



SSNM-based rationale of fertilizer use in perennial crops : A review

A K SRIVASTAVA¹, S N DAS², S K MALHOTRA³ and KAUSHIK MAJUMDAR⁴

National Research Centre for Citrus, Nagpur, Maharashtra 440 010

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ABSTRACT

Behaviour of crops and soils due to non-redressal of spatial variability in soil properties is not expressed uniformly within bigger orchard/field which has been the major triggering factor for not able to break yield barrier through conventional nutrient management strategy. Better response of site specific nutrient management (SSNM) over recommended doses of fertilizers (RDF) including those of farmers' usual fertilizer practices (FFP) signals a wake-up call to address the fertilizer requirements on the principles of SSNM, if the full potential productivity of perennial crops has to be realized and sustain on any given soil type. The SSNM also warrants to tailor the fertilizer application on the basis of spatial variation in soil fertility and tree canopy size within an orchard/field through variable rate fertilizer application to minimize the gap between actual and potential productivity of crops. Application of geospatial tools like GPS and GIS coupled with DRIS-based nutrient diagnostics has substantially aided in developing rationale of fertilizer use using SSNM concept in crops like citrus, avocado, coconut, olive etc. which could well be expanded to other perennial crops.

Key words : Fertilizer requirement, GPS-based grid sampling, Perennial crops, Soil spatial variability, SSNM, Sustainable production, Variable rate fertilizer application

Demographic pressure of burgeoning population coupled with energy crisis has kept researchers on their toes to find possible alternatives of raising factor productivity of perennial crops via efficient fertilizer use. On the other hand, achieving a balance between crop nutrient requirements and soil nutrient reserves is essential for maintaining high yield without any depletion in soil fertility, besides safeguarding environmental degradation (Srivastava and Singh 2004b, 2009a, Srivastava *et al.* 2008, Srivastava 2012a). Such an objective becomes further difficult to accomplish due to shrinking per capita land availability, more so in the developing world. Globally, soil nutrient deficits are estimated at an average of 18.7 N, 5.1 P, and 38.8 (kg/ha/year) with an annual total nutrient deficit of 5.5 Tg (1 Tg = 10¹² g) N, 2.3 Tg P and 12.2 Tg K coupled with a total potential global production loss of 1136 Tg/year considering four major (rice, wheat, maize and barley) cereal crops (Tan *et al.* 2005). These figures indirectly sound an alarm in respect of highly nutrient responsive perennial crops as well (although, such statistics pertaining to perennial

crops are missing), warranting the importance of balanced fertilization.

Horticultural crops in India occupy 9% of the cultivated area but account for about 6% of the fertilizer used. The share of fertilizer use in Horticulture has risen from 2% in the mid 1990s to 6% in 2001-02, out of which fruits accounted for 2% and vegetables 4% (Chanda 2008). Horticultural crops (fruits 704 000 tonnes and vegetables 1460 000 tonnes), thus, used 2.37 mmt N + P₂O₅ + K₂O. Banana was estimated to receive almost 60% of the fertilizer used on fruit crops @ 444 kg N + P₂O₅ + K₂O/ha in the ratio of 0.9:0.6:1, although grape is the most intensively fertilized fruit crop on unit area basis (Tandon and Tiwari 2008). Over all rate of nutrient application in fruits is reported as 145.5 kg/ha (nutrient ratio 1.6:1.0:1.0) compared to 170 kg/ha for vegetables (nutrient ratio 2.2:1.3:1) as per production statistics of NHB for 2010-11. Earlier, Ghosh (1999) based on recommended doses of fertilizers for different fruit crops, projected the requirement of 826 thousand tonnes of N, 570 thousand tonnes of P₂O₅ and 115 thousand tonnes K₂O for the year 2010. Therefore, the perennial crop growers are most concerned about ways and means to improve fertilizer use efficiency via proper application of nutrient diagnostics ensuring maximum yield and quality through viable rationale of fertilizer use (Srivastava and Singh 2002, 2009a, 2009b).

A guesstimate proclaims over 900 million people in the world are undernourished, and malnutrition alone is

¹Principal Scientist, Soil Science (e mail: aksrivastava2007@gmail.com), ²Director (e mail: subratondas@gmail.com), Maharashtra Remote Sensing Applications Centre, Nagpur, Maharashtra, ³ Assistant Director General (e mail: malhotraskraj@yahoo.com), ICAR, New Delhi, ⁴Director (e mail: kamjumdar@ipni.net), South Asia Program, International Plant Nutrition Institute (IPNI), Gurgaon, Haryana

responsible for 3.5 million deaths annually (Srivastava 2012). 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 (Tiwari 2007b). Most of the existing fertilization guidelines have been derived from experimental data on yield responses to individual nutrients after controlling for other soil conditions by way of randomization. But, soil conditions in farm fields, former being more heterogeneous in soil fertility, is distinctly very different from those in the experimental fields, and soil data collected from a farm fields cannot be analyzed using the statistical method developed for experimental data.

Knowing the nutrients required 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 large spatial variation in soil fertility (Srivastava and Singh 2008c, Srivastava *et al.* 2010, Srivastava 2013c, 2013d). Application of uniform single rate of nutrients, hence, most often result in over-application of nutrients at some sites and under-application at other sites, cumulatively leading to reduced fertilizer use efficiency. Under such circumstances, site specific nutrient management (SSNM), a dynamic concept of nutrient management that exploits indigenously and spatially available nutrients within bigger orchards requiring differential fertilizer treatments in patches so as to improve the orchard efficiency (average yield of specified trees in relation to average orchard yield) in ultimate terms (Srivastava and Singh 2008a). The success of SSNM during the last 10 years has been prominently realized on a number of crops, viz. cereals (Biradar *et al.* 2006), black gram (Gupta *et al.* 2007), coconut intercropped with fodder (Lakshmi *et al.* 2007), avocado (Salaza-Garcia and Lazcano-Ferrat 2003), citrus (Srivastava *et al.* 2006, 2009) etc. to cite few success stories. Färe *et al.* (2012) recently introduced a model to answer three questions pertaining to SSNM in production of perennial crops: which input factors of crop production are limiting yield; what action should be taken to remove the limiting factors; and what is the potential gain in revenue from taking the action. The suggested model captured the essence of the law of the minimum in yield and revenue increase only if the limiting nutrients are appropriately adjusted. In the past, various aspects of SSNM have been highlighted in a number of reviews (Nielsen *et al.* 1973, Wibawa *et al.* 1993, Pinter *et al.* 2003, Corwin and Lesch 2005, Elprince 2009, Johnston *et al.* 2009, Zhang *et al.* 2010,

Chan 2012, Srivastava 2013c), but there is hardly any comprehensive coverage addressing the perennial crops. In this background, the present review attempts to highlight certain pertinent issues on the necessity of developing SSNM concept as rationale of fertilizer use to harness better fertilizer use efficiency with emphasis on perennial crops.

SSNM PRINCIPLES

The SSNM 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.

The SSNM aims to apply nutrients at optimal rates and times to achieve high yield and yield efficiency of nutrient use leading to high economic return per unit of fertilizer invested (Dobermann *et al.* 2003a, 2003b). The SSNM also adjusts the fertilizer use to optimally bridge up the deficit between the nutrient needs of a crop and the nutrient supply from naturally occurring indigenous sources such as soil, organic amendment, crop residues, manures and irrigation water (de la Cruz 2008). There are five steps through which the SSNM is accomplished. These are: i. establishment of yield target; ii. estimation of actual yield responses to fertilizer N, P, and K; iii. selection of fertilizer N, P, and K rates based on expected yield responses to fertilizer application considering agronomic efficiencies and nutrient balances; iv. application of fertilizer to meet the crop demand for nutrients at critical growth stages and v. optimization of nutrient use efficiencies (Hach and Tan 2007). The following steps are involved in arriving at fertilizer requirement based on the principles of SSNM (Srivastava 2013c). Below given is the hypothetical example as a case study:

Step i. : Estimating target yield

Actual yield = 8 Mg/ha

Target yield = 10 Mg/ha

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 (-N)

6.5-7.0 Mg/ha (-P)

7.0-7.5 Mg/ha (-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

Phosphorous requirement : $5 - 3.5 = 1.5$ kg P/ha

Potassium requirement : $30 - 22 = 8$ kg K/ha

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

N recovery : 40–50%

Amount of nitrogen required : $20 \times 100/40 = 50$ kg N/ha
 $20 \times 100/35 = 57$ kg N/ha

Amount of phosphorous required : $1.5 \times 100/10 = 15$ kg P/ha
 $1.5 \times 100/8 = 19$ kg P/ha

Amount of potassium required : $8 \times 100/40 = 20$ kg K/ha
 $8 \times 100/50 = 20$ kg K/ha

EXPLOITING SPATIAL VARIABILITY

Characterizing spatial 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 protocols developed by Corwin and Lesch (2005) for site specific evaluation of soil properties (EC appraisal) comprised 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 and viii. GIS database development and graphic display. Of late, Siqueira *et al.* (2010) suggested that relief may be considered an integrating factor that expresses the interaction of various soil and plant attributes. The study further analyzed the potential use of landforms to predict the variability of soil and orange attributes, with large spatial variability in soil and temporal variability in orange quality.

Leaf nutrient-based spatial variability

Spatial variation in leaf nutrient composition within an orchard/field is a common feature. Different production zones in relation to leaf nutrient composition can also be demarcated for rationalized fertilization schedule. Spatial variability of leaf nutrients (N, P, K, B and Fe) in a 30 ha olive orchard

located in southern Spain was examined through spatial using regular 75 m × 75 m sampling grid. Based on the semivariograms, kriged estimates were used to draw contour maps for each leaf nutrient and to study the possibility of saving fertilizer recommendations. Geostatistical analysis of leaf nutrients revealed that N had both strong and moderate patchy distribution, whereas P, K and B had strong patchy distribution. Contour maps of each leaf nutrient achieved by kriging were used to estimate the percentage of farm surface needing fertilization where concentration of the respective nutrients did not exceed the fertilization threshold. The study revealed the necessity of determining spatial variability in nutrient status of olive trees before planning differential fertilizer programme. A consistent saving in N, K and B fertilizers could be achieved in the studied olive orchard both years, for example only 3 and 17% of the surface should be fertilized with N in 1999 and 2000, respectively (López-Grandos *et al.* 2004).

The ratio between nugget semivariance and total semivariance or still was used to define different classes of spatial dependence for leaf nutrient (López-Grandos *et al.* 2002). If ratio was 25%, the leaf nutrient was considered to be strongly spatially dependent, or strongly distributed in patches; if ratio was between 26 and 75%, the leaf nutrient was considered weakly spatially dependent; if the ratio was 100%, or the slope of the semivariogram was close to zero, the leaf nutrient was considered as not being spatially correlated (pure nugget). Semivariogram models were cross-validated (trial-and-error procedure) by comparing leaf nutrient values estimated from the semivariogram model with actual values. Differences between estimated and experimental values are summarized using the cross-validation statistics, i.e. mean square error and standardized mean square error (Hevesi *et al.* 1992).

Yield mapping is a logical starting point in spatially available crop production (Schuman *et al.* 2006a, 2006b). A nitrogen application map can be derived based on established N recommendation and citrus yield map. Jackson *et al.* (1995) reported that N is required for tree growth and fruit production. Replacement of the N removed by fruit harvest is the main N requirement in a mature orchard. They suggested an N application rate of 0.18 kg N per Florida field box (40.8 kg) for oranges and 0.14 kg N per Florida field box (40.8) of grapefruit harvested from the field. Several studies on development of citrus yield maps have been reported (Whitney *et al.* 1999, Chan *et al.* 1999a). Whitney *et al.* (1998) developed a citrus yield mapping system using a modified crop harvesting tracking system (Schueller *et al.* 1999). Whitney *et al.* (1999) analysed variations between ground truth yield versus two yield estimation methods (inverse distance weighted (IDW) and density grid method) using Pearson Coefficient method. The ground truth yield was determined by dividing the harvested area into square cells two tree rows wide (18.2 m) and determining the actual

number of tubs in each square cell. They reported a larger variation in ground truth yield than both the interpolated yield maps. The study did not include accuracy requirement on citrus yield mapping.

Chan *et al.* (1999b) mentioned three major factors that influence the development of a citrus yield map: base map, yield map interpolation method and GPS horizontal accuracy (in recording manually harvested fruit tub location). A base map was used to identify the field boundary of a citrus orchard. Yield map interpolation is based on the analysis of yield data points is therefore essential to accurately representing yield distribution of the region. Chan *et al.* (1999a) compared errors in yield mapping using two interpolation methods; kriging and inverse distance weighted (IDW). Both of these interpolation methods underestimated the overall yield by less than 7% when compared to the actual yield. Whitney *et al.* (1999) used a higher resolution geo-referenced aerial photograph than that used in Chan *et al.* (1999a) for citrus yield mapping. They compared the interpolated yield variation due to density and IDW interpolation methods versus the ground truth by analyzing the whole field area while dividing it into square cells of two-row tree widths (18.2 m). The two interpolation methods overestimated the mean ground truth yield by 8%. Hence, an optimal yield mapping method to represent ground truth yield has not been established. Since the individual effects of base map, GPS horizontal accuracy and yield map interpolation method in yield mapping are not statistically independent and are nonlinear, the integrated effects of these three sources also needs to be investigated. They influence the choice of degree of accuracy of aerial photograph needed for the base map, the needed accuracy of GPS hardware and the interpolation method required in the citrus yield mapping development.

Canopy and nutrient stress: Not surprisingly, the spectral signatures of crop canopies in the field are more complex and often quite dissimilar from those of single green leaves measured under carefully controlled illumination conditions. Even when leaf spectral properties remain relatively constant throughout the season, canopy spectra change dynamically as the proportions of soil and vegetation change and the architectural arrangement of plant components vary. Vegetation indices (VIs) provide a very simple yet elegant method for extracting the green plant quantity signal from complex canopy spectra (Wiegand *et al.* 1999). Vegetation indices have served as the basis for many applications of remote sensing to crop management because they are well correlated with green biomass and leaf area index of crop canopies. Soil-adjusted VIs such as SAVI and modified SAVI have been developed to minimize effects of varying background soil reflectance properties on VI performance (Huete 1988). Narrower band indices such as the photochemical reflectance index, water band index, and normalized pigment chlorophyll ratio index are examples of

reflectance indices that are correlated with certain physiological plant responses and have promise for diagnosing water and nutrient stress (Peñuelas *et al.* 1994, Gamon *et al.* 1997). A canopy chlorophyll content index (Clarke 1997) relies on a VI plus the reflectance in a narrow red edge band (720 nm) to distinguish nutrient stress from other causes of reduced green biomass in cotton.

Hyperspectral (i.e. reflectance for many contiguous narrow wavelength bands) approaches have been proposed and tested with varying degrees of success to detect water-, nutrient-, and pest-induced stress in plants while minimizing unwanted signals from varying soil conditions or biomass amounts. These methods commonly use derivative analysis, peak fitting procedures, and ratio analysis to associate spectral features with a particular stress (Masoni *et al.* 1996, Osborne *et al.* 2002b). Monitoring symptoms caused by other nutrient deficiencies can be problematic because they rarely occur uniformly across a field and often need to be distinguished against background variation in canopy density. Osborne *et al.* (2002a, 2002b) conducted research which showed usefulness of hyperspectral data in distinguishing differences in N and P at the leaf and canopy level. But, the relationships were not constant over all plant growth stages. Adams *et al.* (2000) detected Fe, Mn, Zn and Cu deficiencies in soybean leaves using both leaf fluorescence and hyperspectral reflectance techniques that evaluate leaf chlorosis based on the shape of the reflectance spectrum between 570 and 670 nm (Adams *et al.* 1999).

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 (NDVI) 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, defined as $\frac{\text{reflectance}_{\text{NIR}} - \text{reflectance}_{\text{visible}}}{\text{reflectance}_{\text{NIR}} + \text{reflectance}_{\text{visible}}}$, 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. The semivariograms of selected variables showed a strong spatial dependence with large ranges (varied from 230 m to 255 m). Accordingly, the grove was 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). 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.

Soil fertility-based spatial variability for production zonality delineation

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, Srivastava and Singh 2010). In this context, Geographical Information Systems(GIS)-based fertility mapping could provide an alternative avenue of assessing and managing nutrient variability in agricultural holdings.

Grid soil sampling for soil fertility has been popular but commercial applications have generally relied on coarse sampling grids (regular grids with 100-m spacing or more) and simple interpolation procedures (primarily inverse distance to some power) to minimize costs. The first step in SSNM is to assess spatial variability in soil fertility. Concerns over cost and performance of grid sampling have renewed interest in area sampling schemes which are inherently more economical and more in line with traditional soil fertility sampling guidelines. While grid-sampling and interpolation approaches have limitations, a shift from grid-sampling to area-sampling approaches may or may not improve map accuracy. A number of sampling approaches have been used such as grid-soil sampling and area-based procedures including grid cell sampling and zone or directed sampling (Srivastava 2013f). Soil fertility condition maps and fertility management maps can be created from grid data using a number of geostastical, mathematical interpolation, and graphical procedures (Goovaerts 1997, Burroughs and McDonnell 1998). Thus, for a given spatial data set, different procedures will produce maps of varying quality. For example, the optimal distance exponent for the IDW interpolation procedure may depend upon the coefficient of variation (Gotway *et al.* 1996). Zhang *et al.* (2010) stressed upon developing regionalized nutrient management system using geostatistics and GIS based on spatial availability in soil nutrients.

The performance of kriging relative to IDW methods (with a distance exponent of 1.5) improved with increasing sampling intensity (i.e. IDW was superior to kriging for 100% of cases with the 100-m grid, 79% of the cases with the 61.5-m grid scale, and 67% of the cases with the 30-m grid) in south central Michigan. Practically, there was little difference between these interpolation methods. Grid sampling with a 100-m grid, grid cell sampling, and simulated soil map unit sampling yielded similar prediction efficiencies to those for the field average approach, all of which were generally poor (Mueller *et al.* 2001). It is also clear that the geometry and intensities of the sampling design greatly affect map quality (Wollenhaupt *et al.* 1994). At this

time, there is no consensus on which grid design and data analysis approach are best suited for SSFM. A grid-sampling approach that leads to an accurate condition map depends on many factors but ultimately on the spatial structure of soil properties (Flatman and Yfantis 1996, Sadler *et al.* 1998) including the range of spatial correlation (Mohamed *et al.* 1996).

Zone or directed sampling (Pocknee *et al.* 1996) is a method where soil samples are composited from areas or regions delineated as having similar yield potential or fertility status. In grid cell sampling, composite samples are obtained within rectangular gridded areas. Grid cell sampling has found limited use, in part because of reports that grid point sampling more accurately described soil properties than did grid cell sampling (Wollenhaupt *et al.* 1994). In general, area based sampling schemes depend to some extent on the investigator's ability to classify the study region into areas homogenous with respect to yield or soil fertility status. The concern is that proven guidelines for delineating fertility management zones within fields have not yet been established. The accuracy of maps derived from area-sampling schemes has not been reported. Regardless of the sampling approach, all methods for assessing soil variability are prone to certain errors including errors associated with soil sampling, laboratory analysis, interpolation, and map preparation. The difficulties in providing recommendations to practitioners are compounded by the fact that there is no agreement on how to best assess the map quality (Wollenhaupt *et al.* 1994, Franzen and Peck 1995, Gotway *et al.* 1996).

Spatial maps are fundamentally to SSNM because they represent either the spatial state of a condition of interest, the prescription of inputs needed to manage a particular condition site-specifically, or a record of inputs or outputs (Pierce and Nowak 1999). In his review of variable rate technology (VRT), Sawyer (1994) concluded that the success of VRT depends to a large extent on the quality of fertility management maps. Although methods exist for measuring map quality, in general, maps used in SSNM are rarely examined for quality (Sawyer 1994, Pierce and Nowak 1999). Thus, poor map quality may explain why results of some SSNM agronomic and economic studies have produced mixed or negative results (Wibawa *et al.* 1993). Map quality consists of two components, map precision and map accuracy. The former is a measure of residual variability in map prediction, whereas the latter measures the closeness to the true conditions.

Advances in software aided decision support systems (DSS) like DRIS (Diagnosis and Recommendation Integrated System) and GIS, have led to usage of newer interpretation tools having much wider application potential (Schumann and Zaman 2005, Zaman and Schumann 2006). 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

viz. i. assessing variation, ii. managing variation, and iii. evaluation. The available technologies enable us in understanding the variability and by giving site specific recommendations, the variability can be addressed precisely to make precision citriculture, a viable management strategy. Efforts were made to identify major promising productivity zones for concentrated development of 'Khasi' mandarin orchards in northeast India. An extensive survey of 108 'Khasi' mandarin orchards was carried out covering 590 sq.km from 50 georeferenced collection sites locations across 7 states (20°-22'5" N latitude and 89°37'-97-30° E longitude). Soils predominantly belonged to soil orders Entisol (Haplaquent, Ustifluent, and Udifluent), Inceptisol (Ustochrept and Haplaquent), Alfisol (Rhodustalf, Paleustalf, Haplustalf, Orchrtaqualf, and Rhodustalf), and Ultisol (Palehumult, Haplustult, Plinthaquult, and Plinthustult). Mineralogically, these soils were grouped as illitic-kaolinitic mixed. Climate is characterized by annual rainfall of 120-1145 cm (mean 180 cm) with mean summer and mean winter temperatures varying between 24.6°C - 32.8°C (mean 28°C) and 9.9°C-24.8°C (mean 15°C), respectively. Geology is dominated by sedimentary and metamorphic rocks grading from most ancient to recent (Srivastava and Singh 2010).

Redressal of spatial variability in soil fertility is important to identify the nutrient constraints vis-à-vis 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 analysed 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. DRIS interpretation revealed leaf nutrient optima as : 19.7-25.6 N, 0.9-1.0 P, 9.9-19.3 K, 19.7-24.9 Ca, 2.4-4.8 Mg as macronutrients (g/kg), 85-249 Fe, 43-88 Mn, 3-14 Cu and 17-27 Zn as micronutrients (mg/kg) vis-à-vis productivity of 33-56 kg/tree. Superimposing the variograms for nutrient constraints, three major citrus productivity zones were delineated as : zone I (26-27°8-25' 13-43" N latitude; 92°23-59' 0.82-43"E longitude) without Zn-Mg-P-N constraint, with productivity of 69-104 kg/tree as best productivity zone followed by zone II (26-27° 25-26' 36-51" N latitude; 93°23-58' 2-21" E longitude) having no Zn-P-N constraint with productivity of 52-68 kg/tree and zone III (26-27° 6-44' 20-56" N latitude; 91-92° 33-57' 6-17" E longitude) with no Zn-P constraint, having orchard productivity of 23-51 kg/tree (Srivastava *et al.* 2010), Integrated use of two diverse software-based DSS helped in identifying potential sites for sound land use planning using systematic citrus development program in order to harness sustainability in quality production without any nutrient mining. Such efforts need to be replicated in other perennial crops to establish some definite headway in order to develop

precision oriented decision support tool for fertilizer recommendation.

SOIL FERTILITY VARIOGRAM : DECISION SUPPORT FOR FERTILIZER ADVISORY

Soil fertility variogram is considered synonymous to plant nutriomics (Yan *et al.* 2006) as a decision support tool to work out the fertilizer requirement of perennial crops including citrus (Srivastava 2009, Srivastava 2012b). There is hardly any effort made in the past to develop decision support tool based on soil fertility variograms. An effort was made to ascertain the change in area of either yield zones or nutrient zones using variograms of different sampling sizes (Table 1). The zones of variograms were based through indices earlier worked out for Khasi mandarin using interpretation tool popularly known as DRIS. While area of different zones was worked out through DRIS-based variograms. Different fruit yield zones after variable rate fertilizer application as very low, low, optimum, high and very high were observed as 19%, 13.1%, 23.7%, 19.2% and 42%, respectively, at grid size of 10 m × 10 m and to 0.0%, 10.4%, 22.8%, 21.9% at grid size of 20 × 20 which changed to 2.2%, 9.9%, 29.1%, 20.4%, and 38.5% at grid size of 40 × 40 m and 0.4%, 12.3%, 31.3%, 25.1% and 30.9% at grid size of 60 × 60 m. These observations suggested that fruit yield variation was minimum with grid size of 20 m × 20 m, and varied substantially with bigger size of grid (Fig 1).

Variable rate fertilizer application brought significant changes in available pool of nutrients in soil (Table 1). The initial KMNO₄-N (2010-11) was optimum in 65.4% area, 54.6% area, 55.9% area and 48.0% area at grid size of 10 m × 10 m, 20 m × 20 m, 40 m × 40 m and 60 m × 60 m, respectively, which improved to 71.3% area, 67.3% area, 62.3% area and 80.5% area during 2012-13 after variable rate manuring based on production zones. Bray-P low in 77.5% area, 77.5% area, 72.8% and 67.6% area at 10 m × 10 m, 20 m × 20 m, 40 m × 40 m and 60 m × 60 m grid sizes, respectively, which further reduced to 31.2% area, 30.7% area, 34.5% area and 24.0% area at corresponding grid sizes during 2012-13 after variable rate fertilizer treatment as per production zones. Likewise 22.5% area, 22.5% area, 27.2% area and 32.4% area optimum initially at grid of 10 m × 10 m, 20 m × 20 m, 40 m × 40 m and 60 m × 60 m further improved to 68.8% area, 69.3% area, 65.5% area, and 76.0% area optimum in Bray-P during 2012-13.

Initially 97-100% area was identified as optimum in DTPA-Fe irrespective of grid size, i.e. variation in DTPA-Fe was not so distinct across different grid sizes (Table 1). While DTPA-Cu was optimum in 63% of orchard area at 10 m × 10 m grid followed by 50% at 20 × 20 m grid, 55% at 40 m × 40 m grid and again 50% at 60 m × 60 m grid, suggesting discernable change across grid sizes. While during 2012-13, after fertilizer treatment, no change could be noticed primarily due to major area remained under high to very high

Table 1 Changes in soil nutrient pool in relation to variable rate fertilizer application evaluated under differential grid sampling in Khasi mandarin orchard at Umsaiting, Ribhoi, Meghalaya

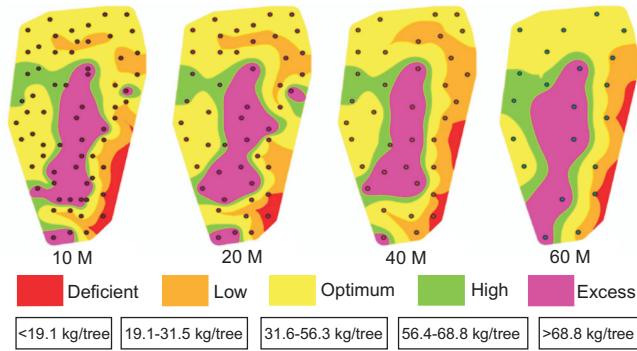
Nutrient indices	20 m × 20 m grid size				40 m × 40 m grid size			
	2010-11		2012-13		2010-11		2012-13	
	Area(m ²)	%	Area(m ²)	%	Area(m ²)	%	Area(m ²)	%
<i>Fruit yield</i>								
Very low	1927.5	2.0	0.3	0.0	2850.0	3.0	2019.5	2.2
Low	13185.0	14.0	9793.8	10.4	18749.8	20.0	9311.5	9.9
Optimum	42844.8	46.0	21405.5	22.8	39273.8	42.0	27300.0	29.1
High	13938.0	15.0	20574.3	21.9	13877.0	15.0	19159.5	20.4
Very high	22023.5	23.0	42145.0	44.9	19168.3	20.0	36128.3	38.5
<i>KMNO₄-N</i>								
Very low	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Optimum	51320.8	54.6	63203.0	67.3	52515.5	55.9	58465.5	62.3
High	37882.8	40.3	28080.3	29.9	36528.3	38.9	35149.8	37.4
Very high	4715.3	5.0	2635.5	2.8	4875.0	5.2	303.5	0.3
<i>Bray-P</i>								
Very low	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low	72755.5	77.5	28790.8	30.7	68397.0	72.8	32388.3	34.5
Optimum	21163.3	22.5	65128.0	69.3	25521.8	27.2	61530.5	65.5
High	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Very high	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>NH₄OAc-K</i>								
Very low	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low	28676.0	31.0	0.0	0.0	29727.8	32.0	0.0	0.0
Optimum	61343.5	65.0	85348.5	90.9	61722.8	66.0	82532.0	87.9
High	3527.3	4.0	8378.8	8.9	2081.8	2.0	11198.5	11.9
Very high	372.0	0.0	191.5	0.2	386.5	0.0	188.3	0.2
<i>Soil-DTPA-Mn</i>								
Very low	35694.0	38.0	26999.3	28.7	34335.5	37.0	36745.3	39.1
Low	49271.3	52.0	61981.3	66.0	49260.8	52.0	52287.0	55.7
Optimum	7089.3	8.0	4938.3	5.3	7988.3	9.0	4886.5	5.2
High	1577.8	1.0	0.0	0.0	1280.3	2.0	0.0	0.0
Very high	584.0	1.0	0.0	0.0	756.5	1.0	0.0	0.0
<i>Soil-DTPA-Zn</i>								
Very low	85762.8	91.0	86902.0	92.5	82256.8	88.0	89056.8	94.8
Low	5657.0	6.0	5574.5	5.9	7056.3	8.0	4516.5	4.8
Optimum	2495.0	3.0	1442.3	1.5	4597.8	5.0	345.5	0.4
High	4.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0
Very high		0.0	0.0	0.0		0.0	0.0	0.0

Area of the orchard is computed as 93918.8 m²; Geographical location of orchard (25°45.388' – 25°41.582' N latitude and 91° 53.765' – 91° 53.896' E longitude)

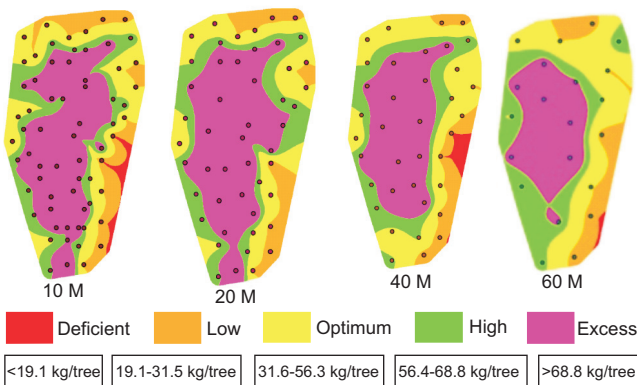
Source : Srivastava (2012b, 2013d)

in DTPA-Fe. Similarly, high level of DTPA-Cu was observed in 11-17% of orchard area using grid sizes up to 40 m × 40 m, but at grid size of 60 m × 60 m, the % area increased to 34% of orchard area, suggesting again the suitability of optimum grid size for refining soil test interpretation. While

no change in area under low Mn zone was observed constituting 51-52% of total orchard area irrespective of grid size during 2010-11. The optimum Mn zone covered just 7-9% of total orchard area upto 40 m × 40 m grid size which increased to 17% at grid size of 60 m × 60 m (Table 1) during



(a) Spatial variation in fruit yield based on DRIS-based different fruit yield classes indices at 10 m × 10 m, 20 m × 20 m, 40 m × 40 m grid sampling (2010-11)



(b) Spatial variation in fruit yield based on DRIS-based different fruit yield class indices at 10 m × 10 m, 20 m × 20 m, 40 m × 40 m and 60 m × 60 m grid sampling (2012-13)

Fig 1 Spatial variation in fruit yield in relation to different grid sampling size (10 × 10m, 20 × 20m, 40 × 40m and 60 × 60m) in the selected khasi mandarin orchard at Umsaitning in Ribhoi district of Meghalaya. Source : Srivastava (2012b, 2013d)

2012-13, these zones went through significant redistribution after fertilizer application. The deficient area in DTPA-Mn reduced to 32.1% and 28.7%, respectively at grid size of 10 m × 10 m and 20 m × 20 m. But, beyond this grid size the changes were not so conspicuous upto grid size of 60 m × 60 m (Table 1).

Differentiation of zones for DTPA-Zn was most conspicuous across different grid zones. There was absolutely nothing under deficient Zn zone constituting 88-91% of total orchard area irrespective of grid size. While under low Zn zone, up to grid size of 20 m × 20 m, only 6-7% area, was covered which increased to 9% with increasing grid size upto 60 m × 60 m during 2010-11. Similarly, under optimum Zn zone, up to grid size of 20 m × 20 m, only 3% orchard area was covered, which reduced to 1% of orchard area with increasing grid size upto 60 m × 60 m during 2010-11. These figures were not improved considerably during 2012-13 suggesting that due to high DTPA-Fe, improvement in DTPA-

Zn may consume more time (Srivastava *et al.* 2010, Srivastava 2012b, 2013d).

VARIABLE RATE FERTILIZER APPLICATION

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 (Miller *et al.* 2005). 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/year) on a tree size basis (0-240 m³/tree), achieved a 38-40% saving in granular fertilizers cost. While, conventional uniform application rate of 270 kg N/ha/year showed that trees with excess nitrogen (>3%) had canopies less than 100 m³ 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 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 with corresponding fertilizer does (g/tree) 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, Srivastava 2013c).

Analysis of tree size of 3040 trees space of 40-acre grove showed a skewed distribution with 51.1% trees having 25-100 m³/tree size classes and a median size of 82 m³/tree. At a uniform fertilization rate of 240 kg N/ha/year, 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 m³/tree, 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/year. For comparison purposes, the eastern half of the grove received the full uniform rate of 240 kg N/ha/year. 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.* 1999). Elprince (2009) suggested multivariable fertilizer recommendation models allowing necessary

adjustments in variable rate fertilizer applications. Later, these logistic models were cross validated and combined in a GIS to derive N and K fertilization class maps using kriged-interpolated data sets of the significant site variables. Chan *et al.* (2002) studied the effect of boundary determination, interpolation method and GPS location error for determining variable rate nitrogen application map based upon yield maps. A general linear model for mean absolute error approximated the error effects.

SITE SPECIFIC NUTRIENT MANAGEMENT

Future gains in productivity and input use efficiency will require soil and crop management technologies that are knowledge-intensive, and are tailored to specific characteristics of individual farms or fields to manage the variability that exists between and within them (Tiwari 2007a). The SSNM approach is one such option that has been tried successfully in India using different approaches. A plant-based SSNM approach developed in the early 1990s by the International Rice Research Institute in collaboration with partners has been adopted by IPNI, India. The scientific principles of SSNM were compiled into a practical guidebook to nutrient management for rice (Dobermann *et al.* 2003a, 2003b).

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 sized 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.

Soil fertility variograms

An exhaustive grid-based (36 m × 36 m grid size) soil sampling within an orchard 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, Olsen-P 6-14 mg/kg, $\text{NH}_4\text{OAc-K}$ 94-134 mg/kg, DTPF-Fe 6-18 mg/kg, DTPA-Mn 4-14 mg/kg, DTPA-Cu 6-14 mg/kg and DTPA-Zn 0.40-0.68 mg/kg compared to conventional soil test values of 102.00 mg/kg alkaline $\text{KMnO}_4\text{-N}$, 7.1 mg/kg Olsen-P, 106.2 mg/kg $\text{NH}_4\text{OAc-K}$, 13.3 mg/kg DTPA-Fe, 11.0 mg/kg DTPA-Mn, 8.1 mg/kg DTPA-Cu and 0.58 mg/kg DTPA-Zn. Using these variations, spatial variograms on GIS (Geographical Information System) version Arc 3.5 and accordingly the spatial variograms were developed. 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.

The SSNM offers the most appropriate option to address the spatial variation in soil fertility using variable rate fertilization (VRF) as per soil test values. Based on grid sampling and geocoding, two contrasting soil types viz., Typic Ustorthent and Typic Haplustert showed a significantly different magnitude of response of Nagpur mandarin to fertilization (Table 2). 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 along with 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 . Such a differential response of fertilization showed no similarity with recommended fertilizer doses earlier worked out through multilocation trials (Srivastava *et al.* 2006, 2009).

The SSNM studies carried out on sweet oranges showed similar 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 returns than those received from farmer's fertilizer practice or the recommended dose of fertilizers (Srivastava 2011). 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. The SSNM could be further fitted precisely into precision farming 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 2013b). Other perennial crops could also find similar technological interventions.

Analysis on site specific changes in soil K fractions

Keeping watch on transformation of various soil nutrient fractions is one of the conventional ways of studying nutrient mining (Srivastava 2011). The SSNM approach, by the virtue of balanced fertilization has proved more effective in buildup of certain soil K fractions using citrus as test crop (Srivastava *et al.* 1998). Monitoring on simple changes in $\text{NH}_4\text{O-Ac}$ will not precisely predict the long term impact of soil fertilization discernible on dynamics of soil K fractions. The

Table 2 Response of site specific fertilizer treatment compared to farmers' practices / recommended doses of fertilizers in Nagpur mandarin grown on smectite Vertisols

Treatment	Yield (kg/tree)	Leaf nutrients concentration				Fruit quality (%)		
		Macronutrients (%)			Micronutrient (ppm)	Juice	TSS	Acidity
		N	P	K	Zn			
<i>Soil Type -1 : Shallow soil (Typic Ustorthent)</i>								
Farmers' Practices: T ₅ (N ₆₀₀ + P ₄₀₀ + K ₀ + M ₁ S ₁)	27.8	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) – RDF	37.5	2.04	0.09	1.15	21.2	45.7	0.56	9.1
Site specific treatment: T ₉ (N ₁₂₀₀ + P ₆₀₀ + K ₆₀₀ + M ₁ S ₁)	53.1	2.38	0.13	1.35	25.7	48.3	0.48	9.6
<i>Soil Type -2 : Deep soil (Typic Haplustert)</i>								
Farmers' Practices: T ₅ (N ₆₀₀ + P ₄₀₀ + K ₀ + M ₁ S ₁)	42.9	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) – RDF	58.5	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 ₁ S ₁)	68.5	2.55	0.13	1.67	31.0	49.8	0.53	9.0

M₁ stands for application of 300 g each of ZnSO₄, FeSO₄, MnSO₄ and 100 g borax/tree; Mo stands for no application of micronutrient fertilizers; S₁ stand for application of 400 g MgSO₄/tree 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.* (1998, 1999, 2006)

genesis of K mining, could also be diagnosed, unless an incisive analysis on potentially available soil K fraction like non-exchangeable K is carried out. A comparison was made between multilocation differential K response experiments and SSNM-based experiments with respect to changes in different soil K fractions (Table 3). Interestingly, the soil

applied N:P:K ratio in all the mulilocation trials varied from 3:1:5 to as high as 6:2:1 in Nagpur mandarin and 8:2:1 in acid lime, possibly signaling the imbalance in fertilization in addition to paving the way for depletion of potentially available soil K fraction(s). On the other hand, in SSNM-based studies, these N:P:K ratios were significantly narrower,

Table 3 Analysis of soil K-fractions for the yield responses obtained at various sites on smectite Vertisols

Sites	Soil type	NH ₄ OAc-K (mg/kg)	Yield response (kg/tree)	Recommendations (N-P ₂ O ₅ -K ₂ O)	Changes in soil-K fractions		
					WS-K	Ex-K	Non-Ex-K
Site I (Panjri) Nagpur mandarin	Typic Haplustert	158.2	41.5	600-200-100 (6:2:1)	13.2 (12.2)	131.6 (132.3)	364.5 (342.1)
Site II (Sahuli) Nagpur mandarin	Typic Haplustert	151.6	52.9	600-200-300 (3:1:1.5)	12.8 (11.4)	128.3 (134.1)	428.8 (308.2)
Site III (Gondkheri) Acid lime	Typic Ustochrept	161.4	53.4	800:200:100 (8:2:1)	14.2 (15.1)	134.6 (140.2)	408.3 (372.4)
SSNM (Nagpur mandarin)							
Site I (Narkhed)	Typic Ustorthent	147.2	53.1	1200-600-600 (2:1:1)	13.4 (11.2)	129.6 (132.4)	478.9 (508.2)
Site II (Narkhed)	Typic Haplustert	167.3	68.5	600-400-300 (2:1.5:1)	8.4 (8.0)	131.7 (140.2)	418.2 (522.3)
SSNM (Sweet orange) Narkhed	Typic Haplustert	186.4	61.4	800:400:600 (2:1:1.5)	10.2 (10.8)	143.4 (151.3)	442.0 (516.1)

Figures in the parenthesis represent the post-harvest changes in soil K fractions

Source: Huchche *et al.* (1996, 1998), Lallan Ram *et al.* (1997), Srivastava *et al.* (2001a, 2006, 2010)

from 2:1:1 to 2:1:1.5 only, signifying the importance of striking a dynamic balance in different nutrients. These two concepts of fertilizer application also provide a basis for obtaining a comparatively higher fruit yield with investment on unit cost of nutrients. The fruit yield with narrower N:P:K ratio was much higher (53.1-52.9 kg/tree) with SSNM than with wider ratio (41.5-68.5 kg/tree) with simple fertilizer response studies. Our earlier studies on Vertisols (Kohli *et al.* 1996) ably demonstrated that wide leaf N/K ratio has produced not only reduced productivity, but fruit quality was also severely affected. In this background, an critical leaf N/K ratio of 2.49 (leaf N 2.42% and leaf K 0.97%) was suggested.

All the six experimental sites, although had different soil physico-chemical properties, but possessed uniform smectite rich mineralogy ranging in $\text{NH}_4\text{OAc-K}$ level of 147.2-186.4 mg/kg, still produced a significant response on fruit yield. Such responses strongly advocate to revise available soil K (NH_4OAc extractable) norms on Vertisols, besides the threshold values below or above, response or no response could be anticipated. Unless this is done, using the vague term like medium or high in soil available K, such acronyms will continue to misguide the researchers, and resultantly the correct production economics would not be harnessed. The revision of such guides needs to be undertaken in the light of soil test-crop response studies of varied nature.

Changes in soil K fractions likewise displayed a different distinctive pattern of variation. The variation in water soluble-K and exchangeable-K was simply not recognizable under both fertilizer response studies (decrease in water soluble-K from 0.90 mg/kg in increase by 1.40 mg/kg and decrease in exchangeable-K from 0.70 to 5.60 mg/kg) and site specific nutrient management studies (decrease in water soluble-K by 0.60 mg/kg to increase by 2.20 mg/kg and decrease in exchangeable K 2.80 – 7.90 mg/kg), although slight reduction in exchangeable-K has invariably taken place. The non-exchangeable-K on the other hand revealed different pattern of changes. In conventional fertilizer response studies all the three sites observed a decrease in non-exchangeable-K, from 20.6 to as high as 35.9 mg/kg, while in SSNM-based studies, the exchangeable-K went through a definite build-up, from 29.3 to as high as 104.1 mg/kg. In addition, the final soil test values of non-exchangeable-K again was higher under SSNM studies (418.2-478.8 mg/kg). These studies lend strong support in favour of SSNM for balanced fertilization, besides necessitating towards revising the K-recommendations on smectite Vertisols (Srivastava *et al.* 2001b, Srivastava 2011).

STRATEGIES AND OPPORTUNITIES

The fall out of a generalized fertilizers recommendation over large areas of small-scale farming leads to the possibility of over or under-application of nutrients, by and large, with its economic and environmental consequences (Srivastava 2013a, 2013e). The more apparent consequences of falling productivity and nutrient efficiency, multi-nutrient

deficiencies, increasing pace of nutrient mining and falling farm income are highlighted by earlier researchers (Ghosh *et al.* 2004, Srivastava and Singh 2004a, 2005, 2008b, Tiwari, 2007a). The environmental impacts are not very apparent yet, probably because of the generally low nutrient application rates, except few crops of very high commercial importance. The SSNM, on the other hand, is an approach for feeding crops with nutrients, as and when they are needed, considering inherent spatial variability associated with fields under crop production. The SSNM also avoids indiscriminate use of fertilizers by preventing excessive/inadequate rates of fertilization, ensuring that all the required nutrients are applied at proper rates and in proper ratios commensurating with the crop's nutrient demands.

The work on precision citriculture in Florida (Whitney *et al.* 1999) is carried out with the 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 increased availability of hyperspectral imaging sensors and advanced analysis tools like partial least squares regression and spectral mixing techniques will further facilitate extend this concept at canopy level. The newer approaches using laser induced fluorescence have considerable potential for pre-visual identification of nutrient and water stress in addition to detection of optimum levels of growth and yield under different fertilization rates under orchard conditions (Srivastava and Singh 2001, 2002).

The most important step towards the calibration of site specific fertilizer requirement is the estimation of the indigenous nutrient supplies, which we define as the cumulative amount of nutrient originating from all indigenous sources (Srivastava *et al.* 2007). There are several approaches to determine 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 pose 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). However, Zhang *et al.* (2010) suggested that the regionalized maps are practical alternative to site-specific soil nutrient management approaches in areas where it is not practical to implement

SSNM due to small field size or other constraints to use intensive soil sampling and chemical analyses.

Strategies

The important strategies could be summarised as :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 and nutrient requirement to be worked out by delineating the role of perennial framework of fruit plants in nutrient dynamics vis-à-vis nutrient supply capacity.

Opportunities

The major opportunities foreseen through SSNM are summarised as : 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 and exploring role of plant nutrition in improving shelf life of fruits through enzyme silencing.

There seems to be greater scope to expand the effectiveness of SSNM using canopy reflectance to grid-based variograms and variable rate nutrient maps. Hence , it is necessary to realize the full impact of SSNM , unless the usefulness of grid soil/leaf sampling , production zone vis-à-vis management zone strategies, aerial imagery vis-a-vis canopy reflectance is exploited in tandem with ultimate aim of rationalizing fertilizer use with productivity maximization.

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