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Spatial Variability Analysis of Soil Properties using Raster based GIS Techniques

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ABSTRACT

The spatial variability studies performed to see the varying effect of soil properties across the fields and to make efficient crop management decisions in the future. The goal of this study was to determine spatial variability of selected soil properties that influences crop growth and its crop yields. The study was conducted in an agricultural field Coimbatore, Tamil Nadu, India. The data collected were analyzed using geostatistics tool with semivariograms, kriging and classical statistics that involved mean, range, standard deviation and coefficient of variation. The statistical analysis showed a high variability for soil pH having a Cv of 11.88%. The parameters such as infiltration, porosity, Field Capacity (FC), Wilting Point (WP) and phosphorus showed considerable variability with a coefficient of variation between 5 and 9% and least variability was found to exist for electrical conductivity (EC), available potassium (K), available nitrogen (N) and Bulk Density (BD) with Cv of 0.037, 0.29, 0.62 and 2.01, respectively. The semivariograms were calculated for the study area with a sampling distance of 5 m and the N, P, K and EC were linear with sill models and each showed a considerable range of spatial dependence measuring a distance between 10 and 25 m. The kriged surface was created for all the soil properties with the exception of BD, porosity and WP as these parameters were found to be spatially uncorrelated. These spatial variations in soil properties in the field may arise from management activities or due to soil textural effects.

Key words: Spatial variability, soil sampling, geostatistics, semivariogram, kriging

INTRODUCTION

Spatial variability of soil properties has a great impact on the site-specific management of soil resources. The causes of soil spatial variability in an agricultural field might be due to various reasons. The tillage operations performed before planting alters the soil physical structure spatially across the fields. The other factors include field topography, crop stress due to infestations and improper irrigation scheduling practices. The necessary farm inputs can be adjusted and applied to the fields precisely by knowing the spatial variability of soil properties and crop growth (Atherton *et al*., 1999).

The introduction of Geographic Information System (GIS), Global Positioning Systems (GPS) and remote sensing in recent years has resulted in more accurate and efficient mapping of field variability. Site specific crop management, otherwise known as precision farming demand for an accurate estimation of soil properties over the field thus limiting the farm inputs and applying based on the requirement. Among various methods used to describe the spatial variability, Geostatistics, based on the theory of regionalized variables, is an important tool for spatial variability analysis that helps in modeling the spatial patterns of data, prediction of data at unsampled locations and assessment of the uncertainty related to these predictions of the data.

Goovaerts (1998) documented in detail about the application of geostatistics and described in detail about the modeling aspects of soil physical, chemical and microbiological properties that varied spatially. Prasad *et al.* (1991) studied the spatial variability of infiltration at different locations of micro watershed on different contour lines and observed variations of infiltration rate in the range of 2.5-5 cm h^{-1}. Goovaerts and Journel (1995) conducted a study on the spatial variability of soil chemical properties (pH, exchangeable cations, CEC, OC content and exchangeable acidity) and showed that the spatial variability of pH and EC was high (within metres).

Huang *et al.* (1999) studied the spatial variations of selected soil chemical properties along a transect across a grassed field and cropped land with 40 samples across a 400 m transect and he reported that the semivariogram of pH exhibiting spherical model with soil pH was high for grassed field than pH in cropped land and also showed that the concentration of phosphorus was obviously higher in cropped land than in grassed field.

Yost *et al.* (1982) studied the spatial dependence of soil chemical properties over a large land of Hawaii and showed that the range for spatial dependence of soil Ca, Mg, K and P was between 32 and 42 km. Various studies in the past have described the spatial variability analysis of soil properties and explained the importance of it. Since assessing the spatial variability is one of the basic and important aspects in site specific management, in this study, an attempt has been made to model the variability in soil properties and understand the spatial variability pattern using geostatistical analysis.

MATERIALS AND METHODS

Study area: The spatial variability study was conducted in field No. 36 A of the eastern block of the university farm. The university farm is situated at 11°N latitude and 77°E longitude with an altitude of 426.7 m above the mean sea level. The mean annual rainfall of Coimbatore is 640 mm distributed in 47 rainy days. The mean maximum and minimum temperatures are 30.6°C and 20.9°C, respectively.

Soil analysis: Soil samples were collected in the study area selected for analyzing soil properties. Before collection, the surface litter was removed at the sampling spot and then a 'V' shaped cut was made using spade to a depth of 15 cm at each sampling point. The samples thus collected were thoroughly mixed and checked for foreign materials. Eventually desired quantity of sample was obtained by quartering and the sample so collected was put into a clean labeled polythene bags.

The samples thus collected and packed were air dried and powdered with wooden mallet. Then the soil material was sieved through a 2 mm sieve and the material obtained finally after passing through the sieve was analyzed for important physical and chemical properties by following the standard procedures.

Spatial variability of soil properties: Spatial variability of selected soil properties was carried out for the study area selected. One hundred and forty four soil samples were collected in the study

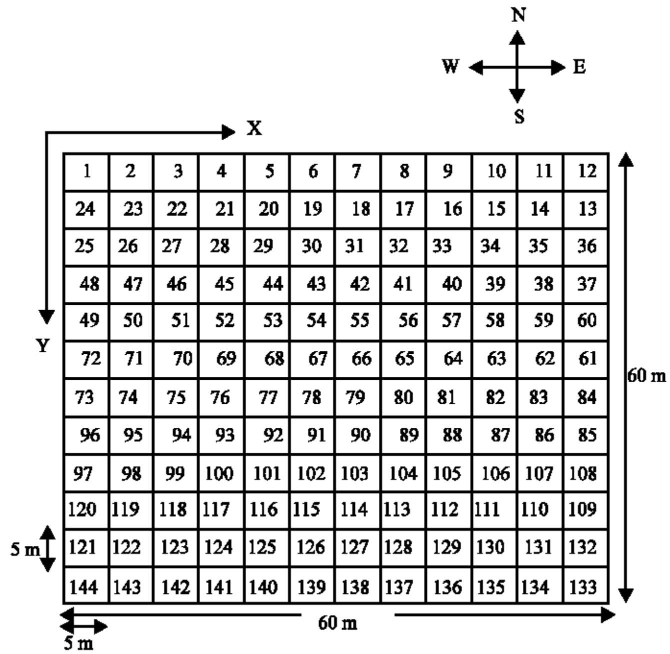

Fig. 1: Field layout for spatial variability analysis

area of 60×60 m with a grid spacing of 5 m to analyze soil properties with the exception of field capacity and available water holding capacity which involved collection of thirty six samples with a grid spacing of 10 m. The infiltration rate was also studied in thirty six places in the study area. The layout for the spatial variability study is depicted in Fig. 1.

The soil samples collected were then analyzed for important soil properties viz., porosity, bulk density and field capacity, available water holding capacity, wilting point infiltration rate, electrical conductivity, pH, available nitrogen, phosphorus and potassium by following the standard procedures. Descriptive statistics like mean, range, variance, standard deviation, coefficient of variation, skewness and kurtosis were computed using the statistical procedures.

Geostatistical and GIS analysis: Geostatistical module in Idrisi raster based GIS software was used for modeling spatial dependency in soil properties and for kriging and simulation. The major steps followed are shown in Fig. 2.

The field data in xyz text format was exported to idrisi software and converted to idrisi vector format. Spatial dependency model was developed to determine if there was any spatial dependency in soil data over space. Semi-variogram graphs were drawn for each soil property and a best fitting model was estimated for different soil properties (data) of the study area. The final step in the GIS modeling process was to interpolate the values at unsampled locations based on the spatial dependency model. Ordinary kriging was performed to interpolate values of selected soil properties for the unsampled locations. A mask file was created to set the extent of interpolation within the desired limits. Theoretically, semivariograms were calculated using the formula:

$$\gamma(h) = \frac{1}{2} N(h) \Sigma[Z_{(i)} - Z_{(I+h)}]^2 \quad (1)$$

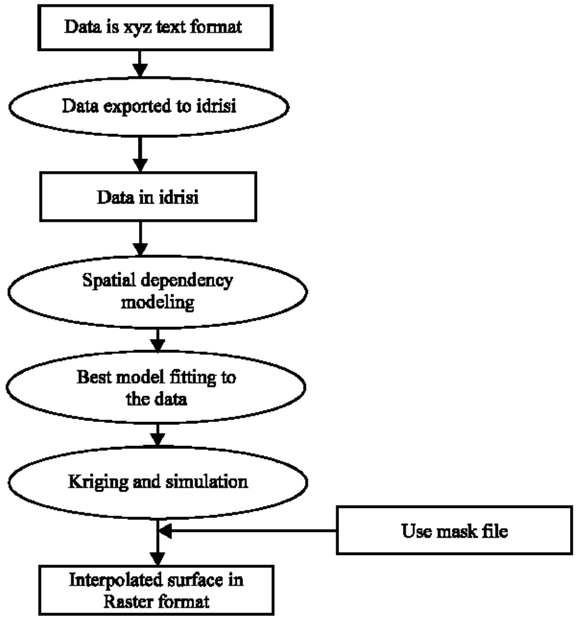

Fig. 2: Steps to do the GIS analysis

Where:

h = Lag distance
$\gamma(h)$ = The semivariance for interval distance class h
$Z_{(I)}$ = Measured sample value at point i
$Z_{(I+h)}$ = Measured sample value at point i+h and
N(h) = Total No. of pairs for the lag interval h

The semivariance is expected to increase as h increases. Ordinary kriging uses the fitted semivariogram for interpolating the surface at unsampled locations.

Semivariogram models

Linear model: The simplest model that can be fitted in one dimension is linear. It has a slope w an intercept or nugget variance Co and it is given by:

$$\gamma(h) = C_0 + wh \text{ for } h>0 \tag{2}$$

$$\gamma(h) = 0 \tag{3}$$

It has no sill. If w = 0, then the semivariogram is said to show a pure nugget effect.

Spherical model: Spherical model can be expressed as:

$$\gamma(h) = C_0 + C\,[3/2\ h/a - ½(h/a)^3] \text{ for } 0<h<a \tag{4}$$

$$\gamma\ \gamma(h) = C_0 + C \quad (5)$$

$$\gamma(h) = 0 \quad (6)$$

where, a is the range, $C_0 + C$ is the sill and C_0 is the nugget variance.

Exponential models: The formula for exponential model is given by:

$$\gamma(h) = C_0 + C\ [1\text{-exp}\ (-h/r)]\ \text{for}\ h>0 \quad (7)$$

where, r is a distance parameter controlling the spatial extent of the function γ(h).

Surface interpolation using kriging: Ordinary kriging was done in the present study with geostat modules that were interfaced with IDRISI software to interpolate values of selected soil properties for unsampled locations. A minimum of 5 samples and a maximum of 20 samples were considered for interpolation. Ordinary kriging was considered to be the best unbiased estimator for this study based on the estimation problems, distance and clustering and also it attempts to produce a set of estimates for which the variance of the errors and bias is minimized.

RESULTS AND DISCUSSION

Spatial variability of soil properties: The variability of soil properties in the current study was described by both classical statistical and geostatistical analysis. The spatial variability of selected soil properties over an area of 3600 m^2 was studied using descriptive statistics to quantify soil variability and geostatistics to determine the degree and range of spatial dependence. All the soil properties including both physical and chemical were analyzed.

Classical statistical analysis: Descriptive statistics like mean, SD, CV, kurtosis and skewness were calculated for the selected properties of surface soil samples collected in the study area with 5×5 m grid spacing with the exception of field capacity and available water holding capacity which involved a grid spacing of 10×10 m (Table 1).

Table 1: Descriptive statistics for selected properties of soils of study area

Property	Min.	Max.	Mean	SD	CV%	Kurtosis	Skewness
Available N (kg ha^{-1})	184.0	188.0	186.13	1.148	0.62	-0.673	-0.2340
Available P (kg ha^{-1})	10.0	14.0	12.16	1.095	9.01	-0.283	-0.2254
Available K (kg ha^{-1})	410.0	414.0	411.76	1.230	0.29	-0.900	0.1100
Electrical conductivity	30.0	34.0	31.88	1.162	3.65	-0.781	0.0710
pH (1:2)	8.2	8.5	8.31	0.987	11.88	-0.940	0.4070
Porosity (%)	36.0	44.0	40.54	2.740	6.76	-1.310	-0.2330
Bulk density (%)	1.5	1.6	1.55	3.112	2.01	-1.156	-0.0720
Infiltration (cm h^{-1})	2.5	2.8	2.64	0.136	5.15	-1.840	0.1660
Field capacity (%)	26.0	32.0	29.33	1.804	6.15	-0.681	-0.0990
Wilting point (%)	16.0	20.0	17.50	1.298	7.41	-0.897	0.2900
Available water holding capacity (%)	7.0	16.0	11.83	2.104	17.78	0.007	-0.2740

The available potassium and nitrogen had the least coefficient of variations of 0.29 and 0.62%, respectively whereas other properties such as bulk density, electrical conductivity, infiltration, field capacity, porosity and wilting point showed coefficient of variation between 2 and 8%. The parameters namely available phosphorus and pH had high coefficient of variation of 9 and 12% whereas available water holding capacity was found to be highly variable compared to other parameters. The minimum and maximum of each soil property didn't vary drastically and the property (AWH) had the highest range (11%). The soil property pH was found to be much skewed (0.41) compared to other parameters.

Soil physical properties: The statistical analysis showed high variability of wilting point with a coefficient of variation of 7.41%. The range was from 16 to 20%. The bulk density showed the least variability with a coefficient of variation of 2.01% which was lesser than those, reported by Carter (1994) and its values ranged from 1.5-1.6 g/cc with a mean value of 1.55 g/cc.

The parameters such as infiltration, porosity and field capacity showed significant variability with coefficient of variations of 5.15, 6.76 and 6.15%, respectively. The ranges of these parameters were from 2.5-2.8 cm h^{-1} for infiltration, 36-44% for porosity which was lesser than those reported by Carter (1994) and 26-32% for field capacity.

The property namely available water holding capacity showed a very high variability with a coefficient of variation of 17.78% and its values ranged from 7-16% with a mean of 11.83%.

Chemical properties: The statistical analysis showed high variability of available phosphorus with a coefficient of variation of 9.01% which was lesser than those reported by Huang *et al.* (1999). The values ranged from 10-14 kg ha^{-1}.

The pH showed relatively high variability with a coefficient of variation of 11.88% and its values ranged from 8.2-8.5. It was more than the neutral value showing alkalinity nature and coefficient of variation was higher than those reported by Huang *et al.* (1999) and Carter and Pearen (1985).

The values of electrical conductivity ranged from 0.3-0.34 dS m^{-1} with a mean value of 0.3188 dS m^{-1} and a coefficient of variation 3.65% and was lesser than those reported by Carter and Pearen (1985).

The properties such as available nitrogen and potassium showed the least variability with coefficients of variation of 0.62 and 0.29%, respectively. The values of available nitrogen ranged from 184-188 kg ha^{-1} with a mean value of 186.13 kg ha^{-1} while the value of available potassium ranged from 410-414 kg ha^{-1}.

Geostatistical analysis of soil properties of study area: The semivariogram of soil property viz., available Nitrogen (N), available Phosphorus (P), available potassium (K) and Electrical Conductivity (EC)were fitted well by linear with sill models (Fig. 3, 4). The soil properties such as pH and available Water Holding Capacity (WHC) were very well fitted by exponential model (Fig. 5). The soil property namely Field Capacity (FC) was fitted with spherical models (Fig. 6). In case of soil properties such as bulk density, porosity and wilting point, no pattern was found to exist and the models could not be predicted for those properties (Table 2).

The spatial dependence was very short ranged for pH, with a range of 4.2 m, than those reported by Yost *et al.* (1982). The short range indicated that continuous measurement of soil pH is essential for proper characterization of variability. The spatial dependence for soil properties such

Table 2: Characteristic parameters of semivariogram of spatial properties of the study area

Property	Model	Nugget	Sill	Range
Available N (kg ha^{-1})	Linear with sill	0.2589	1.0334	17.00
Available P (kg ha^{-1})	Linear with sill	0.7140	0.4564	10.33
Available K (kg ha^{-1})	Linear with sill	0.9670	0.6271	25.00
Electrical conductivity (dS m^{-1})	Linear with sill	0.7411	0.4955	10.00
pH (1:2)	Exponential	0.0900	0.8169	4.20
Porosity (%)	No pattern	8.2810	-	-
Bulk density (%)	No pattern	10.0920	-	-
Infiltration (cm h^{-1})	Exponential	0.0000	2.925	9.00
Field capacity (%)	Spherical	1.6700	1.793	16.72
Wilting point (%)	No pattern	1.3620	-	-
Available water holding capacity (%)	Exponential	0.8790	3.514	8.00

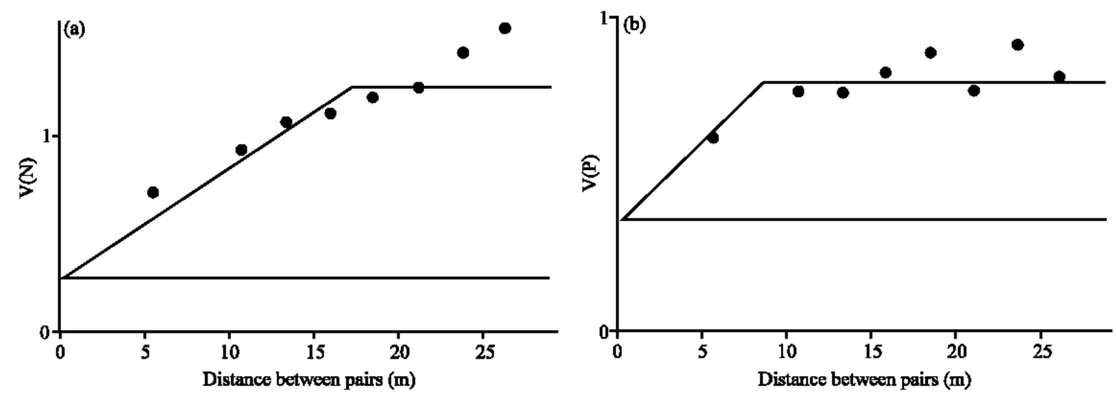

Fig. 3(a-b): Semivariogram of (a) N (left) and (b) P (right) in kg ha^{-1}

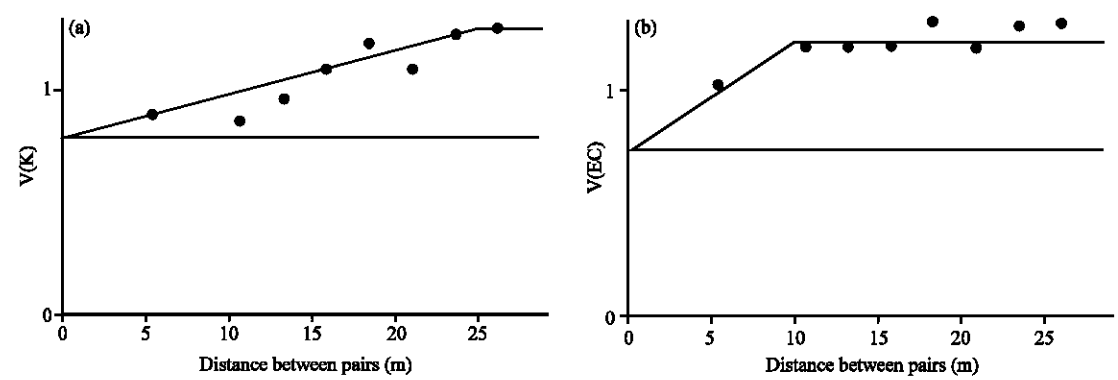

Fig. 4(a-b): Semivariogram of (a) K, kg ha^{-1} and (b) EC in dS m^{-1}

as porosity, bulk density and wilting point could not be detected where the linear relationship between the semivariogram and the lag of wilting point indicated a spatial trend.

The range showed considerable variability among the soil properties. The range of influence for available potassium was higher with a distance of 25 m, lesser than that reported by Yost *et al.* (1982). The ranges of influence for available nitrogen, phosphorus and electrical conductivity were 17, 10.33 and 10 m, respectively. In case of soil properties such as field capacity, infiltration and available water holding capacity, the spatial dependence was moderate and ranged from

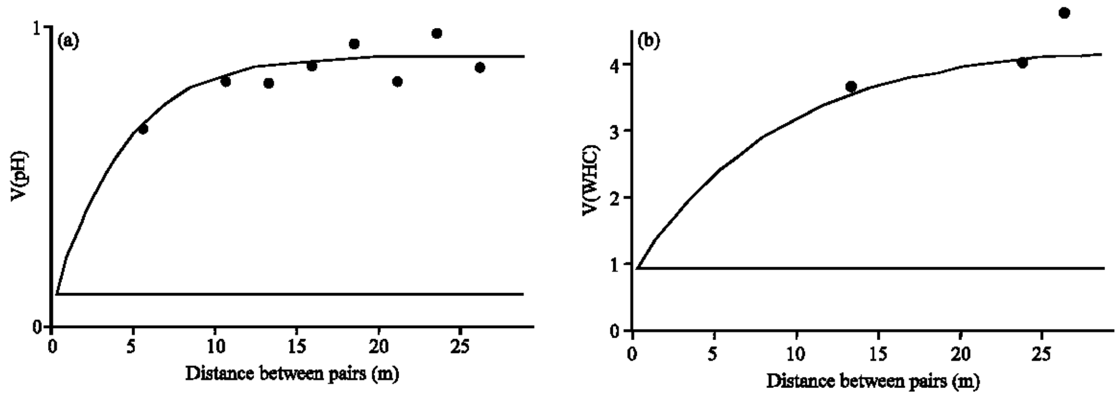

Fig. 5(a-b): Semivariogram of (a) pH and (b) WHC in %

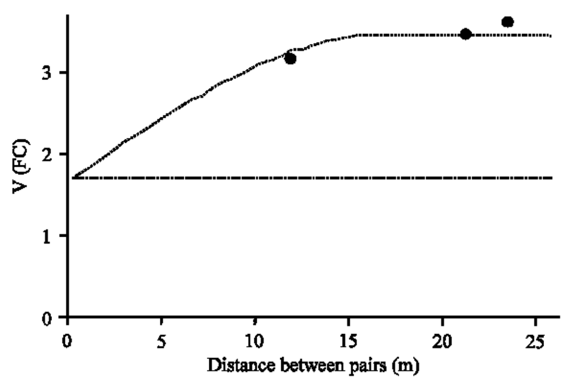

Fig. 6: Semivariogram of FC (%)

8.0-16.72 m. In case of soil properties such as bulk density, porosity and wilting point, the spatial dependence was found to be absent. Only nugget structure was found to exist for all these parameters because of large point to point variation at short distances of separation and it indicates a total absence of spatial correlation at the sampling scale used. In addition, it indicates that continuous measurement of all these parameters is essential for proper characterization of variability.

The small nugget variances for soil properties such as available nitrogen, available phosphorus, available potassium, electrical conductivity, pH, infiltration and available water holding capacity suggest that little variation was present at distances shorter than the first lag (5 m) of the semivariograms. This indicates that the sampling scheme used was adequate to quantify spatial dependence of these properties.

Kriging: The values of soil properties at un-sampled locations were estimated using ordinary kriging method that takes into account of weighted local averaging method. The kriged surface was created for all the properties with the exception of bulk density, porosity and wilting point since these parameters were not found to be spatially correlated.

The kriged surface of the soil properties such as available nitrogen, available phosphorus, available potassium, electrical conductivity, pH, infiltration and field capacity, available water holding capacity showed a considerable range of spatial dependence and each property was found to be spatially correlated (Fig. 7-10).

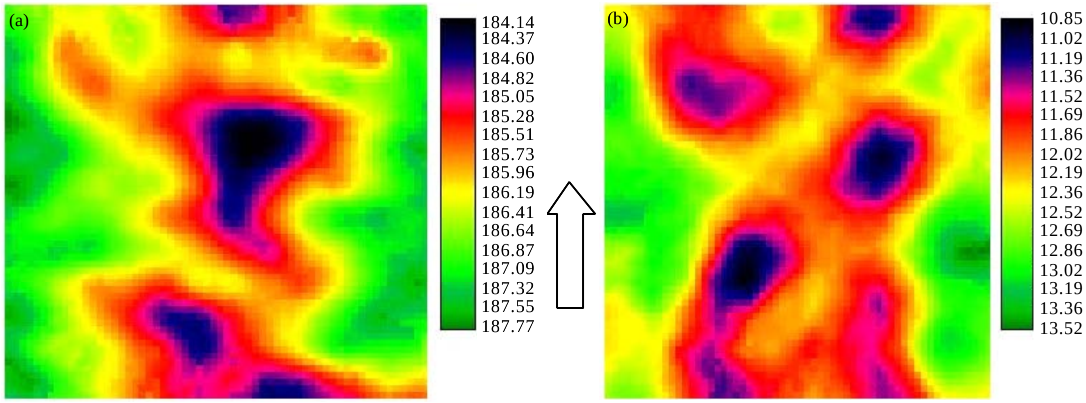

Fig. 7(a-b): Available (a) Nitrogen in kg ha^{-1} and (b) Phosphorus in kg ha^{-1} created using ordinary kriging

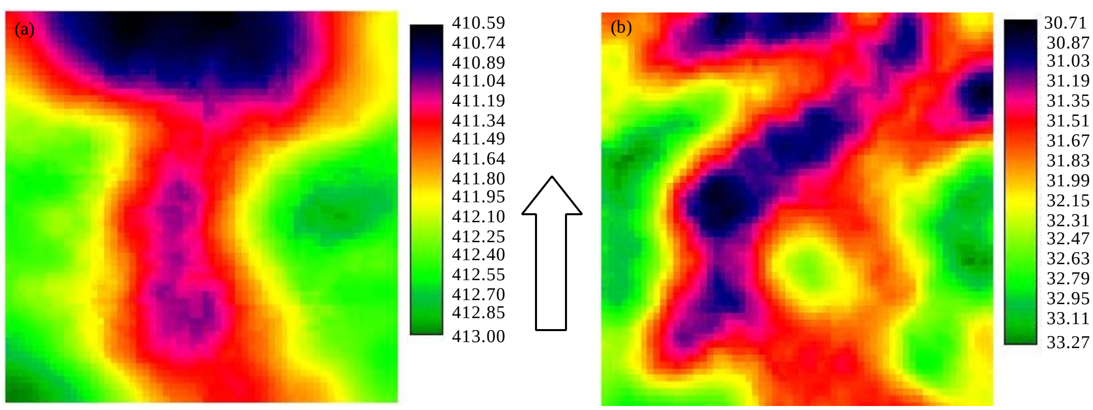

Fig. 8(a-b): Available (a) Potassium in kg ha^{-1} and (b) EC in dS m^{-1} created using ordinary kriging

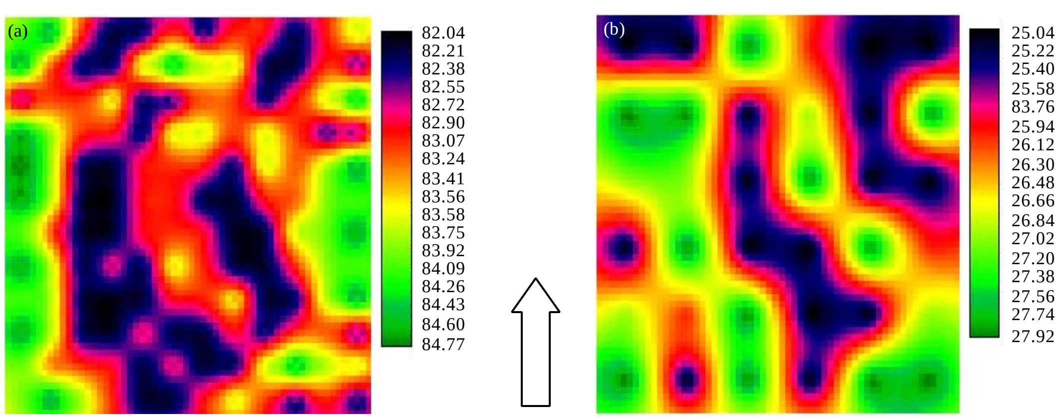

Fig. 9(a-b): (a) pH and (b) Infiltration in cm h^{-1} created using ordinary kriging

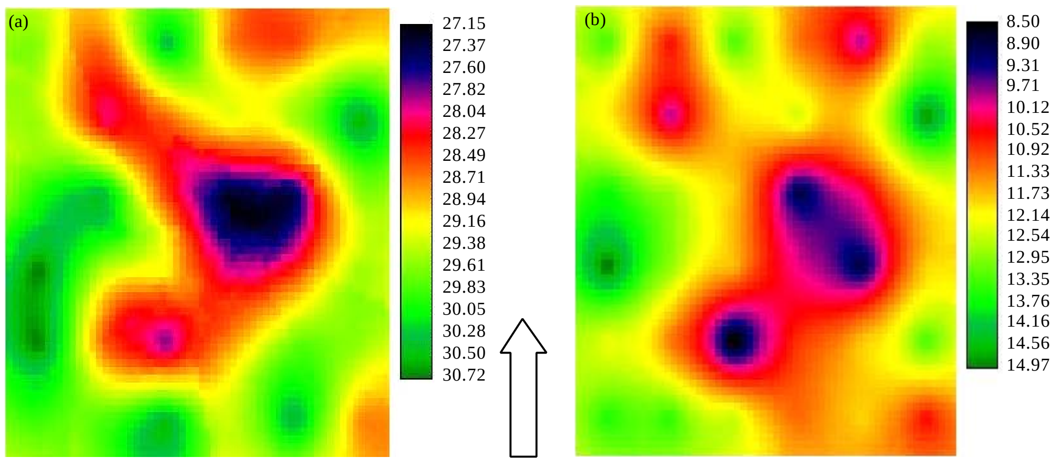

Fig. 10(a-b): (a) Field capacity% and (b) Water holding capacity% created using ordinary kriging

The kriged surface was created for all the properties with the exception of bulk density, porosity and wilting point since all these parameters were not found to be spatially correlated. The kriged surface of all these parameters exhibited an isotropic variation, which indicates that the properties varied similarly in all directions. The anisotropic ratio was set to one for all the parameters considered which reveals that the properties vary similar in all directions i.e., isotropic.

CONCLUSION

A spatial variability study was conducted in an agricultural field taking into account of both physical and chemical properties of soil. The variability of all the soil properties was studied by classical statistics (mean, range, SD, CV, etc.) and geostatistics tool (semivariogram and kriging). The descriptive statistical analysis showed the variation for each soil property with available water holding capacity having high coefficients of variation and least variability was found to exist for available potassium. The semivariograms were calculated for the study area with a sampling distance of 5 m for all the soil properties and fitted with mathematical models that described the spatial dependence of each property. The soil property maps were prepared using kriging interpolation method to aid the growers to make efficient management decisions. The spatial distribution of each soil property maps is different from each other and quantifying this spatial variability helps in grouping the fields into potentially low and high productive areas and management decisions can be made accordingly. Thus, it can be concluded that the study performed in this agricultural field can help the farmers to choose and apply the farm inputs precisely reducing the wastage of inputs thereby benefitting the environment and enhancing the crop productivity with less input costs.

REFERENCES

Atherton, B.C., M.T. Morgan, S.A. Shearer, T.S. Stombaugh and A.D. Ward, 1999. Site-specific farming: A perspective on information needs, benefits and limitations. J. Soil Water Conserv., 54: 455-461.

Carter, M.R. and J.R. Pearen, 1985. General and spatial variability of solonetzic soils in north central Alberta. Can. J. Soil Sci., 65: 157-167.

Carter, M.R., 1994. Spatial variability of soil porosity under reduced tillage in a Humo-ferric Podzol. Can. J. Soil Sci., 75: 149-152.

Goovaerts, P. and A.G. Journel, 1995. Integrating soil map information in modelling the spatial variation of continuous soil properties. Eur. J. Soil Sci., 46: 397-414.

Goovaerts, P., 1998. Geostatatical tools for characterizing the spatial variability of microbiological and physico-chemical soil properties. Biol. Fertil. Soils, 27: 315-334.

Huang, X.W., E.L. Skidmore and G. Tibke, 1999. Spatial variability of soil properties along a transect of CRP and continuously cropped land. Proceedings of the 10th International Soil Conservation Organizing Meeting, May 24-29, 1999, Purdue University and USDA-ARS Soil Erosion Research Laboratory, pp: 1-7.

Prasad, L.R., M.S. Rao and A. Satyanarayana, 1991. Spatial variability of field measured infiltration parameters in Maheswaram watershed area. Indian J. Soil. Conserv., 19: 83-88.

Yost, R.S., G. Uehara and R.L. Fox, 1982. Geostatistical analysis of soil chemical properties of large land areas. i. semi-variograms. Soil Sci. Soc. Am. J., 46: 1028-1032.