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Research Article

Spatial Variability Mapping of Soil Properties at Farm Scale

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ABSTRACT

Knowledge of spatial variation of soil properties is important for precision farming of intensively cultivated farm with diversified cropping systems. In this study, spatial variation of sand, silt and clay content, pH, EC, cation exchange capacity (CEC), base saturation and exchangeable sodium percentage for the soil depth of 0-15 cm of the IARI farm has been quantified and mapped. Sand, silt and clay contents, CEC, base saturation showed medium variation with coefficient of variation (CV) of 15-35%. The soil and CEC had significant and positive correlation with clay ($r = 0.73$, ≤ 0.01) but negative correlation with the sand content ($r = 0.46$, ≤ 0.01). Positive correlation between CEC and organic C content was achieved ($r = 0.46$, ≤ 0.01). The spatial variability maps of soil attributes showed specific distribution pattern in the farm. Evaluation of spatial maps of soil properties through cross validation exhibited unbiased estimation with good accuracy at farm-scale.

Key words: Spatial variability, Inverse Distance Weigtage, Soil properties, IARI farm.

Introduction

Particle size fractions are the physical makeup of the soil which controls its properties for crop growth and productivity. The cation exchange capacity (CEC) of soil represents the capability of soil to retain exchangeable cations. It has pedological and edaphological significance including buffering of the soil pH and nutrient holding capacity (Krogh *et al*., 2000). Soil exchange properties express important characteristics of how soils interact with their hydro-chemical environment, influencing the dynamics of solute transport, buffering capacity and the quality of runoff from catchments (Billett and Cresser, 1996).

Soil properties exhibit a complex degree of spatial and temporal variability, both continuous and scale-dependent. Soil spatial variability analysis on the catchment or watershed (Stutter *et al*., 2004) basis and at farm scale (Amirinejad *et al*., 2011) are of great importance for enhancing the accuracy of soil survey, mapping, pedo-digitalization and precision farming. Therefore, it is a prerequisite to quantify the spatial variability of soils before designing site-specific applications like variable fertilizer, irrigation and seed rates, strategies for future soil sampling, and appropriate tillage, land use and conservation measures (Iqbal *et al*., 2005). Keeping these in view, the present research work was undertaken to generate the farm-scale map of soil physical and physico-chemical properties using spatial interpolation technique for site-specific soil management in the IARI farm.

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Materials and Methods

Study area

This study was carried out at the experimental farm of the ICAR-Indian Agricultural Research Institute, New Delhi (77°8′40.5″-77°10′28.1″ E longitude to 28°37′22.0″-28°38′58.7″ N latitude and elevation of 217-241 m amsl). The climate is semi-arid with hot summer and cold winter. June is the hottest month and January the coldest month. Normal rainfall in last 5 year (*i.e.* 2006-10) was 729 mm, of which 612 mm (84%) was received from June to September and the rest during winter months (November to March). Soils of IARI farm belongs to mixed, hyperthermic, Typic Haplustepts.

Total cultivated area of the farm is about 278 ha, which was divided into 14 administrative blocks (Fig. 1) for efficient farm operation. Diversified crop farming has been carried out in the farm. Cultivation in protected agriculture structures and seed production blocks as well as irrigation with sewage water has also been practiced. Besides seasonal crops, fruit orchards in Shadipur, Todapur and NBPGR blocks were also present in the farm. Block plantation of *Jatropha curcas* and *Eucalyptus* in Genetic block and natural forest in south east corner of the farm can also be found.

Soil sampling and analysis

Grid samples were collected from 100 m × 100 m grid intersection points at 0-15 cm soil depth. The Google Earth image of the farm with superimposing 100 m × 100 m grid helped to identify the location in field. A total of 288 sampling points were georeferenced with the help of GPS. Soil samples were air dried, grinded with mortar and pestle, sieved with 2 mm sieve for soil analysis. Mechanical composition of the soil was determined by the hydrometer method (Bouyoucos, 1962). Organic carbon was

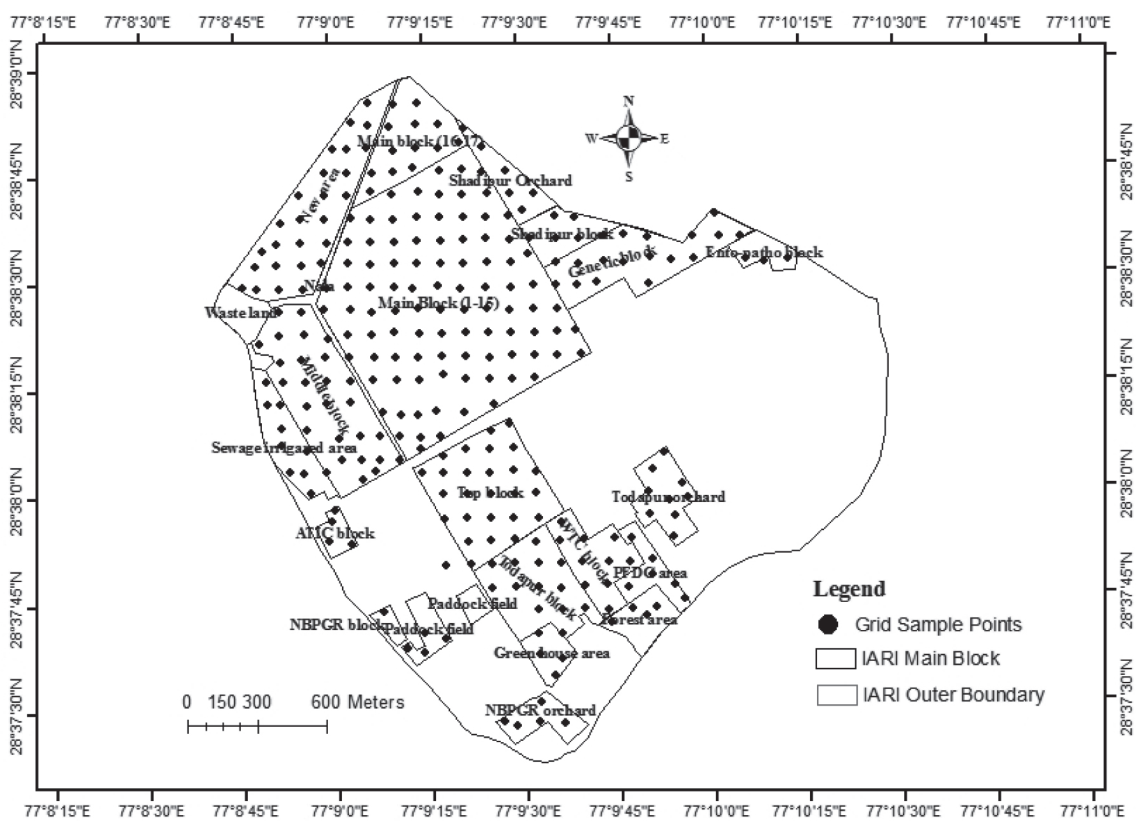

Fig. 1. Location, major blocks and collected grid sample points at IARI farm

determined in soil by wet oxidation method of Walkley and Black (1934). Soil free carbonate was assessed for 2 mm sieved soil samples by pressure calcimeter method (Piper, 1947). Soil pH and electrical conductivity (EC) in 1:2.5 soil and water suspension was measured in a digital pH meter and EC meter respectively. Soil CEC, exchangeable sodium (Na) and potassium was determined by standard method (Page *et al.*, 1982). Exchangeable Ca and Mg were extracted with KCl-triethanol amine solution with pH 8.2 (Sarkar and Halder, 2005) and determined in atomic adsorption spectrometer (AAS). Percent base saturation (PBS) and exchangeable sodium percentage (ESP) was calculated from quantity of CEC and exchangeable base cations.

Classical statistics and spatial interpolation model

The data were analyzed for descriptive statistics and correlation matrix by using MS-Excel. Spatial deterministic interpolator, inverse distance weighting (IDW) was used for generation of continuous surface maps of soil attribute in ArcGIS software ver. 10.1. The basic assumption in IDW interpolation technique is that things that are close to one another are more alike than those that are farther apart. The performance of spatial interpolation was measured through cross validation with statistical indicator of mean error (ME), root mean square error (RMSE) and normalized root mean square error (NRMSE).

Results and Discussion

Soil physical and physico-chemical properties

Descriptive statistics of soil physical (particle size fractions) and physicochemical properties such as pH, EC, CEC, PBS and ESP for grid samples are shown in Table 1. Average clay, silt and sand contents were 20.7, 32.0 and 47.3% respectively. The textural datasets were in agreement with particle size fractions of surface soil as reported by Mohanty (1997) in the same farm. Average soil organic content (SOC) concentration in the farm was low (0.51%) with range of 0.07-1.45%. Soils of IARI farm were neutral to alkaline (pH 5.89-9.10) and non-saline (EC 0.08-1.04 dS m^{-1}). Calcium carbonate equivalent (CCE) of surface soils varied from nil to 7.15% with average value of 0.51%. Surface soil of IARI farm had average CEC of 12.17 cmol (p^+) kg^{-1} with standard deviation of 2.80 cmol (p^+) kg^{-1}. Soil CEC was in consistent with that of surface soils of different soil series at IARI farm as per the report of AISS&LUP (1976). Base saturation of soil varied from 41.4 to 99.3% with average value of 73.7%. The relationship between

Table 1. Descriptive statistics of soil physical and physico-chemical properties of 0-15 cm soil layer at IARI farm

Soil properties	Mean	SE	SD	CV (%)	Minimum	Maximum	Median	Skewness	Kurtosis
Clay (%)	20.7	0.31	5.2	25.1	12.6	48.3	19.6	2.3	7.8
Silt (%)	32.0	0.34	5.8	18.1	10.3	44.1	33.5	-0.9	0.8
Sand (%)	47.3	0.52	8.9	18.8	11.8	70.2	47.1	-0.4	2.1
SOC (%)	0.51	0.01	0.21	41.2	0.07	1.45	0.47	1.32	3.02
CCE (%)	0.48	0.05	0.93	193.8	0.00	7.15	0.23	4.95	28.27
pH	7.96	0.03	0.58	7.3	5.89	9.10	8.08	-1.03	1.04
EC (dS m^{-1})	0.41	0.01	0.18	43.9	0.08	1.04	0.39	0.83	0.72
CEC [cmol (p^+) kg^{-1}]	12.17	0.16	2.80	23.0	7.40	27.40	11.60	1.60	5.23
BS (%)	73.7	0.79	13.5	18.3	41.4	99.3	74.5	-0.1	-0.5
ESP (%)	1.8	0.09	1.5	83.3	0.1	14.0	1.6	4.6	29.8

Abbreviation used: SOC- soil organic carbon, CCE- calcium carbonate equivalent, EC- electrical conductivity, CEC- cation exchange capacity, BS- base saturation, ESP- exchangeable sodium percentage, SE- standard error, SD- standard deviation, CV (coefficient of variation)

Table 2. Pearson correlation matrix of soil physical and physico-chemical properties of 0-15 cm soil layer at IARI farm

	Clay	Silt	Sand	SOC	CCE	pH	EC	CEC	BS	ESP
Clay	1									
Silt	0.30^{**}	1								
Sand	-0.78^{**}	-0.83^{**}	1							
SOC	0.39^{**}	0.15^{*}	-0.33^{**}	1						
CCE	-0.02	-0.17^{**}	0.12^{*}	-0.02	1					
pH	0.01	0.13^{*}	-0.09	-0.29^{**}	0.13^{*}	1				
EC	0.05	0.21^{**}	-0.16^{**}	0.15^{*}	0.01	.00	1			
CEC	0.73^{**}	0.07	-0.47^{**}	0.46^{**}	0.03	-0.14^{*}	0.02	1		
BS	-0.28^{**}	-0.11	0.24^{**}	-0.25^{**}	0.04	0.22^{**}	0.08	-0.55^{**}	1	
ESP	-0.10	-0.01	0.07	-0.01	0.08	0.21^{**}	0.36^{**}	-0.18^{**}	0.19^{**}	1

** and * are significant at 0.01 and 0.05 level, respectively (2-tailed).

soil properties is presented through correlation matrix in Table 2.

Soil pH showed least variability because these were logarithmically transformed measurements of H^+ concentrations in soil solution. According to the classification proposed by Wilding and Drees (1983), soil properties such as sand, silt, clay content, CEC and base saturation had moderate variability with coefficient of variation (CV) within 15-35% while EC and ESP had higher variability (CV>35%). Frequency distribution of soil properties has been shown in

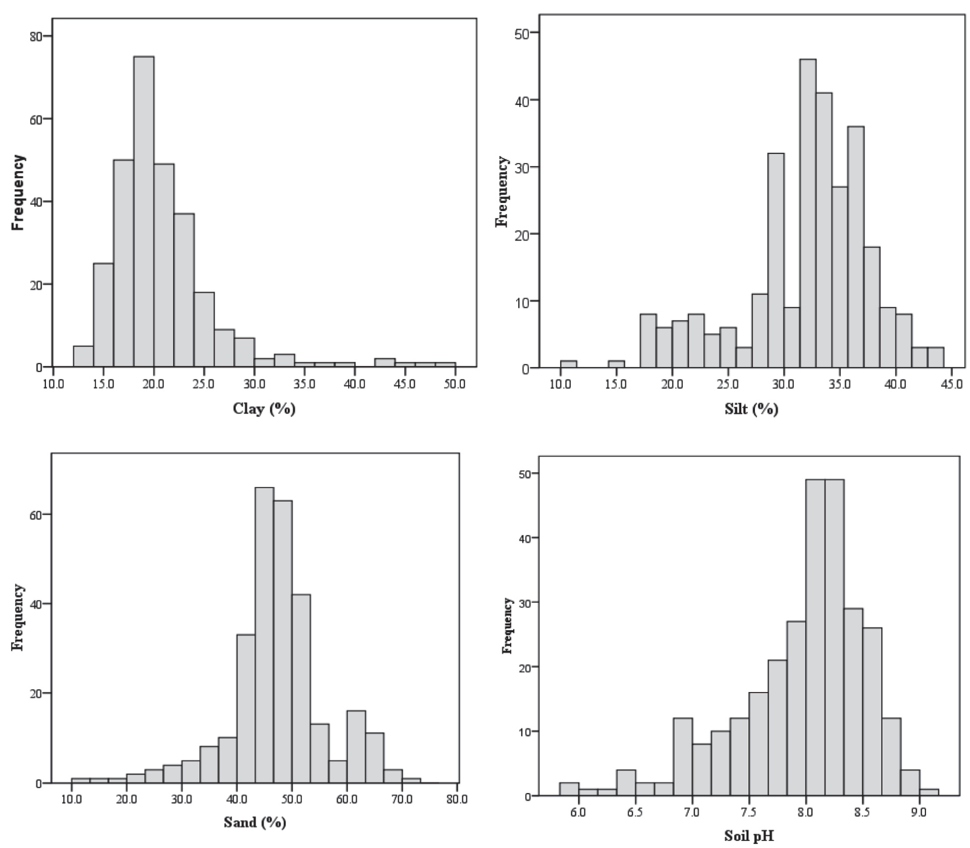

Fig. 2. Histogram of soil particle size fractions (clay, silt and sand) and soil pH of 0-15 cm soil layer at IARI farm

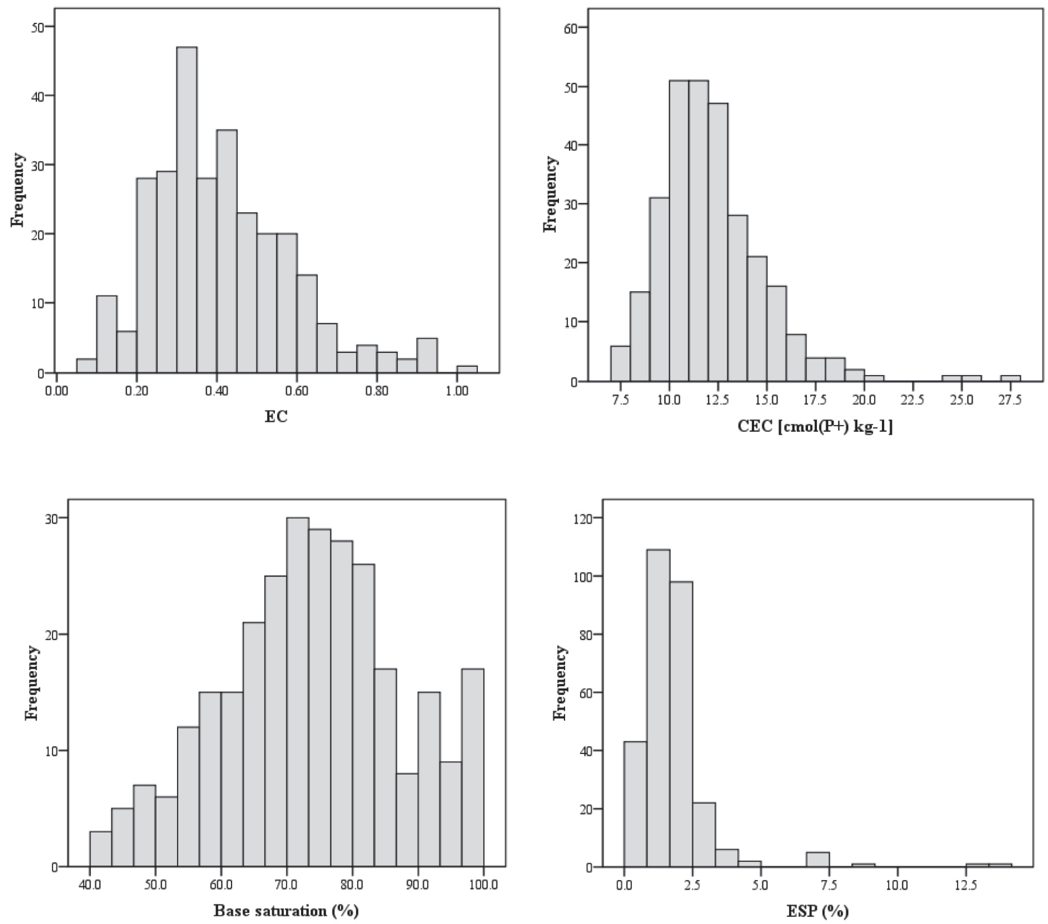

Fig. 3. Histogram of soil physico-chemical properties (EC, CEC, PBS and ESP) of 0-15 cm soil layer at IARI farm

Fig. 2 & 3 for visual understanding of sample data distribution pattern. Silt content, pH, EC and base saturation of soil followed normal distribution as coefficients of skewness and kurtosis ranged between (-1) and (+1). Clay content and CEC were positively and moderately skewed, while ESP was highly positively skewed as per categorization laid down by Ott (1977). Raw datasets of clay and sand contents, CEC and ESP were not normally distributed due to higher coefficients of skewness and kurtosis. The soil attributes being distributed normally or non-normally and its spatial distribution may be associated with differences in cropping system and soil conservation practices (Ryan, 1998), management practices such as tillage and fertilizer conditions (Sabbe and Marx, 1987) and topographic effects on the variability of soil erosion across IARI farm. Such factors could be the sources for a large or very small concentration of soil properties in some of the samples that leads to the non-normal distribution (Tesfahunegn *et al*., 2011).

Spatial distribution of soil properties

Spatial distribution maps of soil physical properties and pH are depicted in Fig. 4. The north-western part of Main Block (1-15) had 35.0 to 48.3% clay content. Several patches with 20-35% of clay content were observed within the farm. Reversely, southern part of the farm had high sand percentage (52.0-70.2%), and sand content decreased from south-east (SE) to north-west direction. There was high silt accumulation between New Area and Main Block alongside the drainage channel. This pattern of distribution of

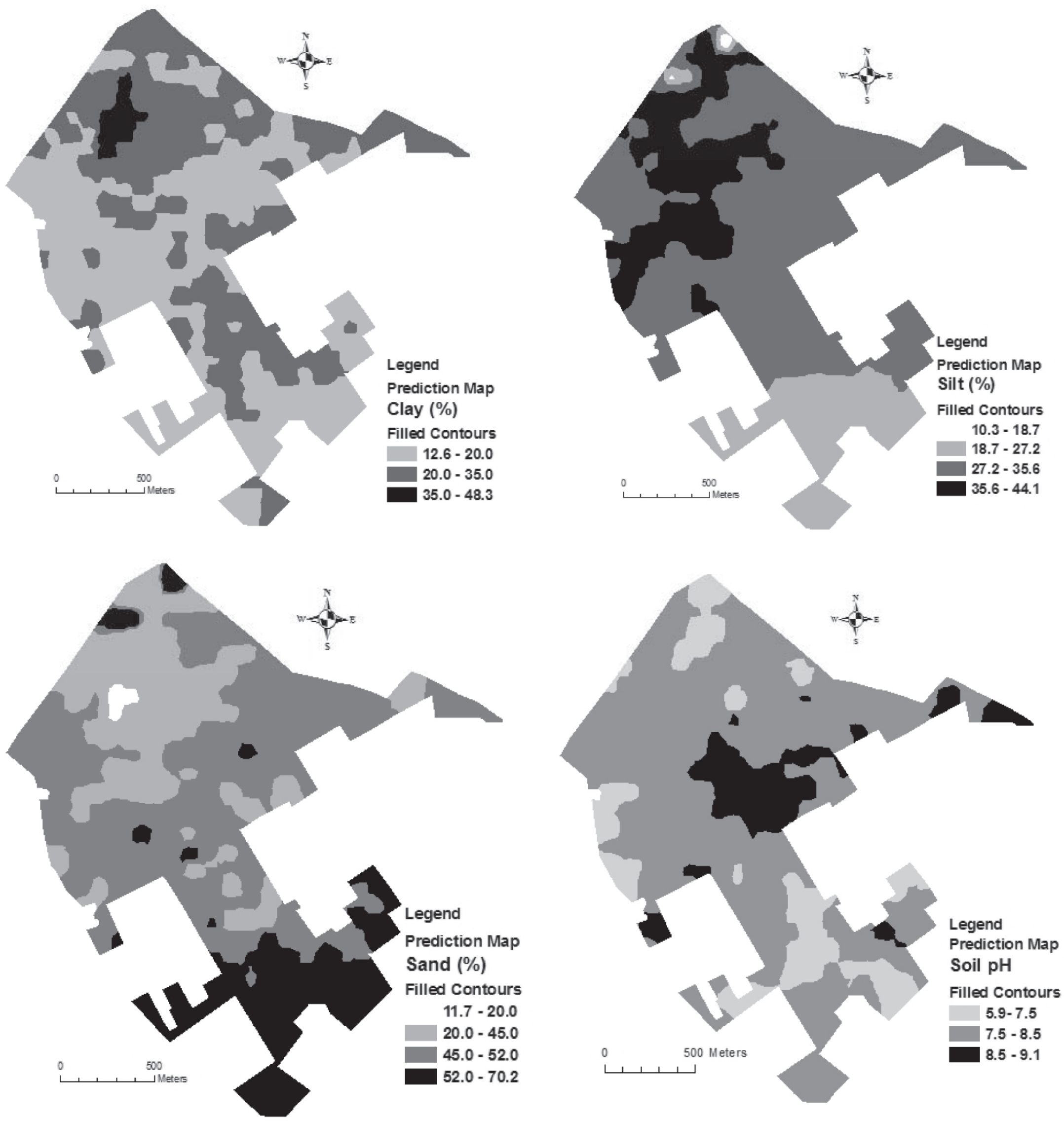

Fig. 4. Spatial variability map of soil particle size fractions (clay, silt and sand) and soil pH in 0-15 cm soil depth at IARI farm

particle size fractions was mainly controlled by the topography and soil erosion. The south-eastern portion of the farm has higher elevation and slope in upper piedmont plain as compared to north-western part *i.e.* old alluvial plain. Hence, the accumulation of finer particles in north-western portion of the farm was obvious.

Distribution of soil physico-chemical properties are given in Fig. 5. Majority of farm area had pH upto 8.5 and a small patch in the south eastern side of main block (1-15) showed pH ranging from 8.5 to 9.1. The parent material of the alluvial soil under semiarid climate at Delhi may be the reason for neutral and alkaline soil reaction. The south western corner of Middle Block *i.e.* adjacent to sewage treatment plant of IARI had soil EC within 0.6-1.0 dS m^{-1}. The soil CEC in major area of the farm varied from 7.4 to 12.0 cmol (p^+) kg^{-1}. The soil CEC of north-western corner of Main Block ranged from 18.0 to 27.4 cmol (p^+) kg^{-1}. Sewage irrigated area, Top Block, NBPGR orchard, Forest area, PFDC area, Main Block-17 and northern portion of Main Block-(1-16) had soil CEC of 12.0-18.0 cmol (p^+) kg^{-1}. The spatial distribution of soil CEC followed

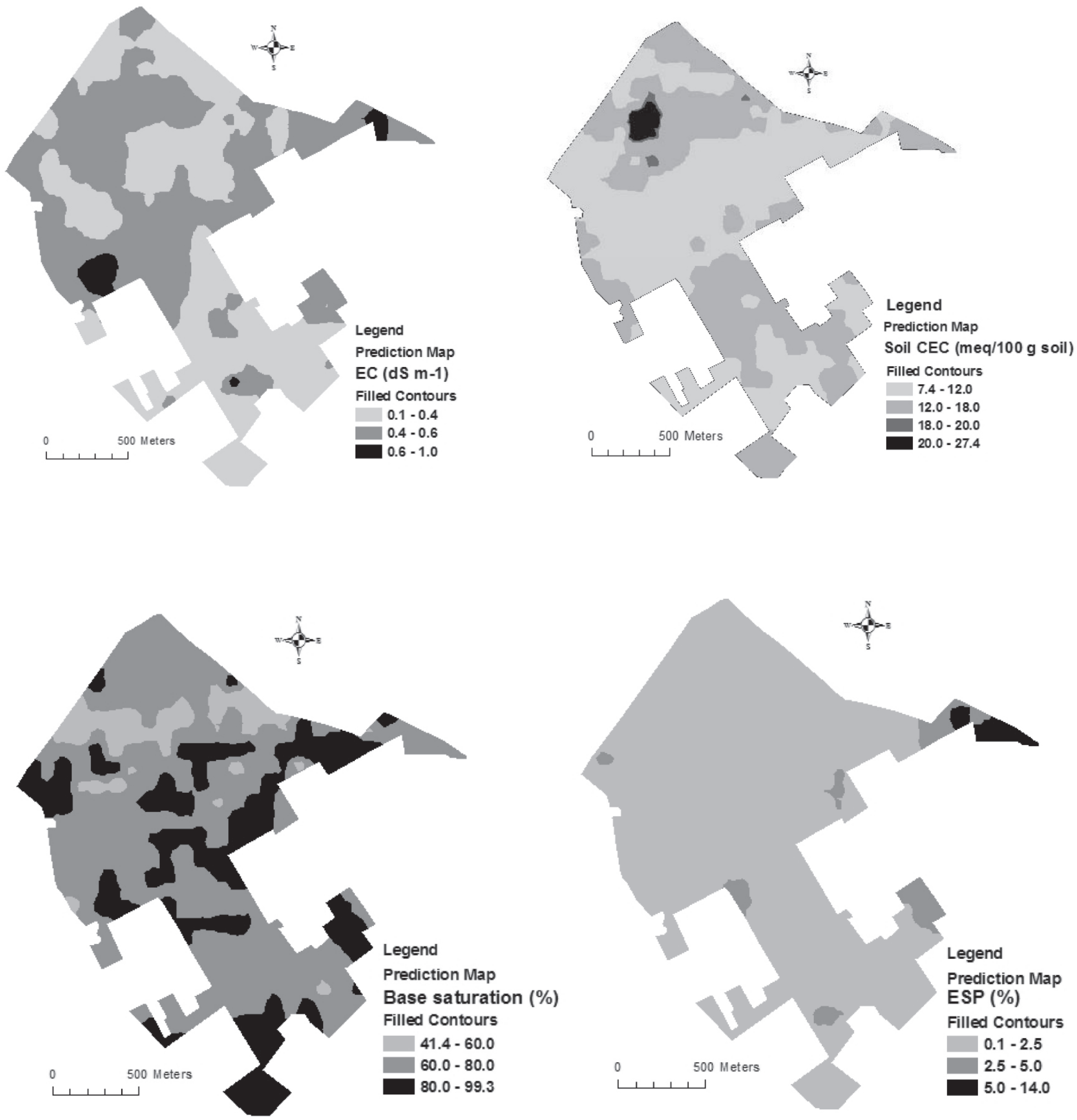

Fig. 5. Spatial variability map of soil physico-chemical properties (EC, CEC, BS and ESP) in 0-15 cm soil depth at IARI farm

similar pattern to clay and opposite to the sand distribution in the farm as evidenced by positive and significant correlation coefficient ($r = 0.73^{**}$, $P \leq 0.01$) between soil CEC and clay content and, negative and significant correlation coefficient ($r = -0.47^{**}$, $P \leq 0.01$) between soil CEC and sand content. Soil CEC was also positively and significantly correlated ($r = 0.46^{**}$, $P \leq 0.01$) with soil organic C content. Dependency of soil CEC on clay and SOC content has also been reported by several authors (Krogh *et al*., 2000; Yong-dong *et al*., 2008).

Major area of the farm showed base saturation between 60 to 80% (Fig. 4). However, soil of NBPGR orchard, Green House area, a portion of Todapur orchard, a few patches of Main Block, Top Block and Genetics Block had base saturation of 80-99%. Base saturation and soil pH had positive correlation ($r = 0.22^{**}$, $P \leq 0.01$), but its value was less than expected, due to complex relationship between soil pH in neutral to alkaline range and base saturation (Tomasic *et al*., 2013). Eastern fringe of the farm had exchangeable sodium percentage of 5.0-14.0. Majority of the

Table 3. Mean error, RMSE and NRMSE of soil physical and physico-chemical properties of IARI farm

Soil attributes	Optimized power value	Mean error	RMSE	NRMSE (%)
Clay (%)	8.38	0.047	3.343	16.1
Silt (%)	2.56	0.049	3.453	10.8
Sand (%)	4.03	-0.020	5.167	10.9
pH	3.31	-0.002	0.420	5.3
EC (dS m^{-1})	1.64	-0.001	0.166	40.5
CEC [cmol (p^+) kg^{-1}]	4.85	-0.008	2.091	17.2
BS (%)	3.00	0.026	11.790	16.0
ESP (%)	1.15	-0.043	1.342	74.6

Abbreviation used: RMSE- root mean square error, NRMSE- normalized root mean square error

farm area had soil with low ESP content (<5%). As per criteria of sodic soil by Chhabra (2005), there was absence of sodic soil in the farm though pH value was greater than 8.5 in south east corner of Main Block. It was also observed that none of soil samples had ESP higher than 15%.

Cross validation of spatial interpolation

The prediction error of soil properties through inverse distance weigtage (IDW) interpolation was shown in Table 3. Optimized power values for IDW interpolation are also provided in the same table. Mean absolute error (ME) and root mean square error (RMSE) of predicted clay content were 0.047 and 3.343 cmol (p^+) kg^{-1}, respectively. Santra et al. (2008) reported ME of 3.76% and RMSE of 5.25 % for clay content of the same study area. Similarly, ME and RMSE values of predicted sand content through IDW interpolation were -0.020% and 5.167%, respectively. The soil CEC map had predicted with unbiased and good accuracy as seen by ME value [-0.008 cmol (p^+) kg^{-1}] closer to zero and low RMSE [2.091 cmol (p^+) kg^{-1}] value. The error observed in the present study for different physico-chemical properties were quite satisfactory compared to the errors observed by many authors elsewhere (Kai-hua *et al.*, 2011; Tesfahunegn *et al.*, 2011). As per qualitative class of Jamieson *et al.* (1991), the prediction of soil pH was excellent (NRMSE<10%) and the prediction of clay, silt, sand contents, CEC and base saturation were satisfactory (NRMSE =10-20 %). However, the prediction of EC and ESP were poor with NRMSE of >30%. The poor performance of ESP may be attributed to high skewness and kurtosis of sample distribution.

Conclusions

Soil particle size fractions *i.e.* clay, silt and sand content of the farm had average value of 20.7, 32.0 and 47.3% respectively with moderate data variability. Soils of IARI farm were neutral to alkaline and non-saline. There was no presence of sodic soil in the farm although small area had soil pH higher than 8.5 but no soil sample had ESP higher than 15%. The surface soil of major area of the farm had CEC value ranging from 7.4 to 12.0 cmol (p^+) kg^{-1}. Cation exchange capacity was positively and significantly correlated with clay content and soil organic carbon concentration. The surface soil of major area of the farm belonged to category of base saturation within 60 to 80%.

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