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Distribution of nutrients and their indexing in major mango-supporting soils of different agro-climatic zones of Karnataka and its impact on yield

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Abstract

Knowledge of the spatial distribution of soil nutrients is essential for site-specific nutrient management, which forms an effective strategy in precision agriculture. As mango is one of southern Karnataka's most important horticultural crops, the present study was conducted on 108 mango orchards under different agro-climatic zones to assess spatial nutrient variability for nutrient management. The soils of the study areas were acidic and non-saline. Nitrogen (N) deficiency was found in 84.26 percent area, whereas phosphorus (P) and potassium (K) contents were medium in most soils. Sulphur was sufficient, and calcium and magnesium contents varied with agro-climatic zones. The micronutrient (Zn, Fe, Mn) status was sufficient, except for copper and boron. The nutrient index for nitrogen was low, while phosphorus and potassium were low to medium. It is inferred that agro-management should include proper nitrogen fertilization, FYM, and boron throughout the growing cycle for better yield and quality.

Key words: Mango-supporting soils, spatial distribution of nutrients, nutrient index, nutrient management

Introduction

The spatial and temporal variation of surface soil nutrients affects crop yield, land use management and the environment (Zhang *et al.,* 2014). Accurate estimation and proper knowledge of factors impacting the distribution of soil nutrients are quite important for soil and crop management and economic return. Soil fertility is the inherent character that signifies the availability of nutrient elements for plant growth (Sarkar *et al.,* 2002; Dinesh *et al.,* 2020). Landscape diversity, topographic features, and diverse climatic variability affect nutrient variability (Menezes-de-Souza *et al.,* 2006). Crop productivity was low in large areas due to poor water availability and multi-nutrient deficiencies in semi-arid conditions.

The mango tree originates from the Indo-Burma region and thrives across tropical, sub-tropical, and semi-arid zones with diverse soil types (Rajan, 2012). Among Indian states, Karnataka ranks as the third-largest mango producer. Notably, the eastern dry zone (EDZ) and southern dry zone (SDZ) within southern Karnataka play a pivotal role in mango production, forming the prominent mango cultivation area of the state. Due to its intensive nutrient requirements, mango orchards deplete substantial amounts of nutrients, leading to a phenomenon known as nutrient mining. Focus on micronutrient deficiency is even more important than the primary nutrients, as these are essential for the quality of nutrients, plant metabolism, and physiology (Durán *et al.,* 2004). For sustaining yield potential of mango, knowledge of spatial nutrient distribution with its proper management is essentially required, but limited research effort was made earlier to identify the spatial extent of deficiency of major, secondary and micronutrients for this SAT climate. In the present study, farm-level information from 108 orchards around major mango-growing taluks was done with the objectives: (i) to assess the status of soil pH, EC, OC, available primary, secondary and micronutrients and factors affecting its availability and (ii) to study the spatial variability with critical nutrient deficiency sites with specific nutrient management.

Material and methods

Study area: Major mango-supporting soils of southern Karnataka were chosen based on proportional contribution to total area, production and productivity along with traditional mango-growing belts, potential and new orchards areas. Our study comprised fifteen major mango-growing taluks under six major agro-climatic zones of southern Karnataka with various soil types under diverse climatic settings (Table 1). From the extreme west, Sorab, under the hilly zone (Fig. 1) to Srinivasapura, under the Eastern dry zone, covers around 400 km of southern peninsular plateau. Elevations varied from 597 to 936 m with varied landform characteristics. Climate varied from sub-humid tropics in the HZ to semi-arid tropics in the EDZ. SDZ could be seen with varied rainfall of 691.1 to 1459.3 mm and PET of 1318.24 to 1887.58 mm. The soils having their parental legacy with archaean granite and gneissic and their mineral make-up, along with varied mineralogy, greatly influence and impact the availability of essential plant nutrients.

Sampling and soil analysis: A total of 108 composite surface soil samples (0-15 cm) were collected from different representative mango orchards from each taluk. Four samples were collected from each orchard using the grab sampler and scoop method and mixed to get the representative composite sample. Collected

Table 1. Climatic and landforms information of major mango-supporting taluks

ACZ	Taluks	Landforms	Elevation (m above MSL)	Rainfall (mm)	Temperature (°C)	Potential Evapo transpiration (mm)	Length of dry Period (days)	Texture of soils	Soil sub-group
HZ	Sorab	Hilly	597	1459.3	25.27	1318.24	166	sc	Rhodic Kandiustalfs
	Tarikere	Hilly	725	928.9	24.56	1408.18	150	c	Rhodic Paleustalfs
NTZ	Channagiri	Plateau	647	808.4	25.00	1509.16	160	scl	Typic Rhodustalfs
STZ	Hunsur	Plateau	792	833.9	23.41	1453.96	133	sc	Typic Rhodustalfs
CDZ	Holalkere	Upland	794	691.1	26.94	1551.80	172	sc	Typic Rhodustalfs
SDZ	Magadi	Midland	925	913.0	24.73	1484.26	135	sl	Dystric Haplustepts
	Ramanagara	Midland	749	899.4	25.31	1568.52	140	c	AquerticHaplustalfs
	Nagamangala	Upland	841	797.0	24.84	1472.53	135	sl	Typic Haplustepts
EDZ	Gubbi	Upland	877	812.2	24.34	1522.80	151	scl	KanhaplicRhodustults
	Tumkur	Upland	812	921.9	24.30	1513.70	147	c	Rhodic Kandiustults
	Chintamani	Upland	859	734.1	24.87	1617.28	160	c	Rhodic Kandiustalfs
	Srivasapura	Upland	837	759.4	24.87	1571.26	140	scl	Kandic Paleustalfs
	Mulabaghilu	Midland	802	812.8	24.87	1399.76	130	sc	Aquic Haplustalfs
	Hoskote	Plateau	906	808.4	24.87	1513.66	143	c	Kandic Paleustalfs
	BangaloreNorth	Upland	936	963.1	25.00	1887.58	145	sc	Rhodic Kandiustults

HZ- Hilly zone; STZ-Southern Transition zone; CDZ-Central Dry Zone; SDZ-Southern Dry Zone; EDZ-Eastern Dry Zone

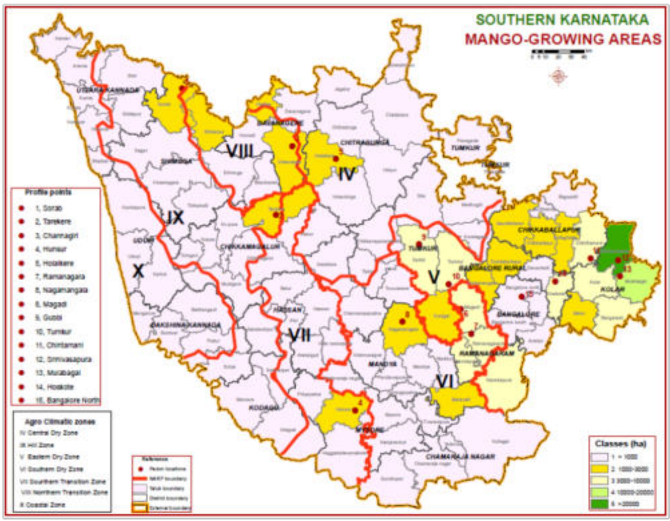

Fig.1 Major mango-growing areas and concentration of orchards of southern Karnataka

samples were dried at room temperature and sieved through 2 mm sieve. Soil pH was measured using pH meter by inserting in the supernatant of 1:2.5 soil into water. The standard dichromate oxidation method determined soil organic carbon content (Walkley and Black, 1934). The alkaline potassium permanganate method assessed available nitrogen using the Kjeldahl apparatus (Subbiah and Asija, 1956). Phosphorus was determined by Olsen's method (Olsen and Sommers,1982; Kumar and Maiti, 2015) using UV–visible spectrophotometer. Available K, Ca and Mg were determined by extraction with neutral normal ammonium acetate and the filtered extract was estimated using atomic adsorption spectrophotometer (AAS) (Page *et al.,* 1982). Soils were extracted with $CaCl_2$ to determine the available S, which was measured by a spectrophotometer at 420 nm (Black, 1965). Cationic micronutrients Fe, Mn, Cu and Zn were determined using AAS by extracting the soils with DTPA extractant (Lindsay and Norvell, 1978). Hot water soluble B was extracted with the method described by Gupta (1967).

Statistical analysis and calculation of nutrient index: Nutrient index of each agro-climatic zone was determined to compare fertility with soil, as per the procedure introduced by Parker *et al.* (1951). Test results of the composite samples for pH, OC, available N, P_2O_5 and K_2O were presented as box plots with standard nutrient ratings (Fig.3). After rating, the composite sample's nutrient index was calculated as per following equation and classified into low, medium and high according to the nutrient index categories (Abah and Petja, 2015; Parker *et al.,* 1951).

$$\text{Nutrient index}= \frac{(1 \text{ x number of samples rated low})+ (2 \text{ x number of samples rated medium}+ (3 \text{ x number of sample rated high})}{\text{Total number of samples}} \quad (1)$$

Multiple correlation analyses along with descriptive statistics were done using SPSS version 20. Principal component analysis (PCA) was done using R software, where principal soil nutrient properties were displayed by biplot analysis. Principal nutrient variables were selected based on component loading values >0.8 and correlated with the yield of specific taluks to make a proper nutrient management plan for the selected sites.

Results and discussion

Spatial variability measured soil properties: The soils were extremely acid (pH 4.02) to slightly alkaline (pH 7.78) (Table 2). Orchard soils of Sorab from HZ, Gubbi, Tumkur from EDZ were strongly acid in reaction, whereas soils of Holalkere, Magadi and Nagamangala from SDZ were slightly alkaline (Table 3).

The electrical conductivity of soils varied from 0.02 to 0.47 dSm^{-1} (mean 0.07 $dS\ m^{-1}$). Organic carbon in the surface ranged from low (0.27 %) to high (1.33 %), with a mean of 0.84 percent. The surface soils had relatively high organic matter content except in Nagamangala and Mulabaghilu (Table 3). Our study supports the earlier findings of a wide range of pH, EC and OM content, which might be ascribed to varied soils and climatic diversity (Reddy *et al.,* 1996; Satyavathi and Reddy, 2004; Shukla *et al.,* 2018).

In all the orchards, N content was low with a mean value of 220.11 kg ha^{-1} (Table 2), whereas P content was high and showed wide variation (mean 72.20 kg ha^{-1}), but deficiency of P was found in Sorab, Holalkere and Magadi (Table 3). The higher available P in a few soil samples might be due to application of a large quantity

Table 2. Descriptive statistics of the area

	Minimum	Maximum	Mean	Median	Std. deviatiom	CV (%)	Skewness
pH	4.02	7.78					
EC (dS m^{-1})	0.02	0.47	0.07	0.05	0.07	100.00	2.98
OC (%)	0.27	1.33	0.84	0.85	0.20	23.81	-0.06
N (kg ha^{-1})	109.76	369.34	220.11	225.79	57.54	26.14	0.02
P (kg ha^{-1})	2.39	303.01	72.20	60.95	60.05	83.17	1.88
K (kg ha^{-1})	40.32	490.56	158.63	145.60	1.44	0.91	1.44
S (mg kg^{-1}	2.57	121.90	42.29	30.12	30.12	71.22	0.95
Ca (mg kg^{-1})	57.05	2521.75	404.39	282.00	344.98	85.31	2.79
Mg (mg kg^{-1})	8.80	271.30	74.86	68.30	49.98	66.76	1.35
Cu (mg kg^{-1})	0.36	5.60	1.95	1.66	1.09	55.90	1.01
Fe (mg kg^{-1})	4.42	221.76	33.22	22.62	31.41	94.55	3.09
Mn (mg kg^{-1})	3.12	124.52	35.54	29.42	20.98	59.03	1.79
Zn (mg kg^{-1})	0.26	4.84	0.99	0.73	0.81	81.82	2.29
B (mg kg^{-1})	0.19	1.13	0.59	0.56	0.23	38.98	0.42

of phosphatic fertilisers. Available potassium was medium in the area (mean 158.63 kg ha^{-1}), with the highest content in Holalkere taluk (Table 3). Calcium was found to be sufficient in soils with an average of 404.39 mg kg^{-1}, but magnesium was deficient, with a mean of 74.86 mg kg^{-1}. In the Eastern dry zone, both Ca and Mg were poor in surface soils. Sulphur was sufficient in the entire area, averaging 42.29 mg kg^{-1}. Average values of available Fe, Mn, Cu, Zn and B were 33.22, 35.54, 1.95, 0.99, and 0.59 mg $kg^{-1,}$ respectively. The deficiency of Cu in some sites might have been aggravated due to the complexation of Cu in the soils, having relatively higher organic carbon. The spatial diversity of cationic micronutrients supports the findings of Shukla *et al.* (2016). Soil properties exhibited low (only for available K_2O) to medium variability, with 100 percent of CV values indicating low, moderate and high degree variability, respectively (Nielsen and Bouma, 1985). Moderate variability of micronutrients supports the study of Shukla *et al.* (2016) of India's Trans-Gangetic Plain and Shivalik Himalayan region. Higher spatial variability of cationic micronutrient content was due to the diversity of weathering regimes and pedogenic processes (Bowen 1979;). Comparatively low soil pH variability and OC status and primary nutrients status are seen in the study areas.

Relationships among soil properties and yield: The correlation between the soil properties and available plant nutrients is shown in Table 4. Soil pH and EC significantly correlate with the availability of plant nutrients. Significant positive relationships (P<0.01) with K, S, Ca, Mg and Zn have been observed in strongly acid soils of Gubbi and Tumkur taluks, as these nutrients were deficient in these soils. A significant negative correlation of pH with P_2O_5, Fe and Mn supports the observations of Shukla *et al. (*2018) in the semi-arid Deccan plateau, which showed reduced solubility of Fe, Mn and Cu with increased alkalinity. Electrical conductivity showed significant positive relation (P<0.01) with K_2O, S and Zn due to the high solubility product of these nutrients. N's availability in surface soils was highly dependent on OC content in soils, as a highly significant correlation between N and organic carbon with a value of r=0.55 (P<0.01) was observed. The deficiency of N in the overall area might be the effect of the medium to low OC content of these semi-arid tropical areas. Organic carbon, the key component of soil organic matter, influences availability of primary and secondary and micronutrients (Tisdale *et al.,* 1985). There was a positive interaction with K_2O, S and Zn found for the mango orchards. Positive correlation among the cationic micronutrients, Cu vs. Fe, Cu vs Mn, and Fe vs Mn (P<0.01) indicates similar sets

Table 3. Spatial distribution of average primary, secondary and micronutrient content in major mango growing soils of Southern Karnataka

Taluks	pH	EC	OC	N	P_2O_5	K_2O	Ca	Mg	S	Fe	Mn	Cu	Zn	B
		dS m-1	%		Kg ha^{-1}						mg kg^{-1}			
Sorab	5.35cdef	0.04cd	1.11a	255.7ab	21.5c	101.7c	291.1b	130a	31.7bc	109a	79.6a	3.37a	0.87bc	0.64ab
Tarikere	5.88bcde	0.07bcd	0.84bcd	266.1a	40.5bc	146.7c	473.8ab	110.3ab	38.9bc	46.5b	41.9bc	2.55ab	0.71c	0.64ab
Channagiri	5.13ef	0.04d	0.77bcd	241.3abc	118ab	117.7c	461.3ab	102ab	29.9bc	46.7b	38.0bc	2.21bc	0.47c	0.56abc
Hunsur	5.81bcde	0.05bcd	0.85bc	201.2bcd	64.1abc	125.9c	370ab	100.4ab	54.1bc	34bcd	25.0c	1.22def	0.89bc	0.68ab
Holalkere	6.58ab	0.09bcd	0.73cd	247abc	17.6c	286.7a	723.8a	97.7ab	37.6bc	14.8de	38.8bc	2.4abc	1.37bc	0.44bc
Magadi	6.34bc	0.09bcd	0.89bc	186.9cd	23.1c	176.7bc	608.6a	88.2ab	61.6ab	19.8cde	53.1ab	2.77ab	0.75c	0.64ab
Ramanagara	5.78bcde	0.06bcd	0.74cd	197.8cd	133.5a	137.5c	610.3a	86.1ab	46.6bc	39.1bc	31.8bc	2.14bc	1.07bc	0.75a
Nagamangala	7.17a	0.11bc	0.62d	223.2abcd	66.6abc	236.8ab	522.4ab	76.5ab	67.8ab	14.3de	14.0c	0.99ef	1.39bc	0.48bc
Gubbi	5.19def	0.04d	0.75bcd	200.6cd	75.7abc	134.4c	501ab	69.5ab	22.7bc	22.3cde	24.9c	0.90f	0.52c	0.39c
Tumkur	4.7f	0.04d	0.86bc	185.7cd	106.8abc	141.4c	181.9b	47.5ab	23.5bc	27.8bcde	27.8bc	2.07bcd	0.79bc	0.51bc
Chintamani	5.06ef	0.06bcd	0.87bc	214.8abcd	127.5ab	188.2abc	134.4b	45.3b	26.6bc	17.5cde	28bc	1.4cdef	0.95bc	0.46bc
Srinivasapura	5.84bcde	0.11b	0.98ab	233.1abc	38.2bc	227.7ab	295.5b	40.5b	41.6bc	16.5de	42.2bc	1.95bcde	0.88bc	0.62ab
Mulabagilu	5.89bcde	0.03d	0.77bcd	225.6abc	64.8abc	114.7c	150.2b	39.2b	45bc	43.9bc	14.6c	1.06ef	0.57c	0.62abc
Hoskote	6.01bcd	0.22a	0.93abc	270.5a	63.3abc	157.9bc	320.6ab	26.1b	101.2a	12.8de	31.9bc	2.2bc	2.89a	0.5bc
Bangalore N.	6.02bcd	0.17a	0.84bcd	155.2d	89abc	155.2bc	150.5b	25.5b	5.9c	0.5e	20.9c	1.02ef	2.08ab	0.79a

(Values in column bearing different subscript are significantly different at P=0.05 level)

Table 4. Correlation among fertility parameters

	pH	EC	OC	N	P	K	S	Ca	Mg	Cu	Fe	Mn	Zn	B
pH	1.00													
EC	0.35**	1.00												
OC	0.09	0.17	1.00											
N	0.17	0.19	0.55**	1.00										
P	-0.21*	-0.04	-0.14	-0.10	1.00									
K	0.40**	0.33**	0.00	0.04	-0.02	1.00								
S	0.51**	0.64**	0.10	0.10	-0.16	0.29**	1.00							
Ca	0.41**	0.16	0.08	0.22*	-0.13	-0.01	0.22*	1.00						
Mg	0.33**	0.09	-0.08	0.11	-0.13	-0.05	0.23*	0.80**	1.00					
Cu	-0.08	0.08	0.20	0.18	-0.16	-0.14	-0.03	0.30**	0.39**	1.00				
Fe	-0.36**	-0.24*	0.17	0.21*	0.06	-0.23*	-0.27**	-0.13	-0.05	0.34**	1.00			
Mn	-0.21*	-0.02	0.23	0.07	-0.26**	-0.12	-0.17	0.10	0.18	0.68**	0.48**	1.00		
Zn	0.31**	0.56**	0.14	0.14	0.02	0.27**	0.50**	0.08	-0.02	0.13	-0.12	0.03	1.00	
B	0.04	-0.03	0.12	0.00	0.01	-0.15	0.09	-0.08	-0.04	0.13	0.08	0.07	-0.06	1.00
Yield	-0.04	-0.07	0.06	0.04	-0.17	-0.21*	-0.07	0.08	0.20	0.18	0.35**	0.22*	-0.03	0.02

of factors that influence the distribution of these micronutrients (Behera and Shukla, 2013; Shukla *et al.,* 2018).

Surface soil properties were taken for the principal component analysis (PCA) and presented as a biplot in Fig. 4. PC1 explains 22.8 percent variability in soil properties, showing high loading values with pH, EC and available S. Whereas PC2 explains 18.5 percent variability of soil properties mainly focused on cationic micronutrients with high loading values of Cu, Mn and Fe. Principal Component Analysis aggregated soil fertility properties into components explaining most spatial variabilities. Similar to the findings of Shukla *et al. (*2018), biplot analysis of PC1 and PC2 revealed two prominent groups of soil properties, in which soil reaction constituted one group and micronutrients created another. These fertility components significantly influenced yield limiting characteristics of mango throughout the area (Table 4). Among the principal soil nutrients, Fe and Mn have a significant positive correlation (r=0.35, $P<0.01$ and r=0.22, $P<0.05$) with yield. The availability of micronutrients in red ferruginous soils influences the most towards sustainable mango production in these traditional mango-growing areas.

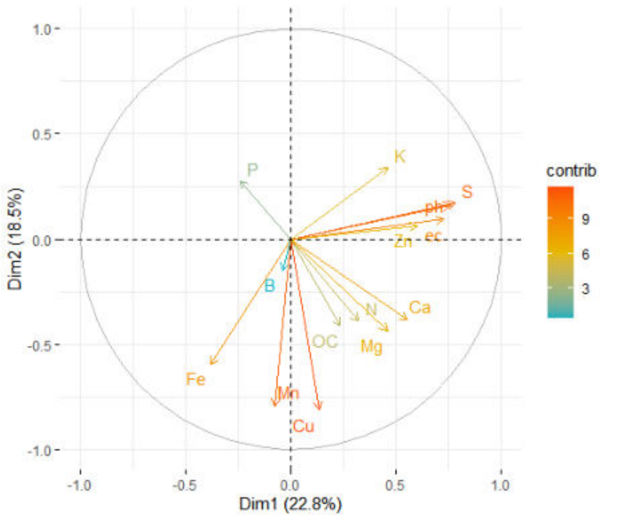

Fig 2. Principal component analysis (PCA) of nutrient parameters. Dim 1 and Dim 2 in biplot represents principal component 1 (PC1) and principal component 2 (PC2), respectively)

Spatial variability in nutrient index: The nutrient index (NI) of the major mango-supporting areas of southern Karnataka was determined through the nutrient rating status of the major taluks, using Eq. 1. Nutrient ratings of the areas were prepared based on the rating chart set by Ravikumar and Somashekar (2013) and Muhr *et al.* (1965). Nutrient indices of the major agro-climatic zones are presented in Fig. 3 and categories with low, medium and high nutrient status were followed by the limits set by Ravikumar and Somashekar (2013). For the entire area, pH was rated low by following the nutrient rating chart, whereas only the central dry zone has a medium index value for pH. Sixty-seven percent of orchard sites were rated low and 33 percent were rated medium for pH. Spatial variation of OC can be found from low to high. The nutrient Index is rated high for all agro-climatic zones for OC, except the southern dry zone. It was found to be low in 3.7 percent sites, medium in 28.7 percent sites and 65.03 percent areas were found to be high in OC. High OC in surface soils is due to litter deposition of perennial mango orchards. Though considerable variation was noticed in the concentration of available N among sampling sites, all the sites were rated low except in CDZ. It was low in 84.26 percent of sites, whereas 15.74 percent sites were medium in N. The variability was high for available P, with 12.96 percent of sites rated low, 28.71 percent of areas rated medium and 58.33 percent areas rated high. EDZ is very much important as per the production of mango. High available P and medium K played a very important role for maintaining mango supply from these mango-growing belts of southern Karnataka. Around 56.48 percent of areas had medium K availability.

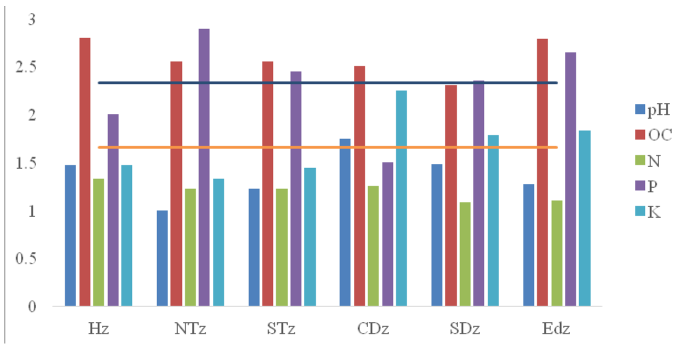

Fig 3. Nutrient index of different agro-climatic zones

Nutrient management: Sustainable crop production needs a proper knowledge of soil and climatic constraints, a proper management technique, and employing contemporary field practices. The productivity potential of soils can be improved by properly understanding soils and their potentials and constraints (Karthika *et al.,* 2022) and, in turn, suitable agro-interventions. The knowledge of variability in soils gives an idea about yield-limiting factors. Acidic soil reaction was one of the major limitations for the sites under Channagiri, Tumkur and Gubbi as the ideal pH for mango production is 5.5 to 7.0 (Sys *et al.,* 1993; Naidu *et al.,* 2006, Singh *et al.,* 2008). As these soils have their genesis from acidic granitic parent material, the surface and sub-surface acidity of some of the sites (dominantly from eastern dry zone) was due to geogenic factors than crop management practices. Application of N fertilizer along with FYM in the package of practices (POP) can tackle this problem. Nitrogen deficiency is a serious problem for the study area. Earlier researchers (Sahrawat *et al.,* 2010; Vasu *et al.,* 2017) also reported N deficiency in soils of similar climatic belts in India.Split doses of nitrogenous fertilizers and proper biomass management may help alleviate the N problem. Cu, Zn and B were deficient in large and hence application of Cu and B through fertigation and/or soil application should be carried out to alleviate the deficiencies.

Nutrient management with proper spatial nutrient distribution knowledge is needed to enhance the productivity of mango raised on varied soils and landforms. Our present investigation showed the climate zone of spatial variability under southern Karnataka. Nitrogen deficiency was the major limiting factor in nearly all the sites, along with copper and boron in large tracts. Integrated nutrient management with a special focus on these nutrients through different sources would enhance mango production and fruit quality.

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