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Mapping of spatial variability in soil properties for site-specific nutrient management of Nagpur Mandarin in Central India

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ABSTRACT

The paper discusses the mapping of spatial variability in soil properties of Nagpur Mandrin growing areas in central India for site-specific nutrient management. Contiguous area of Nagpur mandarin orchards was identified using Cartosat-1-sharpened IRS-P6 LISS-IV data followed by ground truth. Soil samples were collected from 0-20 and 20-40 cm in a grid design (200 × 200 m) using Global Positioning System and analyzed for particle-size, bulk density, moisture retention at -33 kPa, and -1500 kPa, pH, organic carbon, calcium carbonate, available N, P and K and micronutrient cations. The GIS aided kriged thematic maps showed spatial variation in soil properties and soil fertility parameters. The cadastral maps overlaid on kriged thematic soil maps precisely indicated the areas having soil related constraints for site-specific nutrient management to improve the productivity of Nagpur mandarin in central India.

Key words: *Citrus*, soil constraints, kriging, geostatistics, GIS, GPS.

INTRODUCTION

In India, major mandarin-growing states are Punjab, Madhya Pradesh, Maharashtra, Rajasthan, Assam, Karnataka and Meghalaya and specific cultivars of mandarins are cultivated in different regions. Nagpur mandarin (*Citrus reticulata* Blanco), one of the premier commercial citrus cultivars, is widely grown (0.31m ha) along the foot hills of Satpura hill range under hot sub-humid tropical climate in Central India with a production of 2.91 m MT and productivity of 10 MT ha^{-1}.

Soil-water-deficit stress mediated flowering response in Nagpur mandarin is by and large the key factor in the success of orange farming (Jagdish Prasad, 3) and soil properties like presence of free lime, excessive salt, defective drainage, presence of hard pan in the sub-surface, soil texture, mineral composition of soil, cation exchange capacity and soil fertility (Srivastava *et al.*, 14) and water holding capacity, drainage rate, rooting depth, and fertility have been identified as major causes of spatial yield variability (Mann *et al.*, 7; Likhar and Jagdish Prasad, 5 and 6). Site-specific soil management can improve profitability and environmental protection of citrus orchards having large spatial variation in soil and tree characteristics. Knowledge of spatial variation in soil properties is important in precision farming and environmental modeling (Santra *et al.*, 11). Srivastava *et al.* (15) highlighted the importance of spatial variability in soil fertility in identifying nutrient constraints *vis-à-vis* productivity zones to rationalize nutrient use and optimize productivity.

The application of parametric statistics is inadequate for analysis of spatially dependant variables because they assume that measured observations are independent in -spite of their distribution in space. Geo-statistics provide a tool for improving the sampling design by utilizing the spatial dependence of soil properties within a sampling region and useful to understand the spatial interrelationship of soil data which reduces error, biasness and increase the accuracy of data for interpolation (Oliver, 10). Therefore, the present study was undertaken to map the spatial variability in soil properties for site-specific nutrient management of Nagpur mandarin in Katol tehsil of Nagpur district, Maharashtra using geospatial techniques.

MATERIALS AND METHODS

A contiguous intensively cultivated Nagpur mandarin area was identified using Cartosat-1-sharpened IRS-P6 (Indian Remote Sensing) satellite data followed by ground truth. The area (280 ha) is located in Katol tehsil (78° 33' to 78° 34'E; 21° 14' to 21° 15'N) of Nagpur district, Maharashtra (Fig. 1) at an elevation ranging from 480 to 500 m above mean sea level (MSL). The climate of the area is sub-tropical dry sub-humid with mean annual temperature of 33.5ºC and mean annual precipitation of 1050 mm. The area qualifies for 'ustic' and 'hyperthermic' soil moisture and temperature regimes, respectively. Soybean (*Glycine max*), wheat (*Triticum aestivum*)

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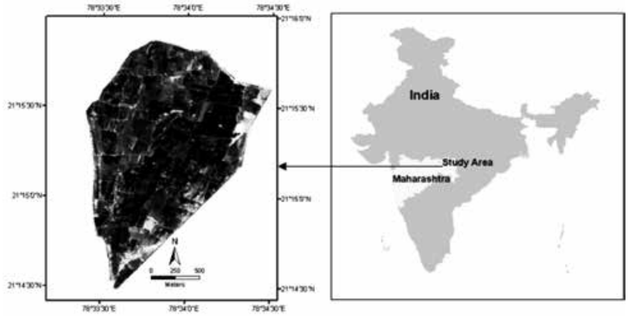

Fig. 1. Location of study area with Cartosat-1-sharpened IRS-P6 LISS-IV data showing the contiguous areas of citrus orchards.

and gram (*Cicer arietinum*) are grown as an inter-crop in orchards upto five years of its planting.

Survey of India toposheets on 1:50000 scale, IRS-P6 LISS-IV data of 7th November, 2008 and 8th January, 2010 (5.8 m resolution) were geo-referenced using WGS 84 zone 44 N datum, Universal Transverse Mercator (UTM) projection and ground control points (GCPs). The ortho-rectified Cartosat-1 data was fused with IRS-P6 LISS-IV data. The cadastral map of the village was scanned using HP Designjet 4500 at 300 dpi. The rasterized cadastral map was co-registered using ortho- rectified Cartosat-1-sharpened IRS-P6 LISS-IV data as a reference. After geo-referencing, the rasterized cadastral map was screen digitized, corrected for digitization errors and validated using ArcGIS to prepare polyline map of the village.

In the present study, a grid size of 200 × 200 m (Fig. 2) was marked on geo-referenced cadastral map (1:5000 scale) of the village. A total of 138 soil samples from 69 grid locations were collected from a depth of 0-20 cm and 20-40 cm wherein maximum concentration of feeder roots occur. The collected soil samples were properly processed and analyzed for particle- size, bulk density, moisture retention at -33 kPa, -1500 kPa, pH, organic carbon, calcium carbonate and available N, P, K, Fe, Mn, Cu, Zn following the standard procedures (Black *et al.*, 1; Jackson, 2). The flow chart of the methodology is presented in Fig. 3.

The datasets containing measured soil variables were analyzed using classical statistical method to obtain minimum, maximum, mean, standard deviation (SD), coefficient of variation (CV), skewness, kurtosis using SPSS version 11.5 software. The data was normalized before interpolation to generate surface maps of soil properties. In the study, logarithmic transformations available in Geostatistical Analyst of ArcGIS software (version 10.1) were applied to normalize the data wherever the data sets of

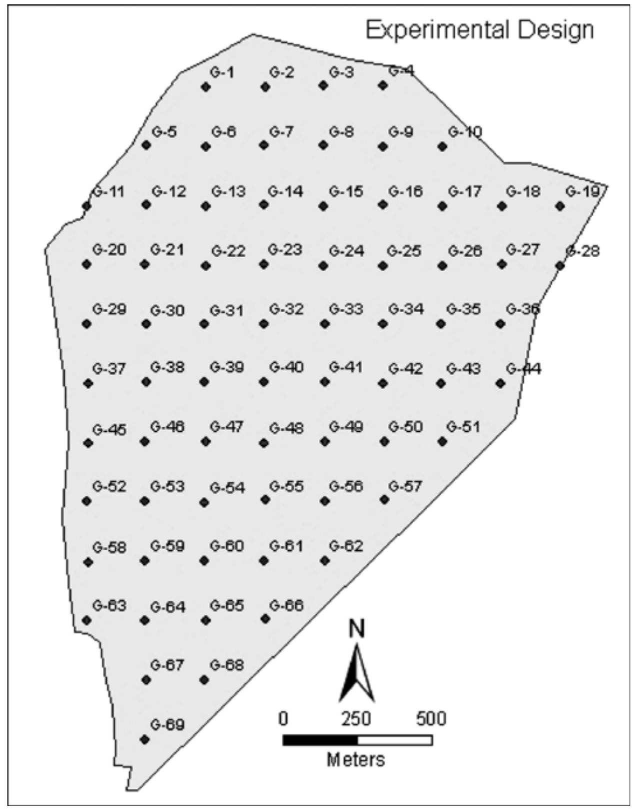

Fig. 2. Experimental design for soil sampling.

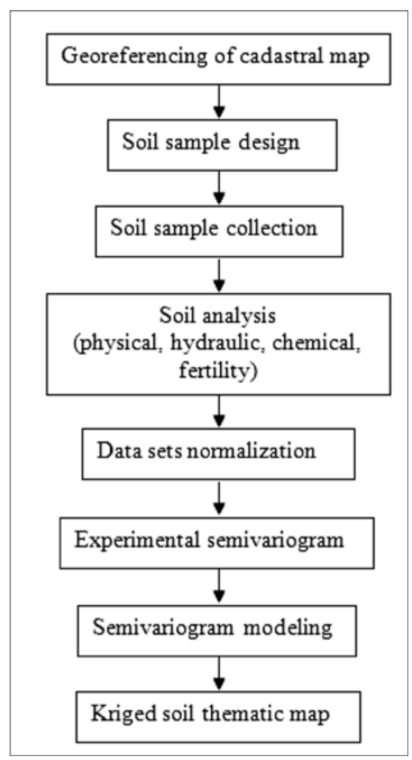

Fig. 3. Flow chart of the methodology.

soil properties were non-normal. Surface maps of basic soil properties were prepared using semi-variogram parameters through ordinary kriging in geostatistical analyst of ArcGIS software and digital cadastral boundaries were superimposed during map composition.

RESULTS AND DISCUSSION

The descriptive statistics of soil physical properties at 0-20 and 20-40 cm depth are presented in table 1. The mean for sand, silt and clay content (0-20 cm) were 17.8, 32.5 and 49.7 per cent with a range of 4.8-59.9, 15.4 to 43.7 and 17.9 to 68.0 per cent, respectively. Sand had the largest variation (CV = 0.70) followed by clay (CV = 0.24) and silt (CV = 0.15). The average bulk density was 1.76 Mg m^{-3} with a range of 1.33 to 2.07 Mg m^{-3} and it was found to be least variable (CV = 0.08). At 20-40 cm depth, the mean value for sand, silt and clay content were 16.4, 31.6 and 52.0 per cent with a range of 3.8 to 57.0, 14.9 to 44.5 and 15.3 to 71.5 per cent, respectively. Sand had the largest variation (CV = 0.74) followed by clay (CV = 0.23) and silt (CV = 0.16). Average bulk density was 1.80 Mg m^{-3} with a range of 1.59 to 1.98 Mg m^{-3} and it was found to be the least variable (CV = 0.04). Soil moisture retention at -33 kPa and -1500 kPa varied from 19.5 to 49.5 and 9.3 to 33.3 per cent with mean value of 35.8 and 25.1 per cent, respectively. The moisture retention at -33 kPa and -1500 kPa were moderately variable with a CV of 0.15 and 0.19, respectively, whereas, moisture retention at -33 kPa and -1500 kPa at 20-40 cm depth, varied from 20.0 to 51.3 and 13.3 to 39.5 per cent with mean value of 35.6 and 25.8 per cent, respectively. The moisture retention at -33 kPa and -1500 kPa were found be moderately variable with CV of 0.15 and 0.17, respectively.

The descriptive statistics of soil chemical and fertility parameters are presented in table 2. The soil pH ranged from 7.3 to 8.9 at both the depths. Organic carbon had variation of 0.44 to 1.01 per cent (mean of 0.87%). Calcium carbonate ranged from 0.23 to 19.2 per cent (mean 6.09 %). The calcium carbonate was found to be highly variable (CV = 0.66) followed by organic carbon (CV = 0.17) while, pH was found least variable (CV = 0.04). Organic carbon varied from 0.37 to 0.99 per cent (mean 0.73 %) at the depth of 20-40 cm. Calcium carbonate ranged from 0.70 to 22.1 per cent with a mean value of 6.58 per cent and was found to be highly variable (CV = 0.60) followed by organic carbon (CV = 0.21). The available N, P and K varied from 165.1 to 351.8, 0.2 to 70.3 and 44.8 to 492.8 kg ha^{-1} with mean value of 219.6 kg ha^{-1}, 12.4 kg ha^{-1} and 219 kg ha^{-1}, respectively. The available Fe, Mn, Cu, and Zn ranged from 7.7 to 63.5, 3.5 to 60.0, 1.0 to 7.4 and 0.14 to 1.5 Mg kg^{-1} with mean values of 29.0, 27.3, 3.7 and 0.5 mg kg^{-1}, respectively. The available P was found to be highly variable (CV = 0.98) followed by available K (CV = 0.53). Available N was found to be moderately variable (CV = 0.15). The micronutrient cations were highly variable with CV ranging from 0.31-0.55. Data

Table 1. Descriptive statistics of soil physical and hydraulic properties.

Soil Property	Minimum	Maximum	Mean	SD	CV	Skewness	Kurtosis
Soil physical properties (0-20 cm depth)							
Sand (%)	4.8	59.9	17.8	12.45	0.70	1.56	2.10
Silt (%)	15.4	43.7	32.5	4.74	0.15	-0.9	2.36
Clay (%)	17.9	68.0	49.7	12.27	0.24	-1.13	0.37
Bulk density (Mg m^{-3})	1.33	2.07	1.76	0.14	0.08	-0.65	0.90
Soil physical properties (20-40 cm depth)							
Sand (%)	3.8	57.0	16.4	12.15	0.74	1.64	2.28
Silt (%)	14.9	44.5	31.6	5.17	0.16	-0.43	1.82
Clay (%)	15.3	71.5	52.0	11.83	0.23	-1.31	1.31
Bulk density (Mg m^{-3})	1.59	1.98	1.80	0.08	0.04	-0.08	0.51
Soil hydraulic properties (0-20 cm depth)							
Moisture retention (-33 kPa) (%)	19.5	49.5	35.8	5.35	0.15	-0.57	0.89
Moisture retention (-1500 kPa) (%)	9.3	33.3	25.1	4.70	0.19	-1.02	1.31
Soil hydraulic properties (20-40 cm depth)							
Moisture retention (-33 kPa) (%)	20.0	51.3	35.6	5.50	0.15	-0.65	1.80
Moisture retention (-1500 kPa) (%)	13.3	39.5	25.8	4.52	0.17	-0.44	1.38

Table 2. Descriptive soil chemical properties and soil fertility parameters.

Soil Property	Minimum	Maximum	Mean	SD	CV	Skewness	Kurtosis
Chemical properties (0-20 cm depth)							
pH	7.3	8.9	8.3	0.35	0.04	-0.98	0.86
Organic carbon (%)	0.44	1.01	0.87	0.15	0.17	-1.44	0.91
$CaCO_3$ (%)	0.23	19.2	6.09	4.04	0.66	1.01	0.75
Chemical properties (20-40 cm depth)							
pH	7.3	8.9	8.4	0.31	0.04	-1.20	2.29
Organic carbon (%)	0.37	0.99	0.73	0.16	0.21	-0.54	-0.50
$CaCO_3$ (%)	0.70	22.10	6.58	3.88	0.60	1.20	2.56
Fertility parameters (0-20 cm depth)							
Available N (kg ha^{-1})	165.1	351.8	219.6	33.08	0.15	1.25	3.08
Available P (kg ha^{-1})	0.2	70.3	12.4	12.15	0.98	2.42	8.13
Available K (kg ha^{-1})	44.8	492.8	219	115.7	0.53	0.49	-0.50
Available Fe (mg kg^{-1})	7.7	63.5	29.0	12.89	0.44	0.66	-0.15
Available Mn (mg kg^{-1})	3.5	60.0	27.3	13.45	0.49	0.63	-0.29
Available Cu (mg kg^{-1})	1.0	7.4	3.7	1.14	0.31	0.87	1.30
Available Zn (mg kg^{-1})	0.14	1.50	0.5	0.29	0.55	1.40	1.97
Fertility parameters (20-40 cm depth)							
Available N (kg ha^{-1})	140.7	271.2	202.8	30.57	0.15	0.45	-0.31
Available P (kg ha^{-1})	0.2	25.1	6.5	5.82	0.89	0.46	1.87
Available K (kg ha^{-1})	33.6	280.0	119.6	68.50	0.57	0.74	-0.50
Available Fe (mg kg^{-1})	6.0	53.0	28.4	11.60	0.41	0.35	-0.71
Available Mn (mg kg^{-1})	4.0	66.0	24.8	12.14	0.49	1.12	1.74
Available Cu (mg kg^{-1})	1.2	6.8	3.4	1.07	0.32	1.07	1.63
Available Zn (mg kg^{-1})	0.04	2.6	0.7	0.48	0.74	1.93	4.79

pertaining to available N, P and K showed variation of 140.7 to 271.2, 0.2 to 25.1 and 33.6 to 280.0 kg ha^{-1} (0-20 cm) with mean value of 202.8 kg ha^{-1}, 6.5 kg ha^{-1} and 119.6 kg ha^{-1}, respectively. The DTPA-extractable Fe, Mn, Cu, and Zn varied from 6.0 to 53.0, 4.0 to 66.0, 1.2 to 6.8 and 0.04 to 2.6 mg kg^{-1} with mean values of 28.4, 24.8, 3.4 and 0.7 Mg kg^{-1}, respectively. Available P was found to be highly variable (CV = 0.89) followed by available K (CV = 0.57) but available N was least variable (CV = 0.15). The micronutrient cations were highly variable with CV ranging from 0.32-0.74.

Kriged spatial maps of sand, silt and clay are presented in Fig. 4. The spatial distribution of sand had a variation of 9-32 per cent at 0-20 cm depth and 7- 31 per cent at 20-40 cm depth; silt varied from 29-40 per cent at 0-20 cm depth and 29-41 per cent at 20-40 cm depth and clay showed variation of 20-64 per cent at 0-20 cm depth and 19-72 per cent at 20-40 cm depth. The higher sand content was observed in southern, eastern and western parts compared to northern part of the area. Concomitantly, higher clay content was observed in central and northern parts of the area. Kriged spatial maps of bulk density, soil moisture retention at -33 kPa and soil moisture retention at -1500 are presented in Fig. 5. Spatial map of bulk density at 0-20 cm depth shows that the bulk density varied from 1.66-1.88 Mg m^{-3} at 0-20 cm and 1.75-1.86 Mg m^{-3} at 20-40 cm depth. The higher bulk density was observed in eastern part compared to other parts of area at 0-20 cm depth, whereas, higher bulk density was observed in eastern and western parts of area at 20-40 cm depth. Spatial map of soil moisture retention at -33 kPa revealed its variation soil moisture retention varied from 26.9-40.4 per cent at 0-20 cm depth and 24.4-39.4 at 20-40 cm depth. The higher soil moisture retention at -33 kPa was observed in northern and central parts (0-20 cm) and eastern and north-eastern parts of the area at 20-40 cm depth. The moisture held at -1500 kPa varied from 18.9-29.8 per cent (0-20 cm) and 20.2-28.2 at 20-40 cm depth. The higher soil moisture retention at -1500 kPa was observed in northern and central parts (0-20 cm) and central part of the area at 20-40

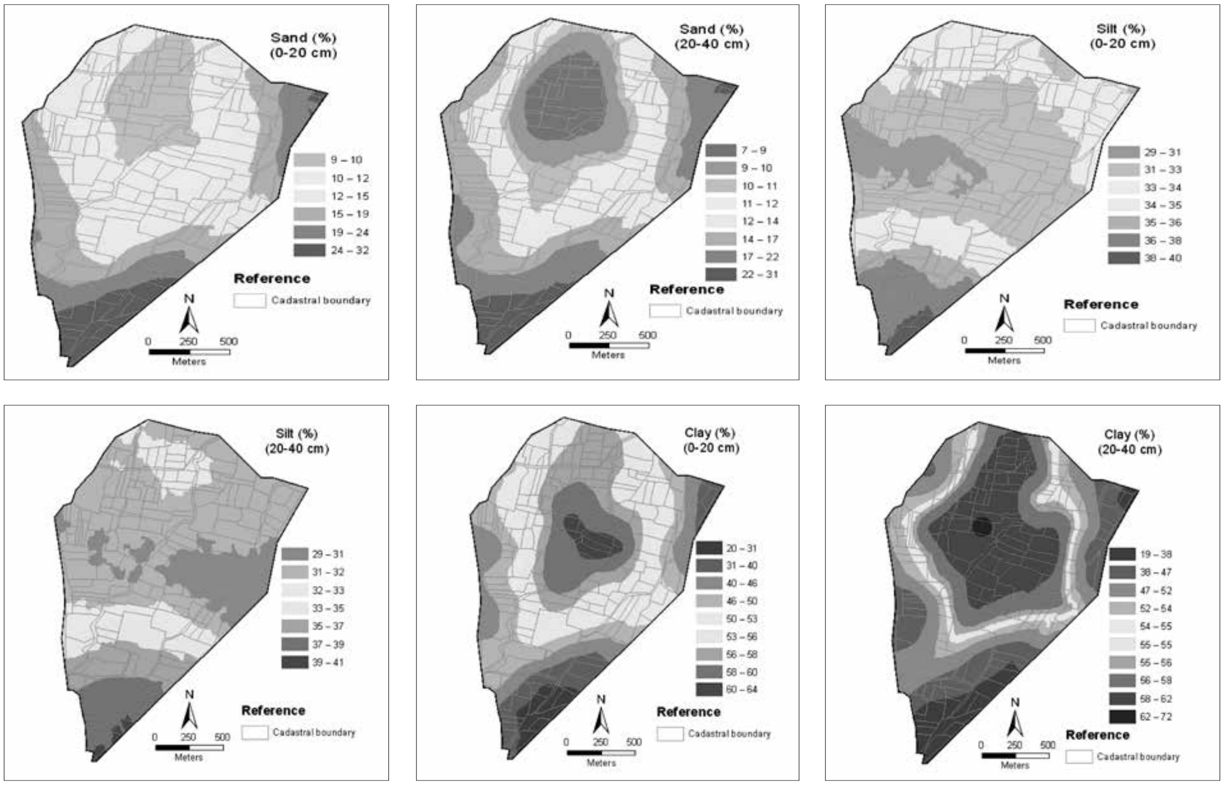

Fig. 4. Kriged maps of soil physical properties.

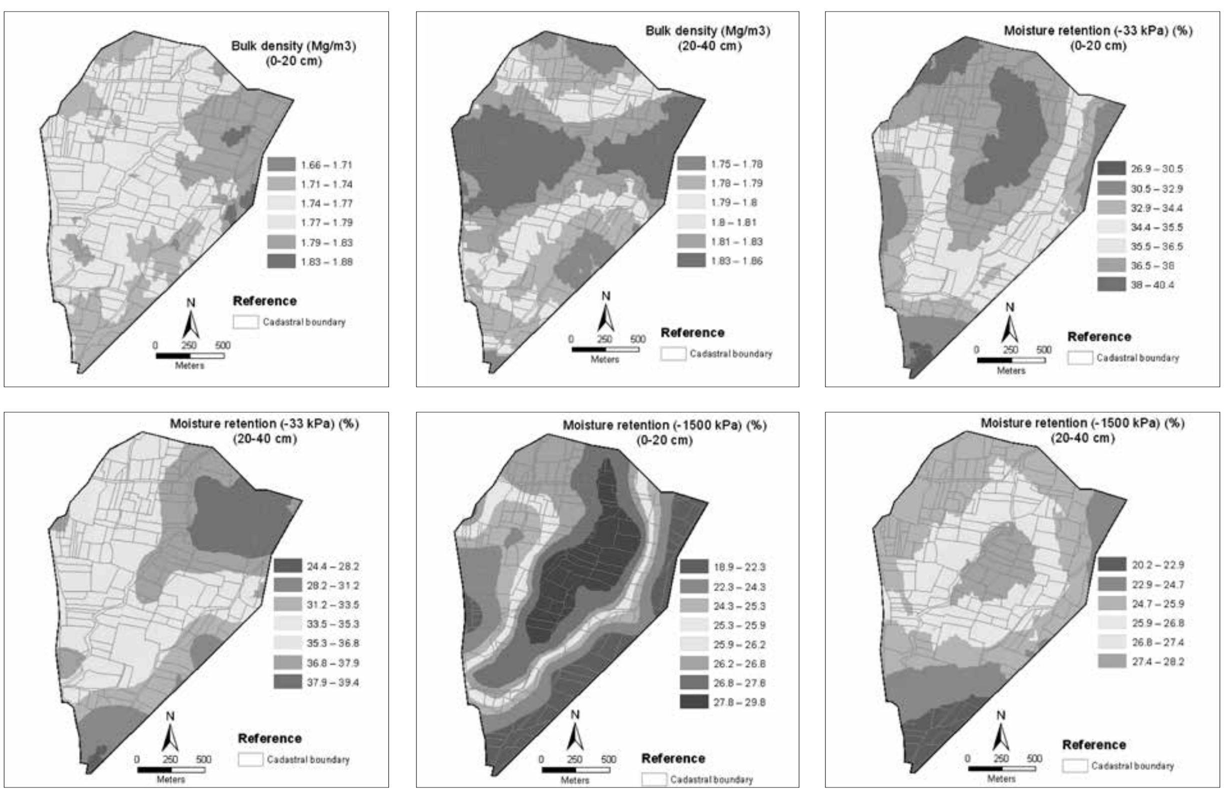

Fig. 5. Kriged maps of soil hydraulic properties.

cm depth. There was high spatial correlation between soil moisture retention at -33 kPa and -1500 kPa and clay content. Areas with higher soil moisture retention at -33 kPa and -1500 kPa corresponded with higher clay content. Srivastava et al. (16) and Jagdish-Prasad et al. (4) reported significant and positive correlation between clay and soil moisture retention at-33 kPa and -1500 kPa.

Kriged maps showed that soil pH varied from 7.94 to 8.76 (0-20 cm) and 8.19 to 8.72 at 20-40 cm depth (Fig. 6). The organic carbon content varied from 0.87-0.97 per cent at 0-20 cm and 0.58-0.83 at 20-40 cm whereas $CaCO_3$ ranged from 2.6-11.1 at 0-20 cm and 3.0-11.0 per cent at 20-40 cm depth. Kriged maps of available N, P and K (Fig. 7) showed that available N varied from 189-241 kg ha^{-1} (0-20 cm) and 171-251 kg ha^{-1} at 20-40 cm depth; available P from 2-17 kg ha^{-1} (0-20 cm) and 3.5-12.7 kg ha^{-1} (20-40 cm) and available K from 70-370 kg ha^{-1} (0-20 cm) to 39.0-280.0 kg ha^{-1} (20-40 cm). Kriged maps of available Fe, Mn, Cu and Zn indicated that available Fe varied from 21-32 mg kg^{-1} (0-20 cm) to 15.5-37.6 mg kg^{-1} (20-40 cm); available Mn from 11-48 mg kg^{-1} (0-20 cm) and 9-32 mg kg^{-1} (20-40 cm); available Cu from 2.9-4.8 mg kg^{-1} (0-20 cm) to 2.5-3.7 mg kg^{-1} (20-40 cm) and available Zn from 0.21-0.73 mg kg^{-1} (0-20 cm) and 0-2.1mg kg^{-1} at 20-40 cm depth (Fig. 8).

The clay content showed variation from 17.9 to 68.0 per cent (0-20 cm) and 15.3 to 71.5 per cent (20-40 cm). The clay content was below 70 per cent (0-20 cm) and 1.7 ha (0.6 %) of area at 20-40 cm had clay >70 per cent (Table 3) which may limit the orange productivity. Srivastava and Singh (13) reported significant negative correlation of clay with yield (r = -0.626) in Nagpur mandarin-growing soils of Nagpur district. Most of the deep black soils

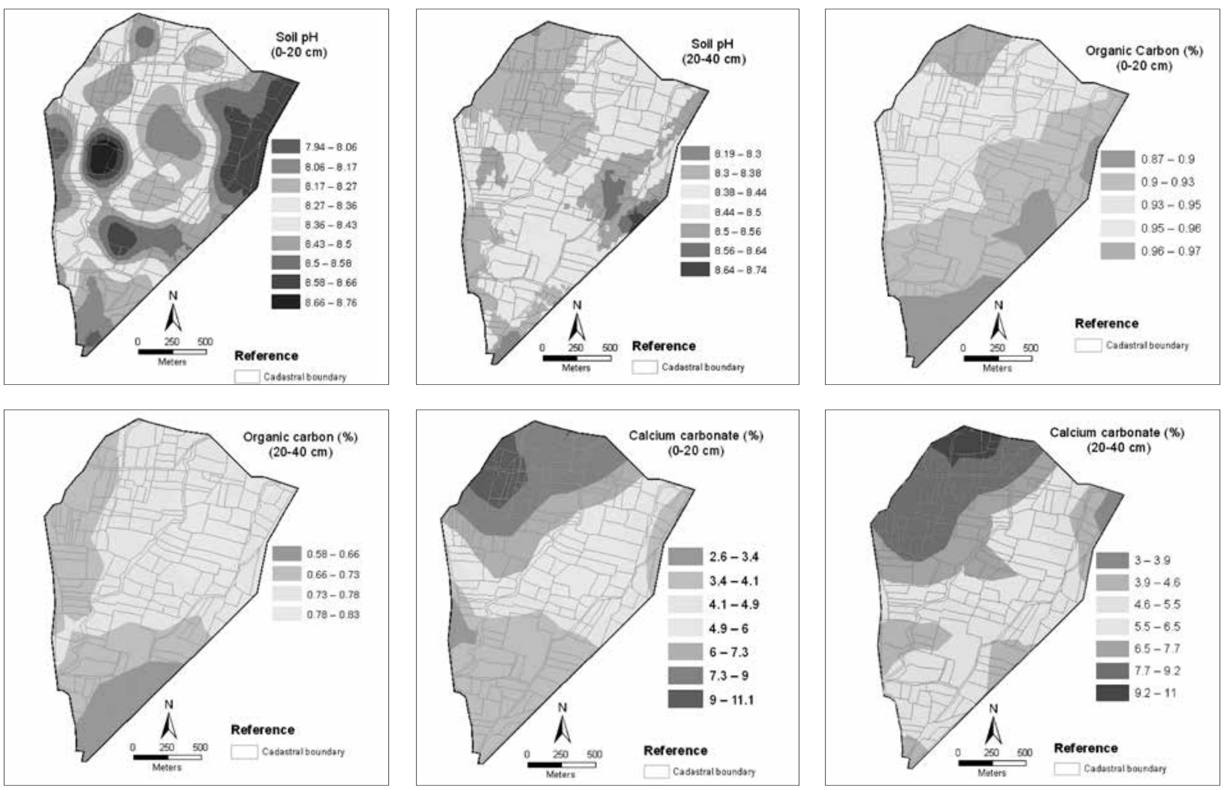

Fig. 6. Kriged maps of soil chemical properties.

Table 3. Soil physical and chemical constraints limiting Nagpur mandarin productivity.

S. No.	Soil Property	0-20 cm depth		20-40 cm depth	
		Area (ha)	Per cent	Area (ha)	Per cent
1	Clay > 70%	Nil	Nil	1.7	0.60
2	pH > 8.5	64.6	23.0	35.7	12.7
3	$CaCO_3$ > 10%	2.9	1.0	2.3	0.8

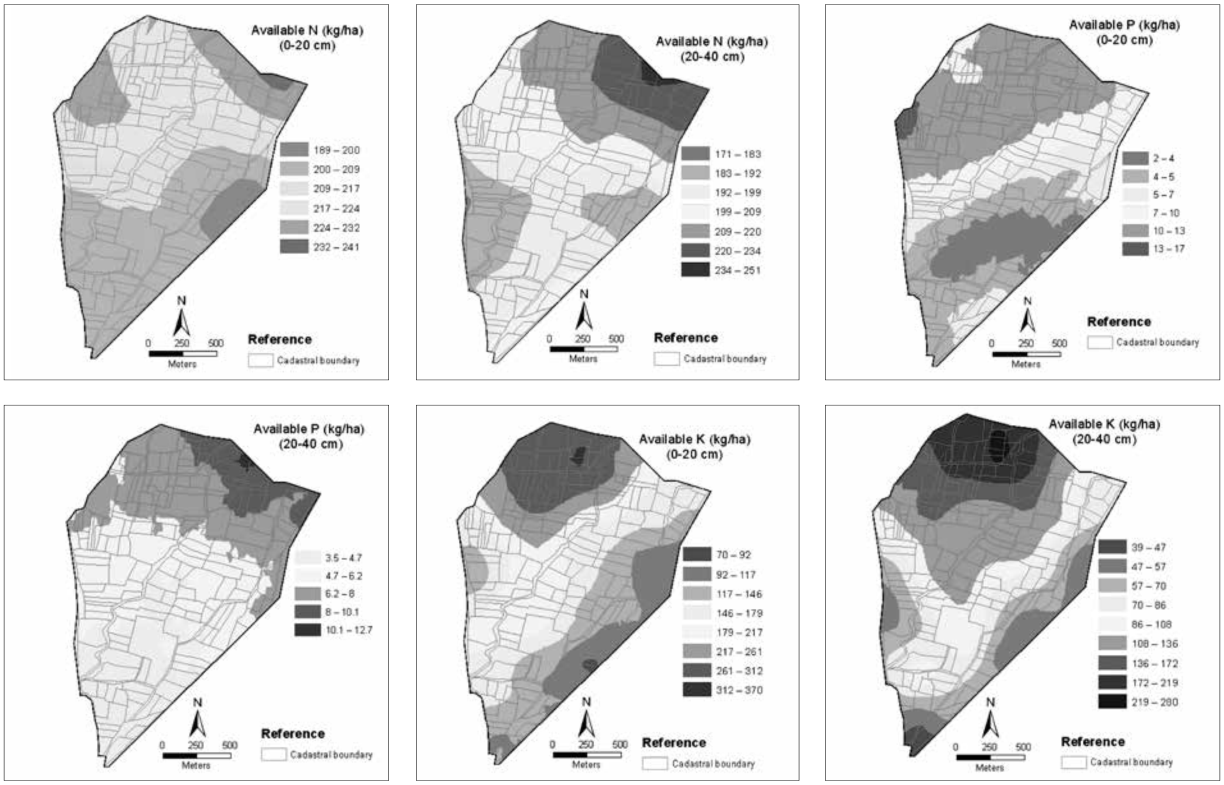

Fig. 7. Kriged maps of available N, P and K.

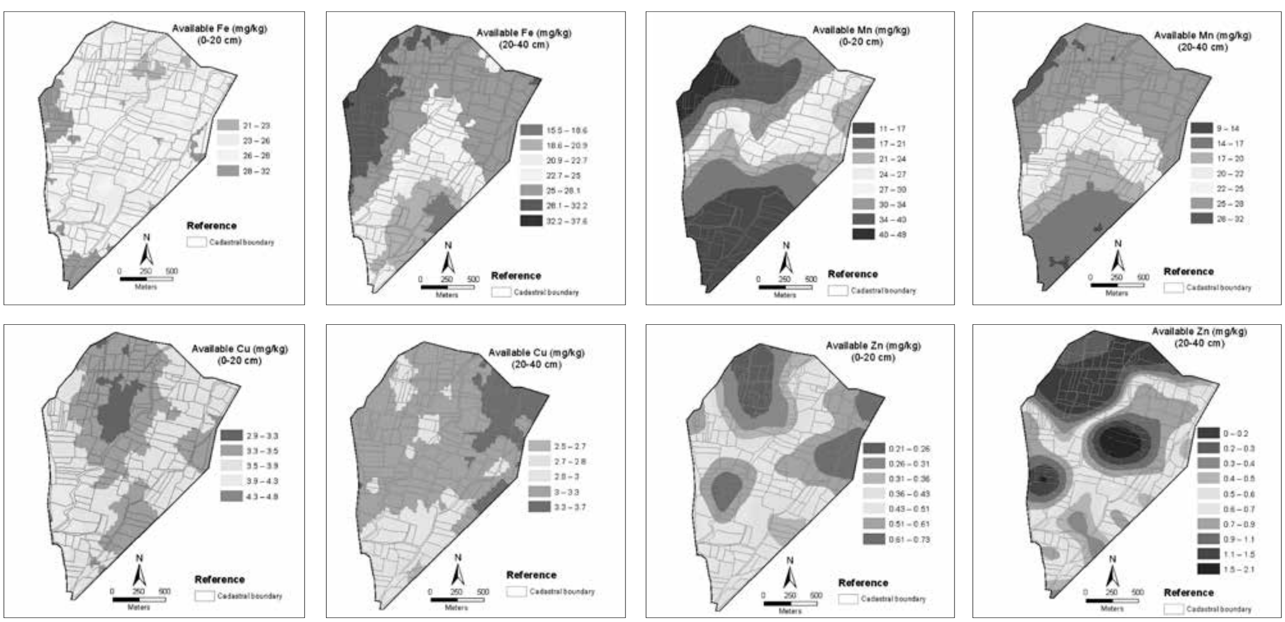

Fig. 8. Kriged maps of available Fe, Mn, Cu and Zn.

pose problem of drainage due to high smectitic clay. Adequate surface and sub-surface drainage need to be provided for better aeration in the root zone. About 5.8 per cent of the samples in the area has a soil depth <40 cm. Orange plants have relatively shallow root system and most of their roots remain in the top 60-100 cm and 80 per cent of feeder roots trail in top 15-20 cm of soil depth. Marathe *et al*.

(8) reported lower canopy volume and fruit yield of Nagpur mandarin in relation to shallow soil depth and clay content.

The data on soil pH (Table 3) indicated that 64.6 ha (23.0 %) at 0-20 cm depth and 35.7 ha (12.7 %) at 20-40 cm depth had pH >8.5 and hence, not suitable for orange cultivation (Naidu *et al.*, 9). Srivastava and Kohli (12) reported that in an Inceptisols with a pH of 8.2 was found to be favourable for better quality of citrus fruits and a soil with a pH of 7.7 (0-15 cm) and a pH of 7.9 at a depth of 15-30 cm was found optimum (Srivastava and Singh, 13). The data on $CaCO_3$ (Table 3) showed that 2.9 ha (1.0 per cent) at 0-20 cm and 2.3 ha (0.8 per cent) at 20-40 cm had $CaCO_3$ content >10 per cent. According to the soil-site suitability criteria for citrus (Naidu *et al.*, 9), non-calcareous soils are highly suitable, soils with $CaCO_3$ up to 5 per cent are moderately suitable, 5-10 per cent are marginally suitable whereas, $CaCO_3$ with >10 per cent are not suitable. However, Srivastava and Kohli, (12) reported that 10 per cent free $CaCO_3$ was favourable for better quality of citrus fruits. Jagdish-Prasad *et al.*, (4) reported that free $CaCO_3$ and powdery lime and massive structure in the soils limited the water and nutrient absorption and consequently the productivity was very poor.

Kriged map of available N was reclassified into very low (<140 kg ha^{-1}), low (140-280 kg ha^{-1}) and medium (280-420 kg ha^{-1}). The data (Table 4) indicated that available N was low in the entire area. Kriged map of available P was reclassified into very low (<7 kg ha^{-1}), low (7-14 kg ha^{-1}) and medium (14-21 kg ha^{-1}), moderate (21-28 kg ha^{-1}), high (28-35 kg ha^{-1}) and very high (>35 kg ha^{-1}) categories. The data showed that available P was very low, low and medium covering 126.4 ha, 152.9 ha and 1.1 ha at 0-20 cm depth, respectively and very low and low categories covering 219.7 ha and 60.7 ha at 20-40 cm depth, respectively. Kriged map of available K was reclassified into low (120-180 kg ha^{-1}), medium (180-240 kg ha^{-1}), moderate (240-300 kg ha^{-1}), high (300-360 kg ha^{-1}) and very high (>360 kg ha^{-1}) categories which pinpointed that available K was low, medium, moderate and high at 0-20 cm depth covering 57.2, 24.2, 15.5 and 3.2 per cent area, respectively and low and medium categories cover 252.7 ha and 27.7 ha at 20-40 cm, respectively. Kriged map of available Fe was reclassified into marginal (5-7.5 mg kg^{-1}), adequate (7.5-10.0 mg kg^{-1}) and high (>10 mg kg^{-1}). The data (Table 4) showed that DTPA-Fe was high in the area whereas the reclassified kriged maps of DTPA-Mn and DTPA-Cu showed adequate availability of Mn (> 10 mg kg^{-1}) and Cu (>2 mg kg^{-1}) in the area. The reclassified kriged map of DTPA-Zn revealed that available Zn was low (<0.5 mg kg^{-1}) and marginal (0.5-0.75 mg kg^{-1}) at 0-20 cm covering 195.1 ha (69.6 %) and 85.3 ha (30.4 %), respectively and low, marginal and adequate (0.75-1.50 mg kg^{-1}) at 20-40 cm depth covering 105.3 ha (37.6 %), 103 ha (36.8 %) and 72.1 ha (25.6 %), respectively. Integrated nutrient management in the areas deficient in nutrients needs to be adopted to improve the productivity.

The kriged maps, generated in GIS framework, precisely demarcated the variation in soil properties

Table 4. Status of available macro and micro nutrients and their extent.

S. No.	Soil Nutrient	Class	Range	0-20 cm depth		20-40 cm depth	
				Area	Per cent	Area	Per cent
1	Available N (kg ha^{-1})	Low	140-280	280.4	100	280.4	100
2	Available P (kg ha^{-1})	Very Low	<7	126.4	45.1	219.7	78.3
		Low	7-14	152.9	54.5	60.7	21.7
		Medium	14-21	1.1	0.4	Nil	Nil
3	Available K (kg ha^{-1})	Low	120-180	160.4	57.2	252.7	90.1
		Medium	180-240	67.7	24.2	27.7	9.9
		Moderate	240-300	43.5	15.5	Nil	Nil
		High	300-360	8.8	3.2	Nil	Nil
4	Available Fe (mg kg^{-1})	High	>10	280.4	100	280.4	100
5	Available Mn (mg kg^{-1})	Adequate	>10	280.4	100	280.4	100
6	Available Cu (mg kg^{-1})	High	>10	280.4	100	280.4	100
7	Available Zn (mg kg^{-1})	Low	<0.5	195.1	69.6	105.3	37.6
		Marginal	0.5-0.75	85.3	30.4	103.0	36.8
		Adequate	0.75-1.50	Nil	Nil	72.1	25.6

including soil fertility parameters. The superimposition of cadastral boundaries on kriged soil maps helped in precise identification of fields with soil physical, hydraulic, chemical properties, and soil fertility constraints for site-specific nutrient management to improve the productivity of Nagpur mandarin orchards of Central India.

REFERENCES

1. Black, C.A., Evans, D.D White, J.L. Ensmingel, L.E. and Clark, F.E. (eds).1965. *Methods of soil analysis*, *Part I*. American Soc. of Agron., No. 9, Madison, WI.
2. Jackson, M.L. 1967. *Soil Chemical Analysis.* Prentice Hall, New Delhi.
3. Jagdish Prasad (1996) Managing Nagpur Mandarin in shallow soils. *Indian Hortic.* **41**: 25-26.
4. Jagdish Prasad, Nagaraju, M.S.S., Srivastava, R., Ray, S.K., & Chandran. P. 2001. Characteristics and classification of some orange growing soils in Nagpur district of Maharashtra. *J. Indian Soc. Soil Sci.* **49**: 735-39.
5. Likhar Chetna, K. and Jagdish Prasad (2011a) Characteristics and classification of orange-growing soils developed from different parent materials in Nagpur district, Maharashtra. *J. Indian Soc. Soil Sci.* **59**: 209-17.
6. Likhar Chetna, K. and Jagdish Prasad (2011b) Productivity and suitability assessment of orange (*Citrus reticulata*)-growing soils in Nagpur. *Indian J. Agric. Sci.* **81**: 500-505.
7. Mann, K.K., Schumann, A.W., Obreza, T.A., Harris, W.G. and Shukla, S. 2010. Spatial variability of soil physical properties affecting Florida citrus production. *Soil Sci.* **175**: 87-499.
8. Marathe, R.A., Mohanty, S. and Singh, S. 2003. Soil characterization in relation to growth and yield of Nagpur Mandarin. *J. Indian Soc. Soil Sci.* **51**: 70-73.
9. Naidu, L.G.K., Ramamurthy, V. Challa, O., Hegde, R. and Krishnan, P. 2006. *Soil site suitability criteria for major crops*. NBSS & LUP Publication. No. 129.
10. Oliver, M.A. 1987. Geostatistics and its application to soil science. *Soil Use and Managt.* **3**: 8-20.
11. Santra, P., Chopra, U.K. and Chakraborty, D.2008. Spatial variability of soil properties and its application in predicting surface map of hydraulic parameters in an agricultural farm. *Curr. Sci.* **95**: 937-45.
12. Srivastava, A.K. and Kohli, R.R. 1997. Soil suitability criteria for citrus: an appraisal. *Agri. Rev.* **18**: 134-46.
13. Srivastava, A.K. and Singh, S. 2002. Soil analysis based diagnostic norms for Indian citrus cultivar. *Comm. Soil Pl. Anal.* **33**: 1689-1706.
14. Srivastava, A.K., Singh, S, and Shrigure, P.S. 1999. Citrus soils, their nature and properties. *J. of Intensive Agric.* **37**: 28-31.
15. Srivastava, A.K., Singh, S., Das, S.N. and Harmandeep, S. 2010. Delineation of productivity zones in mandarin orchards using DRIS and GIS. Better Crops –South Asia, **92**: 9-13.
16. Srivastava, R., Gaikwad S.T. and Jagat Ram. 1998. Water retention characteristics of some swell-shrink soils of Chandrapur district of Maharashtra. *Agropedology*, **8**: 15-18

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