International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(3): 1888-1892

Received: 13-03-2019
Accepted: 15-04-2019

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Geostatistical assessment of spatial variability of soil available potassium under different land uses of a part of Ludhiana district of Punjab

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Abstract
Heterogeneity in soil system primarily causes the spatial variations of different soil parameters. A systematic study was conducted for assessing the spatial variability pattern of soil fertility parameters especially soil available potassium (K) under three different land use systems viz. berseem base land use, rice-wheat and poplar-wheat cropping systems. A total 144 georeferenced surface soil samples were collected from these land uses and analyzed chemically to determine available K and other physicochemical parameters. Classical statistical techniques revealed the degree of variability in terms of coefficient of variations (%CV). Geostatistical tools semivariograms were calculated to find the best fitted model for characterizing the spatial pattern of K. The Gaussian model was found as a best model for describing the spatial variability of K under berseem based land use, whereas, Exponential and spherical models were best for rice-wheat and poplar-wheat system respectively. The semivariogram parameter i.e. the nugget: sill ratio (NS ratio) confirmed the moderate spatial dependence (NS in between 0.25 to 0.75) for available k under these three land uses. The ordinary kriging technique was employed for generating spatial variability maps of available K and these maps would be the useful guides for site specific available potassium management for the study area.

Keywords: Available potassium, coefficient of variation, geostatistics, kriging, spatial variability

Introduction

In traditional farming practices, excessive amount of chemical fertilizers etc. are applied to the farm and crop fields in order to obtain higher yield based on merely the soil test report, without considering the spatial variability of the soil properties occurring within the field itself. Ultimately such practice leads to inefficient farm management practices as it causes under-application and over-application of input resources like fertilizers to the crop field. Under-application of nutrient causes deficiency symptoms in crop plants and cannot meet the optimum yield goal, whereas, the indiscriminate use of chemical fertilizers causes economic losses and so many environmental problems like eutrophication (Tunney, 2002) [14]. Sometimes excessive fertilization causes deterioration of soil fertility status as well as soil health. Soil fertility status is generally influenced by the land use scenario, cropping pattern, parent material, topography and other management practices. Soil fertility parameters are generally characterized by the high degree of spatial variability due to the combined action of physical, chemical and biological processes that operate with different intensities and at different spatial scales (Goovaerts 1997 and Bruland and Richardson 2003) [6, 2]. An improved understanding regarding the soil fertility variability is important to improve the applied nutrient use efficiency. Generally the spatial variability of soil properties occurs due to influence of both intrinsic factors (pedologic and geologic soil forming factors) and extrinsic factors (different agronomic management practices). Castrignano *et al*. (2000) [5] measured the spatial variability of some physical and chemical properties in a field in central Italy, and found that it was the result of superimposed processes acting at different spatial scales over different periods of time. Soil available potassium (K) is considered as a major nutrient and an important soil fertility parameter improving soil health and crop yield. Gorai *et al*. (2017) [7] reported that variation in soil available K caused due to difference in land use pattern. Land use changes influence the spatial variability trend of soil fertility parameters. Assessment of spatial variability of soil available nutrients is a viable option for maintaining optimum soil fertility status through site specific management of nutrients.

Spatial variability analysis of soil properties through classical statistical technique is not so much accurate as it cannot measure the value of a spatially auto correlated soil parameter with its sampling location. Therefore, geostatistics can provide a set of statistical tools like semivariograms, kriging technique for quantifying the spatial variability of soil fertility properties considering the phenomena of spatial dependence. Geostatistics become increasingly popular in the domain of soil science due to its capability of predicting spatially dependent soil properties at unsampled locations through using statistically viable interpolation technique called kriging. The spatial variability maps of different soil fertility properties can be generated using this interpolation technique. Lopez-Granados *et al*. (2005) [9] produced spatial variability maps of soil pH, organic matter and available potassium using kriging technique in southern Spain. Thus the geostatistical tools can be successfully employed for producing spatial variability maps of various soil properties. So such spatial variability maps would enable the crop-growers to make appropriate and site specific nutrient management strategies.

However, as the land use changes influence the potassium variability within the field itself, and the cost of fertilizers increasing day by day, a systematic study has been conducted in three different land use systems for assessing the spatial variability of soil available potassium. Hence, the objectives of this present study were (i) to assess the status of soil available K, (ii) to study the spatial variability of K using geostatistical techniques.

Materials and Methods

Study area

This study was conducted near Ladian village of Ludhiana district of Punjab, situated at 30.89ºN, 75.86ºE. This area located at 250 meter from mean sea level. The annual rainfall of this study site is near about 600 mm and temperature ranges from 1-2 ^{0}C in winter to 45-50 ^{0}C in summer. The study area had three different land use systems such as berseem based land use, rice-wheat cropping system and poplar-wheat based agroforestry system.

Methods

Soil sampling and analysis

A total 144 georeferenced surface soil samples (48 samples from each land use type) were collected from 0-15 cm depth following inter-nodal spacing of 14m in one direction and 7m in the another direction, perpendicular to the previous direction. Trimble SB Handheld Global Positioning System (GPS) used for geo-referencing the sampling points. Collected soil samples were air dried under shaded condition (not sun drying), crushed in a wooden log to break the clods and aggregates and visible root fragments were removed carefully for preparing the samples for chemical analysis.

Soil available potassium along with some other physic-chemical properties like soil texture, pH, EC etc. were determined following the standard protocols. International Pipette Method (G.W. Robinson, 1922) [12] was followed for determining soil texture (relative proportion of and, silt and clay). The 1:2 soil to distilled water solution, used for pH determination using pH meter (Elico LI 127) and that suspension kept overnight to note down the EC reading of the supernatant using EC meter (Elico 304) following the method described by Jackson, 1973. Estimation of soil available potassium was carried out by the neutral normal ammonium acetate method (Merwin and Peech, 1950) [10]. Soil was treated with a neutral 1 M ammonium acetate solution, adjusted to pH 7.0 and shaken for 5 minutes. After shaking, the extract was filtered and potassium present in filtrate was determined with a flame photometer (Elico CL 361).

Statistical analysis

Classical statistical analyses were performed with SAS 9.3 (SAS 2013, Institute Inc. Cary, NC, USA) to calculate the descriptive statistical parameters like mean, median, range, coefficient of variation (CV), skewness and kurtosis to characterize the distribution pattern of soil available K along with the above mentioned properties. One of the important classification criteria based on percent CV value, was utilized to determine the variability of studied soil parameter specially soil available K (Wilding, 1985) [16]. According to this criteria, a parameter will be considered as highly variable if the CV value is more than 35 %, moderately variable (if CV=15-35%) and least variable (if the CV value is <15%).

Geostatistical analysis

The geostatistical analyses were carried out in ArcGIS 10 software. The spatial variability of soil available potassium was assessed through geostatistical techniques in the above-mentioned software. The spatial structure of available K was estimated through variography technique called semivariogram. Semivariogram is a mathematical model and it can be calculated using the following formula:

$$\gamma(h) = \frac{1}{2n(h)}\sum_{i=1}^{n(h)}[z(xi+h)-z(xi)]^2 \ldots \text{(Equation. 1).}$$

Where γ *(h)* is experimental semivariance, (h) is the separation distance between the locations: xi and $xi + h$; *n(h)* is the number of pairs at any separation distance (h). *z(xi)* and *z(xi+h)* are the measured values for the regionalized variables at locations of (*xi*) and (*xi+h*) separated by a vector (h) (Burgess and Webster 1980) [3]. Experimental semivariograms models like Gaussian, Exponential, and Spherical models were selected based on least root mean square error (RMSE) values. A semivariogram mainly consists of three parameters viz. nugget i.e. the local variance occurs due to sampling error or measurement error, sill i.e. the total variance and the range i.e. the separation distance of spatial dependence. The nugget: sill ratio (NS ratio) was used here to measure the spatial dependency of the studied soil parameter. Camberdella *et al*. (1994) [4] gave a criteria based on NS ratio to estimate the spatial dependence of soil properties. This criteria was used to classify the parameter into high (NS ratio<0.25), medium (NS ratio=0.25-0.75) and low (NS ratio >0.75).

The spatial variability map of soil available potassium was generated using the kriging technique, which is an optimal unbiased estimator to estimate the value of a soil property at unsampled locations.

Results and Discussion

1. Descriptive statistics for soil parameters

The descriptive statistical summary of all studied soil parameters are represented in Table 1, 2 and 3. The soil physicochemical properties showed considerable variation in the study area. The relative proportion of sand, silt and clay varied from 40-48%, 14-37% and 30-48% respectively in berseem based land use with the mean values of 45, 26 and 40% respectively. While, the mean values of above textural classes were 34% and 37% (for sand), 25% and 19% (for silt) and 25% and 19% (for clay) for rice-wheat and poplar-wheat cropping systems respectively. Among the, physicochemical properties, the variability of pH was lowest in terms of CV for all land uses, whereas, the variability of EC and silt content was higher (more than 15% CV) for all land uses.

Plant available potassium content in soil in various land use systems is portrayed in Table 1, 2 and 3 and Fig 1. The trend of available potassium followed in different cropping system is: rice-wheat> berseem>poplar-wheat. The poplar-wheat system demonstrated the lowest available potassium content that ranged from 67 to 174 kg ha^{-1} with a mean value of 122 kg ha^{-1} and 17.84 % coefficient of variation. Rice-wheat system exhibited the highest amount of mean available potassium content (179 kg ha^{-1}) and it varied from 134 to 302 kg ha^{-1} with a coefficient of variation of 17.70%. In berseem land use, it ranged from 129 to 213 kg ha^{-1} around a mean value of 156 kg ha^{-1} and 13.08 % CV. The variability of available K was lowest in berseem based land use (CV value of 3.08) and it was highest in poplar-wheat cropping system (CV= 17.84%).

Table 1: Descriptive statistics of selected soil properties for berseem based land use.

Parameter	Mean	Minimum	Maximum	Median	%CV	Skewness	Kurtosis
Sand (%)	45.00	40.00	48.00	45.00	4.90	-0.41	-0.84
Silt (%)	26.00	14.00	37.00	26.00	24.00	0.03	-0.81
Clay (%)	40.00	30.00	48.00	40.00	13.00	-0.43	-0.56
pH	7.81	7.48	7.99	7.83	1.66	-1.18	1.02
EC (dS m^{-1})	0.53	0.38	0.71	0.54	15.10	0.13	-0.62
Available K(kg ha^{-1})	156.00	129.00	213.00	154.00	3.08	0.73	0.89

Table 2: Descriptive statistics of selected soil properties for rice-wheat cropping system.

Parameter	Mean	Minimum	Maximum	Median	%CV	Skewness	Kurtosis
Sand (%)	34.00	28.00	39.00	33.00	7.35	0.64	0.30
Silt (%)	25.00	13.00	35.00	24.00	19.40	-0.21	0.09
Clay (%)	43.00	30.00	49.00	44.00	11.24	-0.88	-0.08
pH	8.19	7.73	8.63	8.21	1.95	-0.43	2.37
EC (dS m^{-1})	0.47	0.21	0.75	0.47	27.66	0.21	0.09
Available K(kg ha^{-1})	179.00	134.00	302.00	176.00	17.70	1.86	5.54

Table 3: Descriptive statistics of selected soil properties for poplar-wheat cropping system.

Parameter	Mean	Minimum	Maximum	Median	%CV	Skewness	Kurtosis
Sand (%)	37.00	31.00	48.00	37.00	9.89	1.09	1.08
Silt (%)	19.00	9.00	30.00	19.00	22.63	-0.02	0.72
Clay (%)	42.00	35.00	49.00	43.00	9.23	-0.18	-1.03
pH	7.99	7.65	8.47	7.98	1.88	0.39	1.33
EC (dS m^{-1})	0.42	0.21	0.58	0.43	19.05	-0.47	0.99
Available K(kg ha^{-1})	122.00	67.00	174.00	123.00	17.84	-0.14	0.85

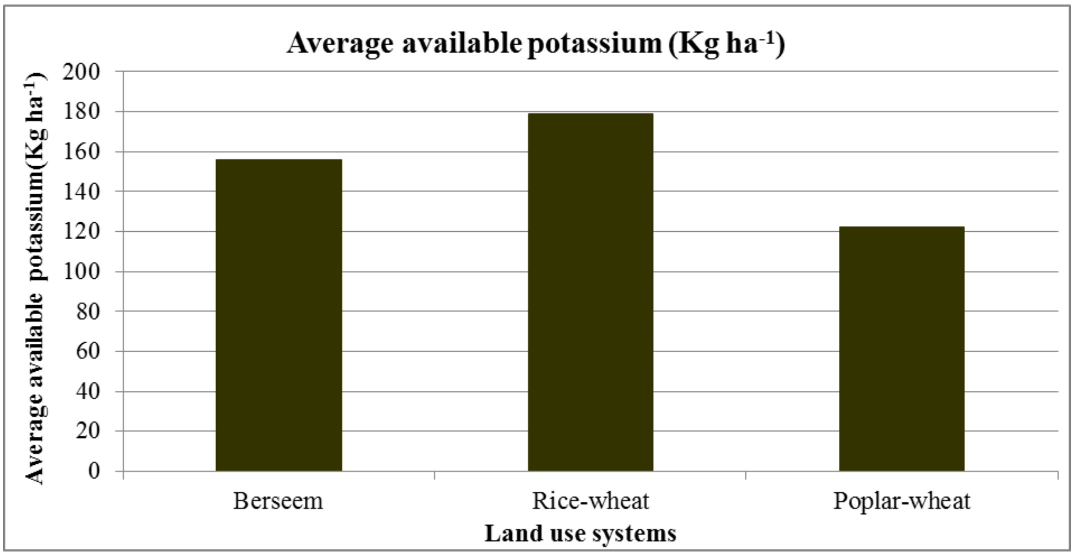

Fig 1: Soil available potassium content (kg ha^{-1}) under different land use systems.

Available K content was higher for all three land use systems (Fig.1 and Table 1, 2 and 3) and it could be attributed to clayey texture in soil and presence of almost unweathered biotite in silt and clay fraction of the soil of that region leading to high release of K and such similar type of result was also found by other coworkers (Pal *et al*. 2014, Sahrawat *et al*. 2016) [11, 13].

2. Geostatistical analysis of soil available K and other properties

To characterize the spatial variability of soil available k and other parameters, different experimental semivariograms models were chosen for different land use systems. It was found that Gaussian model was the best fitted model to describe of spatial variability of available K in berseem based land use; whereas the Exponential and spherical models were best for rice-wheat and poplar-wheat cropping system respectively. Different semivariograms parameters viz. nugget, sill and their ratio for different soil fertility parameters were represented in Table 4, 5 and 6.

Table 4: Semivariogram parameters of soil attributes in berseem based land use

Parameter	Model	Nugget (C_0)	Partial sill (C)	Sill (C_0+C)	Nugget/sill (NS ratio)	Spatial dependence	RMSE
Sand	Gaussian	5.943	0.932	6.875	0.86	Weak	1.043
Silt	Exponential	17.495	3.252	20.747	0.84	Weak	0.967
Clay	Exponential	3.135	13.412	16.547	0.19	Strong	0.965
pH	Spherical	0.004	0.007	0.011	0.36	Moderate	0.990
EC	Spherical	0.014	0.005	0.019	0.74	Moderate	0.941
K	Gaussian	376.286	201.210	577.497	0.65	Moderate	1.051

Table 5: Semivariogram parameters of soil attributes in rice-wheat system

Parameter	Model	Nugget (C_0)	Partial sill (C)	Sill (C_0+C)	Nugget/sill (NS ratio)	Spatial dependence	RMSE
Sand	Spherical	2.848	1.431	4.279	0.66	Moderate	0.947
Silt	Gaussian	9.031	6.181	15.212	0.59	Moderate	1.037
Clay	Exponential	10.585	1.611	12.196	0.87	Weak	1.024
pH	Gaussian	0.014	0.006	0.020	0.70	Moderate	0.127
EC	Spherical	0.012	0.002	0.014	0.86	Weak	1.014
K	Exponential	821.409	269.445	1090.854	0.75	Moderate	1.079

Table 6: Semivariogram parameters of soil attributes in poplar-wheat system

Parameter	Model	Nugget (C_0)	Partial sill (C)	Sill (C_0+C)	Nugget/sill (NS ratio)	Spatial dependence	RMSE
Sand	Gaussian	2.593	3.861	6.454	0.40	Moderate	0.979
Silt	Exponential	6.827	11.739	18.566	0.37	Moderate	0.969
Clay	Exponential	5.391	1.483	6.874	0.78	Weak	0.954
pH	Gaussian	0.012	0.010	0.022	0.54	Moderate	0.866
EC	Spherical	0.015	0.714	0.729	0.02	Strong	0.942
K	Spherical	218.277	158.3614	376.6383	0.58	Moderate	1.106

The NS ratio is an important semivariogram parameter used to determine the spatial dependence of different soil properties. Soil available K showed moderate spatial dependence for all three land uses (NS ratio in between 0.25 to 0.75). The moderate spatial dependence for soil available K was also reported by Vasu *et al*. (2017) [15]. Some soil parameters exhibited weak and some parameters demonstrated strong spatial dependence. Even the same studied parameter show different spatial dependence depending on land use type. Such spatial dependence occurs due to both intrinsic factors and extrinsic factors and Cambardella *et al*. (1994) [4] stated that weak spatial dependence occurred due to extrinsic factors, whereas, intrinsic factors were responsible for strong spatial dependence. The present revealed that the change in land use significantly influenced the spatial distribution pattern of different fertility parameters especially potassium.

The spatial variability maps of soil available potassium for different land uses were generated using ordinary kriging techniques to describe the spatial distribution pattern of K. These spatial variability maps or kriged surface maps of available K for three land uses were depicted in Fig. 2 (a,b and c).

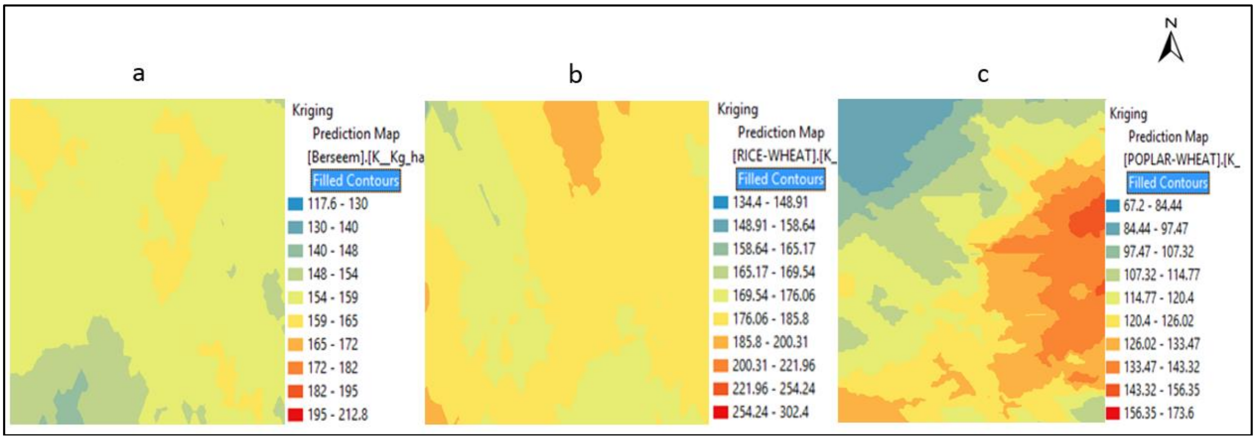

Fig 2: Kriged surface maps of available K for a) berseem, b) rice-wheat and c) poplar-wheat cropping systems.

The spatial variability maps (kriged surface maps) showed prominent spatial distribution of available K in three land uses. It was vivid that degree of spatial variability was highest in poplar-wheat based agroforestry system and it could be attributed to variable of management practices within the field and also due to the presence of poplar plantation because, the above ground vegetation determined the microbial activity and community structure which ultimately caused spatial variation (Bach *et al*. 2010) [1]. Low spatial variation was observed in other two land uses due to following same cropping pattern year after year and homogeneity in management practices.

Conclusion

The present research provides a better understanding about the spatial variability of soil available potassium for various land uses. Poplar-wheat cropping system exhibited better variability of available K in comparison to other land use systems due to difference in agronomic management practices such as tillage practices, choosing in cropping sequences etc. Soil available K exhibited moderate spatial dependence for all three land uses. The result of this study was also suggested that the ordinary kriging technique could be successfully employed for generating the spatial variability maps of available K for all these all uses. These generated spatial variability maps will be helpful for need based or site specific application of available K to improve the crop yield through increasing nutrient use efficiency. Simultaneously, it also will be supportive in reducing the economic investment incurred for different agro inputs through its precise management.

Further studies are required for assessing the spatial variability of other essential nutrients using geostatistical techniques for different land uses and at different spatial and temporal scales.

Acknowledgement

The authors are extremely thankful to Department of Soil Science, Punjab Agricultural University (PAU), Ludhiana, Punjab for providing all required facilities for conducting this research work and the first author is also thankful to Indian Council of Agricultural Research (ICAR) for offering ICAR-Junior Research Fellowship during M.Sc. research work at PAU.

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