Annals of Plant and Soil Research 26(3): 372-386 (2024)
https://doi.org/10.47815/apsr.2024.10374

Citrus nutrition in India-A snapshot of up-to-date progress

L. DEVARISHI SHARMA[1]*, SANTOSH KUMAR SINGH[2], NIVEDITA OINAM[6], HIREN DAS[3], ANIMESH SARKAR[4], LAIKHURAM BANARJEE SINGH[6], RAFIYA CHOUDHURY[5], HRANGBUNG JURIST ANAL[5], I. BHUPENCHANDRA[1] AND RAHUL SADHUKHAN[1]

Department of Natural Resource Management, College of Horticulture, Thenzawl, Mizoram, (CAU-Imphal)

Received, June, 2024; Revised accepted, August, 2024

ABSTRACT

Citrus is a nutrient-loving, responsive plant requiring sufficient nutrient for proper growth and development. Most citrus sites have shown several nutrient deficiencies – the most common being N, P, K, Mn, and Zn. Pedologiacl variation in soil type plays an essential role in both production and quality regulation through variable plant nutrient supply system. The availability of soil and leaf nutrient guidelines for a specific soil, climate and cultivar are preconditions for effective management of nutrients in citrus fruits. High citrus productivity is achievable only when the nutrient fertilization programme is performed based on soil or leaf analysis. Fertigation has many benefits such as increasing the efficiency of fertilizer usage, ensuring water and nutrient supply, human resource-saving, yield and quality. Application of fertilizer on foliarshows a better result than the use of traditional soil fertilizer application. Annually, a substantial quantity of nutrients is removed by the citrus fruits, and these must be restocked to preserve soil fertility and sustain the long term productivity, besides arresting an early citrusdecline due to nutrient starvation.

Keywords: Leaf nutrients, plant available nutrients, foliar application, fertigation, INM

INTRODUCTION

It is claimed and confirmed that citrus has originated in Cathaysian ancient continentand south china. Based on the theories of continental drift, the ecological and geological vicissitude, citrus is assumed to have dispersed gradually into India, Australia and Africa (Srivastava and Malhotra, 2014). It shows that citrus plants are grown abundantly inthetropical and the subtropicalaridclimatehaving 24^0-38^0C at both sides of the equator having hot days and harvested worldwide is observed in the soil order such asOxisol, Ultisol, Alfisol, Inceptisol andcold nights and less exposed to extremelychilly temperature. The maximum production of citrus Entisol (Srivastava and Singh, 2002). Citrus is a nutrient-loving, responsive plant requiring sufficient nutrient for proper growth and development (Srivastava and Malhotra, 2017). The fruit-bearing tree takes a massivequantity of nutrients from the soil, and these must be restocked to preserve soil fertility to produce a high yield of the fruit of good quality (Srivastava, 2009). Macro- and micronutrient feeding has gained significant importance in affecting vigour and fruit yield (Dubey and Yadav, 2003). The nutritional needs of perennial crops are not similar to that of seasonal vegetables because of its plant size, length, growth rate, rooting configuration, the phenomenon of bud variation and its correlation to yield during the next season. Before renewed growth or a commitment of potential return, it is essential to determine the nutritional requirements of fruit trees (Srivastava, 2013).

To preserve the available nutrient content of the soil at a suitable level, the use of accurate diagnostic techniques is necessary and therefore, appropriate quantities of manure, bio-chemical fertilizers are needed to be applied to guarantee higher economic benefits.Energy, economy and climate must be taken into account, as well as a productive use of manure, bio-fertilizer and chemical fertilizers (Srivasstava and Hota, 2020). The best diagnostic method is one that advises the use of nutrients only in the fruit crop's immediate monetary benefit. Diagnostic methods are used for the prevention of nutrient shortages or surplus, and appropriate use of these methods will bring about high fruit production of good quality. Analysis of leaf is the most excellent tool to determine the nutrient application (Bhargava, 2002).

Corresponding author:- ldsharma85@yahoo.com, [1]College of Horticulture, Thenzawl, Mizoram-796186 (Central Agricultural University-Imphal), [2]Department of Soil Science, RPCAU, Pusa, Samastipur, Bihar-848125, [3]Department of Soil Science, Assam Agricultural University, Jorhat, Assam-785013, [4]Department of Agriculture& Farmers Welfare, Govt. of Tripura-799131, [5]School of Agricultural Sciences, Nagaland University, Medziphema, Nagaland-797106, [6]Department of Soil Science, College of Agriculture, Imphal, Manipur-795004 (Central Agricultural University-Imphal)

DIAGNOSIS OF NUTRIENT CONSTRAINTS USING LEA ANALYSIS

Analysis of the leaf encompasses the influence of several variables such as soil and climate. The analysis depends on the precision of the specimenconcerningtheleaf-age, the leaveslocation on the terminal, the terminal type, the sampling period of crop and other developmental conditions. The appropriate time fora sampling of leaveswas found in Ambia flush (February bloom) at 6-8 months of leaf-age in Typic Haplustert. In Mrig flush (July bloom) sampling of leaves at 5-7 months of leaf-age was found in Typic Ustochreptas well as Typic Ustorthent soil types.The methodology adopted to determine the specific age of leaf specimen across citrus-growing countries shows that there is no particular sampling age of leaves. Under a specific set of growing conditions, it must be standardized (Srivastava *et al.*, 1999; Gupta *et al.*, 2008). The nutrient content of leaves between6- and 8 -months old that arecollected from the second, the third and the fourth positions of the shoot show a non-significant statisticaldifferenceinthe level of N, P, K, Ca, Mg, S, Fe, Zn, Mn and Cu.The findings suggested that all the positions of leaf were equally effective for the determination of the nutrient status of the citrus tree (Srivastav and Singh, 2009). The previous studies showthat the N, P, K and Ca content of the leaves of fruit-bearing trees at third and fourth positions of the shoothave similar nutrient content present in the leaves of the non-fruiting growth of the same tree.A non-significant statistical difference in the various nutrientsconcentration viz., N, P, K, Ca, Mg, S, Fe, Zn, Mn and Cu were examined in6 to 8 months old leaves by collecting 30-70 leavesspecimenfrom 2-10% of trees (Srivastava *et al*, 2001). The findings also suggest that 30 leaves of 2 % trees are equally successful as that of 70 leaves of 10 % trees for foliar analysis.Nevertheless, several studies around the citrus growing regions of the world show that the sample sizes of leafvary from 40 to 100 leaves (Srivastava *et al.* 1999).

Nutrient standardsof indexleafof nutrients constraints identification: Diagnosis and Recommendation Integrated System modelling and on-field response are the two different diagnostic approaches that are designed to develop the nutrient requirement of leaf for various citrus cultivars (Table 1). The inequality in diagnostic techniques, apart from cultivar's agro climate and nutrient absorption behaviour, are the key contributing factors to bring forth variability in reference values concerning yield (Kohli *et al.*, 1998; Srivastava and Singh, 2005; Srivastava and Singh, 2006; Srivastava and Singh, 2008a; 2008b).The values of nutrient in the leaf are developed for different citrus cultivars using a combination of surveys, modelling studies, field responses and the adoption of elite orchard techniques and planning. Srivastava *et al.* (2007) surveyed 841 citrus orchard-growing states during 2002-05, including 55 sites in the north-eastern states of Tripura, Mizoram, Arunachal Pradesh, Nagaland, Manipur, West Bengal, Sikkim, Meghalaya, and Assam; and in west-central India, seven sites within the Chindwara District of Madhya Pradesh, plus 79 sites within Amravati, Aurangabad, Nagpur, Jalna, Parbhani, and Nanded of Maharashtra (Srivastava *et al.* 2007). The most important criterion of orchard selection was orchard age with peak efficiency in production. Orchard age varied between 15 and 25 years in north-eastern India for 'Khasi' Mandarin site and 12 to 20 years in central India for 'Nagpur' Mandarin site. Within the representative physiographic positions of both citrus regions, the orchards were further selected to represent low, optimum, and high-performance orchards. The DRIS model was used to determine the nutrient standards for leaves. Findings found a significant variation in the standard values of the leaf nutrients depending on the cultivar type (Table 1).

Table 1: The concentration of leaf nutrient for different citrus cultivars of India

Indices					
	Deficient	Low	Optimum	High	Excess
Nagpur mandarin (*Citrus reticulata* Blanco)					
N, %	< 1.1	1.1 - 1.7	1.7 - 2.8	2.8 - 3.4	> 3.4
P, %	< 0.06	0.06 - 0.08	0.08 - 0.15	0.15 - 0.19	> 0.19
K %	<0.22	022-1.01	1.01 - 2.59	2.59 - 3.38	> 3.38
Ca, %	< 1.1	1.1 - 1.79	1.79 - 3.28	3.28 - 4.02	> 4.02
Mg, %	< 0.31	0.31 - 0.42	0.42 - 0.92	0.92 - 1.38	> 1.38
Fe, ppm	< 55	55 - 75	75 - 113	113 - 133	> 133
Cu, ppm	< 5.9	5.9 - 9.7	9.8 – 18	18 - 22	> 22
Mn, ppm	< 40	40 - 55	55 – 85	85 - 99	> 99
Zn, ppm	< 5.5	5.5 – 14	14 – 30	30 - 38	> 38
Yield, kg/tree	< 13	13 - 48	48 – 117	117 - 152	> 152
Mosambisweet orange (*Citrus sinensis* Osbeck)					
N, %	< 1.28	1.28 - 1.97	1.97 - 2.57	2.57 - 2.68	> 2.68
P, %	< 0.05	0.05 - 0.09	0.09 - 0.17	0.17 - 0.21	> 0.21
K %	< 1.12	1.12 - 1.32	1.32 - 1.72	1.72 - 1.92	> 1.92
Ca, %	< 1.09	1.09 - 1.72	1.72 - 2.98	2.98 - 3.62	> 3.62
Mg, %	< 0.13	0.13 - 0.31	0.31 - 0.69	0.69 - 0.87	> 0.87
Fe, ppm	< 26	26 - 69	69 – 137	137 - 200	> 200
Mn, ppm	< 30	30 - 42	42 – 87	87 - 160	> 160
Zn, ppm	< 9.0	9.0 - 12	12 – 29	29 - 37	> 37
Cu, ppm	< 2.0	2.0 - 6.5	6.5 – 16	16 - 20	> 20
Mo, ppm	< 0.3	0.3 - 0.4	0.4 - 1.1	1.1 - 1.5	> 1.5
B, ppm	< 7.8	7.8 - 13	13 – 23	23 - 44	> 44
Yield, kg/tree	< 46	46 - 76	76 – 138	138 - 168	> 168
Khasi mandarin (*Citrus reticulata* Blanco)					
N, %	< 1.67	1.67 - 1.96	1.96 - 2.56	2.56 - 2.85	> 2.85
P, %	< 0.06	0.06 - 0.08	0.08 - 0.10	0.10 - 0.13	> 0.13
K %	< 0.52	0.52 - 0.98	0.98 - 1.93	1.93 - 2.40	> 2.40
Ca, %	< 1.72	1.72 - 1.96	1.96 - 2.49	2.49 - 2.75	> 2.75
Mg, %	< 0.14	0.14 - 0.23	0.23 - 0.48	0.48 - 0.54	> 0.54
Fe, ppm	< 23	23 - 84	84 – 249	249 - 331	> 331
Cu, ppm	< 1.8	1.8 - 2.1	2.1 – 14	14 - 21	> 21
Mn, ppm	< 19	19 - 42	42 – 88	88 - 111	> 111
Zn, ppm	< 11	11 - 16	16 – 27	27 - 32	> 32
Mo, ppm	< 0.3	0.3 - 0.4	0.4 - 1.1	1.1 - 1.5	> 1.5
B, ppm	< 7.8	7.8 - 13	13 – 23	23 - 44	> 44
Yield, kg/tree	< 19	19 - 32	32 – 56	56 - 69	> 69

Source: Srivastava et al. (2007), Srivastava and Singh (2008 a; 2008b; 2008c)

Examples of most appropriate index leaf sampling were observed at Ambia flush (February flower) 6 to 8 months of leaf age on Typic Haplustert soils (deep black soil), and the Mrig flush (July bloom) 5 to 7 months on Typic Ustochrept soils (shallow red soil). Generally, the leaves of the fruiting terminals had lower N, P, K, Zn, Mn, Fe, Cu and B, but higher Ca and Mg than those of the non-fruiting terminals leaves (Huchche*et al.*, 1999; Srivastava *et al.*, 1994). This study shows a lack of variation in the macro- and micronutrient status of the leaf by collecting 30-70 leaves as sample size concerning deficiencies of N, P, Zn and K. It has come to notice that Khasi mandarin orchards show deficiencies in Zn, P, Ca, Mg, N, and Cu and in Nagpur mandarin orchards showed deficiencies in Zn, P, N, and Fe (Table 2).

Table 2: Leaf nutrients limitations in citrus orchards of India

Nagpur mandarin	Deficient and low nutrients (n=27)					High and excess nutrients(n=30)					Yield kg/tree
	Zn	P	N	Fe	Cu	Mn	Mg	K	Ca		
DRIS indices	-166	-60	-28	-20	16	42	55	63	98		32
Conc., mg/kg[1]	9.2	0.06	1.56	68.3	19.2	91.6	0.92	2.62	3.34		
Mosambi Sweet orange	Deficient and low utrients(n=32)					High and excess nutrients (n=28)					Yield kg/tree
	N	Zn	K	P	Mg	B	Ca	Mo	Fe	Cu	
DRIS indices	-185	-111	-82	-58	38	40	48	74	92	144	39
Conc., mg/kg[1]	1.28	9.1	1.14	0.08	0.70	28.2	3.01	11	138.1	18.1	
Khasi mandarin	Deficient and low nutrients(n=68)						High and excess nutrients(n=40)				Yield kg/tree
	Zn	P	Ca	N	Mg	Cu	K	Mn	Fe		
DRIS indices	-201	-101	-91	-86	-78	-42	104	219	276		22
Conc., mg/kg[1]	10.5	0.06	1.66	1.60	0.18	1.9	-	-	-		

1 N, P, K, Ca, and Mg values are indicated in %

Source: Srivastava *et al.* (2007), Srivastava and Singh (2005, 2006)

DRIS predicted that the optimum value of various leaf nutrients such as N, P, K, Ca, Mg, Fe, Mn, Cu and Zn for Khasi mandarin as 1.86-2.62%, 0.08-0.10%, 0.89-1.86%, 1.62-2.12%, 0.40-0.50%, 119.4-219.4 ppm, 58.7-84.7 ppm, 2.2-3.3 ppm and 20.8-29.8 ppm, respectively, concerning a yield from 28.2-49.6 kg/tree. DRIS has also diagnosed that there were nutrients constraints of N, P, Ca, Mg, Cu_4 and Zn (Fig.1). Various nutrients in the increasing order are shown as Zn<P<Ca<Mg<N<K<Fe<Mn<Cu (Sarangthem*et al.,* 2013).

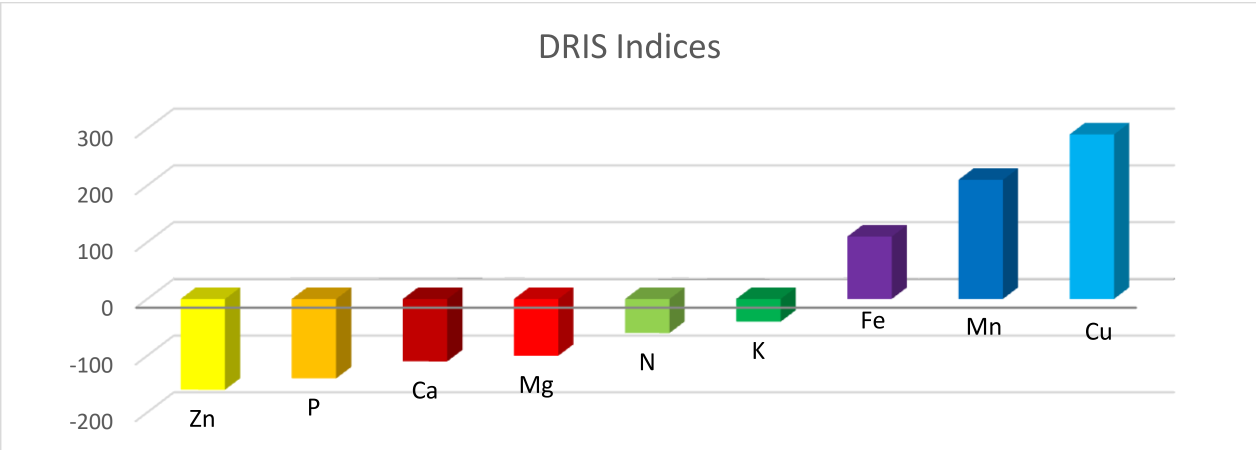

Fig. 1: Identification of nutrient limitations in Khasi mandarin through leaf-based DRIS analysis
Source: Sarangthem*et al.* (2013)

SOIL ANALTSIS-BASED NUTRIENT CONSTRAINTS DIAGNOSIS

Continuous application of fertilizers in the soilfails to sustain theexpected yield due to loss of soil fertility (Srivastava and Singh 2009; Gupta and Srivastava, 2010). Under such circumstances, serious questions arise about the sustainability of crop production owing to multiple nutrient deficiencies (Srivastava and Singh, 2001a). To sustain the soil health by applying optimum nutrientsand soil microbial biomass, invited an extensive study in the past to overcome fertilizer application related yield constraints, particularly on nutrient-deprived soils (Srivastava and Singh, 2004a). It is well known that organic manure is involved in the improvement of soil microbe's buildup and nutrient cycle (Srivastava, 2009). Shifting of fertilization from inorganic to organic gradually L.

paved the way to increase geo-biochemical nutrient cycle (Srivastava and Singh, 2008b). Among the limitations that impair sustainable citrus production, management of nutrient is considered to be the most important and possible approaches to meet the nutrient requirements of crop. Integrated Nutrient Management strategy has undeniably proven its effectiveness in producing crops of high quality and soil health index improvements (Srivastava, 2009). A characteristic feature of the un precedented decline in the productivity of the orchards is seen when the orchards exceed 15 years of age (Huchche*et al.* 2010). Soil nutrient reserve is the most important contributing factor.Soil total carbon, i.e. organic carbon and inorganic carbon, plays a vital role in converting the nutrients into their available form and consequently the result of which will be seen on the performance of the crop.Therefore, in the light of the primary function of soil organic carbon and soil inorganic carbon in maintaining lasting productivity, in view of the above findings, the study was conducted to reserve total carbon (organic and inorganic –Carbon) of the surface soils as well as thesub-surface soils apart fromdifferent nutrients and their correlations with the yield of sweet orange orchard (Srivastava and Singh, 2003).

The average total carbon content ranged between 8.00 g kg^{-1} and 28.70 g kg^{-1} in the surface soil and between 8.60 g kg^{-1} and 31.70 g kg^{-1} in the subsurface soil. A broad range of the available nutrients such as N, P, K, Fe, Zn, Mn, B and Mo are 86.7-202.4 mg kg^{-1}, 5.9-16.8 mg kg^{-1}, 173.4 - 403.2 mg kg^{-1}, 4.3 - 21.7 mg kg^{-1}, 0.34 - 1.17 mg kg^{-1}, 4.6 - 16.7 mg kg^{-1}, 0.32 - 0.68 mg kg^{-1}, and 0.06 - 0.18 mg $kg^{-1,}$ respectively, witha fruit yields between 40.3 and 147.1 $kgtree^{-1}$. Fruit yields had a significant positive correlation with the available nutrients such as nitrogen (r= 0.952, P=0.01), manganese (r= 0.386, P= 0.01), iron (r= 0.448, P= 0.05), and boron (r= 0.582, P= 0.01). However, the fruit yield has the highest degree of relationship with organic carbon (r= 0.986, P= 0.01), but inorganic carbon has a lesser degree of relationship with fruit yield (Srivastava *et al.*, 2001). However, the study suggests that total carbon is the superior parameter governing the productivity of orchards. A significant relationship between total carbon and fruit yield were observed particularly at surface soils (0-15 cm) than in subsurface soils (15-30 cm) of the orchards.High yielding sweet orange orchards with a yield between 74.8 and 147.1 $kgtree^{-1}$possessed available nitrogen between 123.3 and 166.1, available phosphorus between10.7 and 13.7, available potassium between 224.0 and 288.4, available iron between 6.4 and 15.6, available boron between 0.90 and 1.17, available manganese between14.9 and 16.7, available molybdenum between 0.08 and 0.12 $mgkg^{-1}$, organic carbon between 5.5 and 7.8 gkg^{-1}, and inorganiccarbon between 11.7 and 22.6 gkg^{-1} (Srivastava*etal*., 2008). Srivastava (2023) studied different treatments of organic manuring to ascertain the variations in soil organic carbon status.In the first 5 years, the maximum upsurge in soil organic carbon status was produced by the treatment effect of green manure (0.28%), vermicompost, poultry manure along with inorganic fertilizers (0.18%). Continuous use of inorganic fertilizers has many harmful implications on the status of soil organic carbon and thereby causing serious implications on the quality of the soil (Huchche*et al.*, 1998; Srivastava and Bora, 2023).Srivastava and Singh (2008a) studied on soil properties and orchard efficiency of Nagpur mandarin, which is grown on Vertisols, Inceptisols and Entisols within eighteen orchard growing belts of Central India.Models were developed by following the steps of multivariate quadratic regression to find out the thres hold limits of soil properties such as: clay~ 418.1 gkg^{-1} (Y= 60.74 + 51.47cos (0.0098x + 2.91)), water-soluble Ca^{2+}~149.9 mgl^{-1} ($Y = -138.63 + 6.54x - 0.085x^2 + 0.0004x^3 - 0.00007x^4$), free $CaCO_3$~132.1 gkg^{-1} (Y = 43.47 + 26.65cos (0.027x – 3.24)), exchangeable Ca^{2+}~25.9 Cmol $(p^+)kg^{-1}$(Y = 52.15 exp. ((-(29.87 – $x)^2$)/(2 x $^{9.222}$)), available phosphorus~12.8 $mgkg^{-1}$ (Y = 46.09/(1+389.29exp.(-0.94x), available nitrogen~114.6 $mgkg^{-1}$ (Y = 593.96 + 15.49x + 0.14 ($x^2 - 0.0003x^3$), and available zinc~ 0.96 $mgkg^{-1}$ (Y = 56.09 – 34.02 exp. (-3.35 $x^{5.83}$) concerning 82.1% optimum orchard efficiency (Huchche*et al.*, 20).

The method of soil testing is based on how thenutrientsare extracted from the soil by the roots as the way that is done by chemical extractants of the soil and therefore there is a clear relationship amongst the extractable soil nutrients and absorption of nutrients from the soil by plants. One major shortcoming of this strategy is that it must be precise to a soil type as well as modifying the recommendations concerning the targeted productivity (Srivastava and Singh, 2001c; Srivastava *et al.* 2001). Depletion of nutrients from the soil hasaserious impact on both quality and fruit production. Without a detailed fertility evaluation of both soil and cropmay lead to either over fertilization or under fertilization with unbalanced efficiency of fertilizer application (Srivastava *et al.* 2008; Srivastava and Singh, 2001b). Diagnosis and Recommendation Integrated System developed a variant fertility rating for a diverse cultivar of citrus which isgrown in different types of soils. Differential soil fertility criteria have been developed using a software-based analysis method known as the Diagnosis and Recommendation Integrated System (DRIS) for a variety of citrus cultivars grown in contrasting mineralogical buildup soils. For example, Nagpur mandarin, Mosambi and sweet orange grew on soils rich in smectite in central India, Khasi' mandarin grown in kaolinitic-illitic soils in northeast India and Kinnow' mandarin in illitic soils. Fruit yields have further validated such fertility levels from high-performance orchards, and innovative field-based studies focused on the nutrient response (Srivastava and Singh, 2002; 2003; 2008b; 2009).

In order to establish a multi-tier model of soil fertility assessment, a correlation study was undertaken between fruit yield and various nutrients.The yield correlates mainly with nitrogen (r=0.532, P=0.01), potassium (r=0.389, P=0.05), phosphorus (r=0.412, P=0.01), manganese (r=0.489, P=0.01), zinc (r=0.532, P=0.01), and iron (r=0.508, P=0.01). Comparably, soil enzymes viz., dehydrogenase (r = 789, P = 0.05), alkaline phosphatase (r = 782, P = 0.01) and urease (r = 0.712, P = 0.01), correlates directly with fruit yields. (Srivastava *et al.*, 2010).4In Manipur, DRIS predicted that the optimum value of various available soil nutrients such as N, P, K, Ca, Mg, Fe, Mn, Cu and Zn for Khasi mandarin as 142.4-222.3 %, 5.9-8.2%, 110.5-270.3%, 152.4-281.3%, 28.3-79.4%, 32.4-49.2 ppm, 26.6-41.1 ppm, 0.89-1.4 ppm and 1.2-2.4 ppm respectively concerning a yield from 28.2-49.6 kg/tree (Fig. 2). Various nutrients in the increasing order are shown as Ca < Mg < P < Zn < N < K < Cu < Mn < Fe (Sarangthem*et al.*, 2013). Srivastava *et al.* (2008) and Srivastava and Singh (2003) surveyed 41 citrus orchard-growing states during 2002-05, including 55 sites in the north-eastern states of Arunachal Pradesh, Tripura, Mizoram, Nagaland, Manipur, West Bengal, Sikkim, Meghalaya, and Assam; and in west-central India, seven sites within the Chindwara District of Madhya Pradesh, plus 79 sites within Amravati, Aurangabad, Nagpur, Jalna, Parbhani, and Nanded of Maharashtra. Comparative DRIS soil data analysis ascertained a much broader range of index values among the various commercial citrus cultivars (Table 4). DRIS predicted that the optimum value of various available soil nutrients for Nagpurmandarin are in the order: organic carbon < Zn <P <Fe <K. Using the progressive nutrient diagnosis, if organic carbon is corrected by supplying organic manures, the rest of the limiting nutrient has to be corrected by applying the specific fertilizer. There was a shortage of organic C, N, Zn, P, Mn, and K in sweet orange and Khasi mandarin orchards lacked P, Ca, N, Mg, and Zn.

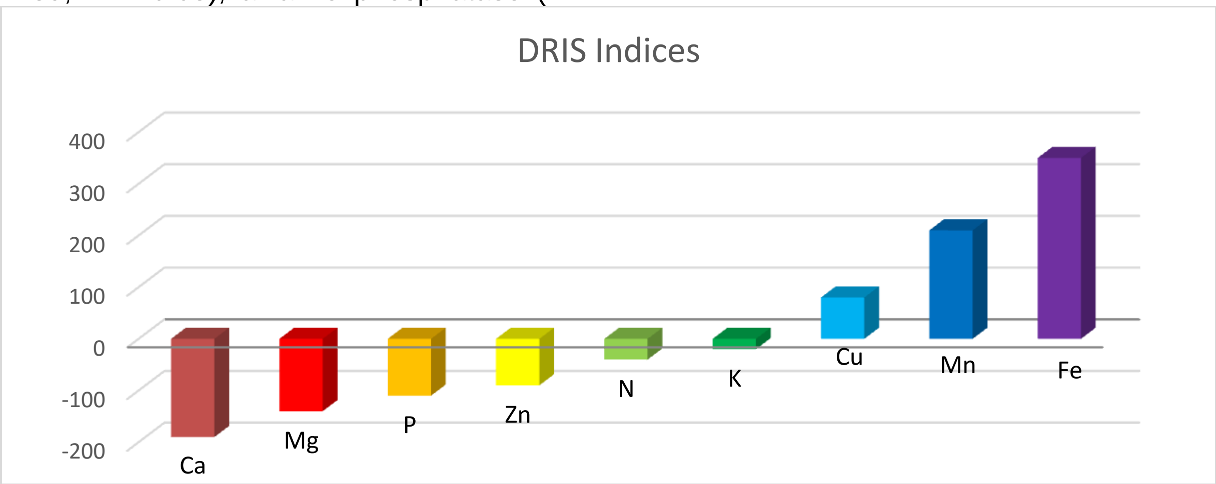

Fig. 2: Identification of nutrient limitations in Khasi mandarin through soil-based DRIS analysis
Source: Sarangthem*et al.* (2013)

SOIL FERTILIZATION

An experiment was conducted on atwelve-year-old Nagpur mandarin between 2004 and 07 to study the comparison between soil application and foliar application of zinc. Zinc is applied at 100 g tree^{-1}, 200 g tree^{-1} and 300 g tree^{-1} with same doses of nitrogen @ 600 g tree^{-1}, phosphorus @ 200 g tree^{-1}, potassium @ 300 g tree^{-1}, and iron @ 60 g tree^{-1}on Haplustert soil in order the determine the intensity of flowering, changes in available soil nutrients, changes in nutrient concentration of the leaf, quality of fruit, fruit setting, tree size, yield and zinc fractions transformation in the soil. Incorporation of zinc in the soils at three doses, as mentioned above, make an increase in tree size, flowering intensity, fruit set intensity against the foliar application of comparable doses.

Table 3: Norms for soil fertility in relation to various Indian citrus cultivars

	Deficient	Low	Optimum	High	Excess
	Nagpur mandarin (*Citrus reticulata* Blanco)				
Organic C, g/kg	< 2.6	2.6 - 3.8	3.8 - 6.2	6.2 - 7.4	> 7.4
N, mg/kg	< 65	65 - 95	95 – 155	155 - 185	> 185
P, mg/kg	< 4.8	4.8 - 6.5	6.5 – 16	16 - 21	> 21
K mg/kg	< 64	64 - 147	147 - 312	312 -395	> 395
Ca, mg/kg	< 306	306 - 408	408 - 616	616 - 718	> 718
Mg, mg/kg	< 43	43 - 85	85 – 163	163 - 203	> 203
Fe, mg/kg	< 4.6	4.6 -11	11 – 25	25 - 41	> 41
Mn, mg/kg	< 4.7	4.7 - 7.4	7.5 – 23	23 - 31	> 31
Zn, mg/kg	< 0.3	0.3 - 0.6	0.6 -1.3	1.3 -1.7	> 1.7
Cu, mg/kg	< 1.1	1.1 - 2.4	2.4 - 5.1	5.1 - 6.5	> 6.5
Yield, kg/tree	< 13	13 - 48	48 – 117	117 - 152	> 152
	Mosambi Sweet orange (*Citrus sinensis* Osbeck)				
Organic C, g/kg	< 3.0	3.0 - 4.9	4.9 - 6.9	7.0 - 8.2	> 8.2
N, mg/kg	< 62	62 - 107	107 - 197	197 - 242	> 242
P, mg/kg	< 4.9	4.9 - 8.5	8.5 – 16	16 - 20	> 20
K mg/kg	< 85	85 - 186	186 - 389	389 - 491	> 491
Fe, mg/kg	< 1.6	1.6 - 4.7	4.7 – 17	17 - 24	> 24
Mn, mg/kg	< 3.7	3.7 - 7.6	7.6 – 16	16 - 20	> 20
Cu, mg/kg	< 0.3	0.3 - 1.8	1.8 - 4.7	4.7 - 6.2	> 6.2
Zn, mg/kg	< 0.1	0.1 - 0.4	0.4 - 1.0	1.0 - 1.3	> 1.3
Mo, mg/kg	< 0.05	0.05 - 0.1	0.1 - 0.16	0.17 - 0.19	> 0.2
B, mg/kg	< 0.2	0.2 - 0.3	0.3 - 0.6	0.6 - 0.7	> 0.7
Yield, kg/tree	< 46	46 - 76	76 – 138	138 - 168	> 168
	Khasi mandarin (*Citrus reticulata* Blanco)				
Organic C, g/kg	< 8.6	8.6 - 15.6	15.6 - 32.5	32.5 - 50.2	> 50.2
N, mg/kg	< 82	82 - 161	161 – 419	419 - 548	> 548
P, mg/kg	< 2.3	2.3 - 4.4	4.5 - 8.7	8.8 - 11	> 11
K mg/kg	< 20	20 - 82	82 – 288	288 - 390	> 390
Ca, mg/kg	< 80	80 - 149	149 – 285	285 - 354	> 354
Mg, mg/kg	< 4.7	4.7 - 31	31 – 84	84 - 111	> 111
Fe, mg/kg	< 31	31 - 39	39 – 181	181 - 252	> 252
Mn, mg/kg	< 8.9	8.9 - 27	27 – 80	80 - 116	> 116
Zn, mg/kg	< 2.2	2.2 - 2.8	2.8 - 5.1	5.1 - 8.7	> 8.7
Cu, mg/kg	< 0.5	0.5 - 0.7	0.7 - 2.9	2.9 - 4.1	> 4.1
Yield, kg/tree	< 19	19 - 32	32 – 56	56 - 69	> 69

Source: Srivastava et al. (2007), Srivastva and singh (2008a; 2008b; 2008c)

The study concludes that incorporation of zinc in the soils at three doses give the optimal conditions for the parameters which contribute to the fruit yield. Soil application of zinc further improves the quality of fruits such as acidity, juice and soluble solids concentrations. The study further highlighted the superiority of zinc application in soil than foliar application concerning the enhancement in Zn fractions of the soil. The enhancement in the zinc fractions such as exchangeable zinc, organically bound zinc, complex zinc, carbonates and acid-soluble minerals zinc with a value between 0.25 mg kg^{-1} and 0.60 mg kg^{-1}, between 0.86 mg kg^{-1} and 2.0 mg kg^{-1}, between 2.71mg kg^{-1} and 4.86 mg kg^{-1} and between 2.56 mg kg^{-1} and 4.96 mg kg^{-1} respectively concerning zinc application with T_1 to T_3 treatments (Srivastava *et al.*, 2008; Srivastava and Malhotra, 2017).

Table 4: Soil nutrient limitationson India's citrus orchards

Nagpur mandarin	Deficient and low nutrients(n=27)					High and excess nutrients (n=30)					Yield Kg/tree
	Org. C	Zn	P	Fe	K	Mg	Ca	Cu	pH	Mn	32
DRIS indices	-116	-104	-98	-92	-52	61	72	81	108	155	
Conc., mg/kg[1]	3.2	0.31	5.0	4.8	143	172	678	5.8	7.9	22.8	
Mosambi Sweet orange	Deficient and low nutrients(n=32)					High and excess nutrients (n=28)					YieldKg/tree
	Org. C	N	Zn	P	Mn	K	Fe	Cu	Mo	B	
DRIS indices	-181	-106	-90	-72	-51	-21	61	89	162	209	39
Conc., mg/kg[1]	4.1	106.8	0.38	7.8	6.2	183	22.8	5.8	0.19	0.60	
Khasi mandarin	Deficient and low nutrients(n=68)					High and excess nutrients (n=40)					YieldKg/tree
	P	Ca	N	Mg	Zn	Org. C	K	Cu	Mn	Fe	
DRIS indices	-110	-82	-78	-58	-49	58	62	70	78	109	22
Conc., mg/kg[1]	3.1	78	152	4.7	2.1	38.6	289	0.9	91	249	

1 N, P, K, Ca, and Mg values are indicated in %.andOrganic Carbon in gkg^{-1}

Source: Srivastava et al. (2007), Srivastva and Singh (2003)

Application of nitrogen @ 1200 g, phosphorus @ 600 g, potassium @ 600 g, zinc sulphate @ 300 g, manganese sulphate @ 300 g and borax @ 100 g $tree^{-1}$is the finest treatments that improve the nutrient concentration of the leaf, quality of fruit and yield on Ustorthent soil type. Where as application of nitrogen @ 600 g, phosphorus @ 400 g, potassium @ 300 g, zinc sulphate @ 300 g, manganese sulphate @ 300 g, borax @ 100 g $tree^{-1}$ along with magnesium sulphate @ 400 g $tree^{-1}$ has proven to be the best treatments for Typic Haplustert soil type. Application of higher quantity of potassium @ 900 g $tree^{-1}$ along with nitrogen @ 600 g and phosphorus @ 400 g is more effective than application of potassium @ 900 g $tree^{-1}$ along with nitrogen @ 1200 g and phosphorus @ 600 g on Typic Haplustert soil type (Srivastava *et al.*, 2006).In various agro-climate regions, the nutrient fertilization response is well-known for theimprovement of growth, yield and fruit quality of citrus (Table 5) showing alarge variation on account of tee age,spacing, soil type, agroclimate, seedlings origin (if any), root stock-scion combnation, flat bed planting versus arised bed planting, irrigated versusu rainfed, hill farming or plai land orchard etc.

FOLIAR APPLICATION OF NUTRIENTS

Application of fertilizer on foliarshows a better result thanthe use of traditional soil fertilizer application in the following cases: i) soils with severe nutrient deficiency, ii) Poor soil conditions, iii) imbalances of the soil nutrients hinders absorption of nutrients by the rootand iv) restricted intake of nutrients by plant roots. Orchards of twelve years old having deficiency in N, P, Fe and Zn were examined between the year 2004 and 2007 to study the comparison between soil application and foliar application of iron with an equal dose of N @ 100 g $tree^{-1}$, P @ 200 g $tree^{-1}$ and K @ 300 g $tree^{-1}$.All the treatments are provided with the basal doses of nitrogen, phosphorus, potassium and ironevenly (Srivastava and Singh, 2004b). Comparing the soil application of $FeSO_4$ (SA_{100}, SA_{200} and SA_{300}) with the foliar application of $FeSO_4$ (FA_{100}, FA_{200} and FA_{300}), foliar application of $FeSO_4$ @ 200 g $tree^{-1}year^{-1}$ (T5) is proved to be the best foliar treatmentsconcerning different parameters viz., flowering intensity, fruit yield, soil fertility changes, fruit set, tree volume, the nutrient concentration of leafandquality of fruit.

Table 5: Recommendations on macronutrients for specific citrus cultivars in India (based on multiple sources)

Cultivar sp.	Doses of application
Kinnow mandarin	100 g N- 25g P_2O_5-50 g K_2O tree^{-1}
Kinnow mandarin	800 g N- 200g P_2O_5-400 g K_2O tree^{-1}
Kinnow mandarin	600 g N- 200 g P_2O_5-200 g K/tree (soil application)-0.4 % Cu-0.5 % Zn (Foliar Spray)
Kinnow mandarin	1 kg N- 0.5 kg P-0.5 kg K tree^{-1}
Khasi mandarin	300 g N- 250 g P_2O_5-300 g K_2O tree^{-1}
Khasi mandarin	600 g N- 300 g P_2O_5-600 g K_2O tree^{-1}
Coorg mandarin	250 g N- 250 g P_2O_5-500 g K_2O tree^{-1}
Nagpur mandarin	800 g N- 300 g P_2O_5-600 g K_2O tree^{-1}
Nagpur mandarin	600 g N- 200 g P_2O_5-100 g K_2O tree^{-1}
Limes and lemons	
Lemon	500 g N- 250 g K_2O tree^{-1}
Acid lime	800 g N- 200 g P_2O_5-100 g K_2O tree^{-1}
Acid lime	600 g N- 200 g P_2O_5-300 g K_2O tree^{-1}
Acid lime	1.4 g N- 1.08 g P-1.1 kg K tree^{-1}
Acid lime	600 g N- 300 g P_2O_5-300 g K_2O tree^{-1}
	Sweet oranges
Sweet orange Mosambi	N (1200 g tree^{-1}), (400-800 g tree^{-1})
Sweet orange	2.72 kg N- 1.81 kg P- 0.60 kg K tree^{-1}
Sweet orange	500 g N- 100 g P_2O_5-400 g K_2O tree^{-1}
Sweet orange	900 g N- 300 g P_2O_5-300 g K_2O tree^{-1}

Source: Srivastava and Singh (2008)

Application of combined T_7- $FeSO_4$ @ 200 g tree^{-1}year^{-1} and FYM @ 10 kg tree^{-1}year^{-1}proved better than T5 which ultimately show the supremacy of T_7 over T_5. Three iron fractions in soil namely, 1) water-soluble iron, 2) exchangeable iron, and 3) complex ironare the main source of Fe to sustain Nagpur mandarin (Srivastava and Singh, 2004b). Micronutrient foliar sprays are more common, and therefore often used. There is a vast difference in the foliar recommendation for micronutrient chelates. Asferrous sulfate ($FeSO_4$) @ 0.25% + copper sulfate ($CuSO_4$) @ 0.25% + $ZnSO_4$ @ 0.5% is sprayed on Coorg mandarin (Desai *et al.* 1991), $ZnSO_4$ @ 0.60 g/l + $MnSO_4$ @ 1.2 g/l are sprayed on Valencia orange (Garcia-Alverez *et al.* 1986), Zn-EDTA @ 0.4% + Cu-EDTA @ 0.2% are sprayed on Kinnowmandarin (Sharma *et al.* 1999). Specific recommendations resulting from the foliar application of nutrients to citrus cultivars indicate more studies of Kinnowmandarin grown in Haryana and Punjab as compared to most other cultivars due to soil associated problems including other cultivars (Table 6).

Table 6: Foliar spray recommendations of various micronutrients in Indian citrus (based on multiple sources)

Cultivar sp.	Foliar spray details
Kinnow mandarin	$ZnSO_4$ (0.1%) – $CuSO_4$ (0.1%)
Kinnow mandarin	$ZnSO_4$ (0.5%) – $CuSO_4$ (0.25%)
Kinnow mandarin	$ZnSO_4$ (0.1%), (0.6%)
Kinnow mandarin	$ZnSO_4$ (0.5%) – $CuSO_4$ (0.3%)- Borax (0.3%)
Kinnow mandarin	Zn-EDTA (0.4%)- Cu- EDTA (0.2 %)
Kinnow mandarin	B (0.2-0.4 %), (0.6 %)
Kinnow mandarin	$ZnSO_4$ -$CuSO_4$ (2 g/l each)
Coorg mandarin	$MnSO_4$- $ZnSO_4$ (2.3 kg/100 gallon)
Wilking mandarin	Zn-Cu-K (0.25% each)
Limes and lemons	
Acid lime	Fe-Zn (0.5% each, 4 sprays)
Kagzi lime	$ZnSO_4$ (0.5%)-K_2SO_4 (4%)
Kagzi lime	$ZnSO_4$ (0.6%)- 200 ppm 2,4-D
Kagzi lime	$ZnSO_4$ (0.5%)- urea (1.5%)
Kagzi lime	Borax (0.2-0.6%)
Sweet orange	
Mosambi sweet orange	-$FeSO_4$ (0.25%)--$MnSO_4$(0.05%)--$CuSO_4$(0.25%)- $ZnSO_4$(0.05%)-$MgSO_4$(0.05)
Sweet orange	-$ZnSO_4$ (0.3%)- $CuSO_4$ (0.6%)
Mosambi sweet orange	- $ZnSO_4$ (0.5 each)- urea (1%)
Sweet orange	- $ZnSO_4$ (0.5%)- B (0.2%)- Fe (0.4%)
Sweet orange	-Fe (2.2-4.4mg/l)- Mn (0.22-0.44 mg/l) + B (1.0-3.0 ppm)- urea (2.7 kg/100 gallon)
Sweet orange var Blood Red	-Fe-Mn-Zn (0.5% each)
Succary and Balady orange	$ZnSO_4$ (300 ppm)- $CuSO_4$ (250 ppm)

DEVELOPMENTS IN FERTIGATION RESEARCH

Judicious use of water and optimum fertilization at an appropriate time are the factors for higher production of citrus (Shirgure*et al.* 2000; 2001c; 2001b).Fertigation is a method of fertilizer applications in which the fertilizers i. e. Water-soluble fertilizers and liquid fertilizers are applied through irrigation water to reach each plant regularly and uniformly. Generally, fertigation is done on a weekly/monthlybasis in areas having inadequate water reserve and scarce rainfall, fertigation is the best way to provide nutrients in the root area of acid lime (Shirgure*et al.*2002; 2003a; 2003b). Fertigation has many benefits such as increasing the efficiency of fertilizer usage, ensuring water and nutrient supply, human resource-saving and improving production, yield and quality.Fertigation (nutrient application through irrigation) has shownitimprove tree growth, quality, yield, soil nutrient reserve and, lastly enhanced nutritional status of plant (Shirgure*et al.*, 2001b).

Shirgure*et al.* (2001c) made a comparison between nitrogen fertigation and circular band placement on acid lime and reported that nitrogen fertigation showed superior results over circular band placement. It was also reported that fertigation @ 80 percent N has a high leaf nutrient concentration, i.e.N, P, and K over circular band placement @ 100 percent N. Further it saves 20 percent of N through fertigation. Garcia-Petillo (2000) conducted a comparative study between fertigation and traditional methods of fertilizer application and revealed that fertigated trees have a higher yield (64 percent) with higher nitrogen concentration in leaf (50 percent) over traditional fertilizer application. It is evident from the above studies that fertigation is much superior as compared to the traditional basin or broadcast application of fertilizer in flood irrigation.

Fertilizer use efficiency (FUE) and Low water use (WUE) efficiency of fertilizer use (FUE) are among the major constraints related to production (Srivastava and Singh 2003a). Basin irrigation is commonly used in citrus orchards, with several disadvantages in terms of transport, percolation, evaporation and loss of distribution, but without significant adverse effects on yield, growth and quality of fruit (Shirgure*et al.* 2001a; 2001b). Micro-irrigation has gained widespread application in citrus orchards in light of growing water scarcity and poor WUE under basin irrigation.Any irrigation method capable of supplying evapotranspiration demand for plants and at the same time keeping the soil moisture content within the desired limits during different ontogenic phases would ensure the sustainability of the production of the citrus orchard, in addition to a long productive life for orchards.Nagpur mandarin fruit yield on vertic Ustochrepts with different micro-irrigation systems was significantly higher (48.2-58.9 kg tree^{-1}) than basin irrigation (32.3 kg tree^{-1}) with corresponding WUE of 0.19-0.24 versus 0.109 tonnes/ha/cm and leaf N content of 2.38-2.42 per cent versus 2.01-2.12 per cent (Shigure*et al.*, 2001c; 2003a).

In Central India (dry sub-humid tropical climate), irrigation @ 20 % depletion of available water content is considered as optimumandN @ 500 g — P_2O_5@ 140 g — K_2O@ 70 g tree^{-1}year^{-1} was observed as optimum fertilizer requirement especially on alkaline calcareous Lithic Ustochrept. Fertigationaids in reducing the fertilizer requirement by 33% and water by 40% (Shirgure*et al.*, 2003; Srivastava *et al.*, 2003). In 14-year-old Nagpur mandarin (*Citrus reticulata* Blanco) irrigation @ 20% depletion of the available water content is considered as optimumand N@ 400 g — P_2O_5@ 140 g — K_2O @ 70 g tree^{-1} year^{-1} was observed as optimum fertilizer requirement which resulted in substantially higher yield (Table 7).

A study on Nagpur mandarin (*C. reticulata*) was performed at NRC's experimental farm for Citrus, Nagpur during 1998-2010. It includes 4 irrigation treatments 1) 10 per cent, 2) 20 per cent, 3) 30 per cent and 40 per cent) depletion of the available water content respectively and 3 fertilizations levels 1) N 600 gplant^{-1}, P 200g plant^{-1} and K 100 g plant^{-1}; 2) and 3) N 400 g plant^{-1}, P 80 g plant^{-1} and K 40 g plant^{-1}. They observed 20 per centavailable water depletion and N 500g plant^{-1}, P 140g plant^{-1} and K 70 g plant^{-1} showed its superiority in enhancing yield, height, TSS, juice content and fruit weightover other treatments (Shirgure*et al.* 2001b).A treatment combination of 30 per cent depletion AWC with N 500g plant^{-1}, P 140g plant^{-1} and K 70 g plant^{-1} influenced positively and enhances juice per cent (42.5%), acidity (7.0%), incremental height (0.40-0.60 m), canopy volume (6.93 m^3) and stock girth (4.07-4.26 cm) in acid lime. Consequently, this treatment combination gave better growth andyield (Shirgureet *al.*, 2003b; 2004b; 2004c).

Table 7: Nagpur mandarin (*Citrus reticulata* Blanco) fertigation schedule under central India's subhumid tropical climate

Month	Crop stage	Micronutrients (g/plant)				Macronutrients (g/plant)		
		$MnSO_4$ (g/plant)	$ZnSO_4$ (g/plant)	$FeSO_4$ (g/plant)	Borax (g/plant)	N (g/plant)	P_2O_5 (g/plant)	K_2O (g/plant)
April	Flush					60		
May-June		Stress period for flowering						
July	Flowering	50	50	50	25	60	30	15
August	Fruit set	50	50	50	25	60	30	15
September	Pea size							
October	Marble size	50	50	50	25	60	30	15
November	Fruit devp.					60	30	15
December	Fruit devp.					60	30	15
January	Fruit devp.					60	30	15
February	Maturity							
March	Color break							
Total		200	200	200	100	480	180	90

Source: Shirgure and Srivastava (2013)

INTEGRATED USAGE OF NUTRIENTS SOURCES

Experimentally, the use of inorganic fertilizers and organic manure is superior over traditional inorganic fertilization. In several trials, for sweet orange- N @ 800 g $tree^{-1}$; P @ 1300 g $tree^{-1}$; K @ 600 g $tree^{-1}$; neem cake @ 15 kg $tree^{-1}$ (Tiwari *et al.* 1997), for Khasi mandarin - N @ 400 g $tree^{-1}$; P @ 150 g $tree^{-1}$; K @ 300 g $tree^{-1}$; FYM @ 25 kg $tree^{-1}$(Ghosh and Besra, 1997), for Meyer lemon-N @150 kg ha^{-1}; P @ 120 kg ha^{-1}; K @ kg ha^{-1}; FYM @ 5 tonnes ha^{-1} (Beridze 444, 1990), for Nagpur mandarin- N @ 600 $gtree^{-1}$; P @ 200 g $tree^{-1}$; K @ 300 g $tree^{-1}$; FYM @ 25 kg $tree^{-1}$ (Huchcheet *al.* 1998). Long-term data on organic and inorganic fertilizer replicates have shown a significant change in soil quality indexes, such as soil microbial diversity, soil microbial nutrients (Cmic, Pmic, Nmic), and organic carbon partitioning but without much differential quantum yield (Srivastava and Ngullie, 2009; Srivastava *et al.,*2010; Srivastava *et al.,* 2015; 2021). Many Actinobacteria produce metabolites with antimicrobial activity which can be explored as a potential alternative to chemical in plant disease management. Moreover, bacterial endophytes have been reported to play a crucial role in bioremediation of organic and inorganic pollutants and promoting plant growth through nutrient enhanced nutrient uptake with rooted background of agroecology (Boraet *al.*, 2019; 2023; 2024). Exploiting citrus-associated microbiomes represents a scientific approach toward sustained and environmentfriendly module of citrus production, though periodically exposed to several threats, with Huanglongbing (HLB) predominantly being most influential (Srivastava et*al,* 2022). Many soil-borne diseases as well as post harvest fungi are effectively addressed through a variety of bioagents belonging to predominant microbial genera represented by Trichoderma spp., Bacillus spp., Gliocadium spp. and fluorescent Pseudomonads (Bora and Bora, 2020;2021; Bora etal., 2024). Development of microbial consortium (microbial concoction), rhizosphere hybridization, identification of microbial corridor and microbial hot spot in a field, besides storing carbon in plant vegetative framework, are some of the upcoming ways to realize the multiple dimensions of agroecology in sustaining the agriculture in years to come with emphasis on on-farm research (Srivastava and Bora, 2023). CLas whole genome sequence is the first report from Northeast India considered being the centre of origin of the genus *Citrus* (Das *et al.*, 2023; Handiqueet *al.*, 2024). This sit e reason, soil health-plant health goes in tandem to ensure as more resilient citrus production system with greater use of microbial antagonists (Nasreen *et al.*, 2020; Saikia *et al.*, 2021).

Dhillon *et al.* (1961) in a study revealed that the combined application of ammonium sulphate and organic manure showed good results in Blood Red Malta sweet orange variety. Reclamation of the soil using dolomite and organic fertilizer proves useful, especially in pummelo Matau Peiya (Chen *et al.* 1997). Ebrahiem and Mohamed (2000) reported that incorporation of FM sugar by-product @ 120 kgtree^{-1} along with nitrogen @ 6.0 kg/tree improves the quality and yield of Balady mandar in Dubey and Yadav (2003) made a comparative study between the treatments, i.e. 1) pig manure @ 110 kg tree^{-1} + Urea-N @750 g tree^{-1}+ MOP @ 650 g tree^{-1} and 2) sole application of pig manure @ 110 kg tree^{-1}in Khasi mandarin. They have witnessed an improvement in yield and lowered fruit drop in the first treatment over the second treatment. But of late, biological control of canker using microbial antagonists alongwith obligate entophytes have shown better results under field conditions (Nasreen *et al.,* 2020). Such attempts would strengthen the outcomes of plant nutrition through plant health resilience.

REMOVAL OF NUTRIENTS

Annually a substantial quantity of nutrients is removed by the citrus fruits. Kohli and Srivastava, (1997), Srivastava and Singh, (2003b) reported that several nutrients in the proportion of N @ 100 kg, P @ 60 kg, K @ 350 kg, S @ 30 kg and Mg @ 40 kg and in other N @ 68 kg, P @ 3.4 kg and K @ 31kg by various cultivars are removed. Labanausk as and Handy (1972) reported that the citrus fruits annually remove nutrients in the proportion of N 55.5 kgha^{-1}, P 51.1 kg ha^{-1}, K 53.7 kg ha^{-1}, S 23.4 kg ha^{-1} and Mg 5.1 kg ha^{-1}with an average yield of 30 tonnes ha^{-1}. Tandon (1987) reported that the citrus fruits annually remove nutrients in the proportion of N 100 kg ha^{-1}, P 60 kg ha^{-1}, K 350 kg ha^{-1}, S 30 kg ha^{-1} and Mg 40 kg ha^{-1} with an average yield of 30 tonnes ha^{-1}.Kohli *et al.* (1997) reported that the citrus fruits annually remove nutrients in the proportion of N 68 kg ha^{-1}, P 3.4 kg ha^{-1} and K 31 kg ha^{-1} with an average yield of 30 tonnes ha^{-1}.

For effective nutrient management in citrus, values developed from soil and leaf analysis should be used as a soil fertility guide. Established DRIS standards in many studies have been observed useful for evaluating crop nutritional imbalances and improving crop productivity. Its verified standards can be used as a basis for calibration and should be subsequently validated by the farmers and organisations involved in the production. Generally, sub-optimal nutrition of micronutrients and particularly zinc is likely to be one of the major nutritional aspects of targeted sustainability in the production of citrus (Srivastava and Pandey, 2021). The citrus decline in any region is due to the lack of knowledge of technology and poor input use also. Although, it is known that the use of mineral fertilizer plays a major role in increasing crop yield, one of the main constraints for crop production is the lack of affordable and sufficient supplies of fertilizer in the experimental area.

FUTURE LINES OF RESEARCH

Amidst these developments, surely a monumental piece of work in citrus at Indian diaspora, a lot more is desired to be addressed. This needs perhaps a more concnerted effort than in the past with introduction of concepts like digital citriculture, precision citriculture and geo-spatial tools driven citrus orchard management. We suggest following future lines researh: i. development of citus cultivar -based soil health card with introduction of soil microbial communities and fruit yield (an interesting issue comes here, whether we need a different soil health card for addressing fruit quality parameters from consumers pont of view so that fresh fruit consumptionmarket is also taken into account); ii. fine tuing of these nutrient standards suitng to regional conditions is mandatory in order to apply these nutrient diagnostics more precisely and percolate these developments down to wire, the end users; iii. need to develop quality index in relation to different commercial citrus cultivars including the peel damage rating and shining index; iv. role nutrient application on post-harvest life o citrus fruits; v. nutrient partitioning as per critical growth stages of citrus cultivars; vi. Fertilizer schedule for rained versus irrigated condition using basin application, drip irrigation,biofertigation, inorganic application, integrated nutrient mode, organic farming, and above all, the nautral farming and later to be linked with good agricultural practices to introduce a concept of crop nutrient holiday using the exploitation of soil legacy nutrients; vii.

need a cultivar specific recommendation for citrus decline; viii. An incisive analysis is further need to have stock on whether or not plant nutrition iscons equetial or inconsequential with respect to surmountng greening disease (huaglongbing) in all citrus regions in India and lastly, all these efforts lead to develop some web -based nutrient expert as a decision support to citrus growers.

REFERENCES

Bhargava, B. S. (2002) Leaf analysis for nutrient diagnosis, recommendation and management in fruit crops. *Journal of the Indian Society of Soil Science* **50**(4): 352-373.

Bora, Popy and L.C. Bora (2020) Disease management in horticulture crops through microbial interventions: An overview. *Indian Journal of Agricultural Sciences* **90** (8): 1389–96.

Bora, Popy and L.C. Bora (2021) Microbial antagonists and botanicals mediated disease management in tea, Camellia sinensis (L.) O. Kuntze: An overview. *Crop Protection*. **148**: 105711.

Bora, Popy, Bora, L.C. and R.P. Bhuyan (2021) Evaluation of botanicals and microbial bioformulations for management of grey blight disease of tea under organic production system. *Indian Journal of Agricultural Sciences*. **91** (1): 54–57.

Bora, P., Gogoi, S., Deshpande, M.V., Garg, P., Bhuyan, R.P., Altaf, N., Saha, N., Borah, S.M., Phukon, M.and N. Tanti, (2023) Rhizospheric *Bacillus* Spp. Exhibit Miticidal Efficacy against *Oligonychuscoffeae* (Acari: Tetrany chidae) of Tea. *Microorganisms* **4** *11*: 2691.

Bora Popy, Saikia, Kakumoni, Hazarkia, Hrishike sh and Ragesh Gavas (2019) Exploring potential of bacterial endophytes in disease management of horticultural crops. *Current Horticulture***7** (1):32-37.4

Bora, P., Saikia, B.,Rahman, M., Ahmed, S. S., Chetia, R., Rahman, N.,Nath, B. C. and W.H. Raja (2024) Enhancing the performance of chilli (*Capsicum annuum*) through twin role of plant growth promotion and disease suppressionvia *Bacillus subtilis*-based bioformulation. *The Indian Journal of Agricultural Sciences*. **94**(1): 039–043.

Dhillon, N. S., Singh K. K. and J.C. Bakshi(1961) The effect of manuring on fruit quality in sweet range. *Punjab Horticulture Journal* **1**: 24-34.

Dubey, A.K. and D.S. Yadav (2003) Response of khasi mandarin (*Citrus reticulate* Blanco) to organic versus inorganic fertilization. *Indian Journal of Agricultural Research* **37**(3): 214-218.

Ghosh, S. P., and K. C. Besra (1997) Growth, yield and physico-chemical properties of sweet orange cv 'mosambi' grown in response to organic and inorganic fertilizers under rainfed laterite soils. In: *National Symposium on Citriculture,* eds. S. Singh, V. J. Shivankar and A. K. Srivastava, pp. 40–44. Nagpur, India: Indian Society of Citiriculture.

Gupta, S.G., Srivastava, A.K., and R.K. Sonkar (2008) Nagpur mandarin evaluation on commercial rootstock in tropical India.*Tropical Agriculture* **85**(4): 1-5.

Handique, M., Bora, P., Ziogas, V., Srivastava, A.K., Jagannadham, P.T.K. and A.K. Das (2024) *Phytophthora* infection reorients the composition of rhizosphericmicrobial assembly in Khasi mandarin (*Citrus reticulata* Blanco). *Agronomy* ***14***: 661.

Huchche, A. D., Ladaniya, M.S., Ram, L., Kohli, R.R. and A. K. Srivastava (1998) Effect of nitrogenous fertilizers and farmyard manure on yield and shelf-life of Nagpur mandarin. *Indian Journal of Horticulture* **55**(2): 108–112.

Huchche, A.D., Ram, L., Srivastava, A.K., Kohli, R. and H. C. Das (1994) Soil-plant nutrient limits inrelation to optimum yield of sweet orange (Citrusinsesnsis Osbeck) cultivar Mosambi. *Indian Journal of Agricultural Sciences*. **73**(4): 209-211.

Huchche, A.D., Ram, L., Srivastava, A.K.,Kohli, R. and H. C. Das (1999) Evaluation of nutritional status of Nagpur mandarin (*Citrus reticulate* Balnco) through foliar sampling. Tropical Agriculture. **72**(6): 93-98. 4.

Huchche, A.D., Srivastava, A.K., Ram, L. and S. Singh (2010) Statistical basis of production sustainability of citrus orchards, *Tropical Agriculture* **7**(1): 1-4.

Ingle, H. V., Kokate, S.S., Athawale, R. B. and S.R. Katole (2002) Effect of foliar application of zinc and iron on growth, yield and quality of acid lime. *Indian Journal of Citriculture* **1**(1): 43-45.

Kohli, R. R. and Srivastava, A. K. (1997) Citrus nutrition- retrospection. *Agricultural Reviews* **18**(2): 128-138.

Kohli, R.R., Srivastava, A.K., Huchche, A.D., Dass, H.C., Ram, Land S. Singh (1998) Diagnosis of leaf nutrient levels for optimum productivity of *Citrus reticulata* Blanco grown in black clay soils under sub-humid tropical climate. *Tropical Agricultural Research and Extension* **1**(2):81-86.

Nasreen Rukshana, Bora Popy and K. K. Medhi (2020) Citrus Canker: Developments down the lane. *Annals of Plant and Soil Research*22(4): 396-404.

Saikia. S., Bora, Popy and L.C. Bora(2021) Bioagent mediated management of citrus canker. *Indian Journal of Agricultural Sciences*. **91** (2): 198–201.

Saranngthem, I., Sharma, L. D. and A.K. Srivastava (2013) Nutrient indexing in Khasi mandarin grown on Indian Alfisols. *Agricultural Advances* **2**(7): 216-223.

Shirgure, P.S. and A.K Srivastava (2013) Plant growth, leaf nutrient status, fruit yield and quality of Nagpur mandarin (*Citrus reticulata* Blanco) as influenced by potassium(K) fertigation with four potash fertilizer source. *Science Journal of Crop Science* **2**: 36-42.

Shirgure, P. S., Srivastava, A. K. and Singh, Shyam (2001 a) Growth, yield and quality of Nagpur mandarin (*Citrus reticulata* Blanco) in relation to irrigation and fertigation. *Indian Journal of Agricultural Science* **71**(8): 547-550.

Shirgure, P. S., Srivastava, A. K. and S. Singh (2001 b) Effect of nitrogen fertigation and band placement fertilizer application in soil-leaf nutrient build-up and incremental growth of acid lime. *Journal of Soil and Water Conservation* **45**(3-4): 176-181.

Shirgure, P. S., Srivastava, A. K. and S. Singh (2001c) Fertigation and drip irrigation in Nagpur mandarin (*Citrus reticulata* Blanco). *South Indian Horticulture* **49-50**: 95-97.

Shirgure, P. S, Srivastava A. K and S. Singh (2002) Economics of drip and fertigation in acid lime orchards.*Journal of Soil and Water Conservation* **46**: 56-60.

Shirgure P. S., Srivastava A.K. and S. Singh (2003a) Evaluating micro-irrigation systems in Nagpur mandarin under subhumid tropical climate.*Tropical Agriculture 80*: 91-96.

Shirgure, P. S., Srivastava A.K. and S. Singh(2003 b) Irrigation scheduling and fertigation in acid lime (*Citrus aurantifolia* Swingle). *Indian Journal of Agricultural Sciences***73**: 363-367.

Shirgure, P. S., Srivastava A.K. and S. Singh (2004a) Growth, yield and quality of acid lime under pan evaporation based drip irrigation scheduling. *Indian Journal of Soil Conservation* **32**: 32-35.

Shirgure, P. S., Srivastava, A.K. and S. Singh ((2004b) Integrated water and nutrient management in acid lime. *Indian Journal of Soil Conservation,* **32**: 148-151.

Srivastava, A.K. (2009) Integrated nutrient management: Concept and application in citrus. In: Tennant P., Beakebhaia N (eds.) Citrus II. *Tree and Forestry Sci. & Biotechnology* **3**:32-58.

Srivastava AK (2013) Nutrient diagnostics in citrus: Are they applicable to current season crop. *Agrotechnology* **2:104**-05 doi.10.4172/2168P-9881.1000e104.

Srivastava, A.K. (2023) Integrating natural farming with agroecology for soil health care under fruit production system. *Annals of Plant and Soil Research* **25**(4): 524-533.

Srivastava, A. K. and P. Bora (2023) Multiple dimensions of agroecology in sustaining agriculture. *Indian Farming* **73**(6): 35-37.

Srivastava, A. K. and D. Hota (2020) Fruit crop under nutrient capped scenario: a timeless journey. *Current Horticulture.* **8**(2): 14-17.

Srivastava, A. K., HuchcheA. D, Lallan Ram and S. Shyam (2007) Yield prediction in intercropped versus monocropped citrus orchards. *Scientia Horticulturae* **114**:67-70.

Srivastava, A. K., Das, A.K., Jagannadham, P.T.K., Bora, Popy, Ansari, F.A. and R. Bhate (2022) Bioprospecting soil and plant health management amidst huanglongbing threat in citrus; a review. *Frontiers inPlant Science*. **13**: 858842.

Srivastava, A.K. and S.K. Malhotra (2014) Nutrient management in fruit crops - review. *Indian Journal of Fertilizers* **10**(12): 72-88.

Srivastava, A. K.and S.K. Malhotra (2017) Nutrient use efficiency in perennial fruit crops-A review. *Journal of Plant Nutrition* **40**: 1928–1953.

Srivastava, A. K., Malhotra, S. K., and N.K. Krishna Kumar (2015) Exploiting nutrient-microbe synergy in unlocking productivity potential of perennial fruits: a review. *Indian Journal of Agricultural Sciences* **85**:459–481.

Srivastava, A.K. and E. Ngullie (2009) Integrated nutrient management: Theory and practice. *Dynamic Soil, Dynamic Plant* **3**: 1-30.

Srivastava, A.K., Ram, L., Huchche, A.D., Kohli, R.R. and H.C. Das (1994) Standardization of leaf sampling technique in Nagpur mandarin under su4bhumid tropical climate. *Indian Journal of Horticulture*. 73(4): 209-11.

Srivastava, A.K.and V. Pandey (2021) Speciality fertilizer centric site specific nutrient management in fruit crops: principles and achievements. *Indian Journal of Fertilizers.17* (5):458-474.

Srivastava, A.K., Singh, S. and L.G. Albrigo (2008) Diagnosiis and remediation of nutrient constraints in citrus. Horticultural*Reviews*.**34**: 277-293.

Srivastava, A. K., S. Singh, A. D. Huchche and L. Ram (2001) Yield based leaf and soil test interpretations for Nagpur mandarin in Central India. *Communications in Soil Science & Plant Analysis* **32**: 585–599.

Srivastava, A. K., Singh, S.and. K. N. Tiwari (2006) Site specific nutrient management in Nagpur mandarin (*Citrus reticulata* Blanco). *Better Crops* **90**(2): 22–24.

Srivastava, A.K. and S. Singh (2001 a) Soil properties influencing yield and quality of Nagpur mandarin (*Citrus reticulata* Blanco). *Journal of the Indian Society of Soil Science* **49**(1), 226-229.

Srivastava, A.K., andS. Singh (2001 b) Development of optimum soil property limits in relation to fruit yield and quality of Citrus reticulate Blanco cv. Nagpur mandarin. *Tropical Agriculture* **78**(3), 174-181.

Srivastava, A.K., and S. Singh (2001 c) Soil fertility limit in relation to optimum yield of Nagpur mandarin (*Citrus reticulata* Blanco). *Journal of the Indian Society of Soil Science* **49**(4), 758-762.

Srivastava, A.K. and S. Singh (2003) Soil plant nutrient limits in relation to optimum fruit yield of sweet orange (*Citrus sinensis* Osbeck) cultivar Mosambi. *Indian Journal of Agricultural Sciences* **73**(4), 209-211.

Srivastava, A.K. and S. Singh (2004 a) Soil plant nutritional constraints contributing to citrus decline in Marathawada region region, India. *Communications in Soil Science and Plant Analysis* 35(17/18): 2537-2550.

Srivastava, A.K. and S. Singh4 (2004 b) Zinc nutrition, a global concern for sustainable citrus production. *Journal of Sustainable Agriculture* **25**(3), 5-42.

Srivastava, A.K. and S. Singh (2008) Analysis of citrus orchard efficiency in relation to soil properties. *Journal of Plant Nutrition* **30**, 2077-2090.

Srivastava, A.K., Singh, S. and K.N. Tiwari (2007) Diagnostic tools for citrus: their use an dimplications*. Btter crops-India*. **1**(1): 26-29.