DOI: https://doi.org/10.67042/njss.2011.4uaeggg2

Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

SPATIAL VARIABILITY OF MICRONUTRIENTS IN TERMITE INFESTED SOIL FORMED ON NUPE SANDSTONE IN THE GUINEA SAVANNA REGION OF NIGERIA.

***Obi[1], J. C. and Ogunkunle[2], A. O.**

[1]Department of Soil Science, University of Uyo, Uyo, Nigeria
[2]Department of Agronomy, University of Ibadan, Ibadan, Nigeria

ABSTRACT

Soil micronutrients are nutrients required by plants in small quantity. They affect plant growth either directly or indirectly. Availability of these elements for crop growth and development may be affected by their distribution on the landscape. Variability in crop yield may indirectly be attributable to soil micronutrient variability. Termites have been implicated through their feeding habit, construction and repair of nest (i.e point centered pedoturbation process) for soil variability. This study therefore, assessed the influence of termite infestation on the spatial variability of iron (Fe), Zinc (Zn), copper (Cu) and manganese (Mn) in the guinea savanna region of Nigeria. These micronutrients were measured at the 0 – 15 cm depth of 20 m x 20 m grid samples in two termite infested (plots 1 and 2) and one none infested (plot 3) plots measuring 100 m x 100 m in Mokwa and Kontagora area of Niger State in Nigeria. Data collected was subjected to descriptive statistics, coefficient of variation (CV), test for normality and spatial dependence. The micronutrients were moderately variable with CV ranging from 7.5 to 33.3%, not dominated with outliers but had similar means and median. The nugget/sill ratio showed moderate spatial dependence for Fe (plot 1), Cu (plot 3) and Mn (plot 1 and 3) with range 36.4 – 73.0% for Mokwa and zero for Kontagora. Strong spatial dependence was observed in Fe (plot 1 and 3), Zn (plot 1, 2, 3), Cu (plot 1 and 2) and Mn (plot 2) in Mokwa and Fe (plots 1 and 3), Zn (plots 1, 2, and 3), Cu (plots 1 and 3) and Mn (plots 2 and 3) in Kontagora. Geostatistical analysis revealed that strong spatial dependence exists for Cu and Mn in infested plots of Mokwa, an indication that termites could be a factor in the variability of some soil micronutrients through pedoturbation.

Keywords: Spatial variability, coefficient of variation, micronutrients, termite infestation, guinea savanna.

INTRODUCTION

Faunal pedoturbation has been considered a major process that influences soil characteristics (Johnson *et al*., 2003; Jouquet *et al*., 2005). Studies have shown that soil properties are highly variable, thus, resulting in variable crop yield. However, feeding, nest building and repairing characteristics of termites, which constitute their influence on

ecological balance, also influence soil variability (Kang, 1978; Wood *et al*., 1983; Umeh *et al*., 1999; Jouquet *et al*., 2005). Influence of termites could be very manifest in locations where termite mounds modify the landscape to a large extent imposing its variation on the soil properties and characteristics. Depending on the dominant species and mound size there is a maximum mound density per unit area as determined or influenced by minimum separation distance. Hence, so long as an area is habitable by termites, faunal turbation will continue to impact soil development and variability; (Wood *et al*., 1983; Umeh *et al*., 1999; Jouquet *et al*., 2005, Obi, 2006) at near constant spatial scales. This process continues over a period that ranges from hundreds to thousands of years (Lal, 1987; 1988; Hulugalle and Ndi, 1993; Lobry de Bruyn and Conacher, 1995) and could serve as source of within-field variability of soil properties (i.e. concentration of soil material collected from diverse location on the mound). Consequently, many authors have emphasized that the extrapolation of results of agronomic experiments is often difficult, because local variability leads to large variation among replications of experimental treatments (Brouwer, *et al*., 1993; Wendt *et al*., 1993; Manu *et al*., 1996; Brouwer and Bouma, 1997).

Proper understanding of variability of micronutrients will enhance soil fertility management and stability of high quality crop production. Soil properties are multivariate in nature and manifest both short and long range variability (Nielsen, *et al*., 1973; Russo and Bresler, 1981). Soil variability could be studied using analysis of variance (ANOVA) or coefficient of variation (CV), but both display disregard for spatial covariance structure of multivariate soil properties, high degree of uncertainty and low confidence (Nielson *et al*., 1995). Geostatistics is a valuable tool for analyzing spatial variability, interpolating between observations and ascertaining the interpolated values with specified error using a minimum number of observations (Burrough, 1991). Spatial statistical analyses are ideal for investigating spatial covariance structure of soil properties, understanding soil forming factors, genetic processes and development of farm management strategies (Trangmar *et al*., 1985). It is believed that understanding of variability of soil micronutrient could help in explanation of variability of soil properties and crop yield. Therefore, the objective of this study is to assess the influence of termite infestation on Iron (Fe), zinc (Zn), copper (Cu) and manganese (Mn) variability in soils formed on Nupe Sandstones in the savanna region of Nigeria.

MATERIALS AND METHODS

Study site

Giant termite mounds are common features of the rural landscape of Niger State. These mounds are particularly numerous in Mokwa, Gbako, Bida, Agaie, Kontagora, Magama and Wushishi Local Government Areas (LGAs) of Niger State, Nigeria. These LGAs with preponderance of termite mounds covered approximately 51,756.96 km^2 (i.e. 68.1% of land area in Niger State). The Local Government Areas of concentration of termite mounds are located between approximately latitudes 8º 30'N and 11ºN and longitudes 4º 30'E and 6º 89 30'E (Fig. 1). The soil of the area is dominantly Typic Kandiustult. Mean annual precipitation is 1175mm/yr, evapo-transipiration is 2149 mm, temperature is 28 ºC and sunshine period is 8 hours. The soil moisture regime is ustic and soil temperature regime is hyperthermic. The area falls within the Guinea Savanna region covered with either wooded bush land or wooded grassland. The study area is on a relatively flat terrain with slope of less than 4%. Parent material is Nupe Sandstone.

Soil sampling

Mokwa in the south and Kontagora in the northern part of the infestation zone were chosen for the study (Fig. 1). In each location, three 100m x 100m plots were selected for the study. The 100m x 100m plots were marked out to include the area of maximum mound density. The whole study area was inundated with termite mounds, but one hectare plots were chosen as being representative for the study. Two plots had termite mounds while the third had no sign of present or previous occurrence of mounds (i.e. plots 1 and 2 were termite infested while plots 3 were non-infested for the two locations). The plots were farmers' fields, none had been cropped for more than five years and had been under similar land use, presently cropped to maize relay cropped with cowpea. The three plots were located as close to each other as possible and an effort was made to ensure that the plots were as similar as possible except for the incidence of termites (mounds).

Soil samples were collected from 0 – 15 cm depth at each of the sampling locations on grid nodes of 20 m x 20 m to give a total of 36 samples per site. The mean inter-termitarial (minimum separation) distance between the mounds in both Mokwa (range 22.6 – 31.1cm) and Kontagora (range 15.5 – 18.9cm) was 22.0cm; hence sampling distance was chosen to be 20.0cm intervals. The mean number, height and base diameter of mounds were 8.0, 4.89m and 3.06m respectively in Mokwa and 10.0, 2.93m and 1.88m respectively in Kontagora. This was based on the assumption that effect of pedoturbation as a result of termites may be observed at this interval. Also, alignment of the sampling was at regular intervals irrespective of the mounds as the plots were farmers' field and they do not orient their agronomic and management practices with respect to the distribution of mounds. All samples were bagged and labeled. Soil samples were air-dried, partially ground and made to pass through 2 mm sieve. Micronutrients (Fe, Zn, Cu and Mn) were extracted with Mehlick No. 3 extraction (Mehlick, 1984) and read with Atomic Absorption Spectroscopy (AAS).

Statistical analysis

Means were used for estimation of properties at unsampled locations within sampling units, while statistics of dispersion (including standard deviation, coefficient of variation, minimum and maximum) were used to indicate the precision of the mean as an estimator. Probability distributions of the soil properties were assessed using skewness and kurtosis. Means, dispersion and probability distribution of the soil properties were analyzed using Statistical Analysis System (SAS Institute, 1989).

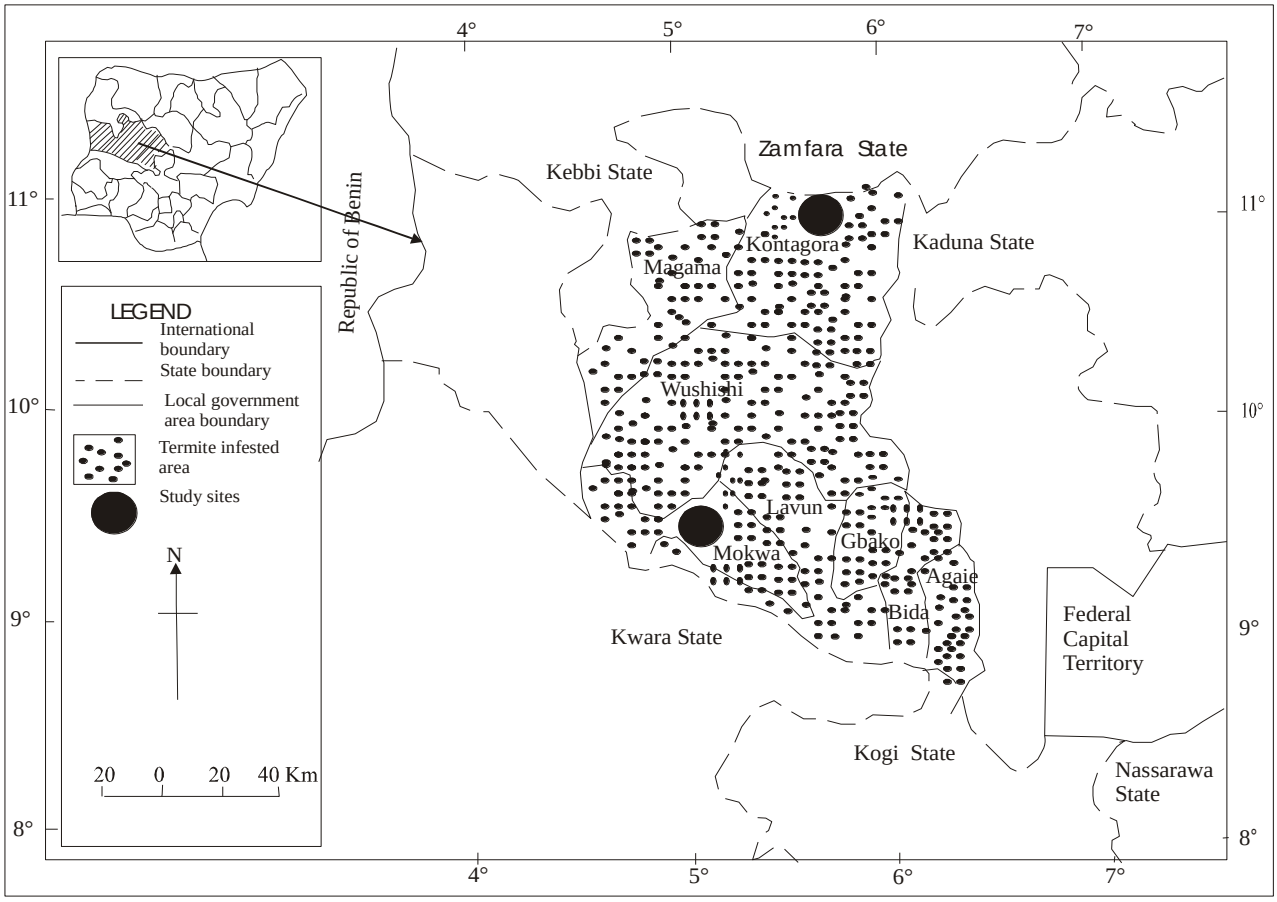


Fig. 1: Location map showing infestation area and study sites

The assumption of classical statistics is that variation of soil properties is randomly distributed with the units, but many soil properties are continuous variables whose values at any location can be expected to vary according to direction and distance of separation from neighbouring samples. Then, spatial dependence was studied using the semivariogram. Semivariance was calculated using:

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

where h is the lag distance
y(h) is the semivariance at lag h,
Z is a random variable (value of soil property),
$Z(x_i)$ is random variable for a fixed location x_i,
N(h) is the number of pairs of values $Z(x_i)$,
$Z(x_i+h)$ separated by a vector h.

Schematic representation of ideal and experimental semivariogram plots are shown in Figures 2 and 3 respectively. In semivariogram plots, the semivariance increases with distance between sampling location, rising to a constant value that approximates the sill at a given separation distance called the range of spatial dependence (a). Ideally, the experimental semivariogram should pass through the origin as shown in Figure 1 when the separation distance is zero, but soil properties display non-zero semivariance as the separation distance tends to zero. The nugget variance or nugget effect (C_0) shown in Figure 2 represents unexplained or random variance frequently caused by measurement error or microvariablity of the property which can not be detected at the scale of sampling.

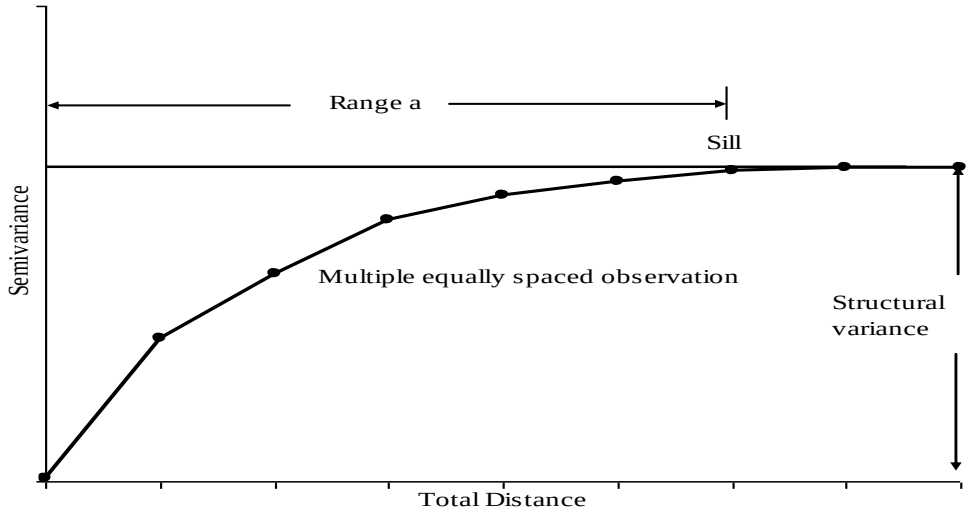


Fig. 2: Ideal semivariogram with zero nugget variance

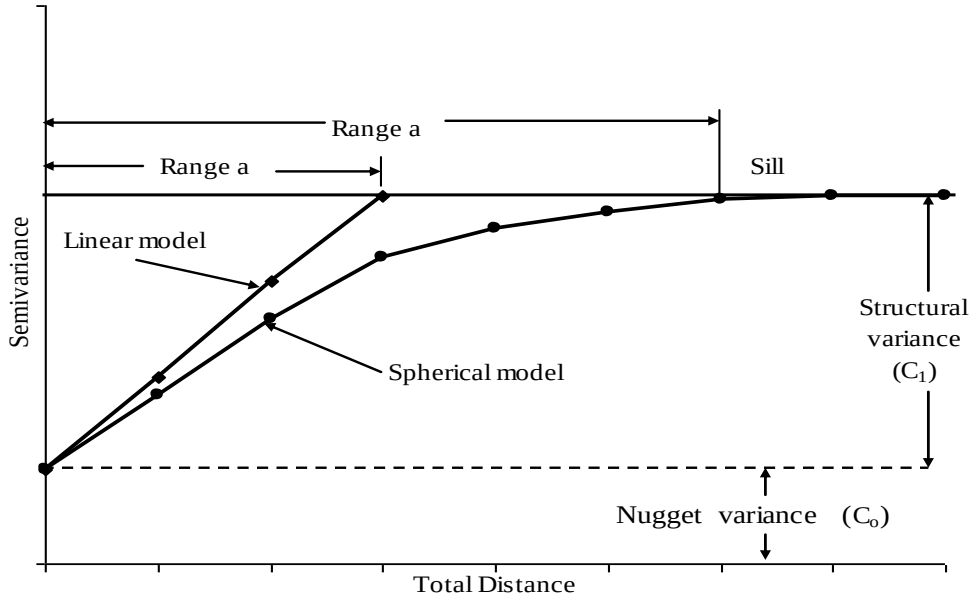


Fig. 3: Experimental semivariogram with nugget variance

Semivariograms (graph of semivariance vs. lag distance) were drawn and fitted with several different models. The best fit model was selected based on maximum R^2. The semivariograms were fitted to either a linear

for $h \leq a$

$$\gamma(h) = C_0 + C_1 \quad \text{for } h > a \qquad (2)$$

or spherical model, which is

$$\gamma(h) = C_0 + C_1\left[\frac{3}{2}\frac{h}{a} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right]$$

$$\gamma(h) = \begin{cases} C_0 + C_1 & \text{for } h \le a \\ & \text{for } h > a \end{cases} \quad (3)$$

where C_0 is the nugget effect,
C_1 is the structural variance,
a the range of spatial dependence and
$C_0 + C_1$ is the sill
Distinct classes of spatial dependence for the soil properties were obtained by the ratio of the nugget to sill. If the ratio was < 25%, between 25 and 75% or >75%, the variable was considered strongly, moderately or weakly spatially dependent respectively (Cambardella, *et al*., 1994).

RESULTS AND DISCUSSION

General variation of soil micronutrients

The mean and median were used as primary estimates of central tendency and standard deviation, coefficient of variation (CV), kurtosis and skewness, minimum and maximum were used as estimates of variability (Tables 1 and 2). The mean and median of the micronutrients were similar with median being almost equal or a little more or less than the mean (Table 1 and 2). This was an indication that outliers did not dominate the measure of central tendency. Cambardella, *et al*. (1994) and Shulka *et al*. (2004a) reported a similarity of means and median for several soils physical, chemical and biological properties.

Among the four soil micronutrients measured, in Mokwa, the CV of all the elements were higher than 15% but less than 35%, an indication of moderate variability except Zn in plots 1 and 3 that were less than 15% (least variable) as shown in Table 1. In Kontagora, the CV of the entire elements were less than 15% (least variable) except for Zn in plot 3 and Mn in the three plots. This result indicated that the entire micronutrients studied in Mokwa and Mn alone in Kontagora was moderately variable for both infested and non-infested plots in the two locations. It was Zn alone that displayed moderate variability in only the infested plot of Kontagora, which created the suspicion that termite, activates might have resulted in homogenisation of soil micronutrients. Therefore, apart from effect on Zn in Kontagora, there was an indication that termite infestation does not affect variability of micronutrients in the study area or that CV was unable to capture it. Hence, as data were collected on grid nodes, which satisfied the requirement for geostatistical analysis, spatial dependence of the soil micronutrients was studied.

.

Table 1: The descriptive statistics of the micronutrients measured in the infested ` (plots 1 and 2) and non infested (plot 3) of Mokwa

	Fe			Zn			Cu			Mn		
Plot	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Count	36	36	36	36	36	36	36	36	36	36	36	36
Mean	77.9	62.2	65.9	103.6	93.3	96.6	75.8	85.0	73.3	6.8	6.9	6.0
Median	76.5	61.5	63.0	100.0	98.0	99.0	73.0	89.0	70.5	6.7	7.3	5.7
Std Dev*	12.6	15.0	10.3	8.9	17.6	7.3	15.8	15.8	14.6	1.7	1.9	2.0
CV*	16.2	24.1	15.6	8.6	18.9	7.5	20.8	18.6	19.9	24.8	28.1	33.3
SE*	2.1	2.5	1.7	1.5	2.9	1.2	2.6	2.6	2.4	0.3	0.3	0.3
Kurtosis	-0.5	0.2	-0.5	1.1	16.0	-0.2	-0.4	-1.1	-1.1	-1.1	-0.4	1.1
Skewness	-0.1	0.04	0.7	0.8	-3.5	0.0	0.4	-0.2	0.3	0.1	-0.5	0.8
Minimum	49.0	24.0	50.0	88.0	8.0	82.0	48.0	57.0	52.0	3.6	2.1	2.7
Maximum	99.0	96.0	89.0	130.0	110.0	110.0	110.0	110.0	100.0	9.5	10.0	12.0
Range	50.0	72.0	39.0	42.0	102.0	28.0	62.0	53.0	48.0	5.9	7.9	9.3

* Std Dev – standard error; CV – coefficient of variation; SE – standard error

Table 2: The descriptive statistics of the micronutrients measured in the infested (plots 1 and 2) and non infested (plot 3) of Kontagora

	Fe			Zn			Cu			Mn		
Plot	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Count	36	36	36	36	36	36	36	36	36	36	36	36
Mean	10.3	10.4	10.5	8.7	8.8	9.6	11.0	9.9	9.8	4.2	4.2	4.1
Median	10.0	10.1	11.0	8.7	9.2	9.1	11.0	10.0	9.8	4.2	4.2	4.1
Std Dev*	1.1	1.0	1.1	1.3	1.3	2.7	1.6	1.3	1.3	0.8	0.8	1.3
CV*	10.6	9.5	10.0	14.7	14.7	27.7	14.5	13.0	12.9	20.0	20.0	30.7
SE*	0.2	0.2	0.2	0.2	0.3	0.5	0.3	0.3	0.2	0.1	0.1	0.2
Kurtosis	-0.5	-0.9	-0.8	0.3	-0.02	-0.5	-0.4	1.1	-0.3	-0.2	-0.2	-0.9
Skewness	-0.4	0.03	-0.2	0.2	-0.5	0.4	0.8	-0.2	0.02	0.5	0.5	-0.3
Minimum	8.0	8.7	8.4	6.0	5.7	4.8	8.9	6.4	7.1	2.8	2.8	1.6
Maximum	12.0	12.0	12.0	12.0	11.1	15.0	14.0	13.0	12.0	6.1	6.1	6.1
Range	4.0	3.3	3.6	6.0	5.3	10.2	5.1	6.6	4.9	3.3	3.3	4.5

* Std Dev – standard error; CV – coefficient of variation; SE – standard error

Spatial dependence of soil micronutrients

The micronutrients (Fe, Zn, Cu and Mn) displayed differences in their spatial pattern. The spatial dependence showed isotropic behaviour that may be caused by low variability in soil management treatments and soil forming factors of which termite played a significant role. Several models were tested but apart from Mn in the termite-infested plot (plot 1) of Kontagora with spherical model, other elements in the entire plots and locations fitted the linear model best (Table 3 and 4 for Mokwa and Kontagora respectively). There was no evidence of anisotropy in the directional semivariogram for micronutrients. Therefore, isotropic models were fitted to the semivariograms. Stationarity was observed in Fe and Cu content of Plot 2 and Mn content of plot 3 both in Kontagora and therefore, semivariogram could not be produced.

Positive nugget effect was observed for all the micronutrients, except Zn (plot 1) and Cu (plot 1 and 2) both in Mokwa and in Zn plot 1 and Cu plot 2 in Kontagora, all being termite infested plots. This may be due to sampling error, random, inherent or microvariability (i.e. short-range variability) that could actually exist at a range shorter than the 20 m grid interval adopted in this study as had been previously reported by Trangmar *et al*. (1985) and Shulka *et al*. (2004b) for some soil physical and chemical properties. Apart from Fe in plot 1, other micronutrients had higher nugget effect in the non-infested compared to infested plots of Mokwa. While infested plots had higher positive nugget effect compared to the non-infested of Kontagora. The expectation was that the point centered nature of pedoturbation process initiated through termite infestation will result to short range variability and more positive nugget effect compared to the non-infested. These not being so were indications that termite activities did not contribute significantly on the dynamics of micronutrients as previous evidence of faunal pedoturbation has been based on the texture of the soil and less on the chemical properties (Johnson *et al*. 2003, Horwath and Johnson, 2003; Nooren *et al*. 1995). However, since variation affects all kinds of soil properties, this could be established using relative size of spatial dependence. The relative size of the nugget effect among the different micronutrients in both infested and non-infested plots can be described by expressing the nugget variance as a percentage of total semivariance or sill (Trangmar *et al*., 1985). The ratio showed moderate (ranging from >25% to <75%) spatial dependence for Fe (plot 1), Cu (plot 3) and Mn (plot 1 and 3) ranging from 36.4 – 73.0% for Mokwa and

none for Kontagora.

Strong spatial dependence (<25%) was observed in Fe (plot 1 and 3), Zn (plot 1, 2, 3), Cu (plot 1 and 2) and Mn (plot 2) in Mokwa (Table 3) and Fe (plots 1 and 3), Zn (plots 1, 2, and 3), Cu (plots 1 and 3) and Mn (plots 2 and 3) in Kontagora (Tables 4). Generally, all micronutrients in both infested and non-infested fall within the range of strong to moderate spatial dependence. These were indications of intrinsic variation in soil texture and mineralogy. Shulka *et al*., (2004b) reported that moderately spatially dependent soil properties were strongly correlated and were functions of intrinsic variation in soil texture and mineralogy and that management could also control variability of some moderately and weakly spatially dependent soil properties. Obi (2006), had previously implicated termites in their influence on soil properties especially texture through pedoturbation as a result of feeding habit, nest construction and repairs.

Table 3: Parameter for semivariogram of soil micronutrients in infested (plots 1 and 2) and non-infested (plot 3) sites in Mokwa

	Fe			Zn			Cu			Mn		
Plot	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Range	50.0	100	70	100	40	100	40	100	100	40	100	63.0
Sill	680	1000	820	1200	1400	200	533.3	2100	7.2	22.0	27.0	32.0
Nugget	5.35	480	60	8.11	0.00	10.0	0.00	0.00	5.26	8.0	0.50	13.9
Nugget/Sill (%)	1.0	48	7.0	1.0	0.00	1.0	0.00	0.00	73.0	36.4	1.9	43.0
R-Square	0.41	0.01	0.20	0.51	0.34	0.04	0.25	0.40	0.49	0.20	0.67	0.15

Table 4: Parameter for semivariogram of soil micronutrients in infested (plots 1 and 2) and non-infested (plot 3) sites in Kontagora

	Fe			Zn			Cu			Mn		
Plot	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Range	100	-	35.0	48.0	100	100	100	-	100	60.0	100	-
Sill	4.20	-	2.50	16.0	74.0	13.0	23.0	-	2.38	4.0	10.5	-
Nugget	0.60	-	0.50	0.00	10.8	1.50	0.00	-	0.09	0.18	0.99	-
Nugget/Sill	14.3	-	0.20	0.00	14.5	11.5	0.00	-	3.80	4.50	9.4	-
R-Square	0.03	-	0.002	0.10	0.44	0.05	0.05	-	0.21	0.38	0.69	-

CONCLUSION

The classical (descriptive) statistics have revealed that termite infestation does not increase variability of soil micronutrients as Fe, Zn, Cu and Mn content was not highly variable when the infested was compared with non-infested plots. These probably could either be because termite infestation does not affect micronutrients that are normally needed by crops in small quantities for optimal performance or that the descriptive statistics used did not capture the variability. The mean and median values of the elements were similar although ranges of the micronutrients levels were higher in Mokwa than Kontagora. This showed that the micronutrients were similar in the 100 m x 100 m and were not dominated with outliers and hence did not influence the measure of central tendency and normally distributed. Further investigation of effect of termite infestation on variability of micronutrients with the aid of geostatistics revealed through the ratio of nugget to sill that strong spatial dependence exist in the distribution of the elements for both infested and non-infested that could not be directly associated with termite infestation except for

Cu and Mn in Mokwa, indicating that termite infestation actually influenced variability of some micronutrients. There was moderate spatial variability of Mn in both Mokwa and Kontagora that further confirm effect of termite infestation on variability of soil micronutrients.

REFERENCES

Brouwer, J. and Bouma, J. (1997). Soil and crop growth variability in the sahel: highlights of research (1990-1995) at ICRISAT Sahelian centre. *Information Bulletin* 49. ICRISAT, Patanchewru Andrah Pradesh, India.

Burrough, P. A. (1991). Sampling designs for quantifying map unit composition. In: *Spatial Variabilities of Soils and Landforms*. M.J. Mausbach and L. P. Wilding (eds) SSA. Special Publication No. 28. Soil Science Society of America Madison, WI. pp. 89-127.

Cambardella, C. A., Moorman, T. B., Novak, J. M., Parkin, T. B., Karlan, D. L., Turcp, R. F. and Konopka, A. E. (1994). Field scale variability of soil properties in central Iowa soils. *Soil Science Society of America Journal* 58:1501-1511.

Horwarth, J. L. and Johnson, D. L. (2006). Mima-type mounds in Southwest Missouri: Expression of point-centered and locally thickened biomantles. *Geomorphology*. 77:306-319.

Hulugalle N. R. and Ndi, N. J. (1993). Soil properties of termite mounds under different land uses in Typic kandiudalf of southern Cameroon, Agric. *Ecosystem and Environment*. 43(1): 69 - 78.

Johnson, D. L., Horwath, J. L. and Johnson, D. N. (2003). Mima and other animal mounds as point-centered biomantles. *Geol. Soc. Amer. Abstracts with programs*. 34(8): 258.

Jouquet, P., Barrė, P., Lepage, M. and Velde, B. (2005). Impact of subterranean fungus-growing termites (Isoptera, Macrotermitinae) on chosen soil properties in West African savanna. *Biol. Fertil. Soils*, 41:365-370.

Kang, B. T. (1978). Effect of some biological factor on soil variability in the tropics. III. Effect of macrotermes mounds. *Plant and Soil* 50:241-251.

Lal, R. (1987). *Tropical Ecology and Physical Edaphology*, John Wiley, Chichester.

Lal, R. (1988). Effect of Macrofauna and soil properties in tropical savanna. *Agric. Ecosystem and Environment*. 24:101 - 106.

Lobry de Bruyn, L. A. and Conacher, A. J. (1995). Soil modification by termites in the central wheatbelt of Western Australia. *Australian Journal of Soil Research* 33(1): 179 - 193.

Manu, A., Pfordresher, A. A., Geiger, S. C., Wilding, L. P. and Hossner, L. R.. (1996). Soil parameters related to crop growth variability in Western Niger, West Africa. *Soil Science Society of America Journal* 60: 283-288.

Mehlick, A. (1984). Mehlick 3 Soil Test Extractant: A Modification of Mehlick 2. *Communications in Soil Science and Plant Analysis*, 15:1409-1416.

Neilsen, D. R., Bigger, J. W. and Erh, K. T. (1973). Spatial variability of field measured soil water properties. Hilgandia 42: 215-259.

Nooren, C.A.M., van Breemen, N., Stoorvogel, J.J., Jongmans, A.G., (1995). The role of earthworms in the formation of sandy surface soils in a tropical forest in Ivory Coast. *Geoderma* 65, 135–148.

Obi, J. C. (2006). Influence of termite mound on soil characteristics, variability and arable crop production in the savanna ecology of Niger State, Nigeria. A *Ph.D thesis* in the Department of Agronomy, submitted to the Faculty of Agriculture and Forestry in partial fulfilment of the requirements for the degree of Doctor of Philosophy, University of Ibadan, Ibadan, Nigeria.

Phillips, J. D. (2007). Development of texture contrast soils by a combination of bioturbation and translocation. *Catena* 70 (2007) 92–104

Russo, D. and Bresler, E. (1981). Soil hydraulic properties as stochastic processes: I. An analysis of field variability. Soil Science Society of *America Journal* 45: 682-687.

SAS Institute. (1989). *SAS/STST User's Guide, Version 6*, 4th Ed, Vol. 1 and 2. SAS Institute, Carry, NC.

Shulka, M. K., Slater, B, K., Lal, R. and Cepuder, P. (2004a). Spatial variability of soil properties and potential management classification of a chernozemic field in lower Austria. *Soil Science* 169: 852-860.

Shulka, M. K. Lal, R. and Ebinger, M. (2004b) Principal component analysis for predicting biomas and corn yield under different land uses. *Soil Science* 169: 215-224.

Trangmar, B. B., Yost, R. S. and Uehara, G. (1985). Application of geostatistics to spatial studies of soil properties. *Advances in Agronomy*. 38: 45-94.

Umeh, V. C., Ivbijaro, M. F. and Ewete, F. K. (1999). Relationship between characteristics of Macrotermes *sp*. Mound material and their surrounding soils. Insect Science Application 19(2/3): 251-255.

Wendt, J. W., Barrada, A. Gaoh, M. G. and Schulze, D. G. (1993). Phosphorus sorption characteristics of productive and unproductive Niger soils. *Soil Science Society of America Journal* 57 (3): 766-773.

Wood, T. G., Johnson, R. A. and Anderson, T. J. (1983). Modification of soils in Nigeria's savanna by soil feeding *Cubitermes* (Isoptera, Termitidae). *Soil Biology and Biochemistry* 15:575-579.