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Spatial variability of arbuscular mycorrhizal spores and particle size distributions of basement complex valley bottom soils of south-western Nigeria

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ABSTRACT

Spatial variability of soil properties have been attributed to factors of soil formation, land use and management. Mycorrhizal fungi are associated intrinsically with soil organic matter and have been reported to be spatially heterogeneous and largely influence soil fertility and crop production. The objective of this study was to assess spatial variability of arbuscular mycorrhizal and its relationship with particle size fractions on valley bottom soils in southwestern Nigeria. The study was conducted on a 9 hectare (900m by 100m) undergraduate internship plot in University of Ibadan, Nigeria. Surface (0 - 15cm) and subsurface (15 – 30cm) soil samples were collected at rigid grid nodes (10m by 100m), processed and analysed for particle size distribution, available phosphorus, organic carbon and arbuscular mycorrhizal fungi (*Gigaspora*, *Scultelospora*, *Acaulospora*, *Entrophospora*, *Glomus*, etc.). Data collected were analyzed statistically using descriptive statistic, statistics of dispersion and geostatistics. The variables that were normally distributed included silt (surface), silt, clay and organic carbon (subsurface). Status of coefficient of variation of the soil properties ranged from least to moderate (7.6% - 42.3% and 0.7% - 42.7% for surface and subsurface soils respectively. There were significant correlations between clay content and *Gigaspora* ($r = 0.43$, $p \leq 0.01$), clay and *Glomus* ($r = -0.24$, $p \leq 0.05$), *Gigaspora* and *Glomus* ($r = 0.43$, $p \leq 0.01$) on the surface. Whereas on the subsurface, clay and *Glomus* ($r = 0.23$, $p \leq 0.05$), available phosphorus and *Gigaspora* ($r = 0.23$, $p \leq 0.05$), *Gigaspora* and *Glomus* ($r = 0.51$, $p \leq 0.05$) were significantly correlated. The semivariance analysis carried out indicated that extent of spatial dependence of the soil properties on both depths varied from strong to moderate (5.9% - 63.3% and 14.3% - 53.0% in surface and subsurface soils respectively) which is as a result of intrinsic variation caused by factors of soil formation. Variability of mycorrhizal spores in the study area is majorly attributable to pedogensis rather than land use and management. Clay and available phosphorus were found to influence distribution of mycorrhizal spores.

Introduction

The influences of geogenetic, pedogenetic, anthropogenic (land use and management) processes are responsible for the complexity of soil spatial variability. Consequently, soils exhibit variability in physical, chemical and biological properties at both micro and macro scales. Spatial variability of soil properties is a major problem in both agricultural and environmental research and management activities. Previous research activities (especially in soil survey and land use planning) emphasized variability of soil physical and chemical properties without adequate integration of the contribution of biological components of the soil fertility and crop yield.

Depending on the factors of soil formation, living organism interact intrinsically with organic matter in the dynamics and roles of biological components of the soil in enhancement of soil fertility. The soil organic matter is colonized by varieties of soil microorganisms (bacteria, actinomycetes, fungi, algae, protozoa etc.) which derived energy for the oxidative decomposition of complex molecules. Major factors that constrain tropical soil fertility and sustainable agriculture are low nutrient capital, moisture stress, erosion, high phosphorus fixation, high acidity with aluminum toxicity, and low soil biodiversity. The fragility of many tropical soils limits food production in annual cropping systems. Some tropical soils under natural conditions have high biological activity, and increased use of the biological potential of these soils to counter the challenges of food production problems is proposed. Most plant species (including the major crops in the tropics) form beneficial associations with arbuscular mycorrhizal (AM) fungi. The fungi that are probably most abundant in agricultural soils are these AM fungi (phylum *Glomeromycota*). These fungi could be the most important and poorly understood resource for nutrient acquisition and plant growth in agriculture.

They account for 5–50% of the biomass of soil microbes (Olsson *et al*., 1999). Hyphae biomass of AM fungi may amount to 54–900 kg ha^{-1} (Zhu and Miller, 2003), and some products formed by them may account for another 3000 kg (Lovelock *et al*., 2004). Pools of organic carbon such as glomalin produced by AM fungi may even exceed soil microbial biomass by a factor of 10–20 (Rillig *et al*., 2001). Mycorrhizal fungi are wide spread constituents of soil communities and influence above ground processes and properties (Gange, *et al*. 2005), plant fitness (Koide and Dickie, 2002) and plant community diversity and productivity (van der Heijden *et al*. 1998). Arbuscular

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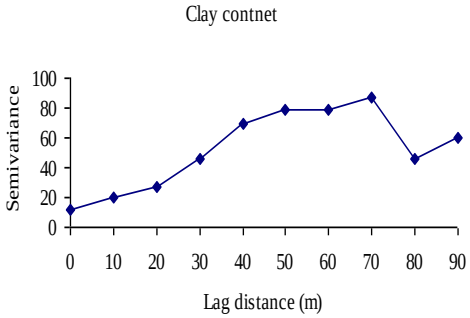
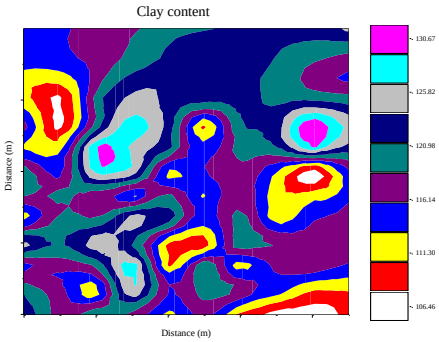
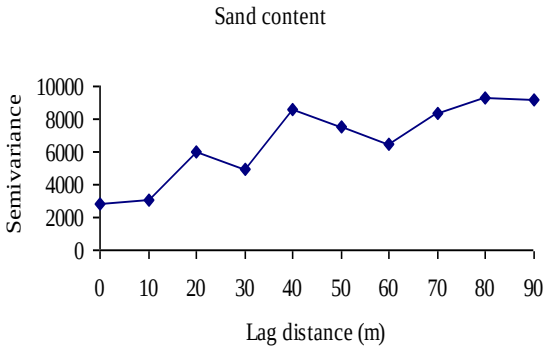
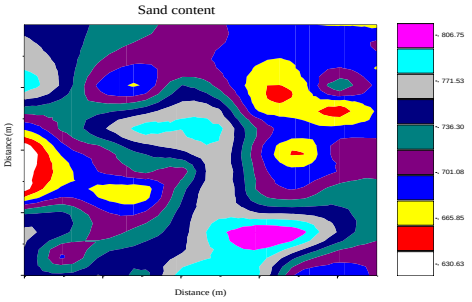
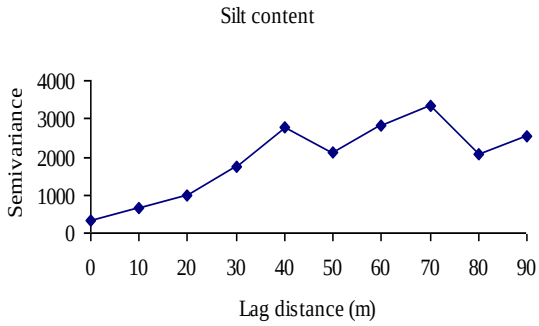
mycorrhizal (AM) fungi increase phosphorus and other nutrients' uptake including biological nitrogen fixation. The roles of AM in maintenance and improvement of soil structure, uptake of relatively immobile elements, both macronutrients (phosphorus) and micronutrients (zinc), the alleviation of aluminum and manganese toxicity, interactions with other beneficial soil organisms (nitrogen-fixing rhizobia), and improved protection against pathogens is critical and distinguishes it from other biota. Mycorrhizal associations enable a better use of sparingly soluble phosphorus pools, thereby increasing the efficiency of added phosphorus fertilizer and of the large relatively immobile phosphorus pools. They also facilitate biological root control of plant pathogens and soil toxins, uptake of immobile nutrients, tolerance to high temperatures and extremely high soil pH (Powell and Baggoraji, 1984, Sieverding and Toro, 1988).











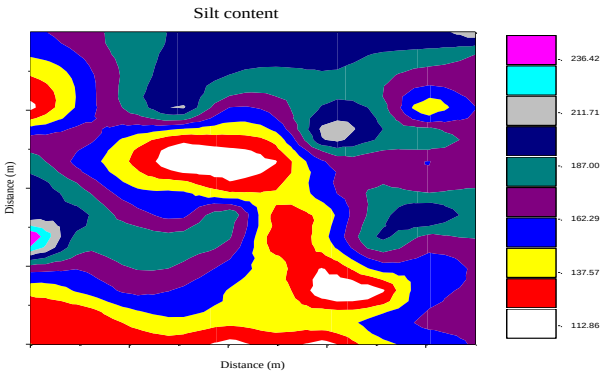
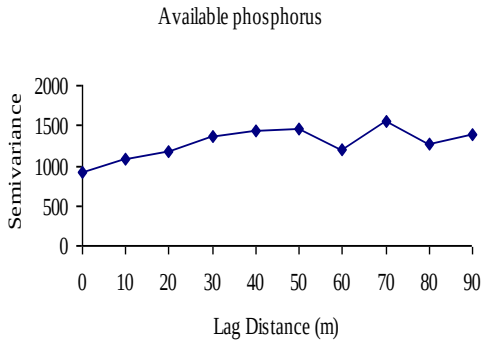
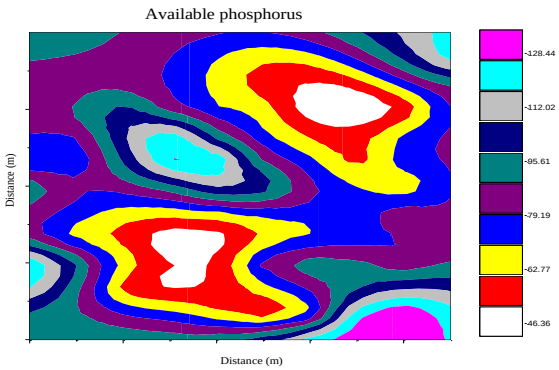
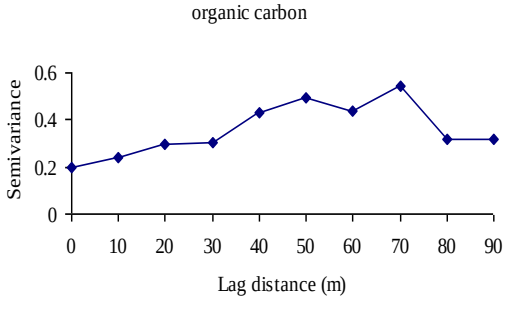


Fig 1: Semivariograms and kriged maps of particle size fractions of the surface soils in study area







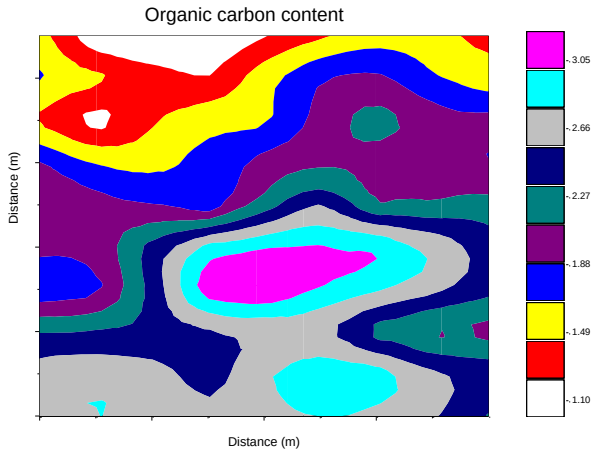


Fig 2: Semivariograms and kriged maps of available phosphorus and organic carbon content of soils at the 0-15cm depth of the study area

Ettema and Wardle (2002) reported that soil organisms show distinct spatial pattern in both composition and abundance. Specifically mycorrhizal spores have been found to be spatially heterogeneous (Pringle and Bever, 2002, Hart and Klironomos, 2002; Egerton-Warburton *et al*. 2003; Carvalho *et al*. 2003; Sinegani *et al*. 2005; Wolfe *et al*., 2007). These heterogeneous mycorrhizal fungi contribute to soil structure by growth of external hyphae into the soil to create a skeletal structure that holds soil particles together. External hyphae create conditions that are favourable for the formation of micro-aggregates, enmeshment of microaggregates by external hyphae and roots to form macroaggregates, and directly tapping carbon resources of the plant from the soils (Miller and Jastrow, 1990, 2000). Particle size distribution (PS) is the most important attribute affecting physical, chemical and biological processes in the soil. The relative distribution of PS largely determines water, heat, nutrient fluxes, water and nutrient holding capacity and soil structure form and stability. Several studies have shown that soil particle size fractions are strongly spatially dependent (Igbal *et al*. 2005; Duffera *et al*. 2007; Wei *et al*. 2008; Suntra *et al*. 2008; Souza *et al*. 2009, Obi *et al*., 2010 and Obi and Nnadi, 2010) and controlled by intrinsic factors (Cambardella, *et al*. 1994).

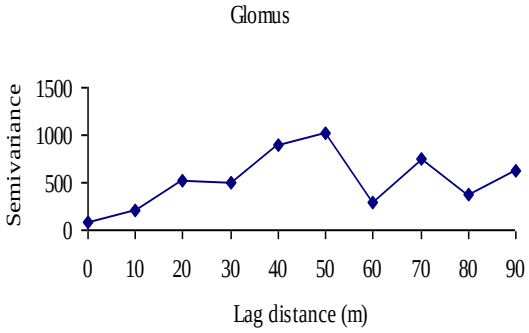
The objective of this study therefore was to assess the influence of particle size distribution on the distribution and spatial variability of vesicular-arbuscular mycorrhizal on valley bottom soils in southwestern Nigeria

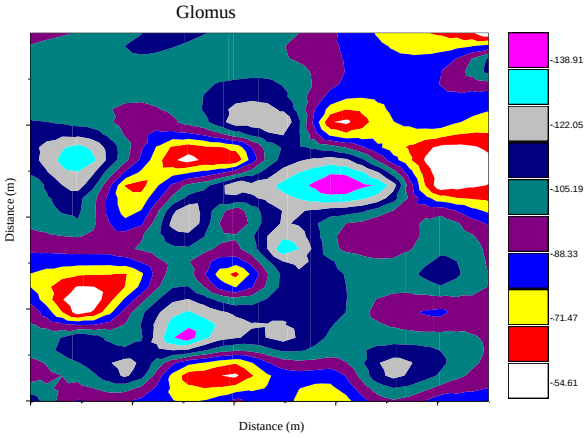
Materials and Methods

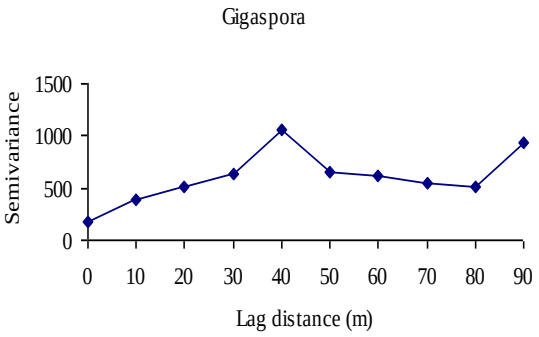
Site description

The study was conducted on a valley bottom plot at University of Ibadan undergraduate internship farm measuring 9.0 hectares (900m by 100m. The valley resulted from the convergence of three slopes (East to West; North to South and South to North), forming a saucer shape. The slopes are generally gentle and concave in shape. The land is about 80-100metres above sea level. Mainly the process of alluviation forms the soils over many years (Akinbola, 1985).

The undergraduate internship students cultivate rainfed maize (Zea mais) and cowpea (Vigna unguiculata) during the rainy season and irrigated green leafy vegetable (*Amaranthus* spp.) in the dry season. University of Ibadan is located approximately between longitudes 3º 44' and 4º 00' E and latitudes 7º 25' and 7º 30' N. The climate of Ibadan area is hot subhumid and lies within the derived savanna zone. Mean annual rainfall is about 1200mm within the rainy season occurring between April and November. The mean monthly temperature ranges between 24ºC and 28ºC. The slope of the landscape is gentle (2-4%). The soils are derived from coarse granite gneiss of the precambarian basement complex but overlayed by slope sediment and classified as Entisol according to USDA Soil Taxonomy (Soil Survey Staff, 2006). This was in view of the fact that the present soil resulted from colluvial and alluvial deposits that ranged from fluvic to gleyic materials. The study of the valley bottom soil is of great interest in view of it's all season availability of water and inherent fertility as a result of eroded material depositions and organic matter accumulation that are useful for year –in year –out cultivation.







Soil sampling and laboratory analysis

Surface and subsurface soil samples (0 – 15cm and 15 – 30cm depth respectively) were collected at grid notes (10m) along transects made at 100m (9 transects) intervals in a rigid grid format with the aid of Dutch augar, a total of 180 samples were taken. Soil samples were processed and analyses performed include particle size distribution using hydrometer method (Gee and Bauder, 1986). Available phosphorus (avail. p) was extracted with Mehlich No. 3 extraction (Mehlich, 1984) and determined colorimetrically. Organic carbon was determined by dichromate oxidation (Nelson and Sommers,

1982) method. Arbuscular, Mycorrhiza Fungi spores were isolated from 300g soil by wet sieving and subsequent floating centrifugation in 50% sucrose (Daple, 1993) and counted under microscope. Slides in Polyvinyl Alcohol (PVLG) and PVLG Melzer's reagent were prepared for taxonomic or character observation and identification.

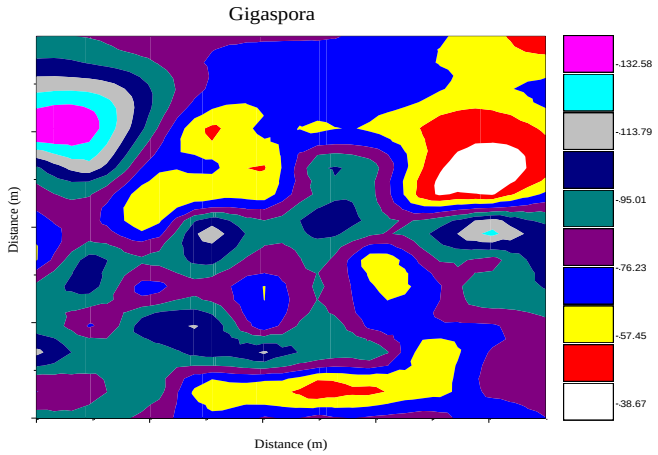
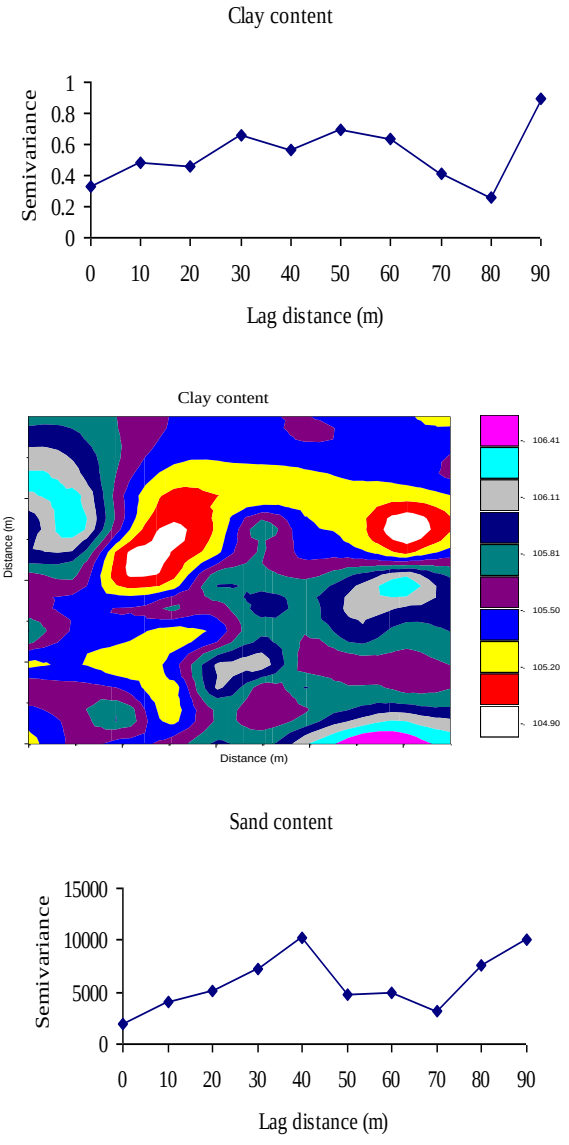
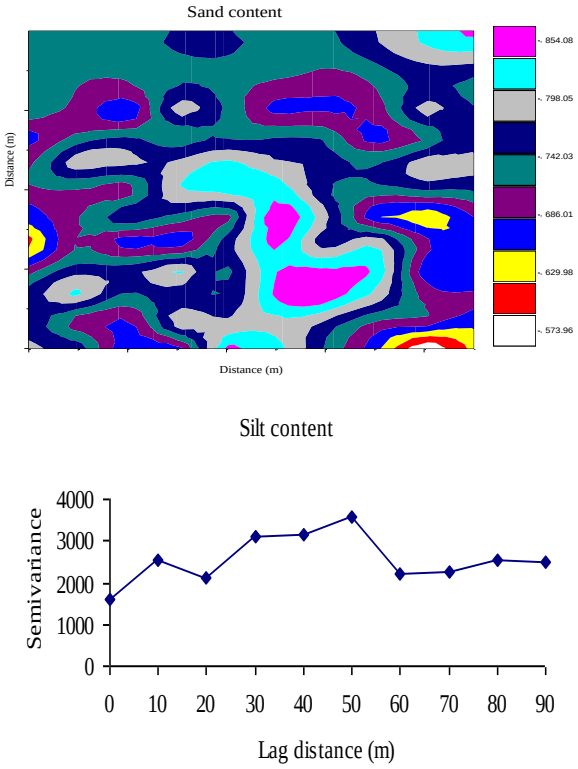


Fig 3: Semivariograms and kriged maps of Mycorrhizal spre distribution on surface soils in study area





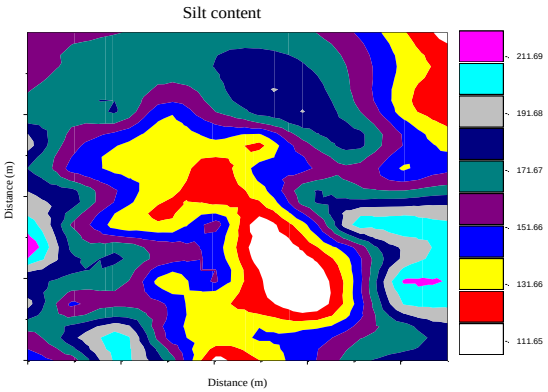


Fig 4: Semivariograms and kriged maps of particle size fractions of the subsurface soils in study area

Statistical analysis

The soil properties were analyzed using classical statistical methods to obtain descriptive statistics, measure of central tendency, normality of distribution, correlation analysis and coefficient of variation using SAS Institute (1996). T test was used to compare the means of surface and subsurface soil at 5% probability level. Data Factor analysis was also used to group the soil properties into statistical factors based on their correlation structure using SAS Institute (1996).

Principal component analysis was performed on standardized variables using correlation matrix to eliminate the effect of different measurement units on the determination of factor loadings (James and McCulloch, 1990, Johnson and Wichern, 1992). The degree of spatial variability for each variable was determined by geostatistical methods using semivariogram analysis (Trangmar *et al*., 1985; Bailey and Gatrell, 1998; McBratney and Pringle, 1999). Spatial dependence was studied using the semivariogram.

Results

Variation of mycorrhizal spores and some soil properties

The result on Table 1 indicated occurrence of *Gigaspora*, *Scutellospora*, *Acaulospora*, *Entrophospora*, *Glomus* and other

taxa that were not taxonomically identified ("others"). The sum of all the spores was reported as "mycorrhizal spores". The most abundant genera of AMF were *Glomus* > *Gigaspora* > *Scutellospora* > *Acaulospora* > *Entrophospora* in both the surface and subsurface horizons. This trend was similar to that observed by Agwa and Al-sodany (2003).

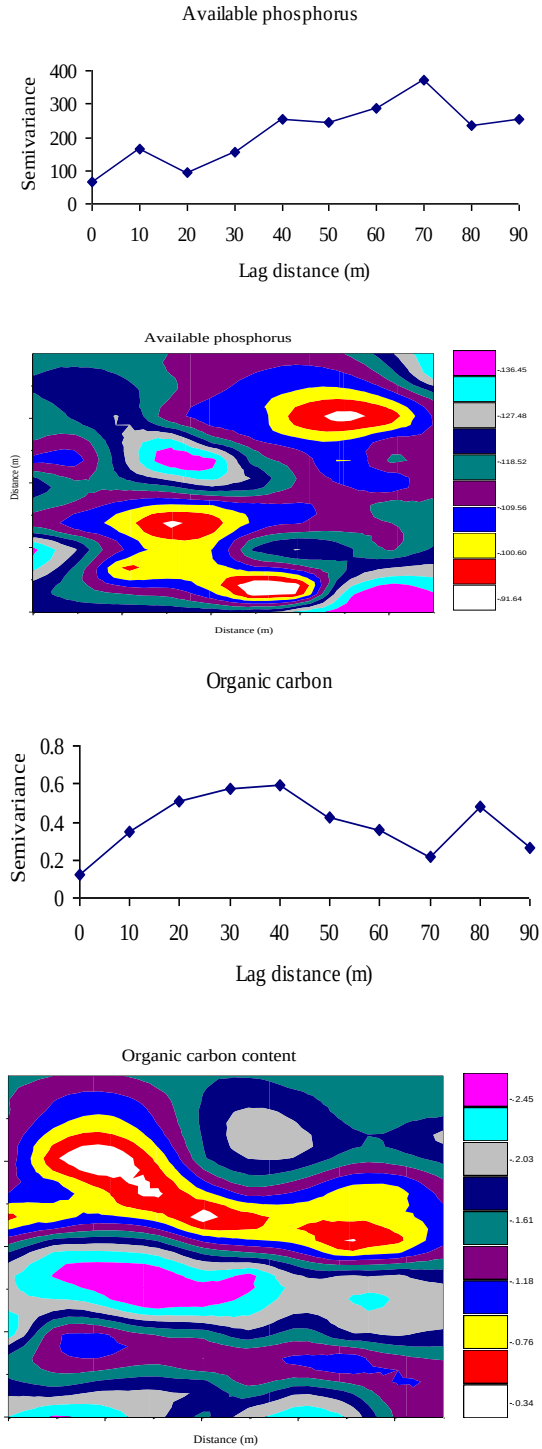


Fig 5: Semivariograms and kriged maps of available phosphorus and organic carbon content of subsurface soils of the study area

The classical statistics of particle size fractions, available phosphorus, and organic carbon and mycorrhizal spores of both the surface and subsurface horizons were shown in Table 1. The mean and median values were used as primary estimates of central tendency, standard deviation, coefficient of variation (CV), minimum, maximum, skewness and kurtosis were used as estimates of variability. Normality of distribution of soil properties was accepted or rejected on the consideration of Pr<W (Shapiro-Wilk test) in relation to the anticipated level of significance. If this value (i.e. Pr<W) is less than the chosen level of significance (such as 0.01 for 99%) then the null hypothesis is rejected and it was concluded that the data did not originate from normal distribution. The entire variables were normally distributed (Table 1) with the exception of silt (surface), clay and available phosphorus contents of both surface and subsurface horizons. The similarity of mean and median values revealed that despite skewness and kurtosis, outliers did not dominate the measure of central tendency and that even the non-normally distributed variables could be assumed to have originated from the same population.

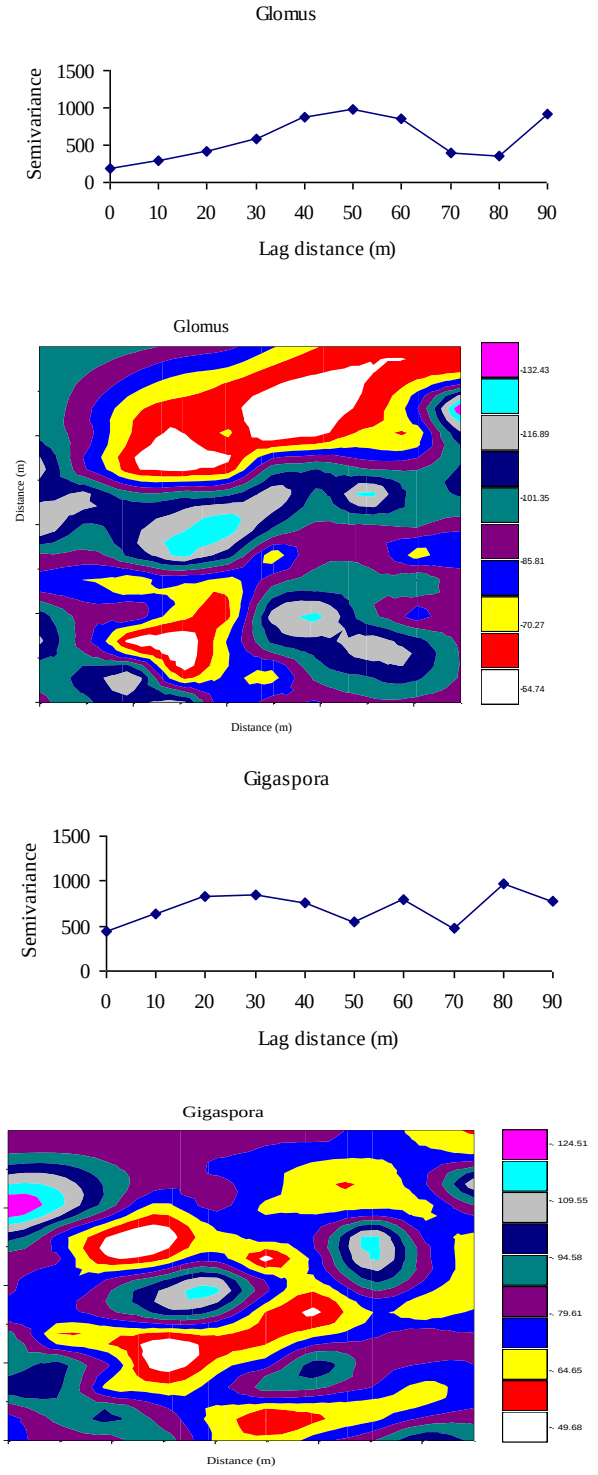


Fig 6: Semivariograms and kriged maps of Mycorrhizal spore distribution on the subsurface soils in study area

Table 1: Descriptive statistics of the particle size fractions, available phosphorus, organic carbon and mycorrhizal spore count of the surface and subsurface soils

	Mean	Median	Min.	Max.	CV	SD	Skewness	Kurtosis	Pr<W
Surface									
Sand	724.7	730.0	510.0	920.0	12.6	91.3	-0.41	-0.17	0.09
silt	157.7	150.0	60.0	340.0	31.0	48.9	0.76	1.67	0.001
clay	117.9	118.9	97.0	153.5	7.57	8.92	-0.05	-0.49	0.19^{+}
Available phosphorus	82.8	78.9	0.27	164.7	42.3	35.0	0.30	-0.17	0.13$^{\#}$
Organic carbon	2.1	2.1	0.41	3.6	32.7	0.6	-0.06	-0.42	0.81
AMF	347.9	350.1	137.6	496.8	19.54	68.01	-0.41	0.67	0.13
Gigaspora	179.3	182.0	29.0	152.0	35.3	28.0	0.23	-0.53	0.12
Scutellospora	155.1	152.6	113.5	104.4	38.1	21.0	0.05	-0.49	0.19
Acaulospora	42.2	42.0	0.1	79.7	38.6	16.3	-0.46	0.13	0.72
Entrophospora	37.7	39.1	8.6	72.2	32.1	12.1	0.20	0.04	0.44
Glomus	196.5	199.0	139.0	149.0	27.1	26.1	-0.32	-0.26	0.06
Others	37.0	39.0	10.0	63.0	30.1	11.1	-0.09	-0.44	0.45
Subsurface									
Sand	741.7	750.0	520.0	900.0	11.6	85.8	-023	-0.56	0.18
silt	154.5	150.0	60.0	280.0	34.6	534	0.37	-0.51	0.01
clay	105.6	105.4	104.0	107.8	0.7	0.80	0.46	-0.31	0.01$^{\#}$
Available phosphorus	114.4	114.7	66.0	144.6	13.6	15.5	-0.34	0.47	0.15^{+}
Organic carbon	1.49	1.45	0.04	2.7	42.7	0.64	-0.33	-0.55	0.04
AMF	340.7	335.5	191.1	523.5	21.5	73.3	0.32	-0.13	0.19
Gigaspora	79.2	74.0	16.0	156.0	36.3	28.7	0.41	-0.31	0.20
Scutellospora	55.7	52.0	10.0	108.0	37.0	20.6	0.43	-0.13	0.08
Acaulospora	38.7	39.0	8.2	78.1	38.1	14.7	0.20	-0.25	0.40
Entrophospora	36.7	34.9	5.3	76.0	35.9	13.2	0.55	0.78	0.07
Glomus	91.6	92.0	31.0	160.0	29.7	27.2	-0.10	-0.32	0.40
Others	38.6	39.0	6.0	80.0	30.8	11.9	0.18	1.01	0.26

Min – minimum, Max – maximum, %CV – coefficient of variation, SD – standard deviation

$^{+}$ = log, $^{\#}$ = square root transformation, Org.Carbon. g/kg, Av.Phosphorus. mg/kg, % Sand, %Silt, % Clay

Table 2: Pearson correlation coefficients of the particle size fractions, available phosphorus, organic carbon and mycorrhizal spores count of the surface and subsurface soils

	Sand	silt	clay	Avail. P	OC	Mycorrhiza	*Gigaspora*	*Sculltelospora*	*Acaulospora*	*Entrophospora*	*Glomus*	others
Surface												
Sand	1.00											
Silt	-0.72**	1.00										
Clay	-0.17	0.10	1.00									
Avail. P	0.09	-0.20*	0.04	1.00								
OC	-0.04	0.01	-0.05	-0.08	1.00							
Gigaspora	0.25*	-0.11	-0.66	0.0 6	0.03	1.00						
Scultelospora	0.18	-0.07	-0.43**	0.03	0.05	0.77**	1.00					
Acaulospora	0.17	-0.10	-0.98*	-0.04	0.05	0.66**	0.45**	1.00				
Entrophospora	0.10	-0.02	-0.24*	0.10	0.01	0.43**	0.21*	0.24*	1.00			
Glomus	0.06	-0.04	-0.14	0.08	0.03	0.40**	0.11	0.14	0.30*	1.00		
Gigaspora	0.17	-0.08	-0.24*	-0.02	-0.12	0.63**	0.43**	0.24	-0.09	0.13	1.00	
Others	0.07	-0.06	0.02	0.20*	-0.09	0.23*	0.03	-0.02	0.09	0.07	0.07	1.00
Subsurface												
Sand	1.00											
Silt	-0.80**											
Clay	-0.02	-0.00										
Avail. P	0.03	-0.08	-0.03									
OC	-0.08	0.06	-0.01	-0.10								
Mycorrhiza	-0.05	0.03	0.23	0.32*	-0.002							
Gigaspora	-0.13	0.07	0.23*	0.20*	-0.11	0.80**						
Scultelospora	-0.10	0.08	0.24	0.10	0.08	0.60**	0.53**					
Acaulospora	-0.01	-0.04	-0.07	0.15	0.01	0.40**	0.10	0.18	1.00			
Entrophospora	0.04	-0.06	0.04	0.18	0.08	0.43**	0.08	0.12	0.33**	1.00		
Glomus	0.04	-0.00	0.19	0.23*	-0.01	0.73**	0.51**	0.24*	0.14	0.23*	1.00	
Others	0.01	0.01	0.03	0.30**	0.03	0.38**	0.24*	0.15	-0.01	0.22*	0.13	1.00

*p<0.05; **p<0.01, OC = organic carbon, Avail. P = available phosphorus

Table 3: Principal components and commonalities of the particle size fractions, available phosphorus, organic carbon and mycorrhizal spores count of the surface and subsurface soils

	Surface soil						Subsurface soil					
	Principal component					C	Principal component					C
	1	2	3	4	5		1	2	3	4	5	
Sand	0.19	-0.10	0.58	-0.22	-0.08	0.82	-0.04	-0.10	0.65	-0.01	0.02	0.89
silt	-0.13	0.07	-0.64	0.19	0.05	0.87	0.02	0.09	-0.66	0.19	0.00	0.89
clay	-0.42	0.05	0.19	0.22	0.29	0.89	0.16	0.00	0.06	-0.52	0.06	0.45
Avail. P	0.02	-0.09	0.31	0.39	-0.00	0.40	0.23	-0.07	0.14	0.41	0.38	0.63
OC	0.11	0.55	0.07	0.04	-0.00	0.99	-0.02	0.56	0.07	-0.02	0.03	0.99
Mycorrhiza	0.49	-0.09	-0.07	0.13	0.19	0.19	0.53	0.02	0.01	-0.02	-0.07	0.98
Gigaspora	0.36	-0.12	-0.10	-0.03	-0.27	0.65	0.43	-0.05	-0.20	-0.22	0.08	0.74
Scultelospora	0.42	-0.05	-0.19	-0.22	0.29	0.89	0.36	0.07	-0.10	-0.24	-0.08	0.56
Acaulospora	0.21	-0.05	-0.04	0.45	-0.43	0.67	0.20	0.02	0.11	0.35	-0.62	0.76
Entrophospora	0.19	-0.02	-0.00	0.47	-0.09	0.44	0.24	0.07	0.20	0.35	-0.25	0.52
Glomus	0.29	0.01	0.01	-0.11	0.63	0.82	0.38	0.00	0.05	-0.14	-0.03	0.52
Others	0.06	-0.10	0.17	0.43	0.26	0.44	0.23	0.02	0.08	0.30	0.60	0.74
Proportion (%)	26.2	21.6	12.0	1.0	0.80		24.0	21.9	13.3	0.90	0.80	
Eigenvalues	3.67	3.03	1.67	1.34	1.18		3.36	3.07	1.85	1.29	1.12	

OC = organic carbon, Avail. P = available phosphorus, C = commonalities

Table 4: Semivariance statistics of the particle size fractions, available phosphorus, organic carbon and mycorrhizal spores count of the surface and subsurface soils

	Surface					Subsurface				
	Nugget	Sill	Range	Co/Co+C (%)	R^2	Nugget	Sill	Range	Co/Co+C (%)	R^2
Sand	3440.7	9792.7	90.0	35.1	0.79	1830.0	9670.0	40.0	18.9	0.96
silt	732.2	2602.6	70.0	28.1	0.65	1782.9	3630.1	50.0	49.1	0.85
clay	10.4	94.6	70.0	11.0	0.94	0.36	0.69	50.0	53.0	0.78
Avail. P	961.7	1519.4	50.0	63.3	0.94	65.3	372.8	70.0	17.5	0.87
OC	0.19	0.53	70.0	36.2	0.91	0.12	0.59	40.0	20.7	0.76
Mycorrhiza	623591	2989341	90.0	20.8	0.92	1211369	4212506	30.0	28.7	0.95
Gigaspora	155.7	949.8	40.0	16.4	0.93	473.5	902.7	30.0	52.5	0.91
Scultelospora	85.3	485.6	80.0	17.5	0.47	221.0	509.0	90.0	43.4	0.68
Acaulospora	105.2	338.5	30.0	31.0	0.98	102.2	236.3	90.0	43.2	0.90
Entrophospora	15.4	254.1	54.0	06.0	0.74	65.7	192.6	40.0	34.1	0.97
Glomus	59.9	1022.8	50.0	05.9	0.94	138.3	970.4	50.0	14.3	0.97
Others	46.5	155.8	40.0	29.8	0.95	12.5	204.4	70.0	06.1	0.92

OC = organic carbon, Avail. P = available phosphorus

Coefficient of variation of the soil properties ranged from 7.6% to 42.3% (clay and available phosphorus respectively) on the surface and 0.7% to 42.7% (clay and organic matter respectively) on the subsurface soil (Table 1). On the surface, the status of sand and clay was least variable; clay, organic carbon, mycorrhizal spores, *Glomus*, *Entrophospora* and "others" were moderately variable; whereas available phosphorus, *Gigaspora*, *Scutellospora* and *Acaulospora* were highly variable. Similar statuses of coefficient of variation were observed at the subsurface soils with the exception of available phosphorus which was least variable, organic carbon and *Entrophospora* (highly variable) contrary to highly and moderately respectively on the surface.

Pearson correlation coefficients (Table 2) indicated that significant relationship exist in 27.1% of the soil property pairs in both soil depths. On the surface, significant correlation exist between sand and silt (r = -0. 72, p<0.01), silt and available phosphorus ((r = -0. 20, p<0.05), clay and *Gigaspora*, *Scutellospora*, *Acaulospora*, *Entrophospora*, *Glomus* (r = -0. 43, -0.98, p<0.01, -0.24 and -0.24, respectively p<0.05), clay and *Glomus* (r = -0. 24, p<0.05), and *Gigaspora* and *Glomus* (r = 0. 43, p<0.01). Whereas in the subsurface, significant correlation exists between sand and silt/mycorrhizal spores (r = -0. 80/0.25, p<0.01/0.05), clay and *Gigaspora* (r = 0. 23, p<0.05), available phosphorus and *Gigaspora* (r = 0. 20, p<0.05) available phosphorus and *Glomus* (r = 0. 23, p<0.05), *Gigaspora* and *Glomus* (r = 0. 51, p<0.01). Highly significant correlation existed between sand and silt, clay and *Gigaspora*, and *Gigaspora* and *Glomus* on both surface and subsurface soils.

Discrimination of soil properties into components

Factor loadings are the simple correlation between properties and each factor (Sharma, 1996). Eigenvalues are the amount of variance explained by each factor (Sharma, 1996). Standardization of soil properties lead to the arrival on variance value 1 for each variable and a total of 12 for the entire data set. Factors with eigenvalues >1 explained more total variation in the data than individual soil properties, and factors with eigenvalues <1 explained less total variation than individual soil properties (Table 3). Therefore, only factors with eigenvalues >1 were retained for interpretation. The distribution of the components (Table 3) on the surface soil indicated that components 1, 2, 3 and 4 contributed 26.2%, 21.6%, 12.0% and 1.0% to the overall variability. The first comprised clay and mycorrhizal spores (*Gigaspora*, *Scutellospora* and *Glomus*). Second component comprised organic carbon, third comprised sand, silt and available phosphorus. The fourth component comprised available phosphorus, *Acaulospora*, *Entrophospora*, and "others". The proportions on the subsurface soil were 24.0%, 21.9%, 13.3% and 0.9% for components 1, 2, 3 and 4 respectively. Component 1 comprised mycorrhizal spores, *Gigaspora*, *Glomus* and *Scutellospora*, 2 comprised organic carbon, and component 3 comprised sand and silt while

component 4 comprised clay and available phosphorus. It is instructive that the groupings of the surface and subsurface soils were similar except that available phosphorus associated with sand and silt on the surface but with clay at component 4 on the subsurface soil. This can only be explained by the increase in the amount of clay down the horizons and the association of colloidal effect of clay with ions and mycorrhiza

Kriging of variation of the parameters in the study area

The maps shown in figures 1 – 6 indicated that complexity of the isolines increased down the slopes with the exception of organic carbon content of the surface soil which was shown as the characteristics of the semivariogram shown in figure 5. This is obviously a confirmation that variability of the soil properties studied including the mycorrhizal spores were as a result of intrinsic variation associated with factors of soil formation. Comparison of the distribution of the soil properties on the surface soil indicated that clay, available phosphorus and gigaspora were similar to each other, while the locations of similarity in the distributions are fewer in sand, silt, organic carbon and glomus. The concentration of materials at the lowest portions of the valley bottom soils may be responsible for high variability which has affected the mycorrhizal distribution in combination with soil hydrological condition. Wei et al. (2008) reported that spatial variation of soil properties are affected comprehensively by topographic factors, land use and erosion in a watershed of black soil region in northern China.

Spatial dependence of soil properties

In spatial statistics, subjects are assumed to be dependent. This implied that no subject is totally independent, but always interdependent. In addition it is commonly assumed for certain tests that the data are stationary and isotropic. The assumption of stationarity requires that data are normally distributed with the similar means and variances. The normality test of the variables studied indicated that all but silt content of the surface soil could not be normalized even after transformation. Yet the report in that section indicated that the mean and median values of silt content were similar. If data are isotropic, the characteristics of patterns within the data are constant in all directions, whereas anisotropic data will exhibit a pattern that varies in different directions. The semivariogram plot of the soil properties studied was shown in Figure 1 (PSF), Figure 2 (available phosphorus and organic carbon) and Figure 3 (spore count of *Gigaspora* and *Glomus*). In as much as the soil properties displayed dissimilarities in their spatial pattern, none of the patterns were anisotropic in directional semivariogram (i.e. the spatial dependence was isotropic). Anisotropy refers to data in which the spatial pattern is not constant in all directions. Several attempts result in the choice of linear as the best model fit. This was partly based on the fact that unity of models facilitate comparisons, thus if both spherical and linear models were possible, then the most common was adopted. Cambarella *et al*., (1994) stated that in situations where differences in R^2 were <0.05 between alternative models, (i.e. spherical and linear), the most common should be adopted to allow direct comparison of nugget, sill and range values among different parameters. The R^2 (range between 68 and 97) obtained in the semivariogram plot revealed the superiority of linear model fitted.

Generally the entire variables studied displayed positive and non zero nugget. The positive and none zero nuggets are regularly as a result of sampling error, random and inherent or short range variability. The variability observed in the study area may have originated primarily from factors of soil formation as land management activities are mild with neither heavy equipments nor large quantities of soil amendments. The land management practiced in the undergraduate students' internship farm was the use of organic amendments (crop residue which were negligible) to sustain continuous farming practiced. Management related sources of soil variability are mainly intensive utilisation of the land with the aid heavy equipment and heavy application soil amendments. Spatial ratio similar to those presented by Cambardella, *et al*., (1994) to define distinctive classes of spatial dependence was adopted in the study. The classes were obtained by the ratio of nugget to sill (C_o/C_o+C) and presented in percentage. If the ratio was <25%, between 25 and 75% or >75%, the variable was considered strongly, moderately or weakly spatially dependent respectively. The resulting semivariogram (Table 4) indicated strong spatial dependence in clay (11.0%), and all the taxonomically identified mycorrhizal spores but *Acaulospora*, and moderate spatial dependence in sand (35.1%), silt (28.1%), available phosphorus (63.3%) and organic carbon (36.2%) on the surface of the soil. On the subsurface, sand (18.9%), available phosphorus (17.5%), organic carbon (20.7%) and *Glomus* (14.3%) were strongly spatially dependent, whereas silt (49.1%), clay (53.0%) and other taxonomically identified mycorrhiza were moderately spatially dependent. These were indications that the entire soil properties considered were either strongly or moderately spatially dependent. Duffera *et al*. (2007) definition of weak spatial dependence with $R^2 < 0.5$ served as confirmation of strong to moderate spatial dependence of the semivariograms which R^2 values ranged between 0.65 and 0.97 (Table 3). The range of semivariograms varied from 50.0m to 90.0m on the surface and 30m 70.0m in the subsurface soils. Generally the ranges of semivariograms were shorter on the subsurface compared to the subsurface soil.

Discussions

The abundance of AMF at both surface and subsurface of the valley bottom soil studied was in the order *Glomus* > *Gigaspora* > *Scutellospora* > *Acaulospora* > *Entrophospora* which was a trend similar to that observed by Agwa and Al-sodany (2003). Other reports indicated that *Glomus* is predominant (Olsson *et al*., 1999, Zhu and Miller, 2003, Lovelock *et al*., 2004). Vertical similarity among the variables measured (i.e. surface versus subsurface) were indications that lateral spatial variation was an intrinsic? result of pedogenesis (alluvial and colluvial processes) rather than antropogenic causes (land use and management imposed). Obi *et al*. (2008) reported that farming systems of the savanna region of Nigeria was dominantly subsistence with low input, low output, rainfed and without the use of heavy equipments. This production system may not have introduced major variation to the soil properties especially the intransient ones like texture and some others associated with it.

The significant correlations were indications that clay and available phosphorus play important role in the dynamics and population of mycorrhizal spores in the soils of the study area. The significant correlation between available phosphorus and mycorrhiza (both *Gigaspora* and *Glomus*) on the surface soil is a confirmation of such relationship already established. Lack of it on the subsurface soil could be as a result of plant nutrients uptake-related factors and water table or soil water regime. Correlations which exist between *Gigaspora* and *Glomus* could be associated with competition. While that with clay may need to be investigated to confirm if it is associated with the size of clay fractions or nutrient content as clay and soil organic matter are repositories of plant nutrients especially in the soil of the tropical region. Additionally, pools of organic carbon such as

glomalin found in the soil had been associated with AM fungi (Rillig *et al*., 2001).

Occurrence of mycorrhizal spores in the field had been reported to be spatially heterogeneous (Pringle and Bever, 2002; Hart and Klironomos, 2002; Egerton-Warburton *et al*. 2003; Carvalho *et al*. 2003; Sinegani *et al*. 2005; Wolfe *et al*., 2007). Spatial analysis of the heterogeneity of the variability revealed that they were strongly to moderately spatially dependent. These are attributable to intrinsic variation controlled by factors of soil formation and particularly associated with texture and mineralogy of the soil rather than land use and management related factors. This had been indicated in the correlation between the mycorrhizal sproes and clay fraction in the soil of the study area. If the spatial dependence were moderate to weak, variability may have been associated with management related factors such as fertilizer application, tillage or land use etc (Trangmar *et al*. 1983). The indications of the groupings achieved with the principal component analysis was a confirmation that in as much as organic matter documented in the study by organic carbon is the repository of plant nutrients in the tropics together with clay, did not associate with mycorrhiza whereas clay did. It was clear that organic matter did not correlate with clay in the study and soils of the sub-Saharan tropics especially of the savanna region that is normally not high in organic matter. This may explain association of the mycorrhizal spores more with clay than organic carbon.

Conclusions

The most abundant genera of AMF was *Glomus* > *Gigaspora* > *Scutellospora* > *Acaulospora* > *Entrophospora* in both the surface and subsurface soil. Despite skewness and kurtosis, outliers did not dominate the measure of central tendency and significant correlation existed in 27.1% of the soil property pairs in both soil depths. Variability of mycorrhizal spores in the study area is majorly attributable to pedogensis rather that land use and management. Additionally, Clay and available phosphorus had been found to influence distribution of mycorrhizal spores.

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