#7489 PRECISION FARMING USING SPATIAL SOIL VARIABILITY MAPS FOR IMPROVED BANANA NUTRIENT MANAGEMENT ON A FERRALSOL IN CENTRAL UGANDA

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ABSTRACT

Banana is one of the most important crops for millions of farmers in Uganda. However, its production has remained low due to limited understanding of the variability of soils for targeted nutrient management. Measures that improve the understanding of soils are instrumental to guide precision nutrient management in highly heterogeneous cropping systems. A study was conducted on a Ferralsol in Wakiso District in Uganda to assess the spatial variability of Soil Organic Carbon (SOC), Total Nitrogen (TN) and soil pH in a mono-cultured banana production. Thirty-six (36) soil samples were collected from an area measuring 120 m x 30 m and sampling was done systematically. The sampling design involved establishing grids of 10 m x 10 m where one composite soil sample was collected from each grid. Four plant samples were randomly collected from banana bunches on standing plants in the demarcated area. Laboratory soil data was geo-statistically analyzed using ordinary kriging interpolation and semi variograms. Results showed that p^H, SOC and TN had weak and moderate spatial dependences with nugget: sill ratios of 92.3, 91.7 and 68.3% for OM, TN and p^H, respectively. A section of soils (southern landscape) of the banana plantation was slightly more acidic than the Northern landscape. Generally, lower SOC values (1.53 -1.01%) were noticed in the southern landscape of the plantation, with the upper south eastern region having the least. The northern part had slightly higher organic matter levels (1.97 -1.62%), with the upper North West region having the highest values. Soil N levels varied the same way as organic matter. Lower N levels were observed in the southern part of the plantation, with the upper South East region having the least nitrogen. The properties also exhibited moderate variation with organic matter (CV=40.949% and total nitrogen CV=40.983%). Generally, selected soil properties in this plantation varied despite the soils being typically Ferralsols under the cropping and management regimes that were investigated. The high soil variability in a banana plantation reveals the need for precision application of inputs (spot application) within the soil fertility zones with low SOC, TN and acidic conditions. There is need to promote use of soil nutrient maps to guide farmers on the proper use of fertilizers under specific soil fertility zones.

INTRODUCTION

Soils are characterized by variation at multiple scales ranging from point measurements to global ones (Minai, 2015; Njoroge et al., 2017). This gives rise to what is basically referred to as spatial variability in soils which occurs when a soil parameter measured at different spatial locations exhibits values that differ across the locations. Soil properties exhibit variability as a result of dynamic interactions between natural environmental factors i.e. climate, parent material, vegetation and topography and those significant differences in the soil nutrients from areas with uniform geology are known to be related to landscape position (Ebanyat, 2009). Uzielli et al. (2006) points out that soils are naturally variable because of the way they are formed and the continuous proceses of the environment that alter them. In Sub-Saharan Africa

(SSA), soil fertility varies spatially and temporally from field to region scale and is influenced by both land use and soil management practices of the smallholder farmers (Tittonell et al., 2005, Hartemink, 2006, Ncube et al., 2009). A better understanding of spatial variation in soils has both practical and theoretical ramifications. Understanding spatial variation is key in making precise quantification of soil properties to influence management or planning processes (Garten et al., 2007; Rücker, 2005). Understanding variability of soil fertility, its distribution and the causes of the observed variability are important in addressing sustainable land use strategies (Jing-wei et al., 2011. Musinguzi et al., 2016, Ebanyat. 2009)). The precise quantification at different scales allows cost effective practices such as site-specific management or precision agriculture that would on the other hand help in resolving problems of pollution and land degradation (Uzielli et al., 2006). In order to tailor effective site-specific corrective land management, analysis of spatial variability of key soil quality parameters and the flow of nutrients in the system needs to be done.

In developing countries in SSA, effective use of fertilizer inputs is affected by soil variability (Musinguzi et al., 2016, Smaling and Braun, 1996). Knowledge of major drivers of variability of soil properties such as SOM, p^H and N has had limited research, especially in Banana production, a commonly grown crop in Uganda (Lekasi, 1997, Taulya, 2013). Efforts to improve nutrient use efficiency can be done through spatial nutrient variation analysis in specific fields to allow site specific soil fertility management. Knowledge about variability of soil properties within a banana plantation can assist in generating effective site-specific designs; this can help to reduce on the misuse of inputs (organic and inorganic fertilizers). Therefore, there is need for spatial variability analysis of soil properties for a more effective way to address soil fertility issues on a farm, particularly at plot level. The objective of this study was to assess spatial variability of organic carbon, total nitrogen and soil p^H in a Ferralsol under banana production.

MATERIALS AND METHODS

Study Area Description

This study was carried out at Makerere University Agricultural Research Institute, Kabanyolo (MUARIK) which is located in the Lake Victoria basin in Wakiso district, Kyadondo County, Central Uganda. It is located approximately 19kmsNorth east of Kampala along the Gayaza-Namulonge road at latitude 0º28ºN and longitude 30º37ºE (Figure 1). It has an elevation of between 1250 – 1320 meters above sea level (Yost and Eswaran, 1990). It receives a mean annual rainfall of 1100mm per annum, with a bimodal distribution in the months of March to June and short rains from September to December. Temperatures range between 21 and32ºC. The soils are predominantly Ferralitic, formed on residuum and colluviums enriched soil, with lateritic gravel being common features among them (Radwanski, 1960; Yost and Eswaran, 1990, Wortmann and Eledu, 1999).

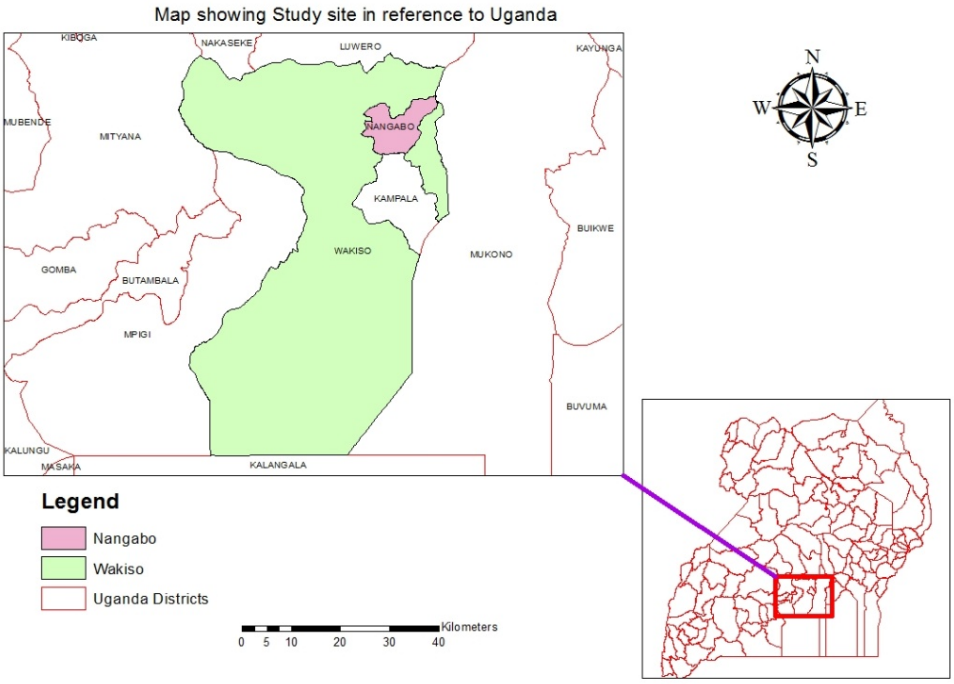


Figure 1. Map of Uganda showing location of the study area

Field Selection and Experimentation Process

The study was carried out on a Ferralsol in a banana plantation with an area of 2.2 hectares, a typical land size for most smallholder farmers in Uganda. The plantation was established in 2007 and had been under paddock for cattle for more than fifteen years. Thirty-six (36) soil samples were systematically collected from an area measuring 120m×30m. The sampling design involved establishing grids of 10mx10m where one composite sample was collected from each grid by picking four (4) sub samples at 5cm from the centre point of the grid. The sub-samples were mixed to form a composite sample and approximately 0.5kg of soil was packed from the composites. Sampling was done for topsoil at 0-20cm depth. Coordinates from the centres of each grid were obtained using a Global Positioning System (GPS).

Table 1. Grid sampling plan

	10m	10m	10m	10m	10m	10m	10m	10m	10m	10m	10m	10m	
A	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	10m
B	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	10m
C	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	10m

The samples were air-dried for three days, crushed and then analyzed for total nitrogen, total organic carbon and pH. Soil variability of selected chemical parameters in the banana plantation was investigated by first assessing the variability of the selected soil properties across the sampled part of the plantation by analysis of variance (ANOVA) which was used to investigate the significance of the variance of the soil properties. The ANOVA was generated by use of GENSTAT biostatistics software. Geo-statistics were applied to spatially characterize and interpolate soil parameters. The total variability was analyzed by descriptive statistics based on the dataset of 36 samples. The results of these statistics were compared with the critical threshold values of Okalebo et al. (2002). The selected soil chemical parameters were spatially analyzed using variography and interpolation techniques. Variography characterizes and models spatial variance of data using a semi-variogram. The semi-variogram determines the increase in variance between samples collected at increasing separation distances from one point to another. A semi-variogram was plotted to show how semi-variance changes as the distance between observations changes (Karl and Maurer, 2010). It measures the spatial dependence between two observations as a function of the distance between them. Semi-variograms are characterized by: (i) the nugget which is the "variability at distances smaller than the shortest distance between sampled points, including the measurement error". (ii) the sill, which is the "total observed variation of the variable" (iii) the range parameter, which is "the distance at which two observations could be considered independent" (Karl and Maurer, 2010) (Figure 2).

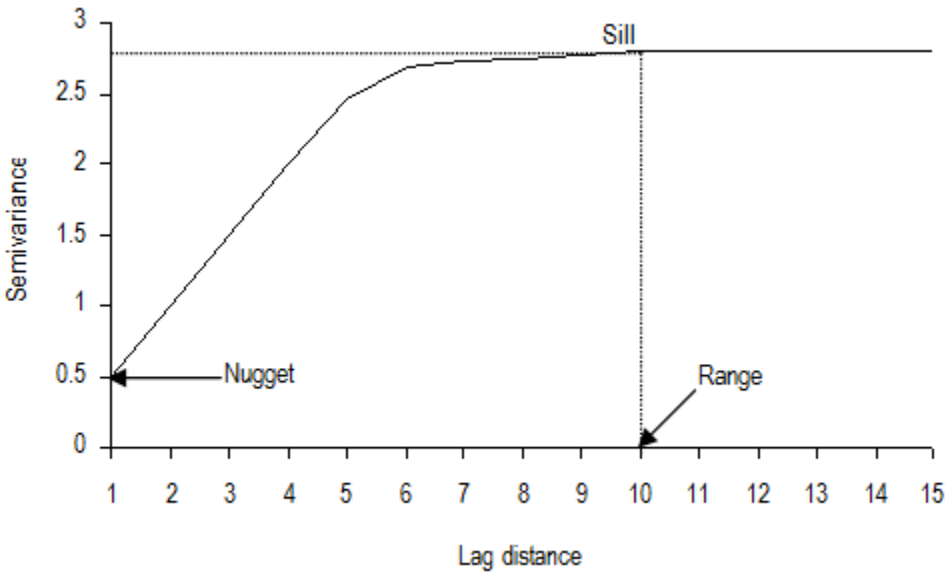


Figure 2. Features of an ideal semi-variogram

A stochastic simulation for interpolation was used to predict values in the field that had not been sampled. Ordinary Kriging was applied (Jafar et al., 2009, Zhang et al., 2011). Semi variograms and Kriging operations were computed using ARCMAP10.2 and in order to identify possible spatial structures of the different soil parameters, semi-variograms were calculated and the best model that described these spatial structures was identified. Kriged and measured values were mapped using ARCGIS ARCMAP10.2. Spatial dependence was defined using the nugget to sill ratio according to Cambardella et al. (1994) and the ranges of spatial variability were defined according to Lopez-Granadoz et al. (2002).

Table 2. Critical ranges for spatial dependence

Percentage (Nugget:Sill)	Inference
<25%	Strong spatial dependence
25-75%	Moderate dependence
>75%	Weak spatial dependence

The performance of each of the interpolation techniques in terms of accuracy of estimates was assessed by comparing the deviation of estimates from the measured data through the use of the cross-validation technique with ARCMAP 10.2.

RESULTS

Spatial Variability of Organic Carbon, Total Nitrogen and Soil pH

Overall, there was evidence of variability in the Banana production systems. Majority of the soil parameters analysed were moderately variable except soil pH. Soil organic matter registered a CV=40.949%, while total nitrogen had a CV=40.983%. However, soil pH exhibited very low variation with a CV of 2.849 % (Table 3).

Table 3. Descriptive statistics for the soil parameters

Parameter	Mean	Median	Min	Max	Critical values	SD	CV (%)
TN (%)	2.7	2.8	0.3	4.5	0.2	1.1	41
pH	6.2	6.2	5.8	6.5	5.2	0.2	3
OM (%)	1.5	1.6	0.2	2.6	3	0.6	41

Spatial Dependence of Selected Soil Properties

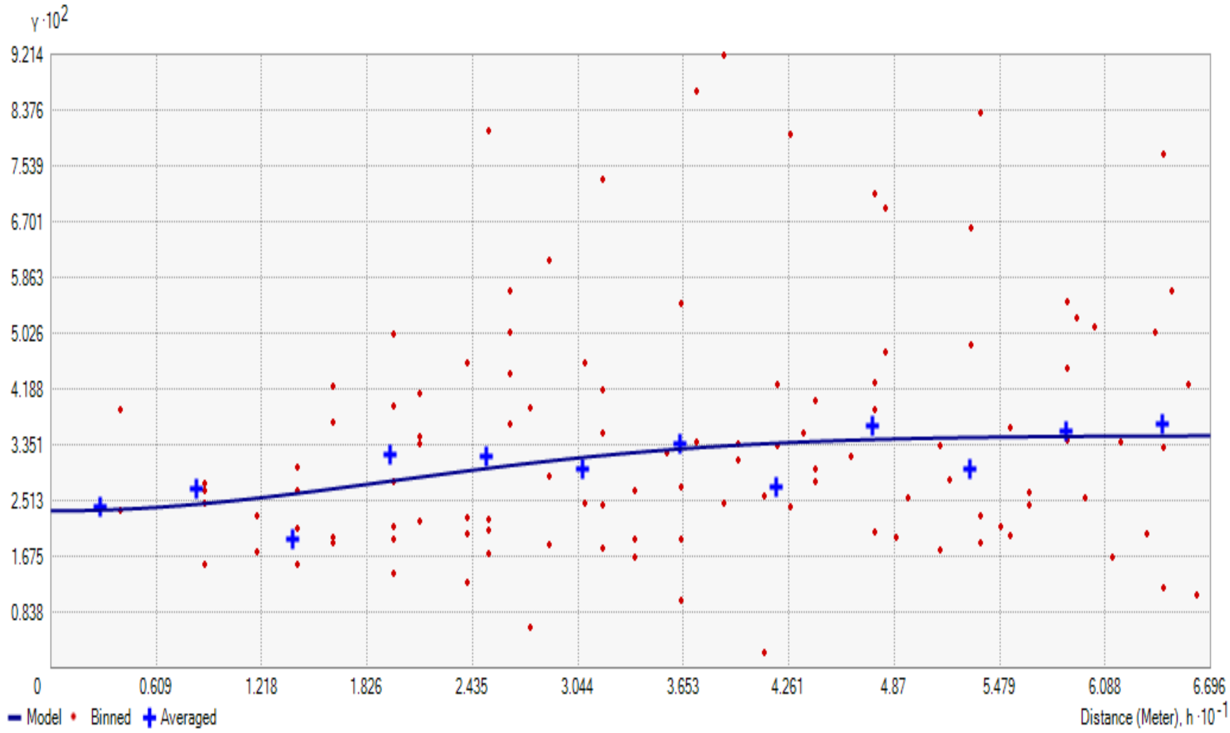
Analysis of individual soil properties for spatial dependence in the banana field confirmed spatial variability for all the parameters. The semi-variograms (Figures 3, 4 and 5) demonstrated weak spatial dependence with Nugget: Sill ratios of 0.923, 0.917 and 0.683 for OM, TN and pH, respectively and ranges of 29.0, 29.2 and 44.8m respectively (Table 4). Only soil pH showed some increase with change in distance, but soil organic matter and nitrogen had a different pattern.

Table 4. Variogram models for the parameters studied

Variable	**Model**	**Nugget**	**Sill**	**Partial Sill**	**Range (m)**	**Nugget: Sill**	**Nugget:Sill (%)**
OM (%)	Spherical	0.35	0.37	0.03	29.0	0.923	92.3
TN (%)	Spherical	0.34	0.37	0.03	29.2	0.917	91.7
p^{H}	Stable	0.02	0.034	0.01	44.8	0.683	68.3

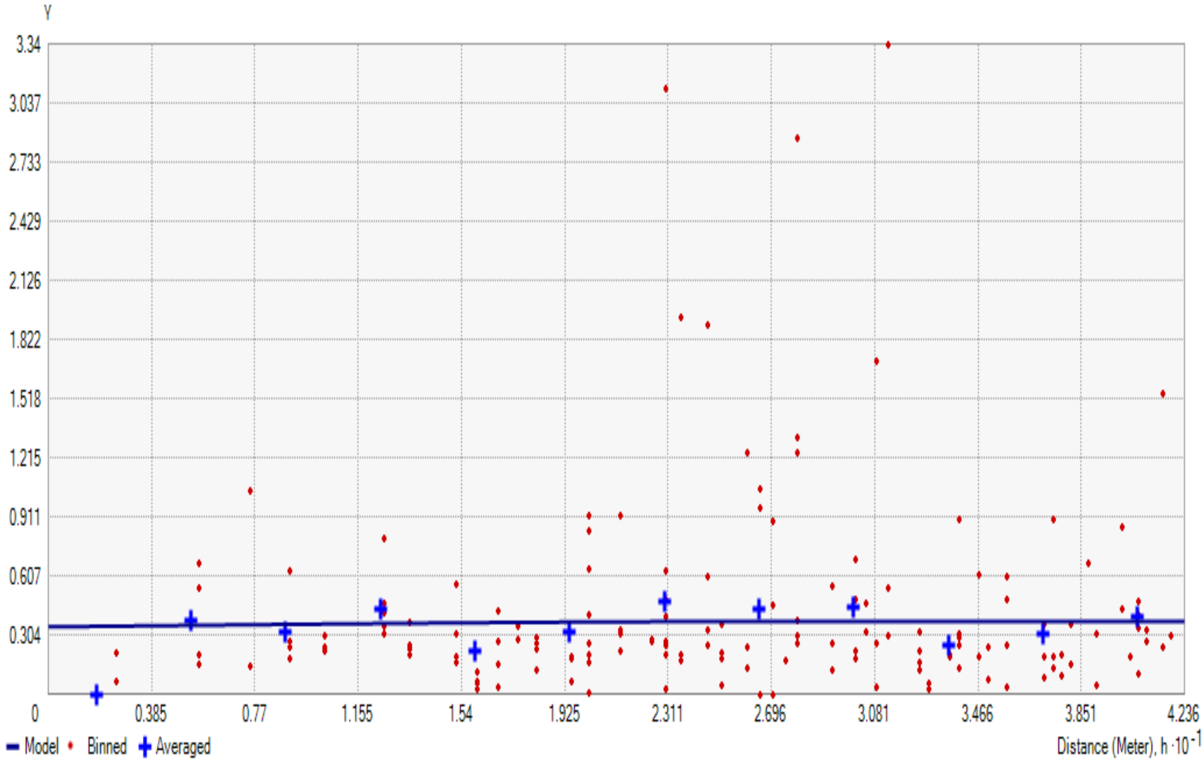
Sill=nugget+partial sill

****Critical values for the nugget:sill ratios are <25% -strong spatial dependence, 25-75%-moderate dependence, and >75% -weak spatial dependence according to Lopez-Granadoz et al. (2002).



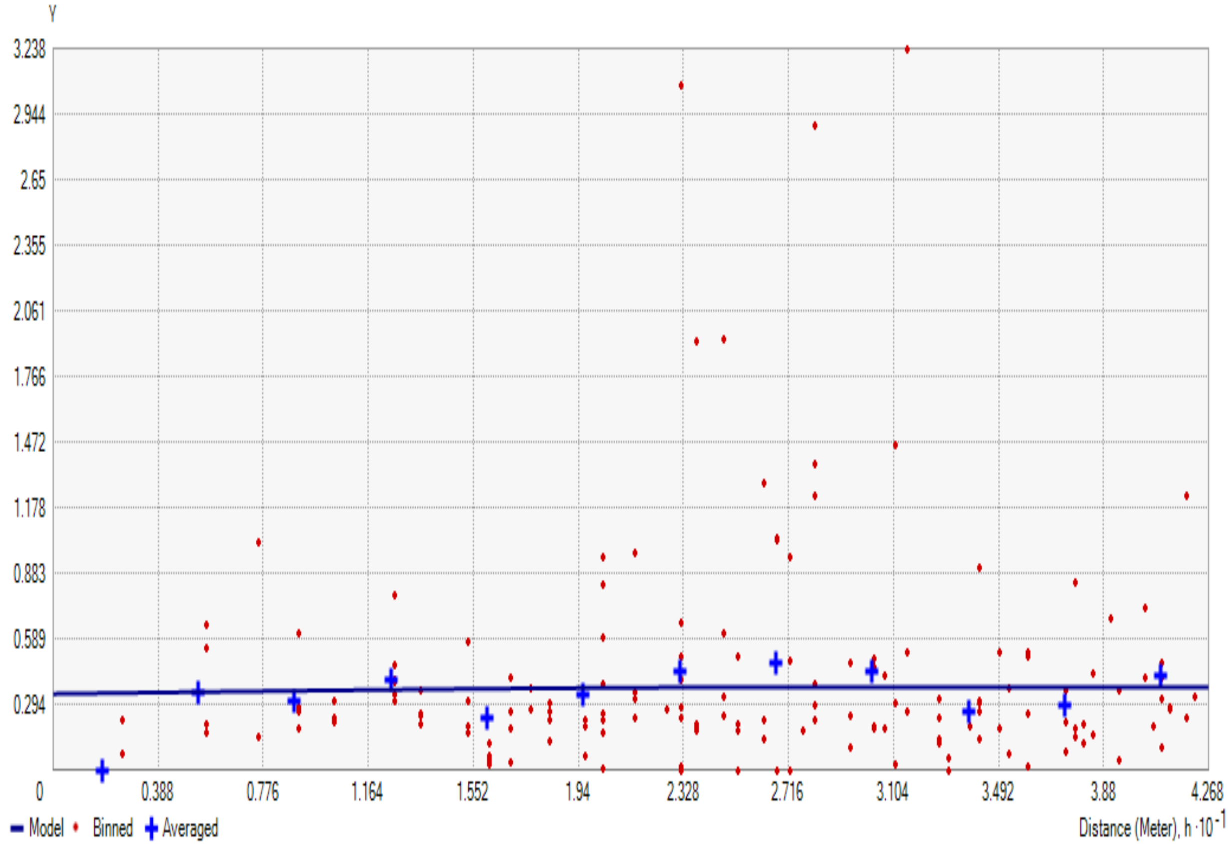
Model: 0.023424*Nugget+0.01086*stable (44.8062)

Figure 3. Semi-variogram for soil pH in the banana plantation



Model: 0.34547*Nugget+0.028817*Spherical (29.029)

Figure 4. Semi-variogram for soil organic matter in the banana plantation



Model: 0.34171*Nugget+0.030991*Spherical (29.169)

Figure 5. Semi-variogram for soil total Nitrogen in the banana plantation

Spatial Interpolation Patterns of Selected Soil Properties - Soil pH

From the Ordinary Kriging method of spatial interpolation for pH, the southern part of the banana plantation was slightly less acidic compared to the Northern one. The central region of the plantation was moderately acidic and the northern region of the banana plantation was slightly more acidic with the upper North east part as the most acidic (Figure 6). Generally, soils in this plantation are slightly acidic with p^H ranging between 6.02 and 6.34.

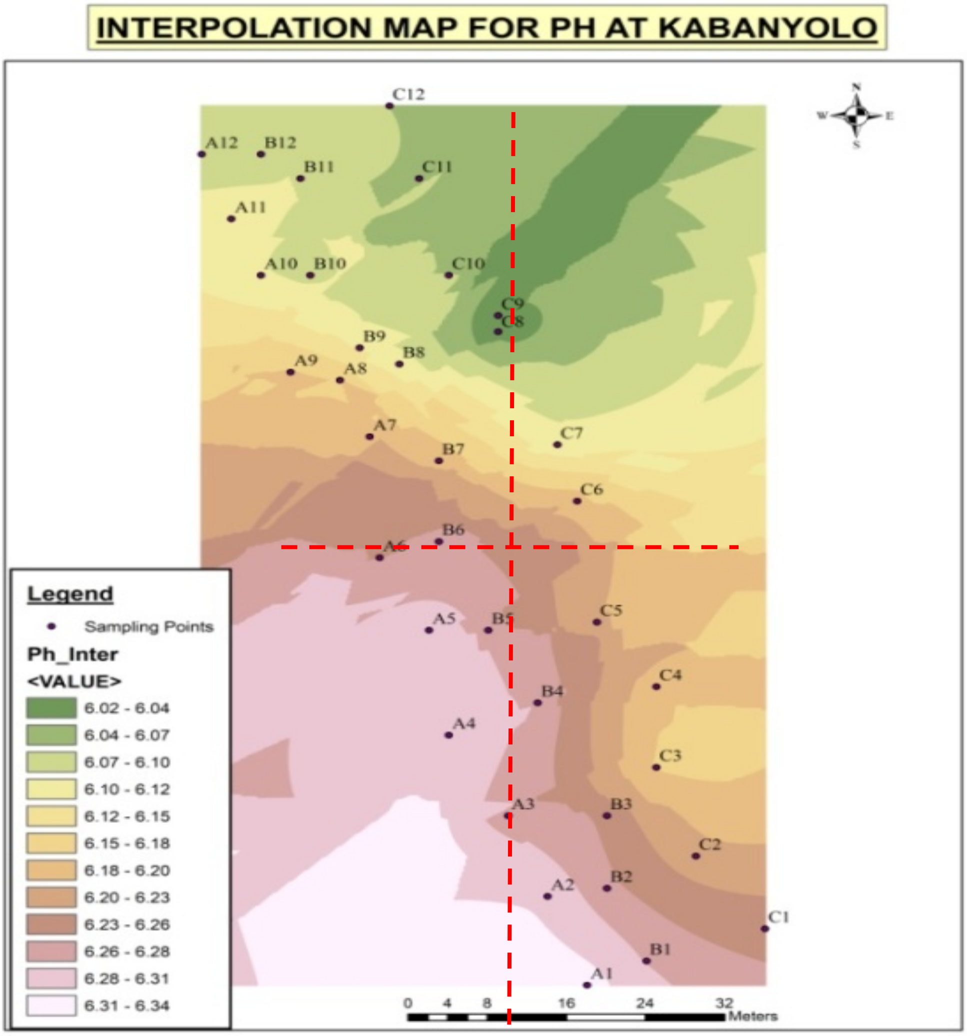


Figure 6. Spatial variation of soil pH in the banana plantation

Soil Organic Matter

From the ordinary kriging method of spatial interpolation for soil organic matter, lower SOM values were noticed in the southern part of the plantation, with the upper south eastern region having the least SOM. The northern part had higher organic matter levels with the upper North Western region having the highest values. The interpolated soil organic matter map shows that none of the regions in the banana plantation have soil organic matter levels greater than 3.0%, which is the critical threshold recommended by Okalebo et al. (2002) and Musinguzi et al. (2016).

The soil organic matter in the field typical of a Ferralsol ranges from 1.005 to 2.054%.

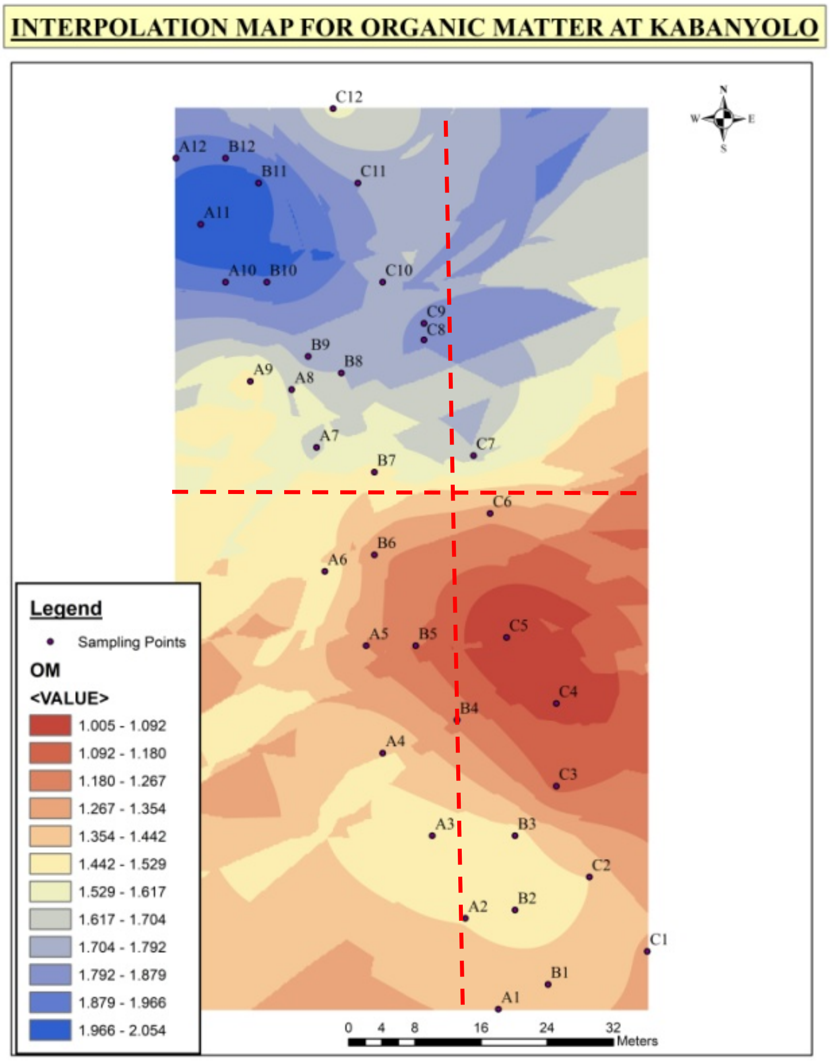


Figure 7. Spatial variation of soil organic matter in the banana plantation

Total Nitrogen

Ordinary kriging results showed high soil N levels in the northern part of the plantation with the upper North eastern region having the highest nitrogen levels. Lower N levels were obtained in the southern part of the plantation, with the upper South Eastern region having the least nitrogen.

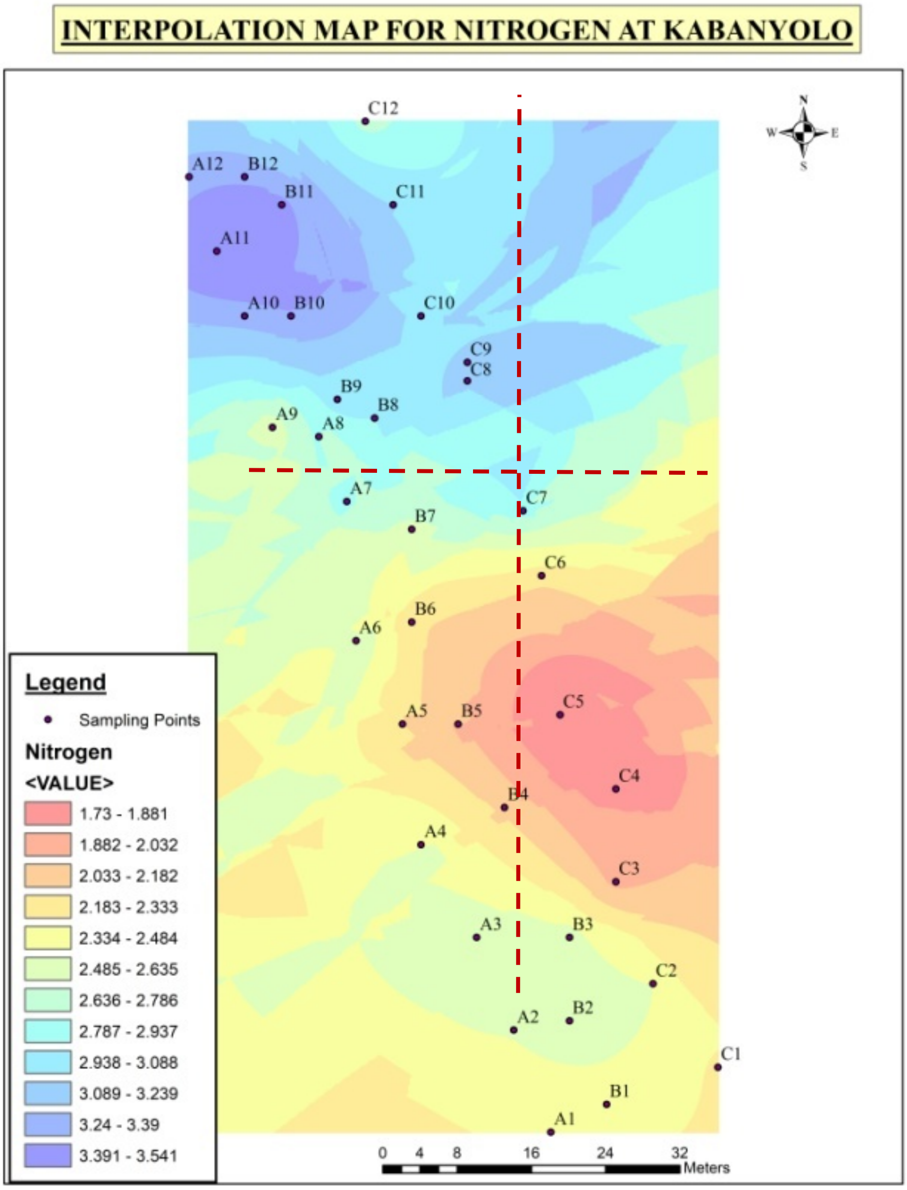


Figure 8. Spatial variation of soil total nitrogen in the banana plantation

DISCUSSION

Spatial Soil Variability in a Banana Farming System

Precision farming is an important soil and crop production practice that has not been applied in most tropical soils. The evaluation of one of the banana farms on one soil type (a Ferralsol) reveals the need for site specific mapping and precision for optimal nutrient management. Total N was too high since it had a maximum of 4.45% which is above the critical value of 0.2% (Okalebo, 2002) and a minimum of 0.28% which is slightly above the critical value. This N could be sourced from the mulching materials that were applied in the banana field. There was generally high nitrogen variability in the soil which could have been due to past land-use (night paddocking) which could have resulted in variation in cattle manures (cow dung and urine). Soil organic matter also resulted in high variation (CV=40.949%) and this was confirmed with the Ordinary kriging interpolation results that showed high soil N levels in the parts that had high soil organic matter.

Generally, Soil Organic Matter (SOM) was slightly below the critical level, with a maximum value of 2.58% which was below the critical value of 3% (Okalebo, 2002), with a minimum value of 0.16%. From the interpolation patterns, the lowest SOM values were noticed in the southern part of the banana plantation and the northern part had higher organic matter. This could have been due to the different mineralisation rates for the different materials used for mulching since a mixture of organic mulch materials was used. These mulches were placed at different densities in the entire plantation. So probably areas with quick-decaying mulch had higher OM and N than those with slow decaying mulch. Despite the high variations discussed above, TN and OM demonstrated weak spatial dependence (91.68 and 92.30%, respectively), implying that there is no clear pattern in their distribution in this plantation. This phenomenon is opposed to the usual strong spatial dependence of soil properties seen in homesteads where the amounts of OM and TN are seen to decrease as one moves away from the home (Tittonel et al., 2005). This could be due to nonuniform distribution of the mulches and also the previous land use could have resulted into non-uniform dung and urine distribution; this could have caused different decomposition rates of the mulches allocated at the different parts of the banana plantation. Therefore, this banana plantation requires spot application of inputs in order to address the non-uniform distribution pattern of TN and SOM

Soil pH showed non- significant variation (CV=2.8%) and a moderate spatial dependence in this banana plantation perhaps because the place was used for banana production without use of agricultural inputs and also it could have been due to uniformity in the parent material which determines soil p^H (Brady, 1990). Soil p^H values ranged from 5.8 to 6.5, which is within the critical range of 5.5-6.5; this could be because of reduced leaching of the bases in the topsoil layers. This implies that management can be easier since p^H distribution has a pattern (showed by the p^H interpolation map) and hence the plantation caretakers can apply lime in the affected areas.

CONCLUSIONS

Soil fertility variability is a major challenge to nutrient management efforts since the most critical parameters such as p^H, SOM and nitrogen are highly variable and with poor spatial dependency on a typically mono-cropped banana system under one soil type. The soil chemical properties demonstrated weak spatial dependence, suggesting the need for precision farming approaches and need for site specific management of nitrogen and organic matter. However, amendments for soil p^H are not troublesome since they exhibit less variability and are within the recommended range for agricultural production. There is need for more application of GIS-enabled field-based mapping to enable precision agricultural management of nutrients in tropical soils of Uganda. This would guide smallholder farms to optimize fertilizer use and minimize wastage that has been evident with generalized application of fertilizers with no regard to spatial variability.

REFERENCES

Cambardella CA, Moorman TB, Parkin TB, Karlen DL, Novak JM, Turco RF, Konopka AE. 1994. Field-scale variability of soil properties in central Iowa soils. Soil Science Society of America Journal 58:1501-1511.

Ebanyat P. 2009. A road to food? Efficacy of nutrient management options targeted to heterogeneous soilscapes in the Teso farming system, Uganda. PhD Thesis, Wageningen, the Netherlands, 218p.

Garten Jr CT, Kang S, Brice DJ, Schadt CW, Zhou J. 2007. Variability in soil properties at different spatial scales (1 m–1 km) in a deciduous forest ecosystem. Soil Biology and Biochemistry 39(10):2621-262

Hartemink AE. 2006. Assessing soil fertility decline in the tropics using soil chemical data. Advances in Agronomy 89:179-225.

Jing-wei J, Hui-chun Y, Yue-fei X, Chong-yang S, Yuan-fang H. 2011. Spatial and temporal patterns of soil fertility quality and analysis of related factors in urban-rural transition zone of Beijing, African Journal of Biotechnology 10(53):10948-10956.

Karl JW, Maurer BA. 2010. Spatial dependence of predictions from image segmentation: A variogram-based method to determine appropriate scales for producing land-management information. Ecological Informatics 5(3):194-202.

Lekasi JK. 1997. Biological management of soil fertility in banana-based cropping systems of Uganda, M.Sc. Thesis, Makerere University, Kampala, Uganda.

Lopez-Granados F, Jurado EM, Atenciano J, Garcia FA, De laorden MJ, Garcia T. 2002. Spatial variability of agriculutral soil parameters in south spain. Plant and Soil 246(1):97-105. doi:10.1023/A:10215684115380.

Minai, J. O. (2015). Assessing the Spatial Variability of Soils in Uganda. MSC Thesis. Purdue University.

Musinguzi P, Ebanyat P, Tenywa JS, Twaha A.B. Tenywa M.M, Mubiru D. 2016. Critical Soil Organic Carbon Range for Optimal Crop Response To Mineral Fertilizer Nitrogen on a Ferralsol. Experimental Agriculture 2016:1-19, Cambridge University Press, doi:10.1017/S0014479715000307.

Ncube B, Twomlow SJ, Dimes JP, van Wijk MT, Giller KE. 2009. Resource flows, crops and soil fertility management in smallholder farming systems in semi-arid Zimbabwe, Soil Use and Management 25(1):78-90.

Njoroge S, Schut AGT, Giller K.E, Zingore S. 2017. Strong spatial-temporal patterns in maize yield response to nutrient additions in African smallholder farms. Field Crops Res. 214:321-330.

Okalebo, JR, Gathua KW, Woomer PL. 2002. Laboratory methods of soil and plant analysis. A working manual. 2:29-68.

Radwanski SA. 1960. The soils and land use of Buganda. Memoirs of the Research Division. Series, 1.

Rücker GR. 2005. Ecology and development of spatial variability of soils on national and hillslopes scale in Uganda. ZEF . Ecology and Development Series, No. 24, 2005.

Smaling EMA, Braun AR. 1996. Soil fertility research in sub-Saharan Africa: new dimensions, new challenges. Communications in Soil Science and Plant Analysis 27:365-386.

Taulya G. 2013. East African highland bananas (Musa spp. AAA-EA) 'worry' more about potassium deficiency than drought stress. Field Crops Research 151:45-55.

Tittonell P, Vanlauwe B, Leffelaar PA, Rowe EC, Giller KE. 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya: Heterogeneity at region and farm scale, Agriculture, Ecosystems & Environment 110:149-165.

Uzielli M, Lacasse S, Nadim F, Phoon KK. 2006. Soil variability analysis for geotechnical practice. Characterization and engineering properties of natural soils 3:1653-1752.

Wortmann P, Eledu CS, 1999. Uganda`s agroecological zones: a guide for planners and policy makers [online]. Centro Internacional de Agricultura Tropical (CIAT), Kampala.

Yasrebi J, Saffari M, Fathi H, Karimian N, Moazallahi M, Gazni R. 2009. Evaluation and comparison of ordinary kriging and inverse distance weighting methods for prediction of spatial variability of some soil chemical parameters. Research Journal of Biological Sciences 4(1):93-102.

Yost D, Eswaran H. 1990. Major land resources areas of Uganda. Soil Management Services. Washington DC.: USA 218p.

Zhang C, Tang Y, Xiali X, Kiely G. 2011. Towards spatial geo-chmical modeling, use of geographically weighted regression for mapping Soil organic contents in Ireland. Applied geochemistry doi:10.1016/j.apgeochem.2011.04.01