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Review article

Site specific nutrient management in citrus

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ABSTRACT

Crop behaviour and soils are not uniform within an orchard which have been the triggering factor for not able to break yield barrier through effective nutrient management programme. Better response of site specific nutrient management (SSNM) over recommended doses of fertilizers (RDF) including those of farmers' conventional fertilization practices (FFP) signals a wake-up call to address the fertilizer requirements on the principles of SSNM, if the full potential of orchard productivity has to be realized on a given soil type. These observations also warrant to tailor the fertilizer application on the basis of spatial variation in available supply of nutrients in soil and tree canopy size within an orchard to minimize the gap between actual and potential productivity of citrus orchards.

1. Introduction

Citrus as a perennial crop occupies globally a place of prime importance amongst major fruit crops including India. The cultivation of citrus in India is dominated by three major cultivars viz., mandarin, sweet orange, limes and lemons occupying collectively an area of 9.23 lakh ha with a production of 86.08 lakh tons and productivity of 9.3 tons/ha. Nagpur mandarin in India is grown in 0.97 lakh ha area under current production with total production of 8.81 lakh tons and productivity of 9.l tons/ha, respectively. The productivity of mandarins within the country is highly variable in space (due to heterogeneous soils) and time (due to varying weather conditions), the major constraint of them emerges an inadequate and unbalanced fertilizer use.

An extensive survey of 18,000 ha area of Nagpur mandarin orchards of central India showed large scale deficiency of three nutrients viz., N, P and Zn, with most of the sites expressing multiple nutrient deficiencies (Srivastava and Singh, 2002; 2005). Reduced longevity of commercial citrus orchards due to varying nutritional constraints is one of the major production related constraint heavily responsible for poor orchard efficiency(Srivastava and Singh 2008a; 2008b). Experiments have shown that soils initially rich in fertility developed a variety of nutrient constraints following the non-synchronisation in demand and supply of nutrients with the growing orchard age (Srivastava *et al*., 1998). For example, when exchangeable K is not rapidly replenished, crops start drawing on the non-exchangeable K, resulting in soil K mining and depletion in soil K reserve. A nutrient level sufficient for one particular productivity level may not hold sufficient for other higher productivity levels.

Knowing the required nutrients for all stages of growth, and understanding the soil's ability to supply those needed nutrients are critical to profitable crop production. The recommendations on fertilizer application may not, however, produce the same magnitude of results when practised on an orchard of large area, because of its inability to accommodate variation in soil fertility status(Srivastava *et al*., 2010). Slight changes in the nature of soil, local climate, and agronomic practices etc. may seriously affect the nutrient utilisation capacity of the plant. However, application of a single rate of nutrients may result in over-application of nutrients at some sites and under-application at others often lead to reduced fertilizer use efficiency. Under such circumstances, site specific nutrient management (SSNM) is adopted in big orchards requiring differential fertilizer treatments in patches as per the nature of surface and sub-surface soil properties so as to improve the orchard efficiency (average yield of specified trees in relation to average orchard yield) in ultimate terms (Srivastava *et al*., 2007).

SSNM 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 crop's need keeping in view, the capacity of these soils to fulfill various demands ((Srivastava *et al*., 2006; 2009). To achieve this, it is necessary to keep an overall nutrient balance in relation to total crop load. 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. Conventionally designed long term fertilizer trials revealed that: i. omission of limiting macro- or micronutrients led to their progressive deficiencies due to heavy removals; ii. sites initially well supplied with P, K or S become deficient when continuously cropped using N alone and iii. fertilizer rates considered optimum still resulted in nutrient depletion at higher productivity levels, if continued, become sub-optimum rates. There is a strong necessity to keep overall nutrient balance in relation to total crop load. Application of a single rate of nutrients may result in over-application of nutrients at some sites and under-application at other sites, often lead to reduced fertilizer use efficiency. Under such circumstances, SSNM is adopted in big orchards requiring variable precision application as per soil variability so as to improve the orchard efficiency (average yield of specified trees in relation to average orchard yield) in ultimate terms.

2. SSNM Objectives

The site specific nutrient management is usually carried out with the objectives: i. identification and quantification of the variability of soil physical and chemical properties ii. understanding the impact of soil variability on crop growth, yield profitability and iii. management of soil variability to improve production, profits, and reduce environmental impact.

2.1. SSNM-based fertilizer requirement : steps involved

The following steps are involved in arriving at fertilizer requirement based on the principles of SSNM. Below given is the hypothetical example as a case study:

Step i. : Estimating target yield
- Actual yield = 8 Mg ha^{-1}
- Target yield = 10 Mg ha^{-1}

Step ii. : Estimating nutrient requirement to get target yield

- 1 Mg of Nagpur mandarin removes : 5 Kg N, 0.50 kg P, and 3 kg K
- Nutrient demand will be : 50 kg N, 5 kg P, and 30 kg K

Step iii. : Estimating indigenous nutrient supply from soil (based on our earlier studies dealing with progressive nutrient response experiment)

- Nutrient omission plots : Yield range : 5.5-6.0 Mg ha^{-1} (-N)

6.5 - 7.0 Mg ha^{-1} (-P)
7.0 – 7.5 Mg ha^{-1} (-K)

- Amount of supply of nutrients from soil : 30 kg N, 3.5 kg P and 22 kg K

Step iv : Calculating fertilizer requirement

- Nutrient requirement : defined as the amount of nutrients added for producing the target yield minus the amount of indigenous nutrient (soil and other sources)
- Fertilizer recovery (%) defined as the percentage of nutrients absorbed by a crop out of the total amount of fertilizers applied

$$FR = \frac{N_0 - (N_{SS} - N_{so})}{RE}$$

Where : N_0, Amount vis-a-vis target yield; FR, Amount of fertilizer required; N_{SS},Amount of indigenous soil; N_{so}, Amount from other sources and; RE, Fertilizer recovery

- Nitrogen requirement : 50 – 30 = 20 kg N $ha^{-1,}$
- Phosphorous requirement : 5 – 3.5 = 1.5 kg P ha^{-1}
- Potassium requirement : 30 – 22 = 8 kg K ha^{-1}

N recovery : 35 – 40%; P recovery : 8 –10%; N recovery : 40–50%

Amount of nitrogen required : 20 x100/40 = 50 kg N ha^{-1}
20 x 100/35 = 57 kg N ha^{-1}

Amount of phosphorous required : 1.5 x 100/10 = 15 kg P ha^{-1}
1.5 x 100/8 = 19 kg P ha^{-1}

Amount of potassium required : 8 x 100/40 = 20 kg K ha^{-1}
8 x 100/50 = 20 kg K ha^{-1}

3. Brief review of literature

Spatial characterization of the variability of soil physico-chemical properties is a fundamental element of i. soil quality assessment, ii. modeling non-point source pollutants in soil, and iii. site-specific crop management. The heterogeneity of soil physico-chemical properties has been known since the classic study of Nielsen *et al.* (1973), which characterized the spatial variability of soil-water properties for a 150 ha field at the University of California's West Side Field Station in the San Joaquin Valley. The characterization of soil spatial variability is fundamental to the understanding of landscape-scale processes of soils. Delineation of the spatial variation of soil properties is a crucial element of: i. non-point source pollutant transport in the vadose zone, ii. soil quality assessment, and iii. site-specific crop management. The protocols developed by Corwin and Lesch (2005) for site specific evaluation of soil proportion (EC appraisal) comprised of eight general steps : i. site description, and EC_a, survey design; ii. EC_a data collection with mobile GPS-based equipment; iii. Soil sampling design; iv. Soil core sampling; v. laboratory analysis; vi. calibration of EC_a to EC_e; vii. spatial statistical analysis; viii. GIS database development and graphic display. For each outlined step detailed discussion and guidelines.

Selected soil properties at six profile depths (0-1.5 m), water table depth, ground conductivity, leaf chlorophyll index, leaf nutrients and normalized difference vegetation index were compared at 50 control points in a highly variable 45-ha citrus grove. Regression analysis indicated that 90% of spatial variation in tree growth, assessed by NDVI (Normalised Difference Vegetation Index), was explained by average soil profile properties of organic matter, color, near-infrared reflectance, soil solution electrical conductivity, ground conductivity and water table depth. Regression results also showed that soil samples at the surface only (0-150 mm) explained 87% of

NDVI variability with NIR (Near Infrared Reflectance) and DTPA-extractable Fe. Excessive available copper in low soil organic matter areas of the grove apparently induced Fe deficiency, causing chlorotic foliage disorders and stunted tee growth. The semivariograms of selected variables showed a strong spatial dependence with large ranges (varied from 230 m to 255 m). This grove can be divided into different management zones of the basis of easily measured NDVI and/or soil organic matter for variable rate application of dolomite and chelated iron to improve tree performance (Qamar-uz-Zaman and Schumann, 2006).

Numerous experimental results have proved that application of SSNM technologies to improve productivity in the country is a necessity. However, large scale implementation of SSNM technologies has proved elusive due to lack of adequate soil testing infrastructures. Large variation in tree canopy and subsequently, the tree-to-tree yield difference are common in many of the large size citrus orchards. Knowing the required nutrients for all stages of growth, and understanding the soil's ability to supply those needed nutrients are critical to profitable crop production. The recommendations on fertilizer application may not, however, produce the same magnitude of yield response when practised in an orchard of large area, because of its inability to accommodate variation in soil fertility status. Slight changes in the nature of soil, local climate, and agronomic practices etc. may seriously affect the nutrient utilisation capacity of the plant. In a study by Ozcan *et al.* 2003, citrus plantation maps overlaid on soil series maps demonstrated that the citrus has not been planted completely on suitable areas. Land suitability assessment showed that citrus plantation in Arikli series would result in 40% yield loss and 58% of land is not used at its potential.

With new advances in technology, grid sampling for precision citriculture is increasing. The first step in the process is to divide large fields into small zones using a grid. Next, a representative location within the grid is identified for precision soil sampling. Grid sampling is integrated into global positioning system (GPS) based soil sampling and nutrient-mapping that in turn uses a geographic information systems (GIS) to employ variable rate technology for fertilizer applications (Schumann *et al*., 2003; Zaman *et al*. 2005). In this context, Geographical Information Systems(GIS)-based fertility mapping could provide an alternative avenue of assessing and managing nutrient variability in agricultural holdings.

Variable rate fertilization is one of the most effective techniques for rationale use of fertilizers executed by matching the fertilizer rate with tree requirement on a per tree size basis. Site specific management of 17-year old 'Valencia' grove (2980 trees) in Florida using automated sensor system equipped with differential global positioning system and variable rate delivery of fertilizers (135-170 kg N $ha^{-1}year^{-1}$) on a tree size basis (0-240 m^3tree^{-1}), achieved a 38-40% saving in granular fertilizers cost. While, conventional uniform application rate of 270 kg N $ha^{-1}year^{-1}$ showed that trees with excess nitrogen (>3%) had canopies less than 100 m^3 with lower fruit yield and inferior quality (Zaman *et al.,* 2005). In another long term experiment, the large fruit yield difference of 30.2 and 48.9 kg $tree^{-1}$ initially observed on shallow soil (Typic Ustorthent) and deep soil (Typic Haplustert) in an orchard size of 11 ha, reduced to respective fruit yield of 62.7 and 68.5 kg $tree^{-1}$ with corresponding fertilizer does (g $tree^{-1}$) of 1200 N – 600 P – 600 K – 75 Fe - 75 Mn -75 Zn – 30 B, and 600 N – 400 P – 300 K – 75 Fe – 75 Mn –75 Zn – 30 B, suggesting the necessity of fertilizer application on variable rate application for rationality in fertilizer use (Srivastava *et al.,* 2006)

Analysis of tree size of 3040 trees space of 40-acre grove showed a skewed distribution with 51.1% trees having 25-100 m^3 $tree^{-1}$ size classes and a median size of 82 m^3 $tree^{-1}$. At a uniform fertilization rate of 240 kg N $ha^{-1}year^{-1}$, the leaf N concentration of 12 trees with different canopy sizes that were randomly sampled in the grove showed optimal levels (2.4-2.6%) in the large trees and excess levels (> 3%) in the medium to small trees (Tucker *et al*. 1995). From the regression line, trees with excess N had canopies < 100 m^3tree^{-1}, and constituted 62% of the grove. Under such conditions, variable rate fertilization can, therefore, save production costs, reduce N leaching, and increase yields per variable acre (Schumann *et al*., 2003). A 30% saving in granular fertilizer cost was estimated for this 'Valencia' grove if variable N rates were implemented on a per tree basis ranging from 129 to 240 kg N $ha^{-1}year^{-1}$. For comparison purposes, the eastern half of the grove received the full uniform rate of 240 kg N $ha^{-1}year^{-1}$. No fertilizer was allocated by spreader to skips or resets of one-to-three year age. Due to a very restricted root system, new resets should be fertilized individually, usually by hand (Tucker *et al*., 1995), ensuring that the granules are accurately placed adjacent to the tree. Application of variable fertilizer rate technology in this grove saved in nitrogen equivalent to the 32 to 43% reduction of N rates achieved through use of fertigation and foliar sprays of urea (Lamb *et al., 1*999).

4. SSNM in Citrus

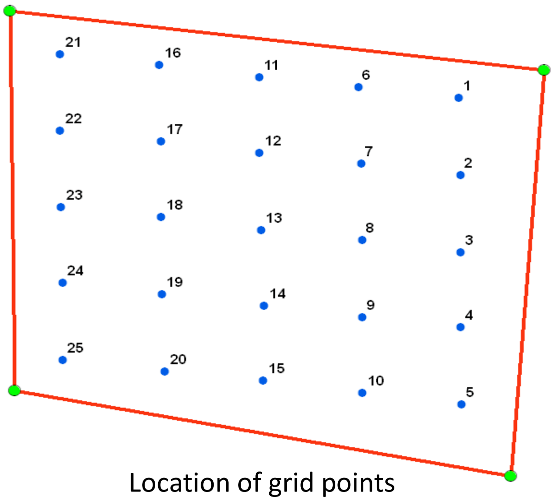
SSNM in Nagpur Mandarin

The studies carried out in Nagpur mandarin grown on Vetisols under subhumid tropical climate of central India are highlighted below:

Spatial Variability in Soil Fertility : An exhaustive grid-based (36 x 36 m grid size) soil sampling within an orchard (Fig.1) showed a large variation in all the macro-(NPK) as well as micronutrients (Fe Mn Cu Zn). These values within the orchard varied extensively viz., alkaline $KMNO_4$ distilled N from 90-188 mg kg^{-1}, Olson-P 6-14 mg kg^{-1}, NH_4OAc-K 94-134 mg kg^{-1}, DTPF-Fe 6-18 mg kg^{-1}, DTPA-Mn 4-14 mgkg^{-1}, DTPA-Cu 6-14 mgkg^{-1} and DTPA-Zn 0.40-0.68 mgkg^{-1} compared to conventional soil test values of 102.00 mgkg^{-1} alkaline $KMNO_4$-N, 7.1 mg kg^{-1} Olson-P, 106.2 mg kg^{-1} NH_4OAc-K, 13.3 mgkg^{-1} DTPA-Fe, 11.0 mg kg^{-1} DTPA-Mn, 8.1 mg kg^{-1} DTPA-Cu and 0.58 mg kg^{-1} DTPA-Zn. Using these variations, spatial variaograms on GIS (Geographical Information System) version Arc 3.5 and accordingly the spatial variograms were developed (Fig. 2 and Fig. 3). Based on these variations, two soil types viz., Typic Ustorthent (Site 1) and Typic Haplustert (Site 2) of varying nutrient supplying capacity was identified for carrying out SSNM experiment in order to rationalize the fertilizer use for precision citriculture.

Geographical location of experimental orchard at Narkhed, Nagpur

Location of grid sampling (36 m x 36 m) within the identified orchard



Location of grid points

Experimental Set-up: The study included two distinct yet representative soil types. Site 1 had a relatively shallow soil profile classified as a Typic Ustorthent (Entisol), while Site 2 was a Vertisol with a deeper soil profile classified as Typic Haplustert (Table 1) at Narkhed teshil, Nagpur. These soil types are both derived form basaltic parent material with typical soil profiles predominantly rich in expanding-type, 2:1 montmorillonitic clay minerals characteristics of the sub-humid typical climate of central India. The Vertisol at Site 2 has interesting slickensides strongly expressed within 52 cm to 1.48 m depth, an indication of significant shrink and swell activity. Established orchards were 12-years old at Site 1 and 8-years old at Site 2. Plant to plant and row to row distances were 6 m. Both orchards used a scion of Nagpur mandarin (*Citrus reticulata* Blanco) budded on rough lemon rootstock (*Citrus jambhiri* Lush). A total of 16 treatments were applied based on soil analysis and the principles of SSNM (Table 2).

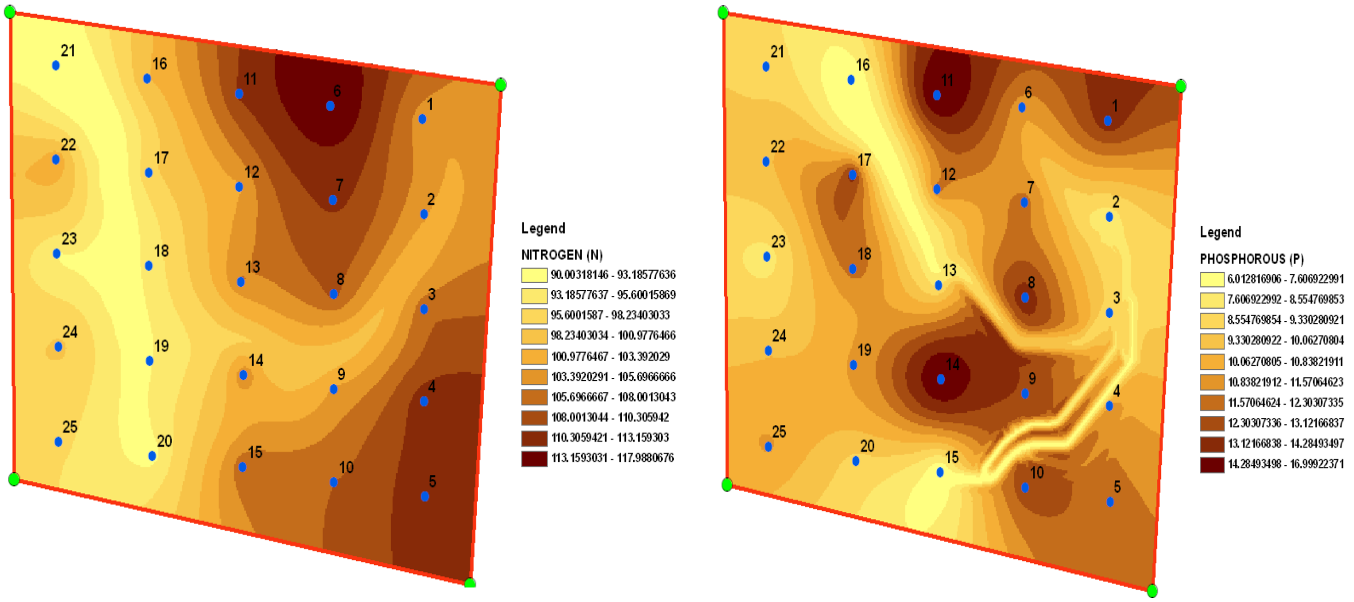
Table 1

Soil physicochemical characteristics and fertility for soil surface horizons.

	Site 1 (entisol) : typic ustorthent	Site 2 (vertisol) : typic haplustert
pH	7.3	7.6
EC (d Sm^{-1})	0.21	0.18
$CaCO_3$ (g kg^{-1})	21.2	20.2
Texture (g kg^{-1})		
Sand	384.0	296.6
Silt	203.8	222.4
Clay	412.2	482.0
Available nutrients (mg kg^{-1})		
N	88.2	96.2
P	7.6	11.4
K	132.6	162.8
Fe	6.1	8.2
Mn	8.0	7.6
Cu	0.9	1.2
Zn	0.7	0.8

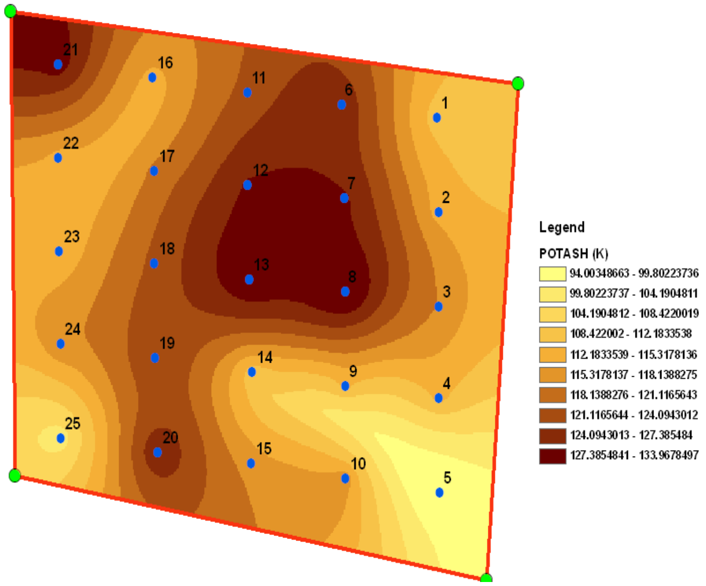
Two levels of input intensity were incorporated in the design based on high and low nitrogen (N) rate. These treatments were replicated four times in a randomized block design. Timing of fertilizer applications were kept the same at both sites. Nitrogen was applied in the months of April, August and October; phosphorus (P) and potassium (K) were applied in August and October. Two seasons of data collection included measurements of tree canopy growth, fruit yield and quality, leaf nutrient concentrations, and a cost:benefit analysis. Only the effective treatments and current recommendations (CR) are discussed in the article using treatments viz., T_8/T_6 (as best SSNM treatment, on Typic Ustorthent and Typic Haplustert, respectively, recommended fertilizer practices (T_{16}) and farmers' fertilizer practices (T_{17}).

Response on Growth and Fruit Yield: Tree volume as a fruit bearing area responded significantly to differential doses of fertilizer application (Table 3). A higher magnitude of increase in tree volume was observed on site 2 having deep soil compared to site-1 having shallow soil due to comparatively higher water storage and nutrient supplying capacity of former site. Considering both the sites, the best site specific fertilizer treatment was observed as T_8 on site-1 and T_6 on site-2. These two site specific treatments T_8 and T_6 showed their superiority over treatments involving either T_{16} (recommended doses of fertilizers) or T_{17} (farmers' practices). The response on fruit yield was very much in line with response on tree volume demonstrating better effectiveness of site specific fertilizer treatments with respect to both tree volume and fruit yield (Table 3). Fruit yield response due to site specific treatment nearly doubled after 3 years of fertilizer application at both the sites compared to either T_{16} or T_{17} suggesting better fertilizer-use-efficiency through site specific nutrient management for yield maximisation. On the other hand, such studies also provided a data base support that in order to improve the orchard productivity, the current farmers' practices of fertilizer application have a vast potential of improvement in central India.



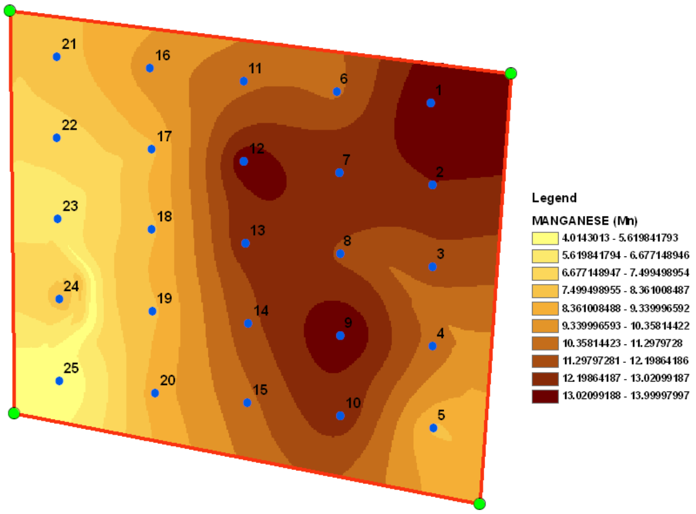
Spatial variability in alkaline $KMNO_4$ extractable N in soil.

Spatial variability in Olson – P in soil.

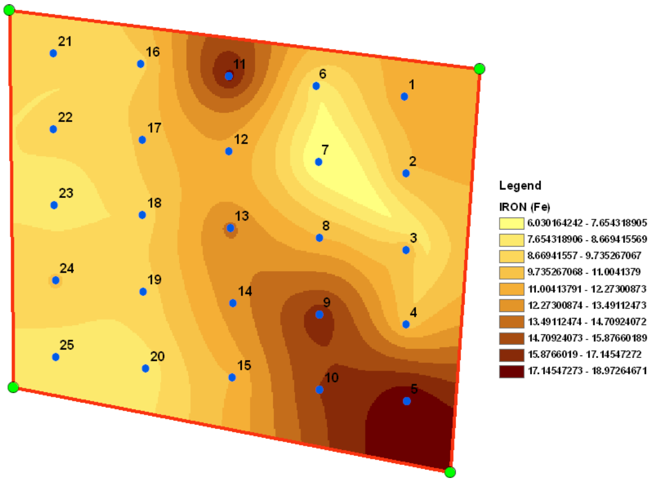


Spatial variability in neutral NH_4OAc – K in soil.

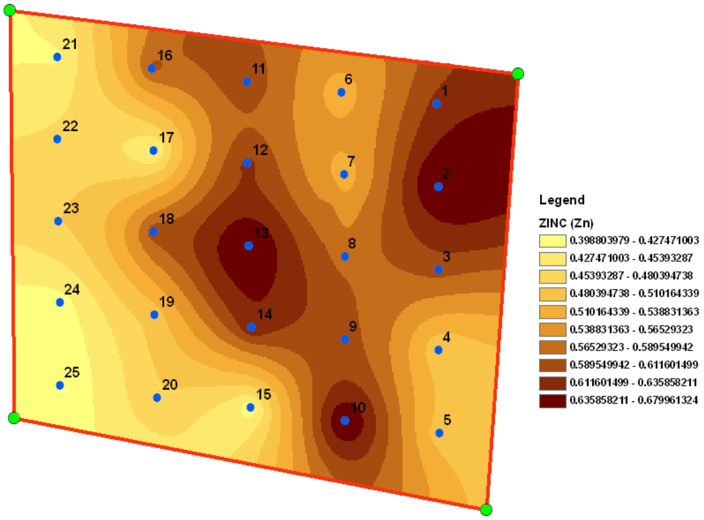
Fig. 2. Spatial variability in available N, P and K across the grid sampling within the identified orchard.



Spatial variability in soil DTPA- Mn in soil.



Spatial variability in soil DTPA- Fe in soil.



Spatial variability in soil DTPA – Zn in soil.

Fig. 3. Spatial variability in DTPA extractable Mn, Fe and Zn across the grid sampling within the identified orchard.

Table 2
Range of fertilizer treatments applied at both the sites within an orchards.

Current recommendation	N	P_2O_5	K_2O	M_1^*	S_1^{**}
	------------Rate (g tree^{-1}) ---------				
	600	**200**	**100**	**X**	**X**
Low N					
T_1	600	400	600	√	√
T_2	600	200	600	√	√
T_3	600	0	600	√	√
T_4	600	600	600	√	√
T_5	600	400	0	√	√
T_6	600	400	300	√	√
T_7	600	400	600	X	X
T_8	600	400	900	√	√
High N					
T_9	1200	600	600	√	√
T_{10}	1200	600	900	√	√
T_{11}	1200	600	1500	√	√
T_{12}	1200	600	1500	√	√
T_{13}	1200	600	0	√	√
T_{14}	1200	600	1200	X	√
T_{15}	1200	600	1200	X	X

*M_1 = 300 g each of $ZnSO_4$, $FeSO_4$, $MnSO_4$ and 100 g borax tree^{-1}
**S_1 = 400 g $MgSO_4$ tree^{-1} and 100 g elemental S tree^{-1}

Changes in Leaf Nutrient Composition: Significant changes in leaf nutrient concentration (Table 4) was observed in response to different fertilizer combinations on both the soil types. Best site specific treatments (T_8 on site-1 and T_6 on site-2) significantly elevated leaf N, P, K and Zn concentrations compared to either T_{16} or T_{17}. These nutrients showing significant responses were within the deficient range in trees fertilized with farmers' practices (T_{17}), which attained an optimum level after 3 years through site specific fertilizer treatments. Application of K in increasing doses from T_5 to T_9 increased leaf Zn concentration from 17.9 to 23.5 ppm on site-1 and from 19.7 to 23.7 ppm on site-2 (data not presented), irrespective of whether or not any micronutrient was included in the treatment, further confirmed through highly significant and positive correlation (r = 0.618, p = 0.01) because of the similar metabolic pathways are involved with regard to biochemical transformation of both the nutrients. However, the effect of K on leaf Zn content was greatest when applied alongwith the micronutrients. The effect further improved at higher levels of application of K and Zn (data not presented). Earlier studies on analysis of tree size of 30-40 trees in space of 40-acre orchard showed a skewed distribution with 51.1% trees having 25-100 m^3 tree^{-1} size classes and a median size of 82 m^{3}tree^{-1}. At a uniform fertilization rate of 240 kg N ha^{-1}year^{-1}, the leaf N concentration of 12 trees with different canopy sizes that were randomly sampled in the orchard showed optimal levels (2.4-2.6%) in the large trees and excess levels (> 3%) in the medium to small trees. From the regression line, trees with excess N had canopies < 100 m^{3}tree^{-1}, and constituted 62% of the grove. Under such conditions, variable rate fertilization can, therefore, save production costs, reduce N leaching and increase yields per variable acre(Zaman *et al*., 2005).

Table 3

Effect of site specific treatments on tree canopy and fruit yield of Nagpur mandarin.

Treatments	Site-1 (Typic Ustorthent)		Site-2 (Typic Haplustert)	
	Tree volume (m^3)	Fruit yield (tons ha^{-1})	Tree volume (m^3)	Fruit yield (tons ha^{-1})
Farmers' fertilizer practices (T_{17})	23.2	7.7	28.4	11.9
Recommended fertilizer practices(T_{16})	25.4	10.4	30.8	16.2
Site specific management(T_8/T_6)*	29.8	14.7	36.4	19.0
CD (*p = 0.05*)	1.2	2.2	1.5	2.4

*Best site specific treatments were T_8 on Site-1 and T_6 on Site-2.

Table 4

Response of site specific treatments on leaf nutrient composition Nagpur mandarin.

Treatments	Site -1(Typic Ustorthent)				Site -2 (Typic Haplustert)			
	N (%)	P (%)	K (%)	Zn (ppm)	N (%)	P (%)	K (%)	Zn (ppm)
Farmers' fertilizer practices(T_{17})	1.98	0.07	0.99	17.8	2.07	0.08	1.05	19.2
Recommended fertilizer practices(T_{16})	2.04	0.09	1.15	21.2	2.40	0.10	1.29	22.1
Site specific management(T_8/T_6)*	2.38	0.13	1.35	25.7	2.55	0.13	1.67	31.0
CD (*p = 0.05*)	0.16	0.04	0.14	2.5	0.16	0.03	0.20	2.3

* Best site specific treatments were T_8 on Site-1 and T_6 on Site-2.

Response on Fruit Quality: Both sites and input regimes demonstrated significant quality responses due to site specific treatments versus other treatments, T_{16} or T_{17} (Table 5). Maximum fruit juice content corresponded with most effective site specific treatments (T_8/T_6), as did TSS. Juice acidity on the other hand, reduced considerably in site specific fertilization (T_8/T_6) compared to either T_{16} or T_{17}. Experiment carried out on site specific management of 17-year-old 'Valencia' orchard (2980 trees) in Florida(USA) using automated sensor system equipped with differential global positioning system and variable rate delivery of fertilizers (135-170 kg N $ha^{-1}year^{-1}$) on a tree size basis (0-240 m^3tree^{-1}) demonstrated a 38-40% saving in granular fertilizers cost. While, conventional uniform application rate of 270 kg N $ha^{-1}year^{-1}$ showed that trees with excess nitrogen (>3%) had canopies less than 100 m^3 with lower fruit yield and inferior quality (Tucker *et al*., 1995). It was further observed that fruits on site-1 matured (optimum TSS/acid ratio > 14:1) earlier than on site-2, irrespective of fertilizer treatments (data not presented) suggesting the role of soil properties in regulating the fruit quality response. The observations from the present studies suggested that fertilization based on the principles of site specific management in any citrus orchard offers a viable option to improve orchard quality production which could be equally effective to address the nutrient mining as a common cause of citrus decline.

Table 5

Response of site specific treatments on fruit quality parameters Nagpur mandarin.

Treatments	Site -1(Typic Ustorthent)			Site -2(Typic Haplustert)		
	Juice (%)	Acidity (%)	TSS (%)	Juice (%)	Acidity (%)	TSS (%)
Farmers' fertilizer practices(T_{17})	44.5	0.62	8.2	45.5	0.77	8.1
Recommended fertilizer practices(T_{16})	45.7	0.56	9.1	46.9	0.62	8.4
Site specific management(T_8/T_6)*	48.3	0.48	9.6	49.8	0.53	9.0
CD (*p=0.05*)	3.1	0.09	0.50	3.2	0.08	0.60

* Best site specific treatments were T_8 on Site-1 and T_6 on Site-2.

Economic Analysis: A cost/benefit analysis of T9 at Site 1 produced a net return of Rs.58,569 ha^{-1} (US$1,325 ha^{-1}) or Rs.2.12 per rupee invested in fertilizers and other inputs. At Site 2, T6 produced a net return of Rs.46,260 ha^{-1} (US$1,045 ha^{-1}) or Rs.1.68 per rupee invested. Across sites, micronutrient and secondary nutrient application had little impact on juice content total soluble solids (TSS), or fruit acidity. However, both sites and input regimes demonstrated significant quality responses to K. Maximum fruit juice contents corresponded with conditions of high K fertility, as did fruit acidity. This latter observation suggests that K fertilization will play a role in influencing the time to fruit maturity since fruits with higher juice acidity take more time to attain the color break stage. Total soluble solids showed a negative response to increased K application. Significant response to improved fertilization strategies over currently recommended doses of fertilizers warrants addressing nutrient requirements on a site-specific basis for improving fertilizer use efficiency.

SSNM in sweet orange on vertisol

A field experiment for 3 years (2006-07 to 2008-09) was conducted to evaluate the effectiveness of whether soil test-based SSNM on productivity, fruit quality, and economics of production of 8-year-old 'Mosambi' sweet orange orchard with scion of sweet orange (*Citrus sinensis* Osbeck) budded on rough lemon rootstock (*Citrus jambhiri* Lush).

Experimental Set-up: A field expeiment based on the principles of SSNM was conduced during *Ambia* season (February bloom) of three years from 2006-07 to 2008-09 (treatments applied every year) on an alkaline and calcareous deep soil (Typic Haplustert) soil with available N, P, K, Fe, Mn, and Zn contents of 103, 11, 186, 11, 8, and 0.98 mg/kg, respectively. In total, 17 treatments were designed viz., $T_1 = N_o + P_{200} + K_{300} + M_1$, $T_2 = N_{400} + P_0 + K_0 + M_1$, $T_3 = N_0 + P_0 + K_{300} + M_1$, $T_4 = N_{400} + P_{200} + K_0 + M_1$, $T_5 = N_{400} + P_{200} + K_{300} + M_1$ (RDF), $T_6 = N_{400} + P_{200} + K_{300} + M_2$, $T_7 = N_{400} + P_{200} + K_{300} + M_0$ (FFP), $T_8 = N_{800} + P_{400} + K_{600} + M_1$(SSNM), $T_9 = N_{800} + P_{400} + K_{900} + M_1$, $T_{10} = N_{800} + P_{400} + K_{1200} + M_1$, $T_{11} = N_{800} + P_{400} + K_{1200} + M_2$, $T_{12} = N_{1200} + P_{400} + K_{300} + M_1$, $T_{13} = N_{1200} + P_{400} + K_{600} + M_1$, $T_{14} = N_{1200} + P_{400} + K_{900} + M_1$, $T_{15} = N_{1200} + P_{400} + K_{1200} + M_1$, $T_{16} = N_{1200} + P_{400} + K_{300} + M_0$ and $T_{17} = N_{1200} + P_{400} + K_{300} + M_1S_1$ where M_0 represents no application of micronutrients, M_1 represents application of 250 g each of Fe, Mn, and Zn sulphates tree^{-1} year^{-1}, M_2 represents application of 500 g each of Fe, Mn and Zn sulphates tree^{-1} year^{-1} and S_1 includes addition of 500 g each of Ca and Mg sulphates tree^{-1} year^{-1}. Eight-year-old Mosambi' sweet orange orchard was used with scion of sweet orange (*Citrus sinensis* Osbeck) budded on rough lemon rootstock (*Citrus jambhiri* Lush) with plant to plant and row to row distances of 6 m. The time of fertiliser application was scheduled in three equal split doses coinciding with emergence of new flush (new leaves) in the months of April, August, and October. Different fruit quality parameters viz., TSS was determined using hand refractometer, juice content volumetrically, and acidity tritrimetrically as per commonly followed procedures.

Yield Response: Fruit yield is an ultimate index of orchard productivity. The current recommended rate of nutrient application (T_5) produced significantly higher fruit yield (44.4 kg tree^{-1}) than treatments with N omission T_1 (37.9 kg tree^{-1}), P and K omission T_2 (37.7 kg tree^{-1}), N and P omission T_3 (36.2 kg tree^{-1}), and K omission T_4(42.0 kg tree^{-1}) (Table 6). The highest fruit yield (61.4 kg tree^{-1}) was observed with treatment T_8 and any further increase in K application rates beyond 600g plant^{-1} year^{-1} (T_9 and T_{10}), at equivalent rates of other nutrients, did not produce any yield improvement. Further increasing N rates, regardless of K application rate (T_{12} to T_{15}), provided no improvement over the yield of T8. It was also observed that application of Ca and Mg caused yield declines T_{17} over T_{12} probably due to uptake antagonism between these nutrients and K under the present experimental conditions.

Interestingly, as a cumulative effect during the third year of experimentation (2007-08), a variety of nutrient deficiencies e.g. N-deficiency under treatment $T_1(N_0 – P_{200} – K_{300} – M_1)$, Fe-deficiency under treatment $T_7(N_{400} – P_{200} – K_{300} – M_0)$, K-deficiency on fruit size under treatment $T_2(N_{400} – P_0 – K_0 – M_1)$, Mn-deficiency under treatment $T_7(N_{400} – P_{200} – K_{300} – M_1)$ and Zn-deficiency, as appearance of multiple sprouts due to horizontal movement of Zn (accumulation in bark), under treatment T_7 $(N_{400} – P_{200} – K_{300} – M_0)$ were observed. These deficiency symptoms were well supported by concentration of respective nutrient in leaves (data not shown).

Fruit yields at two different macronutrient application levels (N_{400}-P_{200}-K_{300} and N_{1200}-P_{400}-K_{300}) was significantly influenced by micronutrient application as fruit yields were higher at T_5 (44.4 kg tree^{-1}) as compared to T_7 (40.2.kg tree^{-1}) and between T_{12} (53.6 kg tree^{-1}) and T_{16} (48.3 kg tree^{-1}), supporting the significance of micronutrients in improving fruit yield. Increasing micronutrient rate at the lower NPK rates showed a significant increase in orange yield (T_5, T_6 and T_7). However, this was not the case when NPK rates were increased (T_{10} and T_{11}) as extra micronutrients displayed no difference.

Fruit Quality Response: Juice content, total soluble solids and juice acidity are the three most important criteria of evaluating quality response of any fertiliser treatment on orange. These quality parameters were significantly influenced by different fertiliser treatments (Table 6) during all the three years of experimentation. Omission of potassium (T_4) from the general recommended dose (T_5) significantly reduced juice and TSS content suggesting a strong influence of K on quality parameters of sweet oranges. Micronutrients also played a significant role in regulating juice content at both the levels of nutrients, i.e. N_{800} + P_{400} on N_{1200} + P_{400}. For example, juice content was improved from 46.9 % with treatment T_7 (without micronutrients) to 48.3% with T_5 (containing micronutrients) at lower level of NPK and from 46.7% with T_{16} (without micronutrients) to 47.9% with T_{12} (with micronutrient) at higher level of macronutrients indicating the indispensable role of micronutrients in fruit quality buildup. This suggested the necessity of maintaining a balance between macro- and micro-nutrients in deciding the optimum fertiliser doses. No positive response of secondary nutrients (T_{17}) was observed with respect to any of three fruit quality parameters over treatments involving micronutrients with NPK (Table 6).

Table 6

Response of different treatments on growth and yield of ‘Mosambi’ sweet orange (Pooled data of 3 years).

Treatments	**Fruit yield (kg tree^{-1})**	**Quality**		
		Juice (%)	**TSS (%)**	**Acidity (%)**
1. $T_1 = N_0 - P_{200} - K_{300} - M_1$	37.9	47.2	8.5	0.46
2. $T_2 = N_{400} - P_0 - K_0 - M_1$	37.7	45.1	8.3	0.41
3. $T_3 = N_0 - P_0 - K_{300} - M_1$	36.2	45.8	8.3	0.46
4. $T_4 = N_{400} - P_{200} - K_0 - M_1$	42.0	46.5	8.3	0.40
5. $T_5 = N_{400} - P_{200} - K_{300} - M_1$	44.4	48.3	8.9	0.44
6. $T_6 = N_{400} - P_{200} - K_{300} - M_2$	46.4	47.7	8.6	0.46
7. $T_7 = N_{400} - P_{200} - K_{300} - M_0$	40.2	46.9	8.3	0.48
8. $T_8 = N_{800} - P_{400} - K_{600} - M_1$	61.4	50.9	9.5	0.44
9. $T_9 = N_{800} - P_{400} - K_{900} - M_1$	58.8	49.6	9.3	0.51
10. $T_{10} = N_{800} - P_{400} - K_{1200} - M_1$	57.9	49.9	9.3	0.61
11. $T_{11} = N_{800} - P_{400} - K_{1200} - M_2$	56.7	49.8	9.2	0.57
12. $T_{12} = N_{1200} - P_{400} - K_{300} - M_1$	53.6	47.9	8.7	0.47
13. $T_{13} = N_{1200} - P_{400} - K_{600} - M_1$	54.2	48.9	8.8	0.49
14. $T_{14} = N_{1200} - P_{400} - K_{900} - M_1$	51.2	49.7	8.9	0.58
15. $T_{15} = N_{1200} - P_{400} - K_{1200} - M_1$	50.8	50.5	8.8	0.63
16. $T_{16} = N_{1200} - P_{400} - K_{300} - M_0$	48.3	46.7	8.4	0.53
17. $T_{17} = N_{1200} - P_{400} - K_{300} - M_1S_1$	48.7	48.3	8.8	0.47
CD(*P=0.05*)	1.98	1.2	0.27	0.031

M_0 stands for no micronutrients.

M_1 stands for micronutrients consisting of 250 g each of $FeSO_4$, $MnSO_4$ and $ZnSO_4$ tree^{-1}

M_2 stands for micronutrients consisting of 500 g each of $FeSO_4$, $MnSO_4$ and $ZnSO_4$ tree^{-1}

S_1 stands for $CaSO_4$ and $MgSO_4$ each @ 250 g tree^{-1}

RDF , FFP and SSNM stand for recommended doses of fertilizers, farmers’ fertilizer practice, and site specific nutrient management ,respectively.

Inclusion of micronutrients in the treatments at both lower and higher levels of NPK also produced a favourable response on total soluble solids (TSS). The TSS with treatment T_5 (8.9%) was significantly different than T_7 (8.3%). Similarly treatment T_{12} involving higher doses of micronutrients produced higher TSS (8.7%) compared to treatment T_{16} with a lower TSS (8.4%). Inclusion of secondary nutrients in treatment T_{17} failed to produce any significant response on TSS when compared with treatment T_{12} (Table 6). The highest TSS (9.5%) was observed with treatment $T_{8,}$ significantly superior to other treatments involving higher doses of K upto 1200 g tree^{-1} either at N_{800} + P_{400} or at N_{1200} +$P_{400.}$ Increasing K rate had no positive effect on TSS, regardless of the N and P rates being applied.

Comparatively lower acidity (0.40-0.44%) was observed with treatment T_2, T_4, and $T_{8.}$ Inclusion of micronutrients in the treatments at both lower and higher levels of NPK produced a favorable response on acidity

(T_5 vs T_7). Similarly T_{12} with micronutrients produced lower acidity (0.47%) compared to treatment T_{16}(0.53%). Inclusion of secondary nutrients in treatment T_{17} failed to produce any significant response on acidity when compared with treatment T_{12} (Table 6). Increasing K rate increased acidity, regardless of the NP rates which were also considered.

Economics of Nutrient Management Approaches: The SSNM treatment in this study (T_8) provided comparatively higher net return than the farms practice (T_6) and the local recommendation (T_5) (Table 7). These results clearly show that some revision of the current fertiliser recommendations are required when full productivity potential on a given soil type is to be realized.

Table 7

Analysis of economic returns from SSNM versus RDF and FFP.

Treatment	Cost* (000' Rs. ha^{-1})	Benefit** (000' Rs. ha^{-1})	Net returns (000' Rs. ha^{-1})
T_7 (FFP)	14.5	110.8	96.3
T_5(RDF)	19.7	121.9	102.2
T_8(SSNM)	30.5	169.0	138.5

*Includes operational charges.

**As per existing farm rate.

RDF , FFP and SSNM stand for recommended doses of fertilizers, farmers' fertilizer practice, and site specific nutrient management, respectively.

Hence, these studies in two commercial cultivars on soils of similar smectite rich mineralogy showing a much remunerative multifarious response than conventional fertilizer recommendation. In years to come, SSNM will find a greater application in precision citriculture using variable rate application technology via canopy sensors and integrating further with programmable fertigation so that nutrients are applied synchronizing crop physiological nutrient demand and supply from soil so that soil sustainability in production pattern becomes more or less a common feature.

5. Strategies and opportunities

The fall out of a generalized nutrient recommendation over large areas of such small-scale farming leads to the possibility of over or under-application of nutrients with its economic and environmental consequences. The more apparent consequences of falling productivity and nutrient efficiency, multi-nutrient deficiencies, high extent of nutrient mining and falling farm income are highlighted by researchers (Ghosh *et al*., 2004 and Tiwari, 2007). The environmental impacts are not very apparent yet – probably because of the generally low nutrient application rates in the country. SSNM, on the other hand provides an approach for "feeding" crops with nutrients, as and when they are needed. It recognizes that inherent spatial variability associated with fields under crop production. The SSNM avoids indiscriminate use of fertilizers by preventing excessive/ inadequate rates of fertilization and by avoiding fertilization when the crop does not require nutrient inputs. It also ensures that all the required nutrients are applied at proper rates and in proper ratios commensurate with the crop's nutrient needs. The major benefit of improved nutrient management strategy to farmer is increased profitability. Nutrient use of the principles of SSNM could provide an avenue to reverse the declining productivity trend and nutrient mining from soils. The systematic implementation of site-specific systems is probably our best opportunity to develop a truly sustainable agriculture system.

The work on precision citriculture in Florida (Whitney *et al*., 1999) is underway with following objectives: i. develop a system to map citrus yields using conventional manual harvest labour and electronically record harvester identity associated with each citrus container loaded in the grove; ii. develop a system to measure and map tree location, canopy volume, and height in citrus grove; iii. determine the feasibility of using GPS/GIS for variable rate application of fertilizers and pesticides, and for monitoring, tracking, and controlling grove equipment; and iv. determine what GPS/GIS information is most valuable and how it may be used effectively to improve management of production and harvesting operations.

The most important step towards the calibration of site-specific fertilizer requirements is the estimation of the indigenous nutrient supplies, which we define as the cumulative amount of nutrient originating from all indigenous sources. There are several approaches to determining indigenous nutrient supply. Thus far, the most popular method in India has been soil testing as it proved to a rapid and reliable indicator for many nutrients. However, the staggering number of land holdings in India and the meager soil testing infrastructure poses a major challenge to wide-scale adoption of SSNM technologies in India. The major challenges for SSNM research and extension in future will be two-fold: i. to retain the demonstrated potential of the approach and ii. to build upon what has already been achieved while reducing the complexity of the technologies as it is disseminated to farmers (Johnston *et al*., 2009).

The important strategies could be summarised as below :

- Development and validation of SSNM-based principles for nutrient management in other important fruit crops.
- Preparing simplified ready reckoner for SSNM using diverse crop and agro-pedological analogues.
- More intervention of geo-informatics like GPS and GIS along with development of nutrient diagnostics and other related aspects to add a new dimension to SSNM.
- NR to be worked out by delineating the role of perennial framework of fruit plants in nutrient dynamics vis-à-vis nutrient supply capacity.
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Opportunities

The major opportunities foreseen through SSNM are summarised as below:

- Tailoring fertilizer requirement according to crop ontogeny, easily implementable with fertigation and INM as well.
- SSNM to be translated into sensor – based DSS (Decision Support System) to variable rate fertilization .
- Exploring the possibility of crop regulation through NM to produce fruit as per market demand.

Exploring role of plant nutrition in improving shelf life of fruits through enzyme silencing.

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