Research Journal of Soil and Water Management 1 (3-4): 68-75, 2010
ISSN: 2075-1095

Field-Level Variability of a Lunnyu-Affected Soil in Masaka, Central Uganda

[1]B. Fungo, [2]S. Grunwald, [3]M.M. Tenywa and [2]P. Nkedi-Kizza
[1]Department of Forest Biology and Ecosystems Management, Makerere University, Masaka, Uganda
[2]Soil and Water Science Department, University of Florida, Gainesville, Florida
[3]Makerere University Agricultural Research Institute Kabanyolo (MUARIK), Kampala, Uganda

Abstract: The study aimed at characterizing the distribution of lunnyu soils in the Lake Victiria Basin of Uganda at field and landscape level. At field-level, soil samples were collected from the center point square grids obtained by laying a 180×180 m plot. At spacing of 20×20 m, 81 sampling points were georeferenced and samples taken at two depths (0-20 and 20-40 cm). And an additional 19 random locations within the plot were taken to make a total of 100 sampled locations. The soil properties analyzed were texture, pH, available P and exchangeable bases. Variograms that were used to describe the spatial structure of the soil properties were generated in VESPER (Variogram Estimation and Spatial Prediction with ERror) Version 1.6. All the soil properties, except silt showed spatial dependence at both depths at the scale of study. Phosphorus, Ca, Na and sand showed shorter ranges of between 42 and 58 m all in the top soil but the other properties in top and subsoil have larger ranges of 149 m. Overall, the spatial distribution of the soil properties in the sampled lunnyu patches are not straightforward. In order to resolve the lunnyu problem, objective identification of lunnyu patches should be sought followed by careful monitoring of crop performance under different soil fertility management interventions.

Key words: Lunnyu soils, spatial variability, management, subsoil, vesper, VESPER, Uganda

INTRODUCTION

Heterogeneity is an inherent quality of soil that typifies its anisotropy and in a natural landscape. It represents a wide variety of spatially varied soil attributes and as a result of the interaction of the processes that rule soil formation (Junior *et al*., 2006). The lunnyu phenomenon has been described by local farmers in Masaka district for example as being a state of infertility occurring in patches ranging between 50-100 m^2. Unlike the basic principles of experimentation established by the classical statistical method that considers soil variability to occur entirely at random, the fact that soil attributes show strong spatial dependence (Journel and Huijbregts, 1991) warrants a geostatistical analysis. It is hypothesized that lunnyu soils are an erosion phase and/or chemical degradation that occurs at landscape positions with greater intensity of hydrological processes (e.g., runoff, erosion). The aim of this analysis was to describe, the spatial variability of lunnyu soils at field level in order to understand the relationship between soil variability and slope.

STUDY AREA AND METHODS

The site where the study was carried out is one of the sites previously identified as a lunnyu-affected area (Tenywa, 2004). The taxonomic unit of the soil is a Chromic Lixisol. With the help of a farmer, boundaries of the area perceived to be lunnyu affected drawn basing on performance history of crops judged by the farmer. The garden was planted with a mixture of bananas (*Musa* sp.) and beans (*Phaseolus* sp.). Soil samples were collected from the center point square grids obtained by laying a 180×180 m plot. The point map for the sampled location is shown in the (Fig. 1). The plot contained 81 sampling points at spacing of 20×20 m. An additional 19 random locations within the plot were taken to make a total of 100 sampled locations. The size of the garden was selected go beyond the supposed boundaries of the lunnyu area. The elevation of the area ranged between 1,281 and 1,311 m above sea level and an almost uniform slope of 12% from top to bottom of the slope (Fig. 2). A Digital Elevation Model (DEM is valuable in describing topography across a site. The DEM was constructed by kriging interpolation of elevation measurements taken during the geo-referencing process.

The total area of the plot was 32,400 m^2. A venture Cx Global Positioning System (GPS) unit configured for World Geodetic System (WGS) datum was used to collect in the Universal Transversal Macator Projection (UTM) coordinate system for each sample point. During the geo-referencing process, the GPS unit was held vertically above the sample point. The soil attributes

Corresponding Author: B. Fungo, Department of Forest Biology and Ecosystems Management, Makerere University, Masaka, Uganda

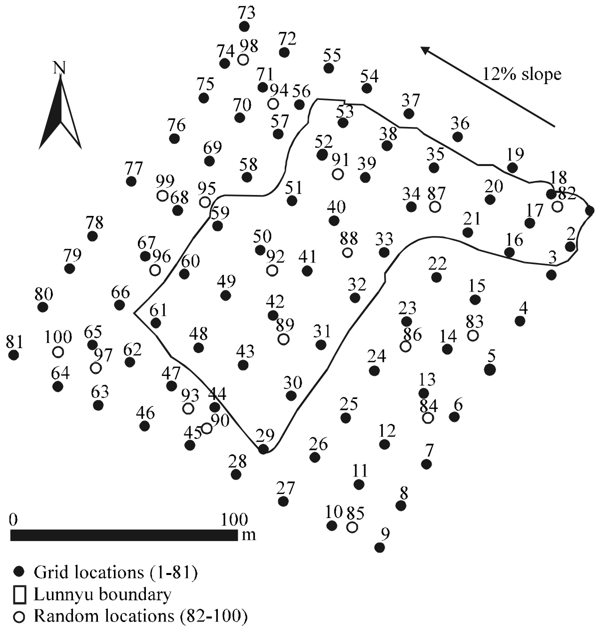

Fig. 1: Point map of sampling locations relative to lunnyu soil

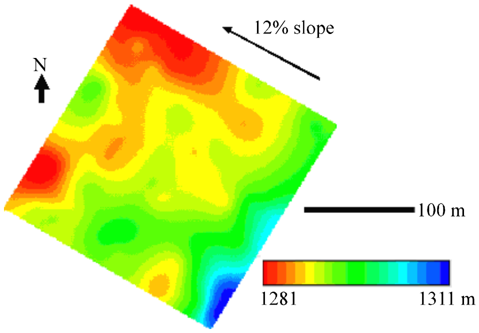

Fig. 2: Digital Elevation Model (DME) for the sampled lunnyu soil in Masaka, Uganda

studied were texture, pH, organic carbon, available P, exchangeable bases (Ca, K and Mg) and Mg, at two depths (0-20 and 20-40 cm) representing top and subsoil, respectively.

Available P was determined using Brady and Kurtz No. 1 method. The soil was extracted by Brady 1 solution and the P determined by the calorimetric procedure using a spectrophotometer. Soil pH was determined using a pH meter.

Exchangeable K, Ca and Mg were measured by treating the soil samples with excess 1 M ammonium acetate solution. Later, the concentrations of exchangeable sodium and K in the extract were measured by flame photometer and the concentration of Ca and Mg was measured by atomic absorption spectrophotometry (Anderson and Ingram, 1989). Laboratory analysis was done in the soils science laboratory of the Faculty of Agriculture, Makerere University. Data were statistically analyzed in three phases:

- Data were described using descriptive statistics (mean, median, standard deviation, coefficient of variation and skewness)
- Geostatistical analysis is most efficient when done on variables that have normal distributions (Webster and Oliver, 1990) because it requires the assumption that the observed data are a realization of a random function which is intrinsically stationarity. Under stationarity, observations of a single realization of the random function at different positions can be treated as a form of replication. The data have to normal to satisfy the stationarity assumption. Therefore, the frequency distribution of each soil property was examined for outliers and the tests for normality using the Anderson-Darling test
- Correlation coefficients between the different variables were calculated. The statistical analysis of data was carried out using GenStat Discovery Version 3 (VSN International Ltd, UK)
- Geostatistical analyses involved three steps. For each variable y, a geostatistical analysis was done by estimating the variogram:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z_u(x_i) - z_u(x_i + h)]^2$$

Where:

$\hat{\gamma}(h)$ = Semivariance at lag h
h = Distance between data pairs ($z_u(x_i)$-$z_u(x_i$+h)) (or: lag)
N = Total number of data pairs ($z_u(x_i)$-$z_u(x_i$+h))
z_u (x_i) = Variable u at location x_i

It included calculation of empirical variograms and determination of the best fitting model $\hat{\gamma}(h) = C_0 + C_1$ f(b) as judged by the mean squared error where, f(b) is any permissible variogram function, c0 the nugget variance, c1 the sill value and b the range (Chiles and Delfiner, 1999; Webster and Oliver, 1990) iograms were used in geostatistical interpolation (ordinary kriging), followed by display of predicted values as a map. The variability structure was assumed to be isotropic for all the variables over the study area. Prediction performance was evaluated using the Root Mean Square Prediction Error

(RMSE). The RMSE provides a summary of the difference between the true (measured) and predicted control point coordinates. The program used for geostatistical analysis was VESPER (Variogram Estimation and Spatial Prediction with ERror) Version 1.6.

RESULTS AND DISCUSSION

Statistical analysis: The descriptive statistics for all measured soil properties in the top and subsoil are shown in Table 1. The lowest coefficient of variation obtained was 6.98% for pH in the topsoil and the highest was 396.62% for exchangeable Na in the subsoil. The variability of available P and exchangeable K were much higher for both top and subsoil depths compared to any other soil property measured.

Conversely, pH was the least variable in both the top and subsoil with coefficient of variation of 6.98 and 7.99, respectively. Exchangeable Mg varied more in the topsoil than in the subsoil but was on average, higher in the topsoil. The ranges in sand, silt and clay were wide in both top and sub soils. In the topsoil, mean sand and clay were all lower than in the subsoil but silt was higher in the topsoil than in the subsoil.

The correlations among the various soil properties are shown in Table 2. For clay content, the correlation observed with other soil properties in both the top and subsoil was negative except for Na and K in the top and subsoil, respectively. At 5% significance level all the soil properties correlated with at least two other properties in the set, except for Na in the subsoil. The highest correlation was observed between clay and sand in the subsoil but was also comparatively higher in the topsoil being negative at both depths.

The highest positive correlation was observed between Mg and Ca in the subsoil. Mg and Na in the top

Table 1: Descriptive statistics of field-level lunnyu soil in the L. Victoria basin, Uganda

Statistic	pH	P (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)	Na (ppm)	Sand (%)	Silt (%)	Clay (%)
Top soil									
Mean	6.46	13.96	6.45	0.76	2.20	0.08	48.66	15.96	35.32
Starndard error of mean	0.05	1.50	0.28	0.08	0.10	0.01	0.70	0.49	0.61
Median	6.50	8.98	6.08	0.39	2.10	0.07	50.00	16.00	34.00
Minimum	5.00	3.78	1.35	0.16	0.22	0.03	10.00	8.00	18.00
Maximum	7.50	99.59	21.00	3.82	7.65	0.47	64.00	46.00	56.00
Coeficient of variation	6.98	107.35	43.95	100.19	46.39	70.56	14.43	31.00	17.21
Skewness	-0.33	3.15	1.49	1.77	1.62	5.24	-2.61	3.08	0.51
Sub soil									
Mean	6.46	10.37	5.59	0.62	1.82	0.10	46.06	12.78	41.32
Starndard error of mean	0.05	1.09	0.21	0.07	0.07	0.04	0.51	0.39	0.64
Median	6.60	6.68	5.33	0.31	1.96	0.05	46.00	12.00	44.00
Minimum	4.90	1.54	1.35	0.16	0.19	0.00	32.00	6.00	24.00
Maximum	7.50	94.59	12.90	2.93	3.62	4.00	60.00	24.00	58.00
Coeficient of variation	7.99	104.74	37.81	108.73	35.80	396.62	11.00	30.25	15.39
Skewness	-0.69	5.14	0.71	2.05	0.23	9.80	-0.17	0.52	-0.14

Table 2: Spearman rank correlation of field-level lunnyu soil properties

Soil properies	Elevation	pH	P	Ca	Mg	K	Na	Sand	Silt
Top soil									
Ph	0.13	-	-	-	-	-	-	-	-
P	0.14	0.33**	-	-	-	-	-	-	-
Ca	0.06	0.27**	0.28**	-	-	-	-	-	-
Mg	0.07	0.16	0.20*	0.66**	-	-	-	-	-
K	0.11	0.15	0.24*	0.56**	0.46**	-	-	-	-
Na	0.10	0.03	0.07	0.28**	0.74**	0.37**	-	-	-
Sand	-0.22*	0.21*	0.33**	0.24*	-0.22*	-0.05	-0.58**	-	-
Silt	0.13	0.10	0.03	0.12	0.44**	0.14	0.61**	-0.53**	
Clay	0.19*	-0.32**	-0.40**	-0.36**	-0.10	-0.05	0.17	-0.73**	-0.19
Sub soil									
pH	-0.05	-	-	-	-	-	-	-	-
P	0.11	0.18	-	-	-	-	-	-	-
Ca	-0.09	0.38**	0.45**	-	-	-	-	-	-
Mg	-0.08	0.31**	0.38**	0.76**	-	-	-	-	-
K	0.16	0.23	0.37**	0.36**	0.28**	-	-	-	-
Na	-0.04	0.13	-0.02	-0.07	-0.06	0.03	-	-	-
Sand	-0.16	0.33**	0.27**	0.19	0.21*	-0.01	0.13	-	-
Silt	-0.05	0.25*	0.02	0.27**	0.17	-0.06	0.04	0.03	-
Clay	0.19	-0.42**	-0.24*	-0.33**	-0.28**	0.03	-0.13	-0.81**	-0.59**

Values with* and ** were significant correlated at 0.05 and 0.01 alpha level, respectively

Table 3: Descriptive statistics of transformed lunnyu soil properties, Uganda

	Top soil				Sub soil	
Statistics	P	K	Na	Silt	P	K
Statistical transformation	Log_{10}	Log_{10}	Square root	Square root	Log_{10}	Log_{10}
Mean	1.07	-0.29	0.26	3.89	0.88	-0.38
Median	1.01	-0.41	0.27	4.00	0.82	-0.51
Minimum	0.58	-0.80	0.20	2.83	0.59	-0.80
Maximum	2.00	0.58	0.33	4.69	1.46	0.47
Standard deviation	0.30	0.36	0.79	0.38	0.21	0.35
Coefficient of variation%	28.13	-126.54	16.22	9.89	23.30	-92.26
Skewness	0.78	0.67	0.02	-0.45	0.86	0.99

Table 4: Sill, nugget, range and Root Mean Square prediction Error (RMSE) lunnyu soil

Soil properties	Nugget	Sill	Range (m)	RMSE	Nugget/Sill ratio (%)
Top soil					
pH	0.12	0.19	149	0.29	63
log P ($mg\ kg^{-1}$)	0.05	0.06	59	0.08	83
Ca ($mg\ kg^{-1}$)	3.53	2.85	43	8.18	124
Mg ($mg\ kg^{-1}$)	0.54	0.35	216	0.78	154
log K ($mg\ kg^{-1}$)	0.09	0.09	149	0.18	100
Square root Na ($mg\ kg^{-1}$)	0.49	0.19	47	3.14	258
Sand (%)	20.92	22.81	46	87.62	92
Clay (%)	26.40	18.87	106	51.43	140
Square root silt (%)	15.29	-	-	96.17	-
Subsoil					
pH	0.15	0.23	149	0.52	65
Log P ($mg\ kg^{-1}$)	0.04	0.01	149	0.04	400
Ca ($mg\ kg^{-1}$)	4.09	1.88	468	6.03	218
Mg ($mg\ kg^{-1}$)	0.38	0.09	149	0.52	422
Log K ($mg\ kg^{-1}$)	0.10	0.04	149	0.20	250
Na ($mg\ kg^{-1}$)	0.00	0.00	149	0.01	0
Sand (%)	21.77	7.34	171	28.77	297
Clay (%)	35.48	8.65	149	46.59	410
Silt (%)	15.06	-	-	16.94	-

soil were almost as highly positive as was Mg and Ca but extremely different correlation in the sub soil. Only sand and clay in the top soil were correlated with elevation. Whereas the correlation between sand and elevation was negative, the one between clay and elevation was positive. This implies that there was more sand at lower elevations than at higher ones while there was more clay at higher elevations.

Geostatistical analysis: Phosphorus, K, Na and silt in the topsoil and P and K in the subsoil were transformed using appropriate statistical distributions (Table 3). To estimate the variograms for each soil property, the exponential model using normalized data was employed. The variograms were estimated to a cutoff distance of 180 m and a lag of 20 m, assuming that there was no anisotropy. The sill variances of pH, P and exchangeable bases in the top and subsoil were generally smaller than those of textural properties, except silt which showed pure nugget effect (Table 4). In the top soil, sand and clay had the highest sill and nugget while silt had a pure nugget.

Phosphorus, Ca, Na and K had shorter ranges between 42 and 58 m while the ranges of the other soil properties ranged between 106 and 216 m. Calcium in the topsoil had the shortest range of 43 m but also had the longest in the subsoil. The patterns of the soil properties in the subsoil were similar to those in the topsoil. Silt, like in the topsoil had a pure nugget (Fig. 3 and 4). Although, the sill variances of the textural properties in the subsoil were higher than those of other properties in the same layer they were generally lower than those in the topsoil. Except for Ca and sand which had longer ranges of 171 and 468 m, respectively all the other properties had on average, an equal range of 149 m.

Again like in the topsoil, the prediction errors of the textural properties were poorer that those of other properties in the subsoil. Noteworthy is the fact that sand and silt had much smaller prediction errors in the subsoil than in the topsoil. Considering the RMSE, soil textural properties were poorly predicted compared to other soil properties. Silt had pure nugget effect in both the top and subsoil.

In most part of the sampled site, soil chemical properties did not show any clear relationship with elevation and relative location of the lunnyu boundary. Noteworthy is that for both top and sub soil, the North-Eastern part of the study area was high in most properties, except clay and Na. This part coincides with part of the lunnyu peninsula. The elevation in this part was moderate. The complexity of the compositional and spatial relationships of the soil properties in this study reflects the inherently variable nature of soils (Brady and Weil, 2002). Soil redistribution for example is controlled by factors such as parent material, climate, terrain, land use and land management interventions. Land management is an important factor to consider in this study because soils respond differently to land use management activities. The mean values of the soil properties were not different from those obtained in previous studies in the same area (Taulya, 2004; Tenywa, 2004; Mulumba, 2004). The low coefficient of variation exhibited by pH is characteristic of the redistribution pattern of soil water which tends to make the pH uniform over the area. On the other hand, Na is a micro-element and its highly varied occurrence in the soil is primarily determined by the source of this element. The high variability of P and exchangeable ions for both top and subsoil, compared to any other soil property measured could be due to differential vertical (leaching) and horizontal movement.

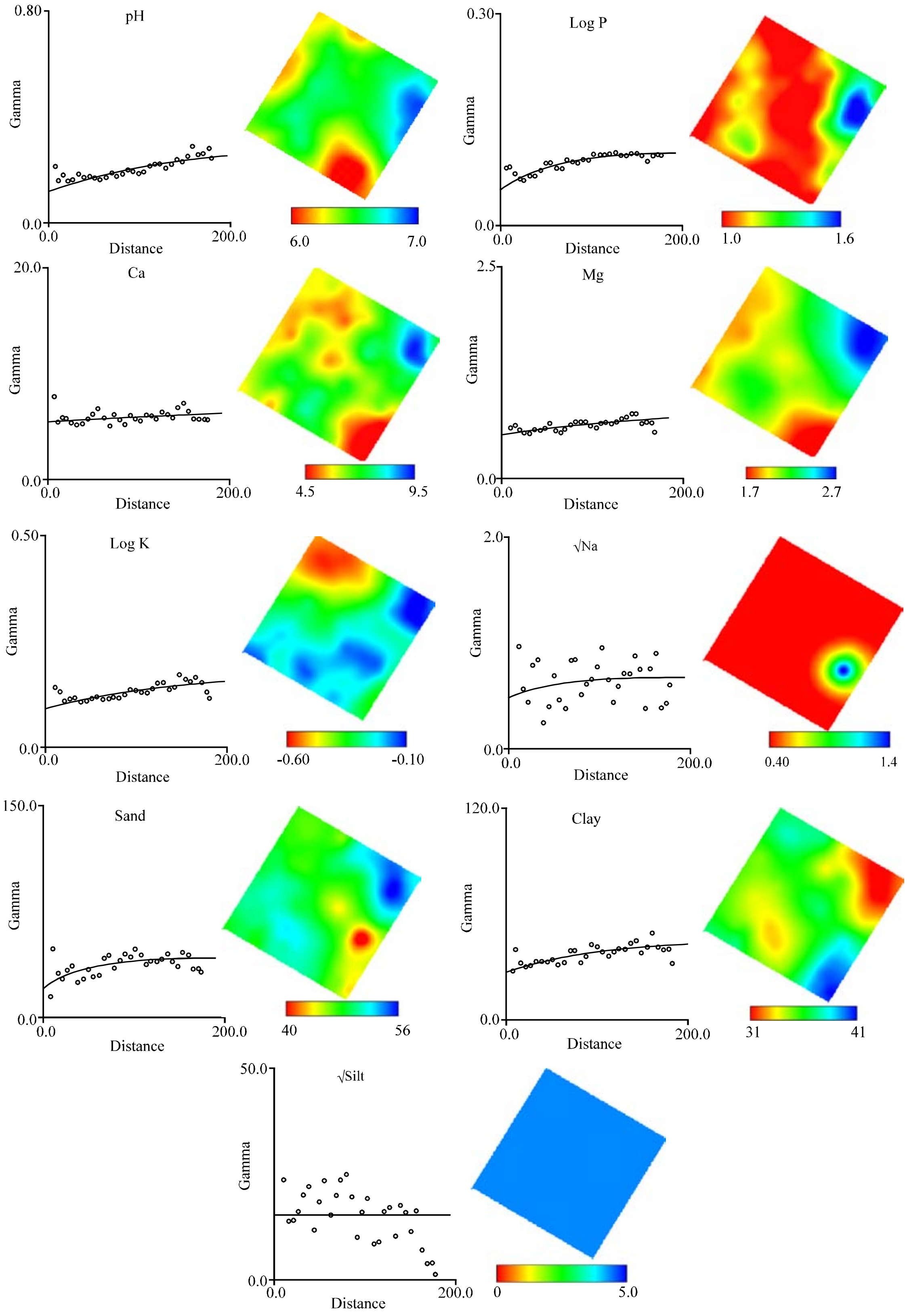

Fig. 3: Top soil properties

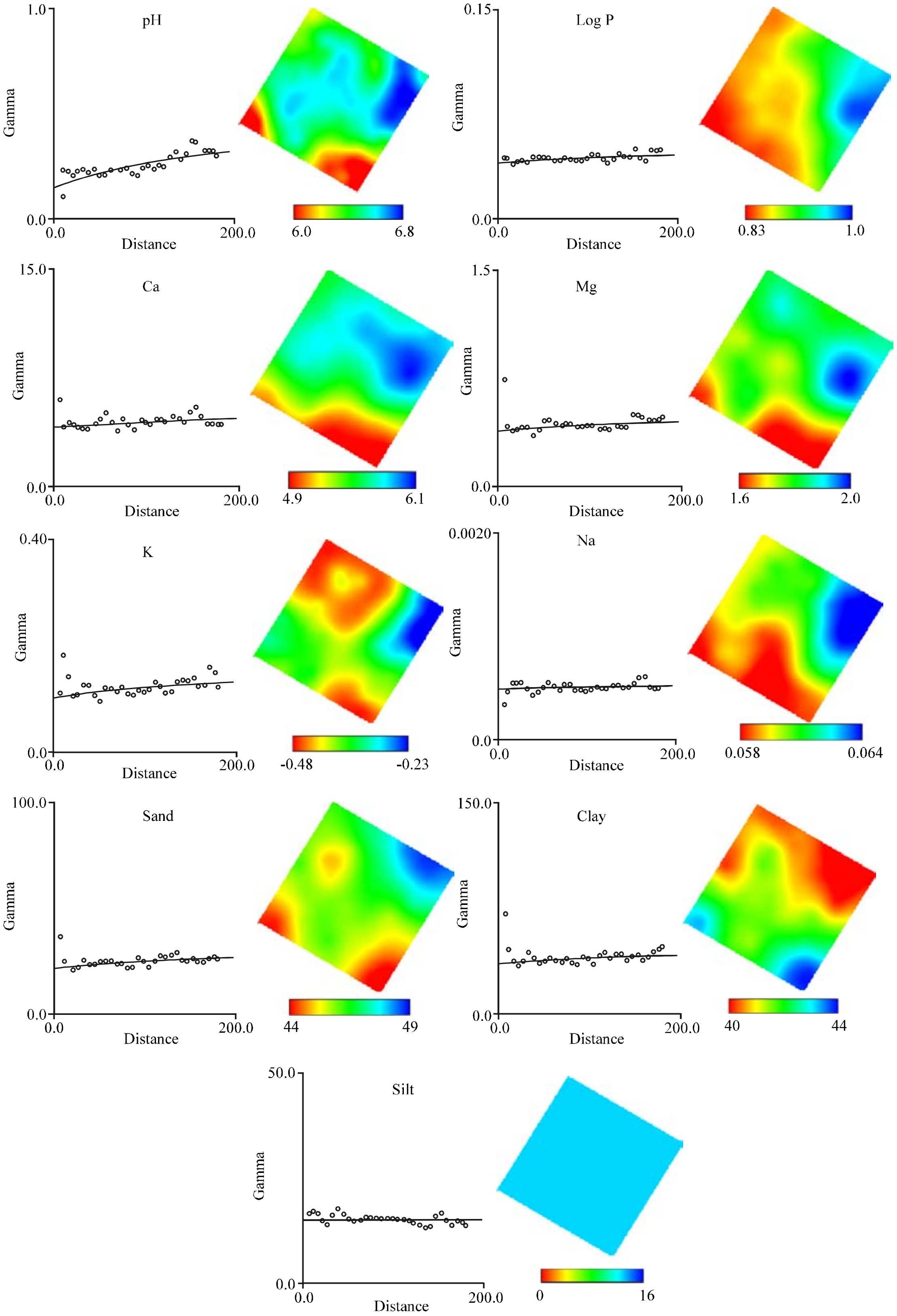

Fig. 4: Sub soil properties

The negative correlation between clay content and other soil properties is expected because the clay binds with the ions, sometimes making them unavailable in soil solution or even on the exchangeable form of soil solids. The proportion of clay and sand has an inverse relationship because the increase in one leads to a decrease in the other. The high positive correlation observed between Mg and Ca in the subsoil is because these two ions have the same factors such as parent material, leaching and utilization by plants that control their occurrence and distribution in the soil. The discrepancy between the top and subsoil Mg and Ca can be explained by the fact that the differential redistribution of these ions during illuviation/eluviation.

Silt had pure nugget effect in both the topsoil and subsoil but it's textural counterparts (sand and clay) showed spatial dependence over a range of 149 m. This implies that the spatial distribution of silt in the sampled area is random at the spatial scale at which it was obtained. Although, Milne suggested soil-landscape processes including erosion-deposition and hillslope solute transport as specific mechanisms for the formation of soil-landscape patterns, deviations from these important catena concept occur.

Silt ranges (minimum-maximum values) were much lower in topsoil (15%) and subsoil (18%) when compared to sand (topsoil: 54%; subsoil: 49%) and clay (topsoil: 39%; subsoil: 34%) content suggesting that most of the textural variability within the study site was due to variations in sand and clay. Silt showed much more homogenous variation across the study site when compared to heterogeneous patterns in sand and clay (compare point maps).

The DEM shows highest values in the southern part of the study area and lowest in the western and northern parts. In contrast, sand showed higher values at lower elevation and clay showed lower values at lower elevation. The spatial distribution patterns of sand and clay do not seem to be correlated to topography which suggests that *in situ* pedogenic processes (e.g., formation of secondary clays; pedoturbation) due to their dominance may mask erosion/deposition process. The low correlation coefficients between elevation and sand and elevation and clay indicate limited influence of erosion on textual classes in the sampled area.

Theoretically, the flat hilltops (summit landscape position) would have greater infiltration-potentially leading to greater eluviation illuviation of clays whereas the steeper backslope regions would be more prone to erosion and A-horizon stripping (Brown *et al.*, 2004). However, given that slope gradient was not so steep and uniformly sloping, coupled with the varied management practices in the sampled area, the redistribution of soil textural classes is not straightforward. Generally, spatial variability of soil chemical properties occurs over shorter distances compared to the physical ones, other factors being constant. The reason could be that chemical properties change rapidly with subtle changes in environmental factors compared to physical soil properties. For example, a short rain may cause dissolution and subsequent horizontal and lateral flow of a chemical substance without necessarily causing physical soil movement. In the topsoil, this effect is more pronounced than in the subsoil because the topsoil is more exposed.

Calcium in the topsoil having had the shortest range of 43 m but also having the longest in the subsoil is further evidence to this proposition. The field that was sampled extends beyond one farmers plot and each plot had different cropping practice. For example whereas the South-Western part of the grid was a fallow about 2 years old, the center part was grown with bananas. (*Musa* sp.) intercropped with common beans (*Phasiolus vulgaris*). The similarity in the patterns of the soil properties in the top and subsoil can be explained by the variability in use practices with in the field (different parts of the field had different crops e.g., bananas, sweet potatoes, beans and fallow).

Range is the distance beyond which spatial dependence between soil samples ceases to exist and it can be used as indicator of the appropriate cell size for a field survey in site-specific management. Thus, range is important both to define the different classes of spatial dependence for these soil variables and to establish the sampling interval for future surveys. The sampling interval should be less than half of the range of the variogram as a rule of thumb (Kerry and Oliver, 2003). Except for Ca and sand which had longer ranges of 171 and 468 m, respectively all the other properties had on average showed an equal range of 149 m. Future studies in this area should consider these ranges to optimize future samplings.

A large RMSE means the errors are widely spread, while a small RMSE means the errors are packed tightly around the mean value. The RMSE of the textural properties were poorer that those of other properties probably because of varied redistribution resulting from land management practices in the sampled field. This situation reveals that soil silt does not show any kind of spatial dependence while sand and clay show only weak spatial dependence indicated by the nugget/sill ratios. According to Wang *et al.* (2001) and Grunwald *et al.* (2007) if the nugget/sill ratio is <25%, a variable has strong spatial dependence between 25 and 75%, the variable has moderate spatial dependence; >75% the variable only shows weak spatial dependence. This implies that all the soil properties have weak spatial dependence, except pH at both depths. There is a possibility that the sample spacing was too coarse to delineate fine-scale spatial variability of soil properties considered in this study.

The fact that was no definite pattern providing evidence of erosion/deposition processes lends support to the absence of any clear relationship of soil chemical properties with elevation and relative location of the Lunnyu boundary the in most part of the sampled site. This further suggests *in situ* masking of pedogenic processes. Noteworthy is that for both top and sub soil, the North-Eastern part of the study area was high in most properties, except clay and Na. This part coincides with just one part of the Lunnyu peninsula. The elevation in this part was moderate.

CONCLUSION

The spatial distribution of the soil properties in the sampled field are not straightforward. All the soil properties except silt showed spatial dependence at both depths at the scale of study. The properties P, Ca, Na and sand showed shorter ranges of between 42 and 58 m, all in the top soil but the other properties in top and subsoil have larger ranges of 149 m. The spatial dependence of variables was observed to be larger in subsoil than in the topsoil which suggests the disturbing effect of tillage on the spatial structure.

ACKNOWLEDGEMENTS

Funding was made available through the Strengthening Agricultural and Environmental Capacity through Distance Education (SAEC-DE), a University of Florida/CIAT joint USAID Africa pilot project. Financial material and moral support were made possible from various individuals and institutions to whom we are indebted with no reservations.

REFERENCES

Anderson J.M. and J.S.I. Ingram, 1989. Tropical Soil Biology and Fertility: A Handbook of Methods of Analysis. CAB International, Wallingford, UK., pp: 38-39.

Brady, N.C. and R.R. Weil, 2002. The Nature and Properties of Soils. 13th Edn., Prentice Hall, New Jersey, ISBN: 0130167630.

Brown, D.J., M.K. Clayton and K. McSweeney, 2004. Potential terrain controls on soil color, texture contrast and grain-size deposition for the original catena landscape in Uganda. Geoderma, 122: 51-72.

Chiles, J.P. and P. Delfiner, 1999. Geostatistics Modeling Spatial Uncertainty. 1st Edn., John Willy and Sons, Inc., New York.

Grunwald, S., K.R. Reddy, J.P. Prenger and M.M. Fisher, 2007. Modelling of the spatial variability of biogeochemical soil properties in a freshwater ecosystem. Ecol. Modell., 210: 521-535.

Journel, A.G. and C.J. Huijbregts, 1991. Mining Geostatistics. 5th Edn., Academic Press, London.

Junior, V.V., M.P. Cavalho, J. Dafonte, O.S. Freddi, V.E. Vazquez and O.E. Ingaramo, 2006. Spatial variability of soil water content and mechanical resistance of Brazilian ferralsol. Soil Till. Res., 85: 166-177.

Kerry, R. and M. Oliver, 2003. Variograms of ancillary data to aid sampling for soil surveys. Precision Agric., 4: 261-278.

Mulumba, L.N., 2004. Land us effect on soil quality and productivity in the Lake Victorial basin of Uganda. Ph.D. Thesis, The Ohio State University, USA.

Taulya, G., 2004. Topsoil depth-banana yield relationships on a chromic luvisol in a Lake Victoria basin microcatchment. M.Sc. Thesis, Makerere University, Uganda.

Tenywa, M.M., 2004. Characterization of unproductive Luunyu soils for improved agricultural productivity in the Lake Victoria Basin. IFS Research Project Grant C/3392-1 Report. Uganda.

Wang, J., F. Bojie, Y. Qiu, C. Liding, and Z. Wang, 2001. Geostatistical analysis of soil moisture variability on Da Nangou catchment of the Loess Plateau, China. Environ. Geol., 41: 113-120.

Webster, R. and M. Oliver, 1990. Statistical Methods in Soil and Land Resource Survey. Oxford University Press, Oxford, pp: 328.