J. Soils and Crops 32 (2) 217-225, December 2022

ISSN 0971-2836 (Print)
ISSN 2582-2756 (Online)

Review Article

CITRUS NUTRITION RESEARCH IN INDIA : A SNAPSHOT OF BREAKTHROUGHS

A.K.Srivastava[1]

History of systematic research in citrus nutrition dates back to 1915 when citrus dieback was reported. Of the different diagnostic tools leaf and soil-based nutrient standards have established their superiority over rest of the diagnostic methods. Optimum leaf nutrients standards developed for different commercial cultivars in India have further warranted the necessity of identifying nutrient constraints through cultivar specific diagnostics in order to inflict precision diagnosis. Similar observations were envisaged through optimum soil fertility limits suggested for Indian citrus cultivars, primarily governed by prevailing soil fertility constraints.Multi-location nutrient specific field response studies lacked heavily on the point of uniformity in yield and quality improvements when replicated at other locations. Site specific nutrient management studies demonstrated soil type-based fertilization, suggesting the fertilizers to be tailored as per canopy size within an orchard to derive rationality in fertilizer use within an orchard. Fertigation has further reduced the optimum fertilizer requirement by 30-40%, in addition to microbial consortium-based integrated nutrient management cutting 30% of conventionally recommended doses of fertilizers.

Citrus, despite being grown across continents (Srivastava and Singh, 2008a ; Mehta *et al*., 2022), is a highly nutrient exhaustive as well as responsive crop (Srivastava, 2013b).There are three basic requirements for successful cultivation of citrus, namely climate relatively free from frost, good quality of irrigation water, and a reasonably deep uniform fertile soil with high internal drainage (Srivastava and Panday, 2021). Citrus nutrition has been a subject of comprehensive research over the last 70 years or so (Kohli *et al*.,1997; Kohli and Srivastava,1997), and will continue to stake claim in the years ahead, not because of growing concerns every now and then in the light of newly emerging soil health related problems, but increasing emphasis laid towards quality citrus production has warranted a worldwide investigation on the subject from various angles (Srivastava *et al*., 2021). However, a substantial success has already been achieved right from the identification of various nutrient constraints in the field using much improved diagnostic techniques (Srivastava,2013b), monitoring methodologies coupled with much better efficiency of applied fertilizers to remediation of variousnutritional constraints providing a better understanding on soil-plant relationship and the other co-factors further affecting their cause and effect (Srivastava and Singh, 2006b; 2006c).

Considering the economics of citrus production, fertilizers alone on an average constitute about 20-30% of total cost of citrus production. This is a significant recurring expenditure, a grower needs to invest every year (Srivastava and Singh, 2008a). The mechanistic steps involved in absorption, translocation, and utilization of applied nutrients, all three being altogether different from one another, but are dependent on each other (Srivastava, 2014). A holistic benchmark analysis of various components leading to remunerative soil and plant nutrition management is, therefore, imperative to sustain the pressure of increasing nutrient demand accruing from intensive cultivation featuring high density planting with low volume fertigation to extensive cultivation, synonymous with high altitude hill citriculture (Srivastava *et al.,* 2005; Srivastava and Hota, 2020). Diagnosis of nutrient constraints and their efficient remediation are the two pillars of citrus nutrition (Srivastava and Malhotra, 2017). The necessity of balanced nutrition has to be, hence, viewed from the angle of striking a balance between shoot and root volume in relation to total plant nutrient requirement (Srivastava and Singh, 2009). The present review takes stock of the work done on citrus nutrition in Indian context with emphasis on diagnosis as well as management of nutrient constraints.

NUTRIENT CONSTRAINTS DIAGNOSIS

The nutrient diagnostic tools *viz*., leaf analysis (Kohli *et al*., 2000; Hundal and Arora, 2001), soil analysis (Srivastava and Singh, 2001; 2002 ; Srivastava, 2013a) , deficiency symptomatology (Srivastava and Singh, 2003a; 2003b; Srivastava *et al*., 2006), juice analysis, and biochemical analysis (Srivastava and Singh, 2006a) to a lesser extent, are commonly used for identifying the nutritional problems of citrusorchards. Of late, some studies propagated peduncle analysis, root analysis and flower analysis at 60-120 days after, but a representative and reproducible sampling in these types of analysis is not practicable. Many studies have confirmed that better interpretation could be made through combined use of leaf and soil analysis with regard to nutritional problems of citrus orchards (Srivastava *et al*., 2001; Srivastava and Singh, 2003a).

Peduncle and root analysis have also been suggested, but a representative and reproducible sampling

---

1. Principal Scientist (Soil Science), ICAR-Central Citrus Research Institute, Nagpur 440033, Maharashtra, India

in both the cases is not practicable. Color standards for identifying nutritional problems in field have also been developed. Practical color charts of 9-shades designed for field nutritional diagnosis, is composed of 172 types from GY2 to GY8 using the Munsell color system based on leaf color measurements (Menesatti *et al*., 2012). Of late flower analysis can be equally effective to leaf analysis for nutritional constraint analysis on the basis of relationship between nutrient concentration of flowers and leaves sampled at 60-120 days after anthesis (Srivastava and Singh 2004a; 2004b).

Leaf sampling technique

Accuracy of foliar analysis, however, depends upon the specificity of sampling with respect to leaf age, position of leaves on the terminal, sampling size, cropping pattern, and the agroclimatic region (Srivastava *et al*., 2019).Nutrient concentration of citrus leaves varies with the progression in new flush through the maturation process, and show some degree of stability at an appropriate age with respect to maturity in dry matter accumulation (Srivastava and Singh, 2005a). Rate of dry matter accumulation is further affected by growing conditions and genotype.Studies showed that the leaves initially act as a sink and later as a source with a period in between known as transition across sink to source happens to be the best time of sampling. Accordingly, the leaf sampling time was suggested as 5-7 months in Nagpur mandarin (*Citrus reticulata* Blanco) and 3-5 months in acid lime (*Citrus aurantifolia* Swingle) by using non-fruiting terminals under hot sub-humid tropical climate of central India (Srivastava *et al*., 2006). The other studies in the past have indicated different periods (4-10 months) for collecting index leaves which varied according to cultivar and region (Srivastava and Singh, 2003b).

A considerable difference in leaf nutrient composition in relation to number of leaves (leaf sample size) collected from individual trees within a plot or from a plant population is commonly observed (Srivastava and Singh, 2004c). The variations in leaf nutrient composition further indicated that leaf sample size as low as 30 leaves covering 2% trees was equally effective as much as 70 leaves covering even 10% trees for foliar analysis (Srivastava and Singh, 2006b). A different leaf analysis standards might be required to counter these discrepancies arising out of sampling techniques. A greater concentration of nutrients at 0-6 feet height than the leaves collected either at 6-12 feet height or at the top of the Valencia trees. Later studies showed lower nutrient concentration in larger than smaller leaves (Srivastava and Singh, 2006c; 2003b; 2004a).

Diagnostic values

The first step to develop a diagnostic norm is the categorization of leaf analysis data. While categorizing the various leaf nutrient levels, the term deficiency and excess have the major point of reference by and large (Srivastava and Singh, 2007). The optimum values of macro- and micronutrients (Table 1) suggested for citrus cultivars grown worldwide suggest a large variation amongst them, and failed to find an universal application due to lack of consistency in diagnosis in space and time. These breakthroughs warranted a strong necessity of developing a cultivar specific nutrient standard to suit regional level growing conditions and transform such breakthroughs into highly nutrient responsive in nature.

Table 1.Optimum limits of leaf nutrients for different citrus cultivars grown in India

Nutrients	Mandarins (*Citrus reticulata* Blanco)			Sweet oranges (*Citrus sinensis* Osbeck)			Acid lime (*Citrus aurantifolia* Swingle)
	Nagpur mandarin	Kinnow mandarin	Khasi mandarin	Mosambi sweet orange	Sathgudi sweet orange	Malta sweet orange	
N (%)	1.70 – 2.81	2.22-2.32	1.97 –2.56	1.98-2.57	2.01-2.42	2.14-2.31	1.53-2.10
P (%)	0.09 – 0.15	0.11-0.15	0.09 – 0.10	0.091-0.17	1.12-1.82	0.10-0.14	0.10-0.15
K (%)	1.02 – 2.59	1.10-1.41	0.99 – 1.93	1.33-1.72	1.93-2.73	1.10-1.56	0.96-1.66
Ca (%)	1.80 – 3.28	2.32-2.79	1.97 – 2.49	1.73-2.98	0.36-0.53	2.89-3.41	3.05-3.43
Mg (%)	0.43 – 0.92	0.38-0.61	0.24 – 0.48	0.32-0.69	53.5-82.1	0.39-0.52	0.40-0.60
Fe (ppm)	74.9 – 113.4	22.4-58.3	84.6 – 249.0	69.5-137.1	48.7-79.3	42.6-81.4	0.25-0.29
Mn (ppm)	54.8 – 84.6	26.3 -56.2	41.6 – 87.6	42.2-87.0	3.7-8.9	28.1-54.3	117-194
Cu (ppm)	9.8 – 17.6	4.2-7.2	2.13 – 14.4	6.6-15.8	16.5-23.2	4.2-8.9	21-63
Zn (ppm)	13.6 – 29.6	21.3-26.9	16.3 – 26.6	11.6-28.7	12.8-23.1	21.3-26.9	8.68-14.8
Yield(kg tree^{-1})	47.7 – 117.2	32.4-56.1	31.6 – 56.3	76.6-137.9	82.9-158.2	23.1-38.9	56.4-70.0

Source: Srivastava and Singh (2003a; 2004b), Srivastava *et al*. (2001), Indira Sarangthem *et al*. (2014)

Soil fertility limits

The quantity of a nutrient extracted through the soil using a suitable extractant is an index of nutrient actually available to trees. The available portion of nutrient determined by soil analysis is at best an estimation, because it is measured by an extractant that cannot be expected to duplicate the action of plant roots in nature (Mousavi *et al*., 2022) . Use of soil testing, specifically for citrus as a guide for fertilizer recommendation is restricted due to lack of calibration for P and K in soils and the crop response(Srivastava and Shirgure , 2018) .The genetic difference in soil properties produces differential production response, which eventually determines the soil quality (Srivastava and Singh, 2001 ; Khandagle *et al*., 2019). It is a concept that describes soil in terms of its capacity to perform three major functions, *viz*., enhanced productivity, environmental protection, and health (Srivastava and Singh, 2004c ; 2006c ;Srivastava *et al*., 2021). The citrus soil differs from other cultivated soils, since the latter remain fallow for 3 to 6 months every year and undergo depletion of soil organic matter causing very little addition of organic-C during fallow phase (Srivastava and Singh 2008a ; Srivastava and Pandey , 2021).On the other hand, biological oxidation of organic matter continues at the same rate in soils under perennial crop (Srivastava *et al*., 2021). These issues gave birth to conceptualization of soil suitability criteria as a dynamic concept of soil fertility evaluation. A different criteria is obtained for the same cultivar, if grown under different agro-climates (Table 2). Such attempts need to be replicated in other fruit crops as well to make soil testing more remunerative of nutrient response.

Table 2. Soil fertilitylimits developed for commercial citrus cultivars grown in India

Nutrients	Mandarins (*Citrus reticulata* Blanco)			Sweet oranges(*Citrus sinensis* Osbeck)			Acid lime (*Citrus aurantifolia* Swingle)
	Nagpur mandarin	Kinnow mandarin	Khasi mandarin	Mosambi sweet orange	Sathgudi sweet orange	Malta sweet orange	
N (mg kg^{-1})	94.8 –154.8	114.3-121.2	161.0- 418.7	107.4-197.2	120.1-152.2	110.5-124.6	106.3-118.2
P (mg kg^{-1})	6.6 – 15.9	7.8-12.3	4.5 – 8.7	8.6-15.8	10.1-12.3	9.2-14.6	9.2-14.6
K (mg kg^{-1})	146.8 –311.9	96.4-131.3	82.3 -287.5	186.4-389.2	162.3-206.4	131.6-181.2	102.4-146.6
Ca (mg kg^{-1})	408.1 616.0	89.4-248.6	148.8- 285.4	512.1-728.4	582.3-812.2	210.6-294.3	210.3-318.7
Mg (mg kg^{-1})	85.2-163.2	72.3-89.6	31.3 – 84.4	119.4-182.3	123.8-198.7	72.9-94.6	89.6-106.3
Fe (mgkg^{-1})	10.9-25.2	5.8-11.1	39.5 – 180.9	1.76-4.70	11.2-16.4	9.8-14.2	4.6-12.3
Mn (mgkg^{-1})	7.5- 23.2	4.3-6.9	27.0 – 80.3	0.44-1.03	10.1-18.3	6.9-9.2	3.2-10.1
Cu (mgkg^{-1})	2.5 – 5.1	0.45-0.69	0.67 – 2.90	0.31-0.57	2.2-3.6	0.82-1.10	0.80-1.40
Zn (mg kg^{-1})	0.59 – 1.26	0.62-0.78	2.84 – 5.14	0.09-0.16	0.54-1.10	0.81-0.96	0.78-0.89
Yield (kg tree^{-1})	47.7 –117.2	32.8-56.2	31.6 – 56.3	76.6-137.9	82.9-158.2	23.1-38.9	22.0-41.2

NUTRIENT MANAGEMENT OPTIONS

Conventionally, foliar fertilization, fertilization, integrated nutrient management and of late fertigation and organic fertilization gained as popular methods of nutrient management practices.

Foliar fertilization

Increase in fruit yield and size due to foliar sprays of urea further indicated an indirect effect of earliness in flowering and fruit set. Foliar sprays of micronutrients are more popular and, therefore, frequently used (Srivastava, 2014). A large variation exists with regard to foliar recommendation of micronutrients *viz*., Fe-EDDH (0.1%) for Valencia orange, Fe-polyflavonoid (1%) for Verna lemon, Fe (50 ppm) + $MnSO_4$ (5 ppm) + Zn (75 ppm) for Washington navel, $MnSO_4$ + $ZnSO_4$ (0.15% each) for Thompson navel, $FeSO_4$ + $CuSO_4$ (0.25% each) + $ZnSO_4$ (0.5%) for Coorg mandarin, $ZnSO_4$ (0.60 g l^{-1}) + $MnSO_4$ (1.2 g l^{-1}) for Valencia orange, Zn-EDTA (0.4%) + Cu-EDTA (0.2%) for Kinnow mandarin, borax + $MgSO_4$ (0.2%) + $ZnSO_4$ (0.1%) for Jiaogan mandarin etc. summarized through reviews of Srivastava and Singh (2003c ; 2004c; 2005b) . These recommendations are more suggestive than interpretative in nature (Srivastava and Singh, 2003c).

Soil fertilization

Response of nitrogen fertilization in improving the growth, yield, and quality of different citrus cultivars is well recognized under different agroclimatic regions of the countries like Brazil, Australia, South Africa, India etc. Contrary to foliar fertilization, soil application of macronutrients is more efficacious. The optimum requirement of macronutrients for different commercial citrus cultivars suggest: 475 g N + 320 g P_2O_5 + 355 g K_2O tree^{-1}for Satsuma mandarin in Turkey, 240 g N + 40 g P_2O_5 + 100 g K_2O ha^{-1} for Dancy tangerine in Spain,1.4 kg N + 1.08 kg P + 1.1 kg K_2O tree^{-1} for acid lime,400-1200 kg N + 200 kg P_2O_5ha^{-1} for kinnow mandarin in India, 120 kg N + 150 kg P_2O_5 + 75 kg S + 6 kg Cu + 0.8 kg Mo + 5.0 kg Zn ha^{-1} for Neck orange in Korea, 1.02 kg N + 0.58 kg P_2O_5 and 0.55 kg K_2O tree^{-1} for Satsuma mandarin in Georgia, 200 kg N + 140 kg P_2O_5 + 210 kg K_2O ha^{-1}for Pera sweet orange in Brazil, 0.5 kg N + 0.5 kg P_2O_5 + 1.0 kg K_2Oha^{-1} for grapefruit in Greece, and 1.5 kg urea + 0.25 kg superphosphate + 1.25 kg potassium chloride + 1.1 kg magnesium sulfate + 0.10 kg zinc sulphate tree^{-1} for Jincheng orange in Chinaas highlighted through previous reviews of Srivastava *et al.*(2021) and Srivastava and Singh (2008c).

The studies carried out worldover have, therefore, shown some diversity in optimum doses of micronutrients standardized through long term field experiments. These include: Fe citrate (2.6- 6 mg kg^{-1}) + $MnSO_4$(1.3-3 mg kg^{-1}) for Satsuma mandarin, Fe + Mn + Zn-EDTA (292 g + 292 g + 315 g ha^{-1}) for Valencia orange, $MnSO_4$ (483 kg tree^{-1}) + $ZnSO_4$ (303.8 g tree^{-1}) for Valencia orange, and Zn-EDTA (30 g tree^{-1}) for Washington navel orange through critical analysis by Srivastava and Singh (2003c) and Srivastava and Malhotra (2014). The combination of two methods is also often used consisting: $ZnSO_4$+ K_2SO_4(0.5% foliar spray) + K_2O as K_2SO_4(210 g tree^{-1} as soil application)for Kinnow mandarin and $ZnSO_4$ + $FeSO_4$ + $MnSO_4$(50 g tree^{-1} each as soil application)+ (0.50% foliar application) for Sathgudi sweet orange highlighted through reviews of Srivastava and Singh (2008c) and Srivastava *et al.* (2021).A complete fertilizers schedule using inorganic fertilizers has been developed for three major citrus cultivars (Nagpur mandarin acid lime and sweet orange) of India (Table 3).Of late, there has been good success in development of customized micronutrient mixture and long term field evaluation with citrus as test crops (Srivastava and Pandey, 2021).

Fertigation

Fertigation (application of nutrients through the irrigation) has still produced better results in improving the tree growth, fruit yield, quality, the reserve pool of soil nutrients, and consequently, the plant nutritional status (Shirgure *et al.,* 2001b; Panigrahi *et al*., 2017; Jeyabaskaran *et al.,*2021). Besides the mobility of nutrients, fertigation has several advantages over broadcast application of granular fertilizers with respect to effective placement of nutrients and flexibility in application frequency, development of uniform root distribution, an important pre-requisite for better fertilizer-use-efficiency, and improvement in fruit quality (Srivastava *et al*., 2003; 2016; Jeyabaskaran *et al.,*2021).The importance of ground coverage of orchard floor by fertigation reported that the treatment having 37% coverage of ground and 82 % of canopy area produced fruit yield higher than the broadcast fertilizer treatment covering 100 % of soil surface and 53% canopy area (Shirgure *et al.*, 2003a; 2003b). Other studies in central India showed far superior results with fertilizers applied through drip irrigation (fertigation) over basal fertilizer application using basin/ flood irrigation (Shirgure *et al.,*2001b; Srivastava and Malhotra,2014). Irrigation at 20% depletion of available water content combined with fertilizer treatment of 500 g N + 140 g P_2O_5 + 70 g K_2O tree^{-1}year^{-1} produced a significantly higher magnitude of fruit yield/m^3 of canopy in addition to higher nutrient status and fruit quality parameters in 14-year-old Nagpur mandarin (*Citrus reticulata* Blanco) on an alkaline calcareous Lithic Ustochrept soil type (Shirgure *et al*., 2001a; 2001b; 2001c ; Shirgure *et al*., 2021).

Site specific nutrient management

Site specific nutrient management is a dynamic concept exercised through plant nutrient uptake based fertilization. It should not mean that every time, a crop is grown, all the nutrients should be applied in a particular proportion. Rather fertilizer application should be tailored according to the crops' need keeping in view the capacity of these soils to fulfill various demands (Srivastava *et al*., 2014). To achieve this, it is necessary to keep an overall nutrient balance in relation to total crop load (Srivastava and Singh, 2016). This may indicate the need for the application of different nutrients at specific times, in a particular order to derive the maximum benefit from the application of a given quantity of nutrients. However, findings from the long term fertilizer trials revealed that: i. intensive cropping with only N input is a short-lived phenomenon, ii. omission of limiting macro- or micro-nutrient leads to its progressive deficiency due to heavy removals, iii. sites initially well supplied with P, K or S become deficient when continuously cropped using N alone, and iv. fertilizer rates considered optimum still resulted in nutrient depletion at high productivity levels, if continued, become sub-optimum rates (Srivastava *et al*., 2014; Srivastava and Singh, 2015; 2016).

Tailoring of fertilizer requirement

Exploiting soil spatial variability is a pre-requisite to tailor fertilizer requirement within an orchard using variable rate application technique. In this regard, attempts were made to tailor fertilizer requirement of citrus without increasing the total dose of fertilizers (Srivastava and Singh, 2015 ; 2016). In a long term experiment on evaluation of differential fertilizer treatments on two contrasting soil types in an orchard showed that with the same level of NPK, application of micronutrients (Zn + Fe + Mn) produced comparatively higher increase in canopy volume and fruit yield on shallow soil (Typic Ustorthent) than deep soil (Typic Haplustert) according to studies carried out in central India (Srivastava and Pandey, 2021).

However, the magnitude of response of micronutrients on fruit yield was almost similar at 600 g N + 400 g P_2O_5 + 600 g K_2O tree^{-1}versus 1200 g N + 600 g P_2O_5 + 600 g K_2O tree^{-1}. These two soil types showed a differential behavior with respect to fruit quality as well. Higher application of K at the rate of 900 g tree^{-1} alongwith 600 g N + 500 g P_2O_5 tree^{-1} produced much higher acidity on Typic Haplustert which developed more green color of fruits, thereby, took comparatively longer time for the color break and attain harvest maturity (Srivastava and Singh, 2006).

Table 3 . Fertilizer schedule developed for different citrus cultivars through long term field nutrient response studies

Fertilizer source	Total fertilizer (g tree^{-1} year^{-1})	Soil application						Foliar application					
		Ambia (g plant^{-1})			Mrig (g plant^{-1})			Ambia (g plant^{-1})			Mrig (g plant^{-1})		
		Apr.	Aug.	Nov.	Sept.	Nov.	Jan.	Apr.	Aug.	Nov.	Sept.	Nov.	Jan.
Nagpur mandarin (*Citrus reticulata* Blanco)													
Urea	1300	433	433	434	433	433	434	-	-	-	-	-	-
Single super phosphate	1260	630	630	-	630	630	-	-	-	-	-	-	-
Muriate of potash	180	-	-	180	-	-	180	-	-	-	-	-	-
$FeSO_4$	200	100	100	-	100	100	-	0.5%	-	0.5%	0.5%	-	0.5%
$MnSO_4$	200	100	100	-	100	100	-	0.5%	-	0.5%	0.5%	-	0.5%
$ZnSO_4$	200	100	100	-	100	100	-	0.5%	-	0.5%	0.5%	-	0.5%
Acid lime (*Citrus aurantifolia*Swingle)													
Urea	1740	580	580	580	580	580	580	-	-	-	-	-	-
Single super phosphate	1260	630	630	-	630	630	-	-	-	-	-	-	-
Muriate of potash	180	-	-	180	-	-	180	-	-	-	-	-	-
$FeSO_4$	200	100	100	-	100	100	-	0.5%	-	0.5%	0.5%	-	0.5%
$MnSO_4$	200	100	100	-	100	100	-	0.5%	-	0.5%	0.5%	-	0.5%
$ZnSO_4$	200	100	100	-	100	100	-	0.5%	-	0.5%	0.5%	-	0.5%
'Mosambi' Sweet orange(*Citrus sinensis* Osbeck)													
Urea	1740	580	580	580	580	580	580	-	-	-	-	-	-
Single super phosphate	1260	630	630		630	630	-	-	-	-	-	-	-
Muriate of potash	180	-	-	180	-	-	180	-	-	-	-	-	-
$FeSO_4$	300	150	150	-	150	150	-	0.5%	-	0.5%	0.5%	-	0.5%
$MnSO_4$	300	150	150	-	150	150	-	0.5%	-	0.5%	0.5%	-	0.5%
$ZnSO_4$	300	150	150	-	150	150	-	0.5%	-	0.5%	0.5%	-	0.5%

In order to prepare 0.5% of $FeSO_4$ solution, dissolve 500 g iron sulphate in 100 liters of water and spray on the plant till drench, likewise prepare the solutions of other micronutrients. The solution of $FeSO_4$ and $MnSO_4$ can be mixed together, but applying $ZnSO_4$ alongwith $FeSO_4$ and $MnSO_4$ should be strictly avoided

Source: Srivastava *et al.* (2021)

Organic fertilization

Our comprehensive reviews on the issue (Srivastava *et al.,* 2002; Wu *et al.,*2015; 2019) has highlighted this issue from various angles.Growing citrus organically is considered as the modern day necessity. We have developed an effective protocol of organic citrus. The application of vermicompost loaded with microbial consortium (100% N-equivalent basis) + IPM$_2$ (foliar application of Horticulture Mineral oil (2%) followed by *Beauveria bassiana* @ 5g l^{-1} and Azadirachtin (1%) @ 4 ml l^{-1}) + IDM$_1$ – Bordeaux paste (CuSO$_4$: Lime : Water = 1:1:10) as pre monsoon/post monsoon trunk application along with *Trichoderma harzianum* native antagonistic strain, NRCfBA44 (100 g plant^{-1}) with carrier material of FYM (1kg) as soil application at root zone) recorded maximum soil and plant nutrients, plant height, canopy volume, fruit yield, number of fruits, fruit weight and lower incidence of insect pests and diseases as compared to other organic treatments (Table 4). Organic citrus practices have a long way to travel before organic cultivation becomes an established practice (Ghodpade *et al*., 2019 ; Hota *et al*., 2020).

Integrated nutrient management

A cultivar displaying sustainable quality production under both intensive and organic farming system may not perform with similar magnitude of success when compared with inorganic fertilization (Ngullie *et al.*, 2015).

Table 4 . Scheduling of different components involved in organic management of Nagpur mandarin in central India

Components	Dose	Time of application
Nutrient Management		
Vermicompost	15 kg tree^{-1}	Three splits with each split containing 5 kg tree^{-1} vermicompost to be applied in the month of April, August and November
Microbial consortium	150 ml tree^{-1}	Three splits with each split having 50 ml microbial consortium tree^{-1} in the months of April, August and November
Insect Pest Management		
Horticultural mineral oil (HMO)	2% (20 m l^{-1})	Application at the time of new flush emergence
Beauveria bassiana (BB)	5 g l^{-1}	Application after 15 days of new flush emergence
Azadirachtin	1% (4 ml l$^{-1)}$	Application at new flush emergence and may be repeated at 10-15 days interval
Disease Management		
Bordeaux paste	CuSO$_4$:Lime: water in 1:1:10	Pre-monsoon (middle of June) and post-monsoon (first week of October) application
Trichoderma (NRCFBA44) inoculation	100 g plant^{-1}	100g culture mixed with 1kg vermicompost FYM and to be applied in July and second application in the month of September

Source: Srivastava *et al.* (2002; 2021)

The major difference lies between the nutrient availability pattern and form in through various modes of nutrient delivery (Srivastava *et al*., 2021). The plants suitable for intensive (conventional) farming get high amount of nutrients at its peak stage, whereas in organic farming the manure applied need to be decomposed first by micro-organisms and follow mineralization process on which conversion to available forms like NO$_3^-$ and NH$_4^+$, hence its availability was low when it was highly required(Srivastava *et al.,* 2008). It is, hence, highly desirable to breed the fruit trees for organic cultivation such that it can change the trees' nutrients absorption pattern, increased nutrient absorption capacity, reduced root losses due to pathogens, ability to maintain a high mineralization activity in rhizosphere via root exudates, increased rooting depth, and associated ability to recover N leached from the top soil (Srivastava and Singh,2006c ; Mukunda Lakshmi *et al*., 2019).

Integrated nutrient management (INM) approach takes into account, the holistic view of the various steps involved in developing and effective fertilization program (Srivastava *et al*., 2015) . A comprehensive integrated nutrient management strategy developed for Nagpur mandarin (Table 5) needs to be replicated for commercial citrus cultivars, which comprises 35% RDF + 35% (RDF equivalent Vermicompost +50 ml microbial consortium). Microbial fortification through rhizosphere hybridization has provided some useful insights (Hota *et al*., 2020).

Table 5. INM-schedule developed for Nagpur mandarin grown on black clay soils of central India

	Ambia crop			Mrig crop		
Components of INM	**April**	**August**	**November**	**August**	**October**	**January**
Vermicompost (kg tree $^{-1}$)	5.0	5.0	5.0	5.0	5.0	5.0
Inorganic fertilizers (g tree $^{-1}$)	300g urea 260g SSP 110g MOP	300g urea 260g SSP 110g MOP	300g urea 260g SSP 110g MOP	300g urea 260g SSP 110g MOP	300g urea 260g SSP 110g MOP	300g urea 260g SSP 110g MOP
Microbial consortium (ml plant $^{-1}$)	50.0	50.0	50.0	50.0	50.0	50.0
Foliar Spray	April	June	September	September	October	December
$FeSO_4$	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
$MnSO_4$	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
$ZnSO_4$	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
Borax	0.25%	0.25%	0.25%	0.25%	0.25%	0.25%

Source: Srivastava and Singh (2015), Srivastava *et al*. (2015)

MOP and SSP stand for muriate of potash and single superphosphate, respectively

PROLOGUE

Some of the issues are still difficult to answer even today in concrete terms, unless supported by an additional research for better conceptual understanding about the diagnosis and management of nutrient constraints in citrus. These include: biochemical response in relation to varying nutrient supply systems especially under multi-nutrient deficiency; establishing the causal relationship between various signaling and transduction mechanisms, by which nutrient deficiency in root system is able to coordinate changes in shoot system; and identification of reactions that are seemingly most sensitive to a nutrient deficiency and thereby, earmarking the targeted genes to be cloned to produce nutritionally efficient biotypes using modern tools of crop improvement like molecular biology and genetic engineering. These efforts would pave the way to develop the polypeptide- based warning system using biochemical markers to facilitate round-the-year nutritional care of crop through a better use of precision oriented informatics keeping in mind the orchard efficiency as an ultimate index of productivity. With the availability of more technical know-how on efficient use of bulky organic manures, prolonged shelf life of liquid based instead of carrier-based microbial bio-fertilizers (Srivastava *et al*., 2022) , and better understanding on citrus - mycorrhiza symbiosis with regard to nutrient acquisition and regulating the water relations, a more effective integrated citrus production system could be evolved in future. In this regard, a conceptual framework of integrated nutrient management need to be developed suiting to different commercial citrus cultivars grown in India to perch citrus nutrition research on abetter scientific footings.

REFERENCES

Ghodpade , R.M., W. P. Badole , A.R. Mhaske , B. Patel and S. S. Balpande , 2020. Impact of farmers organic farming practices on physic-chemical status of soils under vegetable in Nagpur district. J. Soils and Crops. **30**(1) : 155-158.

Hota, D., A.K. Srivastava, S. Dahat and S. Dubey, 2020. Rhizosphere engineering through microbes enhances agronomic performance of acid lime. Progressive Hortic.**52**(2): 120-123.

Hundal, H.S. and C.L. Arora, 2001. Diagnosis and recommendation integrated system (DRIS) approach for diagnosing the nutrient status of Kinnow fruit trees. J. Indian Soc.Soil Sci.**49**(4): 703-709.

Indira Sarangthem, L., D. Sharma and A.K. Srivastava, 2014. Development of nutrient diagnostic technique for Khasi mandarin (*Citrus reticulata* Blanco) grown in Manipur. J. Indian Soc. Soil Sci.**62**(2): 118-125.

Jeyabaskaran, K.J., P.S. Shirgure, V. Pandey, A.K. Srivastava and S. Uma, 2021. Fertigation in horticulture: A guarantee to economized quality production. Indian J. Fertilisers. **17**(4): 364-383.

Khandagle, A., B. S. Dwivedi , S. B. Aher , A.K. Dwivedi , D. S. Yashona and D. Jat , 2019. Effect of long-term application of fertilizers and manures on soil properties. J. Soils and Crops. **29** (1) : 97-104.

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

Kohli, R.R, A.K. Srivastava, and A.D. Huchche,1997.Nutrient requirement of Nagpur mandarin in clay soils of Central India. Indian Farming. **47** (2):25-28.

Kohli, R.R., A.K. Srivastava and A.D. Huchche, 2000.Leaf nutrients limit for optimum yield of Nagpur mandarin (*Citrus reticulata* Blanco). Indian J. Agric. Sci.**70**(5): 328-330.

Mehta, R., B. Gogoi , H.S. Datta and P. Pathak , 2022. Domestication and popularisation of underutilized and wild fruits for diversification : A review. J. Soils and Crops. **32**(10) : 1-18.

Menesatti, P., F.Pallottino, F. Antonnucci, G.Roccuzzo, F.Intrigliolo and C.Costa, 2012. Non-destructive proximal sensing for early detection of citrus nutrition and water stress. In (eds): A. K. Srivastava. Advances in citrus nutrition. Springer Dordrecht Heidelberg, New York, London. pp. 113-124.

Mousavi, S. M., A.K. Srivastava and M. Cheraghi 2022. Soil health and crop response of biochar : An updated analysis. Archiv. Agron. Soil Sci. http://doi.org/10.1080/03650340.2022.2054998.

Mukunda Lakshmi, L., K.T. Venkataramana, P.S. Shirgure, A.K. Srivastava and P. Patil, 2019. Integrated water and nutrient management in Sathgudi sweet orange. Indian J. Agric. Sci.**89**(11): 1932-1936.

Ngullie, E., A. K.Singh, S. Akali and A.K. Srivastava, 2015. Citrus growth and rhizosphere properties. Communi. in Soil Sci.Pl. Analysis, **45**: 1540-1550.

Panigrahi, P., A.K. Srivastava, D.K. Panda and A.D. Huchche, 2017. Rainwater, soil and nutrients conservation for improving productivity of citrus orchards in a drought prone region. Agric. Water Mangt.**185**: 65-77.

Shirgure, P. S., A. K. Srivastava and D. Hota, 2021. Fertigation in citrus , a toolkit for sustainable quality production . Int. J. Innovative Hortic. **10**(1) : 35-46.

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

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

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

Shirgure, P.S., A.K. Srivastava and S.Singh, 2003a. Irrigation scheduling and fertigation in acid lime (*Citrus aurantifolia* Swingle). Indian J. Agric. Sci.**73**(7): 363-367.

Shirgure, P.S., A.K. Srivastava and S. Singh, 2003b. Evaluating micro-irrigation systems in Nagpur mandarin (*Citrus reticulata* Blanco) under sub-humid tropical climate. Tropical Agric. (Trinidad). **80**(2):91-96.

Srivastava, A.K.2013a. Nutrient deficiency symptomology in citrus: An effective diagnostic tool or just an aid for post–mortem analysis. Scientific J. Agric.**2**(6):177-194.

Srivastava, A.K. 2013b.Nutrient diagnostics in citrus: Are they applicable to current season crop. Agrotechnol. **2**: 104-05.

Srivastava, A.K. 2014. Global citrus nutrition research: an incisive analysis. Curr. Hortic.**2**(1):3-4.

Srivastava , A.K., A.K. Das, P.T.K. Jagannadham , P. Bora, F.A. Ansari and R. Bhate , 2022. Bioprospecting micorbiome for soil and plant health management amidst Huanglongbing threat in citrus : A review. Front. Plant Sci. 13:858842 .

Srivastava,A..K., S.N.Das,S.K. Malhotra and K.Majumdar, 2014. SSNM-based rationale of fertilizer use in perennial crops: A review. Indian J. Agric. Sci.**84**(1): 3-17.

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

Srivastava, A.K. and S.K. Malhotra, 2014. Nutrient management in fruit crops: Issues and strategies. Indian J. Fertilizer. **10**(12): 72-88.

Srivastava, A.K. and S.K. Malhotra, 2017. Nutrient –use – efficiency in perennial fruit crops- A Review. J. Pl. Nutri.**40**(2): 1928-1953.

Srivastava, A.K., D.H.Paithankar, K.T.Venkatramana, V. Hazarika and P. Patil, 2019. INM in fruit crops: Sustaining quality production and soil health. Indian J. Agric. Sci.**83**(3): 379-395.

Srivastava, A.K. and P. Patil, 2016. Nutrient indexing in Kinnow mandarin (*Citrus deliciosa* Lour. x *Citrus nobilis* Tanaka) grown in indo-gangetic plains. Communi. Soil Sci. Pl. Anal. .**47**(18): 2115-2125.

Srivastava, A.K. and P.S. Shirgure, 2018. Nutrient diagnostics and fertilizers prescription in citrus : A perspective analysis. J. Ecofriendly. Agric. **13**(2) : 1-17.

Srivastava, A.K., P.S.Shirgure, A.D. Huchche and P.Patil, 2016. Interactive effect of irrigation schedules and fertigation levels on fruit yield, quality and plant nutrition of Nagpur mandarin (*Citrus reticulata*). *Indian* J. Agric. Sci. **86**(11): 1509-1514.

Srivastava, A. K., P.S. Shirgure and S.Singh, 2003. Differential fertigation response of Nagpur mandarin (*Citrus reticulata* Blanco) on an alkaline Inceptisol under sub-humid tropical climate. Tropical Agric. (Trinidad). **80**(2):97-04.

Srivastava, A.K. and S.Singh,2001. Development of optimum soil property limits in relation to fruit yield and quality of *Citrus reticulata* Blanco cv. Nagpur mandarin. Tropical Agric.(Trinidad). **78**(3):174-81.

Srivastava, A.K. and S.Singh, 2002. Soil analysis based diagnostic norms for Indian citrus cultivar. Communi.Soil Sci.Pl. Anal. .**33**(11&12):1689-1706.

Srivastava, A.K. and S.Singh, 2003a. Plant and soil diagnostic norms for optimum productivity of Nagpur mandarin (*Citrus reticulata* Blanco). Fertilizer News.**48**(2):47-63.

Srivastava, A.K. and S. Singh, 2003b. Soil-plant nutrient limits in relation to optimum fruit yield of sweet orange (*Citrus sinensis* Osbeck) cultivar Mosambi. Indian.J. Agric. Sci. **73**(4):209-11.

Srivastava, A.K. and S.Singh, 2003c. Foliar fertilization in citrus – A review. Agric. Rev. **24**(4):250-64.

Srivastava, A.K.and S.Singh, 2004a.Zinc nutrition and citrus decline – A review. Agric. Rev.**25**(3):173-188.

Srivastava, A.K and S.Singh, 2004b. Leaf and soil nutrient guide in citrus – A review. Agric. Rev. **25**(4): 235-251.

Srivastava, A.K.and S.Singh, 2004c. Soil and plant nutritional constraints contributing to citrus decline in Marathawada region, India. Communi. Soil Sci. Pl. Anal. **35**(17/18):2537-2550.

Srivastava, A.K., A.D. Huchche, L. Ram and S. Singh, 2005. Performance of irrigated monocropped versus intercropped 'Nagpur 'mandarin orchards on basalt derived tropical soils. Tropical Agric.**82** (3):159-163.

Srivastava, A.K. and S. Singh, 2005a. Zinc nutrition, a global concern for sustainable citrus production. J. Sust. Agric.**25**(3):5-42.

Srivastava, A.K. and S. Singh, 2005b. Boron nutrition in citrus – current status and future strategies – A review. Agric. Rev.**26**(3):173-186.

Srivastava, A.K.and S.Singh, 2006a. Citrus nutrition and biochemical markers– A review. J. Pl. Nutri.**28**(2):827-855.

Srivastava, A.K. and S.Singh, 2006b. Diagnosis of nutrient constraints in citrus orchards of humid tropical India. J.Pl. Nutri.**29**(3):1-16.

Srivastava, A.K.and S.Singh, 2006c. Managing nutrient deficiencies in citrus crops. Indian Hortic.**51**(1):6-9.

Srivastava, A.K.and S.Singh, 2007.DRIS-based nutrient norms for Nagpur mandarin (*Citrus reticulata*). Indian J. Agric. Sci.**77**(6): 363-365.

Srivastava, A.K. and S.Singh, 2008a. Analysis of citrus orchard efficiency in relation to soil properties. J.Pl. Nutri.**30**: 2077-2090.

Srivastava, A.K. and S.Singh, 2008b. DRIS norms and their field validation in Nagpur mandarin (*Citrus reticulata* Blanco). J. Pl. Nutri.**31**(6):1091-1107.

Srivastava, A.K. and S. Singh, 2008c. Citrus nutrition research in India: Problems and prospects. Indian J. Agric. Sci.**78**:3-16.

Srivastava, A.K. and S.Singh, 2009. Zinc nutrition in Nagpur mandarin on haplustert. J. Pl. Nutri. **32**(7): 1065-081.

Srivastava, A.K. and S.Singh, 2015. Site-specific nutrient management in Nagpur mandarin (*Citrus reticulata* Blanco) raised on contrasting soil types. Communi. Soil Sci. Pl. Anal.**47**(3):447-456.

Srivastava, A. K. and S. Singh, 2016. Site –specific nutrient management in Nagpur mandarin (*Citrus reticulate* Blanco) raised on contrasting soil types. Communi. Soil Sci. Pl. Anal.**47**(4): 447-456.

Srivastava, A.K., S. Singh and A.D. Huchche, 2015. Evaluation of INM in citrus on Vertic Ustochrept: Biometric response and soil health.J. Pl. Nutri.**38**(5):1-15.

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. Communi. Soil Sci. Pl. Anal.**32**: 585-599.

Srivastava, A.K., S. Singh and R.A. Marathe, 2002. Organic citrus: Soil fertility and plant nutrition. J. Sust. Agric.**19**(3): 5-29.

Srivastava, A.K., S. Singh 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 V.Pandey, 2021.Specialty fertilizers-centric site-specific nutrient management in fruit crops: principles and achievements. Indian J. Fertilisers. **17**(5): 458-474.

Srivastava, A.K., Q.S.Wu, S.M. Mousavi and D.Hota, 2021. Integrated soil fertility management in fruit crops: A overview. Int. J. Fruit Sci.**21**(1): 413-439.

Wu, Q.S.,J.D. He, A.K.Srivastava, F. Zhang, and Y.N. Zou, 2019. Development of propagation technique of indigenous AMF and their inoculation response in citrus. Indian J. Agric. Sci.**89** (7):1190-1194.

Wu, Q.S., A.K. Srivastava,S. Wang and J.X. Zeng, 2015.Exogenous application of EE-GRSP and changes in citrus rhizosphere properties. Indian J. Agric. Sci**.85**: 802-806.

Rec. on 08.07.2022 & Acc. on 15.07.2022.