

Full Length Research Paper

Assessment of spatial variability of selected soil chemical properties in a communal irrigation scheme under resource-poor farming conditions in Vhembe District of Limpopo Province, South Africa

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An understanding of spatial variability of chemical soil properties is necessary for proper nutrient management. Therefore spatial variabilities of soil pH, P, K, Ca and Mg in communal irrigation scheme under resource-poor farming conditions were determined. A total of 230 soil samples were collected from two soil depths (0 to 30 and 30 to 60 cm) at 100 m grid intervals. Basic statistics and geostatistical analyses of the data were performed using SAS 9.0 and GS+ 9, respectively. Soils showed high variabilities for all variables that were analyzed. Soil pH exhibited the lowest CV (6.0%) for both layers whereas all other measured variables displayed high CV for both soil layers. Most properties were analyzed by exponential model except for Ca and Mg that were fitted into spherical and Gaussian models respectively. All variables that were fitted into exponential model had strong spatial structure and those fitted into spherical model had a moderate spatial structure. Kriged contour maps displayed positional relationship between the topsoil and subsoil layers. Areas with low K and P can be delineated into separate management zones based on their requirements for these elements. The study showed that geostatistics is a useful tool to map spatial variabilities of soil chemical properties even under resource-poor farming conditions. These maps can be used to encourage/implement variable-rate of input application and inform resource-poor farmers of the benefits of this strategy, thereby reducing variation in soil fertility status caused by application of indiscriminate types and rates of manure and fertilizers.

Key words: Site-specific soil management, soil layers, Kriged contour maps, geostatistics, exponential model, South Africa.

INTRODUCTION

An understanding of spatial variability of soil chemical properties at field and time scale is important for making decisions relating to soil fertilization for sustainable crop production (Cambardella et al., 1994; Couto et al., 1997; Ayoubi et al., 2007; Bai and Wang, 2011; Sharma et al., 2011). Crop production is affected by spatial variability of soil chemical properties within and across the field

(Brouder et al., 2001). Spatial variability of soil nutrients is mainly attributed to the history of fertilizer application of individual farmer, diversity of crop types and field management (Jin and Jiang, 2002; Sen et al., 2007). Khosla et al. (2002) indicated that uniform application of fertilizers often results in over- and under application in various parts of the field due to in-field variability.

Studies on spatial variability of soil properties are often conducted in experimental farms and large commercial farms with sufficient financial resource to purchase inputs such as fertilizers, but not under resource-poor farming

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Table 1. Summary statistics of soil pH, phosphorus, potassium, calcium and magnesium.

Variables	Horizon	Min.	Max.	Mean	S.D	Skewness	C.V
pH	Topsoil	5.2	7.4	6.125	0.352	0.430	6
	Subsoil	5.0	7.20	6.162	0.354	to 0.390	6
P mg kg ⁻¹	Topsoil	0.10	60.10	6.818	8.335	3.510	122
	Subsoil	0.10	20.60	2.023	2.910	4.410	154
K mg kg ⁻¹	Topsoil	6.77	240.32	55.282	37.127	1.950	67
	Subsoil	8.38	174.54	28.435	24.029	3.790	84
Ca mg kg ⁻¹	Topsoil	53.52	2822.40	507.35	354.41	2.610	70
	Subsoil	85.85	1054.00	355.72	236.22	1.370	66
Mg mg kg ⁻¹	Topsoil	20.11	375.61	167.63	61.356	0.560	37
	Subsoil	20.06	490.26	163.94	67.258	1.390	41

conditions where farmers apply different types and rates of manure and/or fertilizers without soil test results. Farmers at Rambuda in communal irrigation scheme generally, apply what they think is sufficient to meet the needs of the crop. However, there were no historical records of the quantities of cattle, goat or chicken manure applied into the soil. This has led to under-fertilization or over-fertilization of different parts of the field and consequently large variations in crop stand and yield in communal irrigation scheme. Investigation of spatial variability of soil chemical properties can provide information that is useful for site-specific nutrient management for resource-poor farmers.

The objective of this study was to determine the spatial variability of soil pH, extractable P, K, Ca and Mg under resource-poor farming conditions at Rambuda irrigation scheme, in Vhembe District, South Africa.

MATERIALS AND METHODS

Study site

The study was conducted at the Rambuda communal irrigation scheme located in Vhembe District (22°59'30" S and 30°25'30" E) of Limpopo Province, South Africa. The total area of the irrigation scheme is 120 ha demarcated into 104 terraced plots under different management practices. It is situated in the subtropical climatic region characterized by warm to hot, moist summers and cool dry winters. The annual rainfall is 956 mm with most rain falling between November and March. The mean minimum average temperature is 15°C and the mean daily maximum temperature is 27°C. The soil was classified according to the taxonomic soil classification system for South Africa (Soil Classification Working Group, 1991) as belonging to Hutton soil form (*Rhodic, mesotrophic, luvic, haplic*) and Oakleaf soil form (*Neocutanic, chromic, luvic; haplic*). Soil types in the study area have very similar characteristics regarding the properties under study and were formed under similar conditions of climate, topography and parent material. Main crops grown in the irrigation scheme are sweet

potatoes, maize and winter vegetables planted on ridges under furrow irrigation.

Sampling and laboratory analysis

A total of 230 soil samples were collected at 0 to 30 cm and 30 to 60 cm depths on a 100 x 100 m grid over 120 ha. Samples were prepared and analyzed according to the procedure described in the Handbook of Standard Soil Testing Methods for Advisory Purposes (The Non-Affiliated Soil Analysis Work Committee, 1990). Soil samples were analyzed for soil pH (1:2.5 soil/water suspension ratio), extractable P (Bray 1), K, Ca and Mg (Ammonium acetate method).

Statistical and geostatistical analysis

Descriptive statistics analyses for minimum, maximum, mean, standard deviation, skewness using Shapiro-Wilky test (Shapiro and Wilk, 1965) and coefficient of variation for each measured soil variable using SAS 9.0 software (SAS Institute, 2010). The Wilk-Shapiro test showed that most measured soil parameters were not normally distributed, except the soil pH, which showed normal distribution (Table 1). Non-normal distributions for pH, P, K and Ca were transformed to normal distributions using log-transformation and weighted techniques. Data for Mg were transformed using the square-root method.

GS+ 9.0 Gamma Designs (Robertson, 2008) software was used to analyze the spatial structure of the data and to describe the semivariograms (Trangmar et al., 1985; Cambardella et al., 1994). All non-normal data were transformed before geostatistical analysis (Iqbal et al., 2005). The semivariogram was calculated by the following equation (Goovartz, 1997):

$$\gamma(h) = \frac{1}{2N(h)} \left\{ \sum_{i=1}^{N(h)} [Z(x_i - h) - Z(x_i)]^2 \right\} \quad (1)$$

where $\gamma(h)$ is the semi variance for interval class h , $N(h)$ is the number of pairs separated by lag distance, which is the distance

Table 2. Semi-variance parameters of soil pH, phosphorus, potassium, calcium and magnesium.

Variable	Horizon	Model	Nugget variance	Sill	Nugget (%)	Spatial class	Range (m)
pH	Topsoil	Exponential	0.0192	0.133	14	Strong	264
	Subsoil	Exponential	0.0078	0.124	6	Strong	9
P mg kg ⁻¹	Topsoil	Exponential	0.105	1.157	9	Strong	276
	Subsoil	Gaussian	0.033	0.355	9	Strong	276
K mg kg ⁻¹	Topsoil	Exponential	0.001	0.332	0.2	Strong	114
	Subsoil	Exponential	0.192	0.615	31	Moderate	6615
Ca mg kg ⁻¹	Topsoil	Spherical	0.001	0.441	0.2	Strong	1028
	Subsoil	Spherical	0.235	0.520	45	Moderate	1439
Mg mg kg ⁻¹	Topsoil	Spherical	2247	4495	50	Moderate	943
	Subsoil	Spherical	3.69	7.738	48	Moderate	1028

spatial location i , $Z(x_i + h)$ is the measured variable at spatial distance location $i + h$. Interpolation maps were generated through ordinary kriging of each measured variable using their respective semi variograms at the topsoil and the subsoil (Isaacks and Srivastava, 1989). The semi variograms and the best-fit models for each measured soil property are presented in Table 2.

RESULTS AND DISCUSSION

Statistical analysis

Majority of soil properties exhibited high coefficient of variation (CV) according to the guidelines and ranges in Wilding and Drees (1983) and Mulla and McBratney (2000) for both soil layers (Table 1), except soil pH which displayed low CV of 6% for both depths. Soil pH is among the least variable soil properties (Mulla and McBratney, 2000). High spatial variability of other properties may be as a result of management practices such as application of manure or fertilizers in the irrigation scheme.

Spatial variability of pH, extractable P, K, Ca and Mg

Distinct spatial structure of each soil property was defined according to the classification used by Cambardella et al. (1994). The semi variograms for pH, extractable P, K, and topsoil Ca were <25% indicating strong spatial dependence. Calcium and magnesium were moderately spatially dependent (Table 2). Cambardella et al. (1994) indicated that strongly spatially dependent properties may be controlled by intrinsic variations in soil characteristics such as texture and mineralogy. Soil pH was strongly spatially dependent, and this regard shows the impact of differences in fertilization history by individual farmers.

The percentage of nuggets (0.2) for topsoil Ca and K were low and close to 0% meaning that there was neither measurement error nor significant short-range variation (Trangmar et al., 1985). Subsoil percentage nugget for Ca and K were moderately spatially dependent.

The range values showed higher variability among the measured soil chemical properties at both depths (Table 2). All variables exhibited the range greater than 114 m except the subsoil pH which had a range of 9 m. Samples separated by distances closer than the range are spatially related and those separated by distances greater than the range are not spatially related, implying random variation (Trangmar et al., 1985; Cambardella et al., 1994). A sampling distance of 114 would be adequate to design a sampling scheme to study soil chemical properties at Rambuda irrigation scheme for P, K, Ca and Mg and indicates spatial relatedness of these properties that can bridge several map units (Cambardella et al., 1994). Sharma et al. (2011) indicated that a 140 m sampling scheme would be adequate to investigate the soil physical and chemical properties. Thus, high range values in this study may indicate that soils in the study area are related to another and spatial variabilities in soil chemical properties may be a result of management practices rather than intrinsic variability in measured soil properties.

Spatial distribution of soil pH, extractable P, K, Ca and Mg across the irrigation scheme

Soils were low in P and K despite favorable soil pH, Ca and Mg conditions for P availability in general (Table 1 and Figures 1 to 5). Kriged maps generally showed that the topsoil layers had higher pH, K, Ca and pH than the subsoil layers across the irrigation scheme (Figures 1 to 5) and vice versa for Mg (Figure 5). Soil pH level of

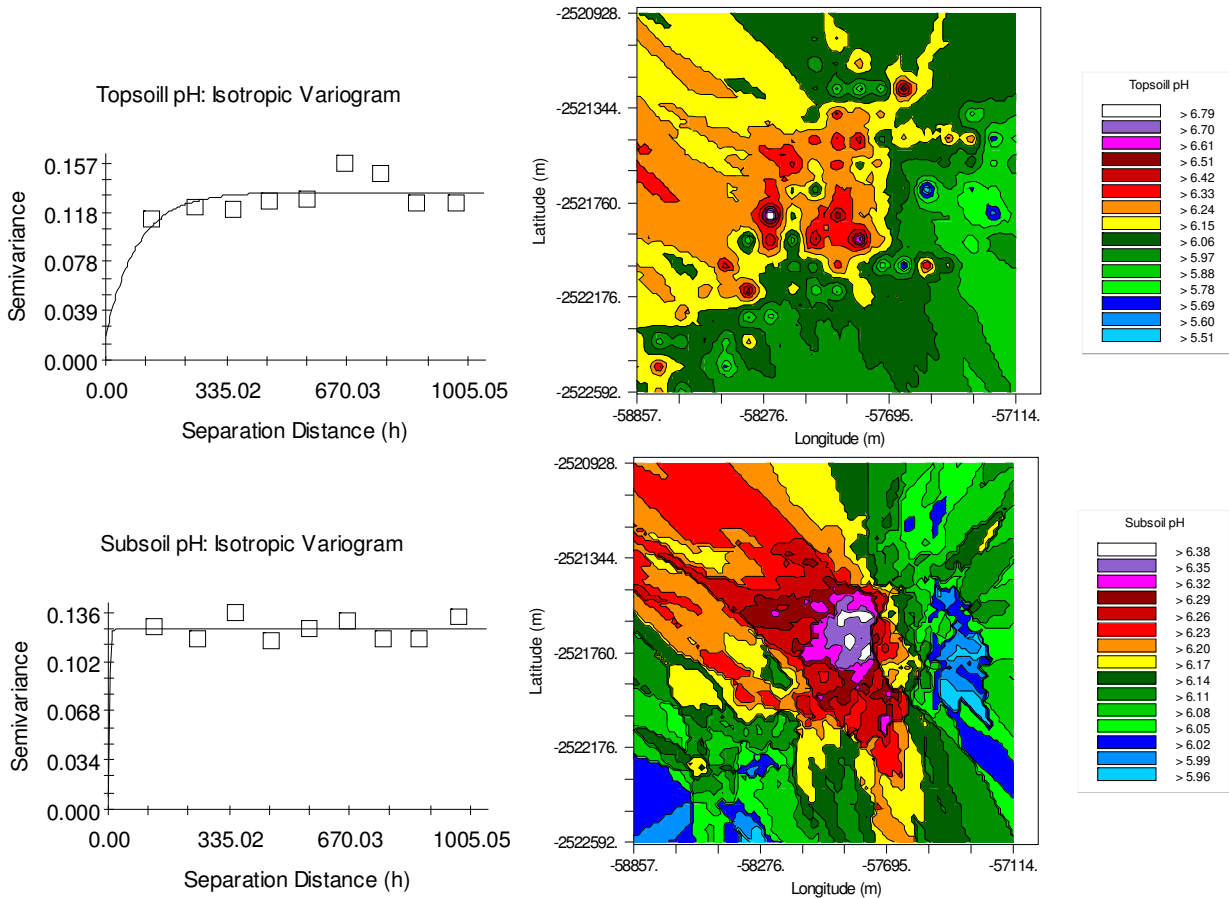


Figure 1. Semi-variograms and kriging maps of topsoil and subsoil pH.

Rambuda irrigation scheme ranged from 5.51 to 6.79 which is considered optimal for most crops (Fertilizer Society of South Africa, 2007). Soils with pH from 6.15 to 6.79 for the topsoil were found in the northwestern part extending from the east to the west of the irrigation scheme. Such soils exhibited low levels of P and K from 0.1 to 4.9 and 35 to 54 mg kg⁻¹ soil, respectively. Such low quantities of P and K were not expected for such an old irrigation scheme where organic manure had been continually applied. The eastern and the southwestern parts of the irrigation scheme were occupied by soils with topsoil P content ranging from 7.2 to 14.2 mg kg⁻¹ (Figure 2).

This might imply that farmers have been applying very low quantities of cattle and chicken manure and the build-up is low because the crops are taking up more than the replenishment. Data on the Management practices employed by the farmers on the plots required here. Soils with high level of topsoil K from 61 to 107 mg kg⁻¹ and medium levels of P from 16.5 to 32.6 mg kg soil were found in the eastern part of the irrigation scheme. Calcium was the most variable of measured soil variables for the topsoil layers.

Calcium and magnesium did not show positional

relationship with pH, P and K. This may be attributed to the history of fertilization and the type of manure applied by individual farmer. There were no recorded data on type and quantities of manure used by farmers, but heaps of cattle, goats and chicken manure were seen temporarily stored on the edges of different plots for application during this study. It was observed during the field survey that some farmers were applying lime on some parts of their plots and the extension officer confirmed that some farmers do indeed just apply lime without soil testing. This might explain higher variability of Ca for the topsoil.

There was positional relationship between the topsoil layers and the subsoil layers for pH, P, K, and Mg measured soil variables except Ca (Figures 1 to 5). Subsoil pH was highly variable and did not exhibit positional relationship with P, K, Ca and Mg distribution. Phosphorus and potassium contents in the subsoil were very low (Table 1 and Figures 1 and 2). They exhibited similar spatial variability, thus in parts where P was low, K was also low and in parts where P was high, K was also high (Figure 2). Brouder et al. (2001) found that P and K changed together in a similar spatial pattern, thus regions of high variability in P were also highly variable in K as

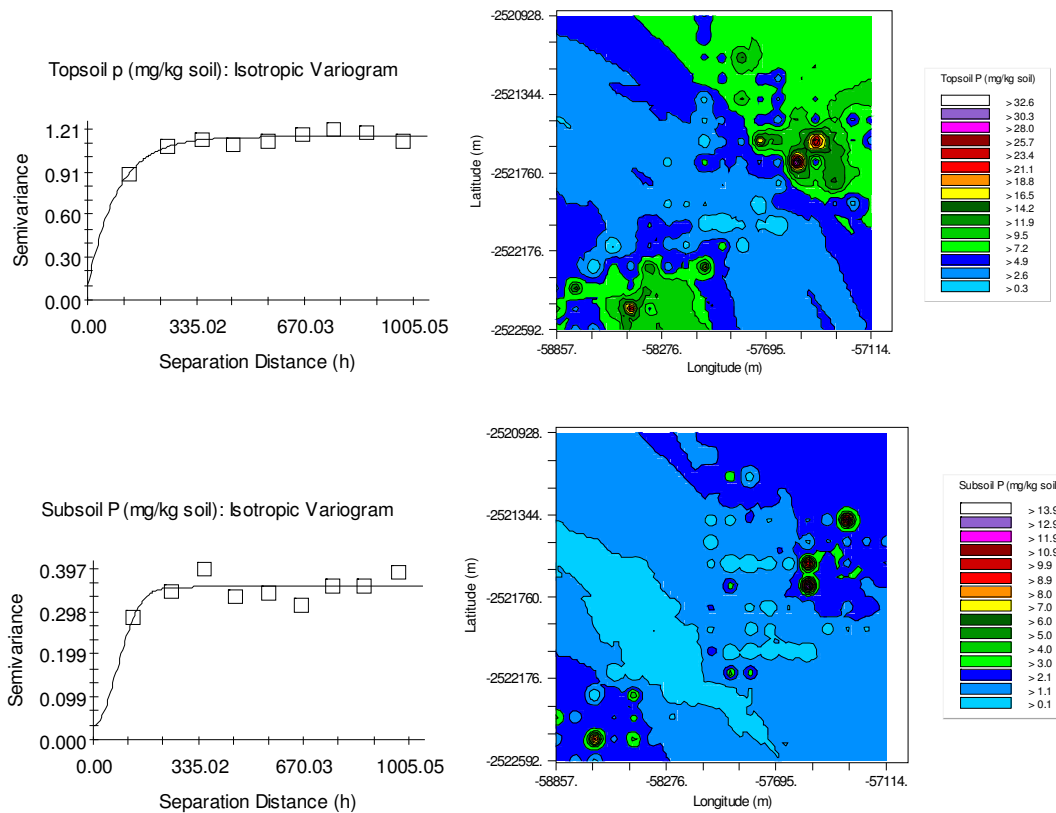


Figure 2. Semi-variograms and kriging maps of topsoil and subsoil phosphorus.

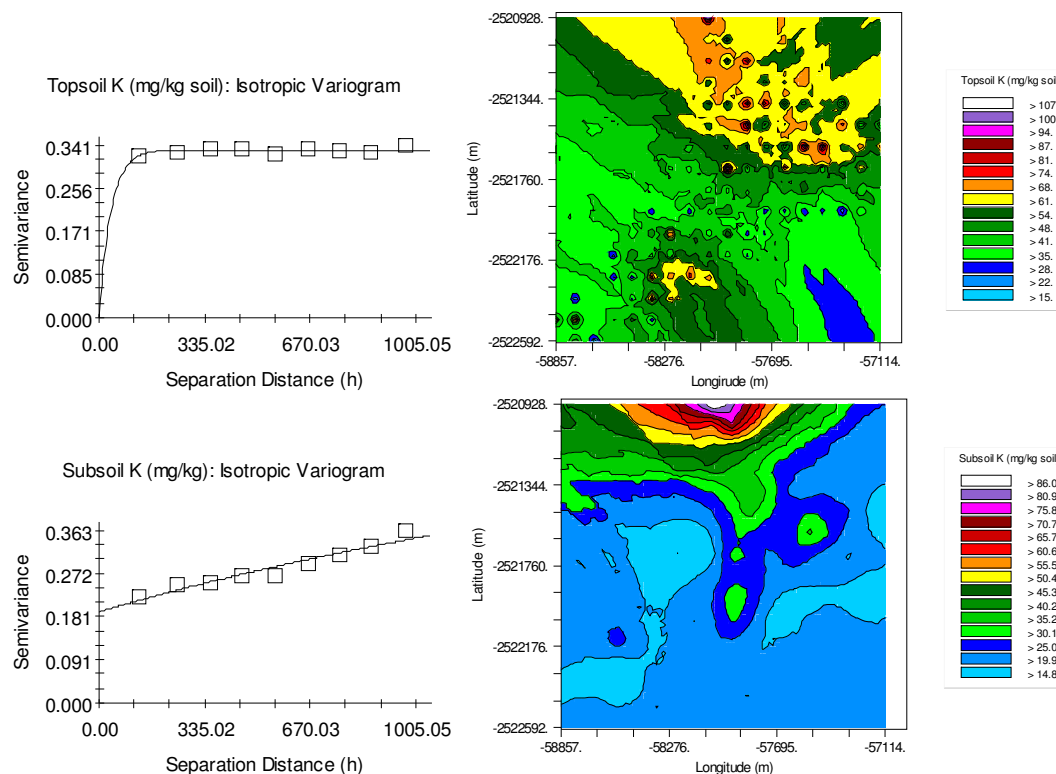


Figure 3. Semi-variograms and kriging maps for topsoil and subsoil potassium.

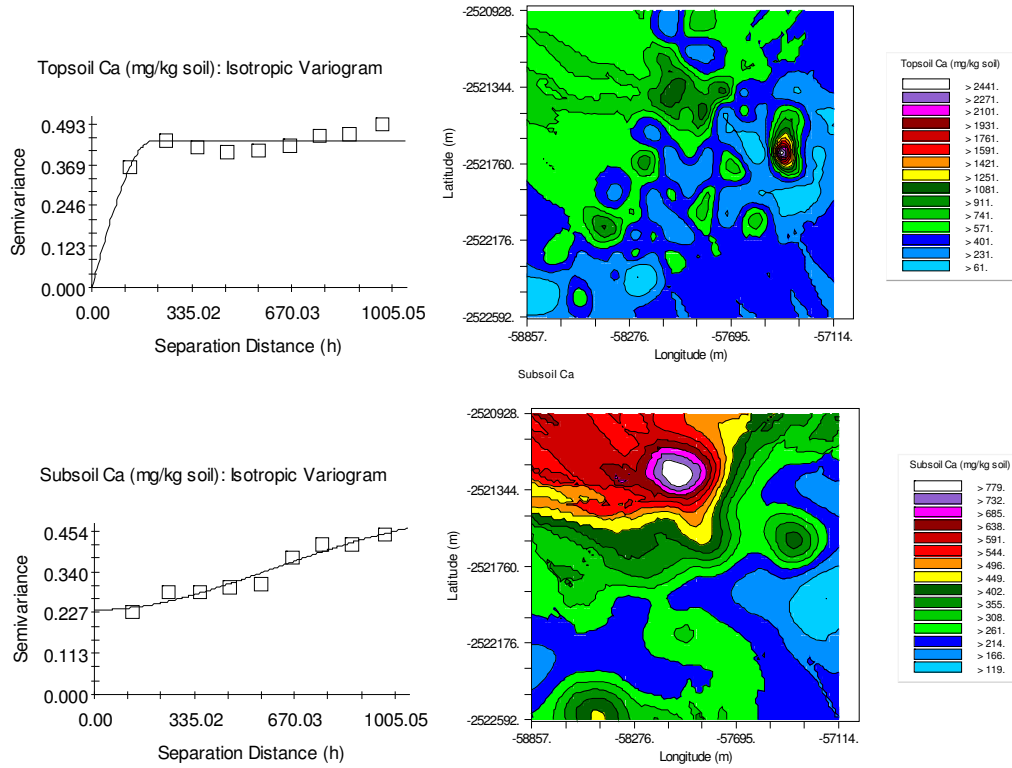


Figure 4. Semi-variograms and kriging maps of topsoil and subsoil calcium.

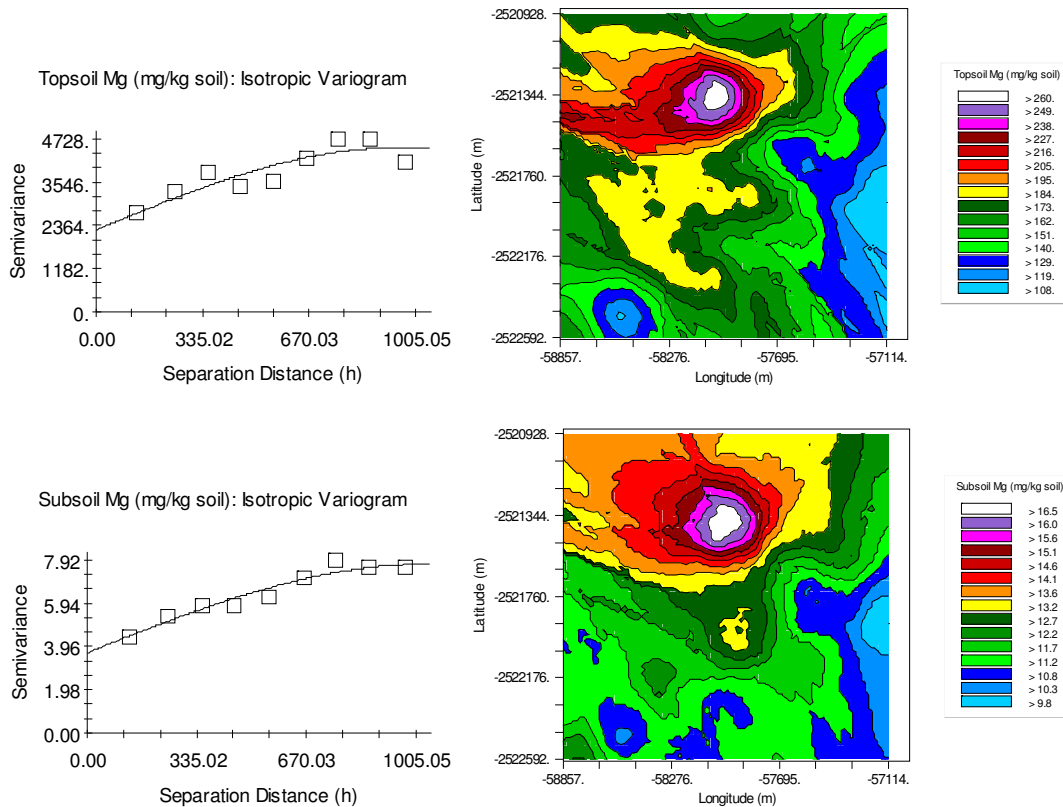


Figure 5. Semi-variograms and kriged maps of topsoil and subsoil magnesium.

was observed in this study. They concluded that, in the field, there is the potential to monitor and manage P and K together (Figures 2 and 3). A similar management strategy can be adopted to monitor and manage P and K at Rambuda irrigation scheme. Soils with P subsoil content from 0.1 to 2.1 mg kg⁻¹ covered the whole irrigation scheme with very small patches where P content was between 3.0 and 13 mg kg⁻¹ scattered across the irrigation scheme. Low subsoil P values may be due to slow mobility of P from the topsoil to the subsoil and P values were high in the topsoil layers than in the subsoil layers and changes in soil P pools from the lower horizon to replenish available P depleted in the topsoil may also account for low P at the deeper depth. Phosphorus moves very slowly except by erosion (Johnston, 2000; Tisdale et al., 2005).

In general, soils with subsoil K content from 14.8 to 25.0 mg kg⁻¹ covered the whole irrigation scheme with a patch of K contents from 30.1 to 70.7 mg kg⁻¹ found in the eastern part of the irrigation scheme (Figure 3). Soils with content 30.1 to 45.3 and 50.4 to 88.0 mg kg⁻¹ subsoil K were found in the northern extending to the south eastern part of the irrigation scheme. This may be attributed to the parent materials from plagioclase from which the soils in this part has originated rather than fertilization history.

In general, K content at Rambuda irrigation scheme was too low for crops such as vegetables and sweet potatoes which require adequate K for good quality. Subsoil Ca and Mg exhibited some positional relationship with Ca and Mg contents from 449 to 779 and 13.2 to 8.5 mg kg⁻¹, respectively were found in the northeastern part. Soils with Ca and Mg contents of 261 to 402 and 11.2 to 12.7 mg kg⁻¹ stretched from the eastern part extending to the western part of the irrigation scheme. A similar trend was exhibited by soils with 119 to 214 and 9.8 to 10.8 mg kg⁻¹ of subsoil Ca and Mg, respectively (Figures 4 and 5).

Conclusion

In general, variability for all the extractable P, K, Ca and Mg may be attributed to differences in management practices rather than soil forming factors as soils have similar properties and conditions of climate, topography and parent material. This variability in nutrient status might be one of the causes of differences in crop stand and yield within a single plot and across the irrigation scheme as observed by plot holders over the years. Areas with very high contents of either of these elements may be as a result of applying varying quantities of different organic manure or fertilizers by plot holders across the irrigation scheme; this was also observed during the field survey. Knowledge of spatial variation of soil chemical properties is important to determine application rates for each area and allows the field to be divided into appropriate management zones.

The question may be asked, whether precision farming is communal irrigation scheme relevant to a resource-

poor farmer in a small-scale but, the reality is that, every country that is striving for sustainable agricultural food production and preservation of soil resources need to consider the importance of site - specific nutrients management.

Geostatistics presents spatial distribution of nutrients elements in the form of simple spatial maps that may be simple to understand by resource-poor farmers and thus, making it easy for the resource-poor farmers to identify areas that require more fertilizers more than others, hence preventing over-application or under-application for fertilizer inputs into the soil.

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