	54.38	48.00	50.17	72.50	74.38	69.38	72.09	98.13	92.50	94.38	95.00	85.88	86.25	90.75	87.62
1.00	55.00	59.38	58.75	57.71	73.75	73.75	70.88	72.79	98.75	103.13	84.38	95.42	84.25	86.88	87.50	86.21
1.25	45.60	51.63	48.63	48.62	78.75	71.25	74.38	74.79	97.50	96.88	100.0	98.12	85.50	86.13	84.38	85.33
1.50	54.38	55.00	43.88	51.10	69.38	76.88	72.50	72.92	95.25	99.38	100.6	98.42	85.63	87.13	86.88	86.54
Mean	49.10	53.07	48.63	-	70.73	72.61	71.81	-	94.62	96.69	94.64	-	84.69	86.27	86.48	-
SEm±		3.80				2.75				1.65				1.36		
CD (P=0.05)		10.30				7.75				4.30				3.85		

the application Zn @ 1.00 and 1.25 mg/kg to the soils of ZARS, GKVK having 1.55 mg DTPA extractable Zn/kg and the lowest Zn uptake was found (0.079 g/pot) in the same soil without the external Zn application (Table 3). Significantly highest (0.250 g/pot) Zn uptake was found in ZARS, Mandya soils containing 2.60 mg DTPA extractable Zn for which 0.75 mg/kg fertilizer Zn was applied. Whereas, the lowest Zn uptake (0.189 g/pot) was observed in 2.28 mg/kg Zn containing soil with 1.25 mg/kg of fertilizer Zn application (Table 3). Zinc mobility and uptake in soil is dependent on many factors such as soil acidity, total Zn value in the soil, organic matter and soil type. Total Zn value may be very low in highly acidic soils due to the intense soil leaching. Zn usability decreases by increasing soil pH, because the minerals solubility reduced and zinc uptake increases by soil colloidal particles such as clay minerals, iron and aluminum oxides, organic matter and calcium carbonate (Alloway, 2008).

Critical limit of soil and plant

Straw yield of finger millet without any Zn application varied from 11.68 to 23.60 g/pot in different soils having different levels of Zn (Table 4). The lowest check yield of 11.68 g/pot was recorded in soils of Pathakote containing 0.35 mg/kg Zn, whereas, the highest check yield of 23.60 g/pot was recorded in soils of ZARS, Mandya having 2.60 mg/kg of DTPA-Zn. Similarly, the maximum yield worked out for different soils under different levels of Zn application was found to be highest (27.00 g/pot) in soils of ZARS, Mandya having 2.60 mg Zn/kg with application of Zn @ 1.00 mg/kg whereas, the lowest yield of 13.09 g/pot was recorded in Kettiganahalli soils having 1.05 mg/kg DTPA-Zn. Similarly, average Zn content of finger millet shoots at panicle initiation stage was found to be highest (96.69 mg/kg) in ZARS-GKVK soil having 1.65 mg/kg DTPA-Zn. However, the lowest Zn content of 48.63 mg/kg was recorded in finger millet grown in Pathakote soils having 0.65 mg/kg DTPA-Zn.

Relative yield (%) worked out for finger millet crop in different soils was found to be highest (88.5%) in ZARS-GKVK soils having 1.95 mg/kg DTPA-Zn, whereas, the lowest relative yield of 16.9% was recorded in Pathakote soils having 0.55 mg/kg DTPA-Zn (Table 4). The scattered diagram of twelve points of relative yield (Y-axis) against DTPA-Zn (X-axis) indicates that the point of intersection of vertical line on the X-axis clearly depicted that 0.66 mg Zn/kg was the critical limit for selected soils of southern Karnataka (Figure 1). Above this critical level (0.66 mg Zn/kg), Zn application is not needed. However, below this critical level (0.66 mg/kg), finger millet will respond to application of Zn fertilizer, but it will not specify the exact quantity to be applied. Similarly, Zn content of finger millet shoot (X-axis) plotted against relative yield (Y- axis) through graphical method indicated that the critical limit of Zn for finger millet was found to be 54.00 mg/kg (Figure 2) below which Zn concentration increases in finger millet, the dry matter of the finger millet increases, but above this critical limit, it will not increase the dry matter yield even if the Zn level increases. Tandon (1995) identified the critical limit of 0.40 ppm to 1.20 ppm for soils for several diagnostic purposes in different crop plants. Similarly, Bennet (1993) clearly indicated that Zn concentration of 15-20 ppm is known to indicate Zn deficiency in general crops.

Table 3 : Effect of graded levels of zinc application on zinc uptake (g/pot) by finger millet under soils containing different levels of Zn

Zinc level units	DTPA-Zn in Pathakote soil (mg/kg)				DTPA-Zn in Kettiganalli soil (mg/kg)				DTPA-Zn in ZARS-GKVK soil (mg/kg)				DTPA-Zn in ZARS-Mandya soil (mg/kg)			
	0.35	**0.55**	**0.65**	**Mean**	**1.05**	**1.25**	**1.40**	**Mean**	**1.55**	**1.65**	**1.95**	**Mean**	**2.28**	**2.30**	**2.60**	**Mean**
Control	0.060	0.052	0.095	0.069	0.078	0.080	0.109	0.089	0.079	0.121	0.135	0.112	0.227	0.210	0.234	0.224
0.50	0.066	0.081	0.076	0.074	0.088	0.090	0.092	0.090	0.131	0.126	0.134	0.131	0.227	0.219	0.243	0.229
0.75	0.089	0.117	0.079	0.095	0.092	0.094	0.093	0.093	0.147	0.132	0.113	0.131	0.210	0.204	0.250	0.221
1.00	0.091	0.106	0.132	0.109	0.095	0.097	0.094	0.095	0.153	0.149	0.131	0.144	0.197	0.213	0.214	0.208
1.25	0.080	0.092	0.074	0.082	0.095	0.094	0.108	0.099	0.153	0.150	0.137	0.147	0.189	0.199	0.206	0.198
1.50	0.095	0.101	0.069	0.088	0.091	0.092	0.091	0.091	0.134	0.134	0.127	0.131	0.200	0.191	0.208	0.199
Mean	0.080	0.091	0.087	-	0.089	0.092	0.097	-	0.133	0.135	0.129	-	0.208	0.206	0.225	-
SEm±		0.005				0.004				0.128				0.010		
CD (P=0.05)		0.014				0.120				0.280				0.023		

Table 4 : Yield and zinc content of finger millet shoot due to graded levels of Zn application

Location	Soil Zn (mg/kg)	Av. shoot Zn content (mg/kg)	Check yield (g/pot)	Maximum yield (g/pot)	Relative yield (%)
Pathakote	0.35	49.10	11.68	18.48	41.8
	0.55	53.07	11.75	21.52	16.9
	0.65	48.63	12.45	17.48	59.6
Kettiganalli	1.05	70.73	12.62	13.09	47.0
	1.25	72.61	11.80	14.40	78.0
	1.40	71.81	12.25	15.40	74.3
ZARS-GKVK	1.55	94.62	11.59	15.70	64.5
	1.65	96.69	12.35	14.48	82.8
	1.95	94.64	14.55	14.50	88.5
ZARS-Mandya	2.28	84.69	22.65	25.80	86.1
	2.30	86.27	21.65	26.20	78.3
	2.60	86.48	23.60	27.00	85.6

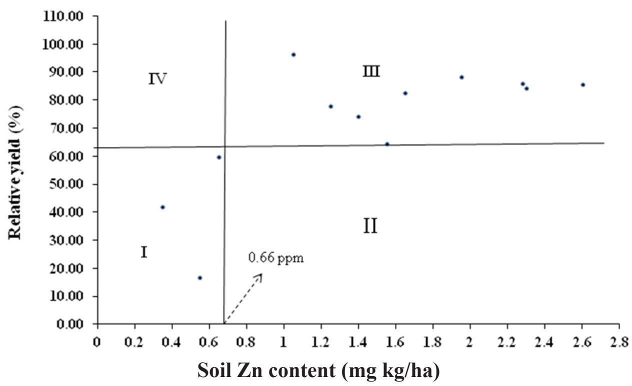

Fig. 1: Critical limit of soil available zinc for finger millet

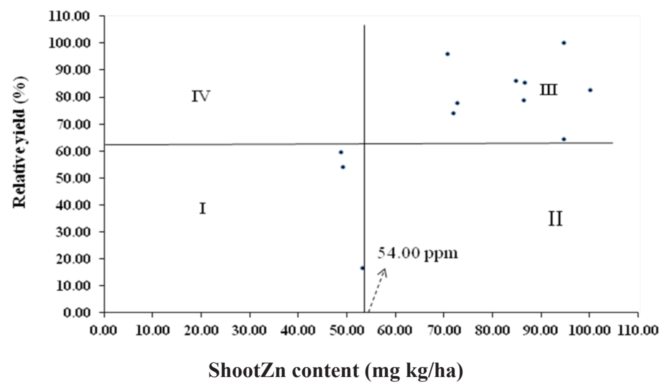

Fig. 2: Critical limit of zinc in finger millet

Conclusion

The result of the present study can be well adopted for red soils of southern parts of Karnataka, particularly where finger millet is a major crop, so that the crop yields can be achieved by maintaining the good fertility status of the soil.

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Received: November 2013; Accepted: March 2014