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Response of turmeric (*Curcuma longa* L.) to micronutrient fertilizer mixtures applied at various levels and methods on the growth, yield and quality of rhizomes

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Abstract
Two field experiments were carried out with turmeric variety BSR 2 on sandy loam and sandy clay soils to assess the effect of newly developed multi-micronutrient mixtures on the growth, yield and uptake of micronutrients. There were fifteen treatment combinations comprising three different grades of newly developed turmeric mixtures which were applied at two levels (15 and 30 kg ha^{-1}) as fully at basal and as split applied equally at basal and on 90 days after planting. The mean data of both the experiments revealed that, split application of micronutrient mixture grade II @ 15 kg ha^{-1} equally at basal and 90 days after planting significantly increased the rhizome yield by 37.6 to 40.2 per cent over recommended NPK without micronutrients and showed 15.5 to 16.9 % increase in rhizome yield over recommended micronutrients application of 50 kg $ZnSO_4$ +100 kg $FeSO_4$ ha^{-1}. The same treatment increased the growth and yield attributes of turmeric crop with better B: C ratio of 2.88. Though it was comparable with the split application of 30 kg grade III micronutrient mixture, it was comparatively economical and the yield increase was also higher hence can be recommended to turmeric grown on the soils having multi-nutrient deficiencies.

Keywords: Turmeric, multi micronutrient mixtures, growth, rhizome yield, curcumin content

Introduction
Micronutrients deficiency is the commonly observed abiotic stress in agriculture and many million hectares of soils in the world becomes deficit in micronutrients availability due to continuous omission or less application of required micronutrients. Zinc (Zn) is the most important element which is universally deficient in almost all the soils throughout the world followed by Fe, Cu and B under specific unfavourable situations (Hadler *et al*, 2007; Datta *et al*, 2017; Hnamte *et al*, 2018) [5, 3, 6]. Indian soils are also showing heavy depletion of micronutrients and analysis of 2.00 lakh soil samples collected from various States of the country revealed predominant deficiency of Zn (36.5 %) followed by B (23.2%) and Fe (12.8%, Arvindkumar Shukla and Behera, 2017). Hence micronutrient deficiencies has become a major yield limiting factor which may be primarily due to their low inherent total soil content or secondarily due to various soil factors such as calcareousness, high pH, low organic carbon, salinity, sodicity, etc which reduced their availability to plants in turn yield loss in many crops (Kulpapangkorna and Mai-leang, 2012; Safarzadeh *et al.*, 2018) [8, 14]. Turmeric (*Cucurma longa L., Zingiberaceae*) is the popular spice crop cultivated widely in India and its underground rhizomes are used as a condiment in dye, drugs and cosmetics, after processing and value addition. It is certified as a natural food colour and has several uses in traditional Indian as well as modern medicines for various human ailments (Ravindran *et al.* 2007, Kumar and Ghosh, 2017) [13, 10]. In India, it is grown in 6% of the total cultivable area under spices and being the largest producer and exporter of turmeric accounting 93.3% world's total production. Further, turmeric is the second largest foreign exchange earner among Indian spices by exporting only 8% of total production annually. It is majorly grown in Andhra Pradesh, Maharashtra, Tamil Nadu, Orissa, Karnataka and Kerala (Vishwanath *et al*, 2011; Thiripurasundari and Selvarani, 2014) [19, 18]. The nutrient requirement of this crop is quite high due to shallow rooting and potential to produce large quantity of dry matter per unit area. Application of chemical fertilizers are widely followed to meet the crop requirement however conjunctive use of fertilizers and organic manures results in better yield and nutrient use efficiency (Kamal and Yousuf, 2012; Rajeev Kumar *et al*, 2013) [7, 12]. However the gap between potential and realized yield of crop is markedly reduced when balanced nutrient management strategies were not adopted. In order to sustain the production system, it is

essential to apply fertilizer nutrients in balanced proportion based on the crop nutrient demand to achieve higher yield. Though major nutrients fertilizers are adequately applied, yield sustenance could not be obtained due to the omission of micronutrient inputs in fertilizer schedule. Recently multi nutrients deficiencies are also reported widely in Indian soils hence greater emphasis has to be placed on the use of multi-nutrient fertilizer sources particularly in the intensively cropped areas to achieve higher rhizome yield and quality of turmeric (Kumar *et al*, 2011; Sanghamithre and Meera, 2014) [9, 16]. In this context, use of micronutrients in a balanced proportion is essential to sustain soil health and crop productivity. Hence the present study was proposed with an aim to develop suitable multi-micronutrient mixtures and to optimize the rate of application in increasing the rhizome yield and quality of turmeric measured in terms of curcumin content.

Materials and Methods

Two field experiments were conducted with turmeric variety BSR 2 on red sandy loam and black sandy clay soils. Fifteen treatment combinations were tried with three different grades of newly developed turmeric micronutrient mixtures which were applied at two levels (15 and 30 kg ha^{-1}) as basal and split application on 90 days after planting. The recommended fertilizer schedule of 150:60:108 kg of NPK as Urea, SSP and MOP was applied as full Pat basal and entire N: K (25:18 kg ha^{-1}) as split applied at basal, 30, 60, 90, 120 and 150 days after planting. The treatments combinations tried were : T_1- NPK control; T_2-T_1+ 15kg $ZnSO_4$+30 kg $FeSO_4$ ha^{-1} as basal; T_3: T_1+ 50kg $ZnSO_4$ +100 kg $FeSO_4$ ha^{-1} as basal; T_4- T_1+ micronutrient mixture Grade I at 15 kg ha^{-1} as 100 % basal ; T_5- T_1+ micronutrient mixture Grade I at 15 kg ha^{-1} as 50 % basal and 50% top dressing on 90 DAP; T_6- T_1+ micronutrient mixture Grade I at 30 kg ha^{-1} as 100 % basal ; T_7- T_1+ micronutrient mixture Grade I at 30kg ha^{-1} as 50 % basal and 50% top dressing on 90DAP; T_8- T_1+ micronutrient mixture Grade II at 15 kg ha^{-1} as 100 % basal ; T_9- T_1+ micronutrient mixture Grade II at 15kg ha^{-1} as 50 % basal and 50% top dressing on 90DAP; T_{10}- T_1+ micronutrient mixture Grade II at 30 kg ha^{-1} as 100 % basal ; T_{11}- T_1+ micronutrient mixture Grade II at 30 kg ha^{-1} as 50 % basal and 50% top dressing on 90DAP; T_{12}- T_1+ micronutrient mixture Grade III at 15 kg ha^{-1} as 100 % basal ; T_{13}- T_1+ micronutrient mixture Grade III at 15kg ha^{-1} as 50 % basal and 50% top dressing on 90DAP; T_{14}- T_1+ micronutrient mixture Grade III at 30 kg ha^{-1} as 100 % basal ; T_{15}- T_1+ micronutrient mixture Grade III at 30 kg ha^{-1} as 50 % basal and 50% top dressing on 90DAP. All the treatments were applied as per schedule and replicated thrice in a randomized block design. Raised beds of 45 cm size and 120 cm width were prepared with 30 cm interval. Turmeric rhizome of variety BSR 2 was planted with a spacing of 45 cm x 15 cm. The crop was grown to maturity after following necessary plant protection and production measures and harvested. Plant growth and yield attributes were recorded at harvest and the fresh rhizome yield per hectare was calculated on plot weight basis. Plant samples were collected at harvest, processed, shade dried and oven dried at 70^0C and ground in a Wiley mill. The ground samples were digested with tri acid mixture (HNO_3: H_2SO_4 :$HClO_3$ at 9:2:1 ratio) and used for determining the micronutrients content using Atomic Absorption Spectrophotometer (Model GBC avanta, Hessey, 1971). Soil samples were also collected at harvest to assess the DTPA extractable micronutrients availability by following the procedure outlined by Lindsay and Norwell (1978) [11]. The data was statistically analyzed as per the method suggested by Gomez and Gomez (1984) [4] and wherever the treatment differences were found significant critical differences (CD) were worked out at 5% level of significance and non-significant comparisons were indicated as NS.

Results and Discussion

Growth and Yield attributes

Perusal of data on growth and yield attributes such as plant height, root length, rhizome length and girth of turmeric showed significant variation in both the soils for the application of various newly developed micronutrient mixtures. Among the three newly developed grades of micronutrient mixtures, split application of grade II at 15 kg ha^{-1} at basal and 90 DAP recorded higher mean plant height (125cm), root length (16.4 cm), rhizome length (14.8 cm) and girth (11.4 cm) in both the soils (Table 1 & 2). This was on par with the addition of same grade II micronutrient mixture at 15 kg ha^{-1} completely as basal and by grade III at 30 kg ha^{-1} as split applied at basal and 90 DAP (117 & 116 cm, 15.4 & 15.7 cm, 13.7 & 13.2 cm and 10.6 cm respectively). The lowest mean plant height (93cm), root length (9.7 cm), rhizome length (8.23 cm) and girth (6.84 cm) was registered in NPK control. Between the soils, higher plant height (117 cm) and rhizome girth (11cm) was recorded in red sandy loam soil while higher rhizome length was noted in black sandy clay soil (14.8 cm). The substantial increase in the growth and yield attributes of turmeric could be ascribed to the direct involvement of micronutrients in improving the photosynthetic activity, protein synthesis and reproduction (Halder *et al*, 2007; Salem and Nasser, 2012; Hnamte *et al*, 2018) [5, 15, 6]. Turmeric is considered as nutrient exhaustive crop, hence omission of micronutrients in the fertilizer schedule reduced the growth and yield attributes of the crop.

Table 1: Effect of multi micronutrients mixtures on the growth attributes of turmeric at harvest

Treatments		Plant height (cm)			Root length (cm)		
		S1	S2	Mean	S1	S2	Mean
T1	NPK control	102	84	93	10.4	8.9	9.7
T2	T1+15 kg $ZnSO_4$+30 kg $FeSO_4$	113	99	106	13.1	11.8	12.5
T3	T1+ 50 kg $ZnSO_4$+ 100 kg $FeSO_4$	116	104	110	14.0	12.4	13.2
T4	T1+ Grade I @ 15 kg	112	98	105	13.1	12.6	12.9
T5	T1+ Grade I @ 15 kg split	114	106	110	8.4	9.9	9.2
T6	T1+ Grade I @ 30 kg	110	99	105	12.0	13.5	12.8
T7	T1+ Grade I @ 30 kg split	118	106	112	13.8	13.9	13.9
T8	T1+ Grade II @ 15 kg	120	113	117	14.3	16.4	15.4
T9	T1+ Grade II @ 15 kg split	132	118	125	15.0	17.7	16.4
T10	T1+ Grade II @ 30 kg	102	101	102	11.0	13.3	12.2
T11	T1+ Grade II @ 30 kg split	108	104	106	12.5	12.6	12.6
T12	T1+ Grade III @ 15 kg	114	109	112	13.7	13.6	13.7
T13	T1+ Grade III @ 15 kg split	116	107	112	13.4	14.0	13.7
T14	T1+ Grade III @ 30 kg	115	103	109	13.9	13.8	13.9
T15	T1+ Grade III @ 30 kg split	117	115	116	14.9	16.4	15.7
	SEd	8.95	7.32		1.74	2.12	
	CD (P= 0.05)	18.35	14.9		3.57	4.35	

Table 2: Effect of multi micronutrients mixtures on the yield attributes of turmeric at harvest

Treatments		Rhizome length (cm)			Rhizome girth (cm)		
		S1	S2	Mean	S1	S2	Mean
T1	NPK control	6.83	9.63	8.2	7.50	6.18	6.8
T2	T1+15 kg $ZnSO_4$+30 kg $FeSO_4$	8.10	11.0	9.6	8.93	7.84	8.4
T3	T1+ 50 kg $ZnSO_4$+ 100 kg $FeSO_4$	9.57	12.6	11.1	9.63	8.05	8.8
T4	T1+ Grade I @ 15 kg	10.2	10.7	10.5	9.83	8.71	9.3
T5	T1+ Grade I @ 15 kg split	11.1	12.5	11.8	10.4	9.70	10.1
T6	T1+ Grade I @ 30 kg	11.8	11.3	11.6	10.3	10.1	10.2
T7	T1+ Grade I @ 30 kg split	12.4	12.5	12.5	10.8	11.2	11.0
T8	T1+ Grade II @ 15 kg	12.2	12.8	12.5	11.5	11.5	11.5
T9	T1+ Grade II @ 15 kg split	13.5	14.0	13.8	12.7	12.5	12.6
T10	T1+ Grade II @ 30 kg	11.0	11.4	11.2	9.5	8.85	9.2
T11	T1+ Grade II @ 30 kg split	11.7	12.5	12.1	10.4	9.74	10.1
T12	T1+ Grade III @ 15 kg	11.8	11.8	11.8	9.8	9.92	9.9
T13	T1+ Grade III @ 15 kg split	12.3	12.8	12.6	10.4	10.3	10.4
T14	T1+ Grade III @ 30 kg	10.7	12.0	11.4	10.0	9.55	9.8
T15	T1+ Grade III @ 30 kg split	11.7	14.1	12.9	11.0	11.0	11.0
	SEd	1.03	0.10		0.86	1.09	
	CD (P= 0.05)	2.12	0.20		1.78	2.24	

Rhizome yield and curcumin content

Addition of micronutrient mixtures significantly influenced the fresh and dry rhizome yield of turmeric in both the soils (Table 3) which varied from 21.0 to 35.3 t and 3.88 to 6.60 t ha^{-1} respectively. Between the two soils, higher fresh and dry rhizome yield was registered in red sandy loam soil than the black sandy clay soils which might be due to better response of turmeric crop to added nutrients. The highest mean fresh (32.1 t ha^{-1}) and dry rhizome yield (5.76 t ha^{-1}) was observed with the split application of micronutrient mixture grade II at 15 kg ha^{-1} equally at basal and after 90 DAP. The yield increase was 37.0 and 40.2 per cent with a B:C ratio of 2.88 and 2.14 respectively in red sandy loam and black sandy clay soils. This was on par with the split application of 30 kg grade III micronutrient mixture (30.8 & 5.23 t ha) at basal and after 90 DAP and basal application of grade II micronutrient mixture at 15 kg ha^{-1} (30.2 & 5.43 t ha^{-1}). The lowest mean fresh (22.9 t ha^{-1}) and dry rhizome yield (4.00 t ha^{-1}) and DMP were noted in NPK control. The increase in rhizome yield could be due to cumulative increase in finger weight, rhizome length and girth of turmeric by the addition of multi-micronutrients which might have brought significant changes in the metabolic activities and photosynthesis. Similar findings have been reported by Kamal and Yousuf (2012) and Anuradha *et al. (*2018) [7, 1].

Table 3: Effect of multi micronutrients mixtures on the rhizome yield and DMP of turmeric

Treatments		Fresh Rhizome yield (t ha^{-1})			Dry matter production (kg ha^{-1})		
		S1	S2	Mean	S1	S2	Mean
T1	NPK control	24.9	21.0	22.9	1477	1177	1327
T2	T1+15 kg $ZnSO_4$+30 kg $FeSO_4$	28.1	23.5	25.8	1605	1105	1355
T3	T1+ 50 kg $ZnSO_4$+ 100 kg $FeSO_4$	30.2	25.1	27.6	1723	1223	1473
T4	T1+ Grade I @ 15 kg	27.6	23.8	25.7	1962	1462	1712
T5	T1+ Grade I @ 15 kg split	29.5	24.7	27.1	2234	1734	1984
T6	T1+ Grade I @ 30 kg	29.7	25.1	27.4	1916	1416	1666
T7	T1+ Grade I @ 30 kg split	30.4	26.2	28.3	2202	1702	1952
T8	T1+ Grade II @ 15 kg	33.9	26.6	30.2	2373	1873	2123
T9	T1+ Grade II @ 15 kg split	35.3	28.9	32.1	2564	2064	2314
T10	T1+ Grade II @ 30 kg	31.7	24.8	28.3	2000	1500	1750
T11	T1+ Grade II @ 30 kg split	32.0	26.9	29.5	2206	1706	1956
T12	T1+ Grade III @ 15 kg	31.3	24.8	28.1	1893	1393	1643
T13	T1+ Grade III @ 15 kg split	33.5	26.0	29.8	2215	1715	1965
T14	T1+ Grade III @ 30 kg	32.4	25.9	29.1	2070	1570	1820
T15	T1+ Grade III @ 30 kg split	34.5	27.1	30.8	2342	1842	2092
	SEd	1.79	0.65	2.53	184	67.3	260
	CD (P= 0.05)	3.58	1.31	NS	369	134	521

Combined application of all the micronutrients had positive influence in increasing the curcumin content in rhizomes which varied from 2.58 to 4.0 per cent. Higher accumulation of curcumin was noted in red sandy loam soils than in black sandy clay soils (Figure 1). The highest mean curcumin content in the rhizome was noted with the split application of grade II micronutrient mixture at 15 kg ha^{-1} as basal and after 90 DAP (3.83 %). Next to this, grade III at 30 kg ha^{-1} split applied as basal and 90 DAP recorded the highest values (3.68%). The lowest curcumin content was observed in NPK control (2.77%). The synergistic interaction between various micronutrients leads to better development of rhizomes and subsequent accumulation of curcumin. The results further indicated that, sufficient quantity of B and Zn in the mixtures might have also favoured the accumulation of curcumin in the rhizomes (Hnamte *et al.*, 2018; Anuradha *et al.*, 2018) [6, 1].

Micronutrient uptake

Similar to rhizome yield, micronutrient uptake in rhizome and plant was also considerably varied with the application of micronutrient mixtures which was computed by accounting the nutrient concentration and rhizome yield recorded in both the soils (Fig. 2 & 3). Most of the micronutrients increased with increasing levels of micronutrient mixtures addition in both rhizomes and plants. Further split application of micronutrient mixtures at basal and 90 DAP showed significant variation and increased the uptake of all the micronutrients. Except B, uptake of all other micronutrients in turmeric rhizomes and plants were higher with the split application of 15 kg of grade II micronutrient mixture at basal and on 90 DAP. The mean total uptake values were 290 g for Zn, 116 g for Cu, 4097 g for Fe and 459 g for Micronutrient ha^{-1}. This was comparable with the application of 30 kg grade III micronutrient mixtures split applied at basal and 90 DAP. The increased uptake might be due to higher rhizome yield coupled with better availability of all the micronutrients for plant absorption. Similar increase in uptake due to the addition of micronutrients might be due to higher availability and synchronized with crop uptake which was reported by several researchers (Zhang *et al*, 2012; Wu and Ma, 2015; Srinivasan *et al*, 2016) [21, 20, 17]. Between the soils, higher micronutrient uptake was registered with red sandy loam soil than the black sandy clay soil and the lowest micronutrient removal was noted in NPK control due to lesser yield and DMP besides lesser soil availability.

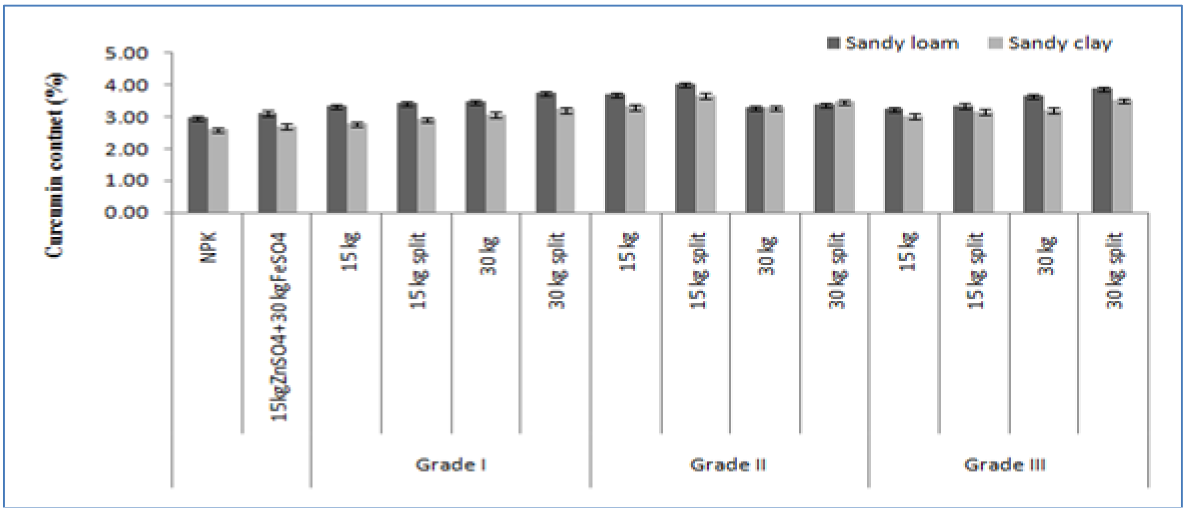

Fig 1: Effect of multi micronutrient mixtures on curcumin content of turmeric rhizomes

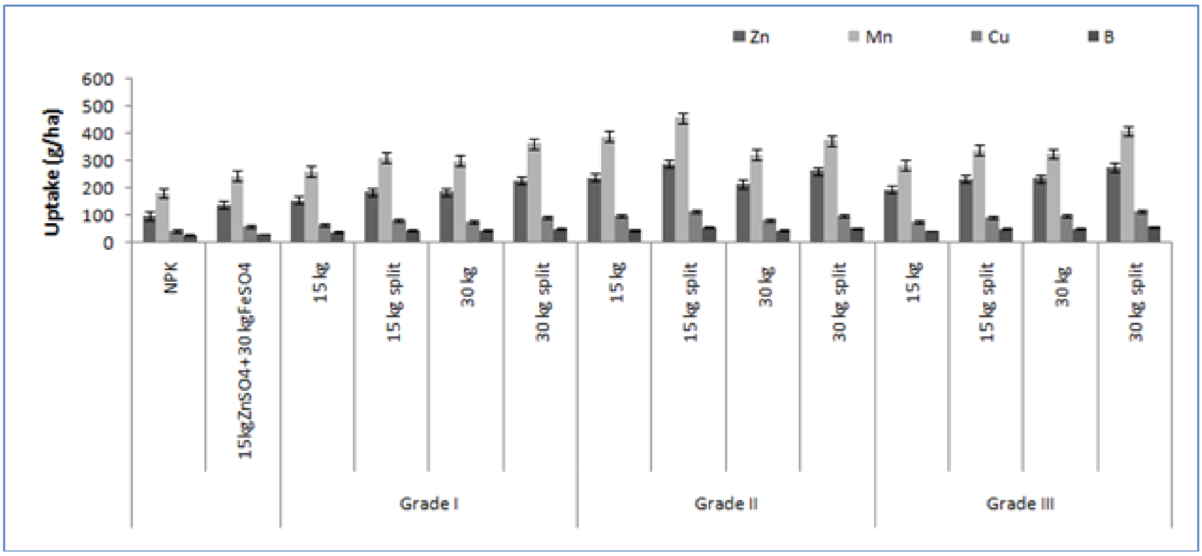

Fig 2: Effect of multi micronutrient mixtures on total micronutrient uptake by turmeric

Conclusions

Use of various grades of micronutrients mixtures markedly influenced the rhizome yield, soil micronutrient availability and their uptake by turmeric. Split application of micronutrient mixture grade II at 15 kg equally at basal and 90 days after planting significantly increased the growth and yield attributes of turmeric irrespective of soil texture. The same treatment increased the fresh and dry rhizome yield by 37 to 40 per cent. This was comparable with the application of micronutrient mixture grade III at 30 kg equally at basal and 90 days after planting. However the response of turmeric crop to added micronutrient mixture was better in sandy loam soil than in sandy clay soil due to better soil fertility and favourable soil environment for rhizome development. The absorption of micronutrients was also enhanced with the addition of micronutrient mixtures which resulted in higher crop uptake and rhizome quality. This study revealed a good response of turmeric to split application of multi micronutrients mixtures which depends on the rate of application and soil texture.

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