Sjournals
Scientific Journals
Scientific Journal of Agricultural (2013) 2(1) 1-14
ISSN 2322-2425

Contents lists available at Sjournals

Scientific Journal of Agricultural

Journal homepage: www.Sjournals.com

Review article

Nutrient management in Nagpur mandarin: frontier developments

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ARTICLE INFO

Article history:
Received 10 January 2013
Accepted 26 January 2013
Available online 28 January 2013

Keywords:
Nagpur mandarin
Nutrient diagnostics
INM
Site specific nutrient management
Microbial consortium

ABSTRACT

Citrus is considered highly nutrient responsive crop. Occurrence of multiple nutrient deficiencies makes the redressal of such nutrient deficiencies all the more complex exercise. Site specific nutrient management studies find a greater weightage over conventional but classical progressive fertilization response studies, if constraint specific fertilization is to be worked out. Simultaneously use of integrated strategies viz., soil application of macronutrients (NPKS) and foliar application of micronutrients (Fe Mn Zn B); fertigation and integrated nutrient management (INM) using rationale of organic manures fortified with microbial consortium based microbial reactor through isolation and characterization of native and dual purpose microbes and inorganic fertilizers have produced encouraging responses to improve production dividends underlying their undeniable utility. But, fertilizer requirement experiments have generated a vast variation in their recommendations depending upon orchard age, soil type and climatic features besides very limited information on micronutrients requirement. Application of these nutrients was substantially reduced (25-30%) using fertigation, thereby, adding an additional component of fertilizer use efficiency which could be effectively achieved through INM as well. There is a still a bigger constraint in form of non-availability of reproducible nutrient diagnostics to determine frequency distribution of nutrient constraints duly verifiable at orchard level. Countrywide studies on development of nutrient diagnostics have suggested optimum range of nutrients based on leaf and soil analysis. For the optimum yield using DRIS (diagnosis and recommendation integrated system) based interpretation tool. Development of morphological descriptors and juice nutrient norms have further aid in defining the nutrient constraint more precisely. Such studies strongly warrant refining diagnostics at regional, and still finer at orchard level, so that once the correct diagnosis of nutrient constraint is made, management becomes a comparatively easier task. Such management study starts with intervention of microbially loaded substrate as a part of rooting medium (rhizosphere engineering) in pre-bearing plants so that an adequate microbial pool of nutrients is built-up by the time plants enter into bearing stage in order to sustain quality production on one hand, and improve orchard longevity on the other hand.

1. Introduction

Differential efficacy of conventional method of fertilization has undoubtedly helped in improving the bulb yield and quality both. But of late, continuous fertilization has failed in maintaining the same yield expectancy on a long term basis due to depletion of native soil fertility (Gupta and Srivastava, 2010; Srivastava and Singh, 2009b). Consequently, the occurrence of multiple nutrient deficiencies raised serious concerns about sustaining crop production (Srivastava and Singh, 2001a) irrespective of agropedological set-up. Sustaining soil health, both from the point of optimum supply of crunch nutrients and soil microbial biomass, attracted massive investigation in the past to overtake fertilizer input induced yield barrier, especially on nutrient depleted soils (Srivastava and Singh, 2004a). Intervention of organic manures in better soil microbial buildup and nutrient cycling is very well documented (Srivastava, 2009b).

Limitations associated with nutrient release pattern of manure synchronizing with physiological demand, uniform availability of quality manure over time and space, equal distribution within the field and safety of organic products, have prompted large scale experimentation with many alternative options. Gradual shift from purely inorganic to organic fertilization warranted many ways and means started gaining wide scale use for enhanced geobiochemical nutrient cycling (Srivastava and Singh, 2008b). Of many constraints impairing the sustained citrus production, nutrient management is claimed to be of paramount importance, and of the viable strategies to fulfill nutritional requirement of crop, INM strategy has proved its utility beyond doubt in order to produce high quality crop, improvements in soil health indices (Srivastava, 2009a). But, most of the INM studies carried on citrus suffered on account of providing a database support for nutrient budgeting vis-à-vis quality yield and changes in biological properties of soil. A holistic benchmark analysis of various components leading to remunerative INM is, therefore, imperative to sustain the pressure of increased nutrient demand accruing from two diverse cultivation methods viz., intensive cultivation (featuring high density planting with low volume fertigation) and extensive cultivation (often adapted under high altitude citriculture). In this background, the significant developments in diagnosis of fertility constraints and their management with emphasis on INM in Nagpur mandarin (*Citrus reticulata* Blanco) are briefly highlighted.

1.1. Production sustainability

Reduced longevity coupled with poor efficiency of commercial 'Nagpur' mandarin orchards collectively render the economics of cultivation non-remunerative more often quite untimely due to unsustainability in production (Srivastava *et al*., 2007). Quadratic regression of orchards age with fruit yield (Fruit yield (Y) = -30.77 + 77.57 x (Orchard age) – 2.32 x^2) and tree efficiency (Tree efficiency (Y) = 7.24 + 0.25 x (Orchard age) – 0.004 x^2) revealed an increase in fruit yield from 37.7 to 66.3 kg $tree^{-1}$ and tree efficiency 8.6 to 11.0 % within 6 to 17 years, and beyond that, both parameters declined invariably. Other biometric relations viz., orchard age versus tree volume (Tree volume (Y) = 11.44 + 3.97 x (Orchard age) – 0.11 x^2) and tree volume versus fruit yield (Fruit yield (Y) = –163.89 + 24.61 x (Tree volume) – 0.20x^2) followed a similar curvilinear quadratic pattern with peak fruit yield coinciding with the orchard age of 17 to 20 years. Such statistical basis can be effectively applied for yield forecasting of citrus orchards on a long term basis (Huchche *et al.,* 2010).

1.2. Soil carbon stock of citrus orchards

Unprecedented decline in productivity of these orchards is a common feature, especially when orchards attain an age beyond 15 years (Huchche *et al*., 2010). Of the many contributory factors, soil nutrient reserve holds prime importance. Stock of total carbon (Organic + Inorganic – C) in soil predominantly governs the transformation and availability of nutrients which in turn displays its direct and indirect implications on crop performance. In the background of key role of soil total-C sustaining long term productivity, the studies were, therefore, carried out with the objective to stock of both organic and inorganic –C in surface and sub-surface soils besides other nutrients and their relationship with productivity of sweet orange orchards.

The total carbon content on average basis was observed to vary from 8.00 to 28.70 g/kg in surface and from 8.60 to 31.70 g/kg in subsurface. A large variation in available nutrients viz., available N from 86.7 to 202.4, P 5.9 to 16.8, K 173.4 to 403.2, Fe 4.3 to 21.7, Mn 4.6 to 16.7, Zn 0.34 to 1.17, B 0.32 to 0.68, and Mo from 0.06 to 0.18 mg/kg was observed with a fruit yield ranging from 40.3 to 147.1 kg/tree. Out of these available nutrients, the fruit yield was positively and significantly correlated with available N (r = 0.952, $P = 0.01$), Fe (r = 0.448, $P = 0.05$), Mn (r = 0.386, $P = 0.01$), and B (r = 0.582, $P = 0.01$). But, the degree of correlationship of fruit yield was highest with organic carbon content (r = 0.986, $P = 0.01$) and to a lesser degree with inorganic carbon content (r = 0.596, $P = 0.01$). However, total carbon content proved to be the best indicator for orchard productivity (r = 0.992, $P = 0.01$). These relationships were more significant at 0-15 cm than 15-30 cm orchards. High performing sweet orange orchards (74.8-147.1 kg/tree) were observed to have 123.3-166.1 available N, 10.7-13.7 available P, 224.0-288.4 available K, 6.4-15.6 available Fe, 14.9-16.7 available Mn, 0.90-1.17 available B, 0.08-0.12 mg/kg available Mo, 5.5-7.8 g/kg organic–C and 11.7-22.6 g/kg inorganic – C (Srivastava, 2009b).

1.3. Delineation of citrus production zones: gis application

Redressal of spatial variability in soil fertility is important to identify the nutrient constraints and productivity zones to rationalize the nutrient use and optimize the factor productivity. Leaf analysis and fruit yield data bank generated through exploration of 7 states across northeast India were analyzed through diagnosis and recommendation integrated system (DRIS) to determine leaf nutrient optima and geographical information system (GIS) to develop spatial variogram of nutrient constraints to delineate major production zones (Srivastava *et al*., 2008).

It is well recognized that crop behavior and soils are not uniform within a given orchard. Resultantly, growers have generally responded to such variability by taking appropriate actions such as improving drainage, changing fertilization time, source etc. Advances in software aided decision support systems (DSS) like DRIS and GIS, have led to usage of newer interpretation tools having much wider application potential. Precision citrus farming basically depends on correctness of measurement and understanding on variability in available supply of nutrients, which can be summarized in three steps namely: i assessing variation, ii managing variation, and iii evaluation of yield response. With this background information, efforts were made to identify major promising productivity zones for concentrated development of 'Khasi' mandarin orchards in northeast India. The zone with no deficiency of Zn-Mg-P-N as Zone I (26-27^0 8-25' 13-43" N latitude; 92^{0}23-59' 0.82-43"E longitude), with an orchard productivity of 69-104 kg/tree and represented by Navgaon (Assam) and Rangpara (Assam) was identified as best production zone followed by Zone II (26-27^0 25-26' 36-51" N latitude; 93^{0}23-58' 2-21" E longitude) having no deficiency of Zn-P-N with an orchard productivity of 52-68 kg/tree and represented by Golpara (Assam), Mirik (Kalimpong), Lisa hills (Darjeeling) and Zone III (26-27^0 6-44' 20-56" N latitude; 91-92^0 33-57' 6-17" E longitude) with no deficiency of Zn-P, having orchard productivity of 23-51 kg/tree and represented by Shergaon, (Arunachal Pradesh), Dirang (Arunachal Pradesh) and Tenga valley (Arunachal Pradesh). Such production zones are of huge advantage to plan and performance based development of citrus industry under any geographical unit (Srivastava *et al*., 2010b).

1.4. Soil properties and orchard efficiency

Orchard efficiency (OE) is one of the indice of evaluating the sustainability in production behaviour of citrus orchards. A wide range of soil properties broadly categorised into particle size distribution, water soluble and exchangeable cations, and soil available nutrients were investigated in relation to efficiency of Nagpur mandarin

(*Citrus reticulata* Blanco) orchards established on smectite rich 3 soil orders (Entisols, Inceptisols and Vertisols) representing 18 locations of central India. The soil properties viz., free $CaCO_3$, clay content, water soluble- and exchangeable-Ca^{2+}, available N, P, and Zn contributed significantly towards variation in OE. The threshold limit of these limiting soil properties was further established using multivariate quadratic regression models as: 132.1 g/kg free $CaCO_3$ ($Y = 43.47 + 26.65\cos(0.027x - 3.24)$), 418.1 g / kg clay ($Y= 60.74 + 51.47\cos(0.0098x + 2.91)$), 149.9 mg/l water soluble Ca^{2+} ($Y = -138.63 + 6.54x - 0.085x^2 + 0.0004x^3 - 0.00007x^4$), 25.9 cmol ($p^+$)/kg exchangeable Ca^{2+}($Y = 52.15 \exp.((-(29.87 - x)^2)/(2 \times 9.22^2))$), 114.6 mg/kg available N($Y = 593.96 + 15.49x + 0.14 (x^2 - 0.0003x^3)$), 12.8 mg/kg available P ($Y = 46.09/(1+389.29\exp.(-0.94x))$), and 0.96 mg/kg available Zn ($Y = 56.09 - 34.02 \exp.(-3.35 x^{5.83})$) in relation to optimum OE of 82.1% (Srivastava and Singh, 2008a). These reference values were very close to those obtained from best fit models, and could be effectively utilised in addressing soil related production constraints for precision-aided citriculture.

2. Nutrient constraints: indices of diagnostics

2.1. Soil fertility indices

The soil test method rests on the assumptions that roots would extract nutrients from the soil in a manner comparable to chemical soil extractants, and that there is a simple direct relation between the extractable concentration of nutrients in the soil and uptake by plants. This is based on the concept that an ideal soil is one where different cations are present in ideal proportions. One serious defect of this approach is that it has to be significantly tailored specific to a soil type, besides adjusting the recommendations in relation to targetted yield (Srivastava *et al*., 2001; Srivastava and Singh, 2001c). Otherwise, soil nutrient depletion has grave implications on production and fruit quality both. In the absence of soil and crop specific fertility ratings, the crop is either under-fertilized or over-fertilized with suboptimum fertilizer use efficiency (Srivastava and Singh, 2001b; Srivastava *et al*., 2008). Differential soil fertility norms were developed using a software-based interpretation tool known as diagnosis and recommendation integrated system (DRIS) for a variety of citrus cultivars grown in soils of contrasting mineralogical buildup, e.g., citrus orchards ('Nagpur' mandarin and 'Mosambi', sweet orange) established on smectite rich shrink-swell soils of central India; kaolinitic-illitic soils / growing as 'Khasi' mandarin in northeast India and illitic soils growing 'Kinnow' mandarin (Table 1). These fertility norms were further validated through the fruit yield obtained from high performance orchards and progressive nutrient response based experiments in field (Srivastava and Singh, 2002; Srivastava and Singh, 2003a; Srivastava and Singh, 2008b; Srivastava and Singh, 2009b).

Table 1
Soil fertility norms (optimum limit) for major commercial cultivars of India

Cultivars	Available macronutrients (mg/kg)			Available micronutrients (mg/kg)			
	N	P	K	Fe	Mn	Cu	Zn
Nagpur mandarin	118.4-121.2	9.2-10.3	178.4-232.5	10.9-25.2	7.5-23.2	2.5-5.1	0.59-1.26
Khasi mandarin	220.8-240.6	6.2-7.8	252-300.8	82.2-114.6	21.4-32.8	0.82-1.62	2.18-4.22
Mosambi sweet orange	107.4-197.2	8.6-15.8	186.4-389.2	4.8-17.3	7.7-15.7	1.76-4.70	0.44-1.03
Kinnow mandarin	118.2-128.4	9.4-16.3	158.3-208.2	3.1-9.3	4.8-7.3	0.58-1.25	0.64-0.98

Source (Srivastava and Singh, 2002; Srivastava and Singh, 2003a; Srivastava and Singh, 2008b; Srivastava and Singh, 2009b).

Various indices of soil fertility were correlated with fruit yield in order to develop multiple-tier system of soil fertility evaluation. The fruit yield was significantly correlated with available N ($r = 0.532$, $P = 0.01$), P($r= 0.412$, $P = 0.01$), K ($r = 0.389$, $P = 0.05$), Fe ($r = 0.508$, $P = 0.01$), Mn ($r = 0.489$, $P = 0.01$), and Zn ($r = 0.532$, $P = 0.01$). While, bacterial and fungal count as an effective parameters of soil microbial population, were more significantly correlated with fruit yield ($r = 0.561$ and $r = 0.612$, $P = 0.01$). With correlation worked to further finer parameters such as soil microbial biomass nutrients (SMBN), viz., C_{mic} ($r = 0.582$, $P = 0.01$), N_{mic}($r = 0.692$, $P = 0.01$) and P_{mic} ($r = 0.698$, $P= 0.01$) further improved, suggesting that microbial biomass nutrients are more sensitive indicators than soil microbial population. Similarly soil enzymes viz., urease ($r = 0.712$, $P = 0.01$), alkaline phosphatase ($r = 782$, $P = 0.01$) and dehydrogenase ($r = 789$, $P = 0.05$) were still highly correlated with fruit yield demonstrating their most sensitive nature to input response in soil fertility fluctuations (Srivastava *et al*., 2010a). These parameters are currently being indexed for further refinement.

2.2. Leaf nutrient Diagnostics

The leaf analysis integrates the effect of many variables like soil and climate, which can be used to a great advantage. The accuracy of foliar analysis depends upon the specificity of sampling with respect to leaf age, position of leaves on the terminal, type of terminal, time of sampling cropping and other growing conditions. The suitable period of leaf sampling was observed at 6-8 months of leaf age in *Ambia* flush (February bloom) in Typic Haplustert soil type and 5-7 months in *Mrig* flush (July bloom) in Typic Ustochrept and Typic Ustorthent soil type. Leaf sampling age followed across various citrus growing countries further suggest that no particular leaf sampling age is followed. It has to be standardized under a given set of growing conditions (Gupta *et al*., 2008; Srivastava *et al*., 1999).

An appraisal of nutrient composition of leaves collected at positions of 2nd, 3rd and 4th leaf on a shoot indicated statistically non-significant variation in the concentration of different nutrients viz., N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn studied in 6 to 8 month old leaves during both the years. These observations indicated that all the leaf positions were equally effective index leaves for finding out the nutrient status of tree. The earlier studies showed that concentration of N, P, K and Ca in 3rd and 4th leaves behind the fruit were nearer to the concentration in leaves from non-fruiting growth. The statistically non-significant variation in leaf N, P, K, Mg, Fe, Mn, Cu and Zn status was observed in 6 to 8 month old leaves considering the leaf sample size varying from 30-70 leaves covering 2 to 10 % trees. These minimum variations in leaf nutrient composition indicated that leaf sample size as low as 30 leaves covering 2 % trees was equally effective for foliar analysis as much as 70 leaves covering even 10 per cent trees. However, many other studies across the world have recommended appropriate leaf sample size as low as 40 leaves and as high as 100 leaves (Srivastava *et al*., 1999).

2.3. Leaf nutrient norms

The leaf nutrients norms were developed employing two diverse diagnostic methods (Field response studies and modelling through DRIS) using different citrus cultivars(Table 2). The difference in diagnostic methods apart from the agroclimate and nutrient uptake behaviour of cultivar are the major contributory factors towards variation in reference values being recommended in relation to yield (Kohli *et al*., 1998; Srivastava and Singh, 2005; Srivastava and Singh, 2006; Srivastava and Singh, 2008b).

Table 2
Leaf nutrient diagnostics (optimum limit) for major citrus cultivars of India

Cultivars	Macronutrients (%)			Micronutrients (ppm)			
	N	P	K	Fe	Mn	Cu	Zn
Nagpur mandarin	1.70 – 2.81	0.09 – 0.15	1.02 – 2.59	74.9 – 113.4	54.8 – 84.6	9.8 – 17.6	13.6 –29.6
Khasi mandarin	1.97 –2.56	0.09 – 0.10	0.99 – 1.93	84.6 – 249.0	41.6 – 87.6	2.13 – 14.4	16.3-26.6
Mosambi sweet orange	1.98-2.57	0.091-0.17	1.33-1.72	69.5-137.1	42.2-87.0	6.6-15.8	11.6-28.7
Kinnow mandarin	2.28-2.53	0.11-0.15	1.34-1.57	82.3-102.8	38.1-41.3	4.8-9.8	14.6-21.6

Source : (Kohli *et al*., 1998; Srivastava and Singh, 2005; Srivastava and Singh, 2008b; Srivastava and Singh, 2009a)

The optimum levels of nutrients for intercropped orchards were collectively determined using non-linear multiple regression analysis ($r^2 = 0.713$, $P = 0.01$) as: 2.18% N, 0.08% P, 1.24% K, 61.2 ppm Fe, 52.3 ppm Mn, 15.8 ppm Cu, and 18.6 ppm Zn in relation to fruit yield of 50.6 kg/tree. In order to obtain fruit yield in intercropped orchards on par to monocultured orchards, different nutrient levels viz., 2.50% N, 0.13% P, 2.78% K, 60.4 ppm Fe, 48.1 ppm Mn, 18.3 ppm Cu, and 29.0 ppm Zn were predicted to be maintained which is a rather difficult task to accomplish. The poor fruit yield of 23.2-46.2 kg/tree was predicted for orchards with intercrops like maize, wheat, and okra. While the optimum level of leaf nutrient concentration vis-à-vis fruit yield predicted for legume based intercropped orchards (67.8-71.3 kg/tree) were significantly higher than monocropped (66.7 kg/tree) and the other intercropped based orchards (Srivastava *et al*., 2007; 2008). The specific intercrop-based yield prediction models could further monitor the desired nutrient level to be maintained in main crop for sustainable citriculture (Table 3).

Table 3
Leaf nutrient composition and fruit yield of main crop ('Nagpur mandarin') under different intercrops in relation to monocropped orchards

Intercrops	Yield		Nutrients concentration in main crop						
	Main crop (kg/tree)	Intercrop (tons/ha)	N	P	K	Fe	Mn	Cu	Zn
			--------(g/kg)-------			-----------(mg/kg)-------			
Wheat (*Triticum aestivum L.*)	33.2	0.80	1.62	0.07	0.89	70.4	54.9	15.3	16.1
Maize (*Zea mays* L.)	28.4	1.20	1.50	0.06	0.82	67.8	50.8	15.7	15.0
Cotton (*Gossypium hirsutum* L.)	50.3	0.10	1.78	0.07	1.30	79.3	58.7	16.8	17.9
Marigold (*Targets exacta* L.)	52.2	2.80	1.96	0.06	1.53	81.4	60.8	18.7	18.6
Chickpea (*Cicer arientinum* L.)	71.7	0.40	2.30	0.11	1.95	87.4	70.4	21.9	22.1
Soybean (*Glycine max*. L.	72.8	0.48	2.40	0.14	2.20	85.6	71.8	22.5	21.9
Okra (*Abelmoschus esculentus* L.)	53.1	0.60	1.88	0.11	1.51	78.8	54.9	19.1	18.2
Intercropped	51.4	-	1.90	0.08	1.44	78.7	59.1	17.1	15.5
Monocropped	68.5	-	2.29	0.13	2.47	79.2	63.8	21.7	23.2
CD (*P* = 0.05)	2.4	-	0.10	0.01	0.20	1.8	3.1	0.92	1.6

CD = Critical difference

Source (Srivastava *et al*. 2007; 2008)

2.4. Nutrient partitioning

Occurrence of nutrient constraint at any phenological growth stage in a highly nutrient responsive crop like citrus could jeopardize the incentive accruing through balanced fertilization (Srivastava and Singh, 2003c). Nutrient partitioning dictated by differential nutrient response across critical growth stages has a strong agronomic and physiological implication in terms of both yield as well as quality. The current state of knowledge on the above subject is very limited. The available K was observed lowest of 200.8 mg/kg at fruit set stage and highest of 302.0 mg/kg at fruit maturity stage (Fig. 1). While leaf K followed the reverse trend being highest (1.25%) at fruit set stage and lowest (0.65%) at fruit maturity stage. The available K in soil showed significant correlation with leaf K only at colour break stage ($r = -0.884$, $P=0.01$). The leaf K accumulation after attaining its peak at fruit set stage continued to drop at later growth stages upto fruit maturity stage. After fruit drop stage, 21.6% of accumulated K in leaf was utilized upto fruit development stage, 11.2% upto colour break stage and beyond this stage a maximum of 25.3% of accumulated K was used upto fruit maturity stage. The water soluble and exchangeable K which constituted 1.2% and 32.8% of K supplying capacity (as a sum of water soluble plus exchangeable plus non-exchangeable K) at fruit set stage reduced to 0.83% and 23.8%, respectively at colour break stage. While non-exchangeable K, which initially formed only 65.8% to 66.0% of K supplying capacity at fruit set stage. These observations showed that crop K demand during fruit set to colour break stages is mainly fulfilled by exchangeable K followed by water soluble K. The water soluble K showed non significant relationship with leaf K at all five growth stages. The exchangeable K was strongly correlated with leaf K ($r = 0.866$, significant at $P=0.01$) at fruit set stage and at fruit maturity stage ($r = 0.911$, significant at $P = 0.01$). While non-exchangeable K showed significant correlation with leaf K at fruit set stage ($r = 0.921$) and at colour break stage ($r = 0.678$) (Srivastava *et al*., 1998).

Dynamics of different nutrients across all six growth stages (January-February as stage I, March-April as stage II, May-June as stage III, July-August as stage IV, September-October as stage V and November - December as stage VI) of Nagpur mandarin trees grown on alkaline calcareous Haplustert was studied (Table 4). Comparison of nutrient dynamics across different growth stages under two diverse performing trees suggested that except stage II, dynamics of different nutrient concentration were significantly different upto stage VI, lending strong support to the fact that nutrient acquisition capacity of sink (i.e. leaves) never attained a complete cessation at any stage of growth. Initially upto stage II, nutrient concentration followed almost a static trend and, thereafter, the expression of sink capacity i.e. partitioning of nutrients became distinctly evident. Interestingly, trees showing high yield performance maintained an optimum nutrient concentration upto stage VI contrary to those with low yield performance. The stages III and IV were identified as most critical stages for nutrient application in order to harness the maximum fertilizer use efficiency through studies on nutrient dynamics. These observations provided valid evidence to recommend the differential nutrient concentration to be maintained at different critical growth stages in order to obtain maximum fertilizer use efficiency vis-à-vis high yield (Srivastava *et al.*, 2010a).

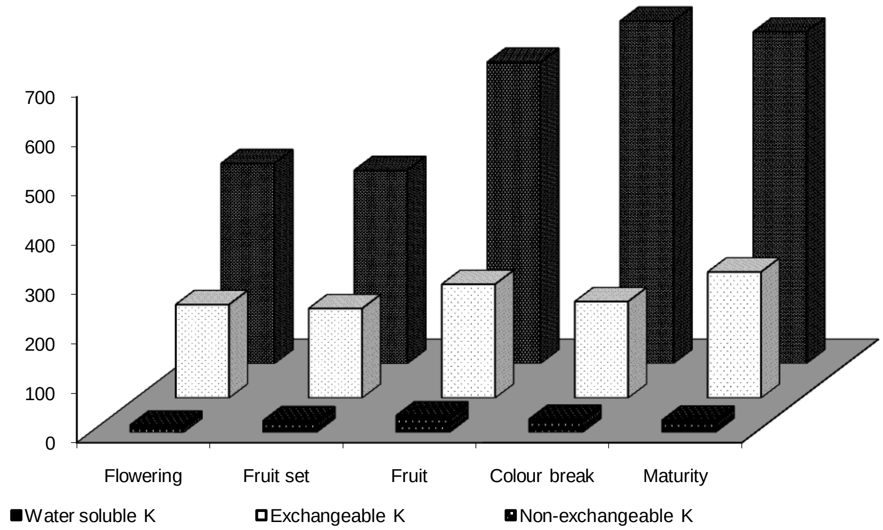

Fig.1. Dynamic of potassium partitioning across critical across critical growth stages of Nagpur mandarin (Srivastava *et al.*, 1998)

Table 4
Nutrient dynamics at critical growth stage of high (52-65 kg/tree) versus low (29- 35 kg/tree) yielding trees

Critical Stages	Yield level	Macronutrients (%)			Micronutrients (ppm)			
		N	P	K	Fe	Mn	Cu	Zn
Stage I (Jan. – Feb.)	High	-	-	-	-	-	-	-
	Low	-	-	-	-	-	-	-
t test (*P=0.05*)		-	-	-	-	-	-	-
Stage II (Mar.-Apr.)	High	1.78	0.07	0.50	21.4	12.5	4.1	8.1
	Low	1.71	0.07	0.47	19.1	10.4	3.1	8.4
t test (*P=0.05*)		NS	NS	NS	NS	NS	NS	NS
Stage III (May – Jun)	High	2.28	0.11	1.21	31.6	18.2	8.1	17.9
	Low	1.94	0.07	0.56	20.2	14.6	5.3	11.3
t test (*P=0.05*)		0.21	0.02	0.24	7.1	1.8	1.1	2.4
Stage IV (Jul.-Aug.)	High	2.32	0.11	1.39	41.8	21.2	9.2	21.8
	Low	2.08	0.08	0.68	26.4	16.1	5.8	16.2
t test (*P=0.05*)		0.18	0.02	0.28	8.4	3.1	1.3	2.8
Stage V (Sept.-Oct.)	High	2.46	0.12	1.52	61.8	31.2	11.3	23.6
	Low	2.12	0.10	0.88	32.4	19.4	6.4	17.8
t test (*P=0.05*)		0.20	0.01	0.37	12.3	4.6	2.4	3.1
Stage VI (Nov.-Dec.)	High	2.38	0.11	1.26	41.6	22.1	8.2	17.6
	Low	1.74	0.07	0.56	21.3	14.7	3.1	10.9
t test (*P=0.05*)		0.24	0.02	0.41	13.1	5.2	2.1	2.8

Source (Srivastava *et al.*, 2010a)

3. Changing strategies of nutrient management

In recent years, soil fertility management has witnessed a fresh look in terms of substrate dynamics-INM, fertigation, SSNM-VRT and fertilization as per nutrient partitioning (crop logging).

3.1. Foliar versus soil application of micronutrients

3.1.1. Foliar application

It must also be cleared when and under which circumstances foliar fertilization is better than common basic soil fertilization, namely e.g. in case of soil deficiencies in nutrients (either due to their total absence or trace elements being bound because of unfavourable soil condition), as this has a negative influence on the plant growth but also in the cases of soil nutrient imbalances (also this having an unfavourable influence, on root absorption or on optimal growth). The experiment was originally initiated in 12-yr-old orchard deficit in N, P, Fe and Zn 2004-07 comparing soil application versus foliar application of Fe, each at three levels viz., 100, 200, and 300 g/tree with constant dose of N, P and K. The basal doses of N, P, K and Fen were supplied uniformly to all the treatments (Srivastava and Singh, 2004b). Amongst the comparison of soil application of $FeSO_4$ (SA_{100}, SA_{200} and SA_{300}) versus foliar application of $FeSO_4$(FA_{100}, FA_{200} and FA_{300}), the foliar application of $FeSO_4$ @ 200 g / tree/ year (T_5) produced the best response over either any of the other foliar applied treatments like T_4, T_6 or soil applied treatments such as T_1, T_2 and T_3 with reference to various parameters viz., flowering intensity, fruit set, tree volume, fruit yield, soil fertility changes, leaf nutrient composition and fruit quality. The treatment T_7 involving combined application of $FeSO_4$ (200 g /tree/ year) and FYM (10 kg /tree/ year) responded much better over treatment T_5 showing the superiority of combined application of $FeSO_4$ and FYM over $FeSO_4$ alone. Water soluble-Fe, exchangeable-Fe and complex-Fe were determined to be the three major soil Fe fractions maintaining Fe-supply to Nagpur mandarin (Srivastava and Singh, 2004b).

3.1.2. Soil application

Infact, soil fertilization is the basic condition for adequate mineral supply to plants since plant's main organ for absorbing nutrient and water is the root. Zinc (Zn) deficiency is the most prevalent nutritional disorder in citrus orchards worldover (Srivastava and Singh, 2009a). The management strategy of Zn deficiency today is still governed by the efficacy of two conventionally used methods of Zn supply to plants via soil or foliar fertilization. A field experiment with 12-yr-old 'Nagpur' mandarin (*Citrus reticulata* Blanco) orchard was, therefore, carried out during 2004–07 comparing soil application versus foliar application of Zn, each at three levels viz., 100, 200, and 300 g /tree with constant doses of N (600 g/tree), P (200 g/tree), K (300 g/tree), and Fe(60 g/tree) on Haplustert soil type with reference to response on flowering intensity, fruit set, tree volume, fruit yield, changes in soil fertility/leaf nutrient status, fruit quality, and transformation of native soil Zn fractions. Soil application of Zn at all the three levels, produced significantly higher increase in tree volume over foliar application on equivalent rates viz., T_1 (2.53 m^3) vs. T_4 (2.06 m^3) and T_2(4.30 m^3) vs. T_5 (2.23 m^3). The yield-determining parameters like flowering and fruit set intensity (no./m shoot length) were, respectively, much higher with soil applied (135.74 and 21.90) than foliar applied Zn (31.20 and 11.6). These observations set the favorable conditions required for yield response, e.g., all the three treatments involving soil application of Zn, T_1 (32.1 kg/ tree), T_2 (52.6 kg/ tree), and T_3 (51.8 kg/tree) were correspondingly superior over T_4 (22.5 kg/tree), T_5 (34.3 kg/ tree), and T_6 (42.1 kg / tree) as foliar application treatments. All the three major fruit quality parameters (juice, acidity, and TSS) were likewise more influenced by soil application than foliar application of Zn. Improvements in soil Zn fractions (mg/kg) viz., exchangeable Zn (0.25–0.60), complex-Zn (2.71 to 4.86), organically bound Zn (0.86 to 2.0), and Zn-bound to carbonates and acid soluble minerals (2.56–4.96) were observed in response to Zn fertilization with treatments T_1–T_3. On the other hand, foliar applied Zn treatments (T_4–T_6) produced no such changes in any of the soil Zn fractions (Srivastava *et al*., 2008).

3.2. Organic manuring versus inorganic fertilization

Long term studies comparing organic versus inorganic fertilization showed that no significant difference with reference to either fruit yield or fruit quality with inorganic fertilizers maintaining better available pool of nutrients in soil. Response of different organic manuring treatments on the changes in oil organic carbon content was studied. The maximum net increase in organic carbon content with first 5 years was produced by treatment effect of vermicompost green manure (0.28%) poultry manure inorganic fertilizers (0.18%), followed by Response of inorganic fertilizers on comparatively marginal increase in organic carbon content refutes the conventional notion that long sustained use of inorganic fertilization has incurred, depletion in soil organic carbon, responsible for deterioration in soil quality and inducing nutrient mining (Gupta and Srivastava, 2010).

3.3. Residual versus cumulative fertilizer response

In perennial crop like citrus, the information on residual versus cumulative response of fertilizers is limited. Earlier multilocation field experiments helped to establish the optimum fertilizer requirements varying 600-800 N – 200-400 P_2O_5 – 100-300 g K_2O/ tree/ year on Ustorthents – Haplusterts. Similarly, the optimum Zn and Fe (200-300 g as $ZnSO_4$ and $FeSO_4$, respectively, /tree/year) requirement was worked out through multilocation experiments on Haplusterts (Srivastava, 2009a). These were treated as recommended doses of fertilizers, and tested for their residual versus cumulative effects in long term experiments laid out on Haplustert. The response of application of 1/6th of RDF for 5 years on canopy volume, fruit yield and quality was significant (Srivastava *et al.*, 2008). Similarly, the response of agewise nutrient dose was also significant including the interaction effect, suggesting that the response of fertilization was gradually getting evident with time lapse. The observations are suggestive of the fact that initially the above nutrient doses imparted reduction in soil fertility over initial fertility, but with fourth year onward, their response on soil fertility changes became significantly evident (Table 5).

Table 5
Changes in organic carbon stock (%) over initial values due to different organic manuring treatments to 'Nagpur' mandarin in central India (Pooled data 2004-2009).

Treatments	Initial	04-05	05-06	06-07	07-08	08-09	Net increase over initial
T_1 - Farmyard manure	0.50	0.59	0.57	0.56	0.62	0.68	0.18
T_2 - Vermicompost	0.51	0.58	0.61	0.64	0.78	0.79	0.28
T_3 - Poultry manure	0.54	0.58	0.63	0.65	0.64	0.72	0.18
T_4 - Neem cake	0.52	0.54	0..57	0.60	0.62	-	0.10
T_5 - Green manure (Sunhemp)	0.58	0.62	0.68	0.74	0.85	0.86	0.28
T_6 - Inorganic fertilizers (NPK)	0.54	0.56	0.55	0.57	0.62	0.61	0.17
CD (*P=0.05*)	NS	0.02	0.02	0.04	0.11	0.08	0.02

T_1 – T_4 were computed on N-equivalent basis T_1(60 kg/tree), T_2(40 kg/tree), T_3(30 kg/tree), T_4(20 kg/tree), T_5 (seeds of *Crotolaria junces* were sown beneath tree canopy), and T_6(600 g N – 200 g P_2O_5 – 100 g K_2O/ tree)
Source (Gupta and Srivastava, 2010)

3.4. Fertigation and fertilizer use efficiency

Various irrigation and fertilizer levels singly and in combination were evaluated through fertigation in terms of response on the tree growth, fruit yield, quality and leaf nutrient composition of Nagpur mandarin (*Citrus reticulata* Blanco) budded on rough lemon (*Citrus jambhiri* Lush.) on an alkaline calcareous Lithic Ustochrept under hot sub-humid tropical climate of central India. Irrigation at 20 % depletion of available water content and fertilizer treatment of 500 g N - 140 g P_2O_5 - 70 g K_2O / tree/ year individually were observed to be optimum irrigation and fertilizer requirement, respectively. Implementation of fertigation helped in reducing the fertilizer and water requirement by 33% and 40%, respectively (Shirgure *et. al.*, 2003; Srivastava *et al.*, 2003).

3.5. Spatial variation in soil fertility and site specific nutrient management

Site specific nutrient management (SSNM) offers the most appropriate option to address the spatial variation in soil fertility using variable rate fertilization (VRF) as per soil test values. The spatial variability in available NPK Fe Mn Cu and Zn was measured through exhaustive grid sampling and their geocoding. Accordingly, two contrasting soil types viz., Typic Ustorthent and Typic Haplustert showed a significantly different magnitude of response of Nagpur mandarin to fertilization (Table 6). Best fertilizer treatments in terms of response on canopy growth, fruit yield, fruit quality and leaf nutrient concentration were observed to be 1200 N - 600 P_2O_5 - 600 K_2O - micronutrients (300 g each of $ZnSO_4$ and $MnSO_4$ alongwith 100 g borax /tree) on Typic Ustorthent soil type. While on Typic Haplustert soil type, 600 g N - 400 g P_2O_5 - 300 g K_2O + micronutrients (300 g each of $ZnSO_4$ and $MnSO_4$ alongwith 100 g borax/tree) and 400 g $MgSO_4$ / tree proved most effective. Higher application of K at the rate of

900 g /tree alongwith 600 g N - 400 g P_2O_5 produced much higher acidity and induced late maturity on Typic Haplustert when compared in combination with 1200 g N - 600 g P_2O_5 (Srivastava *et al.*, 2006). Such a differential response of fertilization showed no similarity with recommended fertilizer doses earlier worked out through multilocation trials.

Table 6
Response of site specific fertilizer treatment compared to farmers'practices/ recommended doses of fertilizers (Nagpur mandarin)

Treatments	Yield (kg/ tree)	Leaf nutrients concentration				Fruit quality (%)		
		Macronutrients (%)			Micronutrient (ppm)	Juice	TSS	Acidity
		N	P	K	Zn			
Soil Type -1: Shallow soil (Typic Ustorthent)								
Farmers' Practices **T_5** (N_{600} + P_{400} + K_0 + M_1S_1)	7.7	1.98	0.07	0.99	17.8	44.5	0.62	8.2
Recommended doses of fertilizers **:** **T_{16}** (N_{600} + P_{200} + K_{100}) – RD	10.4	2.04	0.09	1.15	21.2	45.7	0.56	9.1
Site specific treatment: T_9 (($N_{12\ 00}$ + P_{600} + K_{600} + M_1S_1)	14.7	2.38	0.13	1.35	25.7	48.3	0.48	9.6
Soil Type -2: Deep soil (Typic Haplustert)								
Farmers' Practices (T_5 : N_{600} + P_{400} + K_0 + M_1S_1)	11.9	2.07	0.08	1.05	19.2	45.5	0.77	8.1
Recommended doses of fertilizers : **T_{16}** (N_{600} + P_{200} + K_{100}) – RD	16.2	2.40	0.10	1.29	22.1	46.9	0.62	8.4
Site specific treatment: (T_{6} - N_{600} + P_{400} + K_{300} + M_1S_1)	19.0	2.55	0.13	1.67	31.0	49.8	0.53	9.0

M_1 stands for application of 300 g each of $ZnSO_4$, $FeSO_4$, $MnSO_4$ and 100 g borax/tree; Mo stands for no application of micronutrient fertilizers; S_1 stand for application of 400 g $MgSO_4$ tree^{-1} and 100 g elemental S/tree; So stands for no application of Mg and S; RD stands for recommended doses of fertilizers
Source (Srivastava *et al.*, 2006).

Similarly, SSNM studies carried out on sweet orange showed far superior results over fertilizer treatments based on existing recommendations or farm practice. The higher net economic return with SSNM validates its importance in large-scale orchard adoption to minimize the gap between actual and potential productivity. The SSNM treatment in this study provided a comparatively higher net return than those received from farmer's fertilizer practice or the recommended dose of fertilizers. These results clearly showed that some revision of the current fertilizer recommendation system is required if full productivity potential on a given soil type is to be realized. SSNM could be further fitted precisely into precision Citriculture combining multiple fertilizer application through fertigation with canopy sensors so that both irrigation and fertilizers are jointly given according to canopy size of trees within an orchard (Srivastava *et al.*, 2008).

3.6. Microbial consortium and INM

Exploiting microbial synergisms is one of the popular methods of substrate dynamics and associated changes in nutrient environment of rhizosphere. A large number of microbes were isolated from rhizosphere of citrus orchards established on acid soils of northeast India, neutral alkaline soils of central India and northwest India. The microbial diversity existing within top 0-20 cm rhizosphere soil was characterized and isolated the promising microbes. These microbes comprised of N-fixers (*Azotobacter chroococcum* and *Azospirillum brasilens*), P-solubilizers fungi (*Trichoderma harzianum* and *T. viride*) and P-solubilizing bacteria viz., *Pseudomonas fluorescens,* *P. striata, Bacillus subtilis, B. mycoides, B. polymyxa, B. stearothermophilus, B. cereus, B. coagulans, B. licheniformis, B. circulans, B. pumilus,* and *B sphaericus*. The efficient microbes isolated through soil (*B. polymyxa* 12 x 10^3 cfu /g, *P. fluorescens* 5 x 10^3 cfu /g, *T. harzianum* 12 x 10^3 cfu /g, *A.chroococcum* 16 x 10^3 cfu /g, and *B. mycoides* 3 x 10^3 cfu / g) were brought in broth in order to achieve much high population as a substantial value addition (*B. polymyxa* 33 x 10^7 cfu /ml, *P. fluorescens* 14 x 10^7 cfu /ml *T. harzianum* 32 x 10^7 cfu/ml, *A. chroococcum* 10 x 10^6 cfu/ml and *B. mycoides* 7 x 10^5 cfu /ml) known as microbial consortium (Srivastava *et al*., 2010a) and, then evaluated for 3 weeks for population changes at weekly interval in a complete consortium mode (Table 7). The efficacy of microbial consortium was tested through 40 days long incubation study using organic manure as FYM (OM) and inorganic fertilizers (NPK as IF) in different combinations viz., T_1 = 100% OM + MC, T_2 = 10% OM + 90% IF + MC, T_3 = 25% OM + 75% IF + MC, T_4 = 50% OM + 50% IF + MC, T_5 = 75% OM + 25% IF + MC and T_6 100% IF + MC.

The highest bacterial population was observed with T_1 (52 x 10^4 cfu / g), followed by T_5 (38 x 10^4 cfu / g), T_3(26 x 10^4 cfu / g), T_4(21 x 10^4 cfu / g), T_2 (7 x 10^4 cfu / g) and T_6 (6 x 10^3 cfu / g) in decreasing order. Different INM-based treatments involving MC so developed displayed distinctive advantage over IF in the first pre-bearing 5 years of field evaluation in terms of soil microbial biomass nutrients (C_{mic}, N_{mic}

Table 7
Evaluation of different microbes in consortium mode through a incubation studies

Nature of microbe	Microbial population in soil (cfu / g)	Microbial population in broth (cfu /ml)	Microbial population in consortium mode after(cfu /ml)		
			7 days	14 days	21 days
1. *Bacillus polymyxa*	12 x 10^3	33 x 10^7	42 x 10^5	61 x 10^6	66 x 10^7
2. *Pseudomonas fluorescens*	5 x 10^3	14 x 10^7	58 x 10^6	88 x 10^6	18 x 10^7
3. *Trichoderma harzianum*	12 x 10^3	32 x 10^7	50 x 10^6	81 x 10^6	38 x 10^7
4. *Azotobacte chroococcum*	16 x 10^3	10 x 10^6	7 x 10^6	16 x 10^6	22 x 10^7
5. *Bacillus mycoides*	3 x 10^3	7 x 10^5	12 x 10^4	10 x 10^4	14 x 10^4

Source (Srivastava *et. al*., 2010a)

and P_{mic}) and carbon loading of soil besides bringing significant changes in soil fertility (Srivastava *et al*., 2002). Similar promising response on both root and shoot weight were observed in nursery plants treated with MC compared to untreated plants (Table 8). These results suggested two cardinal points viz., i. the developed microbial consortium holds a good promise in possible INM format and ii. exclusive combination with inorganic fertilizers produced depleting effect of population buildup (Srivastava and Singh, 2003b). The microbial consortium thus developed is currently being assessed through long term field study on development of suitable INM module.

Table 8
Evaluation of microbial consortium in nursery plants

Treatment	Root weight (g)	Shoot weight (g)	Root:shoot	Stem diameter (mm)
Seedlings (Period: 45 days)				
Control	3.17	9.55	1:3.1	9.1
Treated	10.55	28.37	1:2.7	12.3
$t_{P = 0.05}$	5.2	6.9	-	1.86
Buddlings (Period: 124 days)				
Control	4.27	10.3	1:2.4	22.1
Treated	11.3	24.5	1:2.1	29.3
$t_{P = 0.05}$	2.1	6.1	-	2.10

Source (Srivastava *et. al*., 2010a)

4. Perspectives

Out of different diagnostic methods in practice, only leaf analysis complimented by soil analysis, has made some headway. The researches on DRIS with citrus as test crop have shown some distinct advantages over conventional leaf analysis-based interpretation tools in order to make diagnosis possible at any stage of crop development. In this regard, ideally we need 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. This could be further refined through crop logging for various nutrients. Geo-referenced soil sampling has proved to be an effective tool in defining soil variability within an orchard. Once the critical soil properties are identified, the procedural steps can be evolved to address the inconsistency in fertilization response could be conveniently worked out.

The conditions under which citrus trees are most likely to respond to corrective nutrient treatments are still not fully understood. The role of different nutrients in flowering, fruit set, fruit quality (external and internal) and juice shelf life; models defining the critical periods of nutrient supply to assure sustained response and its uptake for helping the management decision under different citrus-based cropping systems; and devising means for improved nutrient uptake efficiency need to be attempted to unravel many of the complexities involved with nutrition. However, using newly emerging techniques of nutrient management like open field hydroponics with restricted root zone and sensor-based SSNM, concerted efforts would be required to develop yield monitors in the light of adequacy level of plant nutrition vis-à-vis development of precision-based citrus production system. These wayforward approaches can be summarized below:

i. Role of improved plant nutrition on changes on anti-oxidant versus drought tolerance

- Field identification of different nutrient deficiencies and their profiling for different antioxidants
- Evaluation of changes in anti-oxidants in response to different nutrients in a progressive nutrient field experiment.
- Establishment of relation between antioxidant systems with indices of drought tolerance.

ii. Expansion of DRIS indices and their validation to different citrus varieties and development of soil fertility diagnostics as per soil type

- Survey and establishment of database for soil analysis, leaf analysis and fruit yield from across different belts
- Modelling for nutrient diagnostics vis-à-vis climate change
- Validation of nutrient diagnostics.

iii. Development of citrus cultivar specific INM module and carbon sequestration vis-à-vis microbial turnover of nutrients and substrate dynamics versus nutrient transformation

- Survey of cultivar specific citrus orchards and intensive collection of soil samples from rhizosphere zone
- Isolation and characterization of microbial diversity within cultivar specific rhizosphere.
- Identification of promising microbes through incubation studies and development of microbial consortium
- Evaluation of microbial consortium in INM module and recommendation for appropriate INM module depending upon region specific varieties.

iv. Development of SSNM into Senor-based DSS (Decision Support System) for variable rate fertilization and improved fertilizer use efficiency

- Development of spatial soil fertility variogram (by developing GPS and GIS database) as decision support tool for precision fertilizer recommendation.
- Development of SSNM strategy and evaluation through long term field experiments
- Development of logical relationship between canopy volume (using canopy sensors) and fertilizer requirement
- Identification and evaluation of variable rate fertilization for possible improvements in fertilizer use efficiency through field experimentation.

v. Development of protocol for organic cultivation of citrus

- Identification of components of organic citrus and nutrient profiling of available organic fertilizer sources of manures.
- Field evaluation of organic practices involving nutrition, insect pests and disease/management alongwith influence on post-harvest handling and processing.

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