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Citrus nutrition: An Indian perspective

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ABSTRACT

Diagnosis and management of nutrient constraints are the two important pillars of sound citrus fertilizer program, although its history in India is as old as cultivation of citrus. Of the different diagnostic tools (leaf nutrient standards, soil thresholds of soil available nutrients, metalloenzyme activity, inflorescence analysis, juice nutrient standards, xylem sap analysis); 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 Indiahave 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 saving 30% cut from conventional RDF. Many other significant advances have taken place to improve the fertilizer-use-efficiency e.g. sensor-based variable rate application, fertigation using magnetized irrigation, open field hydroponics and dual purpose microbially loaded substrate (organic manure) enriched with limited inorganic fertilizers collectively known as INM a plausible alternative.

Keywords: Management, nutrient standards, soil fertility, site specific nutrient management, fertilizers-use-efficiency, citrus

INTRODUCTION

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 and uniform fertile soil with high internal drainage. Citrus nutrition has been a subject of comprehensive research over the last 70 years or so, 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, 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. 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. 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

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requirement (Srivastava and Singh, 2009). The present review takes stock of the work done on diagnosis and management of nutrient constraints in citrus highlighting the Indian perspective

DIAGNOSTIC METHODS

The nutrient diagnostic tools viz., leaf analysis (Kohli *et al.*,2000; Hundal and Arora, 2001), soil analysis(Srivastava and Singh, 2001; 2002) 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 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 Analysis

Leaf analysis is based on four important assumptions viz., i. leaf is the principle site for the plant metabolism, ii.change in the nutrient supply is reflected in the composition of leaf, iii.change is more pronounced at certain stages of development, and iv.concentration of nutrient in the leaf at a specific growth stage is related to crop performance (Srivastava and Hota, 2020). The nutritional status of citrus trees can be determined using two types of testing viz., diagnostic and predictive testing. Diagnostic testing is undertaken to diagnose the causes of poor crop vigor, e.g. patches of poor growth in an otherwise healthy crop or to confirm a diagnosis made on the basis of plant symptoms and/or soil tests (Srivastava and Patel, 2016). Predictive (Prognostic) testing is used in the following three ways: i. analysis of samples collected during the early crop development to predict the likelihood of the nutrient deficiencies appearing before the crop maturity, ii. analysis of fruits to predict its likely behavior in the storage, and iii.analysis of seeds to predict the deficiencies in the succeeding crops. Each form of testing may identify latent deficiencies (hidden hunger) which limit the crop production, while the plants exhibit no obvious symptoms of deficiency. Distinction among the above three types of the testing is necessary, because of the variation in intensity and the pattern of sampling for each method of testing (Menino, 2012; Srivastava and Hota, 2020).

Sampling index leaves: 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) 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).

Differences in nutritional composition are observed in leaves collected from fruiting to that of non-fruiting terminals. Lateral shoots often develop on spring non-fruiting shoots, and their leaves have much lower N, K, and Mg than on unbranched non-fruiting shoots (Srivastava and Singh, 2006a). The finding that leaves from fruiting terminals had a markedly lower nutrient concentration than similar aged leaves from non-fruiting terminals contributed to the success of commercial use of published leaf analysis standards for the two methods of sampling. The leaves behind fruit did not have the same elemental composition as the same age of leaves taken at the same time from non-fruiting terminals (Srivastava and Singh, 2007).

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 leaf sample size influences the nutrient concentration, and recommended on the basis of average size. The variation in nutrient oncentration at different times of day is sufficiently small to allow sampling to be influenced by time of day, though a strict approach could justify a specific sampling time. Many recommendations suggested that a sample of 25-50 leaves from a single tree or 100 leaves comprising both fruiting as well as non-fruiting shoots gave a satisfactory estimate of its nutrient composition. 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).

Interpretation and diagnostic norms: The interpretation of leaf analysis is based on the premise that there is a significant biological relationship between the elemental content in leaf, plant growth, and fruit yield. A variety of interpretation tools have shown their application in leaf analysis of citrus. These are: critical nutrient concentration, nutrient concentration range, nutrient balance using factorial method, Kenworthy's balance index, Moller - Nielson balance concept, crop logging, boundary line concept and DRIS (Diagnosis and Recommendation Integrated System). Of them, DRIS is claimed to have certain distinct advantages over other conventional methods of leaf analysis interpretation (Srivastava and Singh, 2007; 2008b). DRIS diagnoses agree with diagnoses made by the sufficiency range method, but with some additional advantages that DRIS reflects the nutrient balance (fluctuates narrowly across different crop developmental stages), identifies the order in which nutrients are responsible for limiting the fruit yield, and its ability to make diagnosis at any stage of crop development. These merits impart DRIS to be able to identify nutrient constraint early in crop growth, and therefore, provide enough time for remediation of identified problem right in the same season of crop (Srivastava and Singh, 2007; 2008b). Limited efforts in the past have successfully established the DRIS norms for cultivars such as Valencia sweet orange (*Citrus sinensis* Osbeck), Kagzi lime (*Citrus aurantifolia* Swingle), and Kinnow mandarin, (a hybrid of *Citrus deliciosa*Ten and *Citrus nobilis*Lour), but without much success in mandarins.

Diagnostic norms: 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). All the arguments put forward to support the view that deficient, optimum or excessive conditions of a nutrient cannot be determined by means of absolute figures (critical levels) while dealing with species with a great deal of variation in vegetative activity. Accordingly, 4 areas were defined as: deficiency area (values below the statistical lower than normal limit), critical area (values ranging between the previous limit and the top deficiency limit), normal area (leaf content ranging between the top deficiency limit and normal reading), and excess area (leaf nutrient levels above normal limit). 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 applicability due to lack of consistency in diagnosis in space and time. These warrant a strong necessity of developing a cultivar specific nutrient standard to suit regional level growing conditions.

Table 1: Leaf analysis-based nutrient optima-based diagnostic 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 Sarangthemet al. (2014)

SOIL ANALYSIS

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 estimation, because it is measured by an extractant that cannot be expected to duplicate the action of plant roots in nature. 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.

Soil sampling

The accuracy of identifying the soil fertility constraint depends on how well the soil sample represents the area of an orchard. The horizontal and vertical depth of soil sampling is dependent upon the root distribution pattern, since the state of nutrition, size, and yield of trees are closely related to the amount of soil explored by the root system (Srivastava and Singh, 2002). Much of the success in the use of fertilizers depends on the method of fertilizer application in order to reach all the main root subdivisions. The root spread in citrus always exceeds to that of the branches i.e. citrus roots spread far beyond the area covered by the crown. Substantial differences among rootstocks in vertical and horizontal root distribution are well demonstrated. Comparison of grapefruit and sweet orange trees on rough lemon indicated that the grapefruit trees had a higher density of fibrous roots in the surface 25 cm, though the roots systems are not static, it may change its distribution with age and tillage treatment.

Soil property norms: The genetic difference in soil properties produces differential production response, which eventually determines the soil quality (Srivastava and Singh, 2001). It is a concept thatdescribes soil in terms of its capacity to perform three major functions, viz., enhanced productivity, environmental protection, and health. 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. On the other hand, biological oxidation of organic matter continues at the same rate in soils under perennial crop. The soil optimum values are further influenced by size composition, temporal variability (refers to variation in the optimal apparent density during crop growth), and ecotrophic variability (refers to differences in weather condition and soil fertility level). Soil suitability criteria is a dynamic concept. A different criteria is obtained for the same cultivar, if grown under different agro-climates (Table 2).

Table 2: Soil analysis-based soil fertility norms 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 (mg kg^{-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 (mg kg^{-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 (mg kg^{-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

Source: Srivastava and Singh (2001), Srivastava et al. (2001), Srivastava and Singh (2007)

JUICE ANALYSIS

The effects of fertilizer treatments on citrus juice yield and other quality parameters have received an intensive investigation. With most citrus fruits, the total soluble solids and citric acid concentrations, the ratio of solids to acid in the juice (brix), and the juice percentage are the indices used in defining quality and maturity standards. Role of nutrients in regulating the juice quality has necessitated to develop juice nutrient standards, much on the lines similar to leaf nutrient norms or soil fertility standards. This has stimulated more research with reference to effect of various orchard practices on fruit juice quality. Juice is claimed to serve as one of the diagnostics of identifying the nutritional problems of citrus orchards including the salt tolerance behaviour, though it did merit much investigation from the point of view of field identification of the problem.

Fruit nutrient removal: Citrus is a heavy forager of nutrients. Various nutrients are reported to be removed (in kg) in the proportion of: 55.5 N, 51.1 P, 53.7 K, 23.4 S, and 5.1 Mg. These nutrients need to be replenished in order to maintain the regulated nutrient supply through soil.

Nutrient value of citrus juice: Juice has an excellent nutrient value. The citrus cultivar e.g., Valencia orange showed a large variation in the concentration of nutrients with reference to K (1245 – 3025 ppm), Na (0.89-43.3 ppm), Fe (0.80-17.5 ppm), Ca (67-150 ppm), P (104-309 ppm), and Mg (82-155 ppm) in the juice.

Juice nutrient standards: Very limited information is available with regard to juice nutrient standards that can be used as an alternative to leaf analysis. Juice nutrient standards suggested by different workers consist of (in ppm) : 233-269N, 81-113P, 1424-1574 < for Washington navel, 120-310P, > 1400 K, 65-120 Ca, 95-170 Mg for Satsuma mandarin and < 30 Na, < 10 NO_3, > 400 PO_4, > 1700 K, < 100 Ca, and > 90 Mg for Valencia sweet orange (Gallasch*et al.*, 1984; Gattuso and Barreca, 2012). Leaf analysis for mineral content is an accepted method used as a guide to fertilizer needs. However, there are still many objections to its use. It would be logical to use fruit juice analysis as a diagnostic of nutrient constraints, since the purpose of fertilization is to obtain optimum production and maintain fruit quality. Many studies highlighted the advantages and disadvantages of juice analysis in evaluating the nutritional problems. Juice analysis is advantageous in terms of providing rapid means of assessing the nutrient status, better correlation with fruit quality parameters, easier to collect fruit samples, less samples preparation time, and no standardization of sampling procedure. However, some disadvantages are also associated, such as storage and transport of fruit samples.

DEFICIENCY LINKED MORPHOLOGICAL SYMPTOMS

Mobility of nutrient is one such factor which undergoes a definite redistribution during the stage a, plant enters into reproductive phase from vegetative phase. Accordingly various nutrients are classified as very immobile (B and Ca), very mobile (N, P, K, and Mg), immobile (Fe, Cu, Zn, and Mo), and slightly mobile (S). Such a diversification in nutrient mobility within a plant is the reason, why specific plant parts show the characteristic deficiency symptoms. The symptoms on fruits are noticed for very immobile nutrients like B and Ca. Development of visible symptoms is accountable to metabolic disorders which cause changes in micromorphology of plants before these symptoms are identifiable(Fig 1). The way in which the symptoms develop and manifest on younger or older leaves or the fruits, gives a reliable indication about the cause of nutritional disorders. Both deficiency and excess of nutrients can lead to reduction in crop yield coupled with inferior fruit quality (Srivastava, 2013).

Macronutrient deficiencies

Nitrogen deficiency first appears on older leaves and later proceeds towards the younger leaves. The deficiency symptoms are characterized by light yellowish green leaves, veins slightly lighter in color than the tissues in between, new leaves small in size, and thin fragile light green leaves. Deficiency can also be distinguished by general nature of the yellowing of foliage over the entire tree with absence of any distinctive pattern of deficiency symptoms (Srivastava and Singh, 2009; Srivastava, 2013). Phosphorus has the tendency to move from older to younger tissues, therefore, symptoms appear first on older leaves which loose their deep green color. Leaves turn small and narrow with purplish or bronze lusterless discoloration. Some leaves may later develop necrotic areas, and young leaves show reduced growth rate. Fruits become coarse and rough in texture with a thick rind and hollow central core. The symptoms of K-deficiency are: reduced fruit size with very thin peel of smooth texture, pre-mature shedding of fruits, leaf scorching, appearance of resinous yellow spots, and shoots turning S-shaped. Deficiency of Ca is mainly characterized by fading of chlorophyll along the leaf margins and between the main veins especially during winter months. Small necrotic (dead) spots develop in the faded areas. Symptoms of Mg-deficiency occur on mature leaves following the removal of Mg to satisfy fruit requirement. Disconnected yellow areas or irregular yellow blotches start near the base along the mid-rib of mature leaves that are close to fruit. These leaves gradually enlarge and coalesce later to form a large area of yellow tissue to each side of the mid-rib. This yellow area gradually gains in size, until only the tip and the base of the leaves are green showing an inverted V-shaped area pointed on the mid-rib.

Micronutrient deficiencies

Interveinal white chlorosis due to Fe-deficiency appears first on young leaves, a common tendency for chlorosis of all aerial parts after becoming necrotic. In acute cases, the leaves are reduced in size, turn fragile, and very thin that shed early. Mottled chlorosis in Mn-deficiency with green veins and leaf web tissue yellow or white, appears first on younger leaves, then spreads to older leaves. Stems remain yellowish green, often hard and woody. Young leaves commonly show a fine pattern or network of green veins on a lighter green background, but the pattern is not so distinct as in Zn- and Fe-deficiencies because the leaves remain green. Wilting of terminal shoots, frequently followed by death of leaves is usually seen in Cu-deficiency. Leaf color often fades due to reduction in pigments. First symptom is the formation of unusually vigorous large dark green foliage with a lighter mid-rib. Fruit symptoms are more pronounced. Brown stained areas of hardened gum on the rind of the fruit precede the appearance of leaf and twig symptoms. Brown stained areas on the fruits darken, and later turn black (Srivastava, 2013). The young leaves from vegetative shoots are more affected than reproductive shoots in Zn-deficiency. The symptoms of Zn-deficiency are also characterized by irregular green bands along the mid-rib and main vein on a background of light yellow to almost white. In very acute cases of Zn-deficiency, the leaves turn abnormally narrow and pointed with the tendency to stand upright coupled with extremely reduced size of leaves. As the deficiency progresses, the leaves are affected over the entire periphery of the tree, and the twigs become very thin and later die-back rapidly. A profuse development of water sprouts takes place on the main branches of trunk, while other leaves remain free from Zn-deficiency symptoms (Srivastava and Singh, 2005a).In B-deficiency, terminal leaves turn necrotic, and shed prematurely. Internodes of terminal shoots shorten, and usually form a rosette. The apical meristems blacken and eventually die with the breakdown of meristematic tissues. Fruit symptoms are more reliable as hard fruits dry due to lumps in the rind caused by gum impregnations (Srivastava and Singh, 2005b). In Mo-deficiency, as the leaves grow, yellow spots develop deposits of brown gum on the lower leaf surface which later turn black (Srivastava, 2013)

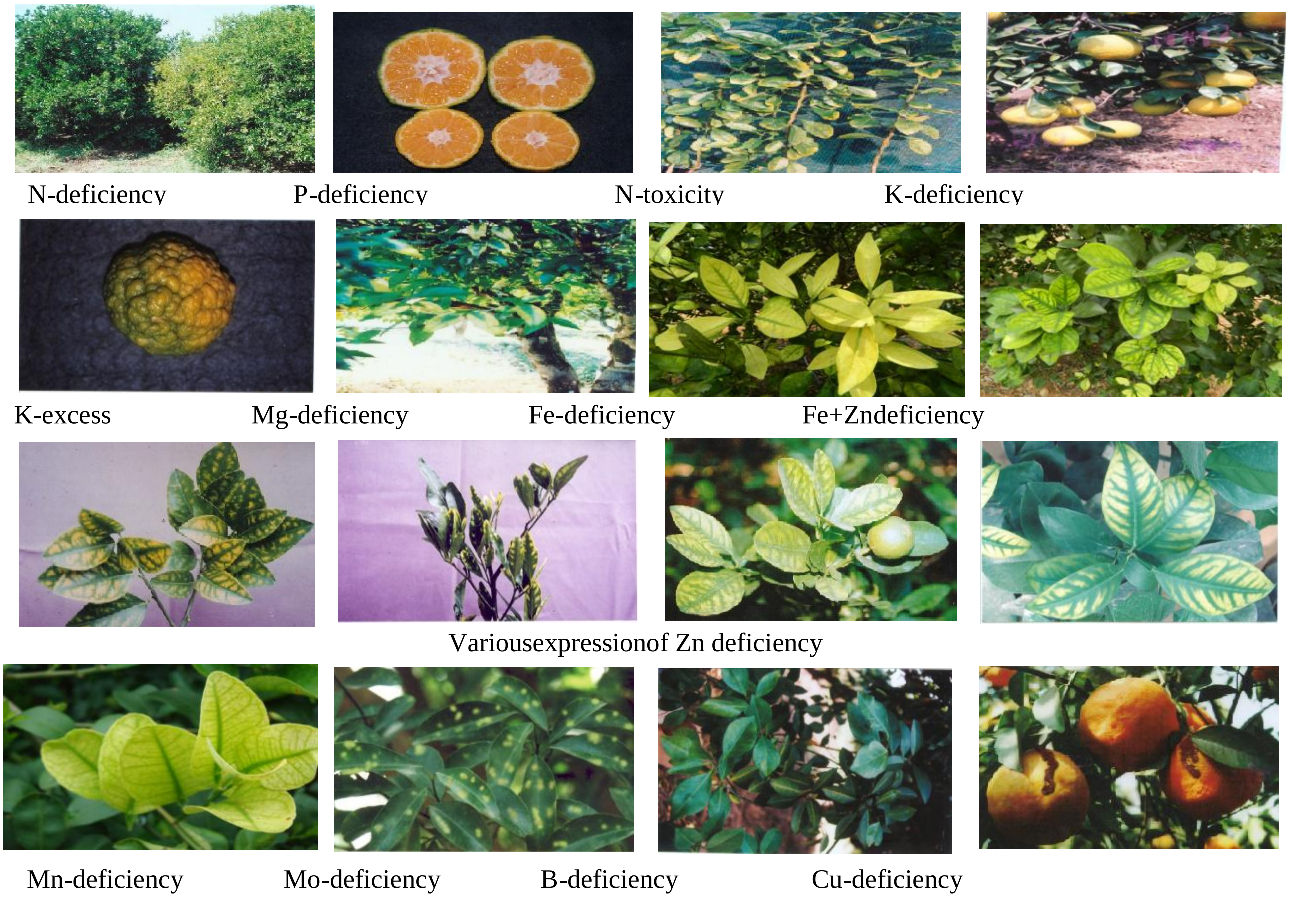

Fig. 1: Description of nutrient deficiency symptoms in citrus (Morphological features)

Biochemical Marker Aided Analysis

For the valid use of enzymatic system as an indicator of activity of certain nutrient element in plant tissue, it is essential for the enzymatic system to be specific for the said element. Hence, for these purposes, the choice is almost completely limited to metalloenzymes. For example, the use of the peroxidase in the diagnosis of Fe- and Mn- deficiencies prompted checking the utility of the method for citrus cultivars grown on differentially fertile soils. Parallel to what was observed with peroxidase, catalase, adolase, and aconitase reduced their levels of activity with Fe-deficiency and increased with Mn-deficiency, facilitated to establish the possibility of using these enzymes as viable mean of distinguishing between Fe- and Mn- deficiency producing morphological symptoms of overlapping nature (Srivastava and Singh, 2006a; Srivastava and Singh, 2009).

NUTRIENT CONSTRAINTS REMEDIATION

Fertilizer Requirement: A Complex Problem

The fertilizer requirement of citrus depends upon the objectivity of fertilization, whether the purpose is to grow the crop or feed the crop. Based on these objectives, two types of fertilization viz., corrective and preventive are usually adopted (Srivastava and Singh, 2004b). An optimum fertilizer program is one in which the cost of each unit of fertilizer applied is at least covered by an extra return of fruit yield obtained in both, the short and long term life of a citrus orchard. In a young tree care program, emphasis is placed on developing the tree canopy which will later produce large crop. Switching from a young tree program to a bearing tree, regime may result in significant reduction in applied fertilizers (Srivastava and Singh, 2003c). Fertilizer programs for citrus are determined by many approaches. These are: surveys, growers' experience, following the fertilization program of high yielding orchards, replacing the amount of nutrients removed in fruits, deficiency symptoms, applying results from sand, soil culture, and field experiments, and soil/leaf analysis. Each one of these has certain advantages and limitations. Some of the difficulties in developing sound recommendation for fertilizer program may be traced in the history of developments dedicated towards determining nutrient requirements. All these studies however, aimed towards the balanced plant nutrition, a fundamental concept of any nutrition program (Srivastava and Singh, 2003c).

Foliar Fertilization

Plants sometimes grow at rates that are faster than the ability of their roots to absorb and translocate mineral nutrients to the leaves or developing fruits. Foliar sprays are useful to maintain optimum nutrient concentration in the plant during the growing cycle by optimizing the movement of nutrients (Srivastava and Malhotra, 2014). Foliar fertilization means the epigean application of plant nutrient, which a plant needs for its nutrition and growth i.e. the non-root feeding or extra radical feeding(Table 4). Foliar sprays of urea (28-31 kg N ha^{-1}) in Valencia orange, multiple application at 1% urea in Codoux clementine mandarin, 10% KCl in Eureka lemon, 5% KNO_3 with 18-20 ppm 2,4-D in Shamouti orange, and only 5% KNO_3 in Valencia orange demonstrate that only two nutrients, N and K are effective through foliar application. 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.These recommendations are more suggestive than interpretative in nature (Srivastava and Singh, 2003c).

Soil Fertilization

The main organ for absorbing water and nutrients by a plant is its roots. Climate and soil related factors such as low temperature, excessive moisture, drought etc. however, disturb nutrient and water uptake during plant growth, the effects of which may vary from a temporary restriction of growth to reduced yield and quality at harvest.

Macronutrient requirement: 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 $tree^{-1}$ for acid lime,400-1200 kg N + 200 kg $P_2O_5ha^{-1}$ for kinnow mandarin in India, 120 kg N + 150 kg P + 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 + 210 kg K 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 $sulphatetree^{-1}$ for Jincheng orange in China (Srivastava *et al.,* 2021; Srivastava and Singh, 2008c).

Micronutrient requirement: 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. 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 $tree^{-1}$-soil application)for Kinnow mandarin and $ZnSO_4$ + $FeSO_4$ + $MnSO_4$(50 g $tree^{-1}$ each - soil application)+ (0.50% - foliar application) for Sathgudi sweet orange. 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). Has been developed and complemented for advisory to citrus growers.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. 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 FUE, 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. Irrigation at 20% depletion of available water content combined with fertilizer treatment of 500 g N + 140 g P + 70 g K $tree^{-1}year^{-1}$ 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).

Site Specific Nutrient Management

Site specific nutrient management is a dynamic concept. 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. 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).

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.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 (TypicUstorthent) than deep soil (TypicHaplustert).

Table 3: Fertilizer Schedule for Different Citrus Cultivars

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													
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													
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													
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
Caution: The solution of $FeSO_4$ and $MnSO_4$ can be mixed together, but avoid applying $ZnSO_4$ alongwith $FeSO_4$ and Mn
Source: Srivastava et al. (2021)

However, the magnitude of response of micronutrients on fruit yield was almost similar at 600 g N + 400 g P + 600 g K $tree^{-1}$ versus 1200 g N + 600 g P + 600 g K $tree^{-1}$. These two soil types showed a differential behaviour 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 $tree^{-1}$ produced much higher acidity on TypicHaplustert which developed more green color of fruits, thereby, took comparatively longer time for the color break and attain harvest maturity (Srivastava and Singh, 2006). The effect of K was more pronounced in combination with 600 g N + 400 g P $tree^{-1}$ than with 1200 g N + 600 g P $tree^{-1}$ irrespective of soil type. The fruits on TypicUstorthent attained an early maturity compared to those on TypicHaplustert. Increasing the application of K from 0 to 900 g $tree^{-1}$ with 600 g N + 400 g P $tree^{-1}$ or K from 600 to 1500 g $tree^{-1}$ with 1200 g N + 600 g P $tree^{-1}$ produced concurrently a higher Zn concentration in leaf and greater available Zn in both the soils. Such a synergism between Zn and K can be befittingly exploited with the objectivity of FUE vis-à-vis quality citrus production (Srivastava and Singh, 2015). These results suggested that the same orchard could produce a differential response of fertilization, and fertilizer application needs to be tailored even within an orchard instead of practising umbrella kind of recommendation.

Organic management of Nagpur mandarin

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 *Beauveriabassiana* @ 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 disease as compared to other organic treatments (Table 4).

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). 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 microorganisms 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. 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 topsoil. A considerable approach is urgently required to sustain the rising organic food requirement.

Table 4: Scheduling of different components involved in organic management of Nagpur mandarin

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% (20ml L^{-1})	Application at the time of new flush emergence
Beauveriabassiana (BB)	5 g L^{-1}	Application after 15 days of new flush emergence
Azadirachtin	1% (4ml 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	100g $plant^{-1}$	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)

Integrated nutrient management (INM) approach takes into account, the holistic view of the various steps involved in developing and effective fertilization program. 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; 2021a; 2021b).

Table 5: INM-schedule developed for Nagpur mandarin grown in central India

Components of INM	Ambia crop			Mrig crop		
	April	August	November	August	October	January
Vermicompost (kg)	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
Microbialconsortium (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)

FUTURE RESEARCH

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, 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 has been developed (Fig. 2) suiting to different commercial citrus cultivars grown in India has been suggested.

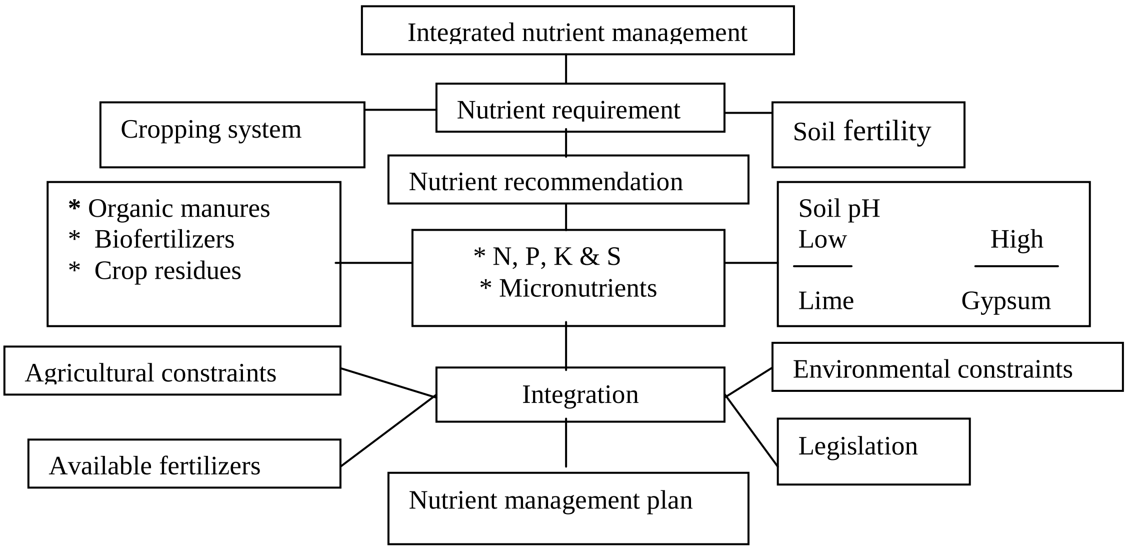

Fig.2. Conceptual framework for integrated nutrient management in citrus

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