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Mapping and Frequency Distribution of Current Micronutrient Deficiencies in Soils of Telangana for their Precise Management

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Analysis of 4,799 geo-referenced surface soil samples, collected using stratified random sampling techniques revealed that 27% soils of Telangana state are deficient in Zn, 17% in Fe, 12% in B, less than 5% in Mn and 2% in Cu. Frequency distribution analysis showed that 34, 11.4, 9.8, 6.3 and 22% soil samples fall under grey area of Zn, Fe, Mn, Cu, and B availability status, respectively. The grey area signifies the soils which may not have acute deficiency of a nutrient but crops respond to application of respective nutrient in these soils. The combination of these two categories may add to the misery of micronutrients deficiencies in the state especially Zn, Fe and B if not managed properly. The maps for each micronutrients, prepared using the status of deficiency in each districts shall be of immense importance in proper management and distribution of micronutrients fertilisers in the state. Area specific micronutrients fertilisers management, based on frequency distribution,would be more profitable than uniform management through single recommendation for whole state.

INTRODUCTION

Soil plays a major role in determining the sustainable productivity of an agro-ecosystem. The sustainable productivity of a soil mainly depends upon its ability to supply essential nutrients to the crop. The deficiency of micronutrients has become a major constraint in optimizing crop productivity and soil sustainability (1, 2). The availability of micronutrients in soil is dependent on the parent material, pedogenic process and soil management which may promote, in some cases a reduction of cationic micronutrients content (9). Reduction in native levels of micronutrients in soils due to continuous shipping away of micronutrients without replenishment has been a cause of concern for all the stakeholders. It is well known that optimum plant growth and crop yields depend upon plant available micronutrients to the crop not on their total concentration.

Telangana, newly formed state of India is situated on the Deccan Plateau, in the central stretch of the eastern seaboard of the Indian Peninsula in between 15.0^{o} to 19.9^{o} N latitude and 77.25 to 81.8^{o} E longitude. State has a total area of 114.84 lakh hectares of which nearly, 43.2% area is under cultivation. As per the Agricultural Census, 2010-11, the number of farm holdings in the State stands close to 55.54 lakh while the area held by these holdings is 61.97 lakh hectares. The state comprises of 10 districts, *viz.*, Hyderabad, Rangareddy, Medak, Nizamabad, Adilabad, Karimnagar, Warangal, Khammam, Nalgonda and Mahabubnagar. Soils in Telangana state mostly fall under *Alfisols*, *Vertisols* and *Inceptisols* soil orders. The major crops of the state are rice, sorghum, maize, cotton, groundnut, castor, soybean and pulses (4). About 31.64 lakh ha area of the state is irrigated (22.89 lakh ha net irrigated) and cropping intensity was around 1.27 during 2013-14.

Though large variation in micronutrients availability exists in soils, farmers normally use blanket fertiliser recommendation without knowing fertility status of their soils. Thus, nutrients recommendation based on large geographical area may lead to over or under use of nutrients with adverse economic or environmental challenges. Due to this unique system of fertiliser application yields as well as produce quality is deteriorating (15). Therefore, balanced fertiliser prescription for optimum yield and fertiliser use efficiency and improved produce quality is necessary to maintain soil, animal and human health.

Georeferenced soil surveys are essential to know the point level micronutrient deficiency and precise mapping. Micronutrient deficiencies at state level were assessed using GPS to identify the nature and extent of deficiencies and suggest suitable amelioration practice(s) to be adopted. Information on delineation of Zn, Fe, Mn, Cu and B deficiencies along with crop survey for nutrient status has been generated for all the districts of Telangana state. Although delineation of micronutrient deficiencies was initiated in 1970 and deficiencies of micronutrients were extensively noticed in soil and crop nutritional surveys carried out in the state under AICRP on Micronutrients (16). The systematic geo-referenced sampling for whole state, which was part of Andhra Pradesh earlier was conducted during the year 2011-14.

The study of distribution of micronutrients is expected to support the rational management with respect to micronutrients. The in-depth knowledge on availability status of micronutrients in soils of the state and corresponding response to the application of the respective micronutrient will be highly useful in developing site specific fertiliser prescription. In this article, an endeavour has been made to analyse the soils for micronutrients availability, their frequency distribution and response to their external application. The micronutrients deficiency status maps for the state have also been prepared which would be helpful in developing right micronutrients prescription.

Soil Sampling, Analysis and Preparation of Deficiency Maps

Four thousand seven hundred ninety nine (4799) geo-referenced surface soil samples (0-15 cm depth) were collected covering all the *mandals* and districts of the state using multi-stratified random sampling technique during the year 2012-2014. The sampling size varied with the size of the district, cropped area and cropping intensity from all 9 districts of the state, *viz*., Adilabad (499), Karimnagar (630), Khammam (354), Medak (407), Mahabubnagar (900), Nalgonda (256), Nizamabad (522), Ranga reddy (468) and Warangal (763). Since, majority of area in Hyderabad districts is not under agriculture the soil samples from such district were not collected. The samples were air-dried, ground and passed through a 2 mm sieve for analysis of micronutrient (Zn, Fe, Mn, Cu and B) by adopting standard procedure. Analysis of Zn, Fe, Mn and Cu was performed using Diethylene Triamine Penta Acetic Acid (0.005 DTPA+0.1 M Triethanolamine and 0.01M $CaCl_2$ solution buffer) extractant as outlined by Lindsay and Norwell (1978) while hot water soluble B was analysed utilizing method suggested by Berger and Truog (1939). The soil micronutrients maps were prepared using Arc GIS to demarcate level of deficiency in various regions of the districts. Critical limits used to categorize level of deficiency were 0.60 mg kg^{-1} soil for DTPA-extractable Zn, 5.0 mg kg^{-1} soil for DTPA-extractable Fe, 0.20 mg kg^{-1} soil for DTPA-extractable Cu, 2.0 mg kg^{-1} soil for DTPA-extractable Mn and 0.40 mg kg^{-1} soil for hot water soluble B.

Table 1 – Average total micronutrients (mg kg^{-1}) contents at different depths in soils of Telangana

Depth	Zn	Cu	Fe	Mn
0-15	16.27	11.80	4500	160
15-30	24.80	13.29	8693	231
30-45	48.00	26.93	4867	536

Soil Micronutrients Status

A. Total Micronutrients Contents in Soils of Telangana

All plant nutrients are present in soils as a part of their mineral and organic fraction however, one or more nutrients are not present in plant usable form in adequate amounts. The result is that the soil may be deficient in a nutrient in spite of containing large amount of it. The available nutrient content at a given time is only a very small fraction of the total amount present. Soil can be rich in total content of micronutrients but poor in plant available amount (**Table 1**).

B. Delineation and Mapping of Available Micronutrients Deficiency

1. *DTPA-extractable Zinc*

Soil Zn is an index of Zn content in fodders and grain, which significantly rely on available Zn content in soils (13). For clear prediction of possible deficiencies, the critical limit has to be refined with reference to the soil and crop characteristics as the soils and crops vary widely in their nutrient supplying capacity and utilization efficiency. Systematic survey and analysis of 4,799 soil samples analysed under the aegis of AICRP on Micronutrients indicated wide spread Zn deficiency in the state. On average, 27% soil samples were deficient in Zn, however status of Zn varies with soil types, agro-ecological zones and more importantly management and productivity of crops and cropping systems (10).

The DTPA-extractable Zn content in soils of the state ranged from 0.10-7.00 mg kg^{-1} soil and based on the critical limit (0.6 mg Zn kg^{-1}), Zn deficiency varied from 7.42 to 51.30%. Among the districts, the highest Zn deficiency was recorded in Adilabad (51.30%) followed by Warangal district (48%) while more than 20% Zn deficiency was reported in Mahabubnagar and Karimnagar districts. The Zn deficiency in Medak, Khammam, Ranga Reddy and Nizamabad districts ranged between 10 to 20% **(Table 2 and Map1).** The soils of Nalgonda district were reported to be less deficient in Zn as only 7.5% soil samples were found to be deficient.

2. *DTPA-extractable Iron*

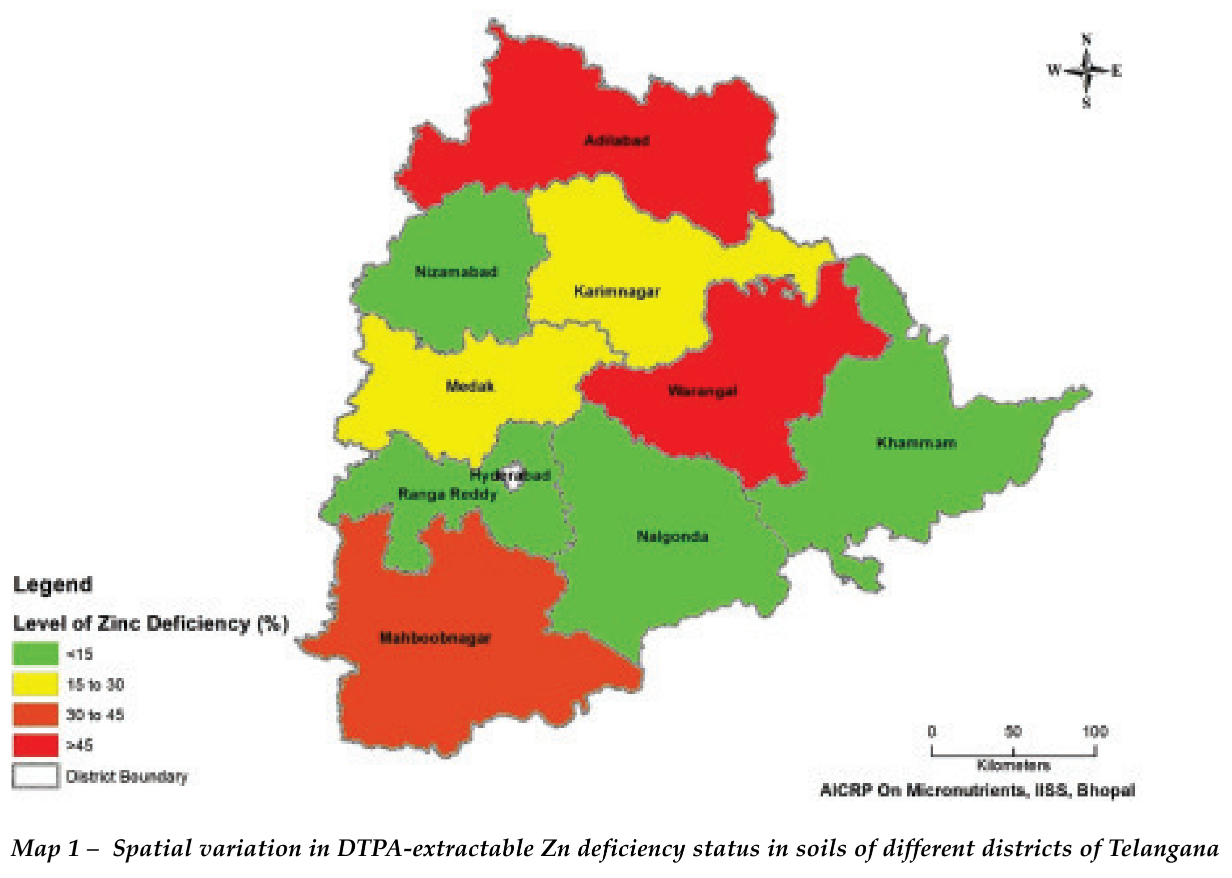
The DTPA-extractable Fe contents in soils across the state varied from 0.69 to 111.4 mg kg^{-1}**(Table 2).** Based on critical limit of 5.0 mg Fe kg^{-1} soil, the deficiency of DTPA- extractable Fe varied from 7.9 to 41.8% with

Table 2 – Available zinc and iron status (DTPA-extractable in mg kg^{-1} soil) in soils of different districts of Telangana						
District	**DTPA-Zn**			**DTPA-Fe**		
	Range	**Mean±SE**	**PSD**	**Range**	**Mean±SE**	**PSD**
Adilabad	0.11-3.94	0.82±0.03	51.30	0.69-49.64	10.99±0.39	15.83
Karimnagar	0.16-7.00	1.18±0.04	20.48	1.04-82.92	34.93±0.93	14.92
Khammam	0.22-5.80	1.66±0.07	14.41	2.06-42.85	16.84±0.51	09.89
Medak	0.18-6.31	1.43±0.06	18.67	2.08-39.62	15.33±0.46	08.85
Mahabubnagar	0.10-3.80	0.75±0.01	27.89	1.04-64.12	12.94±0.31	12.33
Nalgonda	0.20-4.80	1.60±0.05	07.42	0.78-111.42	14.52±0.97	18.75
Nizamabad	0.27-4.90	0.97±0.03	14.18	1.23-65.04	11.27±0.57	41.76
Ranga Reddy	0.11-4.93	1.02±0.03	14.32	2.45-31.25	11.27±0.27	07.91
Warangal	0.10-5.58	0.84±0.03	47.97	1.05-78.25	15.06±0.41	20.71
Telangana	**0.10-7.00**	**1.05±0.01**	**26.86**	**0.69-111.42**	**16.19±0.41**	**17.00**

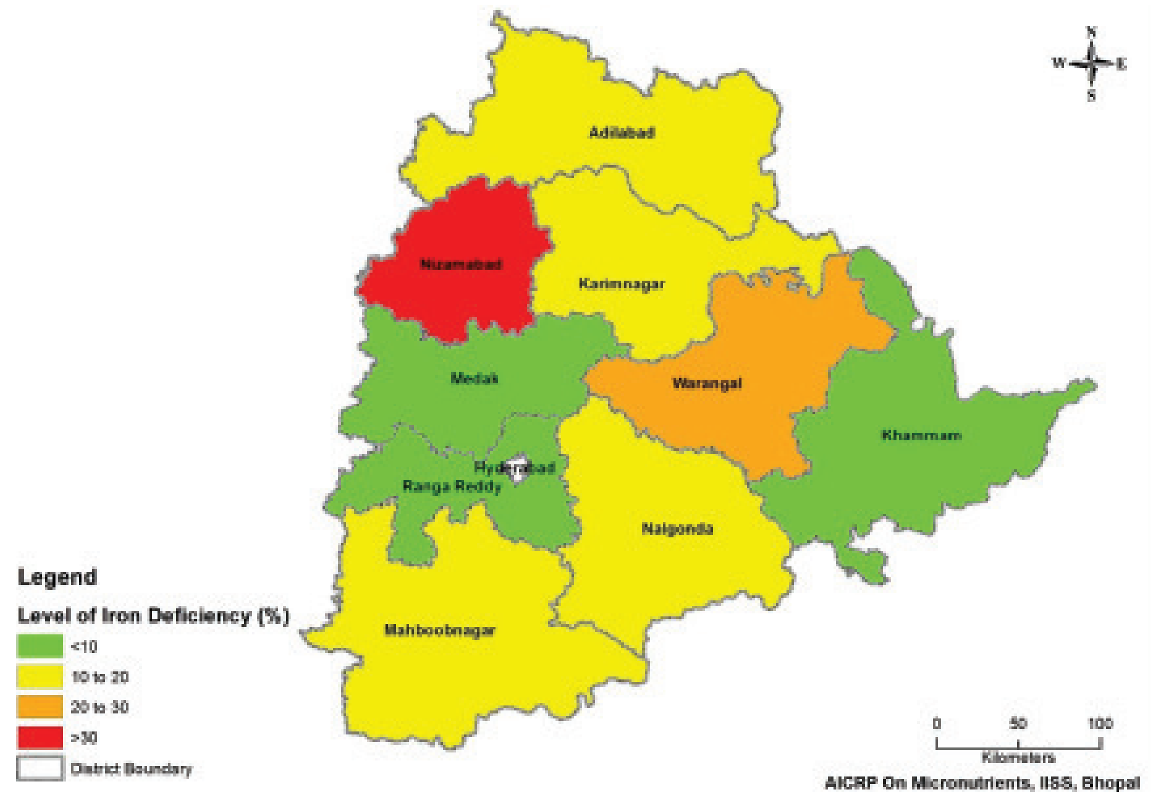
an average of 17.0% in the state. As mentioned in **Table 2,** even though the total Fe content in soils of the state is very high, the available Fe content is much lower due to its conversion into less available ferric (Fe^{+++}) state under arid and semi-arid conditions. The low content of organic matter in soils has also influenced the Fe solubility in soils of the state. Out of 9 districts of the state, soils of districts Nizamabad showed maximum deficiency (41.8%), followed by Warangal (20.7%), Nalgonda (18.7%), Adilabad (15.8%), Karimnagar (14.9%), Mahabubnagar (12.3%), Khammam (9.8), Medak (8.8%) and Ranga Reddy (7.9%).

3. *DTPA-extractable Manganese*

The DTPA-extractable Mn content in soils of different districts of the state varied from 0.30 to 80.51 mg kg^{-1} soil with mean value of



Map 1 – Spatial variation in DTPA-extractable Zn deficiency status in soils of different districts of Telangana

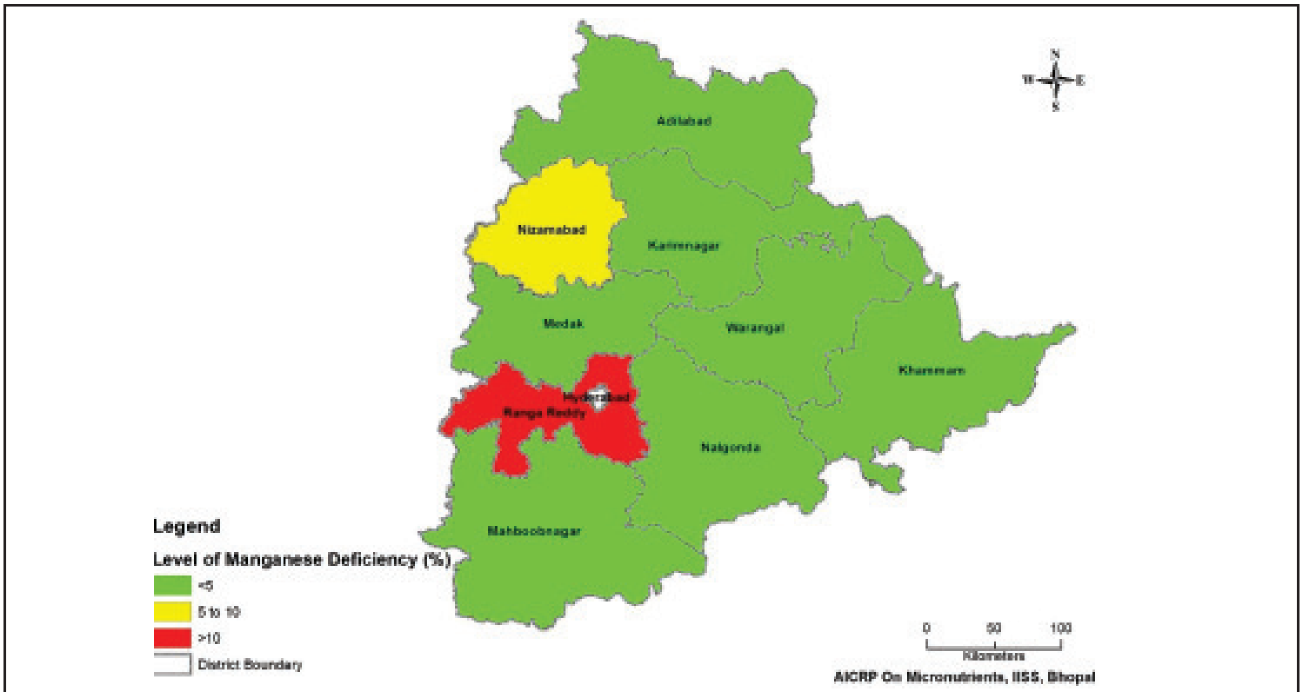


Map 2 – Spatial variation in DTPA-extractable Fe deficiency status in soils of different districts of Telangana

14.70 ± 0.15 mg Mn kg^{-1}. Similar to iron, the total manganese contents in soils of Telangana have been reported to be very high. Based on critical limit of 2.00 mg Mn kg^{-1} soil, most of the soils are sufficient in Mn and on average less than 4% soils are deficient in DTPA-extractable Mn. However, in Rangareddy district, the DTPA-Mn deficiency was as high as 24.8%. Takkar *et al* (1996) and Bhupal Raj (2009) reported that in rice fields, Mn solubility increased with reduction in redox potential. Further, less than 1% Mn deficiency was noticed in soils of Karimnagar, Khammam, Medak and Warangal districts **(Table 3 and Map 3)**. The Mn deficiency in the soils of other districts was observed 1-3% except Nizamabad district (5.2%). In India, the deficiency of Mn has been

Table 3 – Available manganese and copper status (DTPA-extractable in mg kg^{-1} soil) in soils of different districts of Telangana

District	DTPA-Mn			DTPA-Cu		
	Range	Mean±SE	PSD	Range	Mean±SE	PSD
Adilabad	0.30-39.52	15.48±0.37	1.80	0.11-6.85	2.34±0.06	0.60
Karimnagar	2.06-19.18	14.68±0.15	0.00	0.18-9.21	3.11±0.09	0.95
Khammam	3.03-30.85	22.01±0.31	0.00	0.12-15.81	2.10±0.07	0.28
Medak	2.48-48.88	19.33±0.47	0.00	0.14-7.77	1.63±0.06	0.25
Mahabubnagar	1.00-80.51	14.82±0.47	2.56	0.10-4.52	0.91±0.02	4.00
Nalgonda	1.23-80.13	11.14±0.68	2.34	0.18-6.12	1.32±0.06	0.39
Nizamabad	0.87-59.34	13.50±0.47	5.17	0.39-7.92	2.68±0.08	0.00
Ranga Reddy	0.31-19.82	4.58±0.16	24.79	0.09-4.08	1.45±0.04	3.42
Warangal	1.95-35.72	16.04±0.29	0.13	0.12-8.00	1.84±0.04	0.13
Telangana	**0.30-80.51**	**14.64±0.15**	**3.79**	**0.09-15.81**	**1.91±0.02**	**1.35**

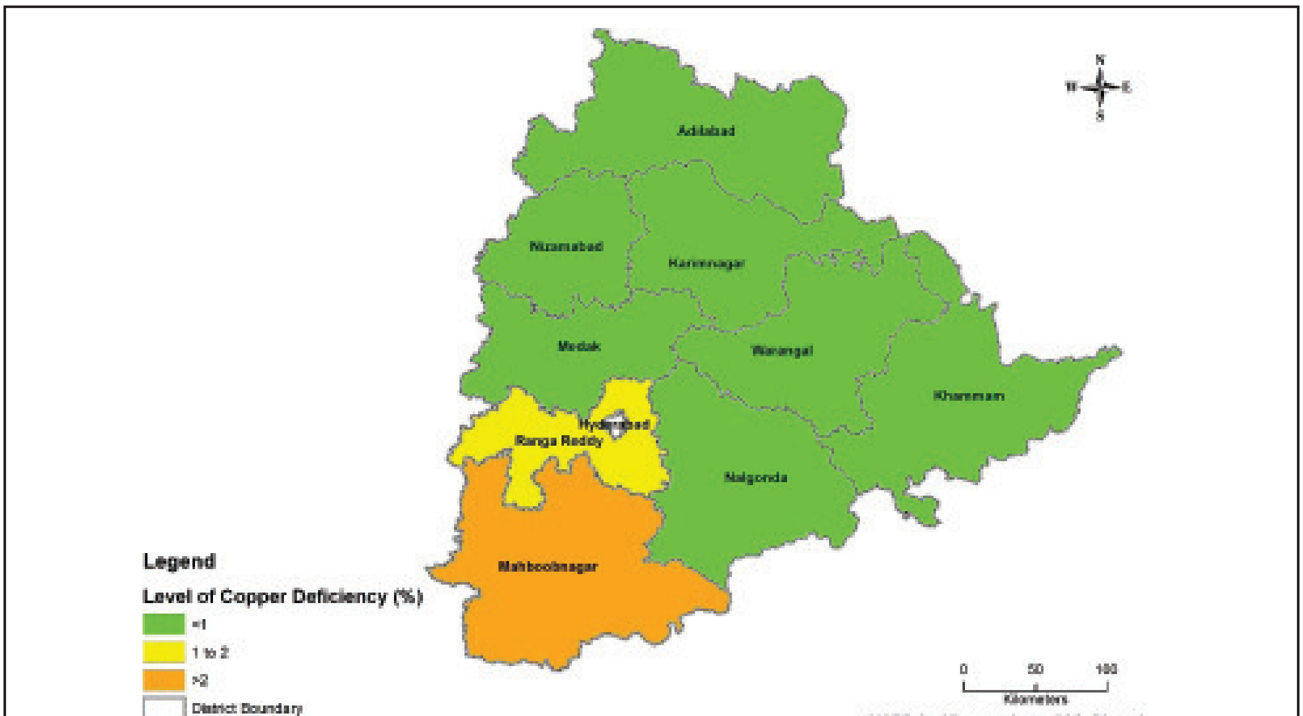


Map 3 – Spatial variation in DTPA-extractable Mn deficiency status in soils of different districts of Telangana

observed in light textured and calcareous soils (6, 11).

4. *DTPA-extractable Copper*

The amount of plant-available Cu varies widely in soils as a function of soil pH and soil texture. Availability of Cu is related to soil pH and with increase in soil pH, the availability of this nutrient decreases. Moreover, Cu is not mobile in soils and it is attracted to soil organic matter and clay minerals. The DTPA-extractable Cu in soils of Telangana ranged from 0.09-15.81mg kg^{-1} soil with an average of 1.91 ± 0.02 mg kg^{-1} with using 0.20 mg Cu kg^{-1}as critical limit. Very few soil samples from Ranga Reddy and Mahabubnagar districts showed Cu deficiency while overall deficiency was



Map 4 – Spatial variation in DTPA-extractable Cu deficiency status in soils of different districts of Telangana

Table 4 – Available boron status (hot water soluble) in soils of different districts Telangana

District	Range	Mean±SE	PSD
Karimnagar	0.21-1.35	0.62±0.01	14.60
Mahabubnagar	0.22-1.14	0.60±0.01	9.22
Nalgonda	0.22-2.02	0.51±0.01	43.75
Nizamabad	0.13-2.44	1.22±0.02	4.41
Ranga Reddy	0.20-1.93	0.84±0.01	4.27
Telangana	**0.13-2.44**	**0.75±0.01**	**11.89**

1.35 % **(Table 3 and Map 4)**. While in all other districts Cu deficiency was recorded to the extent of less than 1% **(Table 3)**.

5. *Hot Water Soluble Boron*

Boron is an essential micronutrient for healthy growth of plants and its deficiency is wide spread in Indian soils. It is required for proper seed filling, both in cereals and oilseed crops and the response of crops to boron varies widely. It is a unique non-metal micronutrient required for normal growth and development of plants. It is mobile in soils and more often gets leached down the soil profile with excess moisture. Boron deficiency and toxicity range is very narrow. Boron concentration and its bioavailability in soils is affected by several factors including parent material, texture, nature of clay minerals, pH, liming, organic matter content, sources of irrigation, interrelationship with other elements, and environmental conditions like moderate to heavy rainfall, dry weather and high light intensity (8).

Hot water soluble B content in soils of Telangana varied from 0.13 to 2.44 mg kg^{-1} soil with an average of 0.75 mg B kg^{-1} soil which in corroboration with the results obtained by Bhupal Raj *et al.* (2009). Considering 0.40 mg B kg^{-1} as critical limit, 11.9% soils of the state were reported to be deficient in B. Among the 5 districts, the highest B deficiency was recorded in Nalgonda (43.75%) while lowest deficiency was observed in Ranga Reddy (4.27%) **(Table 4 and Map 5)**.

C. Frequency Distribution of Micronutrients

In general, crop responses to micronutrients application are recorded when the level of micronutrients is below critical limit, however, sometimes crops may also respond to micronutrients application even when level of micronutrients is above critical limit. This indicate that crop response varied to micronutrients application depending upon crop type, soil type and agro climate of the region (12). Hence, in order to make precision micronutrients recommendation, it is necessary to have frequency distribution of different micronutrients in various response zones.

Map 5 – Spatial variation in hot water soluble B deficiency status in soils of different districts of Telangana

Table 5 – Frequency distribution of micronutrients availability in soils of Telangana state

Category	Zinc		Iron		Manganese		Copper		Boron	
	Frequency distribution class	% samples	Frequency distribution class	% samples	Frequency distribution class	% samples	Frequency distribution class	% samples	Frequency distribution class	% samples
Acute deficiency	<0.3	4.7	<3.5	8.8	< 2.0	3.8	< 0.2	1.1	< 0.3	5.0
Deficiency	0.3-0.6	22.1	3.5-5.5	11.3	2.0-4.0	9.8	0.2-0.4	6.3	0.3-0.5	22.3
Marginal	0.6-0.9	34.2	5.5-7.5	11.4	4.0-6.0	9.0	0.4-0.6	7.1	0.5-0.7	29.6
Adequate	0.9-1.2	15.3	7.5-9.5	11.5	6.0-8.0	8.1	0.6-0.8	7.3	0.7-0.9	17.1
High	1.2-1.5	7.2	9.5-11.5	9.0	8.0-10.0	6.9	0.8-1.0	7.4	0.9-1.1	9.8
Very high	>1.5	16.5	>11.5	48.0	>10.0	62.5	>1.0	70.8	>1.1	16.1

Considering critical limit of different micronutrients, the available status of DTPA-extractable micronutrients (Zn, Fe, Mn and Cu) and Hot water soluble B were categorized in to sufficient or deficient categories.

1. *Frequency Distribution of Zinc and Iron*

In order to develop better Zn prescription, the data on Zn were categorized in to six frequency ranges. Soils having Zn content ≤ 0.60 mg $kg^{-1}$are categorized as deficient while those falling between 0.6 to 1.20 mg $kg^{-1}$are considered as medium in Zn supply, and those above 1.50 mg kg^{-1} are classed as high Zn soils. Of the total samples analysed for Zn in the state, 4.7% samples fall in acute Zn deficient category (< 0.3 mg kg^{-1}) and 22.1% in deficient category (0.3 to 0.6 mg kg^{-1}) which showed wide crop response to Zn application. Samples having Zn levels between 0.6-0.9 mg kg^{-1} are considered potentially susceptible to deficient in near future **(Table 5)**. Now farmers are applying maintenance dose of Zn in this category of soils as a result of awareness created through frontline demonstration under AICRP on Micronutrients in the state. About 15.3% soils having >0.9 to 1.2 mg Zn kg^{-1} soil, classed as moderate Zn deficient may potentially respond to Zn application depending upon the type of crops grown and agro-climatic conditions. Only 16.5% of the soils of the state are having very high level of Zn content (>1.5 mg kg^{-1} soil) and thus, Zn application to these soils may be skipped. However, in soils which has available Zn level between >1.2 to ≤ 1.5 mg Zn kg^{-1} may be given only Zn maintenance doses once in three years to sustain yield levels as well as soil Zn reserve.

Soil samples having Fe content above 7.5 mg kg^{-1} soil are classified as sufficient category and crops grown in these soils do not respond to Fe application **(Table 5)**. About 68% soils in state are having Fe content > 7.5 mg kg^{-1} and these soils do not requireany external Fe application for crop production. Soils having <3.5 mg Fe kg^{-1} are grouped in to acute Fe deficient category and about 9% soils of the state fall in this category and application of Fe is essential in these soils for optimum crop yield. About 11.3% soil samples in the state fall in the category of deficiency (3.5 to 5.5 mg Fe kg^{-1}), which also need immediate attention and proper Fe supplementation is required for optimum crop growth. The soils having Fe content between 5.5 and 7.5 mg kg^{-1} are classed as marginal category and they are susceptible to be deficient if maintenance doses of Fe is not given to the crops grown in these soils. Intensive cropping, particularly with horticultural and corn crops in these soils may exhibit Fe deficiency in crops, if maintenance doses are not provided. About 48.0% soils are having enough Fe content in soil to support the intensive farming provided sufficient moisture is available in the fields.

2. *Frequency distribution of Manganese and Copper*

Although most of the soil are adequate in Mn and Cu, but some of the soils are responding to Mn and Cu application in the areas where intensive cropping with fruits and vegetable crops is in practice. The frequency distribution of the Mn in soils of the state revealed that about 3.8% samples contained a Mn level below the 2.0 mg kg^{-1} soil, which are considered acute deficient and needs external Mn application for optimum crop growth. Further, about 9.8% samples which fall in the range of 2.0 to 4.0 mg Mn kg^{-1} soil may respond to Mn application. About 62.5% soils of the state are having the Mn content more than 10.0 mg kg^{-1} which is considered to be sufficient to meet the crop demand for longer period **(Table 5)**. Regarding Cu only 1.10% samples contained <0.2 mg Cu kg^{-1}soil which is considered as responsive category while another 6.3% samples fall in the category of >0.2-0.4 mg Cu kg^{-1} soil, have potential to Cu deficiency in future **(Table 5)**. More than 70.8% soils in the state have very high level of Cu, which can meet crop demand in future for longer period.

3. *Frequency Distribution of Boron*

Boron is very sensitive element and the range between deficiency and sufficiency is very narrow, hence, application of B should be made only when soil is deficient. Frequency distribution of B availability for the state showed that about 5% the soil samples are having B content less than 0.30 mg kg^{-1} which is considered as acute deficient and those samples which

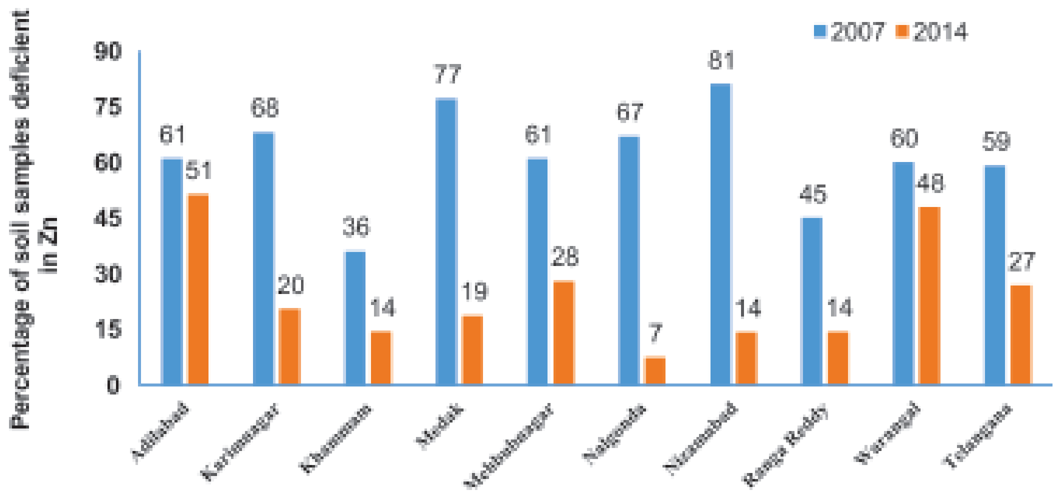


Figure 1 – Periodic changes in Zn deficiency status in soils of different districts of Telangana

fall between 0.3 to 0.5 mg kg^{-1} soils, are grouped in deficient category (22.3%). However, as per critical limit of B for the state (0.40 mg kg^{-1}), about 29.6% samples fall in the range of 0.5 to 0.7 mg kg^{-1} B which is classified as marginal category and they did not show any B deficiency in crops, except some cole crops, which respond to B application. Samples having B content >0.7-0.9 mg B kg^{-1} soil are grouped into adequate B category level (17.1%). The samples having B content above >0.9 mg kg^{-1}soil are classed as high B soils and they do not need external B application **(Table 5)**.

D. Periodical Changes in Deficiency Status of Zinc and Iron

Periodical analysis of Zn and Fe in different districts of Telangana exhibited sizeable changes in per cent deficiency of two elements. On average, Zn deficiency in 2014 reduced to less than half of that reported before 2007 (1996-2007) **(Figure 1)**. This happens due to regular use of $ZnSO_4.7H_2O$ in the state. More than 23 thousand tonnes zinc sulphate is being used in the state of Andhra Pradesh and Telangana in different crops (5). The Zn fertiliser sold by unorganized sector is not indicated in this data. Moreover, micronutrient mixtures with major share of Zn are also used in the state, particularly in vegetable crops. The Fe deficiency, which was almost negligible before 2007, has now increased to a great extent **(Figure 2)**. On an average, 17% soils of Telangana are deficient in Fe with highest figure (42%) in Nizamabad, followed by Warangal (21%), Nalgonda (19%), Adilabad (16%), Karimnagar (15%), and Mahabubnagar (12%). In rest of the district deficiency increased up to 10 percent.

E. Crop Response and Micronutrients Management

Deficiency of micronutrients, judged by soil and plant analysis can be confirmed through crop response to fertilization and magnitude of response to economic level. In view of this, several field experiments were conducted to establish such deficiency through economic

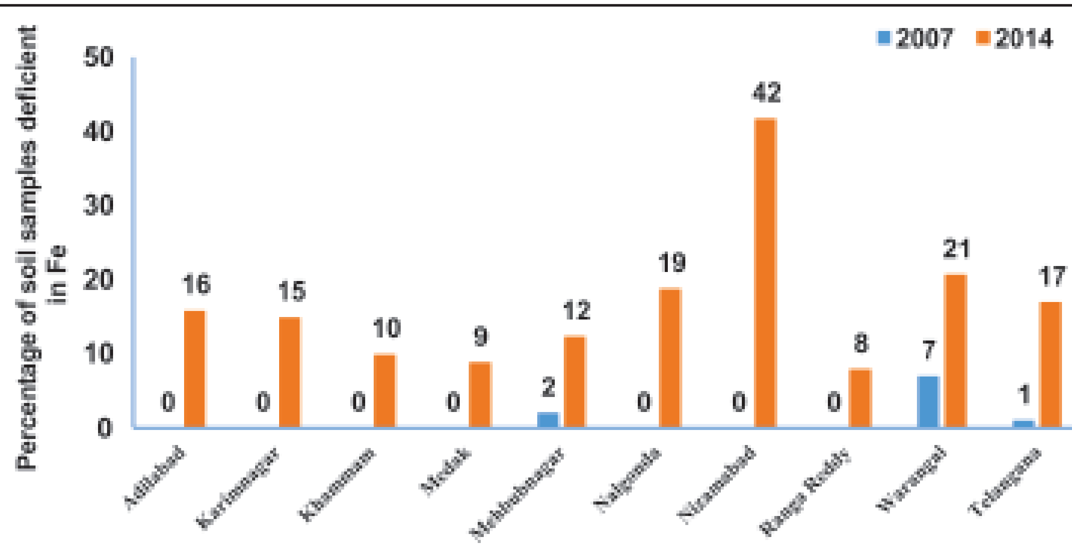


Figure 2 – Periodic changes in Fe deficiency status in soils of different districts of Telangana

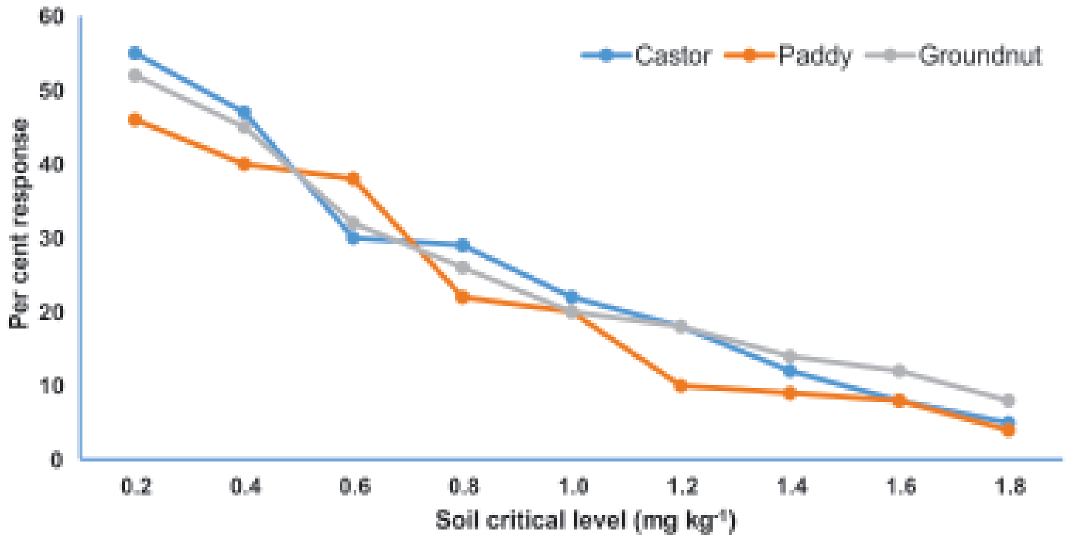


Figure 3 – Response of crops to Zn based on soil test value

response to single or multi-micronutrient deficiencies. The deficiency of micronutrients is diagnosed by appearance of deficiency symptoms, soil and plant analysis and crop response to micronutrients fertilization. Usually crop responses are measured in terms of incremental yield and/ or quality improvement. Sometimes, micronutrient deficiencies are not predictable through soil-plant analysis but crops respond to micronutrient application and the situation is called as *hidden hunger*. When this occurs, the producers loose potential profit in those areas due to non-fertilization of crops with micronutrients. These profits can be captured by proper management of micronutrients in soils and crops and further income could be maximised by understanding and following the crop specific nutrient requirement.

Crops differ in their response level to Zn, depending upon nature and extent of Zn deficiency **(Figure 3)**. Grain response less than 200 kg ha^{-1} is considered uneconomical. Large number of field studies on paddy, groundnut and castor in Nalgonda, Nagarjuna Sagar Project area, Karimnagar, Nizamabad, Ranga Reddy, Hyderabad and Medak districts, showed variable crop response depending on soil type, crop type and level of deficiency. The percent response to Zn application decreased with increasing levels of Zn content in soils, irrespective of the crop. However, on an average, greater response was noted for castor and groundnut crops as compared to paddy **(Figure 3)**.

Sorghum also recorded response of 400 kg ha^{-1} in Ranga Reddy, Hyderabad and Mahabubnagar districts. In Khammam district, the responses were about 200-400 kg ha^{-1}. More than 200 kg ha^{-1} additional groundnut was harvested with Zn application in Nizamabad, Nalgonda and Mahabubnagar districts **(Table 6)**. Chillies grown in Mehaboobabad area of Warangal district recorded a response of 410-1200 kg ha^{-1}.

In *Alfisols* of Ranga Reddy district, application of ferrous sulphate @ 25 kg ha^{-1} to groundnut crop raised the pod yield by 16% (4). In order to correct iron chlorosis in chillies grown in the Telangana state, the beneficial effects of foliar sprays of ferrous sulphate was more than soil application in Nagarjuna Sagar and Sri Rama Sagar projects where average fruit yield enhanced by 18% due to foliar feeding in chillies by 0.2% foliar spray of ferrous sulphate. Crops like maize (41%), sorghum (31%) and green gram (52%) showed greater response to applied iron in these soils (4).

Although the Mn deficiency in not very high in the state, however, experiments conducted on Mn deficient soil responded to Mn application. Foliar sprays of manganese sulphate on sorghum at 50 days after sowing improved grain yield and drought resistance. In other experiments on groundnut conducted in Nalgonda district showed variable

Table 6 – Relative response of crops to Zn application in soils of various districts

Crop	Highly responsive soils (>400 kg ha^{-1} grain or >200 kg ha^{-1} pod yield)	Moderately responsive soils (>200 kg ha^{-1} grain or >100 kg ha^{-1} pod yield)
Rice	Nalgonda, Karimnagar, Nizamabad, Rangareddy and Hyderabad	Medak
Sorghum	Rangareddy, Hyderabad and Mahabubnagar	Khammam
Groundnut	Nizamabad, Nalgonda, Mahabubnagar	-

Table 7 – Response of crops to applied nutrients in soils		
Nutrient	Crop	Response in kg ha^{-1} (%)
Fe	Groundnut	58-239 (37)
	Maize	19-279 (41)
	Sorghum	10-880 (31)
Mn	Groundnut	11-410 (23)

response (58 to 239 kg pod yield ha^{-1}) with Mn application. Under field conditions, responses of 0.53, 2.0, 2.39 and 1.78 q ha^{-1} of pods were recorded due to application of manganese sulphate @ 50 kg ha^{-1} in Nalgonda district (4).

Soil analysis showed negligible Cu deficiency in the state however, rice response studies conducted in 20 *Alfisols* soils, collected from left command of Nagarjuna Sagar Project and surrounding areas of Hyderabad showed that 16 soils responded to application of copper sulphate with average increase in paddy grain yield varied from 2.9 to 39.6%. However, when trials were repeated under on-farm conditions, the response was not economical. In case of B, Foliar feeding of boric acid at 50 days after sowing in sorghum improved the grain yield and drought resistance. Similarly in sunflower, foliar application of 0.2% borax had beneficial effect in increasing oil content and yield. While under dry land conditions, application of borax@ 10 kg ha^{-1} increased pod yield of groundnut by 188-200 kg ha^{-1}.

No response studies with multi-micronutrients has been conducted at cultivators' fields in Telangana state. However, application of S, Zn, B and Mo in groundnut and green gram at Nalgonda and Karimnagar districts showed significant response over NPK alone. The increase in pod yield of groundnut was recorded to the tune of 10, 12.3, 20.7 and 24.6% with application of Zn, Zn+B, Zn+S and Zn+B+S, respectively in Nalgonda district. The similar trends were also noticed in Karimnagar districts **(Table 8)**. The contribution of B in yield enhancement over Zn was 2.3% while 4% over Zn+S. In green gram, the response to Zn, Zn+B, Zn+S, Zn+B+S and Zn+B+S+Mo was 4.4, 19.11, 20.58, 23.52 and 26.4 per cent over NPK, respectively. The response increased by four folds when S was added along with Zn. Application of B over Zn+S enhanced the green gram yield by 4.5% while application of Mo along with Zn+B+S improved the green gram yield by 3% but it was non-significant.

Studies conducted on vegetables (tomato, brinjal and chillies) exhibited variable response to Zn and Fe rates and method of application. Results of experiments conducted at farmers' field revealed that basal application of Zn was superior over foliar feeding of Zn however, the reverse was true for Fe **(Table 9)**. With respect to dose, 25 kg $ZnSO_4$ and 0.5% $FeSO_4$ (3 times sprays) at critical growth stages was more useful. Foliar feeding of zinc sulphate in chilli was not effective, however, application of 12.5 kg zinc sulphate basal along with 3 foliar spray of Zn@ 0.2% was equally effective as application of 25 kg ha^{-1}. In brinjal and chillies, 3 foliar sprays feeding of $FeSO_4$ along with 12.5 kg $ZnSO_4 ha^{-1}$ + 3 foliar feeding of $ZnSO_4$ was most effective in enhancing the fruit yield. Among the crops, the response in tomato was greater than that of brinjal and chilli. In order to get quick response to applied micronutrients and mitigate deficiencies during the growing season, foliar spray is widely used to apply micronutrients in vegetable and fruit crops as sufficient foliage is available in these crops as compared to cereals.

CONCLUSION

Generalized nutrient recommendations over large areas may lead to the possibility of over or under use of micronutrients with adverse economic and environmental challenges. The precision nutrient management concept is expected to provide ways to suitable micronutrient management. GIS maps based on intensive soil sampling are useful

Table 8 – Effect of zinc, boron and sulphur on groundnut and green gram

Treatment	Groundnut				Green gram	
	Nalgonda		Karimnagar		Karimnagar	
	Yield with NPK(t ha^{-1})	Yield response (%)	Yield with NPK (t ha^{-1})	Yield response (%)	Yield with NPK	Yield response (%)
Control	2.6	-	1.99	-	1.36	-
5 kg Zn ha^{-1}	2.86	10	2.18	11	1.42	4.4
5 kg Zn ha^{-1} + 1 kg B ha^{-1}	2.92	12.3	2.28	16.3	1.62	19.11
5 kg Zn ha^{-1} + 40 kg S ha^{-1}	3.14	20.7	2.44	22.6	1.64	20.58
5 kg Zn ha^{-1} +1 kg B ha^{-1} + 40 kg S ha^{-1}	3.24	24.6	2.48	24.6	1.68	23.52
5 kg Zn ha^{-1} +1 kg B ha^{-1} + 40 kg S ha^{-1} + Mo	-	-	-	-	1.72	26.4

Table 9 – Effect of zinc and iron on tomato, brinjal and chillies

Treatment	Tomato		Brinjal		Chillies	
	Yield(t ha^{-1})	Increase (%)	Yield(t ha^{-1})	Increase (%)	Yield (t ha^{-1})	Increase (%)
NPK (No Zn or Fe)	28.8	-	29.9	-	24.3	-
12.5 kg $ZnSO_4$ ha^{-1}	30.5	6	33. 8	13.1	26.2	7.1
25 kg $ZnSO_4$ ha^{-1}	39.0	36	35.1	17.5	29.1	20.0
Foliar spray of 0.2% $ZnSO_4$	-	-	33.4	11.9	25.4	4.5
Foliar spray of 0.5% $FeSO_4$	-	-	33.1	10.8	25.3	4.0
12.5 kg $ZnSO_4$ ha^{-1} + Foliar spray of 0.2% of $ZnSO_4$	39.4	37	36.9	23.6	29.8	23.1
12.5 kg $ZnSO_4$ ha^{-1} + Foliar spray of 0.5% of $FeSO_4$	34.7	21	-	-	-	-
12.5 kg $ZnSO_4$ ha^{-1} + Foliar spray of 0.2 % of $ZnSO_4$+ Foliar spray of 0.5% of $FeSO_4$	40.0	39	39.1	30.7	31.8	31.0
CD (p=0.05)	0.4	-	1.8	-	13.8	-

to assess variability in distribution of native micronutrients and in developing site-specific management practices for optimizing yield without any adverse effect on environment. The frequency distribution of micronutrients would further, aid in developing precise recommendation based on native nutrients status and crop need. Soil micronutrients maps would be highly useful in improving our understanding regarding native and extent of micronutrient problems and this can aid in developing appropriate micronutrients management strategies leading to better yield and environmental stewardship, which ultimately would be helpful in determining their relationship with animal and human health.

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