A.N., Ganeshamurthy; S., Rajendiran; D., Kalaivanan; T.R., Rupa

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Journal of Horticultural Sciences, vol. 14, no. 2, 2019, July-, pp. 98-108
Society for Promotion of Horticulture
India

J. Hortl. Sci.
Vol. 14(2) : 98-108, 2019

Review

Zinc Status in the Soils of Karnataka and Response of Horticultural Crops to Zinc Application : A Meta-analysis

Ganeshamurthy A.N.*, Rajendiran S., Kalaivanan D. and Rupa T.R.
Division of Soil Science and Agricultural Chemistry
ICAR-Indian Institute of Horticultural Research
* Corresponding author, Email:angmurthy@gmail.com

ABSTRACT

Zinc is considered as the fourth important yield limiting nutrient in India, after N, P, and K. From the regular soil analysis data, Indian soils (50%) are found to be deficient in Zn and the zinc deficiency is likely to increase in future. Areas with low soil available Zn are often regions with widespread zinc deficiency in humans. Zinc malnutrition and deficiency in human is alarming and is gaining attention in recent years. Application of zinc to soil and crops is one of the simple and easiest ways to mitigate or alleviate Zn deficiency in human. Moreover Zn uptake, its translocation and yield response of various crops to applied Zn are need to be focused for finding sustainable solutions to the problem of zinc deficiency in crops and humans. In this manuscript, importance of Zn to plants and human, Zn malnutrition problems in India and global level, soil Zn status of Karnataka, various factors that responsible for Zn deficiency in the soils of Karnataka and the response of various horticultural crops to Zn application in the region is discussed. Soil maps are believed to be an important tool to delineate and manage nutrient deficient areas. It also elaborates the effective Zn management strategies to improve crop productivity and farm income.

Keywords: Crop production, Crop quality, Karnataka, Horticultural crops, Zinc deficiency, Zn management

INTRODUCTION

Zinc is one of the essential nutrients for plant growth and development. Though it is required in small quantity, it is crucial for plant development. In plants, Zn is a key constituent of many enzymes and proteins and plays a major role in wide range of processes such as growth hormone production and internode elongation. Zinc is absorbed by the plant through roots mostly in divalent ionic form (Zn^{2+}) from the soil solution. The primary source of Zn in soil is chemical and physical weathering of parent rocks and minerals. Mean soil Zn concentrations ($[Zn]_{soil}$) varied from 50 and 66 µg of total Zn g^{-1} soil are typical for mineral and organic soils, respectively, with most agricultural soils containing 10 to 300 µg Zn g^{-1}(Alloway, 1995). Secondary inputs of Zn to soils arise because of atmospheric (e.g. volcanoes, forest fires, and surface dusts) and biotic (e.g. decomposition, leaching/wash-off from leaf surfaces) processes (Friedland, 1990). Further anthropogenic emission of Zn inputs to soil has increased due to industrial revolutions and resulted in buildup of Zn in soil particularly as a result of mining and smelting activities (Nriagu, 1996). The ratio of Zn emissions arising from anthropogenic and natural inputs is estimated to be >20:1 (Friedland, 1990). However this is much localized and area specific accumulation that leads to Zn contamination in soil and crop Zn toxicity. But in general Zn deficiency is widely realized across the globe,resulting in substantial losses in crop yields and human nutritional health problems. Nearly25% of the world's population is at risk due to Zn deficiency. Zinc deficiency affects about 2.2 billion people world-wide (Prasad, 2012). Many agricultural countries around the world are affected by zinc deficiency (Tuerk and Fazel, 2009). Further it is reported that areas with zinc deficient soils are often regions with widespread zinc deficiency in humans. A basic knowledge of the dynamics of zinc in soils, understanding of the uptake and transport of zinc in crops and characterizing the response of crops to zinc deficiency are essential steps in achieving sustainable solutions to the problem of zinc deficiency in crops and humans (Alloway, 2008). Increasing the amount of zinc in the soil and thus in crops and animals/humans is considered as an effective preventative measure. This paper is mainly discusssoil Zn status of Karnataka and the responses of various horticultural crops to Zn application for effective management and utilization of Zn in crop production as well as to mitigate the Zn deficiency or malnutrition in human/animals.

Physiographic Landforms and Land Use Pattern of Karnataka

Physiographically, Karnataka is part of well defined regions of India such as the Deccan Plateau, the Western Ghats, and the Coastal Plains. It is located approximately between 11.5-18.5°N latitude and 74-78.5°E longitude. The state can be divided into 1. Coastal zone, 2.Malnad area (Central plateau), 3. Northern maidan 4.Northern dry maidan and 5. Southern Karnataka Plateau. It is land of rivers, waterfalls, plains, hills, peaks and plateau. The main rivers are Cauvery, Hemavati, Tungabhadra, Godavari, Krishna, Palar, North and South Pennar, etc. It has a dynamic weather due to land's altitude, topography and the distance from sea. The climate of Karnataka ranges from arid to semi-arid to humid tropical. South West and North East monsoon bring rainfall to Karnataka and mean annual rainfall is around 1355 mm. It experiences four seasons in a year: Summer (March-May); Monsoon (June-September); Post-monsoon (October-December); and Winter (January-February). The land use pattern of Karnataka is described in Table 1 and about 55% of total geographical area is put under cultivation. Mostly rainfed farming is followed in Karnataka and the area-sown more than once in a year is very low (only 8% of cultivated area).

Table 1: The land use pattern of Karnataka

Land use pattern	Area (in m ha)
Total geographic area	19.17
Reporting area for land utilization statistics	19.05
Forest	3.03
Not available for cultivation	1.92
Other uncultivated land excluding fallow land	2.13
Fallow land	1.56
Net area sown	10.40
Area sown more than once	0.84
Total cropped area	11.24

Source: Directorate of Economics and Statistics (2015)

Soils of Karnataka

Soils of Karnataka are grouped into different major soil orders *viz*., Alfisols, Aridisols, Entisols, Histosols, Inceptisols, Ultisols and Vertisols (Fig. 1). According

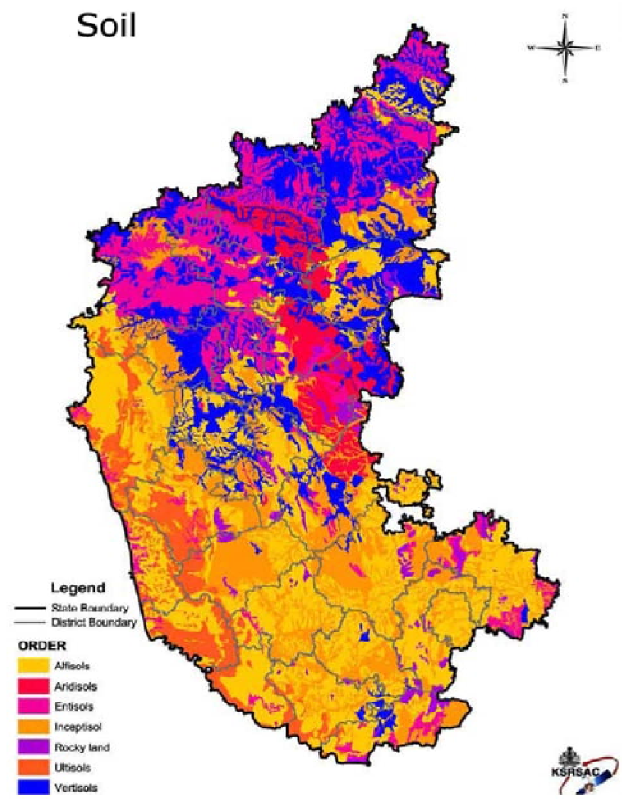

Fig. 1: Major soil orders of Karnataka

to Soil Survey Data, the soils of Karnataka can be divided under nine groups. They are red sandy soils, red loamy soils, shallow black soils, medium black soils, deep black soils, mixed black and red soils, laterite soils, laterite gravelly soils and coastal alluvium. Most of the soils has acidic to neutral to slightly alkaline pH, low-medium organic carbon, medium to high available N and K, low in available P, deficient in Zn and sufficient in other micronutrients.

Soil Zn status of Karnataka

In India, Zn is now considered as fourth most important yield limiting nutrient after N, P and K, respectively. Analysis of 256000 soils and 25000 plant samples from all over the India showed that 49% of the soils and 44% of the plant samples were potentially Zn deficient and that this was the most common micronutrient problem affecting crop yields in India (Arunachalam et al. 2013). Deficiency of Zn has increased in Southern states because of intensive cropping and extensive use of NPK fertilizers without micronutrients. Further it has been reported from periodic assessment of soils that, by the year 2025, Zn deficient soils in India is likely to increase from 49 to 63% as most of the marginal soils brought under cultivation are showing Zn deficiency (Singh, 2006). Families consuming the farm produce from Zn deficient soil leads to low Zn in their blood plasma compared to those who were fed on produce from regular Zn supplied soils. Therefore application of Zn is essential to maintain soil, seeds/crops and blood plasma of humans and animals (Singh, 2009). In view of the emerging Zn deficiencies in Southern States and micronutrient malnutrition problems in rural population, it is inevitable to study soil Zn status as well as its response in various horticultural crops.

More than 75% of the soil samples in Karnataka are found to be deficient in Zn (Fig.2). This might be due to high soil pH, poor organic matter content, excessive removal by crop intensification and faulty management practices like imbalance fertilizer management. In traditional areca nut growing soils of Karnataka, the available zinc content of soils ranged from 2.9 to 8.2 mg/kg with a mean value of 4.17 mg/kg. Similarly Thirthahalli area had 4.7 mg Zn kg^{-1} soil; Sagar area had 3.7mg Zn kg^{-1} soil and Sringeri area had 4.7 mg kg^{-1} soil whereas, zinc status in soils under mulberry (Mysore, Tumkur, Bangalore, Kolar) ranged from 0.40 to 0.69 mg/kg. More than 95% of the samples analyzed were found to be deficient in zinc and the remaining samples recorded just sufficient zinc status in Malaprabha right bank command area (Ravikumar *et al.*, 2007). Agro-ecological regions of Karnataka and their Zn status is depicted in Fig. 2 & 3 (Table 2).

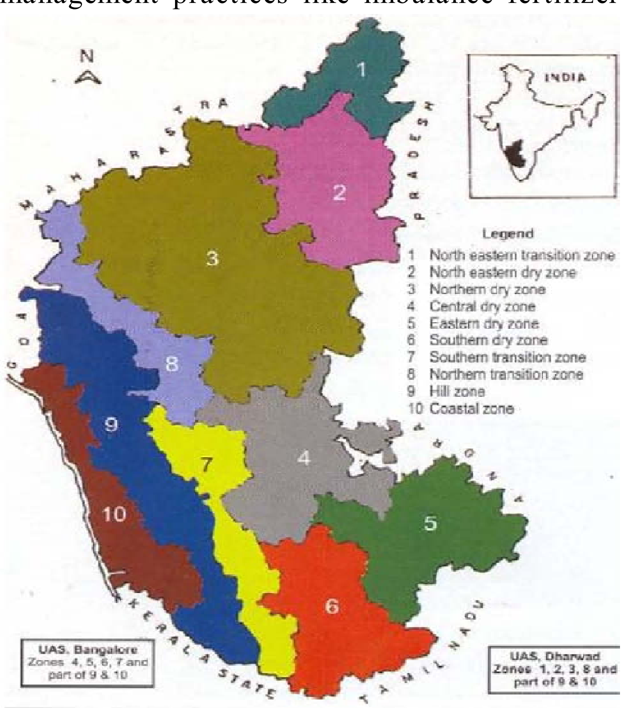

Fig. 2: Agro-ecological zones of Karnataka state

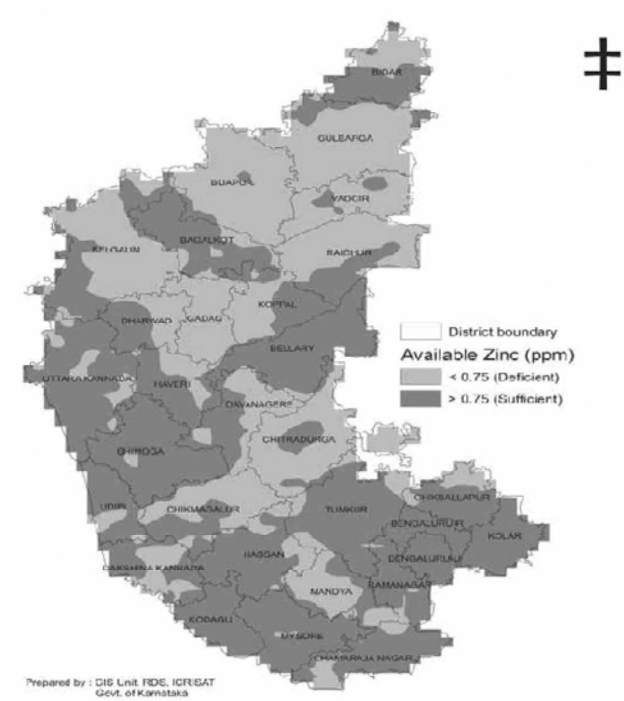

Fig. 3: Soil Zn status of Karnataka

Factors Affecting Zinc Availability in Soils

The total zinc content of the soils is of little importance in predicting the zinc supplying capacity of a soil. The solubility of zinc in soil is controlled by the matrix of iron, aluminium, manganese and other elemental oxides, carbonates, silicates and organic compounds. Soil reaction, organic matter, type and extent of clay, calcium carbonate, iron and aluminium oxides, and soil phosphorus affect the zinc availability to plants. Let us see some of the major soil factors that affect the Zn availability in this region.

Table 2: Response of banana to Zn an on farm study, Doddaballapur, Karnataka

Name of the Farm	Yield (t/ha)		Leaf Zn (mg/kg)		Leaf P (%)	
	No Zn	Zn @0.25%	No Zn	Zn @0.25%	No Zn	Zn @0.25%
CG Farm	65.4	74.5	14.2	24	1.16	0.84
KA Farm	55.6	58.4	15.0	26	0.96	0.64
PS Farm	49.4	60.4	9.0	28	0.91	0.72
MG Farm	64.4	74.4	18.0	32	0.48	0.74

Soil reaction

The pH of Karnataka soils are mostly in neutral to slightly alkaline range particularly in Northern, Central and Southern plateau region. Coastal as well as Western Ghats region and its surrounding areas have acidic pH range (Fig. 4). Availability of zinc decreases with the increase in soil pH. The solubility of zinc is highly dependent on pH and decreases by 100 folds for each unit increase in soil pH. The solubility of zinc is maximum in the pH range of 5 to 7 in the mineral soils and 4.5 to 6.0 in the organic soils. Zinc deficiencies occur usually in soils of pH 6.0 or more. So expected zinc deficiency is mainly in Northern, Central and Southern plateau region. Soil pH may influence the transport of adsorbed zinc to plant tops.Stability of soluble and insoluble organic complex of zinc depends on soil pH. The reduced availability of zinc with increase in soil pH was attributed to the formation of zinc hydroxides.

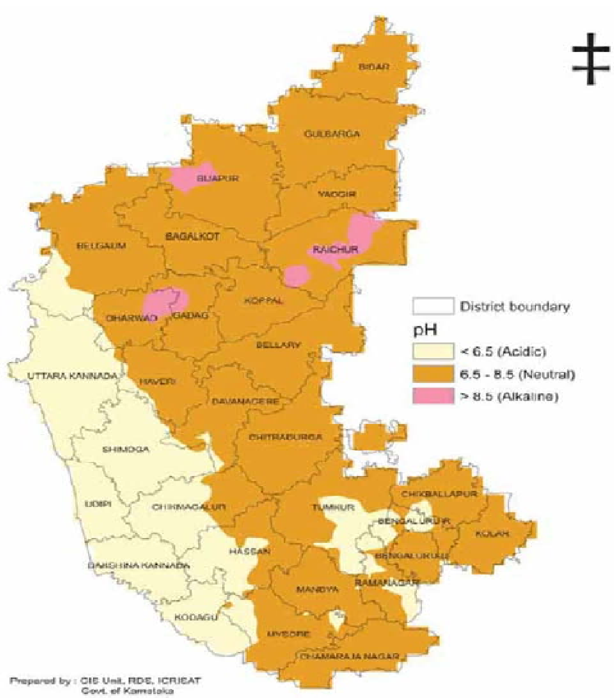

Fig. 4: Soil pH status of Karnataka state

Soil organic matter

Organic matter status of soils of Karnataka is depicted in Fig. 5. Organic matter can have negative influence on available zinc in organic matter rich acid soils of coastal Karnataka.The zinc availability increases with increased content of organic matter. Organic matter plays an important role on the availability of zinc through the formation of soluble organo-metal complexes and stable metalo-organic complexes. Metal complex with fulvic acid fraction of organic matter is highly water soluble. Natural complexing agents present in the organic materials effectively enhance concentration of soluble zinc complexes in soil solution through dissolution of sparingly soluble zinc compound and chelation of zinc ions so liberated.

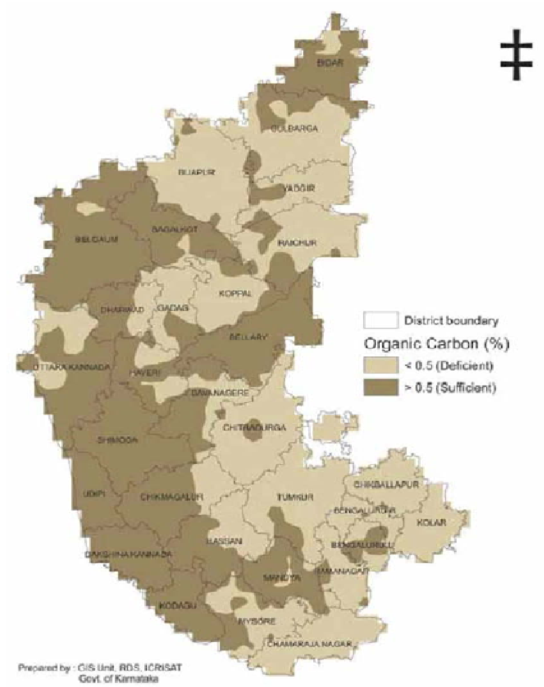

Fig. 5: Spatial distribution of organic carbon in soils of Karnataka

Soil phosphorus

The soil P status of Karnataka is depicted in Fig. 6. A large area is having either sufficient available P in soil or in excess due to accumulations following continuous application of phosphatic fertilizers. Phosphorus induced Zn disorder in plant is commonly associated with high levels of available P or with the application of P to the soil.

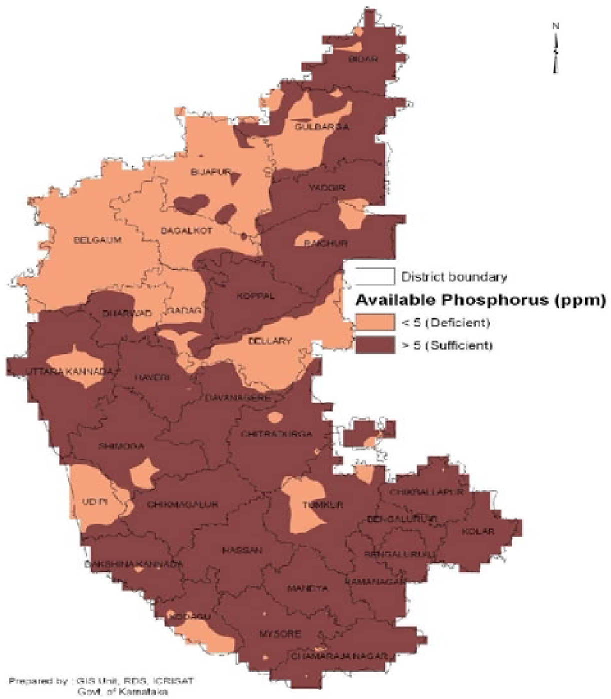

Fig. 6: Soil Phosphorus status of Karnataka

Four possible causes of P induced Zn deficiency

(a) slower rate of translocation of Zn from roots to top

(b) Accentuating Zn deficiency in plants in presence of high available P

(c) Simple dilution effect on Zn concentration in the top owing to growth response of P. Excess P interferes with metabolic functions of Zn within the plant cells. When there is slight or more of yield to P application, Zn concentration at the top of the plant and uptake of Zn reduces

(d) Metabolic disorder with plant cells related to an imbalance between P & Zn. Green house experiments have shown that the concentration and uptake of Zn increased in the roots and decreased in the leaves, nodes and internodes of vegetables due to the increased levels of P application. Zn availability in acid soils of Karnataka with high available phosphorus P (30.8 kg P_2O_5 ha^{-1}) was non-significantly correlated with available Zn.

Considering the above four factors, Karnataka soils having high P status in major area shows P induced Zn deficiency in many crops either in the form of visible symptoms or hidden hunger of varying degree.

Soil Maps as Tools to Delineate and Manage Deficient Regions

Soil testing can be used to diagnose and manage nutrient problems in the farmers' fields. Typical results from ICRISAT on soil Zn status for two districts in Karnataka are included here as an example (Fig.7). A large contiguous tract of land deficient in Zn was identified across Bagepalli and Gudibanda blocks in

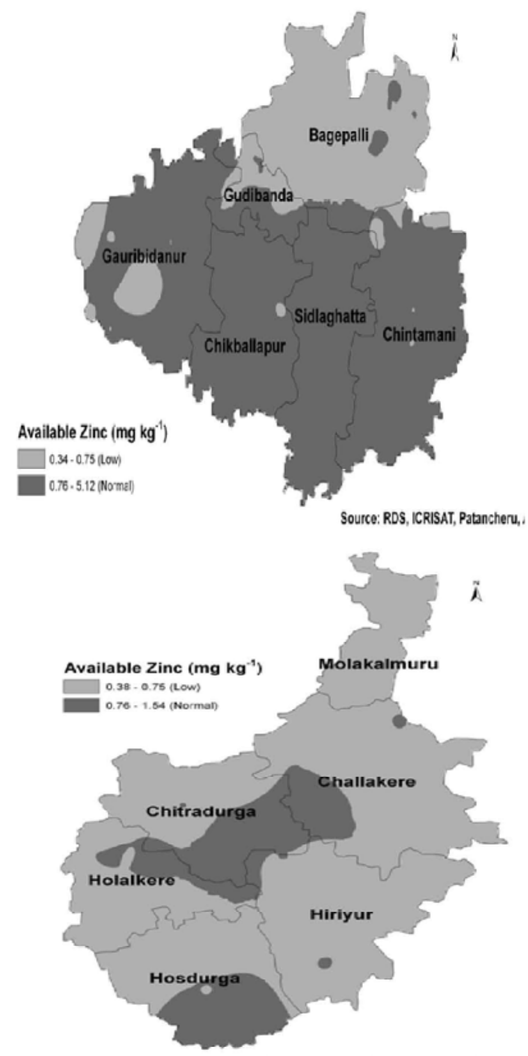

Fig. 7: Block level soil Zn status of Chikballapur and Chitradurga district.

Table 2 : Status of Zn in agro-ecological regions of Karnataka

Agro-ecological region	Districts name (Number of Taluks)	Taluks name	Zn status	Reference
Southern transition zone of Karnataka	Hassan (4), Chickmagalur (1), Shimoga (3), Mysore (3), Davanagere (2).	H.D.Kote, Hunsur, Periyapatna, H.N.Pura, Alur, Arkalgud, Belur, Tarikere, Bhadravathi, Shimoga, Honnali, Shikaripura, Channagiri.	Above critical levels*	Ramana et al. (2000)
Coastal agri-eco zone of Karnataka	Udupi (3), D. Kannada (5), U. Kannada (5)	Karwar, Kumta, Honnavar, Bhatkal, Ankola, Bantwal, Udupi, Belthangadi, Karkala, Kundapura, Mangalore, Puttur, Sulya.	Much higher than the critical levels	Gowda et al. (2001a)
Northern dry and northern transition zones of Karnataka	Koppal (4), Gadag (5), Belgaum (9), Bijapur (5), Bagalkot (6), Bellary (7), Davangere (1), Raichur (2), Dharwad (4), Haveri (6),	Gangavathi, Koppal, Kushtagi, Lingasugur, Sindhanur, Yelburga, Badami, Bagalkote, Bagewadi, Bilgi, Bijapur, Hungund, Indi, Jamkhandi, Mudhol, Muddebihal, Sindhagi, Bellary, Hagaribommanahalli, Harapanahalli, Hadagali, Hospet, Kudligi, Sandur, Siruguppa, Ron, Navalgund, Naragund, Gadag, Mundargi, Ramdurga, Gokak, Raibag, Soundatti, Athani, Hukkeri, Chikodi, Bailhongal, Belgaum, Haveri, Shiggaon, Shirahatti, Kundagol, Savanur, Hubli, Dharwad, Byadgi, Hirekerur, Raneebennur.	Well above the critical levels	Ramana et al. (2000)
Eastern and southern dry zones of Karnataka	Bangalore Rural (4), Ramanagar (4) Bangalore Urban (3), Kolar (5), Chikkaballpur (6) Tumkur (2). Mysore (4), Chamarajnagar(4), Mandya (7), Tumkur (2), Hassan (2).	Gubbi, Tumkur, Anekal, Bangalore South, Bangalore North, Channapatna, Devanahalli, Doddabalapur, Hosakote, Kankapura, Magadi, Nelmangala, Ramanagar, Bagepalli, Bangarpet, Chikkabalapur, Chintamani, Gudibanda, Gowribidanur, Kolar, Malur, Mulbagal, Sidalaghatta, Srinivasapura, K.R.Nagar, T.Narasipur, Mysore, Kollegal, Nanjangud, Turuvekere, Kunigal, Nagamangala, Srirangapatna, Malavalli, Maddur, Mandya, Pandavapura, K.R.Pet, Channarayapatna, Hassan, Chamarajanagar, Yelandur, Gundlupet.	Above the critical level	Gowda et al. (2001b)
North east transition and dry zones of Karnataka	Bidar (5), Gulbarga (2), Gulbarga (5), Yadgir (3) &Raichur (3)	Aland, Bhalki, Basvakalyan, Bidar, Chincholi, Humnabad, Aurad, Afzalpur, Chitapur, Gulbarga, Jewargi, Sedum, Shahapur, Yadgir, Shorapur, Raichur, Deodurga, Manvi.	Below the critical levels	Ramana et al. (2001b)
Hilly and central dry zones of Karnataka	U.Kannada (6), Belgaum (1), Dharwad (1), Haveri (1), Shimoga (4), Chickmangalur (6), Kodagu (3), Hassan (2), Chitradurga (6), Davangere (3), Tumkur (6)	Sirsi, Siddapura, Yellapura, Supa, Haliyal, Mundgod, Khanapur, Soraba, Hosanagar, Sagar, Thirthahalli, Koppa, Sringeri, Mudigere, Narasimharajapur, Chickmagalur, Kalaghatagi, Hangal, Sakleshpur, Virajpet, Somwarpet, Madikere, Challakere, Chitradurga, Davanagere, Harihara, Hiriyur, Hosadurga, Holalkere, Jagalur, Molkalmuru, Arasikere, Kadur, Madhugiri, Pavagada, Koratagere, C.N.Halli, Sira, Tiptur.	Below the critical range	Gowda et al. (2002)

*Critical level of zinc in soil 0.75 mg kg^{-1}

Chikballapur district. Other blocks *viz.* Gauribidanur and Chintamani in Chikballapur district also had pockets potentially deficient in Zn. The results also showed that almost all blocks in Chitradurga district were critically deficient in Zn (Fig.7)

Response of Horticultural Crops to Applied Zn

Zinc is applied to crop by soil application, foliar spray, coating/soaking of seeds or seedling in Zn solution or slurry. Among these methods, soil and foliar application is generally practiced (Ganeshamurthy et al., 2015). The optimum micronutrient content of plant tissues of various horticultural crops is depicted (Raghupathi *et al.* 2014). In case of Zn, optimum range in most of the fruit crops is 20-50 ppm. Further, the response of crops to Zn application is reported by many workers across the country. In the following paragraphs, the response of Zn along with other micronutrient in many horticultural crops studied in the region is briefly elaborated.

Zinc and Boron deficiency are the most important micronutrient disorders in horticultural crops. Foliar spray of 0.15% zinc corrects the deficiency (Ganeshamurthy *et al.*, 2013). Studies in sweet orange have indicated that soil application of zinc sulphate at 1 kg/plant once in every 4 years is the most effective method for controlling Zn deficiency in neutral and alkaline soils. Foliar spray with zinc sulphate (0.3%) along with humectant ($CaCl_2$ at 2%) once in a year during the active flush period is equally effective.

Effect of Zn application in vegetable crops

Zinc fertilizer application can increase yield from 15 to 25% in French bean, capsicum, chili, onion, tomato and cabbage. Screening of a number of tomato varieties for their tolerance to low zinc in the soil indicated that varieties with semi-determinate growth habits like 'Arka Saurabh', 'Arka Vikas' and some F_1 hybrids are least tolerant, whereas those with determinate growth like 'Sioux' and 'Pusa Ruby' are more tolerant and IIHR selection 1098 was the most tolerant. Tolerant varieties obtained adequate zinc from the soil with the help of more fibrous roots and lowering the pH of the rhizosphere. Combined application of B, Zn,Cu, Fe, Mn @ 100 ppm and Mo @ 50ppm produced the highest tomato fruit yield of 26.7 t ha^{-1}compared to the yield of 24.0 tobtained with Zn and 20.0 t ha^{-1} in control (Bhatt *et al.*, 2004). In cabbage, activity of enzyme carbonic anhydrase was found to be a good index of metabolically active zinc. Foliar application of 0.5% $ZnSO_4$ recorded minimum mean weight loss (20.16%) of cabbage heads (Sarma et al., 2005). Application of 20 kg $ZnSO_4$ ha^{-1} to cauliflower cultivar Snowball-16 produced the highest marketable curd yield. Performance of the applied Znwas distinctly superior when applied in conjunction of 22 kg Pha^{-1}. Application of 8 kg Zn ha^{-1} gave16% higher yield of potato than control and 4.5% higher than foliar sprays @ 1kg ha^{-1} (Raghav and Singh, 2004). Foliar spray of1% $ZnSO_4$ to onion produced highest seed yield per plant andunit area with high germination percentage (Khalate *et al.*, 2002), indicating the usefulness of the Zn in improving the seed health. Foliar sprayof $ZnSO_4$@0.75% to 'Pudukottailocal'cucumber produced maximumfruit set, number of fruit/vine,fruit weight and yield (Madhu sudhan and Shakila, 2003). In okra, combined spray of Zn and Mo (20 ppm each) gave highestpod yield of 6.9 t ha^{-1} compared to2.8 t in control (Srihari et al., 1987).Significantly higher okra yield of 5.5 t ha^{-1} was obtained when 40 kg $ZnSO_4$ $ha^{-1}$was applied as basal soil applicationas compared to 4.1 t ha^{-1} obtained with 2.5 kg $ZnSO_4$ ha^{-1} dose appliedto foliage twice and control (Raghavand Sharma, 2003).

Effect of Zn application in Mango

From the results of two years data on application of Zn to Dashehari mango, it is observed that Zn application had increased the mango yield and other quality parameters such as TSS, ascorbic acid and sugar: acid ratio (Singh *et al.*, 2003). Application of Zn increased the mango yield by 21% and fruit quality also enhanced. These parameters are further improved when Zn was applied with other micronutrients (B and Cu).

Influence of Zn on Banana Yield, Leaf Zn and P

On farm studies conducted in four different farms of Doddaballapur, Karnataka revealed that foliar spray of Zn at 0.25% at regular interval had tremendously increased the banana yield (at the scale of 5.01-22.26%) and leaf Zn content and reduced the leaf P content in the most cases when compared to the control treatment (where no Zn is applied). It showed that application of Zn is very useful to the crop growth and development and to attain higher yield.

Response of mandarin orange to Zn application

The effect of Zn and other micronutrients on yield and quality of mandarin orange has been reported by Saraswathy *et al.* (1998) and Dineshbabu and Yadav (2005).Application of Zn along with urea and other micronutrients boosted the number of fruits per tree, fruit weight and yield. In addition, it enhanced fruit juice content, TSS, titratable acidity, total sugars and ascorbic acid content of mandarin orange.

Zinc application on growth and yield of papaya

Papaya showed clear-cut response to Zn and other micronutrients (Fe and B) application (Pant and Lavania, 1998). Application of $ZnSO_4$ (0.15%) through foliar spray improved the number of fruits per plant and fruit yield. Moreover, application of Zn along with other micronutrients further enhanced the plant growth and yield of papaya.

Effect of application of Zn and B on Sapota

Soil application of $ZnSO_4$ (50 g/tree) has increased fruit weight and number of fruits per tree and yield of sapota. Increasing the amount of $ZnSO_4$from 50-100 mg did not show any significant improvement in these parameters. Application of $ZnSO_4$(50 g) along with 25 g borax per tree had further improved fruit weight and number of fruits per tree and yield of sapota and which are at par with that of $ZnSO_4$ (100 g) + borax (50 g) per tree (Saraswathy *et al.* 2004). Moreover, the highest yield and fruit weight and numbers has been observed in plants that received $ZnSO_4$(50 g) + borax (25 g) per tree + 0.5% $ZnSO_4$ spray. From the study, it was clear that the combined practices of both soil and foliar application of Zn is more beneficial to plant than any single practices.

Effect of Zn and B on Pineapple

Application of $ZnSO_4$ alone and in combination with borax influenced fruit weight and quality parameters of in 'Giant Kew' pineapple. When compared among different levels of $ZnSO_4$ application (0.2, 0.4 and 0.6% foliar spray), though 0.6% $ZnSO_4$ spray was found to be superior, application of 0.4% $ZnSO_4$ spray is effective and economical (Kar *et al.* 2012). Further combined application of borax (0.05%) along with $ZnSO_4$ did not show any significant change in these parameters.

Influence of Foliar Spray of $ZnSO_4$ on Grapes

Under field trials, foliar application of $ZnSO_4$ @ 0.4% in 5-year old 'Perlette' grape vines was the most effective in increasing yield, bunch weight and berry weight and quality parameters (Dhillon and Bindra, 1995).

Effect of Zn Application in Guava

In 7-year old 'Allahabad Safeda' guava, application of foliar spray of 0.6% $ZnSO_4$ produced significantly higher yield and quality of fruits. Application of zinc caused 72% fruit set against 64% in control, 166g fruit weight against 143g in control, 499 fruits/tree against 426 in control, 82 kg fruit yield against 60 kg/ tree in control, 11.3% TSS against 9.6% in control, 0.36% acidity against 0.43 in control, and 127 mg ascorbic acid against 103 mg in control. Bronzing', a common disorder in guava occurring on the red soils of poor fertility in Karnataka was found to be caused due to combined deficiencies of phosphorus, potassium and zinc. Severe cases of disorder result in trunk splitting. Foliar spray with DAP (0.5%), potassium sulphate (0.5%) andzinc sulphate (0.3%) controls the disorder. Zinc deficiency alone can be effectively controlled by soil application of zinc sulphate @ 800 g/plant once in 4 years in guava.

CONCLUSIONS

Wide spread Zn deficiency is a reality in soils of Karnataka and is equally distributed in all the agro-climatic regions of the state. District level deficiency maps helps to a great extent in management of Zn deficiency in soils and crops. Horticultural crops respond very significantly to Zn application. Further, the response and amount of Zn required by individual crops vary and it is influenced by climate and soil factors. Many site-specific nutrient management studies need to be done for effective management of Zn. From the available data, it is obvious that application of Zn to horticultural crops enhances the Zn content of the produce. This helps in enhancing the availability of Zn in the food.

AKNOWLEDGEMENT

The authors thank ICAR-NBSSLUP and other sources referred in the text for the information used in the review.

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(Received on 21.5.2018 and accepted on 12.12.2019)