Spatial Variability of Some Soil Chemical and Physical Properties of an Agricultural Landscape

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Abstract

Spatial variations for selected soil chemical and physical properties were examined for a landscape at Navrongo, Ghana. This was done in order to identify their spatial distribution to assist in designing land management that seeks to reduce the extremes of land productivity and support more uniform agricultural production. A landscape of 1.5 km^2 was sub divided in grids of 100 m × 100 m. Soil samples collected at two sampling depths (0–15 cm and 15–30 cm) both disturbed (chemical analysis) and undisturbed (physical analysis) were analysed for their chemical and physical properties. Mini pits (0–70 cm) were used to describe and identify the soil series at each vertex of the grids.Data were analysed both statistically and geo-statistically on the basis of the semi-variogram. Eutric Gleyic Regosol and Endoeutric-stagnic Plintosol were the dominant soil series used for cultivation. The fertility status of the soil is, however, poor and requires external inputs for optimal crop production. Variability within soil properties was high, a phenomenon that could be attributed to human influence. Spatial dependencies of soil properties were generally moderate with nugget: sill ratio (an indicator of spatial dependency) being between 26% and 75%. Spatial dependency was generally lower in the top-soil than in the sub-soil, a probable indication of human activities. Total nitrogen (N) distribution exhibited no spatial dependency, while organic carbon showed strong spatial dependency. Consequently, site-specific fertilization management for N is not possible at the sampling density used in this study. On the contrary, soil organic carbon and available phosphorus can be adequately managed for precision agriculture.

Introduction

The soils in the semi-arid regions of West Africa are highly weathered, well-drained and low in soil nutrients and organic matter (Zougmore, 2003). Increasing pressure on land has necessitated continuous cropping, which has exposed the soils to nutrient deficiencies especially N and P (Bationo *et al*., 2003). This has been aggravated by the negative nutrient balances of most cropping systems (Vlek *et al*., 1997). Annual bush fires are also detrimental to soil fertility, as these result in the reduction of soil organic matter and loss of other soil nutrients (Bagamsah, 2005). Consequently, increasing crop production on these soils is only possible with appropriate soil amendment and crop management practices. Small-scale farmers,

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who cultivate these lands, are often unable to afford soluble fertilizers and, instead, apply animal manure available from kraals.

Due to the bulkiness, weight and lack of technologies to apply manure uniformly to cultivated lands, it is commonly observed that manure application is restricted to fields near the settlements. The differential allocation of manure or other sources of nutrients creates a nutrient gradient across the cultivated lands. The resulting spatial variability of soil fertility poses great challenge to land management and reflects in variable yields over farmlands. Some earlier studies in Ghana show that the effect of variability of soil properties on crop performance could be detrimental, especially when the fields are patchy (Atsivor *et al*., 2001; Haefele & Wopereis, 2005). Without precision-agriculture technologies, which can adapt soil management to the location specific fertility status, it is conceivable that formulating recommendations for managing soils with highly variable properties, based on a few selected sites analysis, may lead to erroneous outcomes.

Apart from farmer-induced soil property variability, it is also known that soil variability may result from edaphic factors such as the parent material (soil forming rock types) and position of soil on the catena, among others (Obi & Udoh, 2011). To date, studies on soil property variability in general and, especially, the extent to which this variability can be spatially correlated are lacking in Ghana. It is hypothesized here that data on soil property variability would assist in designing land management that seeks to reduce the extremes of land productivity and support more uniform agricultural production. The objective of the study is to assess the variability of some selected soil properties from a 1.5 km^2 agricultural land, situated in the interior semi-arid region of northern Ghana, in Navrongo.

Materials and methods

Study area

The study was conducted in Navrongo (Upper East Region in the White Volta basin of Ghana), within the framework of the GLOWA Volta Project in 2005 (Braimah & Vlek, 2004). The study area falls within the Sudan savanna agro-ecological zone, with its characteristic vegetation (grass-land with shrubs and scattered tress) and weather attributes. The study area is characterized by sandy soils, mainly Endo-EutricRegosol. The rainfall pattern of the area is uni-modal with rains occurring between May and October with a peak in July. The onset of rains is, however, very varied.

Data collection

A landscape of 1.5 km^2 was divided into square grids of 100 m × 100 m each by running parallel traverses each of a kilometer in length perpendicular to a baseline of 1.5 km. At the vertex of each of the grid cells, both disturbed and undisturbed soil samples were collected at two depths (0–15 cm and 15–30 cm). The soils were analyzed for their chemical (total N, available P, available K, *p*H, cation exchange capacity (CEC), soil organic carbon (SOC), and physical (texture, bulk density, hydraulic conductivity) properties. Details of the various analyses are described in Kpongor (2007).

Furthermore, mini-pits were dug at each vertices for soil classification using the procedures outlined by Agyare (2004). The mini-pits were 70 cm in depth and 30 cm in diameter. The profiles were described to support the mapping of the spatial distribution of the soils within the area. From each mini-pit profile, the soil diagnostic horizons and their corresponding boundaries, texture, structure, colour, mottles, concretional fractions and root density (or abundance) were determined. The land-use history (homestead or bush-farm) and position on the topography were also recorded.

Data analysis

The data obtained were subjected to statistical analysis, ranging from simple descriptive statistics to more detailed geo-statistics. Soil properties were tested for normality, and those not normally distributed were transformed to normal or near-normal. The Kolmogorov-Smirnov test was then applied, resulting in the use of means and standard deviation to characterise their distribution. Further, the relationship between soil parameters was explored using spearman correlation coefficient. To acheive this, data for the different soil properties were standardised using the z-score (Sokal & Rohlf, 1995) as in Equation 1.

$$Xt = \frac{Xi - X}{S} \qquad \text{Equation 1}$$

where Xt is the standardized value of the sample, Xi is the sample, X is the mean and S is the standard deviation.

In the particular case of assessing the variability of the soil properties in space, the semi-variogram (Isaaks & Srivastava, 1989; Journel & Huijbregts, 1978) as in Equation 2 was applied:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=i}^{N(h)} \left[z(x_i + h) - z(x_i)\right]^2 \qquad \text{Equation 2}$$

where $\gamma(h)$ is the experimental semi-variogram value at a distance interval h, $N(h)$ is number of pairs with a distance interval of h, $z(x_i)$, $z(x_i+h)$ are sample values at two points separated by the distance h. A lag distance 20 m was used for the semi variogram analysis. A semi variogram has three main statistics: nugget, sill and range. The nugget, which is also known as a stochastic variance, is a measure of the variance due to sampling, and measurement errors or other unexplained sources of variation. The sill is the variance of sampled populations at large separation distances if data has no trend. The range is described as the average maximum distance at which two samples are spatially correlated. The parameters of the best-fit empirical model were used to interpolate the respective point soil parameter values in space using ordinary kriging technique. It has the additional advantage of minimizing the influence of outliers (Odeh *et al.*, 1994; Triantafilis *et al.*, 2001).

Results

Description of soil properties

Summary of the statistics for the soil properties is presented in Table 1. Soil properties varied strongly between sampling depths. Low coefficients of variation were recorded for bulk density and *p*H (5% and 13%), moderately varied (CV of between 17% and 42%) in sand and silt content, respectively, and strongly variable (> 50%) in SOC, total N, available P and K, CEC and clay content in the top soil. The soils in the landscape are mainly sandy loams with a mean sand content of 70.9% and 64.9% in the top-soil and sub-soils, respectively (Table 1). The clay content is also low with a mean of 6.9% in the top-soil and 11.1% in the sub-soil. Due to the sandy nature of the soils and their low organic carbon content, water

TABLE 1

Descriptive statistics of soil parameters taken at two depths at grid scale (100 m × 100 m)

	Topsoil (0 – 15 cm)				*Subsoil (15 – 30 cm)*			
Parameter	*Mean*	*Max.*	*Min.*	*CV (%)*	*Mean*	*Max.*	*Min.*	*CV*
*p*H	5.46	8.12	4.48	10	5.46	8.38	4.59	13
SOC (mg g^{-1})	4.0	11.6	0.7	56	2.70	11.3	0.70	56
Nitrogen (mg g^{-1})	0.61	11.04	0.11	85	0.024	0.12	0.01	61
$P_{available}$ (mg kg^{-1})	6.32	44.22	0.93	89	5.9	31.4	1.1	65
$K_{available}$ (mg kg^{-1})	73.61	230.41	8.22	52	71.5	164.6	29.1	35
CEC (cmol(+) kg^{-1}	4.94	21.36	1.51	60	6.30	35.19	2.05	67
Sand (%)	70.9	91.7	18.1	17	64.9	92.4	23.0	20
Silt (%)	24.3	63.6	3.5	36	24.0	63.0	0.2	42
Clay (%)	6.9	32.0	1.2	58	11.1	34.0	0.9	55
BD (g cm^{-3})	1.63	1.78	1.40	5	1.67	1.93	1.36	5
Ks (cm day^{-1})	23	363	0.3	72	25	487	0.03	96

infiltration is high and water holding capacity is low, as indicated by the high (23 and 25 cm day^{-1} for the top and sub-soils, respectively) saturated hydraulic conductivity (Table 1).

SOC content ranged from 0.7 to 11.6 mg g^{-1}, with a mean of 4.0 mg g^{-1} in the top-soil and in the sub-soil from 11.3 to 0.7 mg g^{-1}, with a mean of 2.7 mg g^{-1}. Total soil N content is also very low and well below the standard value of 2.0 mg g^{-1}, moderately acidic with a mean *p*H of 5.5. Mean available P of the soils was 6.3 mg kg^{-1} in the top-soil and 5.9 mg kg^{-1} in the sub-soil. Mean available K was 73.6 mg kg^{-1} in the top-soil and 71.5 mg kg^{-1} in the sub-soil. The mean CEC values of 4.9 and 6.3 cmol (+) kg^{-1} in the top- and sub-soil, respectively, are low for crop growth. These low values are characteristic of highly weathered soils with only single-layered clay minerals (kaolinites) (Nye & Stephen, 1962; Dowuona *et al.*, 1998). All soil chemical variables had higher mean values in the top-soil than in the sub-soil, except for soil CEC. The higher CEC in the sub-soil may be partly attributed to the higher clay content.

Relationship between soil properties

Soil CEC correlated significantly with most of the soil parameters at both sampling depths (Table 2ab). It, however, correlated negatively with sand content and bulk density in the top soil. There were no significant correlation between available P and any of the other chemical properties at both sampling depths, most probably due to the generally low available P content in the soils sampled. Soil *p*H correlated positively with most of the other soil chemical parameters except available K (Tables 2ab). As expected, soil organic carbon was negatively correlated with sand content and bulk density and very highly positively correlated (96% in the sub soil) with total soil N. The latter is not a new finding but has already been reported by Nye & Stephen (1962), who stated that soil carbon is an important reserve for soil N. The correlation between organic carbon and N was higher in the sub soil than in the top soil.

TABLE 2a

Correlation matrix of soil properties in the top-soils (0 – 15 cm)

Soil parameter	p*H*	*SOC* *(mg g^{-1})*	*Total N* *(mg g^{-1})*	*P$_{available}$* *(mg kg^{-1})*	*K$_{available}$* *(mg kg^{-1})*	*CEC* *(Cmol(+)kg^{-1})*	*Silt* *(%)*	*Sand* *(%)*	*Clay* *(%)*	*BD* *(g cm^{-3})*	*Ks* *(cm day^{-1})*
*p*H	1										
SOC (mgg^{-1})	0.33**										
N (mgg^{-1})	0.17*	0.52**									
P$_{available}$(mg g^{-1})	0.44**	0.13	0.09								
K$_{available}$(mg g^{-1})	0.35**	0.33**	0.15*	0.06							
CEC (Cmol(+)kg^{-1})	0.30**	0.41**	0.24**	0.16*	0.13						
Silt (%)	0.09	0.39**	0.09	-0.05	0.03	0.32**					
Sand (%)	-0.13	-0.48**	-0.14	0.02	-0.05	-0.36**	-0.95**				
Clay (%)	0.17*	0.46**	0.17*	0.05	0.08	0.28**	0.40**	-0.67**			
BD (g cm^{-3})	-0.15*	-0.38**	-0.20**	-0.29**	-0.08	-0.17*	-0.09	-0.15*	0.19*		
Ks (cm day^{-1})	0.04	0.09	-0.08	-0.17	-0.13	-0.03	0.11	-0.13	-0.05	-0.05	1

N = 176; significance level: * $P < 0.05$, ** $P < 0.01$, SOC – soil organic carbon, BD – Bulk density, CEC – cation exchange capacity (cmol (+)kg^{-1}, Ks – saturated hydraulic conductivity.

TABLE 2b

Correlation matrix of soil properties in the sub-soils (15– 30 cm).

Soil parameter	p*H*	*SOC* *(mg g^{-1})*	*Total N* *(mg g^{-1})*	*P$_{available}$* *(mg kg^{-1})*	*K$_{available}$* *(mg kg^{-1})*	*CEC* *(Cmol(+)kg^{-1})*	*Silt* *(%)*	*Sand* *(%)*	*Clay* *(%)*	*BD* *(g cm^{-3})*	*Ks* *(cm day^{-1})*
*p*H	1										
SOC (mg g^{-1})	0.04	1									
N (mg g^{-1})	0.02	0.96**	1								
P$_{available}$(mg kg^{-1})	0.01	0.47**	0.44**	1							
K$_{available}$(mg kg^{-1})	0.33**	0.12	0.11	0.02	1						
CEC (Cmol(+)kg^{-1})	0.34**	0.15**	0.14	0.01	0.34**	1					
Silt (%)	0.28**	0.23**	0.19*	-0.09	0.30*	0.50**	1				
Sand (%)	-0.29*	-0.21**	-0.18*	0.12	-0.32**	-0.49**	-0.90**	1			
Clay (%)	0.17*	0.07	0.09	-0.13	0.21**	0.26**	0.34**	-0.71**	1		
BD (gcm^{-3})	-0.15*	-0.11	-0.07	-0.07	-0.14	-0.05	-0.03	0.20**	0.16*	1	
Ks (cmday^{-1})	-0.17*	0.11	0.11	-0.02	0.33**	-0.14	0.02	0.33**	-0.07	-0.20**	1

N = 176; significance level: * $P < 0.05$, ** $P < 0.01$ SOC – Soil organic carbon, BD – Bulk density, CEC – cation exchange capacity (cmol (+)kg^{-1}, Ks – saturated hydraulic conductivity.

Spatial distribution and variations of soil series and properties

The two main soil types of importance in this study were the E-G Regosol and E-S Plinthosol covering 60.2% and 18.2% of the area, respectively (Fig. 1). Eutric Plinthosols covered 11.9%, most of which usually remained uncultivated due to its coarse soil texture and high concretional fractions (iron and magnesium oxides). Eutric Gleysol and Gleyic Arenosol, both lowland soils, covered merely 4.5% and 5.1%, respectively. They are used mainly for rice and dry season irrigated vegetable production.

Variations in the soil attributes for the various soil series are presented in Tables 3ab. Mean soil organic carbon content of the soils varied from 2.6 mg g^{-1} (Endoeutric-stagnic Plintosol) to 4.9 mg g^{-1} (Eutric Gleysol) in the top 15 cm of the soil profile, and 2.1 mg g^{-1} (Gleyic Arenosol) to 4.1 mg g^{-1} (Eutric Plintosol) in the subsoil (15–30 cm). These values were below 20 mg g^{-1}, the threshold for reasonable crop production as set by Landon (1991). Soil *p*H was the least variable soil chemical property with a coefficient of variation (CV) less than 15% (6–14% in the topsoil and 4–14% in the subsoil). All other chemical properties, in both the top and subsoil, were generally highly variable with CVs of more than 35%.

Bulk density showed the lowest CV with a range of 2–6% in the topsoil and 4– 6% in the subsoil for the different soils. Mean bulk density of the soils ranged from 1.52 to 1.65 g cm^{-3} and 1.57 to 1.69 g cm^{-3} in the top and sub soils, respectively. Variability in soil physical properties increased in the order of bulk density < sand < silt < clay. Percentage clay content was the most variable (CV of 49–80% in the topsoil and 36 – 68 % in the subsoil) physical property with mean values of 5–11% and 6–13% in the topsoil and subsoil, respectively.

Spatial variation in soil properties

Geostatistical analysis revealed different spatial distribution models and spatial dependence levels for soil parameters at both sampling depths. Soil available K, CEC, *p*H and sand in the topsoil were best fitted with variogram functions that did not sill at distances considered for the study (Table 4), thus, exhibiting a trend pattern. The remaining soil parameters were fitted with Gaussian, exponential and spherical models. Total N in the topsoil was best fitted with a spherical model, while available soil P (Fig. 3ab), SOC, silt, clay, bulk density and Ks were fitted best with an exponential empirical model. Most of the soil properties were considered to be moderately spatially dependent (ratio of nugget to sill were between 26% and 75%). Total N was non-spatially correlated in the top soil and weakly correlated in the sub soil. SOC (Fig. 2ab) and Ks were strongly spatially dependent (Table 4). Generally, soil properties showed higher spatial dependency in the subsoil, implying other factors such as land use and management activities could be reasons for the lower spatial dependency in the topsoil.

The nugget, which is an indication of micro-variability, was highest for available K in the topsoil. Except for available K, sand, silt and clay content (Fig. 4ab) showed the highest micro-variability, a phenomenon that might be partially attributed to measurement error. The exceptionally high nugget values for available K contradict results from other studies in Spain (Pierce & Nowak, 1999; Lopez-Granados *et al.*, 2002).

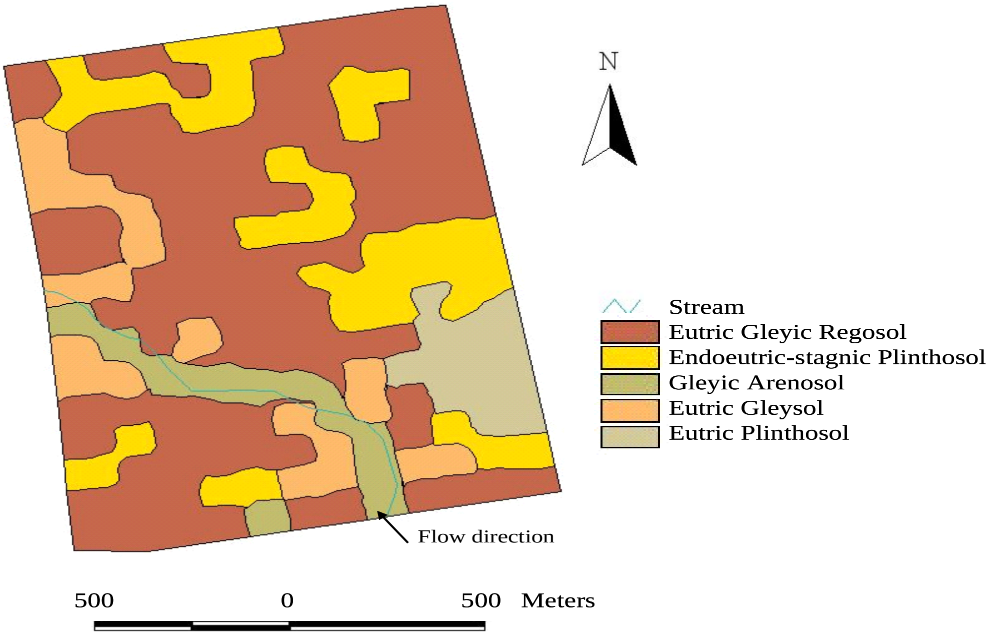

Fig. 1 Spatial distribution of soils in study area in Navrongo, Ghana

Discussion

The low organic carbon content is probably the result of the high temperatures resulting in rapid organic matter decomposition in combination with a generally low input of organic material. The annual burning of vegetation throughout the area further reduces the available above-ground organic matter that could potentially contribute to soil organic carbon. The mean organic carbon content of the topsoils of 4.0 mg g^{-1} is very low and well below the recommended level of 17.0 mg g^{-1} necessary for adequate crop production (Okalebo *et al.*,1992). Though Eutric Gleysol was the best soil series for cultivation in terms of soil parameters desirable for adequate crop production, its low internal drainage (prone to water logging) does not favour upland crop cultivation. More so, it occupied merely about 5% of the total landscape, and is, hence, not important for this study.

The dominant soil types E-G Regosol and E-S Plinthosol are used for the cultivation of sorghum and other crops in spite of their low fertility status. This poor soil fertility is further worsened by the prolonged exposure to wind erosion (surface are left bare of vegetation) in the dry season and to high run-off at the onset of the rains. Considering the sandy nature of these soils, soil management practices that positively impact on SOC content and the use of inorganic fertilizers need to be encouraged to ensure adequate plant nutrition and sustainable food production.

Assessment of variability in soil properties in agricultural soils are necessary to provide appropriate knowledge and for quantifying the degree of variation which is critical for effective plant nutritional management. The

TABLE 3a

Chemical properties of soil series at two sampling depths

Soil series	*N*	*SOC* ($mg\ g^{-1}$) *Mean (CV)*	p*H* *Mean (CV)*	*Nitrogen* ($mg\ g^{-1}$) *Mean (CV)*	$P_{available}$ ($mg\ kg^{-1}$) *Mean (CV)*	$K_{available}$ ($mg\ kg^{-1}$) *Mean (CV)*	*CEC* ($cmol(+)kg^{-1}$) *Mean (CV)*
			0 – 15 cm				
Pu (EutricGleyicRegosol)	106	4.3 (51.85)	5.43 (10)	0.72 (244.76)	6.19(84.9)	76.90 (50.26)	5.03 (63.26)
Tenchera (Endoeutric-stagnicPlintosol)	32	2.6 (45.91)	5.26 (9)	0.23 (57.77)	4.94 (61.45)	71.07 (58.15)	3.41 (44.78)
Kupela (EutricGleysol)	21	4.9 (58.66)	5.72 (13)	0.47 (57.11)	6.65 (69.02)	77.19 (51.94)	6.87 (46.65)
Brenyasi (GleyicArenosol)	8	4.2 (50.94)	5.78 (6)	0.39 (44.59)	7.95 (63.70)	65.21 (20.63)	5.20 (34.13)
Puga (EutricPlintosols)	9	3.1 (45.42)	5.57 (14)	0.27 (45.69)	9.43 (143.17)	43.336 (72.70)	4.5 (40.11)
15 – 30 cm							
Pu (EutricGleyicRegosol)	106	2.7 (56.23)	5.47 (12)	0.24 (60.85)	4.62 (34.15)	71.73 (37.69)	6.14 (74.31)
Tenchera (Endoeutric-stagnicPlintosol)	32	2.3 (40.47)	5.03 (5)	0.23 (48.74)	5.61 (85.17)	148.11 (36.33)	4.73 (55.57)
Kupela (EutricGleysol)	21	3.0 (39.86)	5.91 (14)	0.26 (37.13)	4.38 (28.21)	82.44 (27.9)	9.08 (44.31)
Brenyasi (GleyicArenosol)	8	2.1 (52.80)	6.09 (14)	0.18 (59.43)	5.42 (75.92)	74.26 (28.76)	8.53 (46.35)
Puga (EutricPlintosols)	9	4.1 (86.98)	5.19(4)	0.37 (89.37)	8.33 (103.99)	66.56 (14.42)	5.24 (26.59)

CV = Coefficient of variation, SOC : soil organic carbon, CEC = cation exchange capacity

TABLE 3b

Physical properties of the different soil types at two sampling depths

Soil series	*N*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*Bulk density*	*Ks (cm day^{-1})*
		Mean (CV)	*Mean (CV)*	*Mean (CV)*	*(g cm^{-3})*	*Mean (CV)*
Mean (CV)						
Pu (EutricGleyicRegosol)	106	69.69 (12.85)	23.72 (31.34)	6.59 (48.95)	1.64 (4.51)	19.45 (216.11)
Tenchera (Endoeutric-stagnicPlintosol)	32	75.09 (8.81)	19.35 (31.74)	5.55 (49.23)	1.65 (3.30)	17.81 (101.49)
Kupela (EutricGleysol)	21	58.16 (25.16)	33.21 (38.40)	8.64 (61.63)	1.62 (5.7)	12.49 (146)
Brenyasi (GleyicArenosol)	8	64.69 (31.52)	24.46 (52.11)	10.85 (79.74)	1.52 (5.50)	87.58 (138.69)
Puga (EutricPlintosols)	9	66.14 (28.75)	26.48 (55.54)	5.38 (60.02)	1.65 (2.18)	80.81 (26.83)
15 – 30 cm						
Pu (EutricGleyicRegosol)	106	64.48 (20.44)	40.13 (22.99)	12.54 (50.26)	1.68 (4.42)	21.56 (324.97)
Tenchera (Endoeutric-stagnicPlintosol)	32	71.03 (11.86)	20.91 (29.97)	8.06 (68.29)	1.69 (4.51)	18.15 (111.21)
Kupela (EutricGleyso)l	21	52.43 (29.59)	35.86 (36.32)	11.71 (46.07)	1.66 (5.44)	38.21 (338.34)
Brenyasi (GleyicArenosol)	8	75.03 (18.74)	18.28 (60.91)	6.7 (54.97)	1.57 (5.79)	87.67 (138.86)
Puga (EutricPlintosols)	9	67.72 (5.90)	24.90 (12.97)	5.88 (35.88)	1.69 (4.35)	26.83 (91.23)

(CV): Coefficient of variation in parenthesis

Ks : Saturated hydraulic conductivity.

Soil Organic Carbon (mg g^{-1}) –Top soil (a)

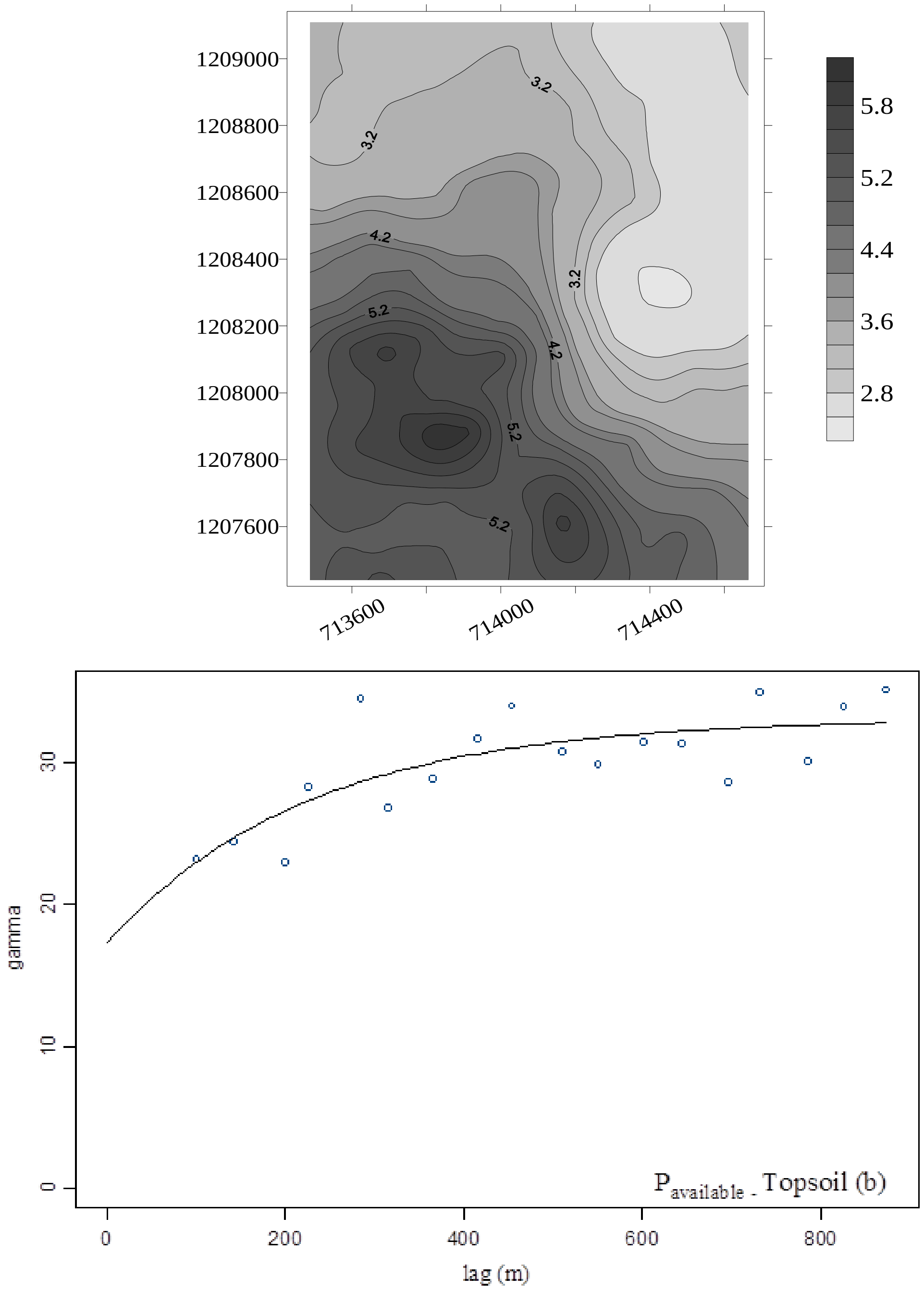

Fig. 2. Map of estimated soil organic carbon distribution (a) in the top soil, and modelled semi-variogram (b) of soil organic carbon (SOC)

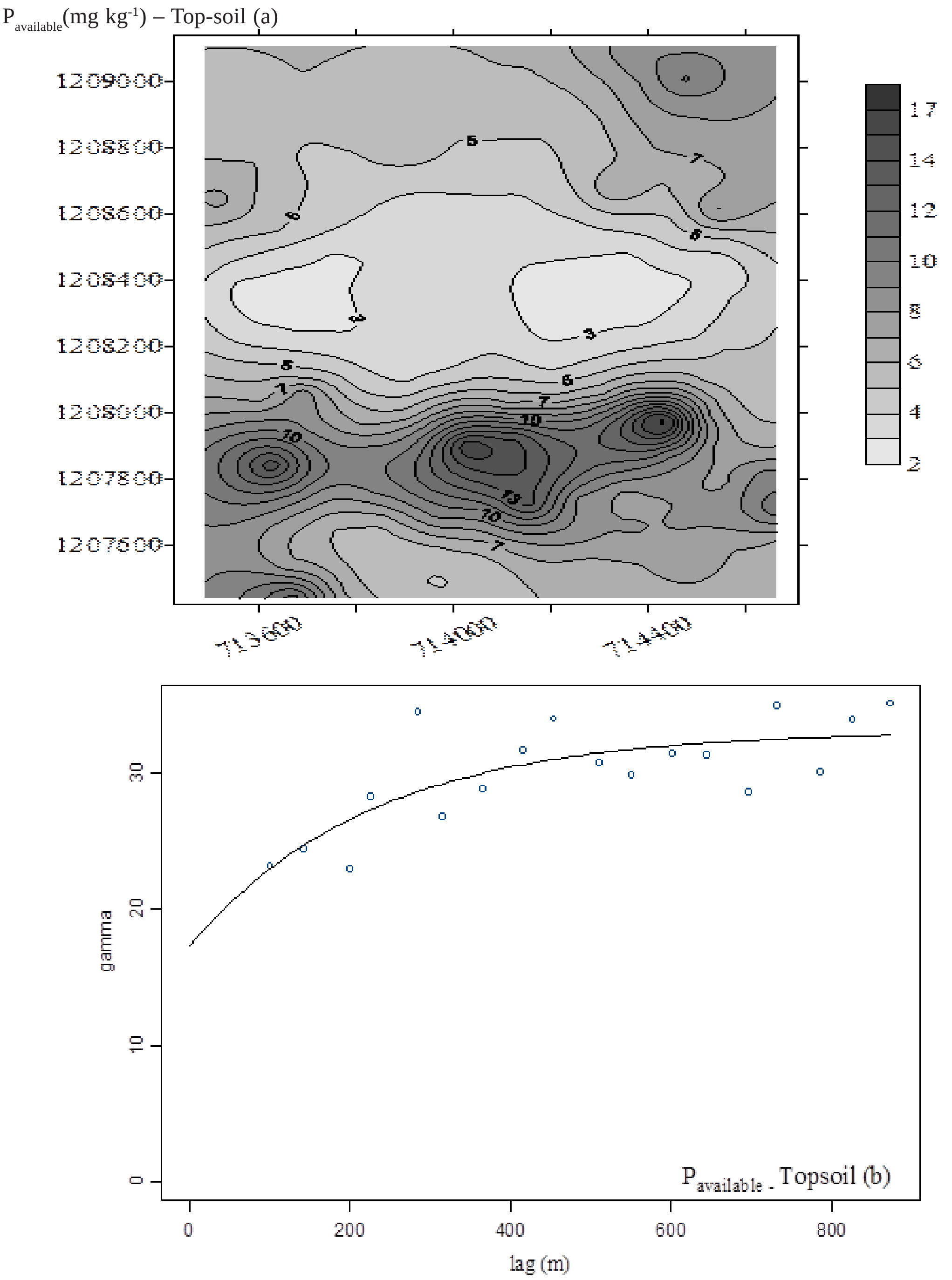

Fig. 3. Map of estimated available P distribution (a) in the top soil, and modelled semi-variogram (b) of available P

TABLE 4.

Modelled semi-variogram parameter models for top and sub soils of the selected landscape

Parameter	*Function*	*Range (m)*	*Sill(m)*	*Nugget*	*Slope*
Top soil					
SOC	Exponential	712	6.40	3.62 (57)	–
N	Spherical	436	1.2E-2	1.2E-2 (100)	–
$P_{available}$	Exponential	225	33.17	17.28 (52)	–
$K_{available}$	Linear	–	–	1480	96.89
CEC	Linear	–	–	6.23	4.5E-3
pH	Linear	–	–	0.29	4.5E-5
Sand	Linear	–	–	83.01	8.4E-2
Silt	Gaussian	774	117.0	63.00 (54)	–
Clay	Gaussian	688.9	18.34	13.73 (75)	–
BD	Exponential	1.08E+3	7.63E-3	4.03E-3 (52)	–
Ks	Gaussian	274.49	32.24	22.00 (68)	–
Sub soil					
SOC	Exponential	2.24E+6	3.61E+2	2.15E-2 (0)	–
N	Spherical	486	2.07E-4	1.97E-4 (95)	–
$P_{available}$	Exponential	1.29E+6	11.70	8.07 (69)	–
$K_{available}$	Spherical	706	6.73E+02	459.6 (68)	–
CEC	Spherical	664	20.5	11.19 (55)	–
pH	Exponential	354	5.6E-01	2.62E-1 (47)	–
Sand	Spherical	810	2.17E+02	91.09 (42)	–
Silt	Spherical	1.28E+3	1.39E+02	52.94 (38)	–
Clay	Spherical	483.46	4.17E+01	26.20 (63)	–
BD	Exponential	216.41	7.22E-3	3.22E-3 (45)	–
Ks	Gaussian	2.7 E-4	6.2 E+3	8.65E-3 (0)	–

prospect for precision management of soil properties generally increases as the degree of spatial dependences increases.

Considerable variations observed within the various soils in this study pose a challenge to the use of only soil mapping units as homogeneous zones for managing nutrient application especially in precision farming.

SOC, total N, available P, bulk density and hydraulic conductivity had same spatial distribution model characterizing their distribution at both depths. Precision management of these parameters will be complex because the parameters varied between depth. Most of the soil properties exhibited a moderate nugget to sill ratios implying spatial dependencies are generally moderate. Nitrogen, which is known to be the most yield limiting soil property was, however, spatially uncorrelated in the top soil and weakly correlated in the sub soil, hence, cannot be easily managed using precision agriculture techniques. This implies the chosen sampling distance of 100 m by 100 m did not characterise the spatial variation of soil total N, and that sampling at shorter distance may be needed to adequately capture the variation.

Given the high cost of soil analysis, increasing the sampling density will bring

Clay (%) – Top soil (a)

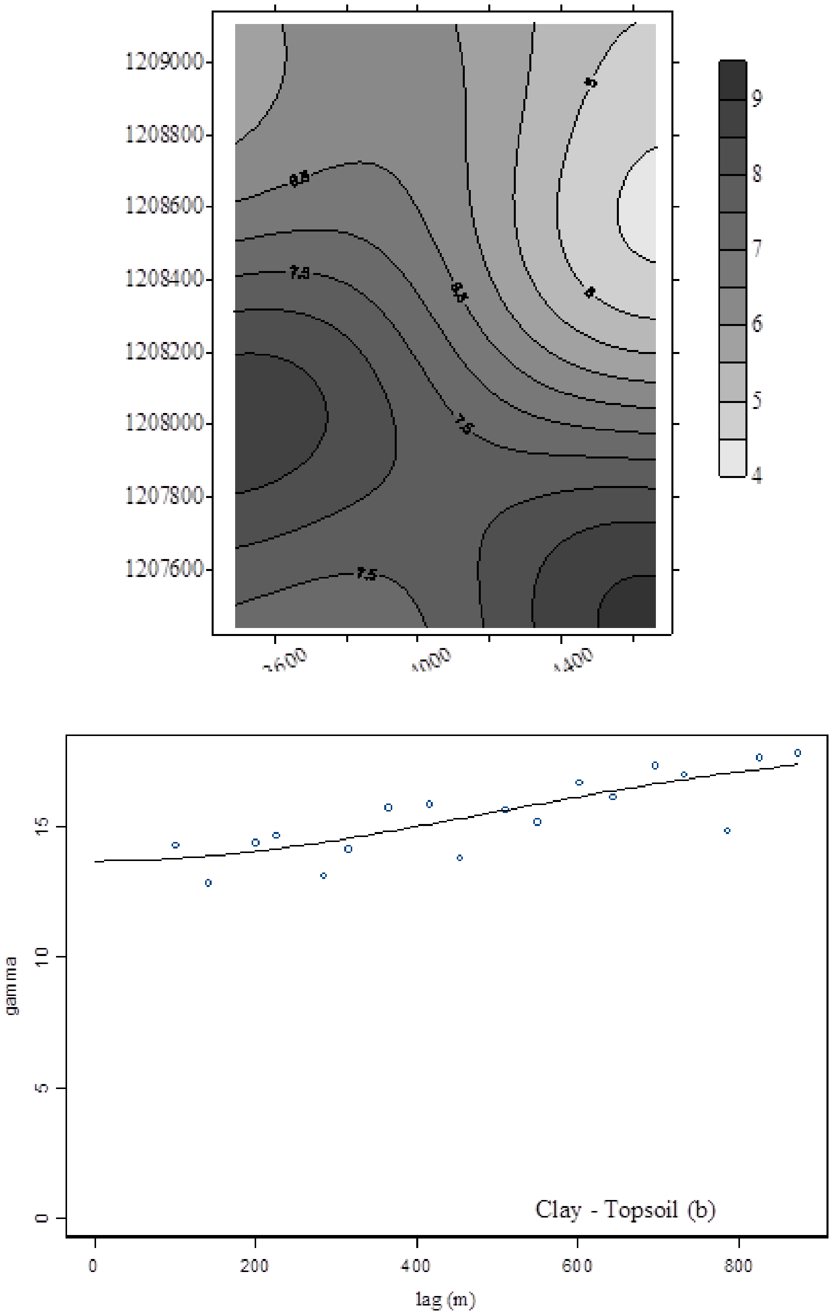

Fig. 4. Map of estimated clay distribution (a) in the top soil, and modelled semi-variogram (b) of clay

along additional cost. It will, therefore, be necessary to consider if increasing the sampling density will result in a more accurate nutrient management and the cost benefit ratio accessed. Site-specific fertilization management for N is not possible at the sampling density used in this study. On the contrary, soil organic carbon and available phosphorus can be adequately managed for precision agriculture.

Conclusion

Considerable variability of soil properties in the various soil series poses a challenge to the use of soil series as a homogenous unit for nutrient management. Variations in soil parameters were very high at both sampling depths. Spatial dependency of the parameters were, however, generally moderate. Prospect for precise nutrient management at this sampling distance are moderate, particularly for SOC, available P and K, while precise management of total N is very low. Extrinsic factors played an important role in the spatial dependency of soil parameter and the level of impact varied among soil parameters and soil depths.

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